SECTION 3
REVISITING THE GAPS

The Colorado Water Plan set an adaptive management framework for future water planning activities, and described five planning scenarios under which demands, supplies, and gaps were to be estimated. The planning scenarios included new considerations, such as climate change, that were not a part of prior SWSI analyses. The CWCB and Division of Water Resources have developed new consumptive use and surface water allocation models that were not previously available for use in prior SWSI phases. As a result of these factors, the Technical Update takes a different and more robust approach to estimating potential future gaps.

3.1 SWSI 2010 GAP METHODOLOGY

Gaps in SWSI 2010 were focused on municipal and self-supplied industrial water users and were defined as a “future water supply need for which a project or method to meet that need is not presently identified.” The gaps accounted for new future water needs and also anticipated yields from Identified Projects and Processes (IPPs) projected to provide future supply. Gaps were calculated using the following formulas:

M&I Water Supply Gap = 2050 net new water needs – 2050 projects

Where:

> 2050 Net New Water Needs = (2050 low/medium/high M&I baseline demands – high passive conservation – current M&I use) + (2050 low/medium/high SSI demands – current SSI use)
>
> 2050 IPPs = Water Provider Anticipated Yield from: Agricultural Transfers + Reuse + Growth into Existing Supplies + Regional In-basin Projects + New Transbasin Projects + Firming In-basin Water Rights + Firming Transbasin Water Rights

Information on specific IPPs and estimated yields were obtained from CWCB interviews and data collected from water providers throughout the State in 2009 and 2010, the original SWSI effort in 2004, and information from basin roundtables from 2008 to 2010. The overall IPP “success” was then adjusted to create varying levels of M&I gap based on the likelihood that a specific IPP would produce its full yield

Agricultural shortages were estimated in SWSI 2010. The shortages were estimated by calculating the difference between the amount of water consumed by a full-irrigated crop and the amount of water actually consumed by crops under water short conditions. The shortages were field-based, meaning that they did not account for water needed for conveyance and other losses. Agricultural shortages were not described as gaps, in part because they were conceptually different than the infrastructure gaps calculated for M&I water uses.

CALCULATING THE GAP

Gaps calculated in SWSI 2010 were based on future water demands and accounted for the degree to which future projects might meet future demands. Gap projections in the Technical Update do not include estimates of basin-identified project yields. This is primarily due to the lack of specific project data that would allow projects to be modeled. Forthcoming basin plan updates will reevaluate projects and consider strategies to address gaps.

REGARDING PROJECTS

IPPs in SWSI 2010 referenced “Identified Projects and Processes” that were being pursued by water providers to meet future demands. The Technical Update refers to these simply as “projects.”

3.2 GAP METHODOLOGY IN THE TECHNICAL UPDATE

The methodology for calculating gaps in the Technical Update is very different from that used in prior SWSIs. The new methodology was necessary to address new analysis needs, to provide basin roundtables with the tools to develop implementation strategies within the adaptive management framework, and to take advantage of new models and data sets.

New Analysis Needs

The Technical Update estimates future available water supplies and gaps under the five different planning scenarios described in the Colorado Water Plan. Previous SWSIs were conducted prior to the Water Plan and, therefore, did not consider the scenarios. The planning scenarios incorporate water supply and demand drivers associated with the potential effects of climate change, population growth, and many other factors.

New Planning Process

In the BIPs, the basin roundtables cataloged various projects and methods to mitigate future water supply gaps. The Technical Update focuses on developing tools and more detailed datasets to help the basin roundtables update their portfolios of projects and methods for meeting future water needs in a targeted manner, with forthcoming updates to their BIPs.

New Models and Data Sets

New analysis tools and data sets have been developed since SWSI 2010. Consumptive use and surface water allocation models developed through the CDSS are now available in most river basins. The CDSS tools allow the evaluation of gaps under a variety of hydrologic conditions. Municipal water demand and conservation data is available via HB10-1051 reporting. The availability of these new tools and data sets allows for a more robust approach to assessing future water availability and potential gaps.

The new gap methodology uses the CDSS tools to evaluate demands and supplies available to meet demands over a range of time and under a variety of hydrologic conditions. As a result, time series of gaps were developed to help examine how gaps change in wet, average/normal, and dry conditions at key locations in each basin (see illustration in Figure 3.2.1). In addition, the CDSS tools were used to estimate M&I and agricultural gaps on the same platform, which creates uniformity in how the respective gaps were estimated. In short, the analyses and data sets are more consistent and robust than what the CWCB was able to achieve in the past.

3.2.1 Important Considerations and General Differences

The new gap methodology has some important differences from SWSI 2010 that need to be understood and considered by basin roundtable members and others who use the findings, tools, and data from the Technical Update. Differences are summarized in Table 3.2.1 on the following page.

Figure 3.2.1 Example Time Series of Gaps

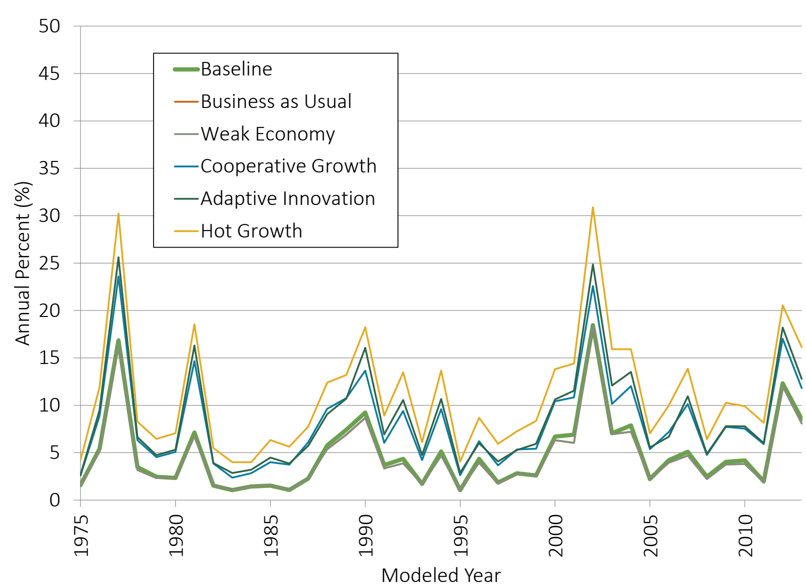


Table 3.2.1 Summary of Differences Between SWSI 2010 and Technical Update

Item	SWSI 2010	Technical Update
Consideration of alternative future conditions	✓	✓
Inclusion of yield from projects (or IPPs) in gap	✓	
Variability in future conditions (2050)		✓
Agricultural gaps using surface water modeling		✓
Quantification of livestock water demands [*]	✓	
Simultaneous consideration of active and passive municipal water conservation [**]		✓
Consideration of climate change		✓
Use of water allocation models reflecting variable supplies, demands, and river operations		✓
Simulation of existing reservoirs		✓
SDO population projections to the year 2050 [***]		✓

[*] Livestock water demands are relatively small on a basin scale and are not simulated in the CDSS tools used in the Technical Update
[**] SWSI 2010 considered active and passive conservation separately, but the Technical Update considers them jointly
[***] SWSI 2010 used complex projections to extend estimates to 2050 because SDO 2050 projections were not available at that time

Results represent 2050 conditions: The planning scenarios in the Water Plan describe assumed future conditions, but they do not contemplate the progression of changes that will occur between now and 2050. As a result, the Technical Update models and data sets represent conditions in the year 2050 and do not depict how drivers of future conditions change between now and then. For example, M&I water demands reflect the needs of Colorado's population in the year 2050 and not prior years. It should be noted that demands and supplies vary in the models, but the variation is reflective of typical ups and downs in future supplies and demands under stable hydrologic cycles, amounts of irrigated land, and population.

Climate change is considered in the Technical Update: Projections of future climate conditions were not a part of SWSI 2010 and have a significant influence on estimated gaps. Planning scenarios that consider a hotter and drier future climate have higher agricultural and municipal diversion demands (for outdoor uses) combined with lower amounts of available water supply—factors that both tend to drive larger gaps.

Agricultural gaps are based on diversion demands and described in new ways: The Technical Update quantifies and describes agricultural gaps differently than 2010.

- Agricultural gaps based on diversion demand: As explained in Section 2, water demands in the agricultural sector are based on diversion demands at a river headgate or wellhead. Unlike SWSI 2010, irrigation conveyance and on-farm efficiencies were considered in the agricultural demands and gaps in the Technical Update. As a result, the agricultural gap in the Technical Update will be significantly larger than the agricultural shortages described in SWSI 2010.
- Total and "incremental" agricultural gaps are provided**:** It is anticipated that basin roundtables may want to understand both the total agricultural gap and the degree to which existing agricultural gaps may increase under various scenarios. To meet this need, total and incremental gaps are provided in the Technical Update, and they are described in more detail below.
    - *Total Gap*: The total agricultural gap reflects the overall shortage of agricultural water supplies to meet diversion demands required to fully irrigated crops.
    - *Incremental Gap*: The incremental gap quantifies the degree to which the gap could increase beyond what agriculture has historically experienced under water shortage conditions.

- Total and incremental gaps are quantified as averages. Shortages in agriculture vary across irrigators depending on the seniority of their water rights and based upon hydrologic conditions and their source of supply (tributaries, main steam rivers, groundwater or surface water, etc.). Because of this variability, agricultural gap reporting focuses on averages, though maximum gaps are also presented in Section 4 results tables.

Municipal gaps focus on maximum shortages:

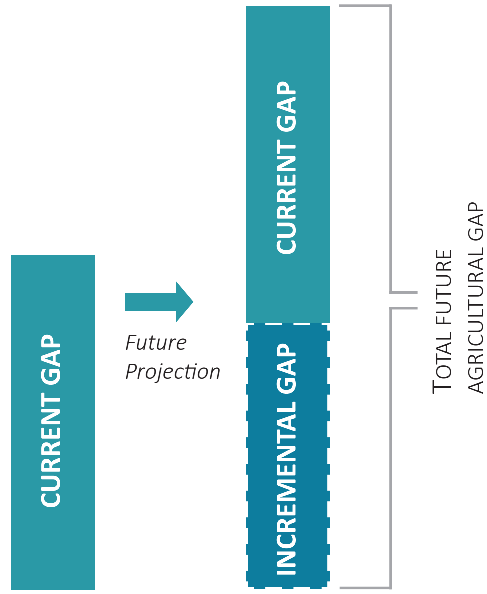
Water providers generally consider and plan for worst-case scenarios. As a result, M&I gaps described in the Technical Update focus on maximum annual shortages or gaps. For perspective, average gaps are presented as well.

Conservation is incorporated into the scenarios:

In SWSI 2010, active and passive conservation measures were considered separately. In the Technical Update, they were jointly considered in the context of the scenario narratives in the Water Plan. Additional levels of conservation beyond what was described in the scenario narratives would be considered a project that a basin roundtable could pursue to help eliminate future gaps.

Water allocation models provide for more robust analyses:

Water allocation models not readily available for use in SWSI 201 are used extensively in the Technical Update. The water allocation models reflect variable supplies, demands, and river operations using existing infrastructure and therefore provide for more robust analyses than prior SWSIs. Using models can lead to different gap results due to the wide variety of additional considerations that influence how supplies are used to meet demands.



3.2.2 Differences in Foundational Municipal Demand Data

In addition to the factors above, two foundational data inputs for estimating municipal water demands have changed since the publication of SWSI 2010—population projections and per capita demand. The changes in both of these data inputs tend to result in lower municipal water demands in the Technical Update than in SWSI 2010.

Population Projections

SWSI 2010 needed to extend the then-current SDO projections for 2035 out to the year 2050 using complex analyses. As noted in Table 3.2.1, the Technical Update was able to rely on newly developed SDO projections for 2050, and estimated high and low ranges based on historical growth statistics.

Figure 3.2.2 provides a comparison of the population projections between SWSI 2010 and the Technical Update. Note that results of population projections are described further in Section 4, but statewide results are shown here for comparison purposes. All of the Technical Update planning scenario projections for 2050 anticipate lower population than the SWSI 2010 high population projection. The Technical Update medium growth projection that is used for *Business as Usual* and *Cooperative Growth* is similar to the SWSI 2010 low population projection (within about 2 percent). The Technical Update high growth projection that is used for *Adaptive Innovation* and *Hot Growth* is similar to the SWSI 2010 medium population projection. Basin-level population projections vary from the comparison above due to the variable distributions under the scenario planning methodology, but mimic similar patterns of lower projections than were developed for SWSI 2010.

BASIN MODELING

In general, modeling was conducted at the basin scale. Due to model availability, some basins were more easily broken out into sub-basins. This was done for the following regions:

- YAMPA-WHITE-GREEN BASIN
  Individual models were available for the Yampa (which includes Green River operations) and White basins. Results of basin analyses were preseted for individual sub-basins and the combined Yampa-Green Basin.

- SOUTH PLATTE BASIN
  A model exists for the South Platte Basin but not the Republican Basin. The results of basin analysis were presented for the South Platte and Republican basins both separately and combined. In addition, the South Plate Basin model does not specifically represent the Metro Basin Roundtable region, and gap results for the Metro region are incorporated in the South Platte Basin Gap results; however, Metro-region M&I demands are specifically quantified and are presented individually (as well as combined with Republican and the remaining South Platte Basin regions).

Per capita and overall municipal demands. The statewide baseline per capita system-wide demand has decreased from 172 gpcd in SWSI 2010 to approximately 164 gpcd, which is nearly a 5 percent reduction in demands between 2008 and 2015. The reduction is associated with improved data availability, conservation efforts, and ongoing behavioral changes. Per capita demand reductions combined with lower population projections compared with SWSI 2010 resulted in lower overall municipal water demands in the Technical Update.

Figure 3.2.3 provides a comparison of the Technical Update results with the SWSI 2010 projected demands for 2050. Note that it is challenging to directly compare the municipal demand projections due to differences in the methodologies. The SWSI 2010 projections selected for Figure 3.2.3 are intended to show a range of the spread in the SWSI 2010 projections relative to the Technical Update projections.

The Technical Update demand projections for all planning scenarios fall within the spread of the SWSI 2010 high population demands with passive-conservation savings and the SWSI 2010 medium population growth with passive and high active-conservation savings. This result was anticipated with the Technical Update methodology, considering that the updated projections represent potential demands under conditions described for each scenario and do not necessarily represent the full potential for conservation programs under each scenario. All of the planning scenarios, with the exception of *Hot Growth*, project municipal water demands that are below the SWSI 2010 low population demands with passive conservation savings.

Figure 3.2.2 Comparison of SWSI 2010 and Technical Update Statewide Population Projections

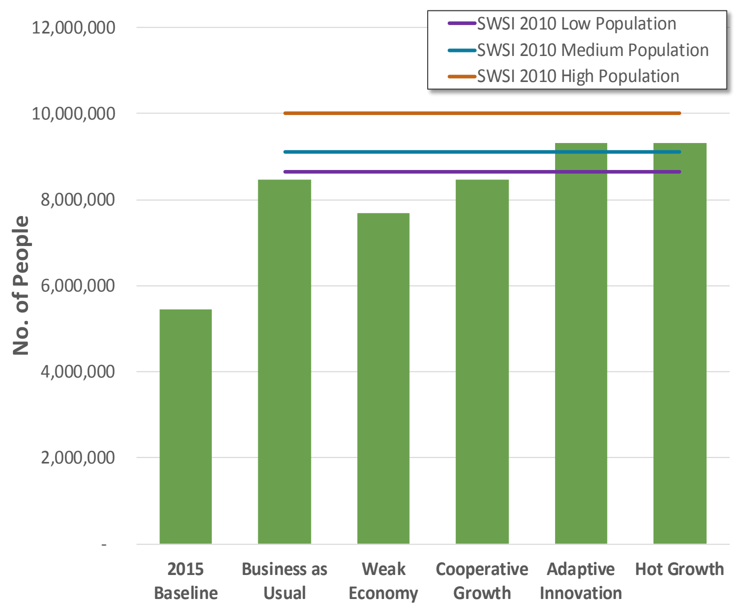


Figure 3.2.3 Comparison of SWSI 2010 and Technical Update Statewide Municipal Diversion Demands

SECTION 4
STATEWIDE & BASIN RESULTS

Statewide and basin-specific results of Technical Update analyses are described in Section 4. Statewide results are described first followed by basin-specific results. Results are described for:

- Agricultural diversion demands
- M&I diversion demands
- Agricultural and M&I gaps
- Environment and recreation conditions
- Available water supply

4.1 KEY ASSUMPTIONS AND LIMITATIONS

The analyses used to estimate demands and gaps incorporated some key assumptions and limitations that are important to consider when reviewing and using the results of the Technical Update:

- As stated in Section 3, future water supply projects (or IPPs) were not included in the Technical Update (see section 3.2.1).
- While the models used for this analysis consider a wide range of detailed information on river diversions, water provider operations, etc., the analyses were conducted and reported at a regional scale for understanding basinwide and statewide demands, supplies, and gaps. Attempting to extrapolate model results for specific water providers is not useful given the regional scale of model input data, the regional focus of the modeling, and the relatively high level of uncertainty associated with individual water provider operations under various scenarios.

Agricultural considerations:

» Livestock water demands were not included in the analysis because they are difficult to quantify, are relatively small compared to irrigation demands and are not a component of the CDSS tools used for the agricultural diversion demand analysis and gap calculations.

» The analysis did not consider different types of crops that may be grown in the future under the different scenarios; however, it accounted for future changes in crop types in a general sense in the *Adaptive Innovation* scenario and assumed that future crops would have 10 percent lower IWR.

M&I considerations:

» Projected water demands for the planning scenarios do not contemplate how municipal water providers or industrial water users would respond to acute drought conditions (e.g., implementation of watering restrictions, etc.).

Operations with respect to transbasin imports/exports:

» Imports from transbasin diversion projects were set at historical levels and reflect historical operations. To accurately reflect how the change in water availability on the Western Slope would have impacted transbasin diversions, it would have been necessary to work with the major transbasin diverters to understand how their operations may change on both the Western and Eastern Slope in response to West Slope shortages and include those operations in the assessment. The level of investigation and modeling necessary to properly assess changed operations was beyond the scope of this current effort. Agricultural and M&I gaps do not directly reflect reductions in supply that would occur if transbasin imports are reduced.

» Data presented in Section 4.2.4 show how much of the historical transbasin imported supply is projected to be potentionally reduced by 2050 in some of the planning scenarios.

Statewide modeling results are shown in the following section followed by the results for each of the eight major river basins

CO
COLORADO STATEWIDE

A
ARKANSAS BASIN

C
COLORADO BASIN

G
GUNNISON BASIN

RG
RIO GRANDE BASIN

NP
NORTH PLATTE BASIN

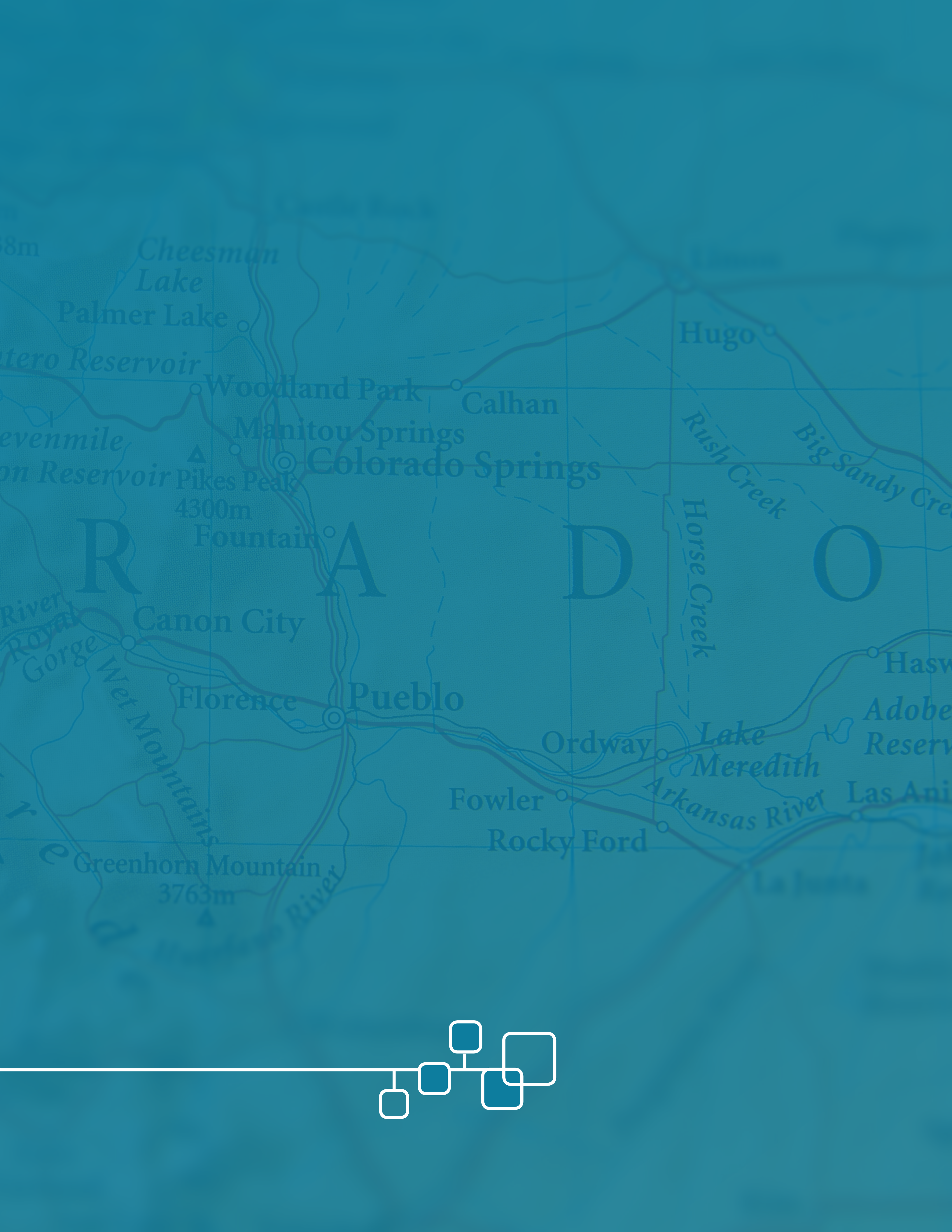
SP METRO
SOUTH PLATTE /METRO BASIN

SW
SOUTHWEST BASIN

YWG
YAMPA-WHITE-GREEN BASIN

The results and findings of the Technical Update pertaining to statewide agricultural and M&I demands and gaps as well as findings related to environmental and recreational attributes and future conditions are summarized in the following section, which is followed by findings in each of the state's eight major river basins.

STATEWIDE


Cheesman Lake
Palmer Lake
Woodland Park
Calhan
Hugo
Manitou Springs
Colorado Springs
Pikes Peak
4300m
Rush Creek
Big Sandy Creek
Fountain
R A D O
Horse Creek
Canon City
Royal Gorge
Wet Mountains
Florence
Pueblo
Ordway
Lake Meredith
Fowler
Arkansas River
Rocky Ford
Las Animas
Greenhorn Mountain
3763m
River

4.2 STATEWIDE RESULTS

4.2.1 Summary of Technical Update Results

Key results and findings of the Technical Update pertaining to statewide agricultural and M&I demands and gaps, as well as findings related to environmental and recreational attributes and future conditions, are summarized below.

Agriculture

- On a statewide basis, current average annual agricultural diversion demands are approximately 13,000,000 AFY.
- Demand for groundwater is approximately 19 percent of the overall demand. Groundwater demands occur primarily in the Arkansas, Republican, Rio Grande, and South Platte basins.
- Future agricultural diversion demands will be affected by changes in irrigated acreage due to urbanization, aquifer sustainability, and agricultural to urban transfers of water.
  - » Urbanization is projected to reduce irrigated lands statewide by 5 percent. Most of the reduction will occur in the South Platte Basin, with more than 12 percent of the basin's irrigated acreage projected to be urbanized.
  - » 6 to 7 percent of irrigated acres supplied by groundwater is projected to be lost due to aquifer sustainability issues. The impacts of this will be focused in the Arkansas, Republican, and Rio Grande basins.
  - » Stakeholders in the Arkansas and South Platte basins estimated that between 33,000 and 76,000 irrigated acres may be lost due to water rights purchases that have already taken place or are very likely to take place in the future. Specific estimates in the South Platte are likely understated because stakeholders did not have a projection of acreage that is likely to be lost in the reach of the South Platte between Denver and Greeley and in the tributaries in this region. The estimated loss of agricultural lands due to permanent water transfers conducted for the Technical Update is different than the amount estimated in SWSI 2010. The SWSI 2010 estimates included water transfers contemplated in portfolios of projects to fill future M&I gaps statewide, whereas the estimates in the Technical Update were focused in the South Platte and Arkansas basins and were conducted for the purposes of reducing agricultural diversion demands based on pending transfers that are very likely to occur in the foreseeable future. Basin roundtables may expand on this in their BIP updates and consider how alternative water transfers or future permanent transfers should be considered as future water supply projects and strategies to mitigate gaps.
- On average, approximately 80 percent of the overall agricultural diversion demand is currently met on a statewide basis, though this varies in each basin.
- Agricultural diversion demands statewide are projected to decrease in three of the five scenarios. In *Business as Usual* and *Weak Economy*, loss of irrigated land is projected to reduce diversion demands by around 9 percent. In *Adaptive Innovation*, demand reductions due to losses of irrigated lands will be offset in part by increases in crop consumptive use demand due to climate change. Adoption of emerging technologies that increase efficiency and decrease consumptive use, however, are projected to reduce overall diversion demand by 20 percent relative to current demand. In *Hot Growth*, irrigated lands are projected to be lost, but climate change is projected to more than offset the demand reductions associated with loss of irrigated lands and result in an overall increase in diversion demand of 5 percent compared to current conditions.
- In basins with significant potential acreage reductions like the South Platte and Republican, diversion demands in all planning scenarios are projected to be less than current.

M&I Demands

- M&I demands currently comprise approximately 10 percent of overall statewide water demands.
- Current statewide population (as of 2015) is 5 percent less than the level projected in SWSI 2010.
- Current population is 5,448,100, and by 2050 is projected by the State Demography Office to increase by more than 3 million people to 8,461,300—a 55 percent increase. Low population projections estimate the population to increase by 41 percent (to 7,683,200 people) while high projections estimate the increase at 71 percent (to 9,312,400 people).
- The statewide baseline per capita systemwide demand has decreased from 172 gpcd in SWSI 2010 to approximately 164 gpcd, which is a nearly 5 percent reduction in demands between 2008 and 2015.
- Statewide per capita demands are projected to decrease compared to current conditions in each scenario except *Hot Growth*. *Adaptive Innovation* assumes the highest levels of conservation and has the lowest projected per capita demand at 143 gpcd, which is 13 percent lower than current per capita demand in spite of assumed hot and dry future climate conditions.
- While per capita usage is expected to decrease compared to current conditions in all but *Hot Growth*, overall statewide M&I water demand is projected to increase from current conditions to 35 percent in *Weak Economy* up to 77 percent in *Hot Growth*.

- Increase in overall M&I demand is very similar in *Adaptive Innovation* compared to *Business as Usual* despite the assumptions in *Adaptive Innovation* of high population growth and hot and dry future climate conditions. In addition, *Hot Growth* and *Adaptive Innovation* have similar assumptions related to population and climate, but *Adaptive Innovation* assumes much more aggressive conservation that result in M&I demands that are 15 percent lower than *Hot Growth*. These results demonstrate the potential benefit of aggressive conservation in managing future M&I demands.
- Self-supplied industrial demands are approximately 13 percent of overall M&I demands statewide, but are a greater proportion in certain basins.

Projected Gaps

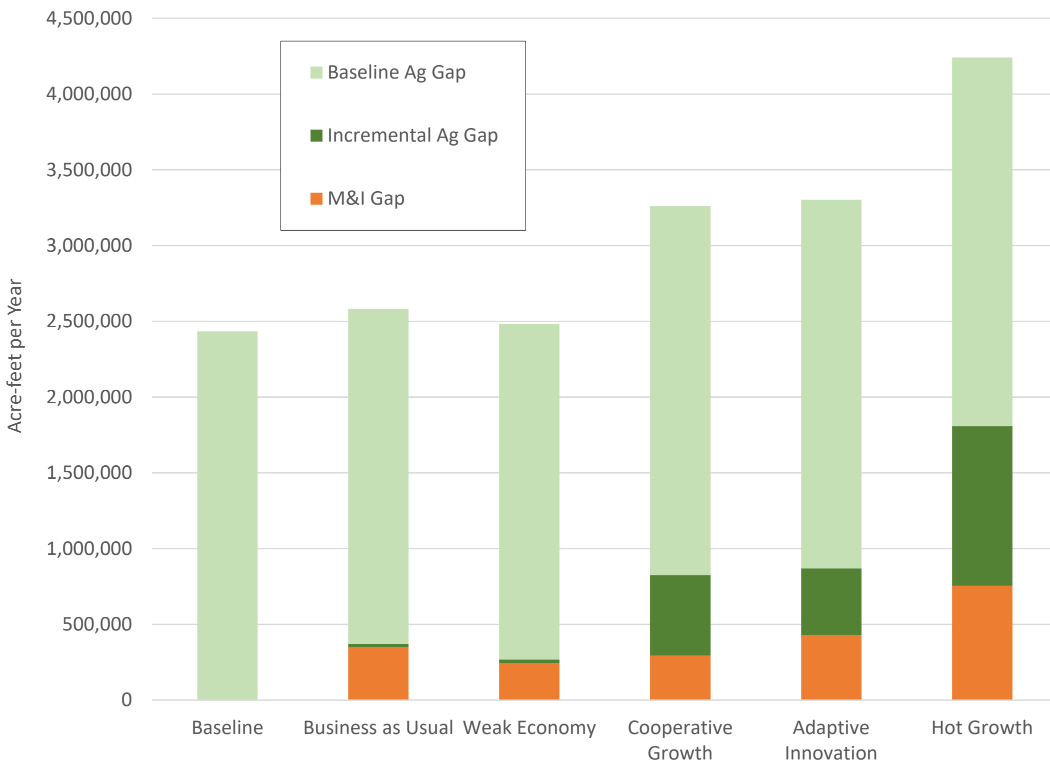
- **Agriculture**
  - » Agriculture currently experiences gaps, and gaps may increase in the future if climate conditions are hotter (which increases irrigation water demand) and supplies diminish (due to drier hydrology). Future gaps may increase by 440,000 AFY (in *Adaptive Innovation*) to 1,053,000 AFY (in *Hot Growth*) or 18 to 43 percent beyond what agriculture experiences, despite the loss of irrigated acreage.
  - » Agricultural gaps under *Adaptive Innovation* are significantly less than *Hot Growth* despite similar assumptions related to future climate conditions, which demonstrates the potential benefits of higher system efficiencies and emerging technologies that could reduce consumptive use. While conservation and efficiency improvements can be a tool for addressing future agricultural gaps, particularly in return-flow-driven systems, it is important to consider projects on a case-by-case basis.
- **M&I**
  - » Municipal and self-supplied industrial users do not currently experience a gap, but increasing population and potentially hotter and drier future climate conditions will create a need for additional supply despite efforts to conserve water. Statewide M&I gaps are projected to be from 250,000 AF (in *Weak Economy*) to 750,000 AF (in *Hot Growth*) in dry years. These gap estimates do not account for yields from water supply projects and strategies that water providers are pursuing.
  - » Municipal conservation efforts, however, create significant future benefits in lowering the gap, as demonstrated by comparing *Adaptive Innovation* and *Hot Growth* (which have similar assumptions on population and climate). Projected future gaps under *Adaptive Innovation* are 325,000 AF less than projected gaps under *Hot Growth*.
  - » Scenarios that include climate change project reduced available supplies for transbasin diversion projects. Reductions in transbasin imports will contribute to projected gaps, potentially to a greater degree than suggested in the analyses, because water providers reuse the return flows from transbasin imports.

Environment and Recreation

- Climate change and its impact on streamflow will be a primary driver of risk to E&R attributes.
- Projected future streamflow hydrographs in most locations across the state show earlier peaks and potentially drier conditions in the late summer months under scenarios with climate change.
- Under climate change scenarios, runoff and peak flows may occur earlier, resulting in possible mis-matches between peak flow timing and species' needs.
- Climate change may lead to more frequent flooding events, especially in disturbed areas, including fire scars. Stream and watershed health may be impacted by these events and thresholds may be crossed, resulting in impaired ecosystem structure and function. While these are important considerations, they were beyond the scope of this analysis.
- Drier conditions in late summer months could increase risk to coldwater and warmwater fish due to higher water temperatures and reduced habitat. The degree of increased risk is related to the level of streamflow decline.
- In many mountainous regions without significant influence of infrastructure, peak flow and low flows are projected to be sufficient to sustain low to moderate risk for riparian plants and fish, but risks are projected to increase in scenarios with climate change.
- In mountainous regions with infrastructure, risks to E&R attributes may vary. Streams that are already depleted may see increased risks in scenarios with climate change; however, some streams may be sustained by reservoir releases, which will help moderate risks in scenarios with climate change.
- Instream flow water rights and recreational in-channel diversion water rights may be met less often in climate-impacted scenarios.

Results describing current and potential future statewide M&I and agricultural gaps are summarized in Figure 4.2.1 and Table 4.2.1. Statewide gaps may vary substantially depending on future climate conditions and population increases, which underscores the need to take an adaptive approach to developing water management strategies, and projects and methods, to fill potential future gaps.

Figure 4.2.1 Summary of Statewide Gap Estimates by Planning Scenario



Results of calculations and analyses that support estimates of the statewide gap are presented in the subsections below.

INCREMENTAL GAP

The incremental agricultural gap quantifies the degree to which the gap could increase beyond what agriculture has historically experienced under water shortage conditions.

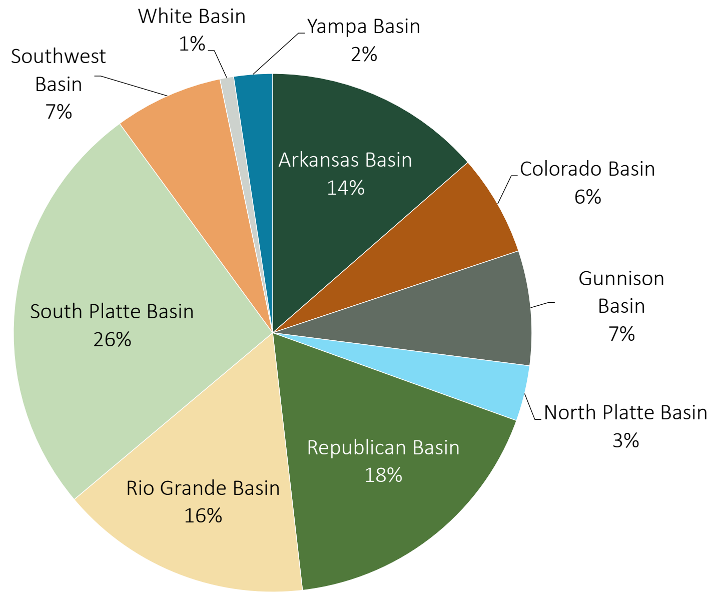
Table 4.2.1 Summary of Statewide Gap Results

Basin	Gap	Baseline	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Arkansas	Ag- Average annual gap (AFY)	617,300	586,400	585,200	701,700	734,800	819,500
	Ag- Average annual incremental gap (AFY)	0	0	0	84,400	117,500	202,200
	M&I- Max annual gap (AF)	0	68,500	53,100	58,500	62,900	108,700
Colorado	Ag- Average annual gap (AFY)	45,300	44,000	44,000	76,200	61,500	103,800
	Ag- Average annual incremental gap (AFY)	0	0	0	30,900	16,200	58,500
	M&I- Max annual gap (AF)	0*	4,200	3,300	5,300	6,600	15,800
Gunnison	Ag- Average annual gap (AFY)	87,300	77,200	77,300	157,600	112,600	222,000
	Ag- Average annual incremental gap (AFY)	0	0	0	70,300	25,300	134,700
	M&I- Max annual gap (AF)	0*	2,300	700	3,500	4,300	11,500
North Platte	Ag- Average annual gap (AFY)	85,700	108,000	107,900	177,900	168,100	231,100
	Ag- Average annual incremental gap (AFY)	0	22,200	22,200	92,100	82,400	145,400
	M&I- Max annual gap (AF)	0	0	0	0	0	0
Rio Grande	Ag- Average annual gap (AFY)	683,900	655,800	661,500	737,400	741,900	826,400
	Ag- Average annual incremental gap (AFY)	0	0	0	53,500	58,000	142,500
	M&I- Max annual gap (AF)	0	3,400	0	2,400	4,000	8,100
Southwest	Ag- Average annual gap (AFY)	126,600	120,300	119,800	276,700	219,000	355,100
	Ag- Average annual incremental gap (AFY)	0	0	0	150,100	92,400	228,400
	M&I- Max annual gap (AF)	0*	7,500	1,800	7,700	13,800	24,800
South Platte /Metro *(and Republican)*	Ag- Average annual gap (AFY)	773,500	606,300	604,000	610,900	577,600	665,400
	Ag- Average annual incremental gap (AFY)	0	0	0	0	0	0
	M&I- Max annual gap (AF)	0*	257,000	184,500	213,300	333,700	543,500
Yampa-White-Green	Ag- Average annual gap (AFY)	14,500	14,800	14,800	66,200	62,300	155,800
	Ag- Average annual incremental gap (AFY)	0	400	300	51,700	47,800	141,400
	M&I- Max annual gap (AF)	0*	5,600	1,600	2,600	3,800	41,700
Statewide Total	**Ag- Average annual gap (AFY)**	**2,434,200**	**2,212,800**	**2,214,500**	**2,804,500**	**2,677,800**	**3,379,100**
	Ag- Average annual incremental gap (AFY)	**0**	**22,600**	**22,500**	**533,000**	**439,600**	**1,053,000**
	M&I- Max annual gap (AF)	**0**	**348,500**	**245,100**	**293,300**	**429,200**	**754,200**

* *CDSS water allocation models in these basins calculate small baseline M&I gaps, but they are either due to calibration issues or they are reflective of infrequent, dry-year shortages that are typically managed with temporary demand reductions such as watering restrictions.*

4.2.2 Statewide Agricultural Diversion Demands

Figure 4.2.2 Proportion of Statewide Irrigated Acreage in Each Basin



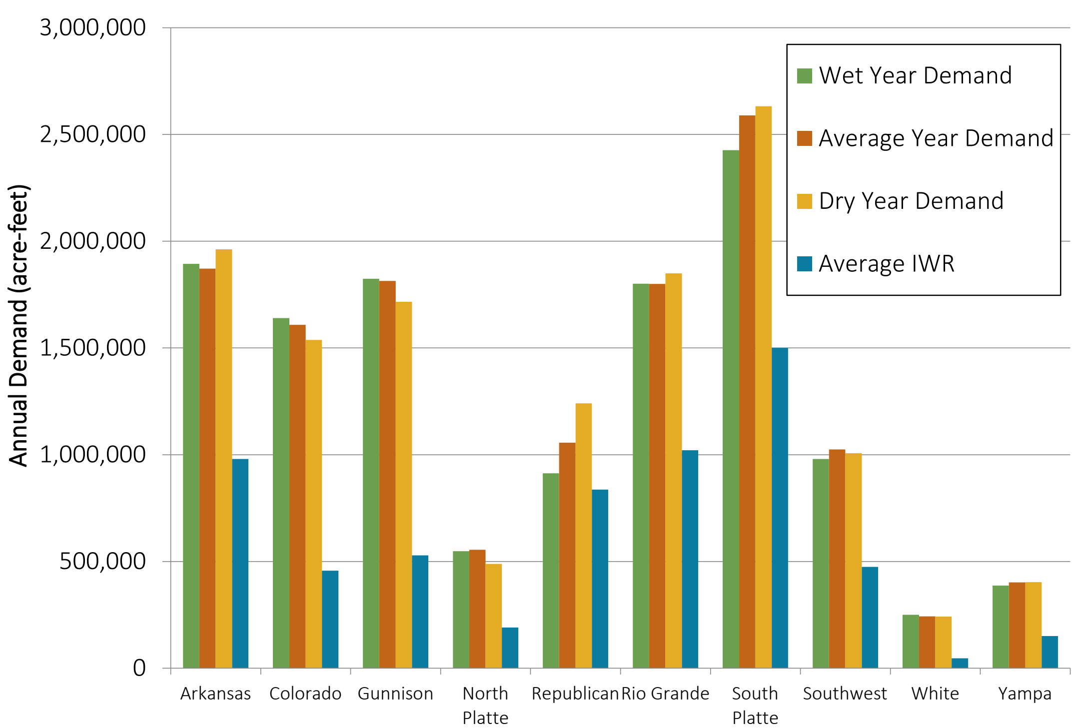
Current Diversion Demands

Currently, 3.28 million acres of agricultural land are irrigated statewide. Irrigated agriculture supports a wide network of agribusiness in Colorado from producers of agricultural goods to those that process and deliver those goods to consumers. Agricultural production in Colorado is a large part of the state's economy, with agribusiness contributing $41 billion annually and employing nearly 173,000 people.[10] Working agricultural operations also remain the economic backbone of many of Colorado's rural communities and provide important ecosystem services such as open space and wildlife habitat.

Figure 4.2.2 shows the proportion of statewide irrigated acreage in each basin. Over a quarter of the irrigated acreage in Colorado is located in the South Platte Basin. The Arkansas, Rio Grande, and Republican Basins also have significant acreage, each with approximately 15 percent of the statewide total. Grass pasture is the predominant crop grown in the state, particularly in the West Slope basins; however, irrigators also grow alfalfa, wheat, cereals/grains, fruits, and vegetables. Much of the irrigated acreage supports ranching operations, either through grass hay production for livestock operations or grazing of irrigated pastures. Refer to the basin-specific results summaries for more information on crops grown in each basin.

Tables 4.2.2 and 4.2.3 and Figure 4.2.3 show the agricultural diversion demand for surface and groundwater supplies summarized by basin for wet, dry, and average hydrological year types compared to average IWR. Results are displayed over a range of hydrological year types to illustrate both how demands and system efficiencies change under different climatic/hydrological conditions and when different types of supplies are used.

Figure 4.2.3 Current Agricultural Diversion Demand by Basin



As discussed in Section 2, the agricultural diversion demand is calculated by dividing the IWR by system efficiency. In dry years for example, IWR is generally higher due to increased temperatures, lower precipitation, and decreased available surface water supplies for irrigation. In these types of years, many irrigators implement additional operational measures to be more efficient with the limited surface water irrigation supplies, resulting in a lower overall dry-year diversion demand. For irrigators with groundwater supplies, the groundwater demand generally increases in response to higher IWR in dry years. System efficiencies range across basins and year types due to availability of irrigation supplies; irrigation practices (i.e., sprinkler or flood applications); and on-farm conditions such as ditch/lateral alignments, soil types, and field topography. Refer to the basin-specific results for more information on conditions that impact the system efficiency and the agricultural diversion demand.

DIVERSION DEMAND

The diversion demand represents the amount of water that would need to be diverted or pumped to meet the full crop IWR and does not reflect historical irrigation supplies. Irrigators often operate under water-short conditions and do not have enough supply to fully irrigate their crop.

Table 4.2.2 Current Irrigated Acreage, Average Annual IWR, and Diversion Demand

Basin	Acreage	Average IWR (AF)	Unit IWR (feet)	Total Diversion Demand (AF)		
				Wet Year	Average Year	Dry Year
Arkansas	445,000	980,000	2.20	1,894,000	1,872,000	1,962,000
Colorado	206,700	456,500	2.21	1,640,000	1,608,000	1,538,000
Gunnison	234,400	528,200	2.25	1,824,000	1,814,000	1,716,000
North Platte	113,600	191,100	1.68	548,000	555,000	489,000
Rio Grande	515,300	1,021,000	1.98	1,801,000	1,800,000	1,849,000
South Platte/Metro (and Republican)	1,433,100	2,337,000	1.63	3,340,000	3,645,000	3,873,000
Southwest	222,500	474,900	2.13	980,000	1,025,000	1,007,000
Yampa-White-Green	107,000	197,000	1.84	637,000	645,000	645,000
Total	**3,280,000**	**6,190,000**	**1.89**	**12,664,000**	**12,964,000**	**13,079,000**

Table 4.2.3 Current Agricultural Diversion Demand for Surface and Groundwater Supplies

Basin	Surface Water Demand (AF)			Groundwater Demand (AF)		
	Wet Year	Average Year	Dry Year	Wet Year	Average Year	Dry Year
Arkansas	1,567,000	1,497,000	1,501,000	327,000	375,000	461,000
Colorado	1,640,000	1,608,000	1,538,000	-	-	-
Gunnison	1,824,000	1,814,000	1,716,000	-	-	-
North Platte	548,000	555,000	489,000	-	-	-
Rio Grande	1,237,000	1,172,000	1,195,000	564,000	628,000	654,000
South Platte/Metro (and Republican)	2,078,000	2,186,000	2,108,000	1,262,000	1,459,000	1,765,000
Southwest	980,000	1,025,000	1,007,000	-	-	-
Yampa-White-Green	637,000	645,000	645,000	-	-	-
Total	**10,511,000**	**10,502,000**	**10,199,000**	**2,153,000**	**2,462,000**	**2,880,000**

As reflected in the Tables 4.2.2 and 4.2.3 (on previous page), the current statewide total agricultural diversion demand is approximately 13 million acre-feet, with more than 80 percent of that demand attributable to surface water supplies.

Future Diversion Demands

The following graphics and tables summarize the acreage, IWR, and the agricultural diversion demand attributable to surface and groundwater supplies in each basin calculated for the five planning scenarios based on the adjustment factors and approach discussed in Section 2. Future agricultural diversion demands were adjusted to reflect:

- Urbanization
- Planned Agricultural Projects
- Groundwater Acreage Sustainability
- Climate
- Emerging Technologies

The two factors anticipated to have substantial statewide impact are urbanization and climate. Table 4.2.4 reflects basin-specific and statewide historical urbanization, projected urbanized acreage and current levels of irrigated acreage for context. Between the late 1980s and early 1990s to present, more than 58,000 irrigated acres were urbanized (based on historical irrigated acreage assessments and current municipal boundaries). By 2050, approximately 152,500 additional irrigated acres are projected to be taken out of production due to urbanization (based on irrigated lands within or intersecting current municipal boundaries). This is approximately 5 percent of the total irrigated land statewide. The largest amount of urbanization is expected in the South Platte Basin, with more than 12 percent of the irrigated acreage in basin projected to be urbanized.

Table 4.2.4 Projected Loss of Irrigated Acreage Due to Urbanization

Basin	Historically Urbanized Irrigated Acreage	Projected Urbanized Irrigated Acreage	Current Irrigated Acreage
Arkansas	N/A*	7,240	445,000
Colorado	6,060	13,590	206,700
Gunnison	2,380	14,600	234,400
North Platte	2	40	113,600
Rio Grande	N/A*	4,010	515,300
South Platte/Metro (and Republican)	49,400	107,310	1,433,100
Southwest	100	3,800	222,500
Yampa-White-Green	135	1,860	107,000
Total	**58,060**	**152,450**	**3,277,600**

* *Neither a 1987 nor a 1993 basin-wide acreage assessment has been developed.*

Future agricultural diversion demands will be affected by climate conditions. Section 2 described two climate projections with warmer and drier futures (“Hot and Dry” and “In Between” projections) that are incorporated into three of the five planning scenarios. Figure 4.2.4 shows annual factors used to adjust IWR and reflect future conditions in “Hot and Dry” and “In Between”. The factors in Figure 4.2.4 were averaged across the West Slope and East Slope basins. “Hot and Dry” and “In Between” generally predict warmer summer conditions in basins at higher elevations. Consequently, the West Slope factors are generally higher than those developed for the East Slope basins. Additionally, projections tend to show warmer conditions during years that were historically cooler and/or had higher precipitation, resulting in higher IWR adjustment factors. The opposite occurs during drought periods, when some warming may occur, but during periods that are expected to already be hot and dry. As a result, IWR adjustment factors during drought years tend to be lower (for example, 2002 or 2012).

Statewide Results

Future statewide agricultural diversion demand estimates range from 10 million AFY in *Adaptive Innovation* to 13.5 million AFY in *Hot Growth*. For basins with limited acreage adjustments, such as the Colorado, Gunnison, and Southwest basins, the agricultural diversion demands in *Business as Usual* and *Weak Economy* are projected to be similar to current demand. In these basins, climate change projections and efficiency adjustments had a significant impact on results, showing more variable demands in *Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth*. For basins with significant irrigated acreage reductions, such as the South Platte and Republican basins, demands in all planning scenarios are projected to be lower than current demand. The largest variation in most basins occurred in the *Adaptive Innovation*. scenario due to the 10 percent reduction in IWR and 10 percent increase to system efficiency. In some basins, such as the Southwest basin, the combined impact of the *Adaptive Innovation* scenario adjustments resulted in lower projected agricultural diversion demands than current.

Figure 4.2.4 Average IWR Change Factors

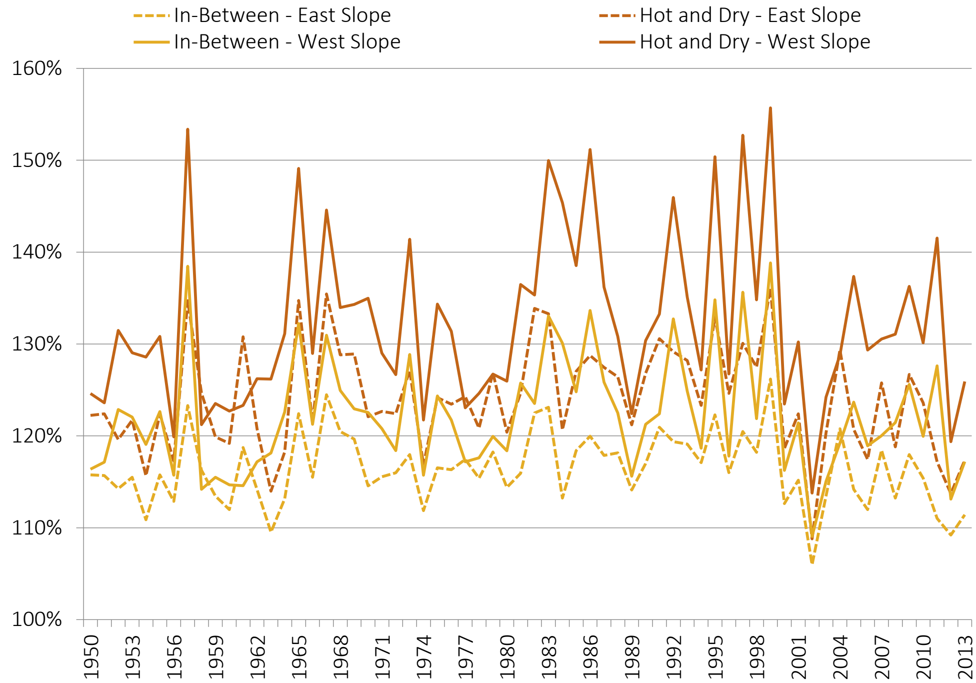
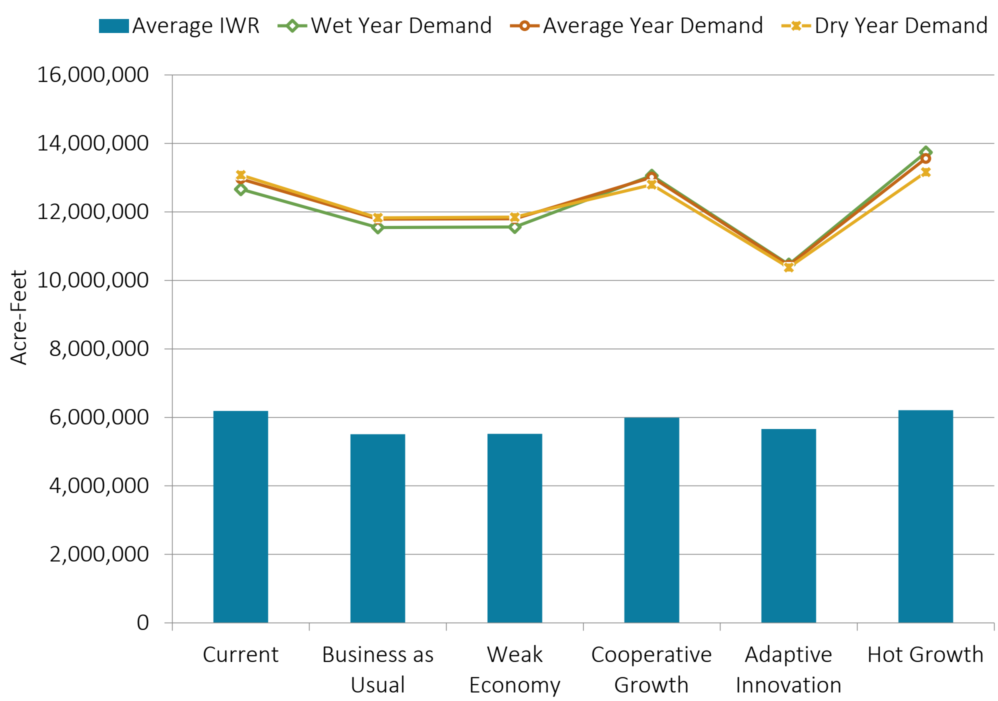


Figure 4.2.5 Statewide Agricultural Diversion Demand Estimates for Scenarios



RETURN FLOWS

Irrigation return flows (irrigation water not consumed by crops) return to streams and are part of the supply that downstream irrigators divert. In effect, diverted irrigation water can be used and reused several times in a basin. The agricultural diversion demand is the amount of water that would need to be diverted or pumped to meet the full crop irrigation demand, it but does not consider the re-diversion of return flows. As a result, it is not appropriate to assume the total diversion demand reflects the amount of native streamflow that would need to be diverted to fully irrigate crops.

Table 4.2.5 Statewide Summary of Projected Agricultural Diversion Demands

Planning Scenario	Acreage	Average IWR (AF)	Total Diversion Demand (AF)		
			Wet Year	Average Year	Dry Year
Current	3,280,000	6,190,000	12,664,000	12,964,000	13,079,000
Business as Usual	2,890,000	5,510,000	11,544,000	11,786,000	11,829,000
Weak Economy	2,890,000	5,520,000	11,559,000	11,802,000	11,846,000
Cooperative Growth	2,840,000	5,990,000	13,059,000	13,012,000	12,796,000
Adaptive Innovation	2,820,000	5,660,000	10,465,000	10,442,000	10,377,000
Hot Growth	2,780,000	6,210,000	13,736,000	13,561,000	13,163,000

Table 4.2.6 Statewide Summary of Projected Surface Water and Groundwater Diversion Demands

Basin	Surface Water Demand (AF)			Groundwater Demand (AF)		
	Wet Year	Average Year	Dry Year	Wet Year	Average Year	Dry Year
Current	10,511,000	10,502,000	10,199,000	2,153,000	2,462,000	2,880,000
Business as Usual	9,755,000	9,714,000	9,393,000	1,789,000	2,072,000	2,436,000
Weak Economy	9,775,000	9,735,000	9,415,000	1,784,000	2,067,000	2,431,000
Cooperative Growth	11,226,000	10,899,000	10,369,000	1,833,000	2,113,000	2,427,000
Adaptive Innovation	8,771,000	8,492,000	8,164,000	1,694,000	1,950,000	2,213,000
Hot Growth	11,848,000	11,399,000	10,723,000	1,888,000	2,162,000	2,440,000

4.2.3 Statewide M&I Diversion Demands

The updated M&I diversion demands include baseline demands (estimated for the year 2015) and projected future demands for the year 2050 for the five planning scenarios. Results of population projections, water usage rates, total municipal demands and total SSI demands are described below.

Population Projections

Approximately 88 percent of the state's population lives along the Front Range in either the Arkansas or South Platte Basins (which includes the "Metro" sub-basin). The statewide baseline population, which is based on 2015, is less than the amount that SWSI 2010 projected for the year 2015. While most basins have increased in population, the Gunnison, North Platte, Rio Grande, and Yampa-White basins have decreased. A basin-level summary is provided in Table 4.2.7.

As described in Section 2, population projections for the five planning scenarios were derived from 2017 SDO population projections and statistically-derived high and low growth projections for each basin. Population projections based on these methodologies are shown in Table 4.2.7.

DROUGHT RESPONSE

M&I demand projections do not represent drought conditions when more aggressive conservation may occur or associated responses to drought when measures such as watering restrictions may be imposed.

POPULATION GROWTH PROJECTIONS

Business as Usual:	Medium
Weak Economy:	Low
Cooperative Growth:	Medium, Adjusted
Adaptive Innovation:	High, Adjusted
Hot Growth:	High

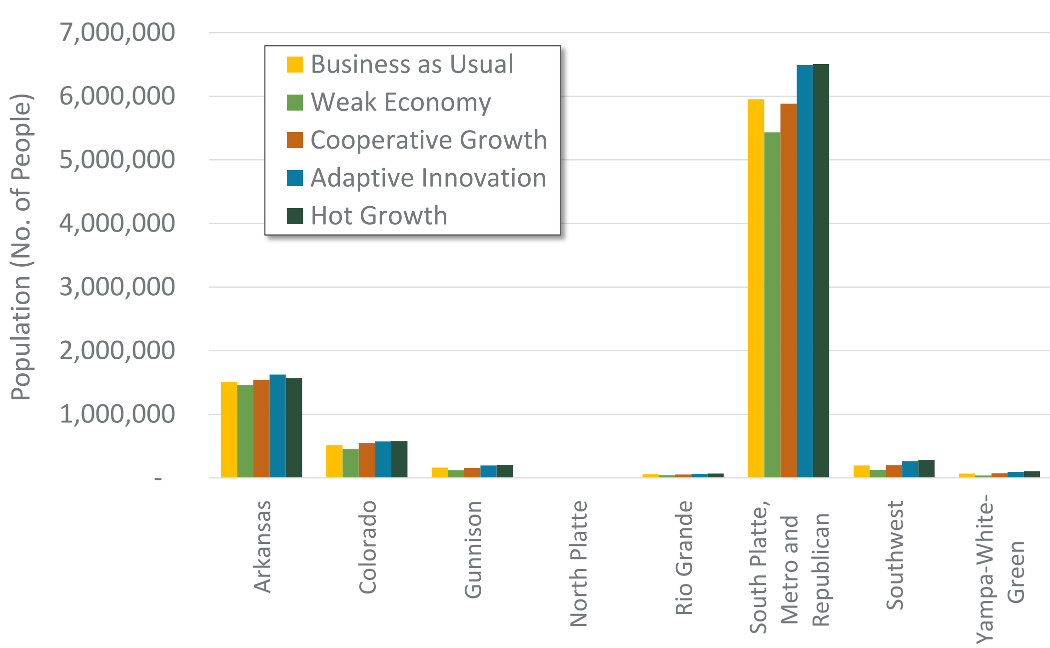
Table 4.2.7 Current and Projected Future Population (in number of people unless otherwise indicated)

Basin	SWSI 2010 Projection for 2015*	SWSI Update Baseline (2015)		Planning Scenarios				
		Population	% of state total	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Arkansas	1,067,000	1,008,400	19%	1,509,500	1,462,800	1,544,400	1,626,000	1,568,000
Colorado	366,000	307,600	6%	515,500	456,300	549,200	572,900	577,800
Gunnison	125,000	103,100	2%	162,600	123,100	158,600	196,000	204,900
North Platte	1,600	1,400	0%	1,300	1,100	1,200	1,400	1,500
Rio Grande	54,000	46,000	1%	55,100	42,300	52,100	63,000	67,300
South Platte/Metro ** (and Republican)	3,964,000	3,829,800	70%	5,954,300	5,433,200	5,884,400	6,492,400	6,507,700
Southwest	123,000	108,000	2%	195,800	125,800	201,000	264,200	282,100
Yampa-White-Green	53,000	43,700	1%	67,300	38,600	70,500	96,600	103,200
Statewide	**5,754,600**	**5,448,100**	**100%**	**8,461,300**	**7,683,200**	**8,461,300**	**9,312,400**	**9,312,400**

* *SWSI 2010 Appendix H, Exhibit 36 (CWCB, 2010a)*
** *Metro region was reported separately in SWSI 2010*
Note: Due to rounding, the statewide total may not precisely match the sum of basin results shown in the table above

Figure 4.2.6 shows population projections for 2050, summarized by river basin. Between the years 2015 and 2050, the population is projected to grow from approximately 5.5 million to between 7.7 million to 9.3 million in the low and high scenarios, respectively, which is an increase of about 41 to 71 percent.

Figure 4.2.6 2050 Projected Population by Scenario by Basin



Municipal Demands

Municipal demands were calculated for each county and then summarized by river basin. Water demands for counties located in multiple basins were distributed between basins by using the portion of the county population located within each basin to prorate the water demands.

The statewide baseline water demands were largely based on water provider-reported data, with approximately 70 percent of the baseline population demands represented by 1051 data as shown in Figure 4.2.7. The figure also shows the sources of other demand data.

The statewide baseline per capita systemwide demand has decreased from 172 gpcd in SWSI 2010 to approximately 164 gpcd, which is nearly a 5 percent reduction in demands between 2008 and 2015. The reduction is associated with improved data availability, conservation efforts, and ongoing behavioral changes. There are more significant differences from SWSI 2010 at a basin level and these are described in Volume 2 titled *Current and Projected Planning Scenario Municipal and Self-Supplied Industrial Water Demands*.

Figure 4.2.7 Statewide Baseline Municipal Demand Data Sources

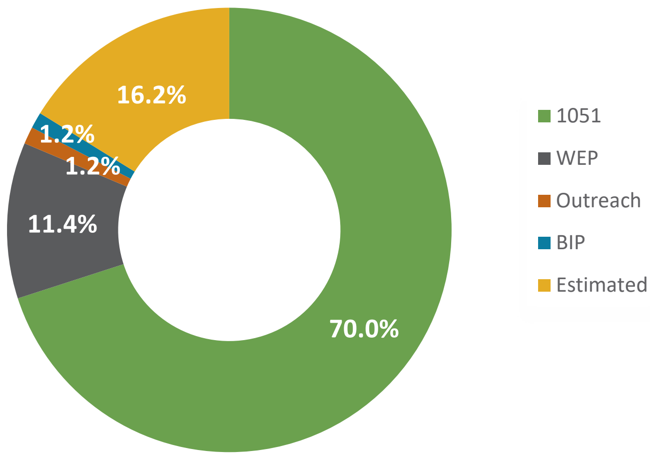


Table 4.2.8 shows baseline and projected per capita demands for basins throughout the state for the five planning scenarios. *Adaptive Innovation* has the lowest per capita demands, and *Hot Growth* has the highest per capita demands, both statewide and within each basin. Note that the statewide per capita demand projections do not match the Water Plan scenario ranking and they were not intended to do so. For example, *Adaptive Innovation* results in the lowest per capita demand, but coupling this with the highest population projection results in the second highest overall demand volume across the scenarios, as further described below.

Table 4.2.8 Per Capita Demand Projections by Planning Scenario for Each Basin (gpcd)

			Planning Scenarios				
Basin	**SWSI 2010 Projection for 2015** *	**2015 Baseline**	**Business as Usual**	**Weak Economy**	**Cooperative Growth**	**Adaptive Innovation**	**Hot Growth**
Arkansas	185	194	179	179	170	164	192
Colorado	182	179	153	156	145	136	165
Gunnison	174	158	146	149	140	133	160
Metro	155	141	138	135	130	126	148
North Platte	310	264	245	254	242	232	270
Rio Grande	314	207	194	198	188	177	209
Republican	see note**	245	236	236	221	214	251
South Platte	188	181	176	174	164	158	190
Southwest	183	198	181	186	173	166	199
White	see note***	252	240	254	240	231	269
Yampa	230	224	172	197	161	150	180
Statewide	**172**	**164**	**157**	**155**	**148**	**143**	**169**

* *SWSI 2010 per capita values from SWSI 2010 Appendix L, Tables 8, 14, 15, and 16 (CWCB, 2011b)*
** *The Republican Basin demands were included in the South Platte Basin demand reporting for SWSI 2010*
*** *The White Basin demands were included with the Yampa Basin demand reporting for SWSI 2010.*

Statewide baseline municipal water demands are comprised of the water use classes shown in Figure 4.2.8. Residential indoor is the largest category of municipal demand statewide followed by residential outdoor and non-residential indoor.

For each planning scenario, residential indoor demands represent the largest category of water demand, starting at nearly 52 gpcd for the 2015 Baseline. The projected residential indoor demands vary greatly across planning scenarios, from 46 gpcd in *Weak Economy* to 36.5 gpcd in *Adaptive Innovation*. Other demand categories show less variability across the scenarios, as shown in Figure 4.2.9.

Adjustments related to climate change that increase demand tended to offset reductions in outdoor use that decreased demand, especially in *Cooperative Growth* and *Adaptive Innovation*. In spite of climate change impacts, however, *Adaptive Innovation* projects the lowest total per capita demand.

CONSERVATION POTENTIAL

The indoor and outdoor demand driver adjustments, coupled with the adoption rate methodology, generally result in higher per-capita demand projections than the active conservation savings projected in SWSI 2010. Unlike SWSI 2010, the Technical Update demand projections are not intended to capture the full range of future active conservation potential. Additional future conservation may still be achieved under each planning scenario through identified projects and processes.

CONSERVATION & GROWTH

The planning scenarios often paired high water-savings drivers with high population growth or low demand reductions with low growth, resulting in a narrowing of the range in demand projections.

Figure 4.2.8 Statewide Baseline Municipal Demand Category Distribution

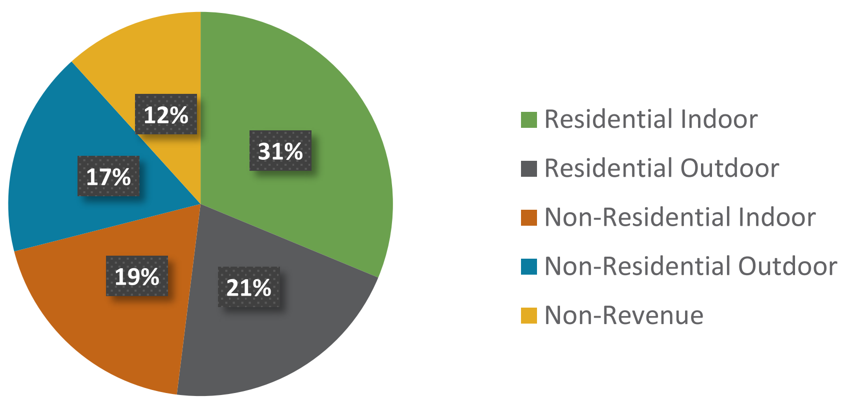


Figure 4.2.9 Statewide per Capita Demand for Five Planning Scenarios by Demand Category

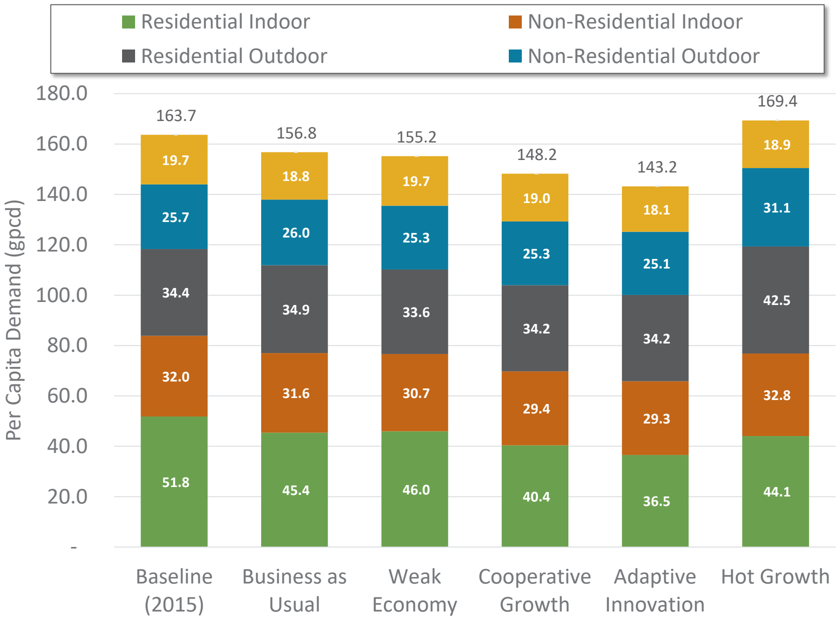


Table 4.2.9 presents baseline and projected demands for basins throughout the state, showing the combined effect of population and per capita demands. The municipal demands are projected to grow from approximately 1.0 million AFY in 2015 to between 1.34 and 1.77 million AFY in 2050.

Table 4.2.9 Statewide Municipal Baseline and Project Demands by Basin (AFY)

Basin	Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Arkansas	219,200	303,400	293,800	294,500	298,100	337,200
Colorado	61,800	88,600	79,900	89,000	87,500	106,600
Gunnison	18,300	26,700	20,500	24,900	29,100	36,800
North Platte	400	400	300	300	400	400
Rio Grande	10,600	11,900	9,400	11,000	12,500	15,700
South Platte/Metro (and Republican)	653,300	1,001,600	896,600	932,800	999,900	1,185,200
Southwest	24,000	39,800	26,200	38,900	49,200	62,900
Yampa-White-Green	11,200	13,500	8,800	13,300	17,200	21,900
Statewide	**998,700**	**1,485,800**	**1,335,500**	**1,404,700**	**1,493,900**	**1,766,700**

Note: Due to rounding, the statewide total may not precisely match the sum of basin results shown in the table above

Figure 4.2.10 Statewide Baseline and Projected Population and Municipal Demands

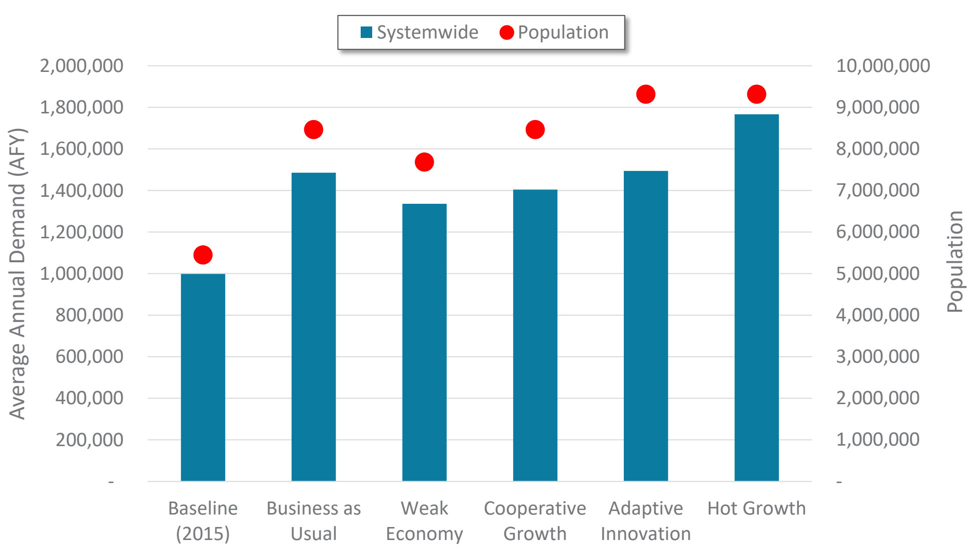


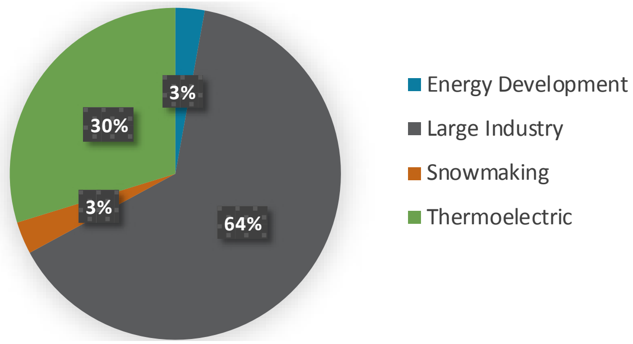
Figure 4.2.10 compares municipal water demands with population projections for each of the planning scenarios. *Business as Usual* and *Cooperative Growth* both use the medium population projection on a statewide basis, with different distributions between counties. Similarly, *Adaptive Innovation* and *Hot Growth* both use the high population projection on a statewide basis, with different distributions between counties. The influence of the population is so significant that the demand projections for all scenarios are relatively similar aside from *Hot Growth*, which has high population coupled with climate change. *Adaptive Innovation* stands out among the others in that it has the greatest reductions in per capita demand but is paired with both the highest population and "Hot and Dry" climate projection. Even with the high population projection and high outdoor demands due to hot and dry future climate conditions, the water-saving measures included in *Adaptive Innovation* are projected to reduce demands to just above *Business as Usual*, demonstrating the benefits of increased conservation.

Self-Supplied Industrial Diversion Demands

As with municipal diversion demands, the updated SSI demands include both baseline demands (estimated as 2015 demands) and demands in the year 2050 for the five planning scenarios. The demand projections do not reflect drought conditions or associated responses. SSI demands were calculated at the county level and then summarized by river basin. No county-level SSI demands had to be distributed between multiple basins.

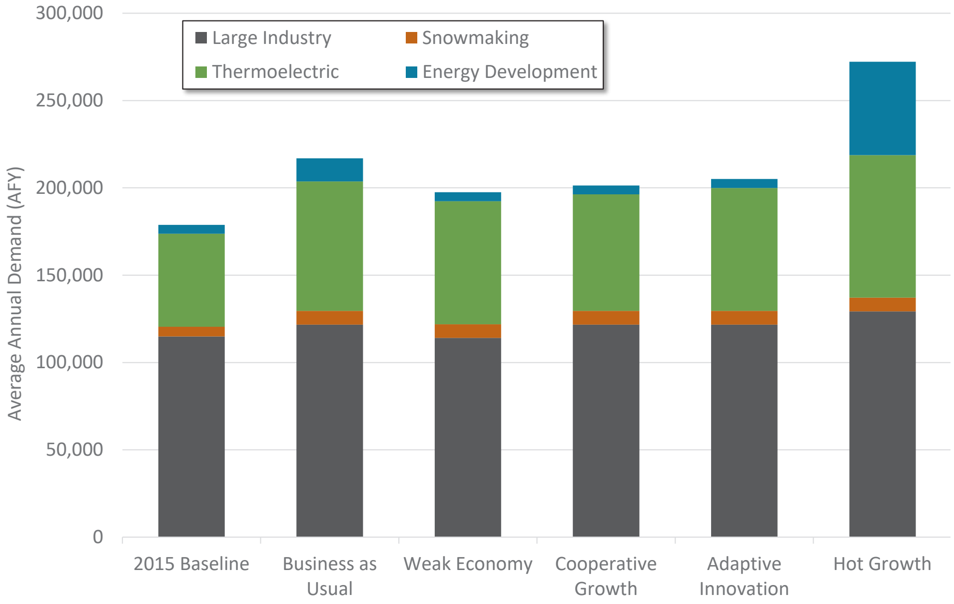
Statewide baseline SSI water demands are comprised of four major industrial uses, as shown on Figure 4.2.11.

Figure 4.2.11 Statewide Baseline SSI Sub-Sector Distribution



The projected demands for all planning scenarios were calculated based on the methodology described in Section 2. The results of the calculations are illustrated in Figure 4.2.12 and shown in Table 4.2.10. With the exception of *Hot Growth*, the updated projections for all planning scenarios were below SWSI 2010 estimates, primarily due to changes in assumptions for thermoelectric demands related to regulations that require an increase in power generation from renewable sources (the assumption was based on input from M&I TAG participants). Thermoelectric demand accounts for a large component of total SSI demand, and the methodology changes had a relatively large effect on the results. Large industry, snowmaking, and energy development projections are generally comparable to the ranges projected in SWSI 2010. There is little variation in the projections aside from *Hot Growth*.

Figure 4.2.12 Statewide Baseline and Projected SSI Demands



Total M&I

Table 4.2.10 and Figure 4.2.13 show statewide municipal and industrial baseline 2015 and projected 2050 water demands for the five planning scenarios. Total statewide M&I demands projected for 2050 range from approximately 1.5 million AFY (*Weak Economy*) to 2.0 million AFY (*Hot Growth*).

For all basins except for the Yampa, municipal demands exceed the self-supplied industrial demands for every planning scenario. Statewide, self-supplied industrial demands are around 15 percent to 18 percent of the municipal demands.

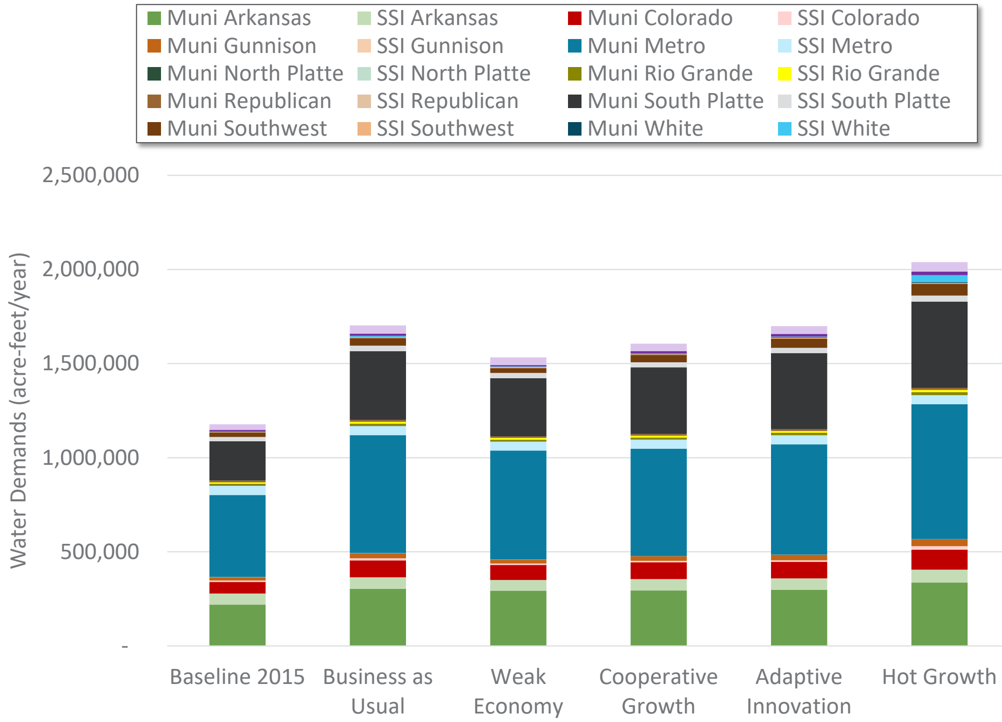
As discussed previously, the Water Plan rankings were the guiding objective in preparing average annual statewide volumetric demands. Statewide municipal projections followed the Water Plan rankings; however, industrial and combined M&I demands deviated to a limited degree, with *Business as Usual* demands exceeding *Adaptive Innovation* demands. These results show that *Business as Usual* and *Adaptive Innovation* futures may be similar, which indicates innovative conservation program measures have the potential to significantly offset the higher population and much warmer climate in *Adaptive Innovation* scenario.

Table 4.2.10 Summary of M&I Demands for Each Basin and Statewide (AFY)

Basin	Demand Type	Baseline 2015	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Arkansas	Municipal	219,200	303,400	293,800	294,500	298,100	337,200
	SSI	58,700	61,700	56,200	60,500	61,100	67,900
	Total	277,900	365,100	350,000	355,000	359,200	405,100
Colorado	Municipal	61,800	88,600	79,900	89,000	87,500	106,600
	SSI	7,800	12,300	7,600	7,800	7,800	18,500
	Total	69,600	100,900	87,500	96,800	95,300	125,000
Gunnison	Municipal	18,300	26,700	20,500	24,900	29,100	36,800
	SSI	300	700	700	700	700	700
	Total	18,500	27,300	21,200	25,500	29,800	37,400
North Platte	Municipal	400	400	300	300	400	400
	SSI	-	-	-	-	-	-
	Total	400	400	300	300	400	400
Rio Grande	Municipal	10,600	11,900	9,400	11,000	12,500	15,700
	SSI	7,900	9,900	9,000	9,900	9,900	10,800
	Total	18,500	21,800	18,300	20,900	22,400	26,500
South Platte /Metro (and Republi-can)	Municipal	653,300	1,001,600	896,600	932,800	999,900	1,185,200
	SSI	72,200	78,200	76,300	75,700	76,900	81,500
	Total	725,500	1,079,800	972,900	1,008,500	1,076,900	1,266,700
Southwest	Municipal	24,000	39,800	26,200	38,900	49,200	62,900
	SSI	2,300	4,300	4,100	3,900	4,100	4,700
	Total	26,300	44,100	30,400	42,800	53,300	67,600
Yampa-White-Green	Municipal	11,200	13,500	8,800	13,300	17,200	21,900
	SSI	29,600	49,800	43,700	43,000	44,600	88,300
	Total	40,800	63,300	52,400	56,300	61,800	110,200
Statewide	**Municipal**	**998,700**	**1,485,800**	**1,335,500**	**1,404,700**	**1,493,900**	**1,766,700**
	SSI	**178,800**	**216,900**	**197,500**	**201,400**	**205,100**	**272,200**
	Total	**1,177,500**	**1,702,700**	**1,533,000**	**1,606,100**	**1,699,000**	**2,039,000**

Note: Due to rounding, the statewide total may not precisely match the sum of basin results shown in the table above

Figure 4.2.13 Baseline and Projected M&I Demands by Basin



4.2.4 East Slope Transbasin Imports

Water from the West Slope of Colorado is a significant source of supply to East Slope municipal and agricultural water users in the South Platte and Arkansas basins. In the future, historical levels of West Slope supply may not be available, and a portion of the demand could go unmet depending on future climate conditions. Table 4.2.11 below provides combined demands for West Slope supplies for both the South Platte and Arkansas basins and combined unmet demands in these basins for the planning scenarios. The amount of unmet demand for West Slope supplies would increase the gap in these basins, likely in an amount that is more than the unmet demand, because municipalities reuse their return flows from water imported from the West Slope.

The focus of this section and Table 4.2.11 is on East Slope transbasin imports, but transbasin imports occur in other basins aside from the South Platte and Arkansas; however, the amount of water associated with these other basin transfers are significantly less. While data describing other transbasin imports and potential changes in the planning scenarios is not presented in the Technical Update report, the modeling data will be available to basin roundtables that choose to evaluate potential future changes to transbasin imports.

Table 4.2.11 Transbasin Demands in the South Platte and Arkansas Basins

	Scenario					
	Baseline	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average Annual Import Demand (ac-ft)	515,000	515,000	515,000	515,000	515,000	515,000
Average Annual Unmet Demand (ac-ft)	0*	0*	0*	26,000	50,000	55,000
Import in Max East Slope Gap Year (ac-ft)	495,000	495,000	495,000	560,000	467,000	467,000
Unmet Demand in Max East Slope Gap Yr (ac-ft)	0*	0*	0*	57,000	122,000	158,000
Percent Unmet Demand in Max East Slope Gap Year	0%	0%	0%	10%	26%	34%

**CDSS water allocation models calculate unmet demands in the baseline and Business as Usual and Weak Economy scenarios. Because historical values were used for import demand, the unmet demands in these scenarios indicate a calibration issue in the source basin.*

4.2.5 Water Availability

The projected availability of future water supplies varies across the state and is influenced by basin-specific hydrology and water uses, geographic location within basins, and compact constraints. As a result, it is difficult to generalize future water availability on a statewide basis and can be complicated to describe within basins. The following general observations can be made:

- No water is currently available or will be available in the future to meet additional needs in the Republican, Arkansas, and Rio Grande basins.
- Water availability is projected to decrease in *Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth* due to the impacts of warmer and drier climate conditions. Peak flows are projected to occur earlier in the runoff season, and streamflows may be diminished later in the summer.
- In locations where available flows occur only periodically under current conditions (mainly during wet years), it may be available less frequently and in lower volumes. If the climate becomes warmer and drier, droughts and periods of low to no flow availability in these basins may be longer in duration.
- In basins where water is generally available every year, volumes of annual available flow may decrease overall and timing may change (peak flows may occur earlier in the runoff season).

4.2.6 Yield of Future Projects

As described in Section 3, the Technical Update analyses did not include future water supply projects and strategies that will help mitigate M&I and agricultural gaps; however, water providers are contemplating a wide variety of projects and strategies to meet their future needs. SWSI 2010 provided information on future projects and strategies that were then being pursued by water providers to meet future demands. The types of projects and strategies included agricultural water transfers (traditional and alternative), reuse, growth into existing supplies, regional in-basin projects, new transbasin projects, firming in-basin water rights, and firming transbasin rights. Ranges of potential yields for these projects and strategies by type and by basin were presented assuming 100 percent and also lower rates of success in achieving the contemplated yield of the projects. Table 4.2.12 shows the amount of yield in each basin for various rates of success that were included in the gap calculations in SWSI 2010.

The data in Table 4.2.12 were not updated in the Technical Update, and yields of future projects in SWSI 2010 were not developed considering future potential impacts of the planning scenarios. Nevertheless, the data in the table show that water providers are currently pursuing significant water supply projects and strategies that will help fill future gaps. Basin roundtables will be encouraged to update and improve the quality of their data describing future projects and strategies during upcoming BIP updates (see Section 5 for more details).

Table 4.2.12 Yields of Identified Projects and Processes from SWSI 2010

	SWSI 2010 Estimated Yield of Identified Projects and Processes (AFY)		
	100% IPP Success Rate (low)	**Alternative IPP Success Rate (medium)**	**Status Quo IPP Success Rate (high)**
Arkansas	88,000	85,000	76,000
Colorado	42,000	49,000	63,000
Gunnison	14,000	14,000	16,000
Metro	140,000	97,000	100,000
North Platte	100	200	300
Rio Grande	5,900	6,400	7,700
South Platte	120,000	78,000	58,000
Southwest	14,000	13,000	15,000
Yampa-White-Green	10,000	11,000	13,000
Statewide	**430,000**	**350,000**	**350,000**

This table reflects data from Table 5-12 in the SWSI 2010 report.

4.2.7 Environment and Recreation Conditions

Future conditions and risks for E&R attributes vary across the state depending on location and planning scenario. Future E&R conditions will be influenced by basin-specific hydrology, water uses, and geographic location within basins. As a result, it is difficult to precisely characterize future E&R conditions and risks on a statewide basis (regional specific observations are included in basin summaries). The following general observations can be made:

- Climate change and its impact on streamflow will be a primary driver of risk to E&R attributes.
- Projected future streamflow hydrographs in most locations across the state show earlier peaks and potentially drier conditions in the late summer months under scenarios with climate change.
- Under climate change scenarios, runoff and peak flows may occur earlier, resulting in possible mismatches between peak flow timing and species' needs.
- Drier conditions in late summer months could increase risk to coldwater and warmwater fish due to higher water temperatures and reduced habitat. The degree of increased risk is related to the level of streamflow decline.
- In many mountainous regions without significant influence of infrastructure, peak flow, and low flows are projected to be sufficient to sustain low to moderate risk for riparian plants and fish, but risks are projected to increase in scenarios with climate change.
- In mountainous regions with infrastructure, risks to E&R attributes may vary. Streams that are already depleted may see increased risks in scenarios with climate change. However, some streams may be sustained by reservoir releases, which will help moderate risks in scenarios with climate change.
- Instream flow water rights and recreational in-channel diversion water rights may be met less often in climate-impacted scenarios.

Modeling results for each of the eight major river basins are listed alphabetically in the following sections.

The Arkansas River originates in the central mountains of Colorado near Leadville, then travels eastward through the southeastern part of Colorado toward the Kansas border. The Arkansas Basin is spatially the largest river basin in Colorado, covering slightly less than one-third of the state's land area. A large amount of land is devoted to agriculture, with one-third of agricultural lands requiring irrigation. Increasing urbanization is occurring throughout portions of the Arkansas Basin, and in the recent past, persistent drought has heavily affected the basin.

The Arkansas River Compact of 1948 apportions the waters of the Arkansas River between Colorado and Kansas, while providing for the operation of John Martin Reservoir. Since the early 20th century, Colorado and Kansas have litigated claims concerning Arkansas River water, which has led to the development of rules and regulations to administer the basin's water resources for compliance with the compact.

ARKANSAS

LIMON
KIT CARSON
Big Sandy Creek
Rush Creek
Nee Noshe Reservoir
Adobe Creek Reservoir
District 17
Arkansas - Fowler to Las Animas
District 67
Arkansas - Las Animas to Stateline
Meredith Lake
Horse Creek Reservoir
LAMAR
ROCKY FORD
LA JUNTA
Apishapa River
Timpas Creek
Purgatoire River
Two Buttes Creek
PRITCHETT
District 19
Purgatoire River
District 66
Cimarron River
24
70
59
385
94
40
71
96
350
10
89
116
287
160

4.3 ARKANSAS BASIN RESULTS

4.3.1 BASIN CHALLENGES

The Arkansas Basin will face several key opportunities and challenges pertaining to water management issues and needs in the future. These were described in Colorado's Water Plan and are summarized below.

Table 4.3.1 Key Future Water Management Issues in the Arkansas Basin

<table>
<tr><th>Agriculture</th><th>Environment and Recreation</th><th>Municipal and Industrial</th><th>Compacts and Administration</th></tr>
<tr><td>• Concerns over permanent agricultural transfers and the effects on rural economies are substantial in the lower portion of the basin downstream of Pueblo Reservoir.</td><td>• As the most rafted river in the world, the Arkansas River Voluntary Flow Agreement provides a benchmark for cooperative integration of municipal, agricultural, and recreational solutions in support of recreational boating and a gold-medal fishery.</td><td>• Replacement of municipal water supplies that depend on the non-renewing Denver Basin aquifer and declining water levels in designated basins is becoming critical, exacerbated by continued growth in groundwater-dependent urban areas.
• Rural areas within the Arkansas Basin have identified water needs but face challenges in marshalling resources to identify and implement solutions.</td><td rowspan="2">• All new uses require augmentation. Increasing irrigation efficiency, i.e., conversion from flood to center-pivot irrigation for labor and cost savings, will require 30,000 to 50,000 AF of augmentation water in the coming years.
• Regional solutions are emerging, like the Southeastern Colorado Water Conservancy District (SECWCD) Regional Water Conservation Plan, which can serve as a model for future regional initiatives to address the needs of the Arkansas Basin.</td></tr>
<tr><td colspan="3">• Collaborative solutions, as demonstrated in the Super Ditch and alternative transfer methods pilot projects, are needed to forestall or minimize loss of irrigated acreage in agriculture.
• Concerns over water quality include drinking water in the Lower Valley and the impact of fires and floods in the Fountain Creek watershed.
• The great majority of surface storage reservoirs in the Arkansas Basin were constructed between 1890 and 1930. Many of these facilities are in need of repair or restoration.</td></tr>
</table>

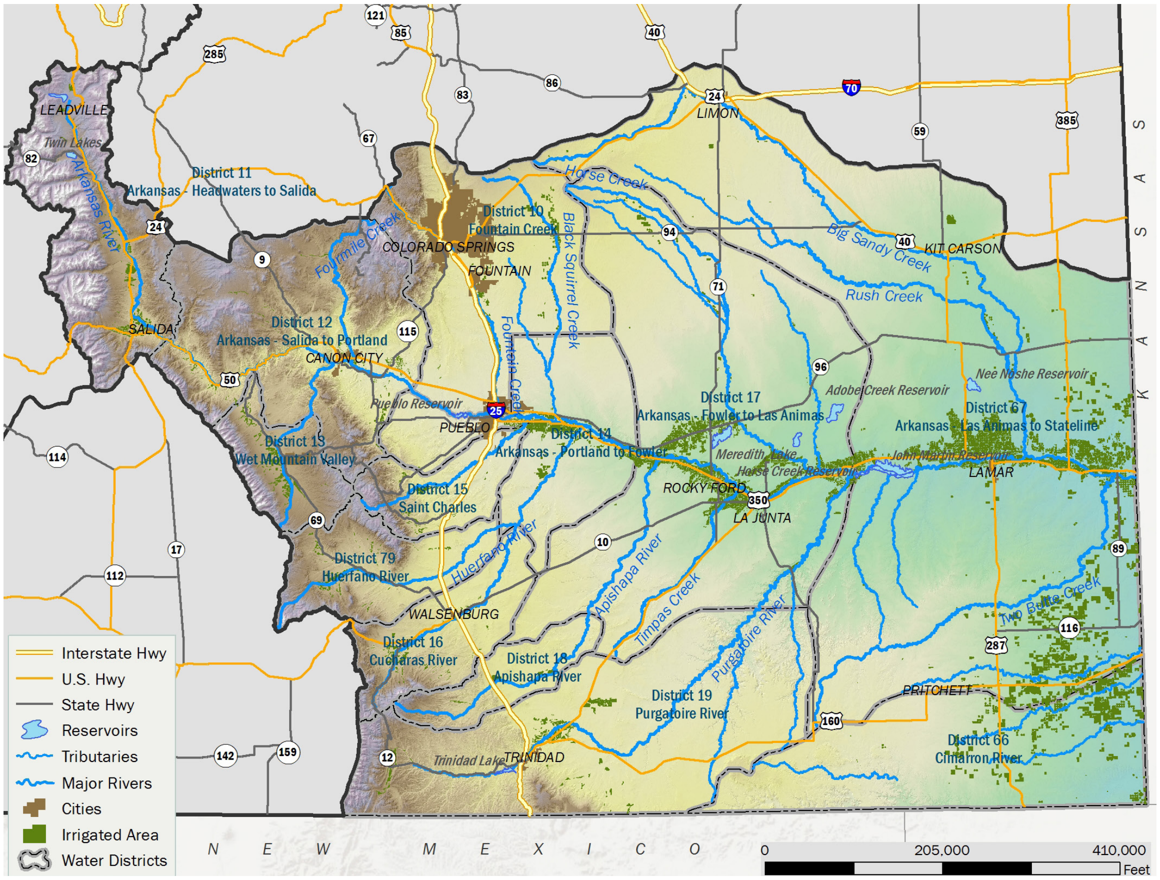


Figure 4.3.1 Map of Arkansas Basin

4.3.2 Summary of Technical Update Results

Key results and findings of the Technical Update pertaining to agricultural and M&I demands and gaps as well as findings related to environment and recreation attributes and future conditions are summarized in Table 4.3.2 below.

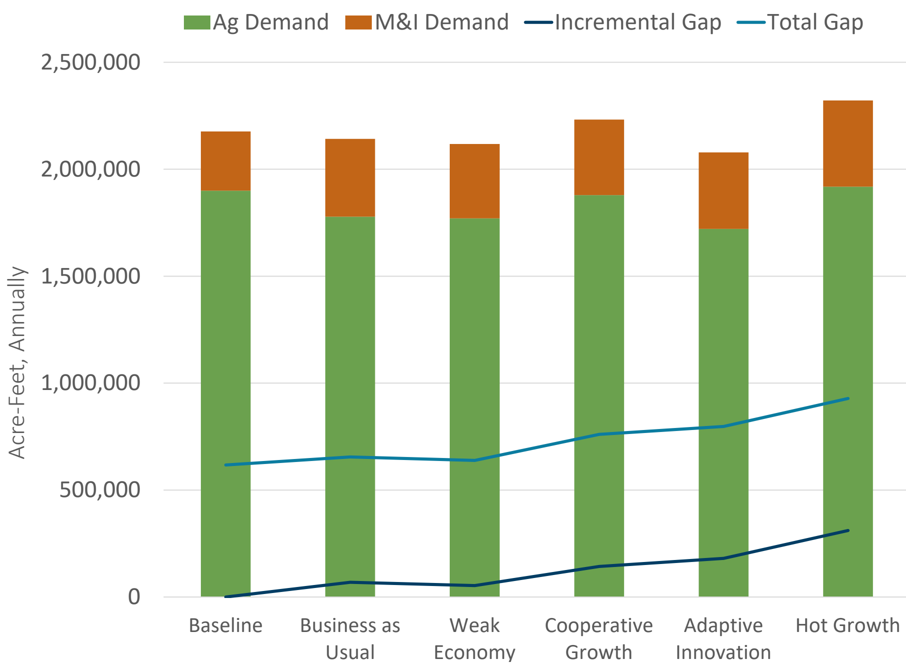
Table 4.3.2 Summary of Key Results in the Arkansas Basin

Agriculture	Environment and Recreation	Municipal and Industrial
• Agricultural demand will remain steady or be slightly reduced due to urbanization (20,000 acres), additional reduction of acres in the Southern High Plains Groundwater Basin, and increased sprinkler use (note that return flow reductions from increased sprinkler use would need to be mitigated). • Agricultural diversion demand gaps may increase due to a warmer climate as much as 10 percent.	• At high elevations, flow magnitude is not projected to significantly change under climate-impacted scenarios, but the annual hydrograph may shift with earlier snowmelt. Risks to riparian and fish habitat would remain low to moderate. • At montane elevations (between 5,500 and 8,500 feet), flow magnitude in climate-impacted scenarios is projected to drop significantly, creating high risk for riparian and fish habitat during the runoff season.	• M&I demand in this basin will grow to become a higher percentage of overall demand (from 13 to 17 percent). At the same time, municipal per capita use is projected to decline by various amounts depending on the scenario. • Municipal demand is driven by population growth in the Colorado Springs and Pueblo area, as well as modest increases in large industry and thermoelectric demand. • Gaps may be exacerbated by reductions in West Slope supplies.

Table 4.3.3 Summary of Diversion Demand and Gap Results in the Arkansas Basin

	Current (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average Annual Demand						
Agricultural (AFY)	1,899,900	1,778,300	1,770,200	1,878,900	1,721,200	1,918,000
M&I (AFY)	276,700	363,300	347,900	353,200	357,600	403,500
Gaps						
Ag (avg %)	32%	33%	33%	37%	43%	43%
Ag (incremental- AFY)	-	-	-	84,400	117,500	202,200
Ag (incremental gap as % of current demand)	-	-	-	4%	6%	11%
M&I (max %)	0%	19%	15%	17%	18%	27%
M&I (max-AF)	0	68,500	53,100	58,500	62,900	108,700

Figure 4.3.2 Summary of Diversion Demand and Gap Results in the Arkansas Basin



Summary of Environmental and Recreational Findings

- A surface water allocation model was not available in the Arkansas Basin, so the available flow dataset only includes natural flows and natural flows as impacted by climate drivers; no management drivers are factored in. Management drivers impact river flows in the eastern plains. Because a water allocation model that incorporates management is not available, no data-based insights into flow change and risk to non-consumptive attributes in the eastern plains could be developed.
- At high elevation locations (e.g., near Leadville), peak flow magnitude is not projected to change substantially, but April and May streamflow may increase, and June flows may decrease under "In-Between" and "Hot and Dry" climate projections. Subsequent risk for riparian/wetland plants and fish habitat would remain low or moderate. Mid- to late-summer streamflow is projected to decrease by 30 to 40 percent, and risk for trout could change from low (current) to moderate (under all climate-driven scenarios).
- At montane locations (elevation approximately 5,500 ft to 8,500 ft), peak flow magnitude is projected to drop 40 to 60 percent under "In-Between" and "Hot and Dry" climate projections, putting riparian/wetland plants and fish habitat at high to very high risk. Mid- to late-summer flows are projected to drop 25 to 45 percent, keeping cold water fish risk low or moderate, although the risk may be higher in July and/or during dry years.

4.3.3 Notable Basin Considerations

Section 4.1 described several analysis assumptions and limitations that apply to all basins and should be considered when reviewing and interpreting analysis results. Additional considerations specific to the Arkansas Basin are listed below:

- Agricultural and M&I gaps in the Arkansas Basin could increase due to reductions in transbasin imports. The gap increase could be more than the reduction in transmountain imports because return flows from transmountain imports are used to extinction within the Arkansas Basin (by either the importing entity or by downstream agricultural and M&I water users).
- Water allocation models were not available in the Arkansas Basin; however, the StateCU portion of the ArkDSS was used to estimate agricultural diversion demands. The ArkDSS is being developed and will allow more robust modeling in the future.
- The analysis assumed that there is no unappropriated water available for new uses. As a result, increased demands in various scenarios contributed directly to the gap. Because of this, increases in demand in one sector will lead to decreases in supply in another sector.
- Agricultural diversion demands were calculated based on irrigated acreage and crop water needs. Because no unappropriated water is available in the basin, the gap evaluation focused on historical water shortages and additional future demands. In other words, given the lack of additional supply, the analysis focused on physical shortages and did not need to consider the presence of junior water rights and whether those rights were fulfilled. Additional future diversion demands contribute directly to the gap because no unappropriated supplies are available in the basin.
- Basin stakeholders have cautioned that large reductions in irrigated land could result in socio-economic impacts that cause a reduction of municipal population in rural areas.
- The analysis does not consider specific alternative crops that may be grown in the future under the different scenarios; however, it accounts for future changes in crop types in a general sense in *Adaptive Innovation* and assumed that future crops would have 10 percent lower IWR.

4.3.4 Agricultural Diversion Demands

Agricultural Setting

Producers irrigate more than 472,000 acres in the Arkansas Basin, with nearly half of these acres located along the river between Pueblo Reservoir and the state line. The fertile soils in the river valley support a wide variety of crops, including pasture grass, alfalfa, corn, grains, wheat, fruits, vegetables, and melons. Many of the large irrigation systems in this area rely on surface water diversions from the mainstem Arkansas River, supplemented with groundwater and Fryingpan-Arkansas Project deliveries. Pasture grass is the primary crop grown outside of the Arkansas River Valley, with concentrated areas of irrigated acreage under the Trinidad Project on the Purgatoire River, along Fountain Creek downstream of Colorado Springs, and in the southeastern corner in the Southern High Plains Ground Water Management District.

The basin also provides water to three of the fastest growing municipalities in the state—Colorado Springs, Aurora, and Pueblo—and competition for water is high. An over-appropriated basin, coupled with the constraints of developing new water supplies under the Arkansas River Compact, have historically led municipalities to purchase and transfer irrigation water rights to municipal uses to meet their growing needs. Beginning in the 1970s, large transfers of irrigation water rights in the Colorado Canal (including Twin Lake shares) resulted in the dry up of 45,000 acres in Crowley County alone, which contributed to socioeconomic and environmental impacts in the Lower Arkansas River Valley. More recently, however, the basin has been proactive at looking for solutions to share water supplies and has been one of the front runners in developing alternative transfer methods such as lease/fallow pilot projects and interruptible supply agreements in which irrigation rights can be temporarily leased to municipalities for a limited number of years (e.g., three years out of every 10 years).

Planning Scenario Adjustments

Section 2 described ways in which inputs to agricultural diversion demand estimates were adjusted to reflect the future conditions described in the planning scenarios. Discussions with stakeholders in the Arkansas Basin regarding what agriculture in the basin may look like by 2050 focused on three major areas: additional dry up of acreage for municipal purposes, declining groundwater aquifer levels in the Southern High Plains region, and irrigation practices. As discussed in more detail below, dry up of acreage and declining aquifer levels impact the amount of projected 2050 irrigated acreage. In addition, irrigation practices affect projected 2050 efficiencies.

Population projections by 2050 in the basin reflect significant increases for Colorado Springs and Pueblo. With limited acreage in close proximity, smaller amounts of irrigated acreage are expected to be urbanized by their growth compared to urbanization that may occur around smaller agricultural towns such as Salida, Canon City, and Lamar. Portions of two irrigation ditches, Fort Lyon Canal and Bessemer Ditch, have been purchased by municipalities, and their water rights are in the process of being transferred for municipal uses. It is anticipated that portions of these ditches, totaling 12,600 irrigated acres, will be dried up by 2050. Although additional purchase of irrigation water rights is expected, the stakeholders in the basin are hopeful that leasing agreements or other solutions may limit the permanent dry up of irrigated acreage in the future.

From a groundwater sustainability perspective in the basin, more than 85,000 acres in the southeast corner of the basin are irrigated by groundwater pumped from a series of deep aquifers, including the Ogallala, Dakota/Cheyenne, and Dockum aquifers. This area is largely disconnected from the mainstem of the Arkansas River and is managed as the Southern High Plains Designated Groundwater Basin (SHPDGWB). After review of groundwater reports documenting downward trends in groundwater levels, discussions with stakeholders, and conversations with landowners in the area, the acreage in this area was reduced between 10 and 33 percent across the planning scenarios. This range reflects the uncertainty associated with estimating the future water availability in the basin and the potential for increased pumping as projected climate change increases crop demands in the area.

Table 4.3.4 summarizes the planning scenario adjustments described above and other adjustments that impact agricultural diversion demands in the various scenarios, including constraints on improved irrigation efficiencies in the lower basin.

Table 4.3.4 Planning Scenario Adjustments to for Agricultural Demands in the Arkansas Basin

Adjustment Factor*	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Change in Irrigated Land due to Urbanization & Municipal Transfers	19,840 Acre Reduction	19,840 Acre Reduction	19,840 Acre Reduction	19,840 Acre Reduction	19,840 Acre Reduction
GW Acreage Sustainability	10% Acre Reduction (SHPDGWB)	15% Acre Reduction (SHPDGWB)	20% Acre Reduction (SHPDGWB)	33% Acre Reduction (SHPDGWB)	33% Acre Reduction (SHPDGWB)
IWR Climate Factor	-	-	18%	26%	26%
Emerging Technologies	20% Increased Sprinkler Use (H-I Area)	20% Increased Sprinkler Use (H-I Area)	20% Increased Sprinkler Use (H-I Area) 100% use of Sprinklers (SHPDGWB)	20% Increased Sprinkler Use (H-I Area) 100% use of Sprinklers (SHPDGWB) 10% IWR Reduction	20% Increased Sprinkler Use (H-I Area) 100% use of Sprinklers (SHPDGWB)

** See Section 2.2.3 for descriptions of adjustment methodologies and assumptions*

Agricultural Diversion Demand Results

Table 4.3.5 and Figure 4.3.3 summarize the acreage, IWR, and the agricultural diversion demand for surface water supplies in the Arkansas Basin for current conditions and the five planning scenarios. The largest variation in the basin occurred in *Adaptive Innovation* due to a 10 percent reduction in IWR and a 10 percent increase to system efficiency, both of which reduce diversion demands. In this basin, several planning scenarios projected less agricultural demand than the current demand, mainly due to reduced irrigated acres and resulting decreased IWR. Only *Hot Growth* had a slightly increased demand over baseline.

SYSTEM EFFICIENCY

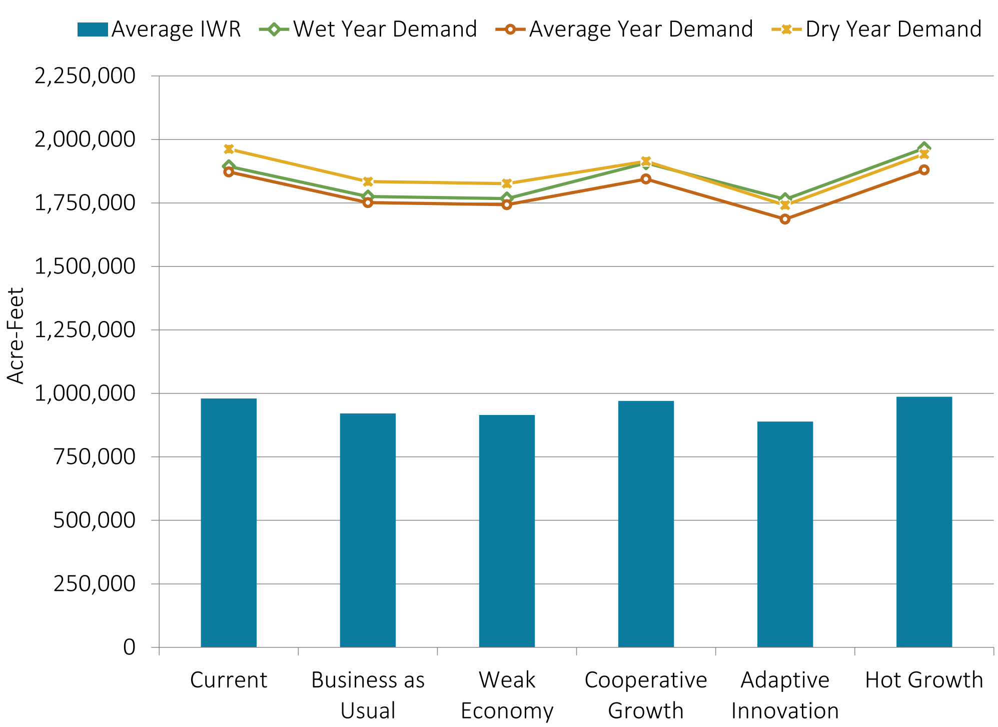
In some cases, diversion demands can be higher in wet years because system efficiency decreases due to the relative abundance of supply.

Table 4.3.5 Summary of Agricultural Diversion Demand Results in the Arkansas Basin

	Current (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Irrigated Acreage (acres)	445,000	417,700	413,600	409,500	398,900	398,900
Average IWR (AFY)	980,000	921,000	915,000	970,000	889,000	987,000
Diversion Demand						
Average Year (AFY)	1,872,000	1,751,000	1,743,000	1,844,000	1,686,000	1,880,000
Wet Yr. Change	1%	1%	1%	3%	5%	5%
Dry Yr Change	5%	5%	5%	4%	3%	3%

Average agricultural diversion demand was calculated using the average hydrologic years (i.e., years classified as neither wet or dry) from 1950-2013

Figure 4.3.3 Agricultural Diversion Demands and IWR Results in the Arkansas Basin



4.3.5 Municipal and Industrial Demands

Population Projections

The Arkansas Basin includes about 19 percent of the statewide population. Between the years 2015 and 2050, it is projected to grow from approximately 1.0 million to between 1.46 million and 1.63 million people in the low and high growth projections, respectively, which is an increase in population of 45 to 61 percent. Table 4.3.6 shows how population growth is projected to vary across the planning scenarios for the Arkansas Basin.

Table 4.3.6 Arkansas Basin 2015 and Projected Populations

2015 Population	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
1,008,400	1,509,500	1,462,800	1,544,400	1,626,000	1,568,000

Current Municipal Demands

In the Arkansas Basin, baseline water demands were largely based on 1051 data as shown on Figure 4.3.4.

Figure 4.3.5 summarizes the categories of municipal, baseline water usage in the Arkansas Basin. On a basin scale, the residential outdoor demand as a percentage of the systemwide demands is one of the lowest reported throughout the state, at approximately 17 percent. Conversely, the baseline non-revenue water demand is one of the highest statewide, at approximately 18 percent of the systemwide demands.

Figure 4.3.4 Sources of Water Demand Data in the Arkansas Basin

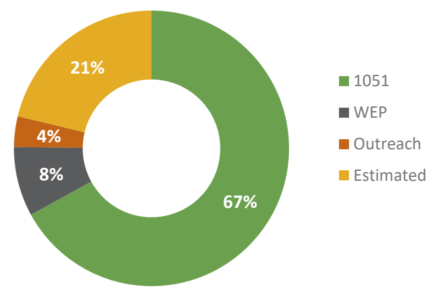
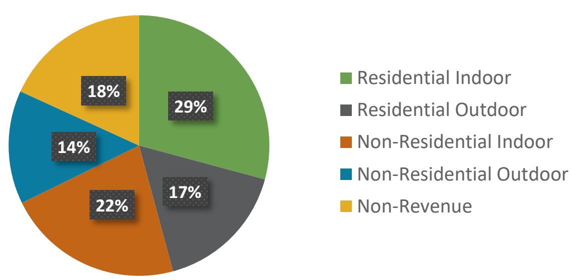


Figure 4.3.5 Categories of Water Usage in the Arkansas Basin



DEMANDS

The Arkansas Basin average baseline per capita system wide demand has increased from 185 gpcd in SWSI 2010 to approximately 194 gpcd.

Projected Municipal Demands

Figure 4.3.6 provides a summary of per capita baseline and projected water demands for the Arkansas Basin. Systemwide, all of the projected per capita demands decrease relative to the baseline. Th *Hot Growth* is projected to be nearly as high as the baseline, with lower residential indoor but higher residential and non-residential outdoor demands that are significantly influenced by hotter and drier climate conditions.

The Arkansas Basin municipal baseline and projected diversion demands in Table 4.3.7 show the combined effect of population and per capita demands. Municipal demands are projected to grow from approximately 219,000 AFY in 2015 to between 294,000 and 337,000 AFY in 2050. El Paso County accounts for around half of the baseline demand, followed by Pueblo County at about one-third of basin demand.

Figure 4.3.6 Arkansas Basin Municipal Baseline and Projected Per Capita Demands by Water Demand Category

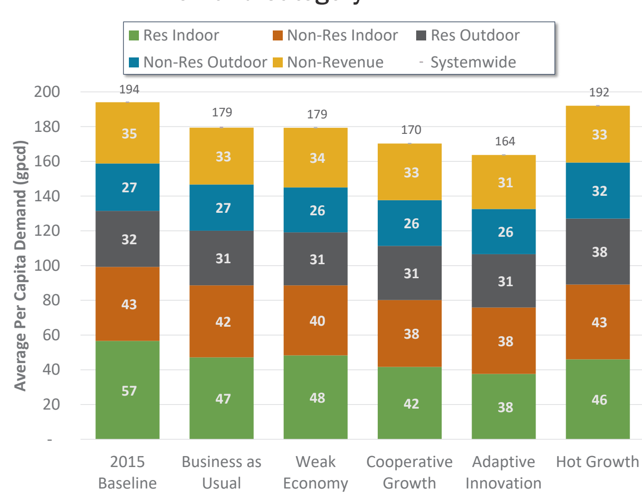


Table 4.3.7 Arkansas Basin Municipal Baseline and Projected Demands (AFY)

Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
219,200	303,400	293,800	294,500	298,100	337,200

The baseline and projected demand distributions are shown on Figure 4.3.7, which also shows how the population varies between the scenarios. All of the planning scenarios result in an increase relative to the baseline. Except *Hot Growth*, the systemwide demand projections are similar, which demonstrates how the pairing of drivers and population can offset each other and narrow the range of results. Higher levels of conservation associated with *Adaptive Innovation* help limit the impacts of the "Hot and Dry" climate projection and higher population.

Self-Supplied Industrial Demands

The Arkansas Basin includes about 33 percent of the statewide SSI demand. SSI demands in this basin are associated with the large industry and thermoelectric sub-sectors, with no demands projected for snowmaking or energy development sub-sectors. Basin-scale SSI demands are shown on Figure 4.3.8 and summarized in Table 4.3.8.

Total M&I Diversion Demands

Arkansas Basin combined M&I demand projections for 2050 range from approximately 350,000 AFY in *Weak Economy* to 405,000 AFY in *Hot Growth*, as shown on Figure 4.3.9. SSI demands account for 16 to 17 percent of the projected M&I demands. On a basin scale, the demand projections do not follow the statewide sequence of the scenario rankings described in the CWP, with *Adaptive Innovation* falling out of sequence.

Figure 4.3.7 Arkansas Basin Baseline and Projected Population and Municipal Demands

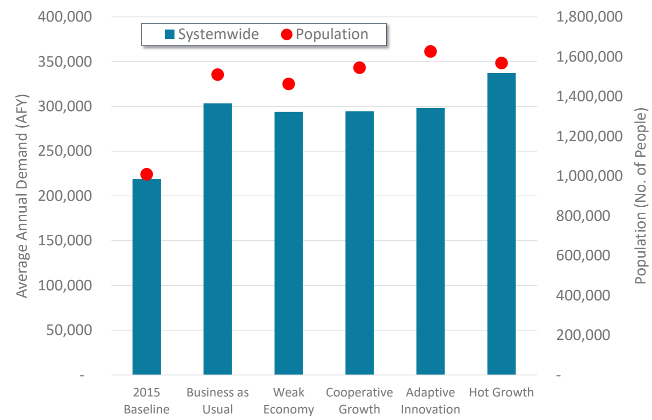


Figure 4.3.8 Arkansas Basin Self-Supplied Industrial Demands

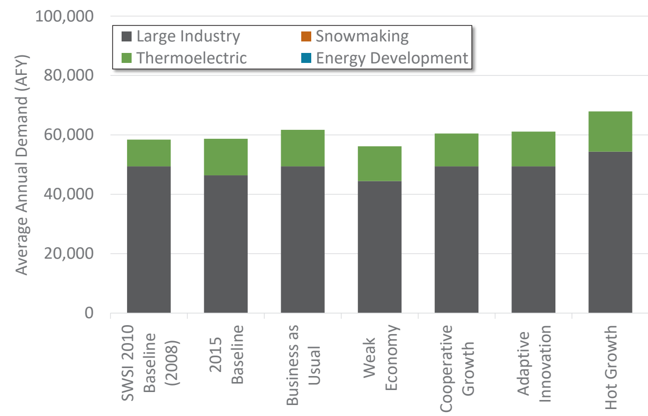


Figure 4.3.9 Arkansas Basin Municipal and Self-Supplied Industrial Demands

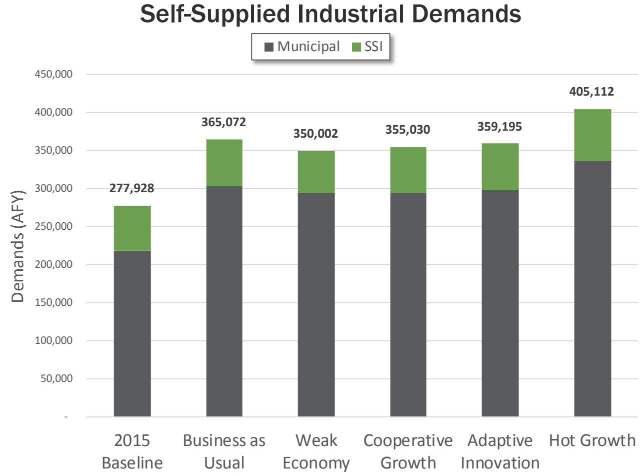


Table 4.3.8 Arkansas SSI Baseline and Projected Demands (AFY)

Sub-sector	Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Large Industry	46,400	49,400	44,460	49,400	49,400	54,340
Snowmaking	-	-	-	-	-	-
Thermoelectric	12,320	12,320	11,700	11,090	11,700	13,550
Energy Development	-	-	-	-	-	-
Sub-Basin Total	58,720	61,720	56,160	60,490	61,100	67,890

4.3.6 Water Supply Gaps

The agricultural and M&I diversion demands were compared against available water supply modeled for current conditions and the five planning scenarios. Gaps were calculated when water supply was insufficient to meet demands.

Agricultural

The Arkansas Basin agricultural diversion demands, demand gaps, and consumptive use gaps for the baseline and planning scenarios are presented in Table 4.3.9 and illustrated on Figure 4.3.10. An annual time series of gaps in terms of percent of demand that was unmet is shown on Figure 4.3.11.

> **INCREMENTAL GAP**
>
> The incremental agricultural gap quantifies the degree to which the gap could increase beyond what agriculture has historically experienced under water shortage conditions.

Table 4.3.9 Arkansas Basin Agricultural Gap Results (AFY)

		Scenario					
		Scenario	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand	1,899,900	1,778,300	1,770,200	1,878,900	1,721,200	1,918,000
	Average Annual Gap	617,300	586,400	585,200	701,700	734,800	819,500
	Average Annual Gap Increase from Baseline	-	-	-	84,400	117,500	202,200
	Average Annual Percent Gap	32%	33%	33%	37%	43%	43%
	Average Annual CU Gap	313,100	297,100	296,400	362,500	381,500	425,300
Maximum	Demand in Maximum Gap Year	2,303,900	2,152,100	2,141,500	2,149,300	1,932,700	2,157,900
	Gap in Maximum Gap Year	1,446,400	1,369,600	1,366,600	1,532,000	1,566,100	1,749,800
	Increase from Baseline Gap	-	-	-	85,600	119,700	303,400
	Percent Gap in Maximum Gap Year	63%	64%	64%	71%	81%	81%

Study period for Water Supply analysis is 1975-2013, reflecting different baseline demand than described in Agricultural Diversion Demands section.

Figure 4.3.10 Projected Averages Annual Agricultural Diversion Demand, Demand Met, and Gaps in the Arkansas Basin

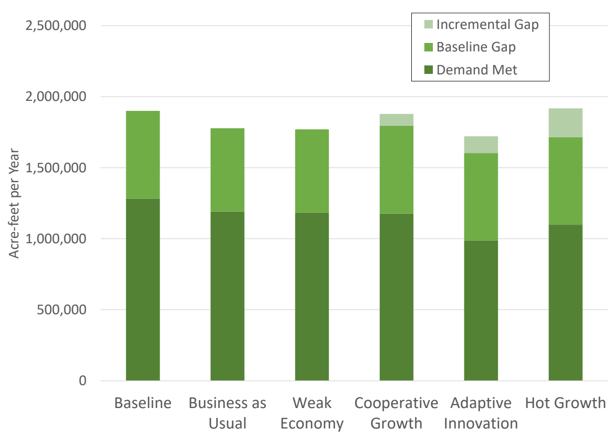
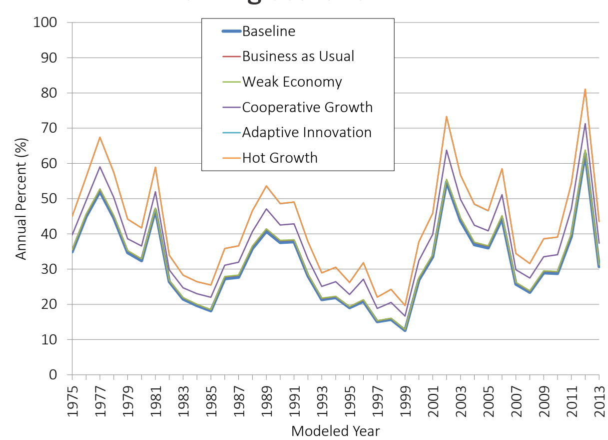


Figure 4.3.11 Annual Agricultural Gaps (expressed as a percentage of demand) for Each Planning Scenario



The following are observations on agricultural diversion demands and gaps:

- Agricultural diversion demands are projected to be similar or even reduced as compared to baseline in all five planning scenarios due to urbanization, transfers of agricultural water rights to municipal uses, and declining aquifer levels in the Southern High Plains, all resulting in reduced irrigated acres.
- The agricultural gap as a percent of demand is relatively large in this basin (32 to 43 percent). Current farming practices help to minimize this gap, which is projected to remain consistent in *Business as Usual* and *Weak Economy*; however, climate changes reflected in *Cooperative Growth*, *Adaptive Innovation* and *Hot Growth* are projected to increase water supply gaps up to 40 percent of demand.

M&I

The diversion demand and gap results for M&I uses in the Arkansas Basin are summarized in Table 4.3.10 and illustrated on Figure 4.3.12. Note that annual time series of M&I gaps are not available for the Arkansas Basin due to the lack of available CDSS tools.

The following are observations on M&I diversion demands and gaps:

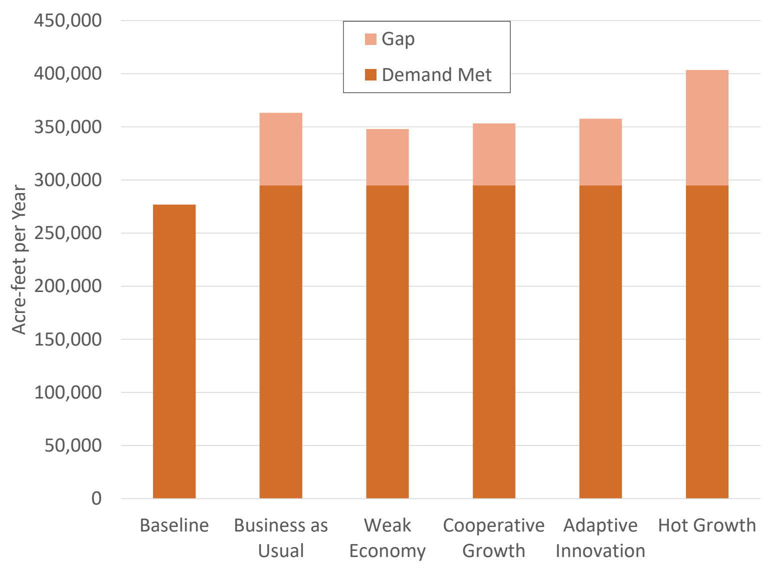
- M&I diversion demand in this basin is projected to grow to become a higher percentage of overall demand (from 13 to 17 percent).
- Municipal demand is driven by population growth in the Colorado Springs and Pueblo area, as well as modest increases in large industry and thermoelectric demand.
- The M&I gap in *Adaptive Innovation* is projected to be less than in *Business as Usual* even with high levels of projected population growth and increased outdoor water demands due to a hotter and drier climate.
- M&I gaps may be exacerbated by reductions in transbasin imports in planning scenarios that include considerations of climate change.

Table 4.3.10 Arkansas Basin M&I Gap Results

		Scenario					
		Scenario	**Business as Usual**	**Weak Economy**	**Cooperative Growth**	**Adaptive Innovation**	**Hot Growth**
Average	Average Annual Demand	276,700	363,300	347,900	353,200	357,600	403,500
	Average Annual Gap	0	68,500	53,100	58,500	62,900	108,700
	Average Annual Percent Gap	0%	19%	15%	17%	18%	27%
Maximum	Demand in Maximum Gap Year	276,700	363,300	347,900	353,200	357,600	403,500
	Gap in Maximum Gap Year	0	68,500	53,100	58,500	62,900	108,700
	Percent Gap in Maximum Gap Year	0%	19%	15%	17%	18%	27%

Study period for Water Supply Analysis is 1975-2013, reflecting different baseline demand than described in M&I Demand section.
Baseline demand also may vary slightly from previous section due to differences in geographic distribution of demand for counties that lie in multiple basins.

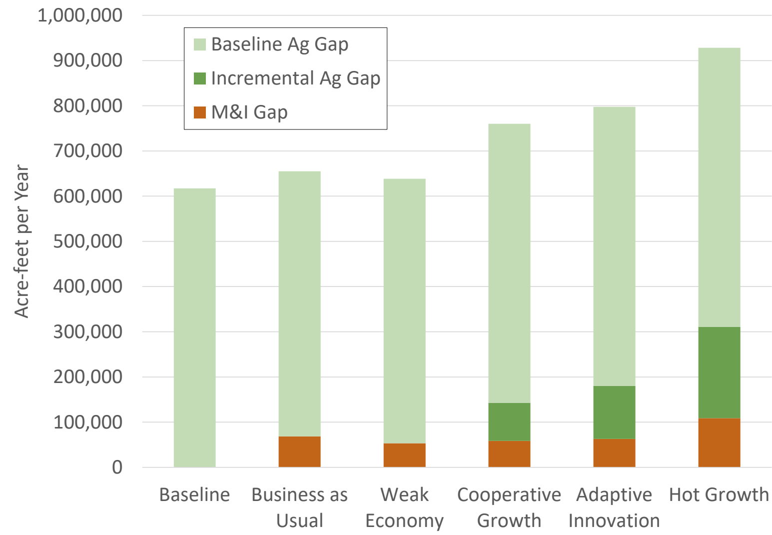
Figure 4.3.12 Projected Maximum Annual M&I Demand Met and Gaps in the Arkansas Basin



Total Gap

Figure 4.3.13 illustrates the total combined agricultural and M&I diversion demand gap in the Arkansas Basin. The figure combines the average annual baseline and incremental agricultural gap and the maximum M&I gap. In *Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth*, gaps are driven by both agricultural and municipal demands, which increase in the "Hot and Dry" climate projection.

Figure 4.3.13 Projected Average Annual Agricultural Gaps and Maximum M&I Diversion Demand Gaps in the Arkansas Basin



Supplies from Urbanized Lands

By 2050, irrigated acreage in the Arkansas Basin is projected to decrease by more than 19,000 acres due to urbanization or lands that are no longer irrigated because of planned water right transfers from agricultural to municipal use in the Arkansas Basin. Irrigation supplies for these lands could potentially be used for M&I needs in the future (subject to a variety of unknowns such as seniority and type of water supply, willingness to change the use of water through water court, etc.). Acreage associated with planned transfers was derived based on stakeholder input.

The average annual historical consumptive use associated with potentially urbanized acreage and planned water right transfers for each scenario is reflected in Table 4.3.11. The data in the table represent planning-level estimates of this potential supply and has not been applied to the M&I gaps. The data in the table do not represent supplies from permanent water transfers that may be considered by a basin roundtable as a future strategy to meet gaps (note that SWSI 2010 included estimates of permanent transfers beyond those currently planned as a strategy for meeting potential future M&I gaps).

Table 4.3.11 Estimated Consumptive Use from Lands Projected to be Urbanized by 2050 and Planned Transfers in the Arkansas Basin

	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Urbanized Acreage and Lands Subject to Planned Transfers (acres)	19,800	19,800	19,800	19,800	19,800
Estimated Consumptive Use (AFY)	29,600	29,700	29,400	25,200	27,900

4.3.7 Available Supply

For the purposes of the Technical Update, it was assumed that due to compact constraints, there are no available water supplies now or in the future that can meet new demands.

4.3.8 Environment and Recreation

A surface water allocation model is not currently available in the Arkansas Basin. As a result, hydrologic datasets in the Flow Tool include only naturalized flows and naturalized flows as impacted by climate change. A total of three water allocation model nodes were selected for the Flow Tool within the Arkansas Basin (Figure 4.3.14). The figure also shows subwatersheds (at the 12-digit HUC level) and the relative number of E&R attributes located in each subwatershed.

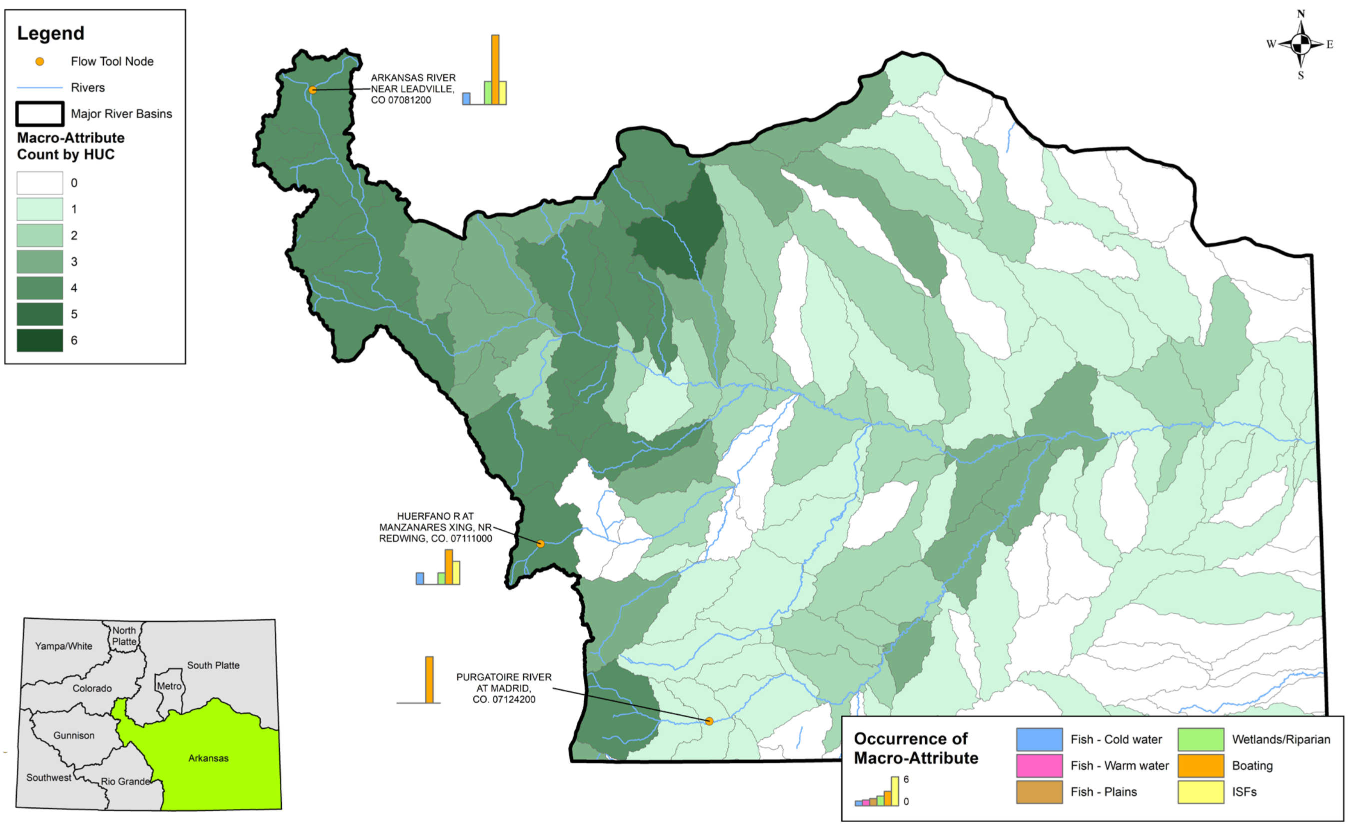
- Arkansas River near Leadville, Colorado (07081200)
- Huerfano River at Manzanares Crossing, near Redwing, Colorado (07111000)
- Purgatoire River at Madrid, Colorado (07124200)

The sites were selected because they are above major supply and demand drivers, and because future flow changes would likely be associated only with climate-change factors. Management drivers impact river flows on the eastern plains. Because a water allocation model that incorporates management is not available, no data-based insights into potential flow changes and risks to E&R attributes could be developed at this time. The Flow Tool results for the Arkansas Basin include only naturalized flows and naturalized flows as impacted by climate change factors ("In-Between" and "Hot and Dry" climate projections). These data do not represent changes in flow due to irrigation, transbasin imports, and/or storage.

NATURALIZED FLOW

Naturalized flows reflect conditions that would occur in the absence of human activities. Baseline flows reflect current conditions as influenced by existing infrastructure and river operations. While observations regarding naturalized flows may be informative, baseline flows reflect actual conditions and the diverse operations of the river's many users.

Figure 4.3.14 Flow Tool Nodes Selected for The Arkansas Basin



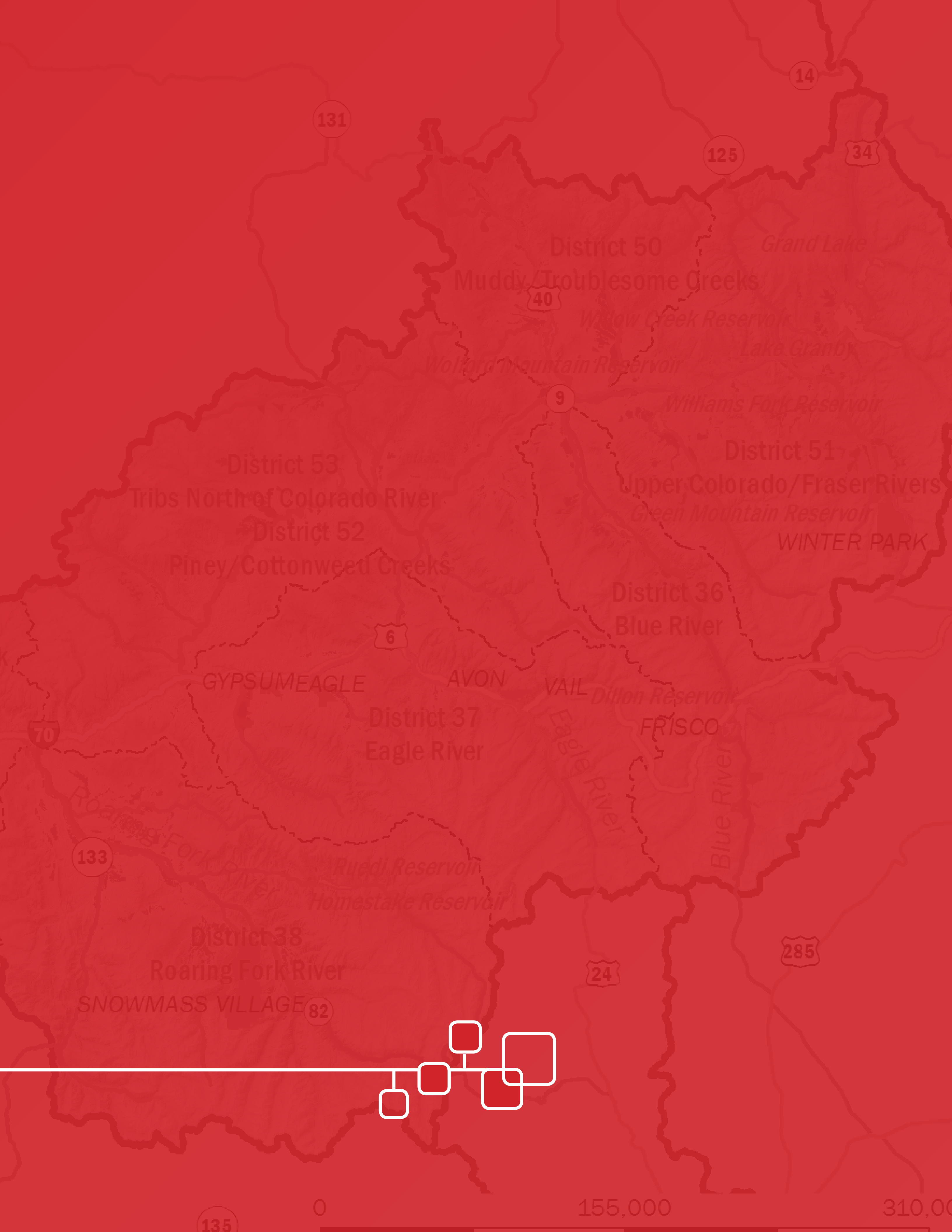
Results and observations from Flow Tool analyses using flow data developed in the water supply and gap analyses for baseline conditions and the planning scenarios are described in Table 4.3.12.

Table 4.3.12 Summary of Flow Tool Results in the Arkansas Basin

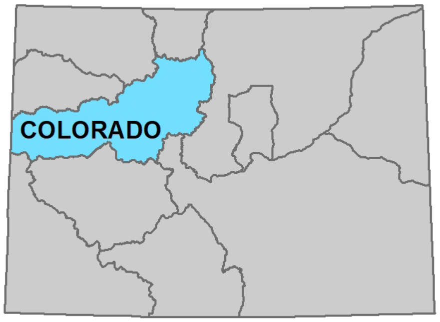
Category	Observation
Projected Flows	At high elevation locations (e.g., near Leadville), peak flow magnitude are not projected to change substantially. However, the timing of peak flow may shift to earlier in the year, with April and May flow magnitudes rising and June flows decreasing under the In-Between and Hot and Dry climate change projections.
	At montane and foothills locations (elevation range from approximately 5,500 feet to 8,500 feet), peak flow magnitude will likely drop under the In-Between and Hot and Dry climate change projections.
	Across all locations, mid- and late-summer streamflow is projected to decrease due to climate change.
Ecological Risk	At high elevations, peak-flow related risk for riparian/wetland plants and fish habitat remains low or moderate under future climate change projections.
	At lower elevations, the decline in peak flow magnitude is projected to increase the risk status for riparian/wetland plants and fish habitat. The reduction in peak flow may also adversely affect recreational boating.
	Metrics for coldwater fish (trout) indicate that even with climate-induced changes to mid- and late-summer flows, flows are projected to be sufficient to keep risk low or moderate, though risk may be higher in July and/or during dry years.
E&R Attributes	Because future flows under the five scenarios were not modeled in the Arkansas Basin, projected changes to flow at the selected nodes and the associated changes in risk to E&R attributes are entirely attributable to projected changes in climate. These climate-induced changes are similar to the general pattern seen in many parts of Colorado: earlier peak flow and reduced mid- and late-summer flows, with reduced peak flow magnitudes in some locations.

The mainstem Colorado Basin in Colorado encompasses approximately 9,830 square miles and extends from Rocky Mountain National Park to the Colorado-Utah state line. Elevations range from more than 14,000 feet to about 4,300 feet. Snowpack in the high country is an important water source to both sides of the Continental Divide, as the state's largest transbasin diversions are here. Ranching and livestock production typify agriculture in the upper reaches, while the Grand Valley has a long history of fruit and vegetable production. With major ski areas as well as boating and fishing opportunities, water drives a robust recreation and tourism economy throughout the basin.

COLORADO


District 50
Muddy/Troublesome Creeks
Grand Lake
Willow Creek Reservoir
Lake Granby
Wolford Mountain Reservoir
Williams Fork Reservoir
District 51
Upper Colorado/Fraser Rivers
Green Mountain Reservoir
WINTER PARK
District 53
Tribs North of Colorado River
District 52
Piney/Cottonweed Creeks
District 36
Blue River
GYPSUM
EAGLE
AVON
VAIL
Dillon Reservoir
FRISCO
District 37
Eagle River
Eagle River
Blue River
Roaring Fork River
Ruedi Reservoir
Homestake Reservoir
District 38
Roaring Fork River
SNOWMASS VILLAGE
131
14
125
34
40
9
6
70
133
82
285
24
135
0
155,000
310,00

4.4 COLORADO BASIN RESULTS

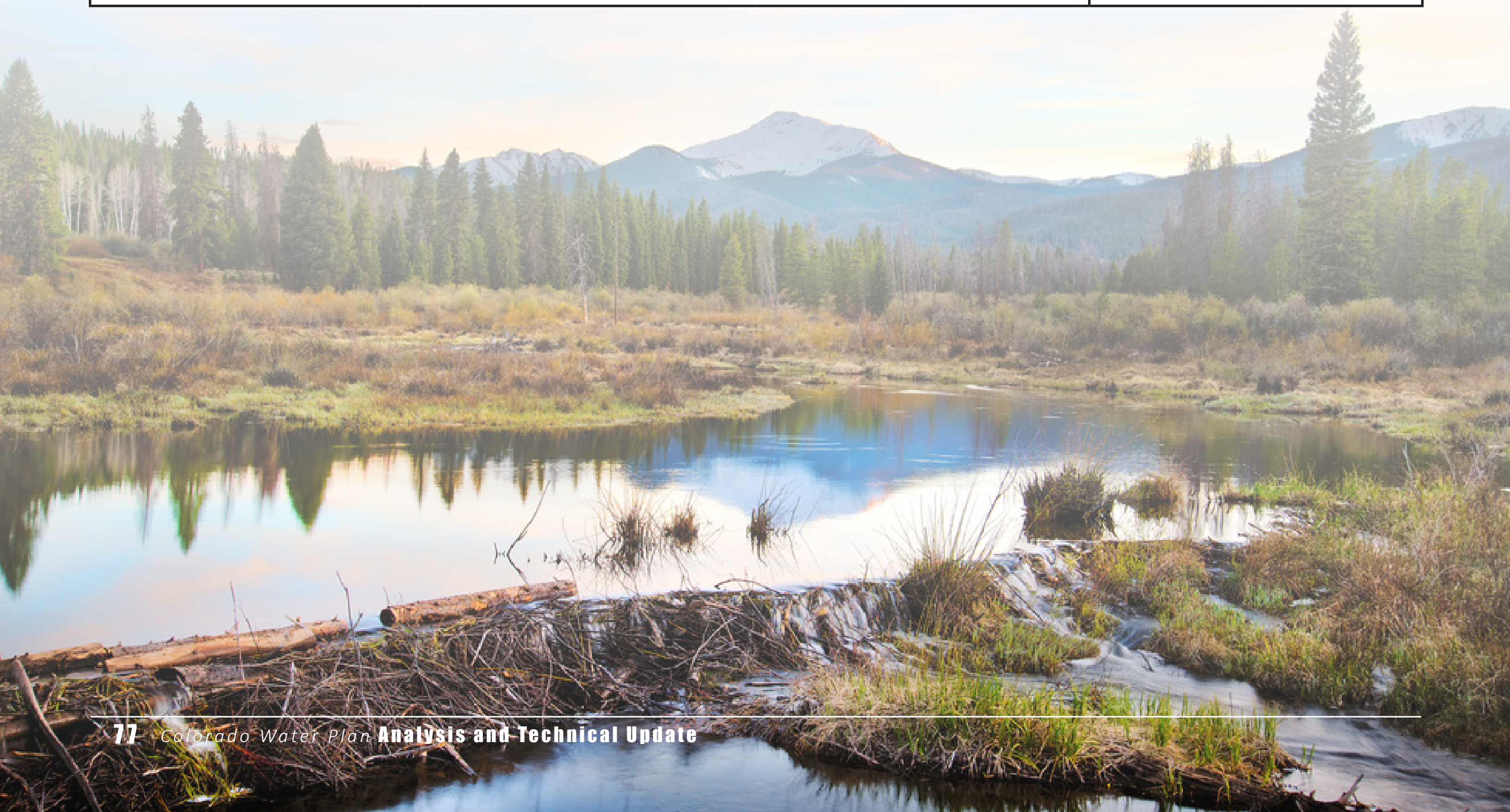


4.4.1 BASIN CHALLENGES

Key future water management issues in this basin include competing resources for agriculture, tourism and recreation, protection of endangered species, and the threat of a Colorado River Compact call. These challenges are described in Colorado's Water Plan and summarized below in Table 4.4.1.

Table 4.4.1 Key Future Water Management Issues in the Colorado Basin

Agriculture	Environment and Recreation	Municipal and Industrial	Compacts and Administration
• Despite the importance of agriculture, continued urbanization of agricultural lands could reduce irrigated acres in the basin.	• Success of the Upper Colorado River Endangered Fish Recovery Program is vital to the river's future. The program is designed to address the needs of endangered fish while protecting existing and future use of Colorado River water. • Recreational use and environmental conservation are major drivers in the basin and are important for economic health and quality of life.	• Development of conditional transbasin water rights is a concern, and Colorado must consider the effect on in-basin supplies.	• There is concern over a potential compact shortage during severe and sustained drought and the potential effects to in-basin supplies. Demand management to conserve water per the recently signed Drought Contingency Plan is a pressing issue.
• Selenium and salinity are of concern in parts of the basin.			



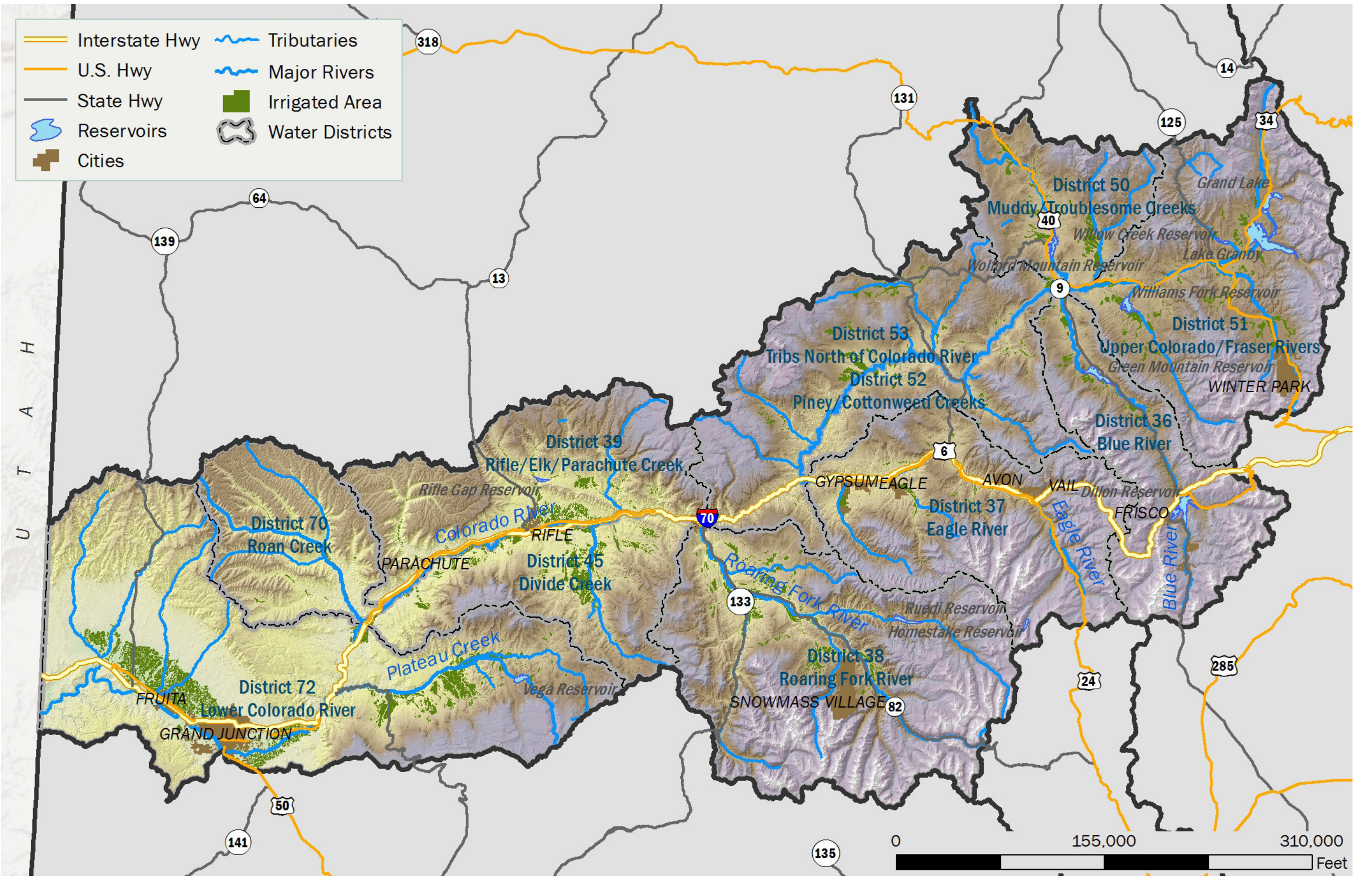


Figure 4.4.1 Map of the Colorado Basin

4.4.2 SUMMARY OF TECHNICAL UPDATE RESULTS

Key results and findings of the Technical Update pertaining to agricultural and M&I demands and gaps, as well as findings related to environmental and recreational attributes and future conditions, are summarized below in Table 4.4.2.

Table 4.4.2 Summary of Key Results in the Colorado Basin

Agriculture	Environment and Recreation	Municipal and Industrial
• Although irrigated area is estimated to decrease by 13,600 acres as cities expand onto irrigated land, IWR may increase in a warmer future climate. • Emerging technology, including adoption of higher system efficiencies, may mitigate climate impacts and reduce demand below baseline. • The future incremental gap ranges from 0 to 4 percent of baseline demand • Scenarios that assume current climate conditions (Business as Usual and Weak Economy) have agricultural gaps around 3 percent of demand. Gaps (as a percentage of demand) increase in scenarios that assume a warmer and drier future climate.	• In climate-impacted scenarios, peak flow generally moves earlier in the year. • Aquatic and riparian attributes may be affected differently based on location and potential changes in stream flow magnitude and timing.	• Per capita municipal usage is projected to decrease in the future. • Municipal demand is projected to increase for all scenarios due to increased population; however, except for Hot Growth, the systemwide demand projections for all future scenarios are similar, showing that pairing of drivers and population can offset each other and even out the results. • Increases in SSI demands in Business as Usual and Hot Growth represent anticipated energy development.

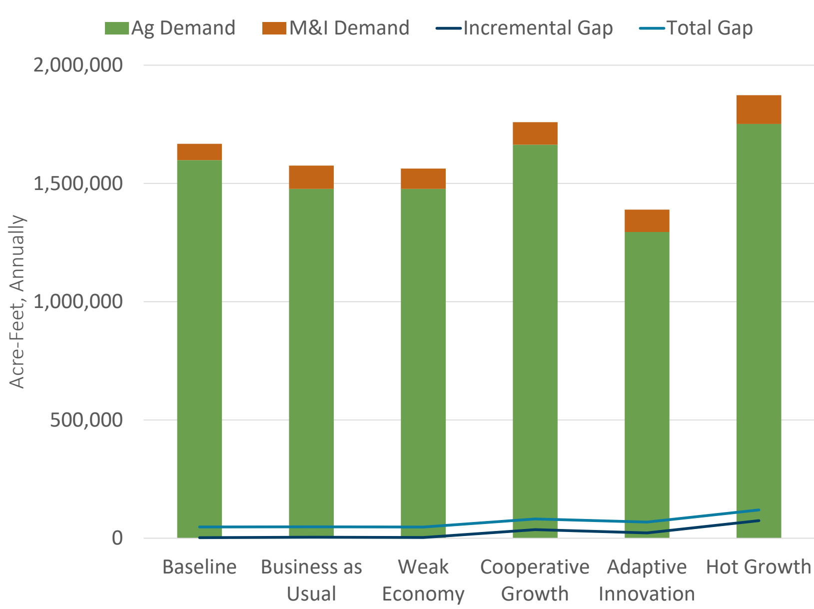
Results describing current and potential future M&I and agricultural demands and gaps are summarized in Table 4.4.3 and in Figure 4.4.2.

Table 4.4.3 Summary of Diversion Demand and Gap Results in the Colorado Basin

	Current (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average Annual Demand						
Agricultural (AFY)	1,598,900	1,476,800	1,476,800	1,663,800	1,294,900	1,751,600
M&I (AFY)	68,500	98,400	85,800	95,400	94,500	121,400
Gaps						
Ag (avg %)	3%	3%	3%	5%	5%	6%
Ag (incremental-AFY)	-	-	-	30,900	16,200	58,500
Ag (incremental gap as % of current demand)	-	0%	0%	2%	1%	4%
M&I (max %)	0%	4%	4%	6%	7%	13%
M&I (max-AF)	0*	4,200	3,300	5,300	6,600	15,800

**CDSS water allocation model in this basin calculates small baseline M&I gaps, but they are either due to calibration issues or they are reflective of infrequent, dry-year shortages that are typically managed with temporary demand reductions, such as watering restrictions.*

Figure 4.4.2 Summary of Diversion Demand and Gap Results in the Colorado Basin



Summary of Environmental and Recreational Findings

- In climate-impacted scenarios, peak flow is projected to move earlier in the year, with March, April and May flows increasing substantially and June flows decreasing; possible mis-matches between peak flow timing and species' needs may occur. Flow magnitude could decrease some, but peak-flow risk for plants and fish is projected to remain moderate.
- In some areas (e.g., Crystal River above Avalanche Creek near Redstone), peak flow magnitude is projected to increase substantially, potentially over-widening the creek channel and causing habitat issues during low-flow periods.
- Under *Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth*, mid- and late-summer flows may be reduced by 60 to 70 percent and create high risk for fish from loss of habitat and, in trout regions, high water temperatures.
- Downstream from major reservoirs (e.g., Frying Pan, Green Mountain), diminished peak flows could create high to very high risk for riparian/wetland vegetation and fish habitat if sediment is not flushed, while consistent mid- and late-summer flows could keep risk to fish low to moderate.

- Several recreational in-channel diversions and Instream Flow water rights may be unmet more often with diminished June to August flows.
- In critical habitat for endangered species, highly reduced flows in mid- and late-summer will make it more difficult to meet flow recommendations.

4.4.3 NOTABLE BASIN CONSIDERATIONS

Section 4.1 described several analysis assumptions and limitations that apply to all basins and should be considered when reviewing and interpreting analysis results. Additional considerations specific to the Colorado Basin are listed below:

- The Colorado River Model includes operations that allow Ruedi Reservoir, Wolford Mountain Reservoir, and Green Mountain Reservoir to make releases from their contract accounts to meet M&I demands aggregated by location throughout the basin. In most years, these contract supplies are sufficient to meet the projected M&I demands in the planning scenarios.
- Historical transbasin diversions from the Colorado Basin are included in the model as an export demand. In certain planning scenarios, the export demand cannot be fully met as a result of changed hydrology or increased agricultural demands of senior water users. When this occurs, the export demand is shorted in the Colorado Basin model, and that shortage is reflected on the East Slope as reduction in transbasin imports.
- Water demands for energy development were based primarily on SWSI 2010 data and were varied based on the language in each scenario. The demand data were not updated per Technical Advisory Group input because estimates of water needs have varied substantially, and defendable updated datasets are not currently available.

4.4.4 AGRICULTURAL DIVERSION DEMANDS

The irrigated agriculture industry across the Colorado Basin is highly diverse. Large ranching operations dominate agriculture in the basin's higher elevations, particularly around the towns of Kremmling, Collbran, and Rifle. Farming regions focused on the cultivation of fruits, vegetables, and alfalfa are more prevalent in the lower basin due to a longer growing season and warmer summer temperatures. The largest of these farming operations, the Grand Valley Project, irrigates about a quarter of the 206,700 acres irrigated in the entire basin. Mixed between these agricultural operations are many growing municipalities, such as Grand Junction.

Planning Scenario Adjustments

Section 2 described ways in which inputs to agricultural diversion demand estimates were adjusted to reflect the future conditions described in the planning scenarios. Adjustments in the Colorado Basin focused on urbanization, potential future climate conditions, and implementation of emerging technologies.

2050 population projections reflect significant increases for counties across the Colorado Basin. The impact of urbanization, however, is tied to the proximity of existing municipalities to agricultural operations. The impact of urbanization to resort communities, such as the towns of Winter Park, Breckenridge, Glenwood Springs, Snowmass Village, Vail and Avon, is limited due to lack of adjacent irrigated acreage to urbanize. The impact of urbanization is expected to be much larger in agricultural-based communities, such as Fruita, Grand Junction, Palisade, Eagle, and Rifle. In total, nearly 14,000 acres of irrigated land are expected to be urbanized, with one-third of that expected to occur in municipalities located within the Grand Valley Project and Grand Valley Irrigation Company service areas.

IWR could increase in this basin due to climate change by 20 percent and 31 percent on average in the "In-Between" and "Hot and Dry" climate projections, respectively.

In *Adaptive Innovation*, in addition to assuming reduced IWR, the average irrigation efficiency was assumed to increase by 10 percent. Irrigation systems efficiencies vary across the Colorado Basin depending upon irrigation infrastructure and practices, averaging just under 30 percent basinwide. System efficiencies were increased by 10 percent for ditches that provide water solely for irrigation purposes in *Adaptive Innovation*. Structures that carry water both for irrigation and for other purposes (e.g., power operations) were not adjusted.

Table 4.4.4 summarizes the planning scenario adjustments described above and other adjustments that impact agricultural diversion demands in the various scenarios.

Table 4.4.4 Planning Scenario Adjustments for Agricultural Demands in the Colorado Basin

Adjustment Factor	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Change in Irrigated Land due to Urbanization	13,600 Acre Reduction	13,600 Acre Reduction	13,600 Acre Reduction	13,600 Acre Reduction	13,600 Acre Reduction
IWR Climate Factor	-	-	20%	31%	31%
Emerging Technologies	-	-	-	10% IWR Reduction 10% System Efficiency Increase	-

See section 2.2.3 for descriptions of adjustment methodologies and assumptions.

Agricultural Diversion Demand Results

Table 4.4.5 and Figure 4.4.3 summarize the acreage, IWR, and the agricultural diversion demand for surface water supplies in the Colorado Basin for current conditions and the five planning scenarios. Demand is lower than current conditions in *Business as Usual* and *Weak Economy*, because irrigated acreage is projected to be urbanized. Although *Cooperative Growth* and *Hot Growth* feature the same reduction in irrigated acres, higher IWR could drive demand above current levels. In *Adaptive Innovation*, the reduction in IWR, increase in system efficiency, and reduction in acreage results in the lowest demand among all scenarios even with the potential effects of a hotter and drier climate.

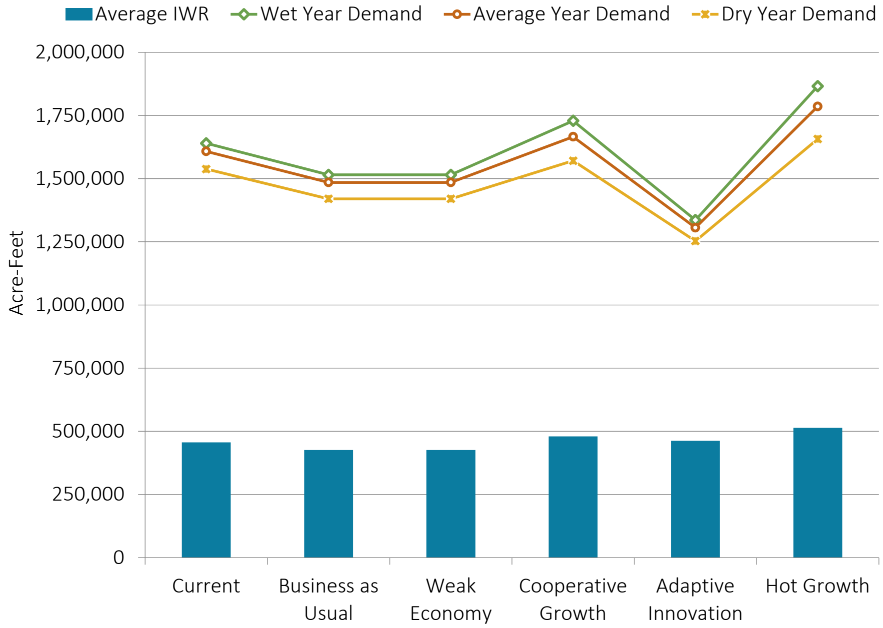
SYSTEM EFFICIENCY

In some cases, diversion demands can be higher in wet years because system efficiency decreases due to the relative abundance of supply.

Table 4.4.5 Summary of Agricultural Diversion Demand Results in the Colorado Basin

	Current (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Irrigated Acreage (acres)	206,700	193,100	193,100	193,100	193,100	193,100
Average IWR (AFY)	456,500	426,000	426,000	480,000	463,000	514,000
Diversion Demand						
Average Year (AFY)	1,608,000	1,485,000	1,485,000	1,666,000	1,306,000	1,786,000
Wet Yr. Change	2%	2%	2%	4%	2%	4%
Dry Yr. Change	-4%	-4%	-4%	-6%	-4%	-7%

Figure 4.4.3 Agricultural Diversion Demands and IWR Results in the Colorado Basin



4.4.5 Municipal and Self-Supplied Industrial Diversion Demands

Population Projections

The Colorado Basin includes about 6 percent of the statewide population. Between the years 2015 and 2050, it is projected to grow from approximately 310,000 to between 460,000 and 580,000 people in the low and high growth projections, respectively. Using the specific numbers, this is an increase in population of 48 percent to 88 percent. Table 4.4.6 shows how population growth is projected to vary across the planning scenarios for the Colorado Basin.

Table 4.4.6 Colorado Basin 2015 and Projected Populations

Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
307,600	515,500	456,300	549,200	572,900	577,800

Current Municipal Demands

The Colorado Basin baseline water demands were largely based on water-provider-reported data, with approximately 43 percent of the baseline population demands represented by WEPs, 25 percent from 1051 data, and 9 percent from BIPs. The remaining baseline water demand had to be estimated. Figure 4.4.4 shows the proportions of each data source among all sources.

Figure 4.4.4 Sources of Water Demand Data in the Colorado Basin

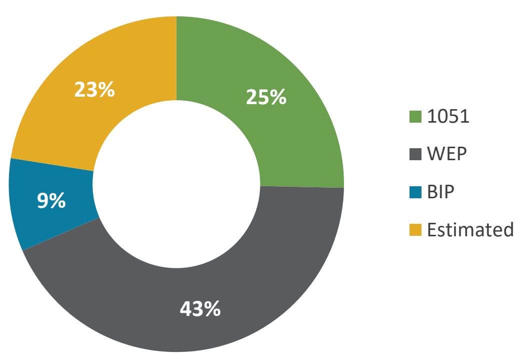


Figure 4.4.5 shows the proportion of each category of municipal baseline water usage in the Colorado Basin. On a basin scale, the residential indoor demand as a percentage of the systemwide demands are relatively high, at 44 percent of the systemwide demands.

Figure 4.4.5 Categories of Municipal Water Usage in the Colorado Basin

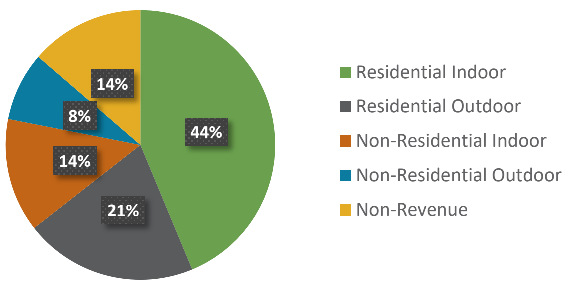
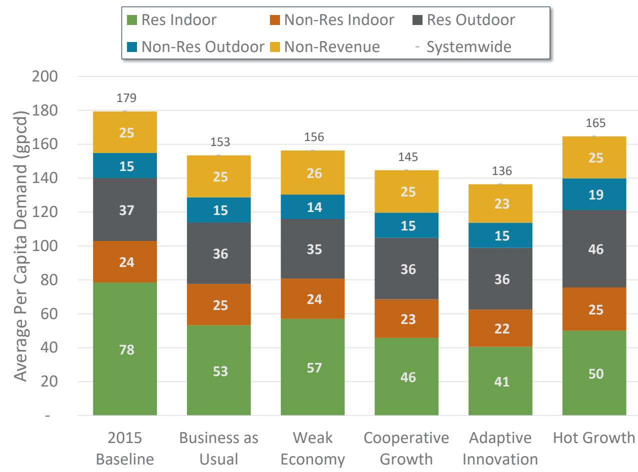


Figure 4.4.6 Colorado Basin Municipal Baseline and Projected per Capita Demands by Water Demand Category



Projected Municipal Demands

Figure 4.4.6 provides a summary of per capita baseline and projected water demands for the Colorado Basin.

Systemwide, all of the projected total per capita demands are projected to decrease relative to the baseline. Consistently across all scenarios, residential indoor demand is the greatest individual demand category while non-residential outdoor is the lowest. Aside from *Hot Growth*, there is minimal variation in outdoor demands across scenarios. This is due to the scenario pairing of water demand reductions and climate drivers, particularly for *Adaptive Innovation,* which has high outdoor reductions coupled with the "Hot and Dry" climate. Outdoor demands increased significantly for the *Hot Growth* scenario, due to an increase in outdoor demands coupled with the "Hot and Dry" climate.

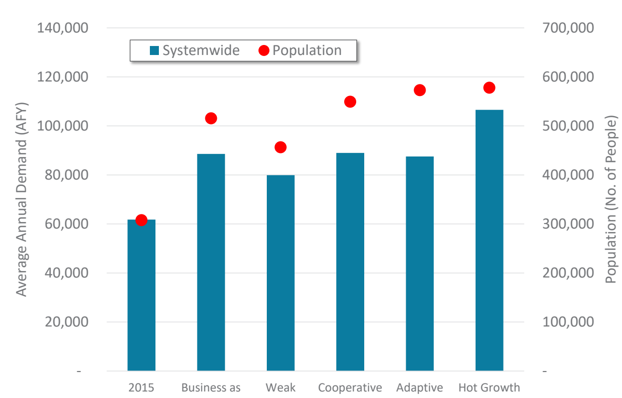
The Colorado Basin municipal baseline and projected diversion demands provided in Table 4.4.7 show the combined effect of population and per capita demands. Municipal demands are projected to grow from approximately 62,000 AFY in 2015 to between 80,000 and 107,000 AFY in 2050. Mesa County accounts for about 28 percent of the baseline demand, followed by Garfield County at about 23 percent of the basin demand.

Table 4.4.7 Colorado Basin Municipal Baseline and Projected Demands (AFY)

Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
61,800	88,600	79,900	89,000	87,500	106,600

Figure 4.4.7 shows baseline and projected diversion demand by scenario, as well as population for each scenario. All projection scenarios result in an increase relative to the baseline. Except for *Hot Growth*, the systemwide demand projections for all the Colorado Basin scenarios are similar, which demonstrates how the pairing of drivers and population can offset each other and even out the results.

Figure 4.4.7 Colorado Basin Baseline and Projected Population and Municipal Demands



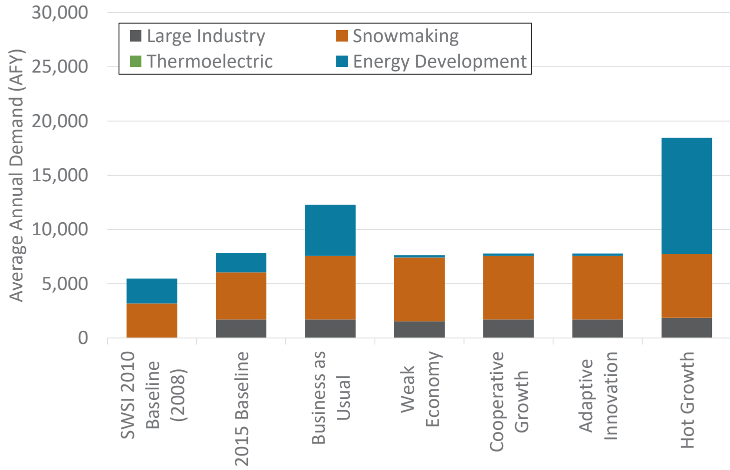
Self-Supplied Industrial Demands

The Colorado Basin currently includes about 4 percent of the statewide SSI demand. SSI demands in this basin are associated with the large industry, snowmaking, and energy development sub-sectors, with no demands projected for the thermoelectric sub-sector. Basin-scale SSI demands are shown on Figure 4.4.8 and summarized in Table 4.4.8.

Large-industry demands are related to a mining facility in Grand County. This facility was not represented in SWSI 2010 but was added because it is a significant use. Projected large-industry demands range from 1,530 AFY to 1,870 AFY.

The baseline snowmaking demand is 4,340 AFY as compared to 3,180 AFY in SWSI 2010. Projected demands increase to 5,890 AFY under all scenarios.

Figure 4.4.8 Colorado Basin Self-Supplied Industrial Demands



Energy development demands are located in Garfield and Mesa counties. The baseline energy development demand in the Colorado Basin has been updated to 1,800 AFY from 2,300 AFY in SWSI 2010. Projected demands range from 200 AFY to 10,700 AFY.

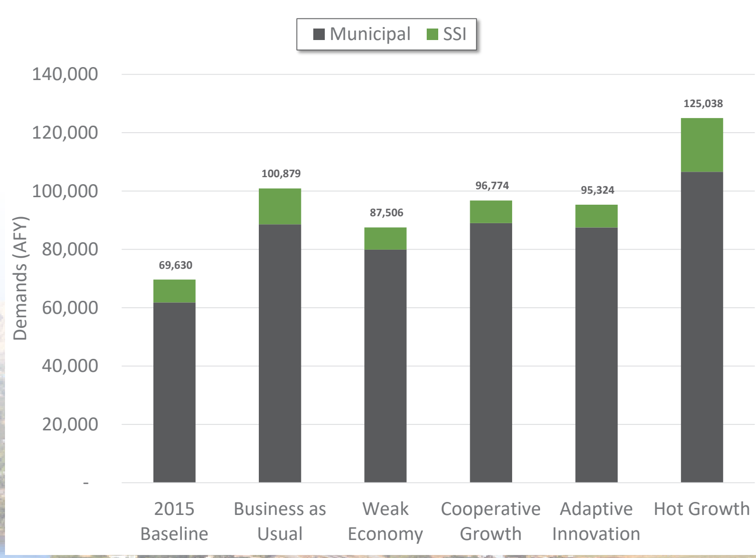
Table 4.4.8 Colorado Basin SSI Baseline and Projected Demands (AFY)

Sub-sector	Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Large Industry	1,700	1,700	1,530	1,700	1,700	1,870
Snowmaking	4,340	5,890	5,890	5,890	5,890	5,890
Thermoelectric	0	0	0	0	0	0
Energy Development	1,800	4,700	200	200	200	10,700
Sub-Basin Total	7,840	12,290	7,620	7,790	7,790	18,460

Total M&I Diversion Demands

Colorado Basin combined M&I diversion demand projections for 2050 range from approximately 88,000 AFY in *Weak Economy* to 125,000 AFY in *Hot Growth*, as shown in Figure 4.4.9. SSI demands account for between 8 and 15 percent of M&I demands. On a basin scale, the demand projections do not follow the statewide sequence of the scenario rankings described in the Water Plan, with *Adaptive Innovation* falling out of sequence.

Figure 4.4.9 Colorado Basin Municipal and Self-Supplied Industrial Demands



4.4.6 Water Supply Gaps

The agricultural and M&I diversion demands were compared against available water supply modeled for current conditions and the five planning scenarios. Gaps were calculated when water supply was insufficient to meet demands.

INCREMENTAL GAP

The incremental agricultural gap quantifies the degree to which the gap could increase beyond what agriculture has historically experienced under water shortage conditions.

Agricultural

The Colorado Basin agricultural diversion demands, demand gaps, and consumptive use gaps for the baseline and planning scenarios are presented in Table 4.4.9 and illustrated on Figure 4.4.10. An annual time series of gaps in terms of percent of demand that was unmet is shown on Figure 4.4.11.

Table 4.4.9 Colorado Basin Agricultural Gap Results (AFY)

		Scenario					
		Scenario	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand	1,598,900	1,476,800	1,476,800	1,663,800	1,294,900	1,751,600
Average	Average Annual Gap	45,300	44,994	43,000	76,200	61,500	103,800
Average	Average Annual Gap Increase from Baseline	-	-	-	30,900	16,200	58,500
Average	Average Annual Percent Gap	3%	3%	3%	5%	5%	6%
Average	Average Annual CU Gap	25,100	24,400	24,400	42,400	40,400	57,800
Maximum	Demand in Maximum Gap Year	1,598,800	1,477,500	1,477,500	1,587,200	1,258,000	1,668,300
Maximum	Gap in Maximum Gap Year	148,000	141,100	141,000	166,500	131,400	210,400
Maximum	Increase from Baseline Gap	-	-	-	18,500	-	62,400
Maximum	Percent Gap in Maximum Gap Year	9%	10%	10%	10%	10%	13%

Study period for Water Supply analysis is 1975-2013, reflecting different baseline demand than described in Agricultural Diversion Demands section.

Figure 4.4.10 Projected Average Annual Agricultural Diversion Demand, Demand Met, and Gaps in the Colorado Basin

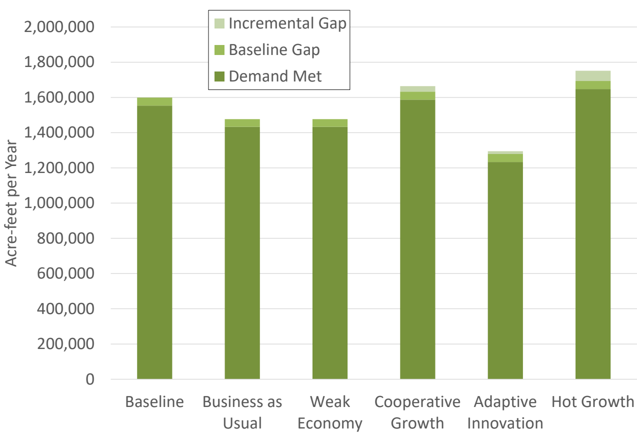
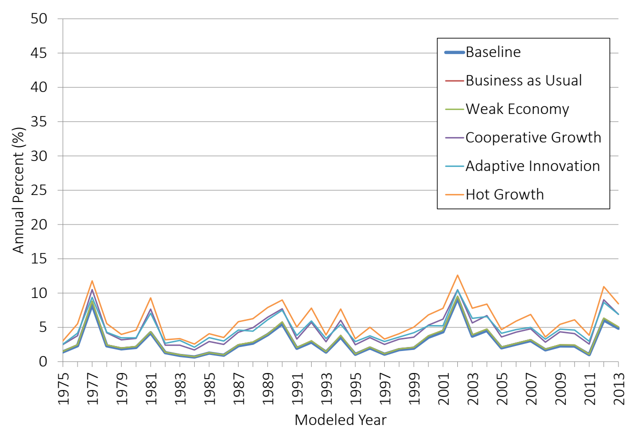


Figure 4.4.11 Annual Agricultural Gaps (expressed as a percentage of demand) for Each Planning Scenario



The following are observations on agricultural diversion demands and gaps:

- Although irrigated area is estimated to decrease by 13,600 acres as cities expand onto irrigated land, basin-wide IWR and diversion demand may increase in a warmer future climate.
- Emerging technologies, including the adoption of more efficient irrigation practices, modernizing irrigation infrastructure (e.g., automation) and crops with lower irrigation requirements, may mitigate climate impacts and reduce demand below baseline.
- The future incremental gap ranges from 0 to 4 percent of baseline demand.
- Scenarios that assume current climate conditions (*Business as Usual* and *Weak Economy*) have agricultural gaps around 3 percent of demand. Gaps (as a percentage of demand) increase in scenarios that assume a warmer and drier future climate.

M&I

The diversion demand and gap results for M&I uses in the Colorado Basin are summarized in Table 4.4.10 and illustrated in Figure 4.4.12. An annual time series of gaps in terms of percent of demand that was unmet is shown in Figure 4.4.13.

Table 4.4.10 Colorado Basin M&I Gap Results (AFY)

		Scenario					
		Scenario	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand	68,500	98,400	85,800	95,400	94,500	121,400
	Average Annual Gap	0*	1,200	800	1,900	2,300	4,700
	Average Annual Percent Gap	0%	1%	1%	2%	2%	4%
Maximum	Demand in Maximum Gap Year	68,500	98,400	85,800	95,400	94,500	121,400
	Gap in Maximum Gap Year	0*	4,200	3,300	5,300	6,600	15,800
	Percent Gap in Maximum Gap Year	0%	4%	4%	6%	7%	13%

CDSS water allocation model in this basin calculates small baseline M&I gaps, but they are either due to calibration issues or they are reflective of infrequent, dry-year shortages that are typically managed with temporary demand reductions such as watering restrictions.

Figure 4.4.12 Projected Maximum Annual M&I Demand Met and Gaps in the Colorado Basin

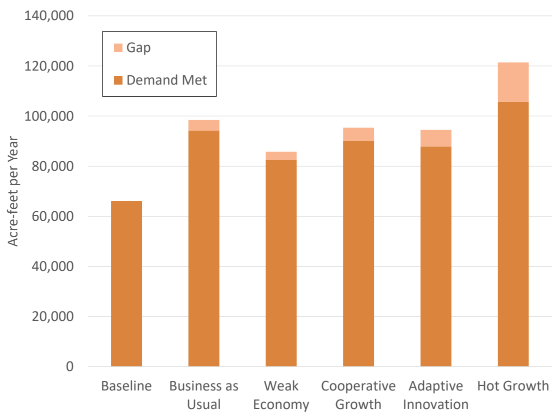
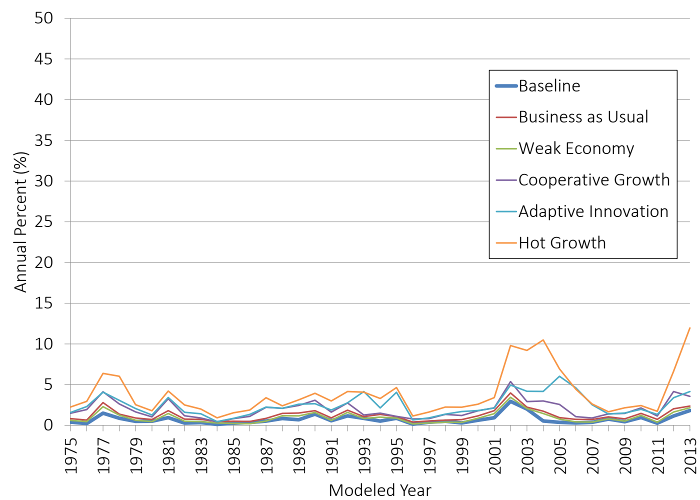


Figure 4.4.13 Annual M&I Gaps (expressed as a percentage of demand) for Each Planning Scenario



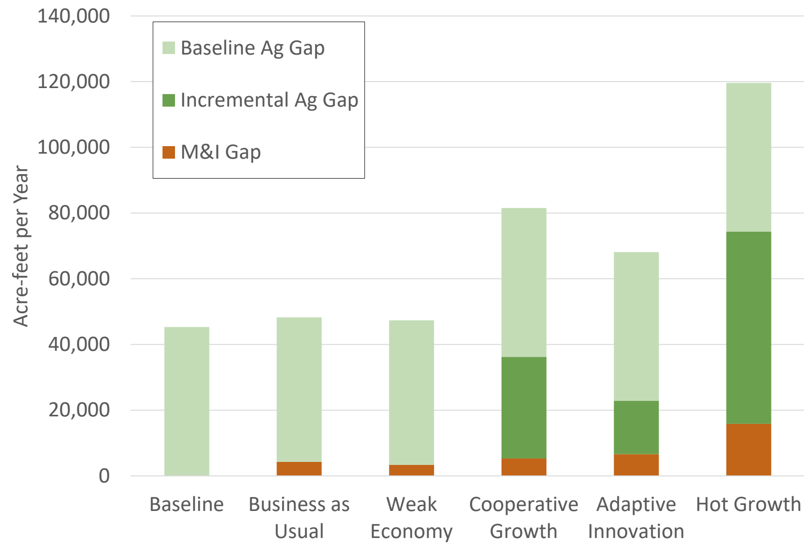
The following are observations on the M&I diversion demands and gaps:

- Average annual M&I gap in the Colorado Basin is far less than the agricultural gap, ranging from 500 AF to more than 4,700 AF.
- The maximum M&I gap for the five planning scenarios ranges from 2,300 AF to nearly 16,000 AF.
- Per capita municipal usage is projected to decrease.
- Overall municipal demand is projected to increase for all scenarios due to increased population; however, except for *Hot Growth*, the systemwide demand projections for all future scenarios are similar.
- Increase in SSI demand in *Business as Usual* and *Hot Growth* represent anticipated energy development.

Total Gap

Figure 4.4.14 illustrates the total combined agricultural and M&I diversion demand gap in the Colorado Basin. The figure combines average annual baseline and incremental agricultural gap and the maximum M&I gap. In *Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth*, gaps were driven by agricultural demands, which increase in the "In Between" and "Hot and Dry" climate projections.

Figure 4.4.14 Projected Average Annual Agricultural Gaps and Maximum M&I Diversion Demand Gaps in the Colorado Basin



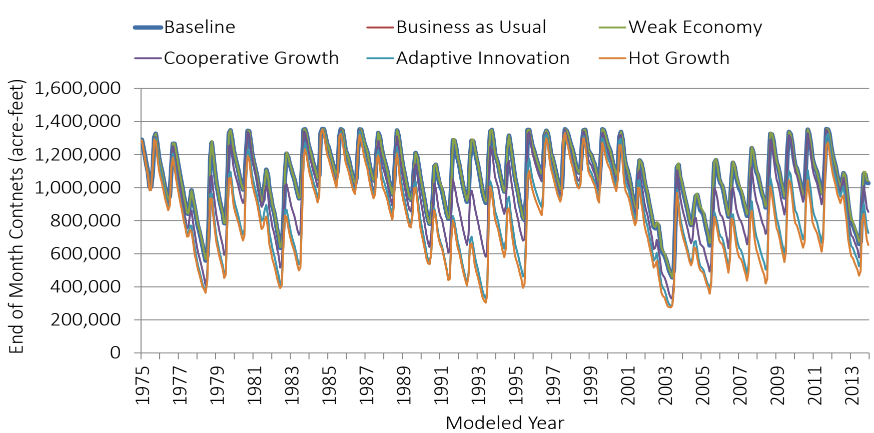
Supplies from Urbanized Lands

By 2050, irrigated acreage in the Colorado Basin is projected to decrease by 13,600 acres due to urbanization. Irrigation supplies for these lands could potentially be used for M&I needs in the future (subject to a variety of unknowns such as seniority and type of water supply, willingness to change the use of water through water court, etc.). The average annual historical consumptive use associated with potentially urbanized acreage for each scenario is reflected in Table 4.4.11. The data in the table represent planning-level estimates of this potential supply and has not been applied to the M&I gaps.

Table 4.4.11 Estimated Consumptive Use from Lands Projected to be Urbanized by 2050 in the Colorado Basin

	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Urbanized Acreage (acres)	13,600	13,600	13,600	13,600	13,600
Estimated Consumptive Use (AFY)	28,300	28,300	30,800	29,700	32,100

Figure 4.4.15. Total Simulated Reservoir Storage in the Colorado Basin



Storage

Total simulated reservoir storage from the Colorado water allocation model is shown on Figure 4.4.15. Baseline conditions show the highest levels of water in storage (in general) and the lowest is in *Hot Growth*. *Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth* show lower amounts of water in storage during dry periods than the two scenarios that do not include the impacts of a drier climate; however, storage levels generally recover from dry periods back to baseline levels. Storage in the Colorado Basin is critical to minimizing gaps as described in Section 4.4.3 and as demonstrated by the large degree of fluctuation in basin-wide storage amount.

4.4.7 Available Supply

Figures 4.4.16 through 4.4.19 show simulated monthly available flow for the Colorado Basin at locations representative of the Shoshone Power Plant diversion (near Dotsero) and the "Cameo Call", which are generally the controlling rights on the mainstem of the Colorado River. Streamflow and available flow nearly double between the upstream and downstream locations due to inflows from the Roaring Fork, Parachute Creek, and Rifle Creek. The figures show that flows are projected to be available each year, though the amounts will vary annually and across scenarios (available flows under the scenarios impacted by climate change are less than in other scenarios). Peak flows are projected to occur earlier in the year under scenarios impacted by climate change.

Figure 4.4.16 Simulated Hydrographs of Available Flow at Colorado River near Dotsero, CO

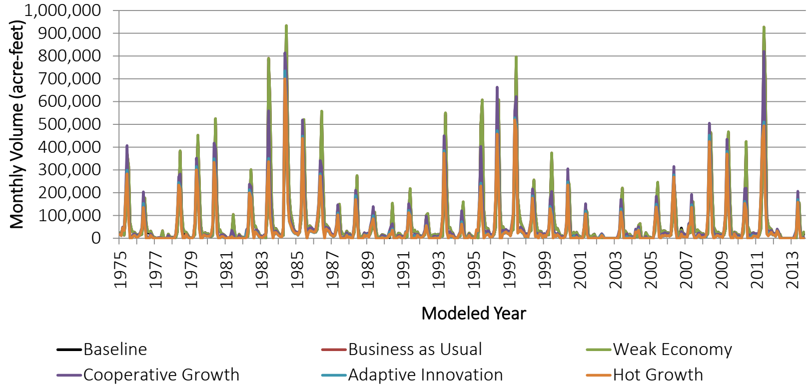


Figure 4.4.17 Average Monthly Simulated Hydrographs of Available Flow at Colorado River near Dotsero, CO

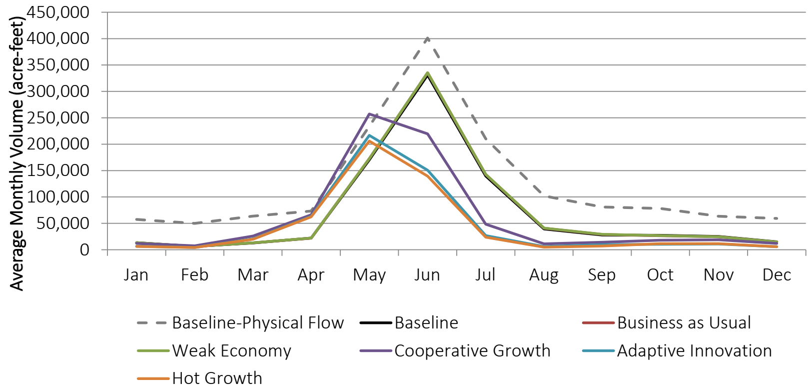


Figure 4.4.18 Simulated Hydrographs of Available Flow at Colorado River near Cameo, CO

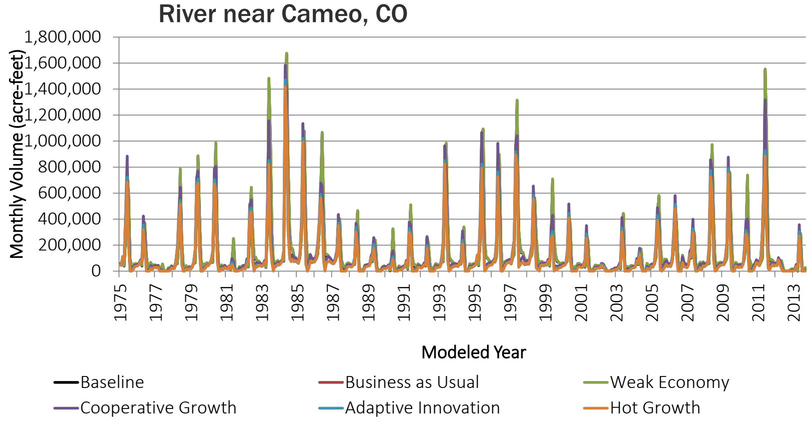
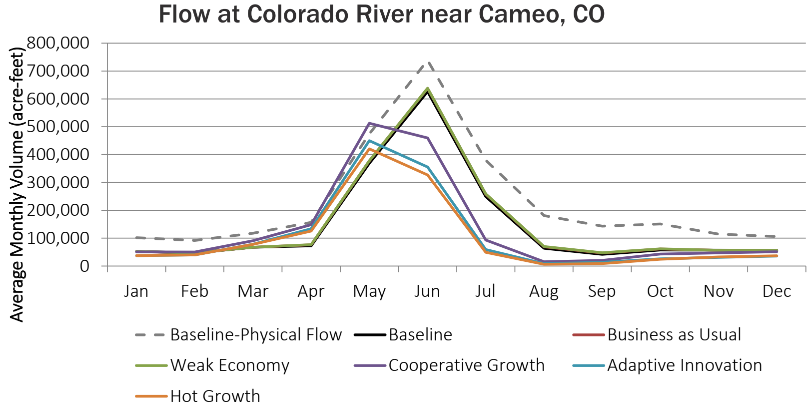


Figure 4.4.19 Average Monthly Simulated Hydrographs of Available Flow at Colorado River near Cameo, CO



4.4.8 Environment and Recreation

A total of eleven water allocation model nodes were selected for the Flow Tool within the Colorado Basin (see Figure 4.4.20). In addition to nodes, Figure 4.4.20 also shows subwatersheds (at the 12-digit HUC level) and the relative number of E&R attributes located in each subwatershed.

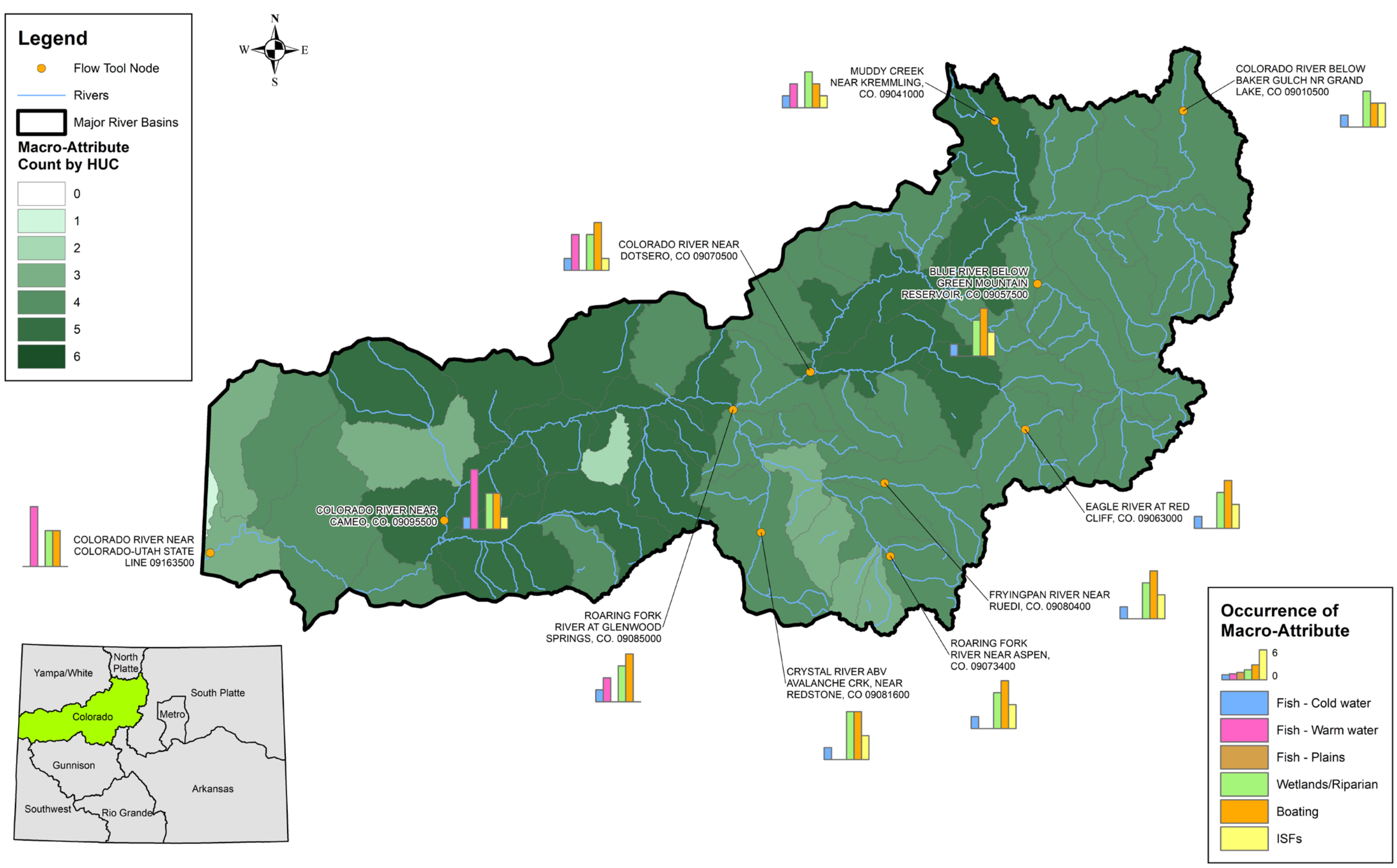
Nodes include:

- Colorado River below Baker Gulch near Grand Lake, Colorado (09010500)
- Muddy Creek near Kremmling, Colorado (09041000)
- Blue River below Green Mountain Reservoir, Colorado (09057500)
- Eagle River at Red Cliff, Colorado (09063000)
- Colorado River near Dotsero, Colorado (09070500)
- Roaring Fork River near Aspen, Colorado (09073400)
- Fryingpan River near Ruedi, Colorado (09080400)
- Crystal River above Avalanche Creek, near Redstone, Colorado (09081600)
- Roaring Fork River at Glenwood Springs, Colorado (09085000)
- Colorado River near Cameo, Colorado (09095500)
- Colorado River near Colorado-Utah State Line (09163500)

NATURALIZED FLOW

Naturalized flows reflect conditions that would occur in the absence of human activities. Baseline flows reflect current conditions as influenced by existing infrastructure and river operations. While observations regarding naturalized flows may be informative, baseline flows reflect actual conditions and the diverse operations of a river's many users.

Figure 4.4.20 Flow Tool Nodes Selected for the Colorado Basin



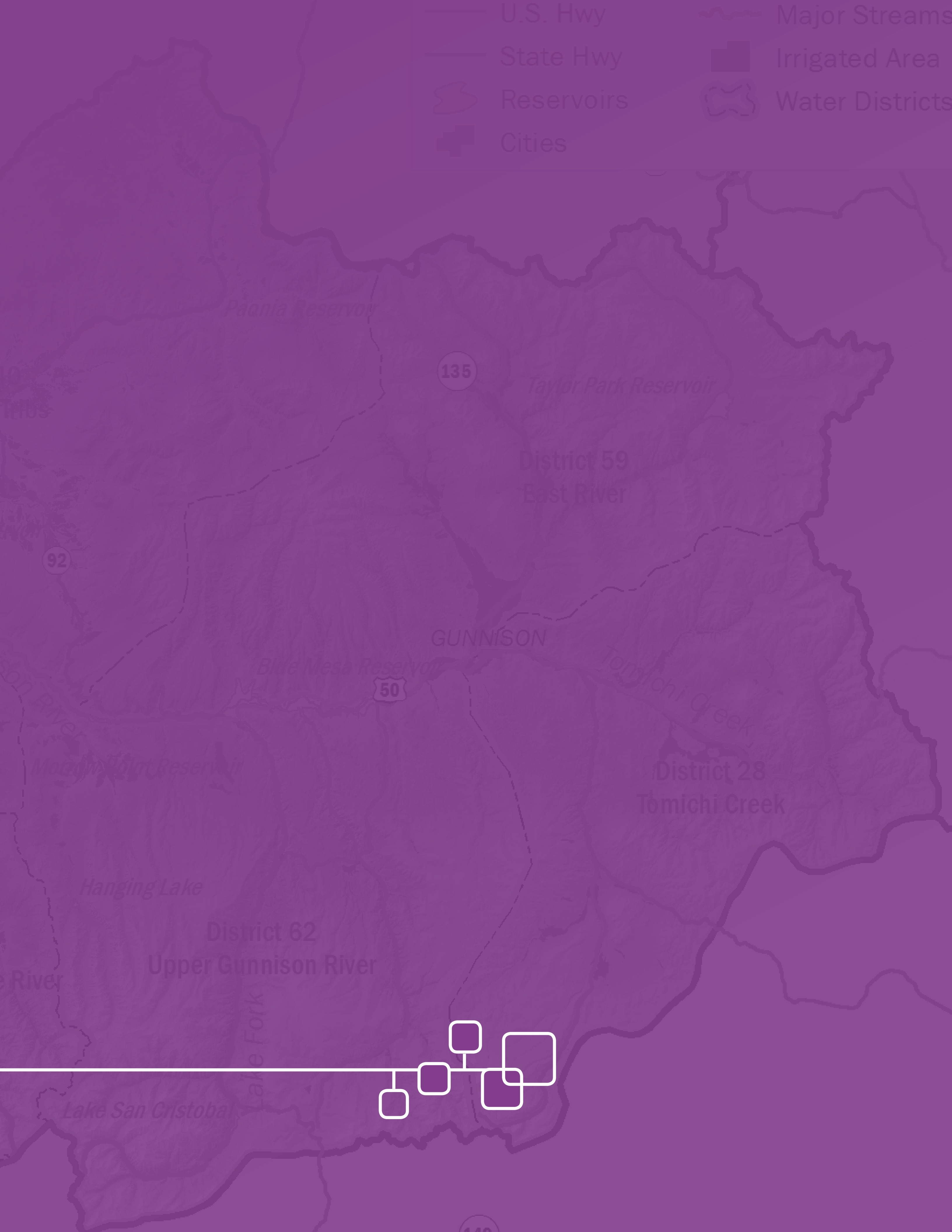
Results of Flow Tool analyses using flow data developed in the water supply and gap analyses for baseline conditions and the planning scenarios are described below.

Table 4.4.12 Summary of Flow Tool Results in Colorado Basin

Category	Observation
Projected Flows	Annual flow in headwaters (Colorado River below Baker's Gulch) under baseline conditions is below natural conditions, and this departure increases under climate change scenarios. Moving downstream through Dotsero, Cameo, and to the state line, annual flow under baseline conditions rebounds slightly closer to naturalized conditions.
	Under climate change scenarios (*Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth*), annual depletions are projected to increase from headwaters to the state line.
	Similar to the alterations in annual flows, peak flow magnitudes on the Colorado River under baseline conditions are below natural conditions from the headwaters through Dotsero, and are closer to natural conditions at lower elevations (Cameo and State Line).
	Under climate change scenarios (*Collaborative Growth*, *Adaptive Innovation*, and *Hot Growth*), peak flow magnitudes on the Colorado River are projected to decrease further below natural conditions. Decreases in peak flows (from naturalized to baseline) are more pronounced at locations below large reservoirs (e.g., Blue River below Green Mountain Reservoir, Fryingpan River below Reudi Reservoir). This dampening of peak flows is projected to worsen under climate driven scenarios. In some locations (notably, Crystal River above Avalanche Creek), peak flow magnitude is projected to increase under some scenarios.
	Under the scenarios with climate change influences, snowmelt and timing of peak flow is projected to shift earlier in the year. In many areas from headwaters to lower elevations, June flows are projected to decrease well below naturalized conditions, while April and May flows could similar to baseline or increase slightly.
	Under baseline conditions, mid- and late-summer flows in headwaters subject to transbasin exports are currently depleted compared to naturalized conditions. The difference between baseline and naturalized conditions lessens farther downstream.
	Under scenarios with climate change, mid- and late-summer flows in headwaters are projected to drop well below naturalized, but farther downstream, this drop is projected to be less pronounced. In many locations, mid- and late-summer flows under climate change scenarios are projected to be well below naturalized. The Fryingpan below Reudi Reservoir is an exception to the large projected decreases in mid- and late-summer flows, because releases are made steadily from the reservoir.
Ecological Risk	Decreased peak flows that are prevalent across the basin under baseline conditions create risk for riparian/wetland plants and fish habitat.
	This risk increases under climate change scenarios. Projected decreases in mid- and late-summer flows create risk for fish from loss of habitat and, in trout regions, increased water temperatures. Downstream from major reservoirs (e.g., Fryingpan, Green Mountain), projected diminished peak flows create increased risk for riparian/wetland vegetation and fish habitat if sediment is not flushed, while projected consistent mid- and late-summer flows keep risk to fish low to moderate.
ISFs and RICDs	Several Instream Flows (ISFs) throughout the basin and Recreational In-channel Diversion (RICD) are likely to be regularly unmet if June-August flows decrease as projected under climate change scenarios.
	In critical habitat for endangered species, projected reduced flows in mid- and late-summer will make it more difficult to meet flow recommendations. For example, projected August flows under climate change scenarios on the Colorado River at Cameo suggest that flow recommendations for endangered fish will not be met during August in approximately one-third of years.
E&R Attributes	Under baseline, *Business as Usual*, and *Weak Economy*, current flow issues related to E&R attributes arise from timing/water delivery issues.
	Under climate change scenarios, the shift in the timing of peak flow, reductions in total runoff, and increasing demands for consumptive uses contribute to reductions in mid- and late-summer flows. Several water management programs implemented in the context of the Upper Colorado Endangered Fish Program (e.g., Coordinated Reservoir Operations Program) have demonstrated that flow timing and magnitude, along with stream temperature, can be improved through water management that explicitly considers the needs of E&R attributes.

The Gunnison Basin stretches across more than 8,000 square miles of western Colorado, extending from the Continental Divide to the confluence of the Gunnison and Colorado rivers near Grand Junction. The basin is largely forested, with forest covering approximately 52 percent of the total basin area. About 5.5 percent of the basin is classified as planted or cultivated land, and these lands are primarily concentrated in the Uncompahgre River Valley between Montrose and Delta with additional pockets near Gunnison and Hotchkiss. Key future water management issues in this basin as described in The Colorado Water Plan include agricultural water shortages and increased growth and tourism in the headwaters region.

GUNNISON


U.S. Hwy
State Hwy
Reservoirs
Cities
Major Streams
Irrigated Area
Water Districts
Paonia Reservoir
135
Taylor Park Reservoir
District 59
East River
92
GUNNISON
Blue Mesa Reservoir
50
Tomichi Creek
District 28
Tomichi Creek
Hanging Lake
District 62
Upper Gunnison River
Lake Fork
Lake San Cristobal

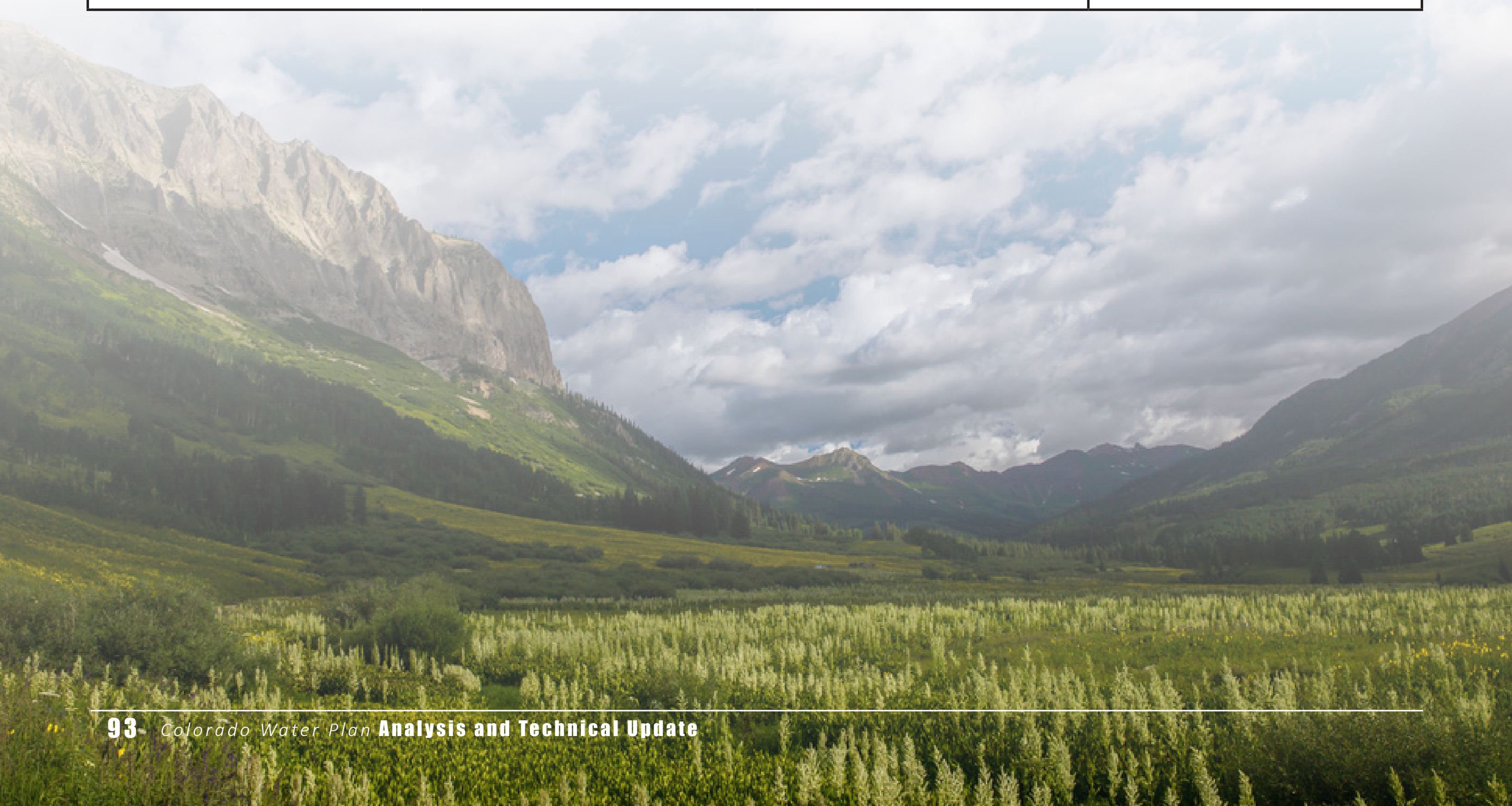
4.5 GUNNISON BASIN RESULTS

4.5.1 BASIN SUMMARY

Key future water management issues in this basin as described in The Colorado Water Plan include agricultural water shortages and increased growth and tourism in the headwaters region.

Table 4.5.1 Key Future Water Management Issues in the Gunnison Basin

<table>
<tr><th>Agriculture</th><th>Environment and Recreation</th><th>Municipal and Industrial</th><th>Compacts and Administration</th></tr>
<tr><td>• Addressing agricultural water shortages in the upper portion of the basin is an important goal of the community. Lack of financial resources is an impediment.</td><td>• The Gunnison River Basin faces a complex set of environmental issues associated with water quality, water quantity and associated impacts to fish and wildlife habitat in the context of regulatory drivers associated with the Endangered Species Act (ESA) and the Clean Water Act (CWA).</td><td>• Growth in the headwaters region will require additional water management strategies.</td><td rowspan="2">• Possible future transbasin diversions have been a concern, along with the potential effect this might have on existing uses within the basin.</td></tr>
<tr><td colspan="3">• The area between Ouray and Montrose is rapidly growing. Tourism is important in the headwaters areas, but agriculture is dominant in the Uncompahgre Valley. A rapid influx of retirees and growth in the Uncompahgre Valley may dramatically change agricultural uses and other land uses in the area.</td></tr>
</table>



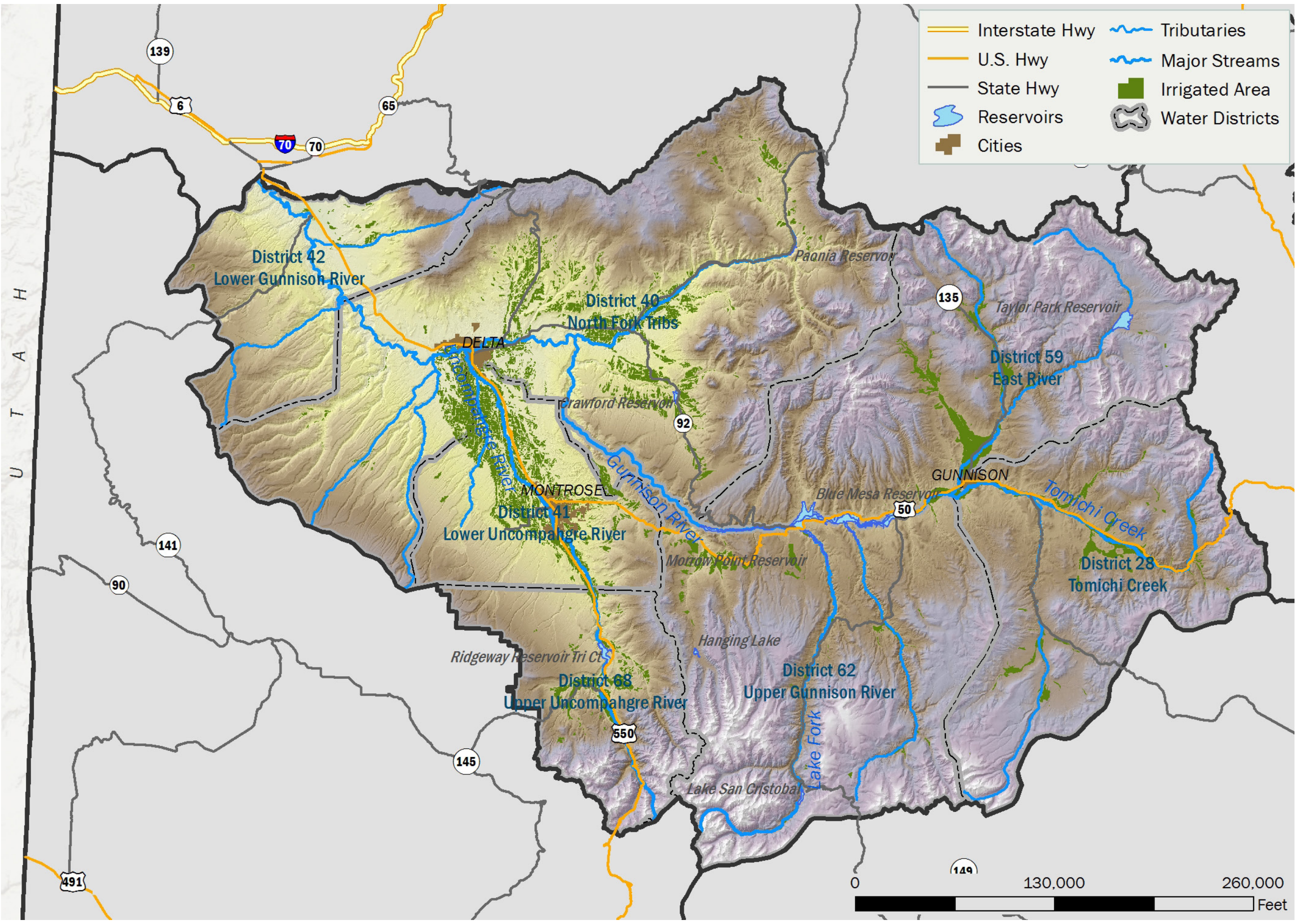


Figure 4.5.1 Map of the Gunnison Basin

4.5.2 SUMMARY OF TECHNICAL UPDATE RESULTS

Key results and findings of the Technical Update pertaining to agricultural and M&I demands and gaps as well as findings related to environmental and recreational attributes and future conditions are summarized below in Table 4.5.2.

Table 4.5.2 Summary of Key Results in the Gunnison Basin

Agriculture	Environment and Recreation	Municipal and Industrial
• Agricultural demand is a major factor in this basin and represents 99% of the total water demand. • Increases in agricultural demand and gaps will occur with a warmer and drier climate. • Increases in system efficiency and reductions in irrigation water requirements significantly reduce diversion demand and the gap in Adaptive Innovation.	• Aquatic and riparian attributes may be affected differently based on location and potential changes in streamflow magnitude and timing. • Flow recommendations, Instream Flow water rights, and recreational in-channel diversions may be met less often in climate-impacted scenarios.	• Population increases are the main driver for increased M&I demands in the planning scenarios, as per capita water use decreased for every scenario except Hot Growth. • Growth in Montrose County accounts for 50% of the M&I demand. • The only SSI use in the basin is snow-making, and it is a relatively small proportion of demands.

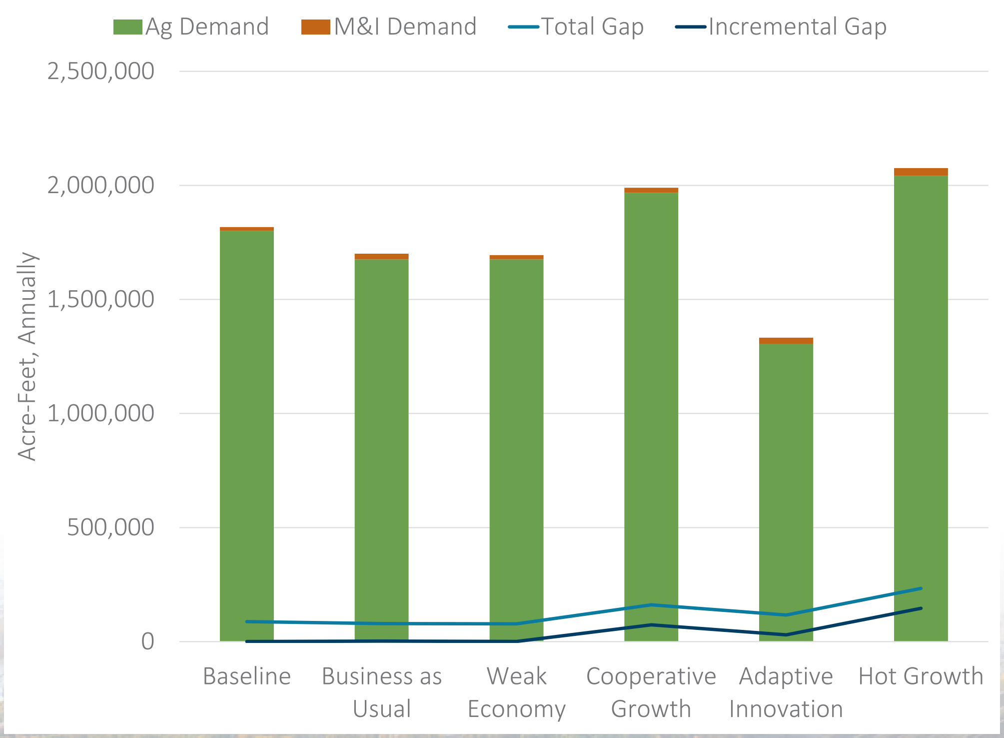
Results describing current and potential future M&I and agricultural demands and gaps are summarized in Table 4.5.3 and in Figure 4.5.2.

Table 4.5.3 Summary of Diversion Demand and Gap Results in the Gunnison Basin

	Current (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average Annual Demand						
Agricultural (AFY)	1,800,200	1,675,500	1,675,500	1,967,200	1,305,700	2,041,500
M&I (AFY)	17,000	24,800	19,100	22,900	26,400	34,100
Gaps						
Ag (avg %)	5%	5%	5%	8%	9%	11%
Ag (incremental-AFY)	-	-	-	70,300	25,300	134,700
Ag (incremental gap as % of current demand)	-	-	-	4%	1%	7%
M&I (max %)	0%	9%	4%	15%	16%	34%
M&I (max-AF)	0*	2,300	700	3,500	4,300	11,500

*CDSS water allocation model in this basin calculates small baseline M&I gaps, but they are either due to calibration issues, or they are reflective of infrequent, dry-year shortages that are typically managed with temporary demand reductions such, as watering restrictions.

Figure 4.5.2 Summary of Diversion Demand and Gap Results in the Gunnison Basin



Summary of Environmental and Recreational Findings

- Reduced peak flows below major reservoirs on the Uncompahgre and Gunnison mainstems under baseline conditions create high risk to riparian/wetland habitat and may not support sediment dynamics needed to maintain fish habitat.
- Across most locations, mid- and late-summer flows drop, but risk to fish remains moderate; however, the metric used to assess risk for fish does not include the month of July because historically July flows have been sufficient. Under *Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth*, July flows drop substantially, which increases the risk for fish.
- In several locations, Instream Flow water rights may be met less often. At least one RICD may be met less often.
- In critical habitat for endangered species, much reduced flows in mid- and late-summer will make it more difficult to meet flow recommendations.
- In at least one location (Cimarron River), winter flows become extremely low and puts fish at risk.

4.5.3 NOTABLE BASIN CONSIDERATIONS

Section 4.1 described several analysis assumptions and limitations that apply to all basins and should be considered when reviewing and interpreting analysis results. An additional consideration with respect to the Gunnison Basin is that agricultural system efficiencies in this basin are generally lower than in other basins due to factors described in the next section. The associated return flows, however, become the supplies for downstream irrigators and are reused.

4.5.4 AGRICULTURAL DIVERSION DEMANDS

Agricultural Setting

Agriculture in the Upper Gunnison Basin, above Blue Mesa Reservoir, is dominated by large cattle ranches located along the tributaries and mainstem river. Ranchers generally rely on flood irrigation to fill the alluvial aquifer during the runoff season, as supplies are typically scarce later in the irrigation season. Agricultural diversion demands are higher in this basin due to the presence of gravelly soils, which leads to generally lower irrigation efficiencies than in other basins.

Several Bureau of Reclamation Projects provide supplemental irrigation supplies for much of the irrigated acreage in the Lower Gunnison Basin. The most notable irrigation projects in the area include the Uncompahgre, Paonia, Smith Fork, Fruitland Mesa, Bostwick Park, and the Fruitgrowers Dam projects. Lower elevations and warmer temperatures in the Lower Gunnison Basin provide conditions to grow a variety of fruits, vegetables, corn grain, and root crops on more than 185,000 acres of the total 234,000 irrigated acres in the basin.

Planning Scenario Adjustments

Section 2 described ways in which inputs to agricultural diversion demand estimates were adjusted to reflect the future conditions described in the planning scenarios. Adjustments in the Gunnison Basin focused on urbanization, potential future climate conditions, and implementation of emerging technologies.

Many of the municipalities in the basin are surrounded by or near irrigated lands, and many counties in the basin are projected to have significant population increases by 2050. The resulting urbanization of irrigated acreage from this growth was estimated to be approximately 14,600 acres, primarily around Gunnison, Montrose, Delta, and the corridor between Cedaredge and Orchard City.

Table 4.5.4 summarizes the planning scenario adjustments described above and other adjustments that impact agricultural diversion demands in the scenarios.

Table 4.5.4 Planning Scenario Adjustments for Agricultural Demands in the Gunnison Basin

Adjustment Factor*	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Change in Irrigated Land due to Urbanization	14,600 Acre Reduction	14,600 Acre Reduction	14,600 Acre Reduction	14,600 Acre Reduction	14,600 Acre Reduction
Increase in IWR due to Climate	-	-	22%	30%	30%
Emerging Technologies	-	-	-	10% IWR Reduction; 10% System Efficiency Increase	-

**See Section 2.2.3 for descriptions of adjustment methodologies and assumptions.*

Agricultural Diversion Demand Results

Table 4.5.5 and Figure 4.5.3 summarize the acreage, IWR, and the agricultural diversion demand for surface water supplies in the Gunnison Basin for current conditions and the five planning scenarios. The largest variation in the basin occurred in the *Adaptive Innovation* scenario due to 10 percent reduction in IWR and 10 percent increase to system efficiency, both of which reduce diversion demands. The combined effect of the *Adaptive Innovation* scenario adjustments resulted in an agricultural diversion demand that is lower than the current demand. Diversion demands increased in *Cooperative Growth* and *Hot Growth* due to higher IWR resulting from a warmer and drier future climate.

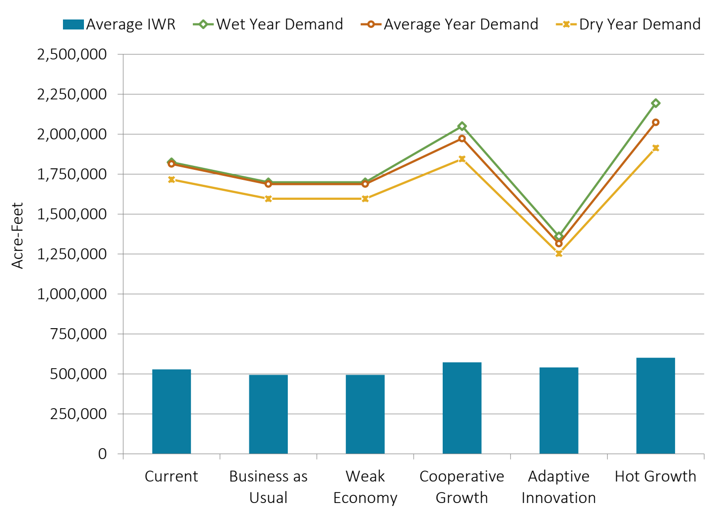
> **SYSTEM EFFICIENCY**
>
> In some cases, diversion demands can be higher in wet years because system efficiency decreases due to the relative abundance of supply.

Table 4.5.5 Summary of Agricultural Diversion Demand Results in the Gunnison Basin

	Current (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Irrigated Acreage (acres)	234,400	219,800	219,800	219,800	219,800	219,800
Average IWR (AFY)	528,200	494,000	494,000	573,000	541,000	601,000
Diversion Demand						
Average Year (AFY)	1,814,000	1,688,000	1,688,000	1,973,000	1,315,000	2,074,000
Wet Yr. Change	1%	1%	1%	4%	3%	6%
Dry Yr Change	-5%	-5%	-5%	-6%	-5%	-8%

Average agricultural diversion demand was calculated using the average hydrologic years (i.e., years classified as neither wet or dry) from 1950-2013

Figure 4.5.3 Agricultural Diversion Demands and IWR Results in the Gunnison Basin



Municipal and Self-Supplied Industrial Diversion Demands

Population Projections

The Gunnison Basin includes about 2 percent of the statewide population. Between the years 2015 and 2050, it is projected to grow from approximately 100,000 to between 120,000 and 200,000 people in the low and high growth projections, respectively, which is an increase in population of 19 to 99 percent. Table 4.5.6 shows how population growth is projected to vary across the planning scenarios for the Gunnison Basin.

Table 4.5.6 Gunnison Basin 2015 and Projected Populations

Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
103,100	162,600	123,100	158,600	196,000	204,900

Current Municipal Demands

Sources of water demand data such as 1051 or WEP data made up less than 50 percent of the available information in the Gunnison Basin, and baseline water demands were largely estimated as shown on Figure 4.5.4.

Figure 4.5.5 summarizes the categories of municipal, baseline water usage in the Gunnison Basin. On a basin scale, the residential indoor demand as a percentage of the systemwide demands are relatively high, at almost 40 percent of the systemwide demands.

Figure 4.5.4 Sources of Water Demand Data in the Gunnison Basin

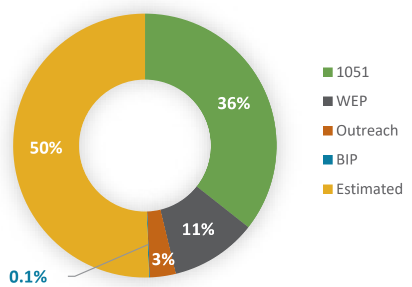
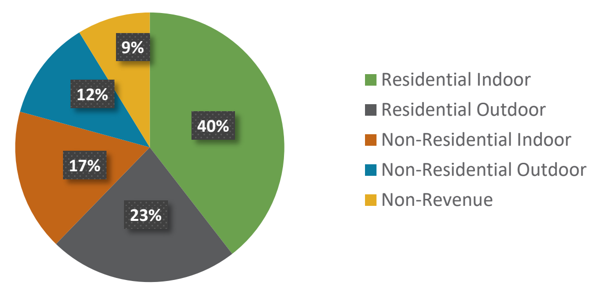


Figure 4.5.5 Categories of Water Usage in the Gunnison Basin



Projected Municipal Demands

Figure 4.5.6 provides a summary of per capita baseline and projected water demands for the Gunnison Basin. Systemwide, the per capita demands are projected to decrease relative to the baseline except for *Hot Growth*. Outdoor demands are projected to increase significantly for *Hot Growth* due to hotter and drier climate conditions.

The Gunnison Basin municipal baseline and projected diversion demands provided in Table 4.5.7 show the combined effect of population and per capita demands. Municipal demands are projected to grow from approximately 18,000 AFY in 2015 to between 21,000 and 37,000 AFY in 2050. Montrose County accounts for almost half of the baseline demand, followed by Delta County at about one-fifth of the basin demand.

Figure 4.5.6 Gunnison Basin Municipal Baseline and Projected per Capita Demands by Water Demand Category

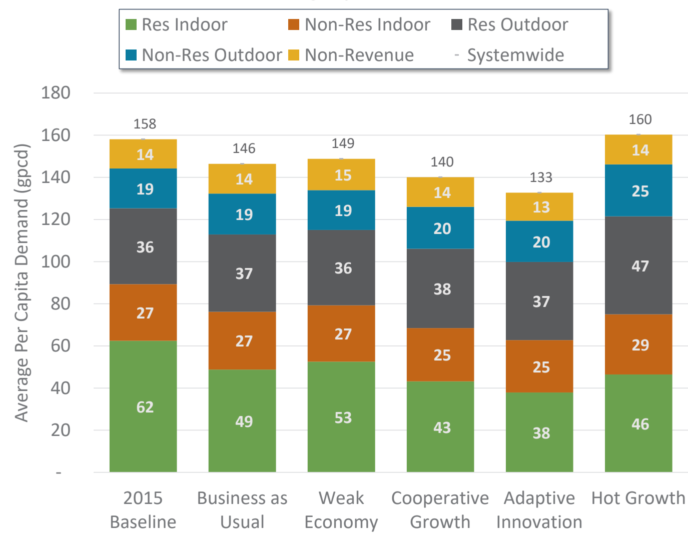
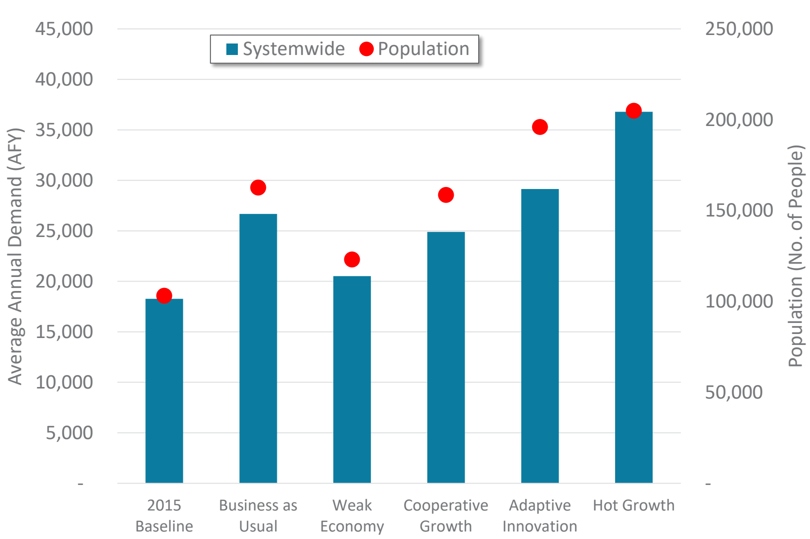


Table 4.5.7 Gunnison Basin Municipal Baseline and Projected Demands (AFY)

Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
18,300	26,700	20,500	24,900	29,100	36,800

The baseline and projected demand distributions are shown on Figure 4.5.7, which also shows how the population varies between the scenarios. All of the planning scenarios show an increase relative to the baseline. Demands generally follow the population patterns; however, increased outdoor demands for the "Hot and Dry" climate projection have a greater impact on gpcd, resulting in higher demands for *Hot Growth*. Higher levels of conservation associated with *Adaptive Innovation* help limit the impacts of the "Hot and Dry" climate projection and higher population.

Figure 4.5.7 Gunnison Basin Baseline and Projected Population and Municipal Demands



Self-Supplied Industrial Demands

The Gunnison Basin currently includes less than one percent of the statewide SSI demand. SSI demands in this basin are associated exclusively with the snowmaking sub-sector. There are no demands projected for the large industry, thermoelectric, or energy development sub-sectors. Basin-scale SSI demands are shown on Figure 4.5.8 and summarized in Table 4.5.8.

The baseline snowmaking demand is 270 AFY as compared to 260 AFY in SWSI 2010. All snowmaking occurs in Gunnison County. Projected SSI demands increase to 650 AFY under all scenarios.

Figure 4.5.8 Gunnison Basin Self-Supplied Industrial Demands

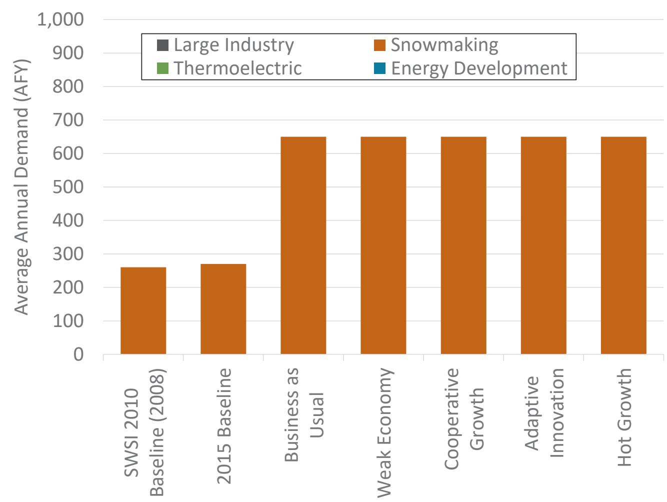


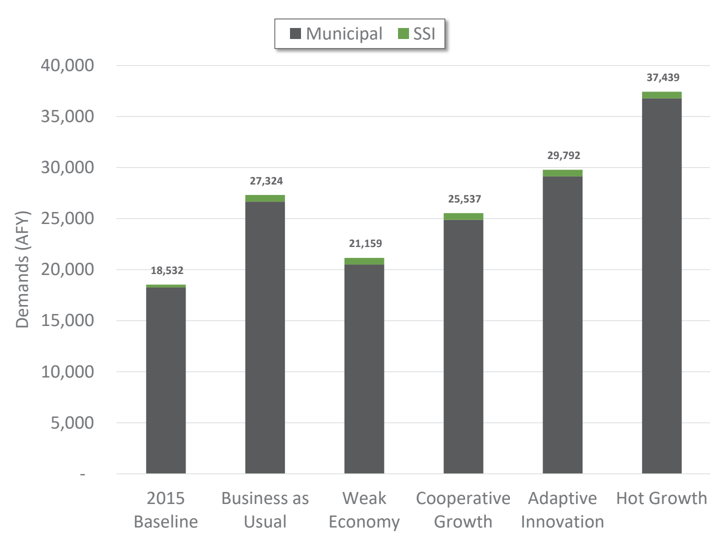
Table 4.5.8 Gunnison SSI Baseline and Projected Demands (AFY).

Sub-sector	Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Large Industry	-	-	-	-	-	-
Snowmaking	270	650	650	650	650	650
Thermoelectric	-	-	-	-	-	-
Energy Development	-	-	-	-	-	-
Sub-Basin Total	**270**	**650**	**650**	**650**	**650**	**650**

Total M&I Diversion Demands

Gunnison Basin combined M&I demand projections for 2050 range from approximately 21,000 AFY in *Weak Economy* to more than 37,000 AFY in *Hot Growth* as shown on Figure 4.5.9. Under every planning scenario, municipal demands are the majority (at least 97 percent) of the total M&I demands. On a basin scale, the demand projections follow the statewide sequence of the scenario rankings described in the CWP.

Figure 4.5.9 Gunnison Basin Municipal and Self-Supplied Industrial Demands



4.5.5 Water Supply Gaps

The agricultural and M&I diversion demands were compared against available water supply modeled for current conditions and the five planning scenarios. Gaps were calculated when water supply was insufficient to meet demands.

Agricultural

The Gunnison Basin agricultural diversion demands, demand gaps, and consumptive use gaps for the baseline and planning scenarios are presented in Table 4.5.9 and illustrated in Figure 4.5.10. An annual time series of gaps in terms of percent of demand that was unmet is shown on Figure 4.5.11.

> **INCREMENTAL GAP**
>
> The incremental agricultural gap quantifies the degree to which the gap could increase beyond what agriculture has historically experienced under water shortage conditions.

Table 4.5.9 Gunnison Basin Agricultural Gap Results (AFY)

		Scenario					
		Scenario	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand	1,800,200	1,675,500	1,675,500	1,967,200	1,305,700	2,041,500
	Average Annual Gap	87,300	77,200	77,300	157,600	112,600	222,000
	Average Annual Gap Increase from Baseline	-	-	-	70,300	25,300	134,700
	Average Annual Percent Gap	5%	5%	5%	8%	9%	11%
	Average Annual CU Gap	43,200	38,200	38,300	74,800	64,700	104,000
Maximum	Demand in Maximum Gap	1,841,100	1,713,900	1,713,900	1,833,600	1,247,600	1,912,700
	Gap in Maximum Gap Year	339,700	313,500	314,800	432,600	319,600	590,800
	Increase from Baseline Gap	-	-	-	93,000	-	251,100
	Percent Gap in Maximum Gap Year	18%	18%	18%	24%	26%	31%

Study period for Water Supply analysis is 1975-2013, reflecting different baseline demand than described in Agricultural Diversion Demands section

Figure 4.5.10 Projected Average Annual Agricultural Diversion Demand, Demand Met, and Gaps in the Gunnison Basin

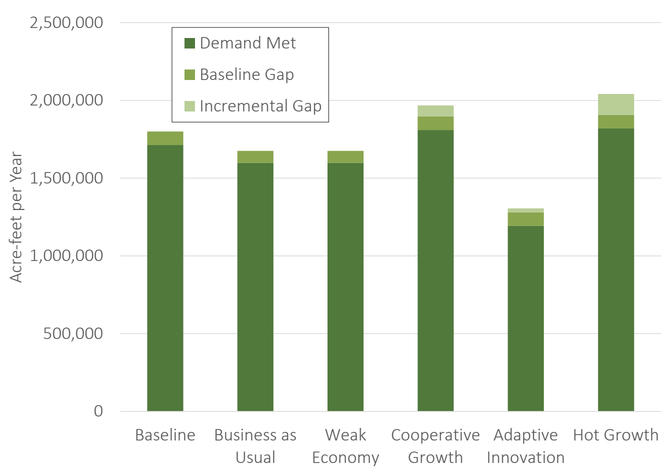
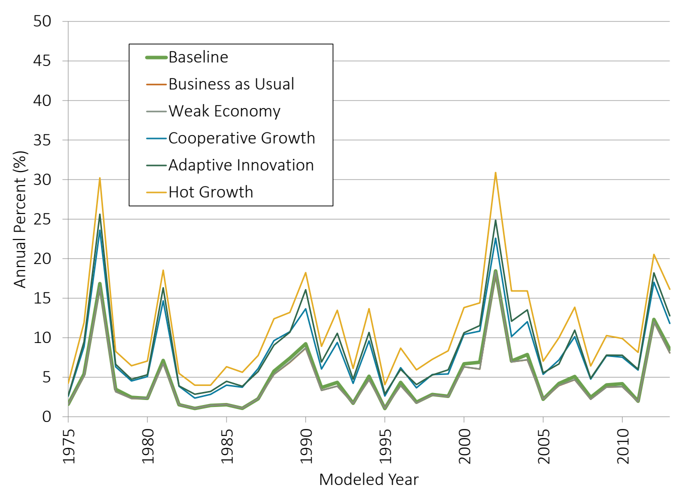


Figure 4.5.11 Annual Agricultural Gaps (expressed as a percentage of demand) for Each Planning Scenario



The following are observations on agricultural diversion demands and gaps:

- Agricultural diversion demands are projected to decrease in three of the five planning scenarios due to urbanization and the associated reduction of irrigated acres and the adoption of emerging agricultural technologies (in *Adaptive Innovation*).
- Agricultural diversion demands are projected to increase by 9 to 13 percent above current in *Cooperative Growth* and *Hot Growth* due to climate impacts.
- Agricultural gaps are projected to increase beyond existing gaps in the climate-impacted planning scenarios.
- While the gap as a percent of demand is projected to be relatively small in average years (5 to 11 percent), it may nearly triple (in terms of percent of demand) in maximum gap years.

M&I

The diversion demand and gap results for M&I uses in the Gunnison Basin are summarized in Table 4.5.10 and illustrated on Figure 4.5.12. An annual time series of gaps in terms of percent of demand that was unmet is shown on Figure 4.5.13.

Table 4.5.10 Gunnison Basin M&I Gap Results (AFY)

		Scenario					
		Scenario	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand	17,000	24,800	19,100	22,900	26,400	34,100
	Average Annual Gap	0*	1,000	200	1,400	2,200	5,000
	Average Annual Percent Gap	0%	4%	1%	6%	8%	16%
Maximum	Demand in Maximum Gap Year	17,000	24,800	19,100	22,900	26,400	34,100
	Gap in Maximum Gap Year	0*	2,300	700	3,500	4,300	11,500
	Percent Gap in Maximum Gap Year	0%	9%	4%	15%	16%	34%

**CDSS water allocation model in this basin calculates small baseline M&I gaps, but they are either due to calibration issues or they are reflective of infrequent, dry-year shortages that are typically managed with temporary demand reductions, such as watering restrictions.*

Study period for Water Supply Analysis is 1975-2013, reflecting different baseline demand than described in M&I Demand section. Baseline demand also may vary slightly from previous section due to differences in geographic distribution of demand for counties that lie in multiple basins.

Figure 4.5.12 Projected Maximum Annual M&I Demand Met and Gaps in the Gunnison Basin

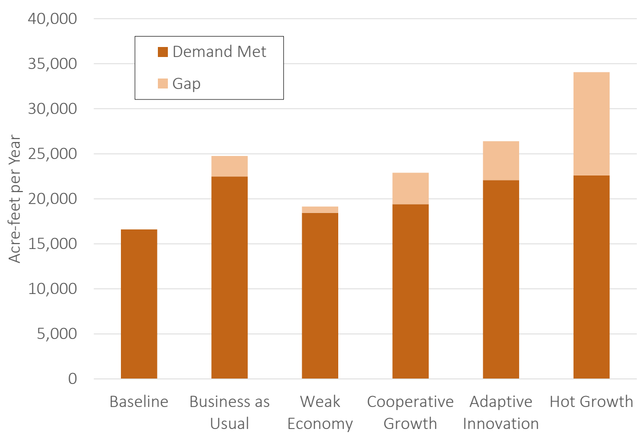
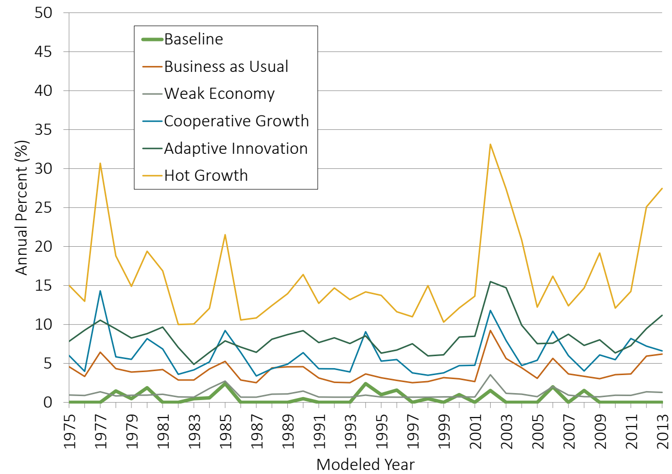


Figure 4.5.13 Annual M&I Gaps (expressed as a percentage of demand) for Each Planning Scenario



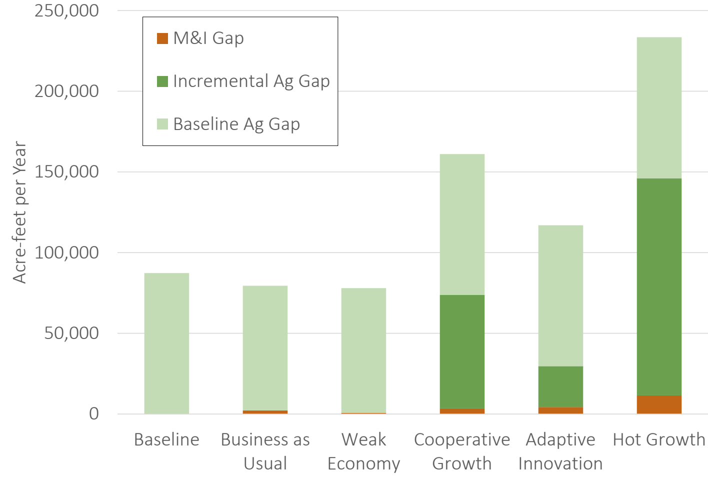
The following are observations on M&I diversion demands and gaps:

- The average annual M&I gap in the Gunnison Basin is projected to be less than the agricultural gap, ranging from 200 AF to over 5,000 AF.
- The maximum M&I gap for the five planning scenarios is projected to range from 700 AF to more than 11,000 AF.
- Population increases are the primary driver for increased M&I demands in the planning scenarios, as per capita water use is projected to decrease for every scenario except *Hot Growth*.
- The only SSI use in the basin is snowmaking, which is not projected to increase over baseline.
- For *Hot Growth*, the maximum M&I gap is much larger than other scenarios (at 34 percent of demand), which reflects lower supplies, large population growth, and less conservation.

Total Gap

Figure 4.5.14 illustrates the total combined agricultural and M&I diversion demand gap in the Gunnison Basin. The figure combines the average annual baseline and incremental agricultural gaps and the maximum M&I gap. In *Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth*, gaps were driven by agricultural demands, which increase in the *"Hot and Dry"* climate projection.

Figure 4.5.14 Projected Average Annual Agricultural Gaps and Maximum M&I Diversion Demand Gaps in the Gunnison Basin



Supplies from Urbanized Lands

By 2050, irrigated acreage in the Gunnison Basin is projected to decrease by 14,600 acres due to urbanization. Irrigation supplies for these lands could potentially be used for M&I needs in the future (subject to a variety of unknowns such as seniority and type of water supply, willingness to change the use of water through water court, etc.). The average annual historical consumptive use associated with potentially urbanized acreage for each scenario is reflected in Table 4.5.11. The data in the table represent planning-level estimates of this potential supply and has not been applied to the M&I gaps.

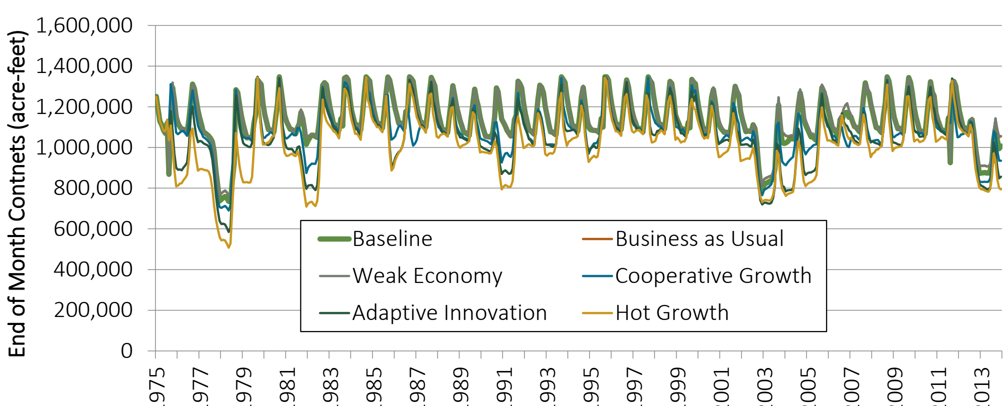
Table 4.5.11 Estimated Consumptive Use from Lands Projected to be Urbanized by 2050 in the Gunnison Basin

	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Urbanized Acreage (acres)	14,600	14,600	14,600	14,600	14,600
Estimated Consumptive Use (AFY)	30,300	30,300	33,100	31,600	33,000

Storage

Total simulated reservoir storage from the Gunnison River water allocation model is shown in Figure 4.5.15. Baseline conditions show the highest levels of water in storage (in general), and the lowest is in *Hot Growth*. *Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth* show lower amounts of water in storage during dry periods than the two scenarios that do not include the impacts of a drier climate; however, storage levels generally recover back to baseline levels after dry periods.

Figure 4.5.15 Total Simulated Reservoir Storage in the Gunnison Basin



4.5.6 Available Supply

Figures 4.5.16 and 4.5.17 show estimated simulated monthly available flow in the Gunnison River at a location below the Aspinall Unit and Gunnison Tunnel diversions but upstream of the Redlands Canal, which is the primary calling right in the lower basin. The canal diverts for power and irrigation, and return flows accrue to the Colorado Basin, which reflects a total depletion to the Gunnison River.

The figures show that flows are projected to be available in many years, though the amounts will vary greatly on an annual basis and across scenarios (available flows under the scenarios impacted by climate change are less than in other scenarios). In *Hot Growth* and *Adaptive Innovation*, very little flow may be available at this location for long periods of time during dry times. Peak flows are projected to occur earlier in the year under scenarios impacted by climate change.

Figure 4.5.16 Simulated Hydrographs of Available Flow at Gunnison River Below Gunnison Tunnel

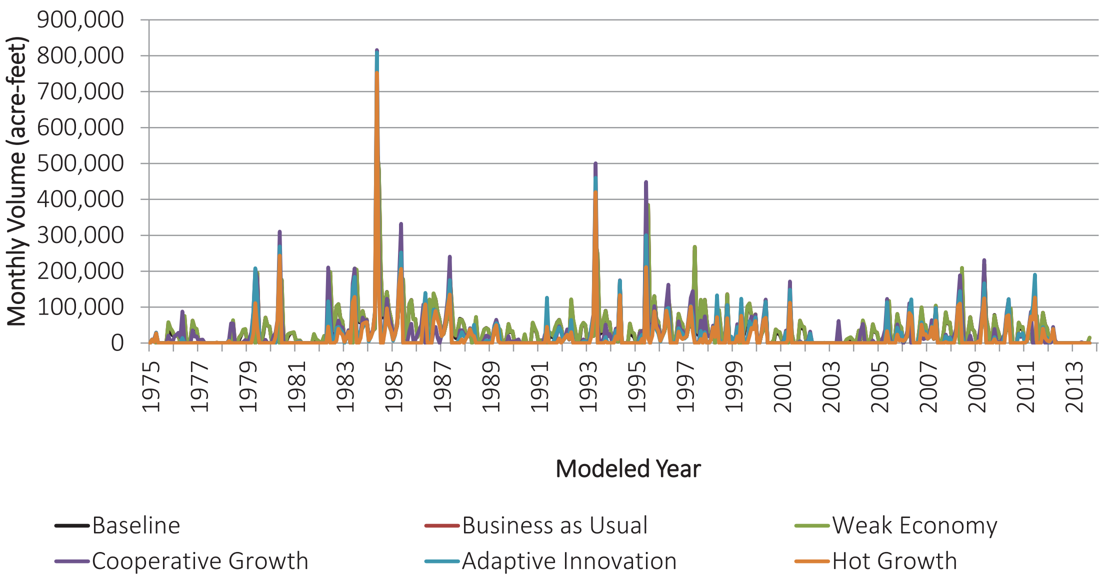
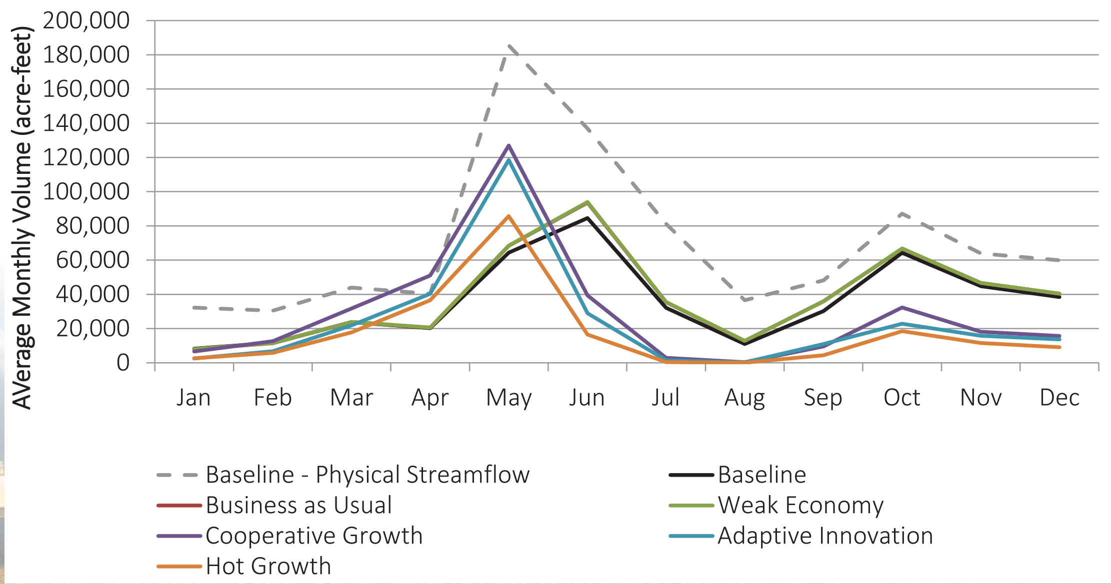


Figure 4.5.17 Average Monthly Simulated Hydrographs of Available Flow at Gunnison River Below Gunnison Tunnel



4.5.7 Environment and Recreation

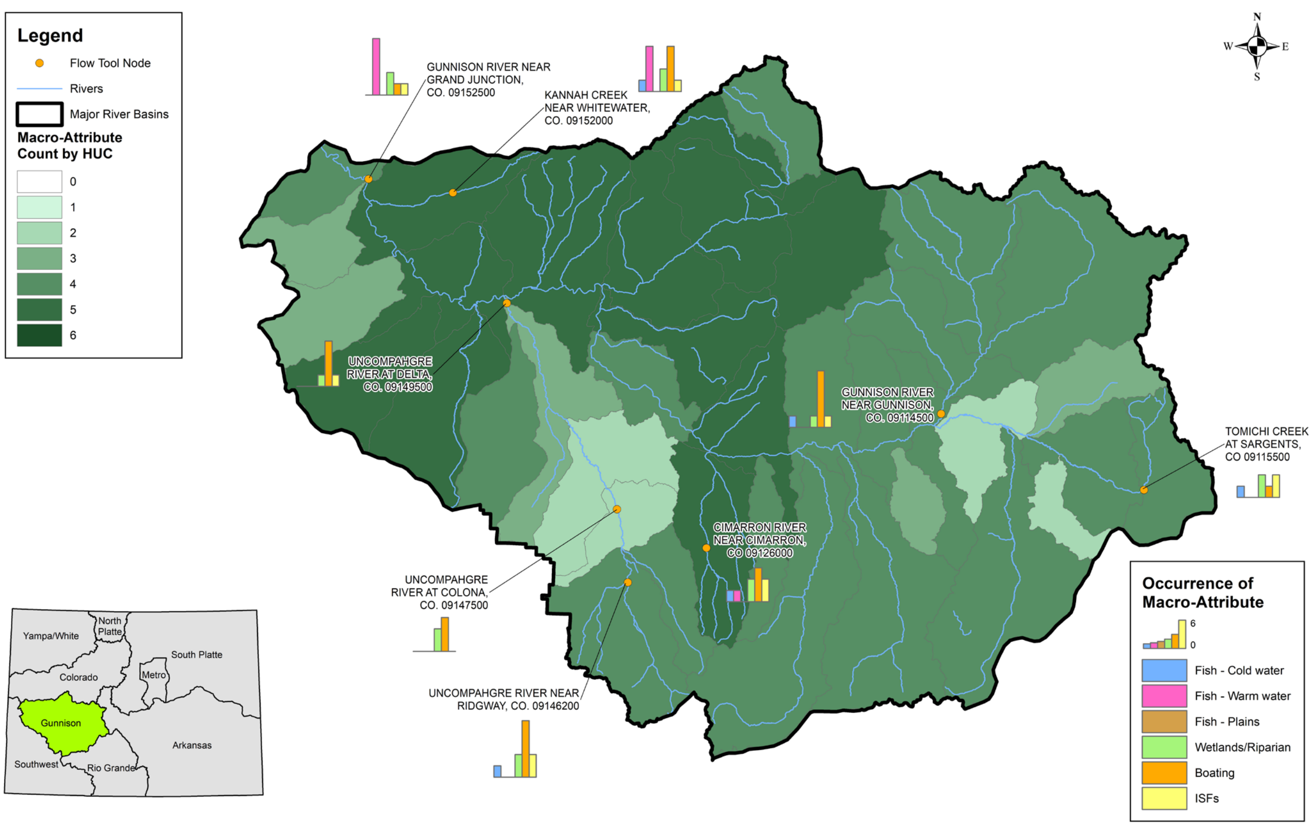
A total of eight water allocation model nodes were selected for the Environmental Flow Tool in the Gunnison Basin (see list below and Figure 4.5.18). Figure 4.5.18 also shows subwatersheds (at the 12-digit HUC level) and the relative number of E&R attributes located in each watershed.

- Gunnison River near Gunnison, Colorado (09114500)
- Tomichi Creek at Sargents, Colorado (09115500)
- Cimarron River near Cimarron, Colorado (09126000)
- Uncompahgre River near Ridgway, Colorado (09146200)
- Uncompahgre River at Colona, Colorado (09147500)
- Uncompahgre River at Delta, Colorado (09149500)
- Kannah Creek near Whitewater, Colorado (09152000)
- Gunnison River near Grand Junction, Colorado (90152500)

NATURALIZED FLOW

Naturalized flows reflect conditions that would occur in the absence of human activities. Baseline flows reflect current conditions as influenced by existing infrastructure and river operations. While observations regarding naturalized flows may be informative, baseline flows reflect actual conditions and the diverse operations of a river's many users.

Figure 4.5.18 Flow Tool Nodes Selected for the Gunnison Basin



Results of Flow Tool analyses using flow data developed in the water supply and gap analyses for baseline conditions and the planning scenarios are described below.

In the Gunnison Basin, pattern of flow varies as a function of elevation, major diversions, and location relative to reservoir storage. Observations related to projected changes in flow, potential ecological risks, etc. are provided in Table 4.5.12.

Table 4.5.12 Summary of Flow Tool Results in the Gunnison Basin

Category	Observation
Projected Flows	At higher elevations (e.g., Gunnison River at Gunnison), mean annual flow under baseline conditions are close to naturalized conditions. Under climate-impacted scenarios (*Cooperative Growth*, *Adaptive Innovation*, *Hot Growth*), annual flows are projected to decrease.
	At locations lower in the basin (e.g., Gunnison River near Grand Junction), baseline annual flows are further depleted, and under climate change scenarios, depletions continue to grow.
	In some locations (e.g., Gunnison River at Gunnison), peak flow magnitude under baseline conditions is below naturalized conditions, but under climate change scenarios, peak flow magnitudes increase. As a general rule, however, peak flows change little from baseline under *Business as Usual* and *Weak Economy* scenarios but decrease more substantially under climate change scenarios.
	Below major reservoirs on the Uncompahgre and Gunnison mainstems, peak flow under baseline conditions can be half of the naturalized condition. Peak flows continue to decrease from naturalized under climate change scenarios.
	Under all climate change scenarios in all locations, runoff and peak flows occur earlier, with June flows decreasing and April and May flows increasing. This change in peak flow timing may cause mis-matches between flow dynamics and the flows needed to support species.
	At higher locations in the Gunnison Basin, mid- and late-summer flows under baseline conditions are 0 to 20 percent depleted from naturalized conditions. Under climate change scenarios, these flows drop further below naturalized.
	At lower elevations on mainstem rivers (e.g., Uncompahgre at Delta; Gunnison River near Grand Junction), mid- and late-summer flows under baseline conditions are 30 to 50 percent below naturalized. Under climate change scenarios, these flows are also projected to fall further below naturalized.
Ecological Risk	Ecological risk (riparian/wetland plants and fish habitat) related to projected changes in peak flow magnitude is generally low to moderate at higher elevations. Under climate change scenarios this risk is projected to increase at most locations.
	At lower elevations and on mainstems, peak flows are already reduced in general and reductions are projected to increase under climate change scenarios.
	Mid- and late-summer flows are projected to decline under climate change scenarios, though flow-related risk to coldwater fish (trout) is projected to remain moderate. However, the metric used to assess risk for fish does not include the month of July because historically, July flows are sufficient. Under *Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth*, July flows are predicted to drop, increasing risk for fish by reducing habitat and increasing stream temperatures. In at least one location (Cimarron River), winter flows are projected to become low, also putting fish at risk.
ISFs and RICDs	In several locations, ISFs may be met less often, and at least one RICD (in Gunnison), may be met less often. In critical endangered species habitat, lower mean annual flows and reduced flows in mid- and late-summer will make it more difficult to meet flow recommendations.
E&R Attributes	Under baseline conditions and the *Business as Usual* and *Weak Economy* scenarios, current flow issues related to E&R attributes arise from in-basin diversions and storage of peak flows in reservoirs.
	Under climate change scenarios, the shift in the timing of peak flow, reductions in total runoff, and increasing consumptive demands are projected to contribute to reductions in mid- and late-summer flows. Several water management programs implemented in the context of the Upper Colorado Endangered Fish Program, including on the Gunnison River below the Apsinall Unit, have demonstrated that flow timing and magnitude can be planned in a way that better meets the needs of E&R attributes.

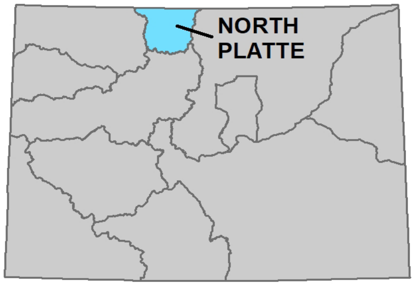
The North Platte Basin, also known as North Park, is a high-altitude valley covering about 2,000 square miles in north-central Colorado. It includes all of Jackson County and the small portion of Larimer County that contains the Laramie River watershed. Both the North Platte and Laramie Rivers flow north into Wyoming and are subject to use-limitations described in Supreme Court decrees.

The basin is also affected by the Platte River Recovery Implementation Program (PRRIP), which was developed to manage endangered species recovery efforts on the Platte River in Central Nebraska. Water use in the basin is dominated by irrigated pastures associated with ranching operations. The basin also has a major wildlife refuge in addition to numerous public lands and recreational opportunities. The basin exports a portion of North Platte water—approximately 4,500 AFY—to the Front Range.

NORTH PLATTE

District 76
Sand Creek
127
Sand Creek
Laramie River
District 48
Laramie River
Lost Lake
Barnes Meadow Reservoir
Chambers Lake
14
34
36

4.6 NORTH PLATTE BASIN RESULTS



4.6.1 BASIN CHALLENGES

The North Platte Basin will face several key issues and challenges pertaining to water management, endangered species, and resource development in the future. These are described in The Colorado Water Plan and summarized below.

Table 4.6.1 Key Future Water Management Issues in the North Platte Basin

<table>
<tr><th>Agriculture</th><th>Environment and Recreation</th><th>Municipal and Industrial</th><th>Compacts and Administration</th></tr>
<tr><td>• Gaining knowledge of the basin's consumptive uses and high-altitude crop coefficients.</td><td>• Maintaining healthy rivers through the strategic implementation of projects that meet prioritized nonconsumptive needs.
• Enhancing forest health and management efforts for wildfire protection and beetle-kill effects.</td><td>• Increasing economic development and diversification through strategic water use and development.</td><td rowspan="2">• Maintaining compliance with the equitable apportionment decrees on the North Platte* and Laramie** rivers that quantify the amount of available water and lands that can be irrigated.
• Successfully resolving endangered species issues on the Platte River in Central Nebraska through the PRRIP in a manner that does not put pressure on water users to reduce existing uses.
• Promoting water-rights protection and management through improved streamflow-gaging data.</td></tr>
<tr><td colspan="3">• Continuing to restore, maintain, and modernize critical water infrastructure to preserve current uses and increase efficiencies.
• Quantifying and strategically developing available unappropriated waters within the basin.</td></tr>
</table>

**The North Platte decree limits total irrigation in Jackson County to 145,000 acres and allows 17,000 AF reservoir storage annually during the irrigation season. In addition, the decree limits exports from the basin within Colorado to 60,000 AF over 10 years.*
***The Laramie River decree limits Colorado's total diversions and exports from the Laramie River to 39,750 AFY, divided among specific water facilities.*

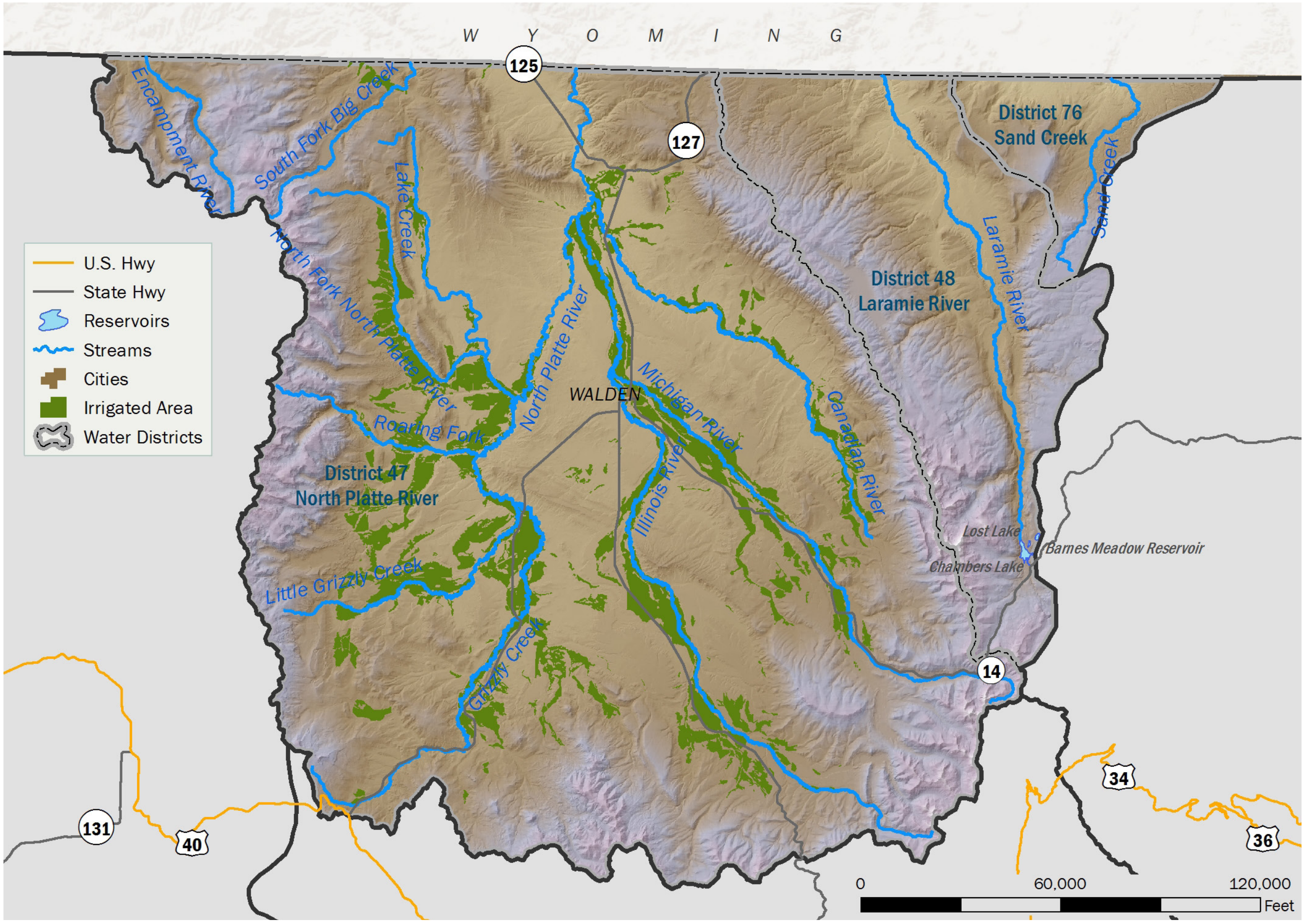


Figure 4.6.1 Map of the North Platte Basin

4.6.2 SUMMARY OF TECHNICAL UPDATE RESULTS

Key results and findings of the Technical Update pertaining to agricultural and M&I demands and gaps, as well as findings related to environmental and recreational attributes and future conditions, are summarized in Table 4.6.2 below.

Table 4.6.2 Summary of Key Results in the North Platte Basin

Agriculture	Environment and Recreation	Municipal and Industrial
• An additional 10,600 acres will increase agricultural demand in the future. • Although some technology improvements may occur, climate impacts may increase the agricultural demands and gap by 8 to 14 percent.	• In climate-impacted scenarios, peak flow generally moves earlier in the year. • Risks for trout increase in climate-impacted scenarios.	• Relatively small M&I demands are a reflection of the rural nature of this basin. There is little anticipated municipal growth, and no SSI water demand now or projected for the future.

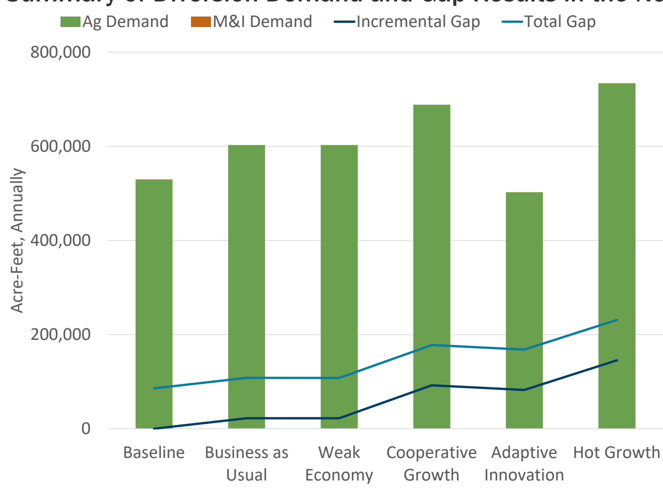
Results describing current and potential future M&I and agricultural demands and gaps are summarized in Table 4.6.3 and in Figure 4.6.2.

Table 4.6.3 Summary of Diversion Demand and Gap Results in the North Platte Basin

	Current (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average Annual Demand						
Agricultural (AFY)	529,200	602,400	602,400	688,300	502,300	733,500
M&I (AFY)	400	400	300	300	400	500
Gaps						
Ag (avg %)	16%	18%	18%	26%	33%	32%
Ag (incremental-AFY)	-	22,200	22,200	92,100	82,400	145,400
Ag (incremental gap as % of current demand)	-	4%	4%	17%	16%	27%
M&I (max %)	0%	4%	4%	4%	5%	10%
M&I (max-AF)	0*	20	10	10	20	50

**CDSS water allocation model in this basin calculates small baseline M&I gaps, but they are either due to calibration issues or they are reflective of infrequent, dry-year shortages that are typically managed with temporary demand reductions, such as watering restrictions.*

Figure 4.6.2 Summary of Diversion Demand and Gap Results in the North Platte Basin



Environmental and Recreational Findings

- Peak flows are projected to shift earlier in the year (April and May flows increase, offsetting June flow decreases) while magnitude may remain similar, keeping riparian/wetland and risk to fish habitat low to moderate. Possible mis-matches between peak flow timing and species needs may occur.
- Mid- and late-summer flows in North Park are moderate risk for trout under natural conditions, moderate to high risk under baseline conditions, and are projected to become high and very high risk for trout under *Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth.*

4.6.3 NOTABLE BASIN CONSIDERATIONS

- Irrigation demands reflect full season demand, but basin irrigators generally end irrigation earlier in the season. In general, North Platte Basin irrigators tend to get a first cutting of grass/hay around mid-July; falling stream flow conditions in late summer and, in some years, early frosts can make it difficult to get a second cutting. In addition, many farmers do not have access to supplemental storage that would provide late-season supplies. If this trend continues, agricultural gaps may not be as large as projected.
- The Technical Update used water allocation models that reflect a strict application of water administration. In the North Platte Basin, some water users refrain from placing a call to share the benefit of available supplies, but these practices are not reflected in the models
- SSI water demands for fracking are not included in the overall M&I diversion demands. Water demand data for fracking was researched, but reliable sources of data were not found. The M&I diversion demands technical memorandum includes a recommendation to improve this dataset.

4.6.4 AGRICULTURAL DIVERSION DEMANDS

Agricultural Setting

Ranchers in the North Platte River and Laramie River basins irrigate more than 113,000 acres of grass and hay to support numerous cow-calf operations throughout the basin. These high mountain meadows are generally flood irrigated, and with limited storage in the basin irrigators rely on diversions of spring and summer runoff for supplies. With low population projections for the basin, future agricultural diversion demands in the basin will be most impacted by the ability to maintain and even increase irrigated acreage and potential impacts from climate change.

Planning Scenario Adjustments

Section 2 described ways in which inputs to agricultural diversion demand estimates were adjusted to reflect the future conditions described in the planning scenarios. The North Platte BIP identifies parcels of historically irrigated or potentially irrigable land that may be irrigated in the future if infrastructure improvements are made and water rights secured. Altogether, the North Platte BIP identified seven planned agricultural development projects throughout the basin that totalled a potential increase of 10,576 irrigable acres. Due to a short growing season and the prevalence of irrigated pasture grass related to ranching operations in the basin, it is reasonable to assume that these planned agricultural projects will also be operated for hay and cattle ranching. The North Platte basin roundtable consistently emphasizes the importance of maintaining and increasing irrigated acreage in the basin allowable under the Nebraska v. Wyoming Equitable Apportionment Decree and foresees implementing the planned agricultural projects in all planning scenarios.

Table 4.6.4 summarizes the planning scenario adjustments described above and other adjustments that impact agricultural diversion demands in the various scenarios, including increased irrigated acres.

Table 4.6.4 Planning Scenario Adjustments for Agricultural Demands in the North Platte Basin

Adjustment Factor*	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Change in Irrigated Land due to Urbanization	-	-	-	40 Acre Reduction	40 Acre Reduction
Planned Agricultural Development Projects	10,576 Acre Increase	10,576 Acre Increase	10,576 Acre Increase	10,576 Acre Increase	10,576 Acre Increase
IWR Climate Factor	-	-	25%	39%	39%
Emerging Technologies	-	-	-	10% IWR Reduction 10% System Efficiency Increase	-

** See Section 2.2.3 for descriptions of adjustment methodologies and assumptions*

Agricultural Diversion Demand Results

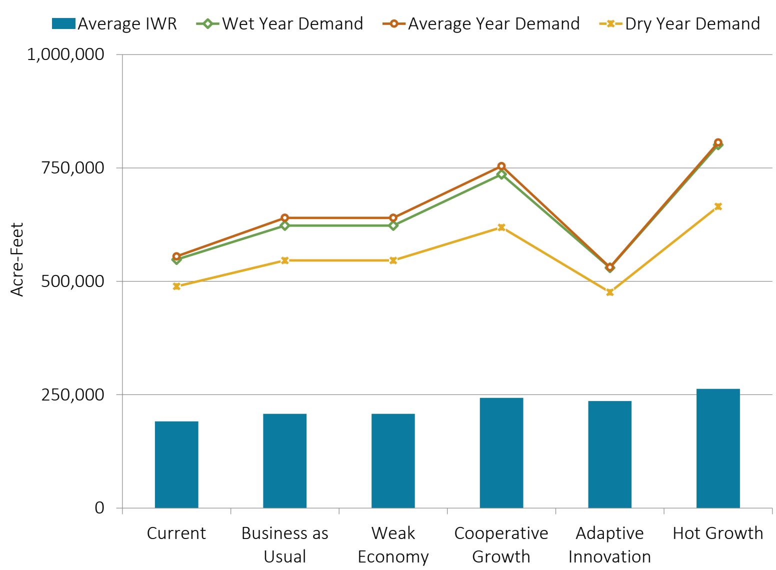
Table 4.6.5 and Figure 4.6.3 summarize the acreage, IWR, and the agricultural diversion demand for surface water supplies in the North Platte Basin for current conditions and the five planning scenarios. Agricultural diversion demands are projected to increase by 2050 due to additional irrigated acres; however, despite increased irrigated acres, *Adaptive Innovation* projects decreased demands as compared to baseline due to 10 percent reduction in IWR and 10 percent increase to system efficiency. *Hot Growth* projected the largest increase in demand due to higher IWR resulting from a warmer and drier future climate.

Table 4.6.5 Summary of Agricultural Diversion Demand Results in the North Platte Basin

	Current (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Irrigated Acreage (acres)	113,600	124,200	124,200	124,200	124,200	124,200
Average IWR (AFY)	191,100	208,000	208,000	243,000	236,000	263,000
Diversion Demand						
Average Year (AFY)	555,000	640,000	640,000	754,000	531,000	806,000
Wet Yr. Change	-1%	-3%	-3%	-2%	0%	-1%
Dry Yr Change	12%	15%	15%	18%	10%	17%

Average agricultural demand is calculated from the average of the "average" hydrologic years from 1950-2013

Figure 4.6.3 Summary of Agricultural Diversion Demand Results in the North Platte Basin



4.6.5 Municipal and Self-Supplied Industrial Diversion Demands

Population Projections

The North Platte Basin includes about 0.02 percent of the statewide population. Between the years 2015 and 2050, it is projected to change from approximately 1,400 to between 1,100 and 1,500 people in the low and high growth projections, respectively. This ranges from a 22 percent decrease in population to an increase of 8 percent. On a basin scale, the North Platte Basin represents the lowest baseline population and the lowest basinwide growth in the state. Table 4.6.6 shows how population growth is projected to vary for the North Platte Basin under each planning scenario.

Table 4.6.6 North Platte Basin 2015 and Projected Populations

Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
1,353	1,279	1,055	1,210	1,364	1,457

Current Municipal Demands

The North Platte Basin baseline demands relied entirely on estimated data from neighboring counties. No municipal data were available for utilities within Jackson County, which is the only county in the North Platte Basin.

Figure 4.6.4 summarizes the categories of municipal, baseline water usage in the North Platte Basin. Because there was no water provider-reported data available for Jackson County, the statewide weighted average demand category distribution was used for the North Platte Basin.

Projected Municipal Demands

Figure 4.6.5 provides a summary of per capita baseline and projected water demands for the North Platte Basin. Systemwide, the projected per capita demands are projected to decrease relative to the baseline except for *Hot Growth*. The residential indoor demand is the greatest demand category in the baseline, but the residential outdoor demand exceeds the residential indoor demand in *Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth*. Outdoor demands increased significantly for *Hot Growth* due to an increase in outdoor demands driven by the "Hot and Dry" climate factor (described in Section 2).

The North Platte Basin municipal baseline and projected demands provided in Table 4.6.7 show the combined effect of population and per capita demands. Municipal demands are projected to grow from approximately 400 AFY in 2015 to between 300 and 440 AFY in 2050.

The baseline and projected municipal demands are shown in Figure 4.6.6, which also shows how the population varies between the scenarios. *Hot Growth* is the only planning scenario in which the projected demands increase from the baseline; all other planning scenarios show an overall decrease in demands by 2050.

DECREASING GPCD

The North Platte Basin average baseline per capita systemwide demand has decreased from 310 gpcd in SWSI 2010 to approximately 264 gpcd.

Figure 4.6.4 Categories of Water Usage in the North Platte Basin

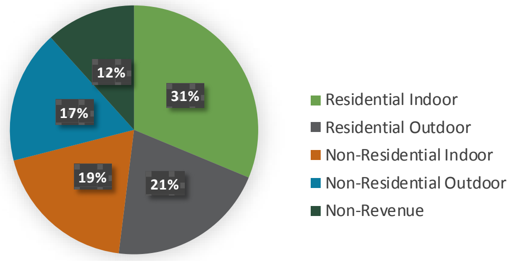


Figure 4.6.5 North Platte Basin Municipal Baseline and Projected Per Capita Demands by Water Demand Category

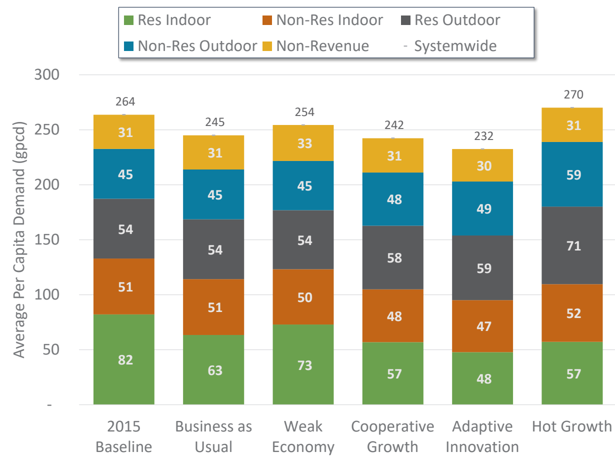


Figure 4.6.6 North Platte Basin Baseline and Projected Population and Municipal Demands

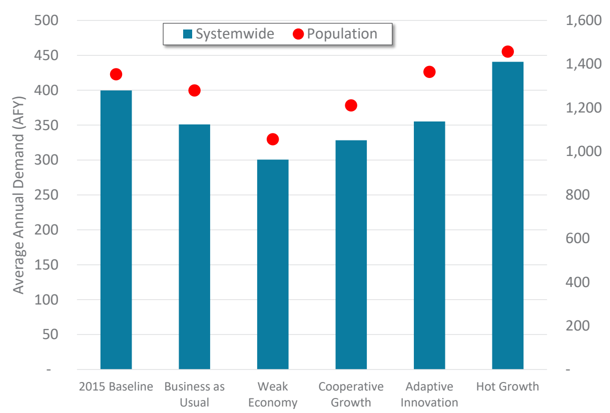


Table 4.6.7 North Platte Basin Municipal Baseline and Projected Demands (AFY)

Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
400	350	300	330	360	440

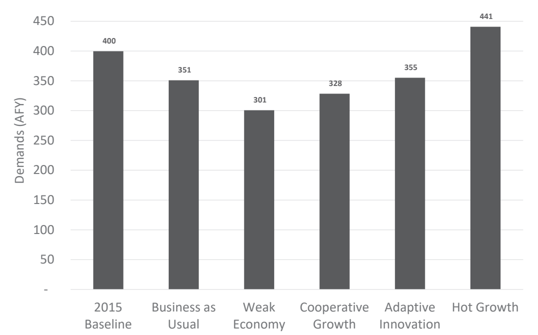
Self-Supplied Industrial Demands

The analysis does not include baseline and projected industrial demands in the North Platte Basin. Water demands for fracking occur in the basin, but no reliable sources of data were identified that could be used to quantify the water demands.

Total M&I Diversion Demands

North Platte Basin combined M&I demand projections for 2050 range from approximately 300 AFY under *Weak Economy* to 440 AFY in *Hot Growth*, as shown in Figure 4.6.7. On a basin scale, the demand projections follow the statewide sequence of the scenario rankings described in the CWP.

Figure 4.6.7 North Platte Basin Municipal and Self-Supplied Industrial Demands



4.6.6 Water Supply Gaps

The agricultural and M&I diversion demands were compared against available water supply modeled for current conditions and the five planning scenarios. Gaps were calculated when water supply was insufficient to meet demands.

Agricultural

The North Platte Basin agricultural diversion demands, demand gaps, and consumptive use gaps for the baseline and planning scenarios are presented in Table 4.6.8 and illustrated on Figure 4.6.8. An annual time series of gaps in terms of percent of demand that was unmet is shown on Figure 4.6.9.

INCREMENTAL GAP

The incremental agricultural gap quantifies the degree to which the gap could increase beyond what agriculture has historically experienced under water shortage conditions.

Table 4.6.8 North Platte Basin Agricultural Gap Results (AFY)

		Scenario					
		Scenario	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand	529,200	602,400	602,400	688,300	502,300	733,500
	Average Annual Gap	85,700	108,000	107,900	177,900	168,100	231,100
	Average Annual Gap Increase from Baseline	-	22,200	22,200	92,100	82,400	145,400
	Average Annual Percent Gap	16%	18%	18%	26%	33%	32%
	Average Annual CU Gap	40,300	50,800	50,800	83,600	92,000	108,500
Maximum	Demand in Maximum Gap Year	521,600	582,400	582,400	659,400	494,900	694,000
	Gap in Maximum Gap Year	296,900	336,700	336,700	394,800	320,800	441,000
	Increase from Baseline Gap	-	39,800	39,700	97,900	23,800	144,100
	Percent Gap in Maximum Gap Year	57%	58%	58%	60%	65%	64%

Study period for Water Supply Analysis is 1975-2013, reflecting different baseline demand than described in Agricultural Diversion Demands section

Figure 4.6.8 Projected Average Annual Agricultural Diversion Demand, Demand Met, and Gaps in the North Platte Basin

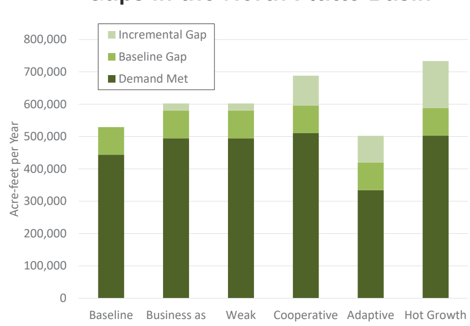
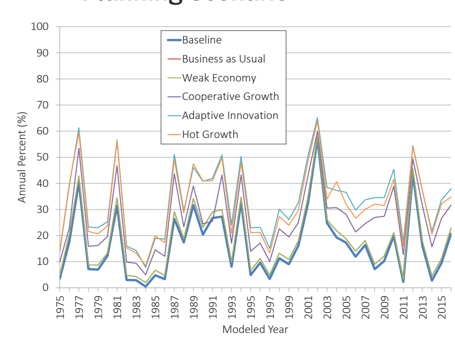


Figure 4.6.9 Annual Agricultural Gaps (expressed as a percentage of demand) for Each Planning Scenario



Observations on agricultural demands and gaps include:

- An additional 10,600 acres will increase agricultural diversion demand in the future.
- Although some technology improvements may occur, climate impacts will serve to increase the agricultural gap by 8 to 16 percent.
- Annual agricultural gaps can vary significantly and are more pronounced in dry years.

M&I

The diversion demand and gap results for M&I in the North Platte Basin are summarized in Table 4.6.9 and illustrated on Figure 4.6.10. An annual time series of gaps in terms of percent of demand that was unmet is shown on Figure 4.6.11.

Table 4.6.9 North Platte Basin M&I Gap Results (AFY)

		Scenario					
		Scenario	**Business as Usual**	**Weak Economy**	**Cooperative Growth**	**Adaptive Innovation**	**Hot Growth**
Average	Average Annual Demand	400	370	310	350	380	460
	Average Annual Gap	0	0	0	1	2	21
	Average Annual Percent Gap	0%	0%	0%	0%	1%	5%
Maximum	Demand in Maximum Gap Year	400	370	310	350	380	460
	Gap in Maximum Gap Year	0*	15	13	13	18	45
	Percent Gap in Maximum Gap Year	0%	4%	4%	4%	5%	10%

* *CDSS water allocation model in this basin calculates small baseline M&I gaps, but they are either due to calibration issues or they are reflective of infrequent, dry-year shortages that are typically managed with temporary demand reductions, such as watering restrictions.*
Study period for Water Supply Analysis is 1975-2013, reflecting different baseline demand than described in M&I Demand section.

Figure 4.6.10 Projected Maximum Annual M&I Demand Met and Gaps in the North Platte Basin

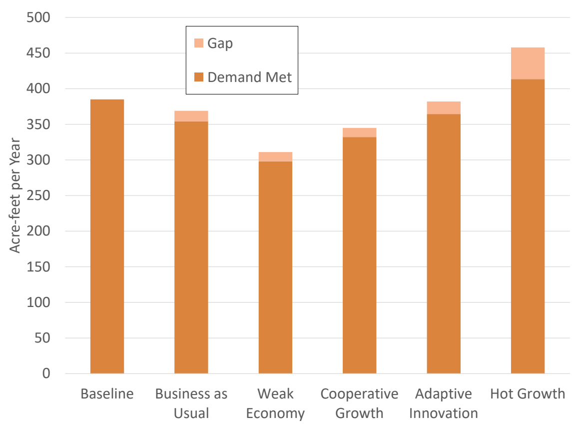
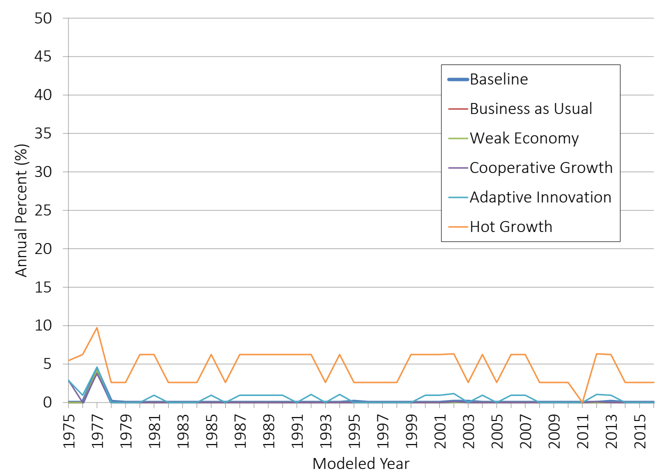


Figure 4.6.11 Annual M&I Gaps (expressed as a percent of demand) for Each Planning Scenario



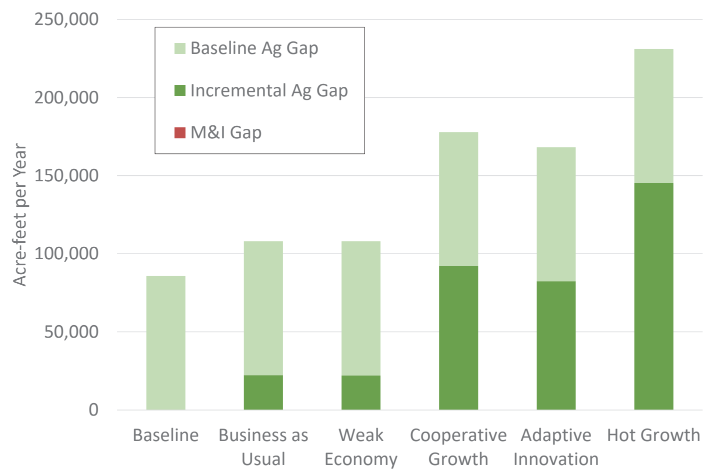
The following are observations on M&I diversion demands and gaps:

- Relatively small M&I demands are a reflection of the rural nature of this basin. There is little anticipated municipal growth.
- Consistent M&I gaps are only present in *Hot Growth*.

Total Gap

Figure 4.6.12 illustrates the total combined agricultural and M&I diversion demand gap in the North Platte Basin. The figure combines the average annual baseline and incremental agricultural gaps and the maximum M&I gap. In all future scenarios, gaps are driven by agricultural demands, which increase due to more irrigated acres and climate impacts.

Figure 4.6.12 Projected Average Annual Agricultural Gaps and Maximum M&I Diversion Demand Gaps in the North Platte Basin (AFY)



Supplies from Urbanized Lands

By 2050, irrigated acreage in the North Platte Basin is projected to decrease by only 40 acres due to urbanization, reflecting the rural nature of the basin. These decreases are only projected to occur in *Adaptive Innovation* and *Hot Growth*. Irrigation supplies for these lands could potentially be used for M&I needs in the future (subject to a variety of unknowns such as seniority and type of water supply, willingness to change the use of water through water court, etc.). The average annual historical consumptive use associated with potentially urbanized acreage for each scenario is reflected in Table 4.6.10. The data in the table represent planning-level estimates of this potential supply and has not been applied to the M&I gaps.

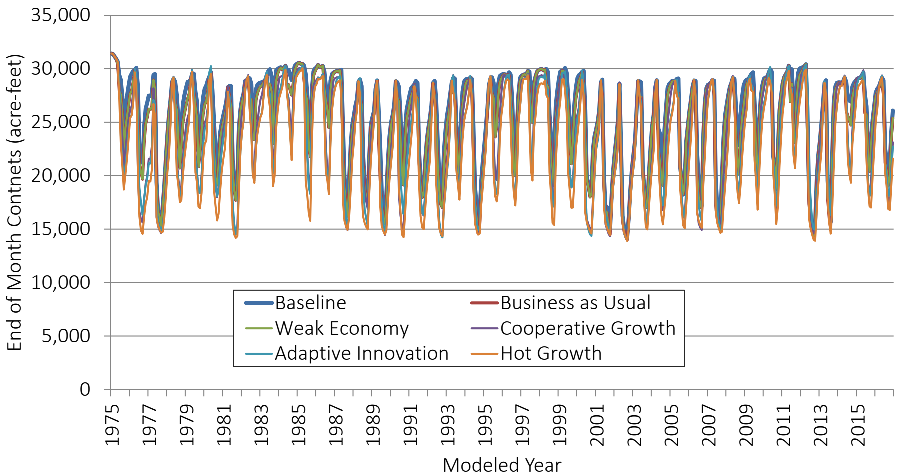
Table 4.6.10 Estimated Consumptive Use from Lands Projected to Be Urbanized by 2050 in the North Platte Basin

	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Urbanized Acreage (acres)	-	-	-	40	40
Estimated Consumptive Use (AFY)	-	-	-	50	50

Storage

Total simulated reservoir storage from the North Platte River water allocation model is shown in Figure 4.6.13. Baseline and *Weak Economy* scenarios show the highest levels of water in storage (in general) and the lowest is in *Hot Growth*; however, storage levels for all future scenarios track closely with baseline throughout the study period.

Figure 4.6.13 North Platte Basin Total Simulated Storage



4.6.7 Available Supply

Figures 4.6.14 and 4.6.15 show simulated available flow at a location on the Lower Michigan River upstream of the confluence with the North Platte River. The location represents water availability near the senior calling rights, which include the Hiho Ditch, Kiwa Ditch, and diversions to storage in Carlstrom Reservoir. Water availability is only moderately impacted by the calling rights, and flows are projected to be available in most years (but vary greatly on an annual basis). Peak flows are projected to increase at this location but could diminish in the late summer in climate-impacted scenarios.

Figure 4.6.14 Simulated Hydrograph of Available Flow at Michigan River at Cumberland Ditch

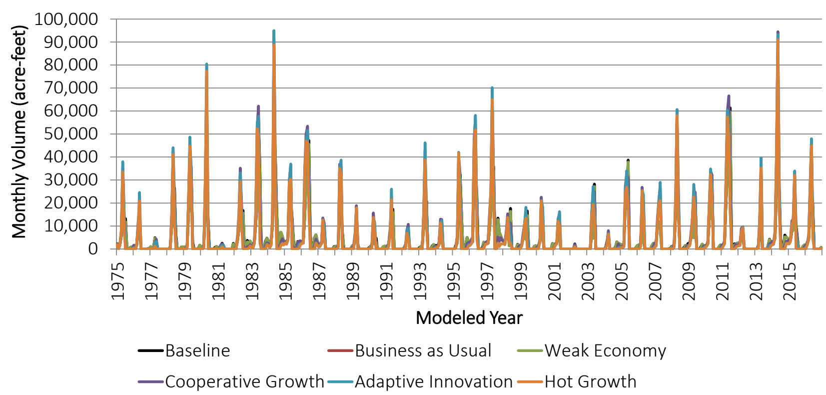
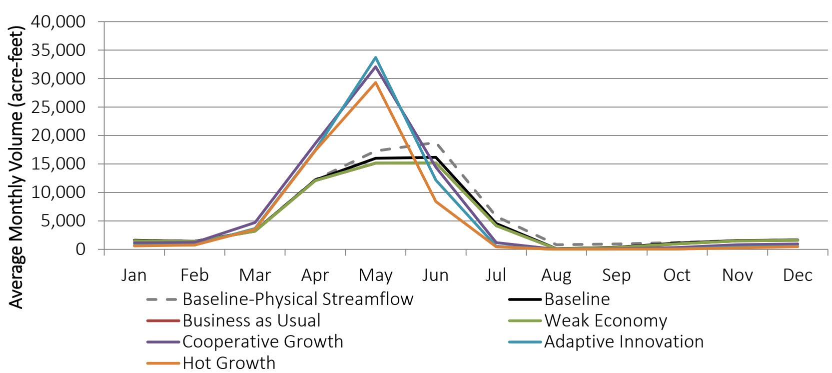


Figure 4.6.15 Average Monthly Simulated Hydrographs of Available Flow at Michigan River at Cumberland Ditch



4.6.8 Environment and Recreation

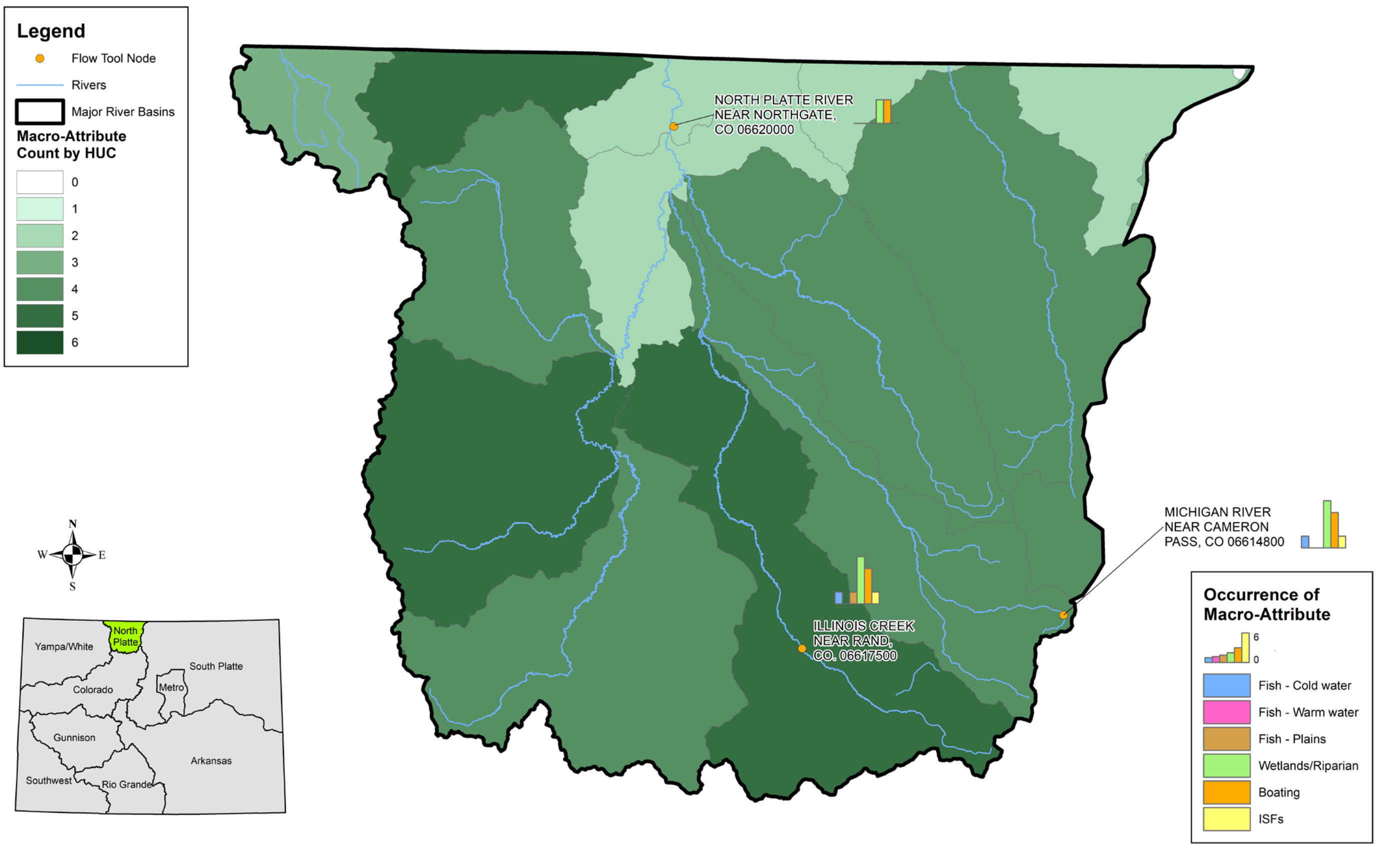
A total of three water allocation model nodes were selected for the Flow Tool within the North Platte Basin (see list below and Figure 4.6.16). Figure 4.6.16 also shows subwatersheds (at the 12-digit HUC level) and the relative number of E&R attributes located in each subwatershed.

- Michigan River near Cameron Pass, Colorado (06614800)
- Illinois Creek near Rand, Colorado (06617500)
- North Platte River near Northgate, Colorado (06620000)

NATURALIZED FLOW

Naturalized flows reflect conditions that would occur in the absence of human activities. Baseline flows reflect current conditions as influenced by existing infrastructure and river operations. While observations regarding naturalized flows may be informative, baseline flows reflect actual conditions and the diverse operations of a river's many users.

Figure 4.6.16 Flow Tool Nodes Selected in the North Platte Basin



Results and observations describing Flow Tool analyses using flow data developed in the water supply and gap analyses for baseline conditions and the planning scenarios are described in Table 4.6.11.

Table 4.6.11 Summary of Flow Tool Results in the North Platte Basin

Category	Observation
Projected Flows	Mean annual flows in North Platte Basin under baseline conditions are 20 to 35 percent below naturalized conditions.
	Unlike all other basins analyzed, mean annual flow changes little under all scenarios, including climate change scenarios.
	Although there is little projected change in mean annual flow in future scenarios compared to baseline, peak flows do change. Peak flow magnitude under baseline conditions are approximately 15 percent below naturalized conditions at higher elevations and decrease further below naturalized conditions where the North Platte leaves Colorado near North Gate.
	Under *Business as Usual* and *Weak Growth*, projected peak flows change little. Under scenarios with climate change, peak flow magnitude may increase slightly. The timing of peak flows is also projected to change, shifting earlier in the year (April and May flows increase, offsetting June flow decreases).
	Under baseline conditions, mid- and late-summer flows in North Park are 30 to 60 percent below naturalized conditions, depending on location. This condition may not be as ideal for trout as many other locations in Colorado at similar elevation. Under climate change scenarios, mid- and late-summer flows are likely to decline further.
Ecological Risk	Baseline peak flow magnitudes create some risk for maintaining riparian/wetland plants and fish habitat, but this risk may lessen under climate change scenarios as peak flow magnitude increases. However, earlier and larger peak flows may lead to lower mid- and late-summer flows, and these lower flows could increase risk for trout under *Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth*. Also, the change in peak flow timing under climate change scenarios may lead to mis-matches between peak flows and species' needs.

The Rio Grande drainage basin in Colorado is bound by the San Juan Mountains to the west, the Sangre de Cristo Range to the north and east, the Culebra Range to the southeast, and the Colorado-New Mexico state line to the south. Between the mountains lies the San Luis Valley, an expansive, generally flat area with an average elevation of 7,500 feet and precipitation of less than eight inches per year. Despite the low precipitation, agriculture has long been the basis of the Rio Grande basin economy. Principal crops are potatoes, followed by alfalfa, native hay, barley, wheat, and small vegetables like lettuce, spinach and carrots. Mountainous areas of the basin are forested and sparsely populated.

The northern third of the valley is a closed basin, meaning runoff from the surrounding mountains and diversions from the Rio Grande recharge the basin's two stacked aquifers, known as the unconfined and confined aquifers, rather than contributing or returning to the Rio Grande. Irrigated agriculture in the Rio Grande Basin relies on well pumping from the aquifers as well as surface deliveries from the Rio Grande and Conejos River. These diversions are both applied directly to crops and, in the closed basin, recharged into the unconfined aquifer.

The Rio Grande Compact establishes Colorado's obligations to ensure water delivery at the New Mexico state line with some allowance for credits and debits via accounts in Elephant Butte Reservoir. The compact dictates that Colorado calculate its delivery obligation based on the flow at indexed stations, which effectively caps Colorado's allowable consumptive use even in wet years. Key future water management issues in this basin center around sustainability of the groundwater supply, but also include maintaining and providing domestic supply for new growth and operating within the constraints of the Rio Grande Compact.

RIO GRANDE


District 25
San Luis Creek
MOFFAT
Saguache Creek
San Luis Creek
285
69
17
112
150
15
370
MONTE VISTA
ALAMOSA
District 35
Trinchera Creek
Trinchera Creek
District 21
Alamosa La Jara
SAN LUIS
District 24
Culebra Creek
District 22
Conejos River

4.7 RIO GRANDE BASIN RESULTS

4.7.1 BASIN CHALLENGES

Key future water management issues in this basin center around sustainability of the groundwater supply, but also include maintaining and providing domestic supply for new growth and operating within the constraints of the Rio Grande Compact. These challenges are described in the Colorado Water Plan and are summarized below.

Table 4.7.1 Key Future Water Management Issues in the Rio Grande Basin

Agriculture	Environment and Recreation	Municipal and Industrial	Compacts and Administration
• Groundwater use for agriculture is currently at unsustainable levels. • Community-based solutions offer best hope of minimizing effects of reducing irrigated acres.	• The Rio Grande Basin has an abundance of terrestrial and aquatic wildlife populations, rare and important habitats, diverse ecosystems, and exceptional recreational opportunities; however, the increasingly water-short nature of the Basin makes sustaining these attributes challenging.	• All cities and towns are supplied by groundwater wells and must comply with the State Engineer's Well Rules and Regulations. • Growth of commercial uses throughout the basin, new homes near Alamosa, and second homes in the surrounding mountains are creating a need for additional water supplies and well augmentation.	• The Rio Grande Compact and sustained drought make the objective of groundwater sustainability difficult.
• Groundwater is a key component of water supply in the basin for both M&I and agriculture. Groundwater management presents an ongoing challenge.			

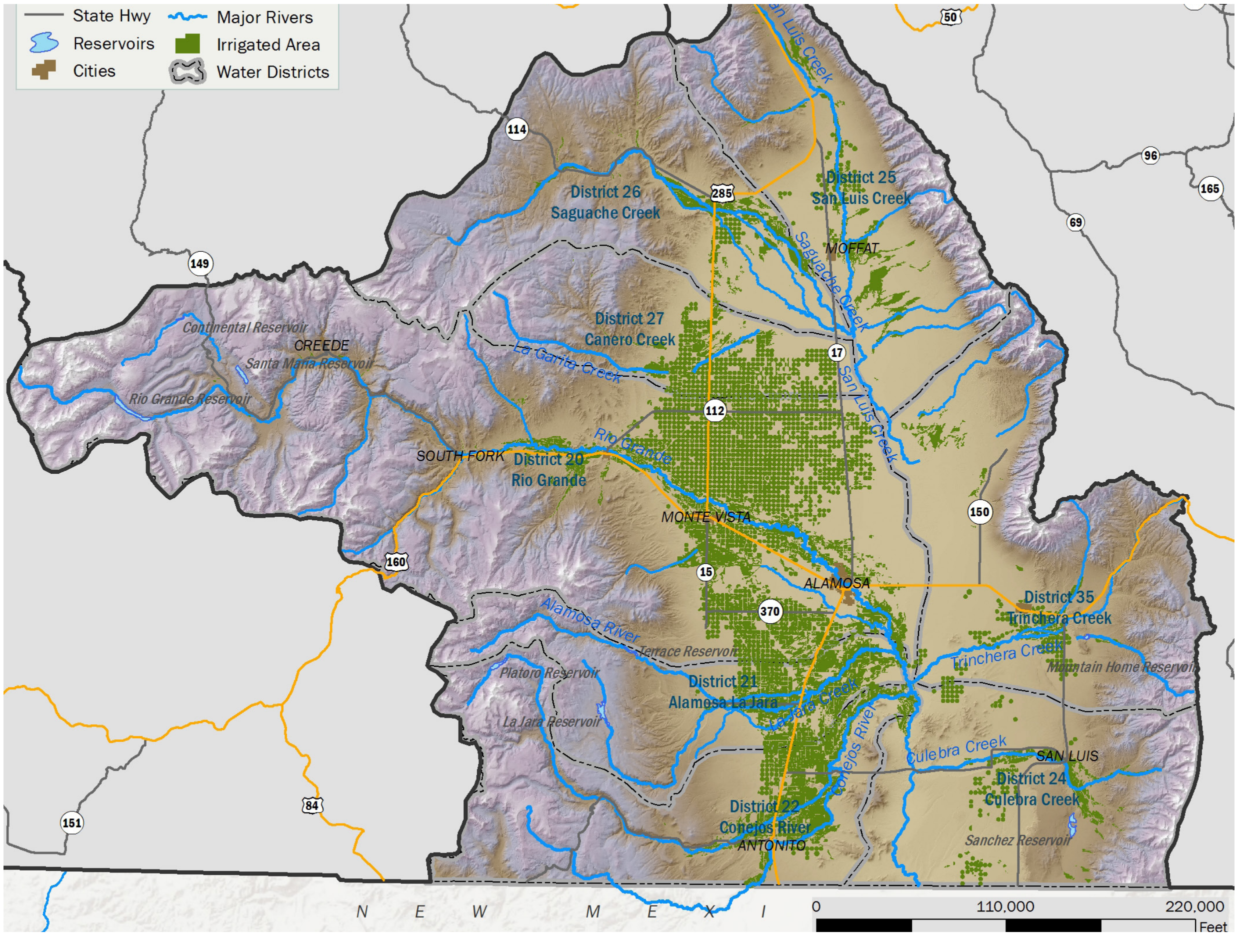


Figure 4.7.1 Map of the Rio Grande Basin

4.7.2 SUMMARY OF TECHNICAL UPDATE RESULTS

Key results and findings of the Technical Update pertaining to agricultural and M&I demands and gaps, as well as findings related to environmental and recreational attributes and future conditions, are summarized below in Table 4.7.2.

Table 4.7.2 Summary of Key Results in the Rio Grande Basin

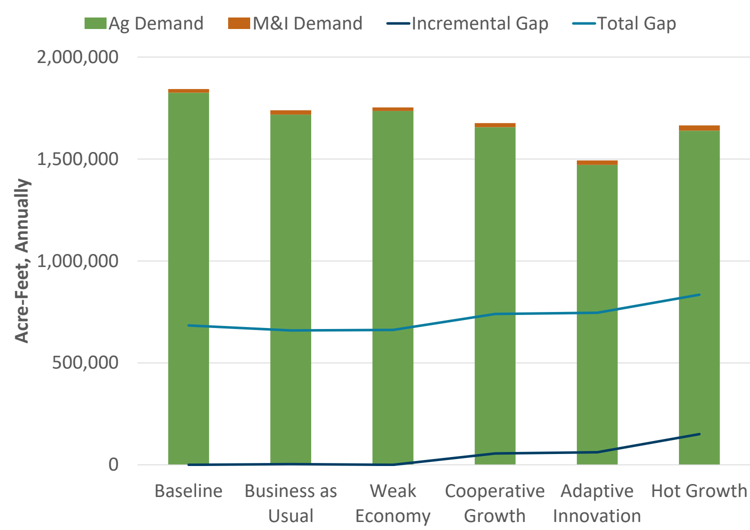
Agriculture	Environment and Recreation	Municipal and Industrial
• Future agricultural demand is lower than baseline, based on current and future acreage reductions due to groundwater administration and need to restore and sustain aquifer levels. • Agricultural demand in the scenarios is related to acreage reductions to offset climate-induced increases in IWR. Demand under Adaptive Innovation is lower than other scenarios, reflecting a higher system efficiency and reduction in IWR from emerging technologies. • As a percentage of demand, the gap is similar for Baseline, Business as Usual, and Weak Economy but larger larger for remaining scenarios despite lower demand.	• Flow magnitude in mountainous areas is not projected to significantly change under climate-impacted scenarios, but the annual hydrograph may shift with earlier snowmelt. Risks to riparian and fish habitat would remain low to moderate in most cases.Mid- and late-summer streamflow is projected to drop substantially in mountainous regions represented in the Flow Tool. Risk to cold water fish may remain moderate but increase in July and/or dry years.	• Both per capita use and total demand are significantly lower in the Technical Update baseline than in the SWSI 2010 baseline. • Aside from *Hot Growth*, outdoor demands are similar for all scenarios. This is due to the scenario pairing of water demand reductions and climate drivers.

Results describing current and potential future M&I and agricultural demands and gaps are summarized in Table 4.7.3 and in Figure 4.7.2.

Table 4.7.3 Summary of Diversion Demand and Gap Results in the Rio Grande Basin

	Current (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average Annual Demand						
Agricultural (AFY)	1,825,200	1,717,800	1,735,700	1,656,300	1,471,400	1,638,900
M&I (AFY)	17,700	21,100	17,700	20,100	21,700	25,800
Gaps						
Ag (avg %)	37%	38%	38%	45%	50%	50%
Ag (incremental-AFY)	-	-	-	53,500	58,000	142,500
Ag (incremental gap as % of current demand)	-	-	-	3%	3%	8%
M&I (max %)	-	16%	0%	12%	18%	31%
M&I (max-AF)	0	3,400	0	2,400	4,000	8,100

Figure 4.7.2 Summary of Diversion Demand and Gap Results in the Rio Grande Basin



Summary of Environmental and Recreational Findings

- A surface water allocation model was not available in the Rio Grande Basin, so the available flow dataset only includes natural flows and natural flows as impacted by climate drivers in mountainous areas; no management drivers are factored in.
  - » Management drivers impact river flows in areas downstream of mountainous areas in the Rio Grande and Conejos basins. Because a water allocation model that incorporates management is not available, no data-based insights into flow change and risk to non-consumptive attributes could be developed.
- In general, overall peak flow magnitude is not projected to change substantially under climate-impacted scenarios, but the peak may shift to earlier in the year (April/May streamflow magnitude may increase and June streamflow magnitude may decrease). Subsequent risk for riparian/wetland and fish habitat may remain low or moderate in most cases, although there are some indications that risk could increase in smaller streams.
- Mid- and late-summer streamflow is projected to drop substantially in all locations, with July streamflow decreasing 40 to 60 percent on the Rio Grande and tributaries and up to 70 percent on the Conejos River under the “In-Between” and “Hot and Dry” climate projections. Risk to cold water fish due to decreasing streamflow may remain moderate in most years but could be higher in July and/or during dry years.

4.7.3 NOTABLE BASIN CONSIDERATIONS

Section 4.1 described several analysis assumptions and limitations that apply to all basins and should be considered when reviewing and interpreting analysis results. Additional considerations specific to the Rio Grande Basin are listed below:

- The analysis assumed that there is no available water for meeting new uses. As a result, additional future M&I demands contribute directly to gaps.
- Basin stakeholders have cautioned that large reductions in irrigated land could result in socio-economic impacts that cause a reduction of municipal population.
- Stakeholder input was the basis of projected decreases in irrigated land due to groundwater sustainability and climate change.
- The Rio Grande Basin average baseline per capita systemwide demand has decreased significantly from 314 gpcd in SWSI 2010 to approximately 207 gpcd. The BIP was the primary source of water demand data.
- Aquifer sustainability will be a primary focus of future water management strategies and activities in this basin.
- The analysis did not consider specific different types of crops that may be grown in the future under the different scenarios; however, it accounted for future changes in crop types in a general sense in *Adaptive Innovation* and assumed that future crops would have 10 percent lower IWR. This is in line with the Rio Grande BIP recommendation to explore opportunities to reduce pumping through alternative cropping rather than drying up productive farm ground.

4.7.4 AGRICULTURAL DIVERSION DEMANDS

Agricultural Setting

Irrigated acreage in the Rio Grande Basin, particularly in the San Luis Valley, is inherently tied to the basin's unique surface and groundwater supplies. Surface water supplies diverted from streams fed by snowmelt are highly variable from year to year, with annual runoff in high flow years yielding up to eight times[11] more than in drought years. Groundwater from the upper unconfined aquifer and the deeper confined aquifer provides a more consistent irrigation supply. Although recharge to the unconfined aquifer occurs relatively quickly, decades of withdrawals greater than recharge have severely depleted it. Although the deeper confined aquifer supplies fewer wells than the unconfined aquifer due to its depth, it also experiences withdrawals that exceed recharge. Daily administration of the Rio Grande Compact, which primarily restricts surface water diversions through curtailment to meet compact deliveries, further impacts water availability in the basin. Surface and groundwater supplies combined support the irrigation of approximately 515,000 acres in the basin, predominantly in potatoes, grass, alfalfa, and small grains; however, the future of agriculture in the basin is threatened by more frequent periods of drought and declining aquifer levels.

Spurred by the drought in the early 2000s, declining levels of the unconfined aquifer in the Closed Basin, reduced confined aquifer pressure valleywide, and passage of Senate Bill 04-222 mandating the promulgation of groundwater rules and regulations by the Division of Water Resources (DWR), the Rio Grande Water Conservation District (RGWCD) created the first Special Improvement District of the Rio RGWCD (Subdistrict No. 1). Subdistrict No. 1 operates to replace injurious stream depletions caused by the subdistrict wells, recover aquifer levels, and maintain a sustainable irrigation water supply in the unconfined aquifer. The impacts to streams covered by the subdistricts are derived from a basin-wide groundwater model, developed through the Rio Grande Decision Support System (RGDSS).[12]

Subdistrict No. 1 began operations in 2012 and includes approximately 174,000 irrigated acres in the Closed Basin area. Subdistrict No. 2 covering the Rio Grande Alluvium and Subdistrict No. 3 covering the Conejos area began operating in 2019. Subdistricts No. 4, No. 5 and No. 6 covering the San Luis Creek, Saguache, and Alamosa/La-Jara Creek areas, respectively, are under development.

Due to the large amount of acreage in the subdistrict areas, management of these subdistricts will likely shape how irrigated agriculture will look by 2050.

Planning Scenario Adjustments

Section 2 described ways in which inputs to estimates of agricultural diversion demands were adjusted to reflect the future conditions described in the planning scenarios. Adjustments in the Rio Grande Basin focused on urbanization, groundwater sustainability, potential future climate conditions, and implementation of emerging technologies.

Population projections for the basin indicate that under all scenarios except *Weak Economy*, the basin's population will increase modestly and municipal water demands will grow. Irrigated acreage surrounding small towns in the basin is vulnerable to urbanization. For all scenarios other than *Weak Economy*, approximately 4,010 acres were estimated to come out of production due to urbanization of irrigated lands in the basin.

Much more significant are reductions in irrigated acreage to reach water use levels that the aquifers can sustainably support. In total, 40,000 irrigated acres were removed from the Subdistrict No.1 area, and 5,000 irrigated acres were removed across the basin in all planning scenarios.

IWR in the Rio Grande Basin is projected to increase on average by 15 percent under the *In-Between* climate projection and 18 percent on average under the "Hot and Dry" climate projection. Faced with this information, stakeholders in the basin discussed what the ultimate effects on the basin may be if IWR increases to these levels, particularly in light of the Rio Grande Compact. The group decided that as the compact will continue to limit surface water availability, any increase in IWR would likely lead to irrigated acreage being taken out of production because there would not be sufficient surface water supplies to meet these increased demands.

To account for this future potential outcome, it was assumed that the percent increase in IWR by Water District would result in the same percent decrease in irrigated acreage. With basinwide unit IWR historically averaging 2 AF per year and crop consumptive use in the basin historically averaging 1.3 AF per year, this is potentially an underestimate of the total acreage that may come out of production under potential future climate conditions. This approach, however, resulted in the removal of approximately 70,000 acres in *Cooperative Growth* and approximately 81,000 acres in *Adaptive Innovation* and *Hot Growth* across the basin. Note that IWR is reduced by 10 percent in *Adaptive Innovation* to account for technological innovations that may mitigate the increased IWR due to climate adjustments.

Table 4.7.4 summarizes the planning scenario adjustments described above and other adjustments that impact agricultural diversion demands in the various scenarios.

Table 4.7.4 Planning Scenario Adjustments for Agricultural Demands in the Rio Grande Basin

Adjustment Factor*	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Change in Irrigated Land due to Urbanization	4,010 Acre Reduction	-	4,010 Acre Reduction	4,010 Acre Reduction	4,010 Acre Reduction
Change in Irrigated Land for Groundwater Sustainability	45,000 Acre Reduction	45,000 Acre Reduction	45,000 Acre Reduction	45,000 Acre Reduction	45,000 Acre Reduction
IWR Climate Factor	-	-	15% 70,000 Acre Reduction	18% 81,000 Acre Reduction	18% 81,000 Acre Reduction
Emerging Technologies	-	-	-	10% IWR Reduction	-

**See section 2.2.3 for descriptions of adjustment methodologies and assumptions*

Agricultural Diversion Demand Results

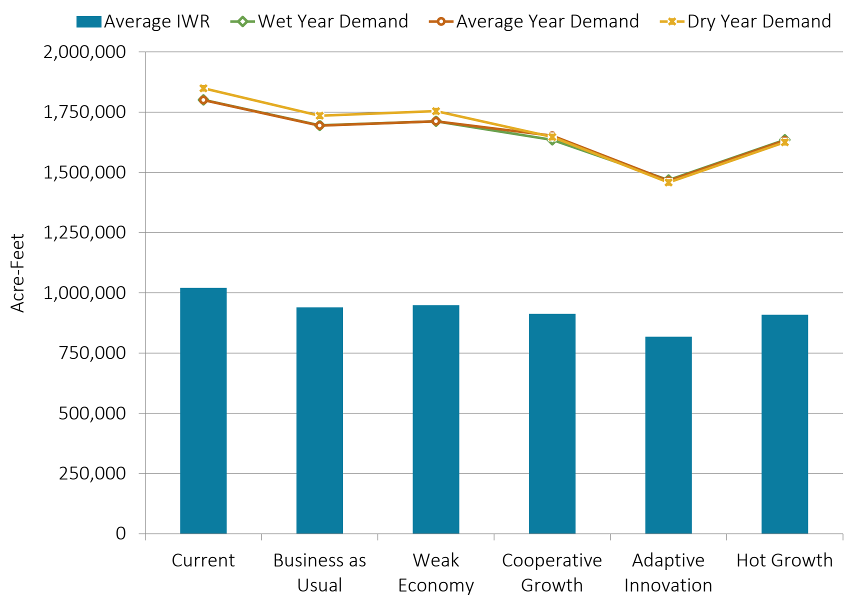
Table 4.7.5 and Figure 4.7.3 summarize the acreage, IWR, and the agricultural diversion demand for surface water supplies in the Rio Grande Basin for current conditions and the five planning scenarios. All scenario demands are lower than Baseline, because of irrigated acreage reduction to better manage the aquifer. Demand in climate impacted scenarios (*Cooperative Growth*, *Adaptive Innovation* and *Hot Growth*) is no higher than in *Business as Usual* and *Weak Economy* because compensating reductions in irrigated acreage are assumed to be implemented.

Table 4.7.5 Summary of Agricultural Diversion Demand Results in the Rio Grande Basin

	Current (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Irrigated Acreage (acres)	515,300	466,300	470,300	396,500	385,200	385,200
Average IWR (AFY)	1,021,000	940,000	949,000	913,000	818,000	909,000
Total Surface and Groundwater Diversion Demand						
Average Year (AFY)	1,800,000	1,694,000	1,712,000	1,652,000	1,465,000	1,632,000
Wet Yr. Change	0%	0%	0%	-1%	0%	0%
Dry Yr Change	3%	2%	3%	0%	-1%	0%

Average agricultural diversion demand was calculated using the average hydrologic years (i.e. years classified as neither wet or dry) from 1950-2013

Figure 4.7.3 Agricultural Diversion Demands and IWR Results in the Rio Grande Basin



4.7.5 Municipal and Self-Supplied Industrial Diversion Demands

Population Projections

The Rio Grande Basin currently includes less than 1 percent of the statewide population. Between the years 2015 and 2050, it is projected to change from approximately 46,000 people to between 42,000 and 67,000 people in the low and high growth projections, respectively. This ranges from an 8 percent decrease in population to an increase of 46 percent. Table 4.7.6 shows how population growth is projected to vary across planning scenarios.

Table 4.7.6 Rio Grande Basin 2015 and Projected Populations

Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
46,000	55,100	42,300	52,100	63,000	67,300

Current Municipal Demands

Approximately 79 percent of the baseline municipal demands were derived from BIP data, which represents the highest reliance on BIP data for any basin in the state. Data from WEPs represent demands for another 9 percent of the population, requiring about 12 percent of the basin's baseline population demands to be estimated (see Figure 4.7.4).

The BIP data did not include breakdowns of water use by demand category. Because there was insufficient demand category data available to apply county-specific distributions, the statewide weighted average demand category distribution was used for the Rio Grande Basin, as shown on Figure 4.7.5.

Figure 4.7.4 Sources of Water Demand Data in the Rio Grande Basin

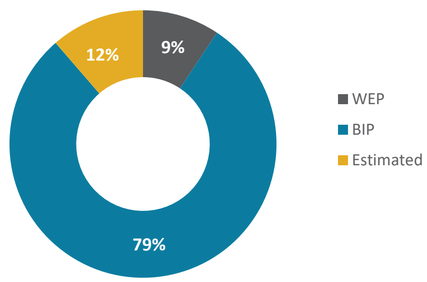
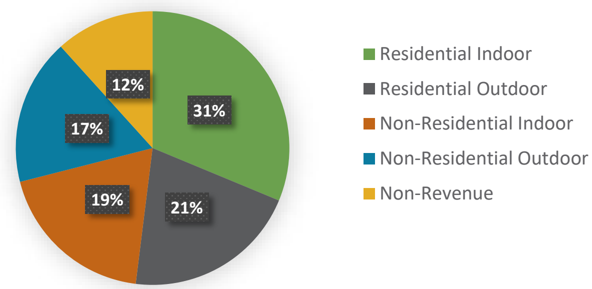


Figure 4.7.5 Categories of Municipal Water Usage in the Rio Grande Basin



Projected Municipal Demands

Figure 4.7.6 provides a summary of per capita baseline and projected water demands for the Rio Grande Basin. Systemwide, projected per capita demands decrease relative to the baseline except for *Hot Growth*. Residential indoor demand is generally the greatest demand. Outdoor demands increased significantly for *Hot Growth*, due to a general increase in outdoor demands coupled with the "Hot and Dry" climate.

The Rio Grande Basin municipal baseline and projected diversion demands provided in Table 4.7.7 show the combined effect of population and per capita demands. Municipal demands are projected to change from approximately 11,000 AFY in 2015 to between 9,000 and 16,000 AFY in 2050. Alamosa County accounts for around one-third of the baseline demand, followed by Conejos and Rio Grande counties, each at about one-quarter of the basin demand.

Figure 4.7.6 Rio Grande Basin Municipal Baseline and Projected Per Capita Demands by Water Demand Category (pgcd)

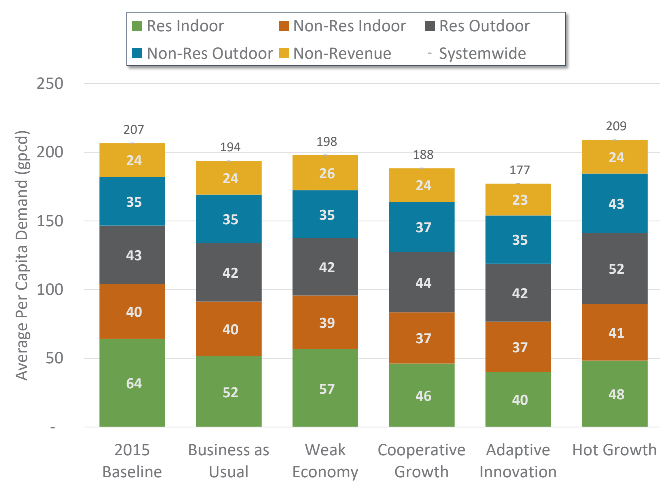
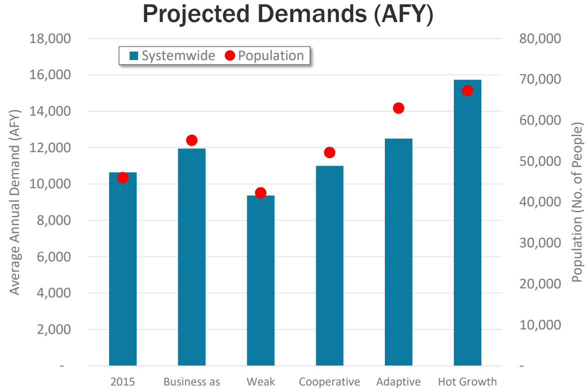


Table 4.7.7 Rio Grande Basin Municipal Baseline and Projected Demands (AFY)

Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
10,600	11,900	9,400	11,000	12,500	15,700

Figure 4.7.7 Rio Grande Basin Municipal Baseline and Projected Demands (AFY)



The baseline and projected demand distributions are shown in Figure 4.7.7, which also shows how the population varies across scenarios. All of the projection scenarios except for the *Weak Economy* result in an increase in systemwide demand relative to the baseline.

DECREASING GPCD

The Rio Grande Basin average baseline per capita systemwide demand decreased from 314 gpcd in SWSI 2010 to approximately 207 gpcd.

Self-Supplied Industrial Demands

The Rio Grande Basin includes about 4 percent of the statewide SSI diversion demand. SSI demands in this basin are associated with Large Industry (fish and aquaculture, agricultural product processing) and Energy Development (solar power generation and future oil and gas development), with no demands projected for the thermoelectric sub-sector. A minor amount of snowmaking occurs in the basin, but the required amount of water is insignificant compared to other SSI demands, and it was not considered in the demand analysis. Basin-scale SSI demands are shown in Figure 4.7.8 and tabulated in Table 4.7.8.

Figure 4.7.8 Rio Grande Basin SSI Baseline and Projected Demands (AFY)

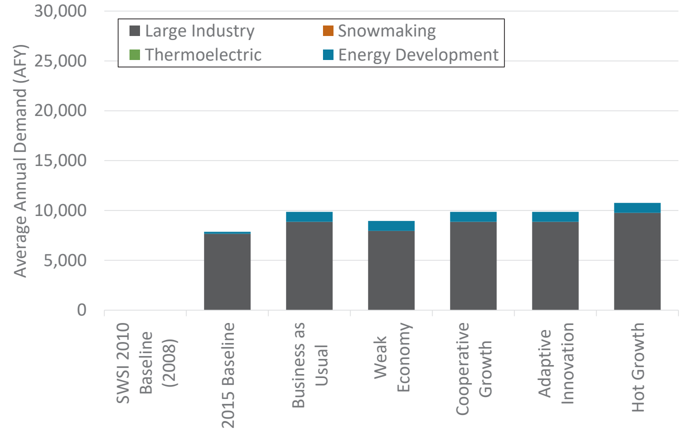


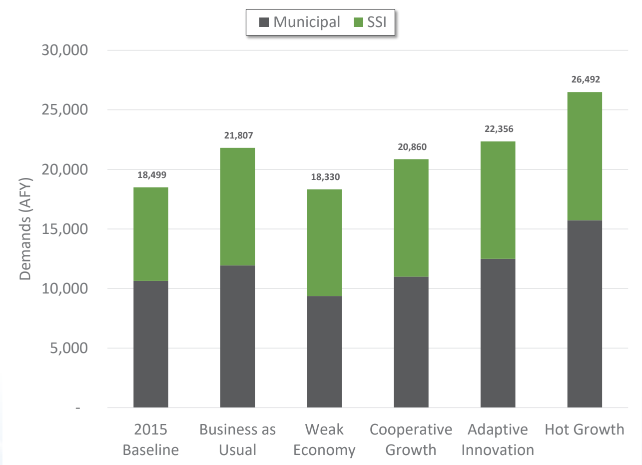
Table 4.7.8 Rio Grande Basin SSI Baseline and Projected Demands (AFY)

Sub-sector	Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Large Industry	7,660	8,860	7,960	8,860	8,860	9,760
Snowmaking	0	0	0	0	0	0
Thermoelectric	0	0	0	0	0	0
Energy Development	200	1,000	1,000	1,000	1,000	1,000
Sub-Basin Total	7,860	9,860	8,960	9,860	9,860	10,760

Total M&I Diversion Demands

Rio Grande Basin combined M&I demand projections for 2050 range from approximately 18,000 AFY in *Weak Economy* to 26,000 AFY in *Hot Growth*, as shown in Figure 4.7.9. SSI demands account for about 40 to 50 percent of the M&I demands. On a basin scale, the demand projections follow the statewide sequence of the scenario rankings described in the CWP.

Figure 4.7.9 Rio Grande Basin Municipal and Self-Supplied Industrial Demands



4.7.6 Water Supply Gaps

The agricultural and M&I diversion demands were compared against available water supply for current conditions and the five planning scenarios.

Agricultural

Because the Rio Grande Compact limits agricultural water use and because the system is over appropriated, current water supply was assumed to be equal to historical diversions and pumping, with no additional supply available. The current agricultural gap was estimated as the difference between the current agricultural diversion demand and historical diversions and pumping for wet, dry, and average years.

INCREMENTAL GAP

The incremental agricultural gap quantifies the degree to which the gap could increase beyond what agriculture has historically experienced under water shortage conditions.

The Rio Grande Basin agricultural diversion demands, demand gaps, and consumptive use gaps for the baseline and planning scenarios are presented in Table 4.7.9 and illustrated in Figure 4.7.10. An annual time series of gaps in terms of percent of demand that was unmet is shown in Figure 4.7.11.

Table 4.7.9 Rio Grande Basin Agricultural Gap Results (AFY)

		Scenario					
		Scenario	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand	1,825,200	1,717,800	1,735,700	1,656,300	1,471,400	1,638,900
	Average Annual Gap	683,900	655,800	661,500	737,400	741,900	826,400
	Average Annual Gap Increase from Baseline	-	-	-	53,500	58,000	142,500
	Average Annual Percent Gap	37%	38%	38%	45%	50%	50%
	Average Annual CU Gap	348,300	333,400	336,300	374,600	376,900	419,800
Maximum	Demand in Maximum Gap Year	2,058,800	1,935,400	1,956,200	1,814,100	1,605,700	1,789,700
	Gap in Maximum Gap Year	1,059,702	1,017,391	1,026,351	1,112,661	1,110,956	1,238,485
	Increase from Baseline Gap	-	-	-	52,959	51,254	178,783
	Percent Gap in Maximum Gap Year	51%	53%	52%	61%	69%	69%

Study period for Water Supply Analysis is 1975-2013, reflecting different baseline demand than described in Agricultural Diversion Demands section

Figure 4.7.10 Projected Average Annual Agricultural Diversion Demand, Demand Met, and Gaps in the Rio Grande Basin

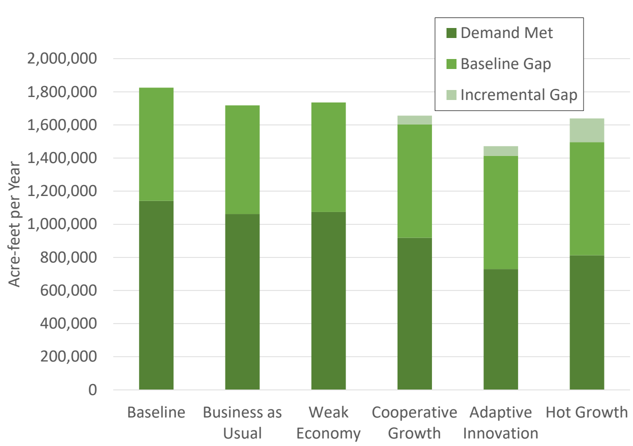
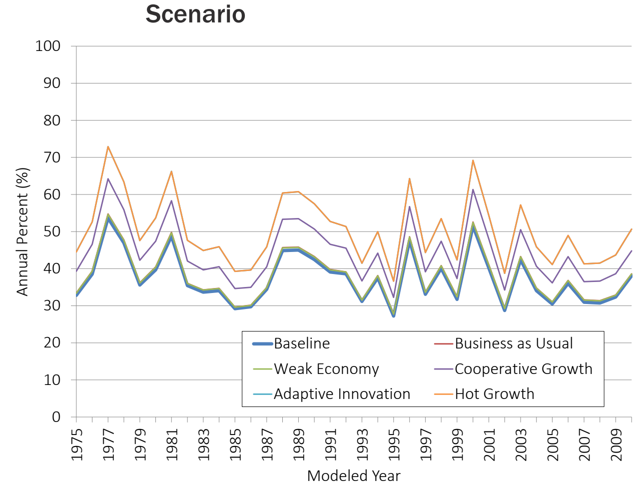


Figure 4.7.11 Annual Agricultural Gaps (expressed as a percentage of demand) for Each Planning Scenario



The following are observations on agricultural diversion demands and gaps:

- *Business as Usual* and *Weak Economy* do not include climate-adjusted hydrology or demands; therefore, changes in these scenarios relative to baseline are related strictly to changes in irrigated acreage and their impact on diversion demands.
- The inclusion of climate-adjusted hydrology and demands in *Cooperative Growth*, *Adaptive Innovation* and *Hot Growth* complicates the analyses for these scenarios. The analysis looked at the projected water supply under different year types available to senior and junior water rights in the basin and identified water rights that may no longer have constant supplies under the projected hydrology.
- Agricultural diversion demand is a major factor in this basin, with M&I demand only 1 to 1.5 percent of agricultural demand.
- Although agricultural diversion demand is expected to fall, gaps in excess of 650,000 AFY persist regardless of the planning scenario. Between 38 and 50 percent of agricultural demand is projected to be unmet in the planning scenarios.
- Despite reduced demand, the size of the gap is projected to increase relative to baseline in the three scenarios that are climate-impacted, because the available supply is forecast to be reduced.

M&I

The M&I gap for each scenario was estimated as the difference between the projected diversion demands and the current levels of municipal diversions and pumping. The diversion demand and gap results for M&I uses in the Rio Grande Basin are summarized in Table 4.7.10 and illustrated in Figure 4.7.12. Time series of M&I gaps were not developed in the Rio Grande Basin, because a CDSS water allocation model is not available at this time.

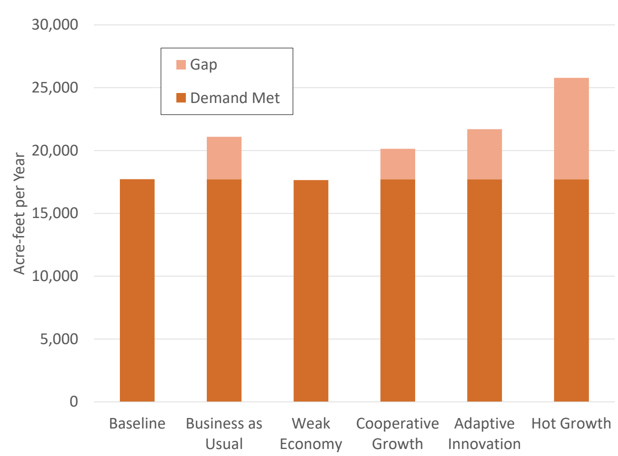
Table 4.7.10 Rio Grande Basin M&I Gap Results (AFY)

		Scenario					
		Scenario	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand	17,700	21,100	17,700	20,100	21,700	25,800
	Average Annual Gap	-	3,400	-	2,400	4,000	8,100
	Average Annual Percent Gap	-	16%	-	12%	18%	31%
Maximum	Demand in Maximum Gap Year	17,700	21,100	17,700	20,100	21,700	25,800
	Gap in Maximum Gap Year	-	3,400	-	2,400	4,000	8,100
	Percent Gap in Maximum Gap Year	-	16%	-	12%	18%	31%

The following are observations on the M&I diversion demands and gaps:

- Average annual M&I gap in the Rio Grande Basin ranges from 0 AF to more than 8,100 AF.
- Municipal diversion demand and SSI diversion demand contribute nearly evenly to total M&I diversion demand, with municipal accounting for just a little more than half. This is unique among Colorado's river basins.
- Population growth is the main driver for the modest increases in M&I demands in the planning scenarios, as per capita water use decreased for every scenario except *Hot Growth*.
- For *Hot Growth*, the M&I gap is much larger than other scenarios, at 31 percent of demand.

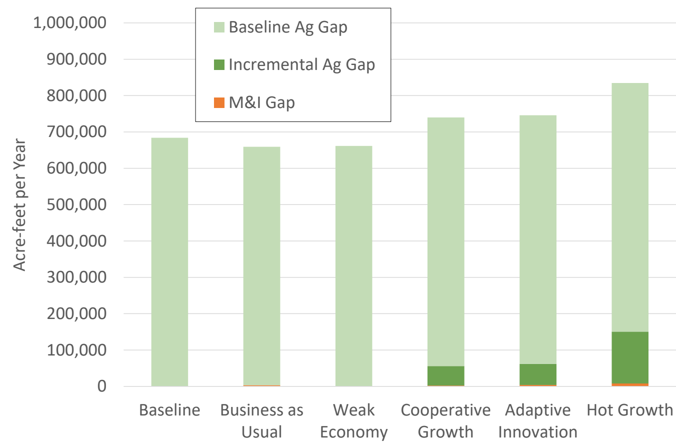
Figure 4.7.12 Projected Maximum Annual M&I Demand Met and Gaps in the Rio Grande Basin



Total Gap

Figure 4.7.13 illustrates the total combined agricultural and M&I diversion demand gap in the Rio Grande Basin. The figure combines the average annual baseline and incremental agricultural gap and the maximum M&I gap. In *Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth*, gaps were driven by agricultural demands, which increase in the "Hot and Dry" climate conditions.

Figure 4.7.13 Projected Average Annual Agricultural Gaps and Maximum M&I Diversion Demand Gaps in the Rio Grande Basin



Supplies from Urbanized Lands

By 2050, irrigated acreage in the Rio Grande Basin is projected to decrease by 4,000 acres due to urbanization. Irrigation supplies for these lands could potentially be used for M&I needs in the future (subject to a variety of unknowns such as seniority and type of water supply, willingness to change the use of water through water court, etc.). The average annual historical consumptive use associated with potentially urbanized acreage for each scenario is reflected in Table 4.7.11. The data in the table represent planning-level estimates of this potential supply and has not been applied to the M&I gaps.

Table 4.7.11 Estimated Consumptive Use from Lands Projected to be Urbanized by 2050 in the Rio Grande Basin

	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Urbanized Acreage (acres)	4,000	-	4,000	4,000	4,000
Estimated Consumptive Use (AFY)	5,300	-	5,400	4,600	5,100

4.7.7 Available Supply

For the purposes of the Technical Update, it was assumed that due to compact constraints, there are no available water supplies now or in the future that can meet new demands.

4.7.8 Environment and Recreation

A surface water allocation model is not currently available in the Rio Grande Basin. As a result, hydrologic datasets in the Flow Tool include only naturalized flows and naturalized flows as impacted by climate change. A total of four water allocation model nodes, all in the mountains and foothills west of the San Luis Valley, were selected for the Flow Tool within the Rio Grande Basin (see list below and Figure 4.7.14). Figure 4.7.14 also shows subwatersheds (at the 12-digit HUC level) and the relative number of E&R attributes located in each subwatershed.

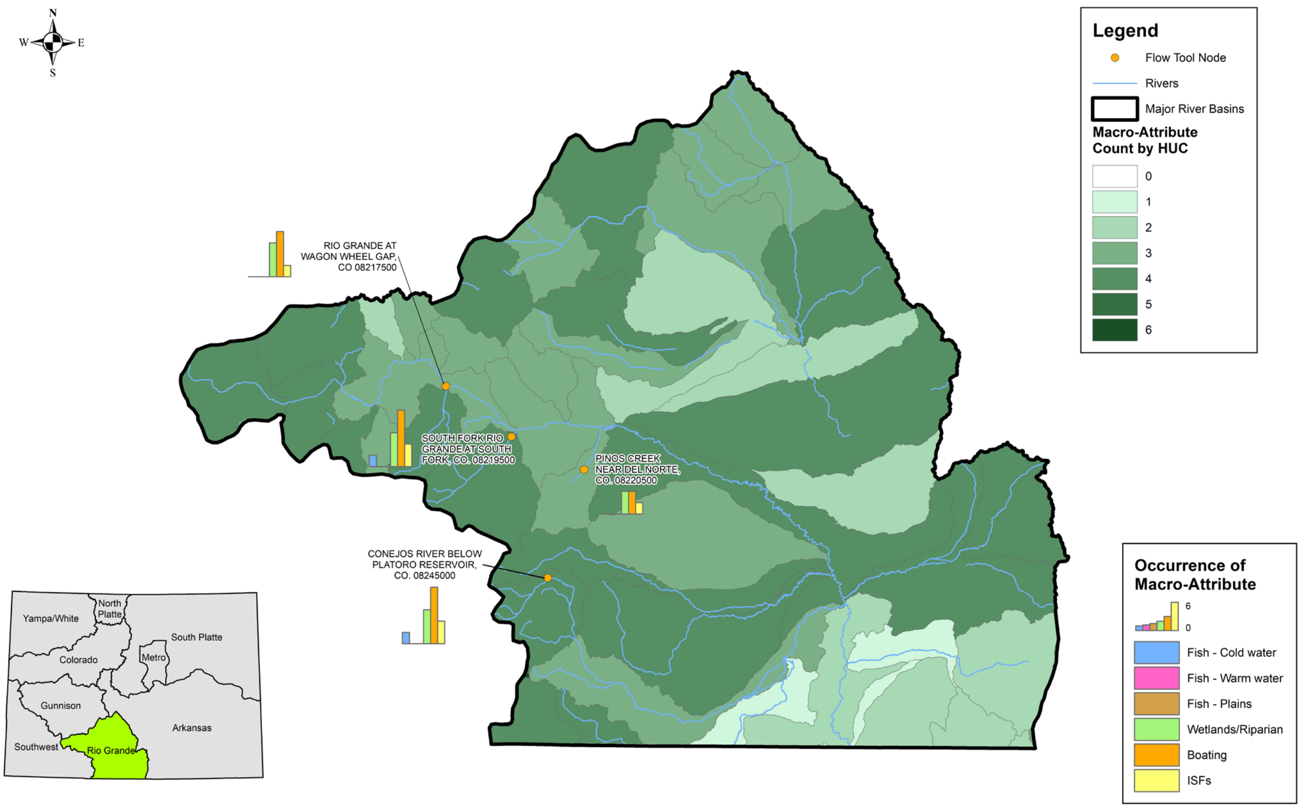
- Rio Grande at Wagon Wheel Gap, Colorado (08217500)
- South Fork Rio Grande at South Fork, Colorado (08219500)
- Pinos Creek near Del Norte, Colorado (08220500)
- Conejos River below Platoro Reservoir, Colorado (08245000)

These sites were selected because they are above major supply and demand drivers where future flow changes would likely be associated with only climate change factors. Management drivers impact river flows in areas downstream of mountainous areas in the Rio Grande and Conejos basins. Because a water allocation model that incorporates management is not available, the Flow Tool results for the Rio Grande Basin include only naturalized conditions and naturalized conditions as impacted by climate drivers ("In-Between" and "Hot and Dry" climate change projections) to illustrate a representative potential change in flow due to climate. These data do not represent changes in flow due to irrigation, transmountain imports, and/or storage.

NATURALIZED FLOW

Naturalized flows reflect conditions that would occur in the absence of human activities. Baseline flows reflect current conditions as influenced by existing infrastructure and river operations. While observations regarding naturalized flows may be informative, baseline flows reflect actual conditions and the diverse operations of a river's many users.

Figure 4.7.14 Flow Tool Nodes Selected in the Rio Grande Basin



Results and observations from Flow Tool analyses using flow data developed in the water supply and gap analyses for baseline conditions and the planning scenarios are described below in Table 4.7.11.

Table 4.7.12 Summary of Flow Tool Results in the Rio Grande Basin

Category	Observation
Projected Flows	For the selected locations, overall peak flow magnitude is not projected to change substantially under climate change projections; however, the timing of peak flow may shift to earlier in the year, with April and May flow magnitudes rising and June flows decreasing under the "In-Between" and "Hot and Dry" climate change projections.
	Mid- and late-summer flow may be reduced in all locations under the "In-Between" and "Hot and Dry" climate change projections, with July streamflow decreasing by roughly half on the Rio Grande and tributaries and even more on the Conejos River.
Ecological Risk	Peak flow related risk for riparian/wetland and fish habitat is projected to remain low or moderate in most cases, although there are some indications that risk could increase in smaller streams.
	Risk to trout due to decreasing mid- and late-summer streamflow may remain moderate in most years but could be higher in July and/or during dry years.
E&R Attributes	Because future flows under the five scenarios have not been modeled in the Rio Grande Basin, projected changes to flow and associated changes in risk to E&R attributes within the Flow Tool are attributable only to projected changes in climate. These climate-induced changes—earlier peak flow and reduced mid- and late-summer flows—are similar to the general pattern seen in many parts of Colorado.

The South Platte Basin is the most populous basin in the state. Approximately 85 percent of Colorado's population resides in the South Platte Basin, and the Front Range area of the basin is Colorado's economic and social engine. The basin also has the greatest concentration of irrigated agricultural lands in Colorado.

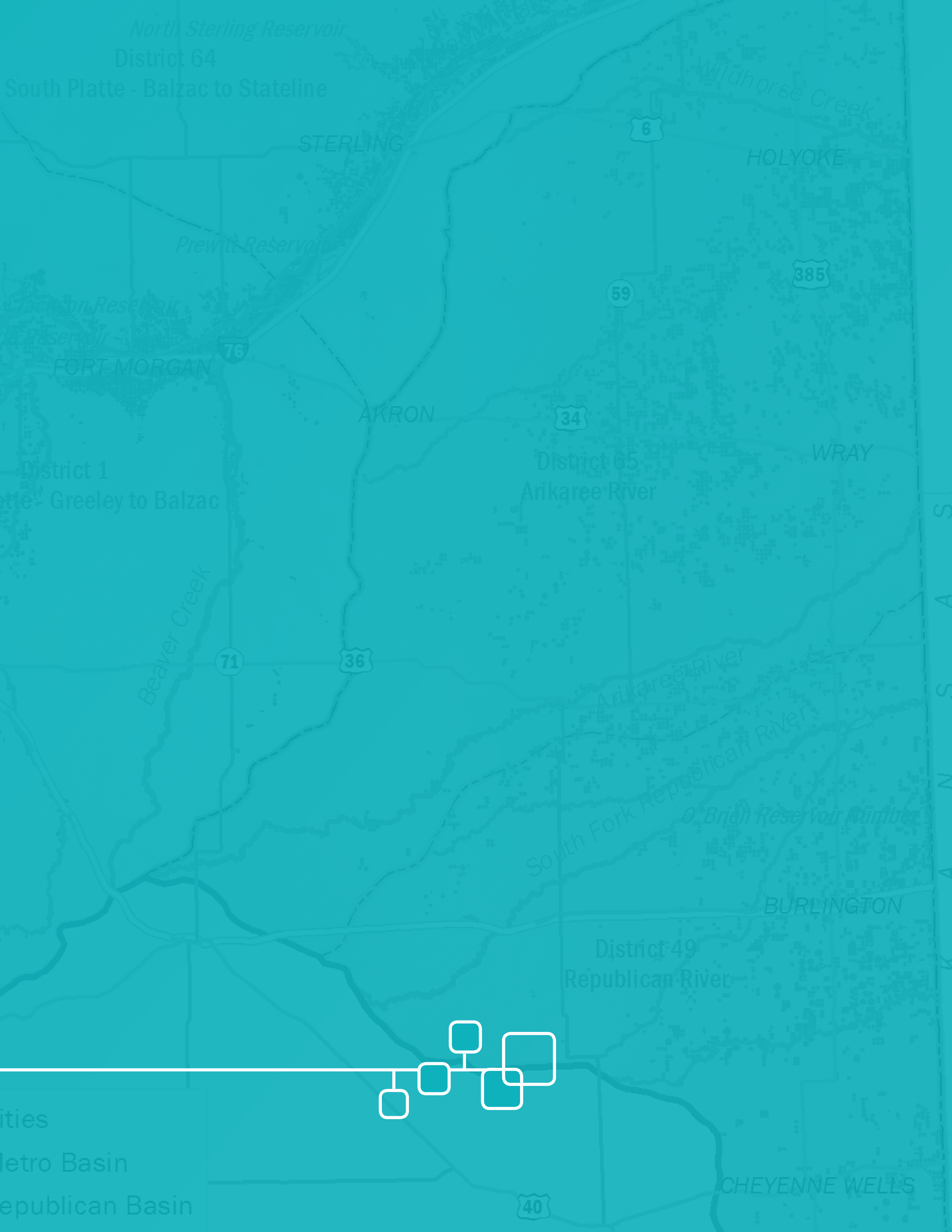
The topographic characteristics of the South Platte Basin are diverse. The western portions of the basin and its mountainous and subalpine areas are mostly forested, while the High Plains region is mainly grassland and planted or cultivated land.

The hydrology of the South Platte Basin is highly variable, with an approximate average annual native flow volume of 1.4 million AF About 400,000 AF of transmountain imports and 30,000 AF from nontributary groundwater aquifers supplement the water supply in the South Platte Basin. Yet, surface-water diversions in the South Platte Basin average about 4 million AF annually, with groundwater withdrawals totaling an additional annual 500,000 AF on average. The amount of diversion in excess of native flow highlights the return flow-dependent nature of the basin's hydrology, and the basinwide efficient use and reuse of water supplies.

The Republican Basin in Colorado is located on the Northeastern High Plains. Land uses in the basin are primarily agricultural. The topographic characteristics of the Republican Basin, which are similar to the High Plains region of the South Platte Basin, consist mainly of grassland and planted or cultivated land. The Republican Basin in Colorado is underlain by the High Plains or Ogallala aquifer, which is one of the largest aquifer systems in the United States, extending from South Dakota to Texas.

The Technical Update largely keeps the analysis at the basin scale. There are some exceptions where subbasin (river basin) analysis of major waterways was more straightforward. To that end, both the South Platte, Metro and Republican basins were explicitly analyzed where possible. Those results are shown in the following sections. In other sections, of this report where statewide analysis is shown, the entire South Platte Basin (with values from the South Platte, Metro and Republican combined) are shown.

SOUTH PLATTE / METRO



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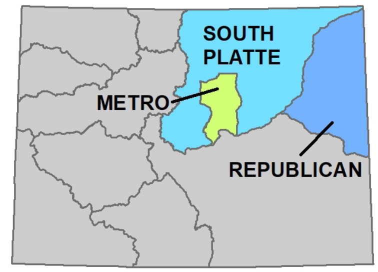
4.8 SOUTH PLATTE BASIN RESULTS



4.8.1 BASIN CHALLENGES

Key future water management issues in this basin will be focused on meeting future water supply demands for a variety of sectors while complying with interstate compacts and maintaining Coloradans' quality of life. These challenges are described in the Colorado Water Plan and are summarized below.

Table 4.8.1 Key Future Water Management Issues in the South Platte Basin

<table>
<tr><th>Agriculture</th><th>Environment and Recreation</th><th>Municipal and Industrial</th><th>Compacts and Administration</th></tr>
<tr><td>• Agriculture is the dominant water use in the basin, but agricultural water transfers are likely to have negative effects on rural communities and the environment.
• Depletions to the Ogallala Aquifer and long-term impacts to water supplies are a concern to agricultural viability.</td><td>• Environmental and recreational features in the basin are important to Colorado's quality of life and tourism economy.</td><td>• Competition for additional M&I supplies is substantial and increases costs to customers.
• Lack of new storage projects has led to reliance on non-renewable groundwater supplies in quickly-urbanizing areas of the South Metro region.
• Value judgements regarding irrigated landscaping complicate discussions about water development.</td><td rowspan="2">• A significant amount of the South Platte Basin's supply originates in the Colorado Basin and is subject to compact compliance.
• Aquifer storage, while promising, poses control and administrative issues.
• Republican River Compact compliance.
• Coordination among water authorities in the Republican Basin is a challenge.</td></tr>
<tr><td colspan="3">• Water quality will continue to be a challenge for all segments of water use.
• Increases in M&I water use efficiency is critical but will reduce the quantity of water available for agriculture and the environment.</td></tr>
</table>

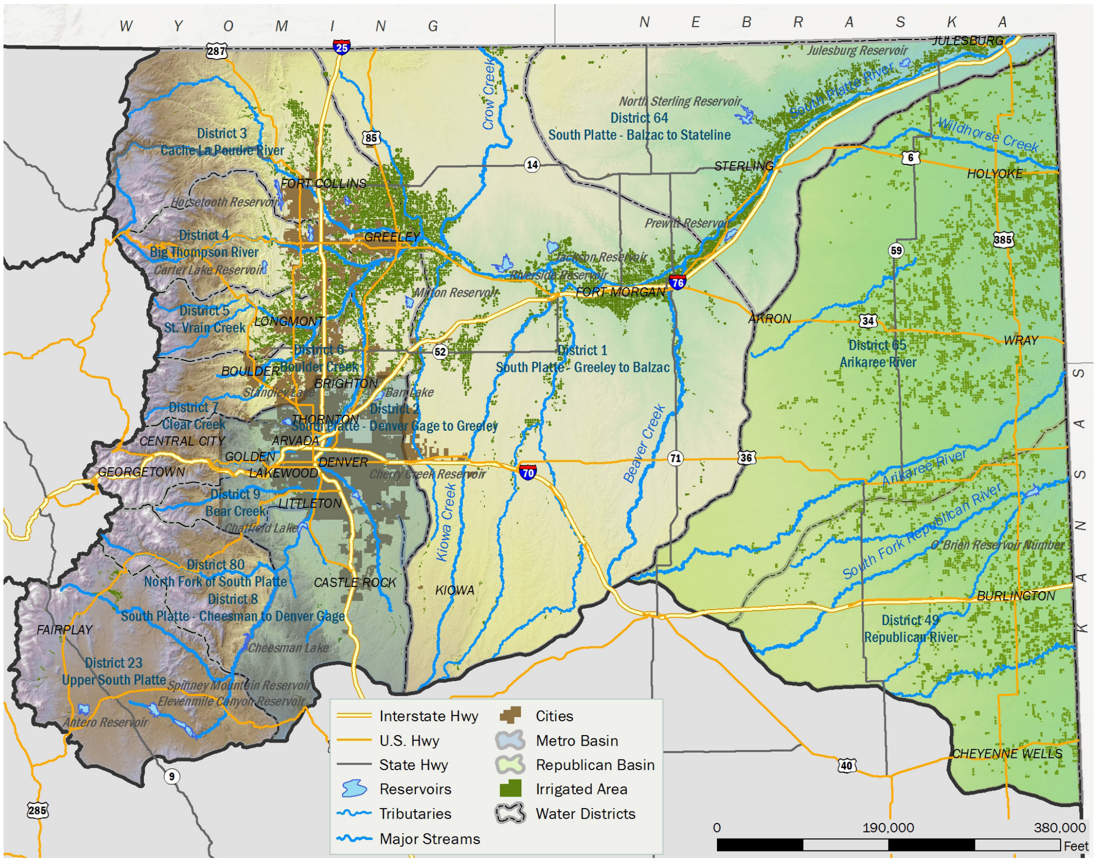


Figure 4.8.1 Map of the South Platte Basin

4.8.2 SUMMARY OF TECHNICAL UPDATE RESULTS

Key results and findings of the Technical Update pertaining to agricultural and M&I demands and gaps as well as findings related to environment and recreation attributes and future conditions are summarized below in Table 4.8.2.

Table 4.8.2 Summary of Key Results in the South Platte and Republican Basins

Agriculture	Environment and Recreation	Municipal and Industrial
• Future agricultural demands in the South Platte Basin are projected to decrease due to loss of irrigated lands from lack of groundwater sustainability. • Future agricultural demands in the South Platte Basin are projected to decrease due to loss of irrigated lands from urbanization and agricultural water transfers. • Agricultural gaps as a percentage of total demand in the South Platte Basin are not projected to greatly increase.	• In several locations in the mountains and foothills, climate-impacted scenarios show variable responses in peak flows. • On the plains, especially east of Interstate 25, flow conditions are projected to be poor for all aspects of ecosystem health. • In the mountains and foothills, climate-impacted scenarios show diminished mid- and late-summer flows.	• M&I demands in Adaptive Innovation are projected to be very similar to Business as Usual despite higher population and hotter/drier climate assumptions in Adaptive Innovation. This result demonstrates the value of higher levels of conservation. • Significant future gaps are estimated for each planning scenario, and they could be exacerbated by reductions in West Slope supplies.

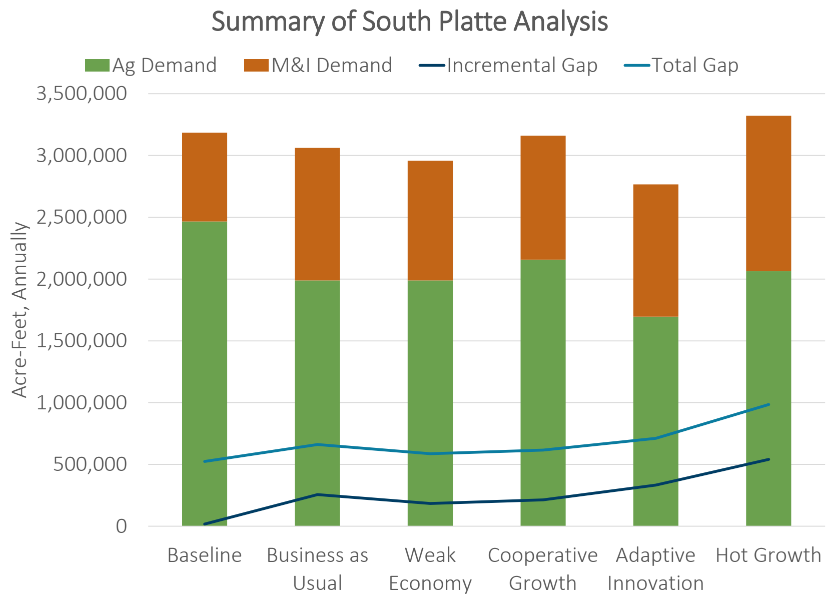
Results describing current and potential future M&I and agricultural demands and gaps are summarized in Table 4.8.3 and Figure 4.8.2.

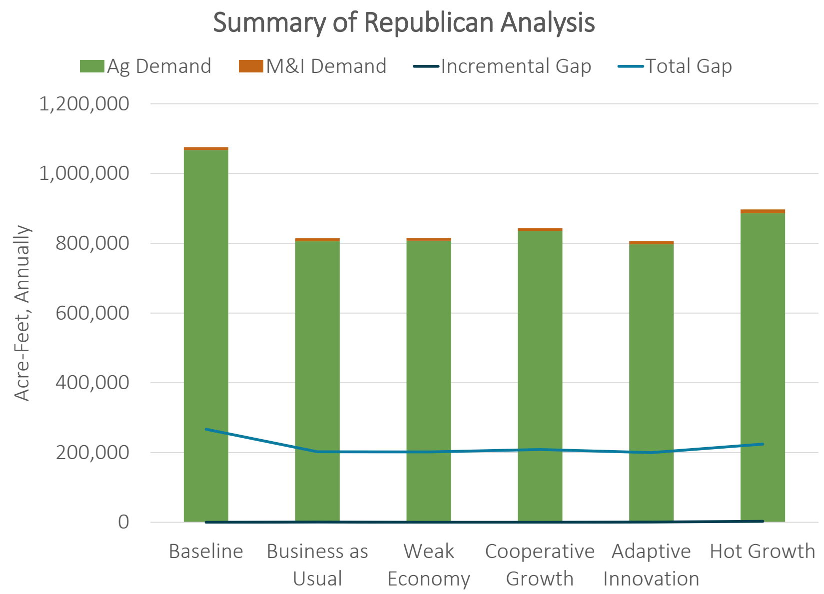
Table 4.8.3 Summary of Diversion Demand and Gap Results in the South Platte and Republican Basins

		Current (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
South Platte	**Average Annual Demand**						
	Agricultural (AFY)	2,465,800	1,988,700	1,988,700	2,157,400	1,696,500	2,063,100
	M&I (AFY)	718,700	1,073,000	968,900	1,002,800	1,070,100	1,257,700
	Gaps						
	Ag (avg %)	21%	20%	20%	19%	22%	22%
	Ag (incremental-AFY)	-	-	-	-	-	-
	Ag (incremental gap as % of current demand)	-	-	-	-	-	-
	M&I (max %)	0%	24%	19%	21%	31%	43%
	M&I (max-AF)	0*	256,300	184,500	213,300	333,200	540,700
Republican	**Average Annual Demand**						
	Agricultural (AFY)	1,067,200	805,500	807,500	835,300	797,200	885,800
	M&I (AFY)	8,400	9,200	7,900	8,100	8,900	11,200
	Gaps						
	Ag (avg %)	25%	25%	25%	25%	25%	25%
	Ag (incremental-AFY)	-	-	-	-	-	-
	Ag (incremental gap as % of current demand)	-	-	-	-	-	-
	M&I (max %)	0%	8%	0%	0%	6%	25%
	M&I (max-AF)	-	700	-	-	500	2,800
Total	**Average Annual Demand**						
	Agricultural (AFY)	3,533,000	2,794,200	2,796,100	2,992,700	2,493,700	2,948,900
	M&I (AFY)	727,100	1,082,200	976,800	1,010,900	1,079,100	1,268,900
	Gaps						
	Ag (avg %)	22%	22%	22%	20%	23%	23%
	Ag (incremental-AFY)	-	-	-	-	-	-
	Ag (incremental gap as % of current demand)	-	-	-	-	-	-
	M&I (max %)	0%	24%	19%	21%	31%	43%
	M&I (max-AF)	0*	257,100	184,500	213,300	333,700	543,500

**CDSS water allocation model in this basin calculates small baseline M&I gaps, but they are either due to calibration issues or they are reflective of infrequent, dry-year shortages that are typically managed with temporary demand reductions, such as watering restrictions.*

Figure 4.8.2 Summary of Diversion Demand and Gap Results in the South Platte and Republican Basins





Summary of Environment and Recreation Findings

- In several locations in the mountains and foothills, *Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth* project variable responses to peak flows, in some cases increasing peak flow (thus improving or maintaining risk to plants and fish habitat) and in other cases diminishing peak flows and increasing risk to riparian/wetlands and fish habitat to high or very high.
- In the mountains and foothills, *Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth* project diminished mid- and late-summer flows, increasing risk to fish. This risk may remain moderate; however, the metric used to assess risk for fish does not include the month of July because historically July flows are sufficient. Under *Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth*, July flows may drop substantially, increasing risk for fish.
- On the plains, especially east of Interstate 25, flow conditions are projected to be poor for all aspects of ecosystem health. Peak flows for riparian/wetlands are high risk under baseline conditions and are projected to remain so under all scenarios. Mid- and late-summer flows are very high risk for plains fishes and risk is projected to increase under all future scenarios.
- The recreational in-channel diversions may be met less often in the future.

4.8.3 NOTABLE BASIN CONSIDERATIONS

Section 4.1 described several analysis assumptions and limitations that apply to all basins and should be considered when reviewing and interpreting analysis results. Additional considerations specific to the South Platte Basin are listed below:

- Imports from transmountain diversion projects were set at historical levels and reflect historical operations. In climate-impacted scenarios, transmountain imports are projected to decrease, which could increase agricultural and M&I gaps. Gaps in the South Platte Basin would likely increase more than the reduction in transmountain imports because return flows from transmountain imports are used to extinction within the South Platte Basin by either the importing entity or by downstream agricultural and M&I water users.
- Stakeholders in the South Platte Basin suggested that purchase and transfer of senior irrigation water rights resulting in permanent reductions in irrigated acreage to municipal uses will continue through 2050 even though alternative water transfers have the potential to reduce reliance on transfers resulting in permanent dry up. Stakeholder estimates of acreage associated with these transfers were accounted for in the agricultural diversion demand and the modeling effort the same way urbanized lands were considered. Acreage purchased, transferred, and/or urbanized was quantified, but was not modeled as a future water supply strategy in this effort as it was unknown what municipal entity may benefit from resulting supply.
- Aquifer sustainability will be a primary focus of future water management strategies and activities in the Republican Basin.
- Due to on-going permitting efforts in the basin, the Cache La Poudre basin (Water District 3) was excluded from the CDSS surface water allocation model. Shortages to agriculture and M&I demands within the basin were informed by the results from nearby basins with similar characteristics (e.g. storage, C-BT supplies) to reflect the impact of climate adjustments on hydrology.
- No groundwater modeling was performed in either the South Platte or Republican basin. Groundwater pumping in the planning scenarios was estimated based on the premise that current groundwater pumping would either stay the same or be reduced in the future based on sustainability of groundwater supplies. Groundwater pumping was effectively reduced to account for sustainability concerns by removing acreage served by groundwater supplies.

4.8.4 AGRICULTURAL DIVERSION DEMANDS

Agricultural Setting

South Platte Basin

Approximately 854,000 acres are irrigated in the South Platte Basin. It is the highest producing basin in the state in terms of the value of agricultural products sold. Irrigated lands are located along and adjacent to the South Platte River and its tributaries and stretch to the state line.

Farmers divert surface water and pump groundwater. In many cases, both sources of supply are available to irrigate South Platte Basin farms. Much of the surface water supply in the basin is generated via return flows as an upstream irrigators' inefficiencies become the water supply for downstream irrigators.

The amount of irrigated land in the basin is anticipated to decrease in the future. Urbanization will impact irrigated lands in and around the basin's municipalities by 2050. The majority of urbanization of irrigated land (60 percent) is projected to occur in the St. Vrain River, Big Thompson River, and Cache La Poudre River basins. These basins have some of the highest concentrations of irrigated land adjacent to municipalities that are projected to increase in population. Although large population increases are also anticipated in and around the Denver Metropolitan area, the concentration of irrigated land that could be urbanized is less. Acquisition of senior water rights by "buy and dry" methods is also expected to reduce the amount of irrigated land in the basin.

Republican Basin

The Republican Basin has nearly 580,000 irrigated acres, making it one of the highest producing basins of irrigated crops in the state. The basin has very limited surface water supplies. As a result, irrigators rely on groundwater supplies from the High Plains Aquifer (also known as the Ogallala Aquifer). Approximately 10 percent of total pumping is subject to the Republican River Compact, with the remaining 90 percent pumped from "storage" in the High Plains Aquifer. Groundwater pumping is managed by several groundwater management districts in the basin.

The current amount of irrigated land in the basin is expected to decline in the future. Absent the development of an alternative means to reduce consumptive use, irrigated lands will need to be retired to maintain compliance with the Republican River Compact. In addition, declining saturated thickness in the High Plains Aquifer will also lead to the retirement of groundwater-irrigated lands.

Planning Scenario Adjustments

South Platte Basin

The South Platte Basin is expected to experience the largest municipal growth in the state by 2050, straining already limited water supplies and increasing competition among municipal, industrial, agricultural, environmental and recreation users in the basin. The planning scenarios contemplate various pressures that may affect basin agriculture and consider increased urbanization of irrigated lands, increased municipal conversions of agricultural water supplies, limited augmentation supplies, and higher irrigation demands due to a warmer climate.

Adjustments to agricultural diversion demands were made to reflect the above considerations. Stakeholder outreach was conducted to estimate the amount of irrigated land that could be lost from transfers of water from agriculture to municipal providers and the loss of groundwater-irrigated land due to insufficient augmentation supplies. In addition, the Agricultural Technical Advisory Group provided input on the level of future increases in irrigation efficiency and reductions in future IWR due to advances in agronomic technologies. Table 4.8.4 summarizes the adjustments that were made in each of the planning scenarios to reflect assumed future conditions in agriculture.

Republican Basin

The sustainability of groundwater supplies will be the primary source of future pressure to irrigated agriculture in the Republican Basin. As described previously, irrigated lands are likely going to be retired to comply with the Republican River Compact and also as a result of declining water levels in the High Plains Aquifer. Stakeholder outreach informed the assumptions that were used to reduce irrigated acreage under each of the planning scenarios. Table 4.8.4 summarizes the planning scenario adjustments used to reflect these conditions and other adjustments that impact agricultural diversion demands basin

Table 4.8.4 Planning Scenario Adjustments for Agricultural Demands in the South Platte and Republican Basins

Sub-basin	Adjustment Factor*	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
South Platte	Change in Irrigated Land due to Urbanization & Municipal Transfers	105,900 Acre Reduction	105,900 Acre Reduction 20% SW Acre Reduction (WD 1 & 64)	105,900 Acre Reduction 20% SW Acre Reduction (WD 1 & 64)	105,900 Acre Reduction 20% SW Acre Reduction (WD 1 & 64)	105,900 Acre Reduction 20% SW Acre Reduction (WD 1 & 64)
	Groundwater Acreage Sustainability	20% GW-Only Acre Reduction (Central)	20% GW-Only Acre Reduction (Central)	20% GW-Only Acre Reduction (Central)	20% GW-Only Acre Reduction (Central)	20% GW-Only Acre Reduction (Central)
	IWR Climate Factor	-	-	15%	24%	24%
	Emerging Technologies	85% GW Only Acreage in Sprinkler	85% GW Only Acreage in Sprinkler	90% GW Only Acreage in Sprinkler	90% GW Only Acreage in Sprinkler 10% IWR Reduction 10% System Efficiency Increase	90% GW Only Acreage in Sprinkler
Republican	Change in Irrigated Land due to Urbanization	1,410 Acre Reduction	-	1,410 Acre Reduction	1,410 Acre Reduction	1,410 Acre Reduction
	Groundwater Acreage Sustainability	135,420 Acre Reduction	135,420 Acre Reduction	135,420 Acre Reduction	135,420 Acre Reduction	135,420 Acre Reduction
	IWR Climate Factor	-	-	4%	11%	11%
	Emerging Technologies	-	-	-	10% IWR Reduction	-

**See section 2.2.3 for descriptions of adjustment methodologies and assumptions*

Agricultural Diversion Demand Results

Table 4.8.5 and Figures 4.8.3 and 4.8.4 summarize the acreage, IWR, and agricultural diversion demand in both the South Platte and Republican basins for current conditions and the five planning scenarios. Note that in the South Platte Basin, surface water and groundwater sources are used for irrigation, and a breakout of diversion demand for these sources is included in the technical memorandum *Current and Projected Planning Scenario Agricultural Diversion Demands* (see Volume 2). All agricultural diversion demands in the Republican Basin were from groundwater sources.

SYSTEM EFFICIENCY

In some cases, diversion demands surface water can be higher in wet years because system efficiency decreases due to the relative abundance of supply.

Future agricultural diversion demands in both the South Platte and Republican Basins are anticipated to be lower in the future due primarily to the loss of irrigated land. While assumptions of a warmer climate increase IWR in *Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth*, the loss of irrigated land may offset the additional IWR demand, resulting in lower future demands. Projected increases in IWR due to a warmer climate are the same in *Adaptive Innovation* and *Hot Growth*, but the agricultural diversion demand is lower in *Adaptive Innovation* due to the assumed 10 percent reduction in IWR from emerging technologies and a 10 percent increase in system efficiency. Agricultural diversion demands in the South Platte are relatively consistent in wet, average, and dry years due to surface water irrigation system efficiencies that fluctuate in differing hydrologic conditions. Republican Basin irrigation is provided from groundwater, and system efficiencies of wells do not fluctuate. As a result, agricultural diversion demands in the Republican Basin change to a greater degree in response to hydrologic conditions.

Table 4.8.5 Summary of Agricultural Diversion Demand Results in the South Platte and Republican Basins

		Current	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
South Platte	Irrigated Acreage (acres)	854,300	701,100	701,100	722,400	722,400	679,900
	Average IWR (AFY)	1,500,000	1,225,000	1,225,000	1,341,000	1,264,000	1,323,000
	Total Surface Water and Groundwater Diversion Demand						
	Average Year (AFY)	2,589,000	2,081,000	2,081,000	2,268,000	1,771,000	2,202,000
	Wet Yr. Change	-6%	-6%	-6%	-4%	-4%	-4%
	Dry Yr Change	2%	2%	2%	1%	2%	-1%
Republican	Irrigated Acreage (acres)	578,800	442,000	443,400	442,000	442,000	442,000
	Average IWR (AFY)	837,000	635,000	636,000	661,000	649,000	721,000
	Groundwater Diversion Demand						
	Average Year (AFY)	1,056,000	800,000	802,000	833,000	799,000	888,000
	Wet Yr. Change	-14%	-15%	-15%	-14%	-13%	-13%
	Dry Yr Change	20%	21%	21%	18%	14%	14%

Figure 4.8.3 Agricultural Diversion Demands and IWR Results in the South Platte Basin

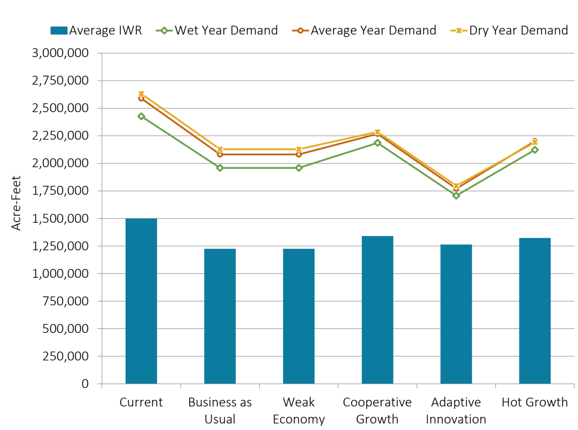
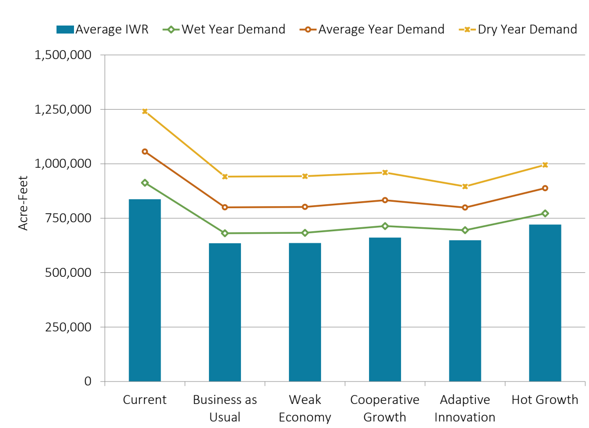


Figure 4.8.4 Agricultural Diversion Demands and IWR Results in the Republican Basin



4.8.5 Municipal and Self-Supplied Industrial Diversion Demands

For purposes of the M&I demand reporting, the South Platte Basin includes three sub-basins—the Metro Region as defined by the basin roundtables, the Republican Basin, and the remainder of the South Platte Basin. SWSI 2010 included the Republican Basin demands in the reporting of the South Platte Basin demands, but separately reported M&I demands for the Metro Region. The Republican Basin was evaluated separately in the water supply and gap analysis in the Technical Update, and the Metro Region demands were analyzed in the South Platte Basin modeling of water supplies and gaps. The three sub-basins are each summarized in the following subsections, along with the combined South Platte Basin.

Population Projections

The South Platte Basin as a whole is currently the most populous basin and includes about 70 percent of the statewide population. The Metro Region holds the majority of the population at 51 percent of the statewide total. The remaining portion of the South Platte Basin has 19 percent of the statewide population, and the Republican Basin has less than 1 percent.

Between the years 2015 and 2050, the South Platte Basin as a whole is projected to grow from approximately 3.8 million people to between 5.4 million and 6.5 million people in the low and high growth scenarios, respectively, which represents an increase in population of 42 to 70 percent. Table 4.8.6 shows how population growth is projected to vary across the planning scenarios for the South Platte Basin.

Table 4.8.6 South Platte Basin 2015 and Projected Populations

Sub-basin	Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Metro Region	2,768,000	4,062,000	3,817,000	3,922,000	4,162,000	4,318,000
Republican Basin	32,000	35,000	30,000	34,000	38,000	41,000
Remaining South Platte Basin	1,030,000	1,857,000	1,586,000	1,929,000	2,292,000	2,149,000
Total South Platte Basin	3,830,000	5,954,000	5,433,000	5,884,000	6,492,000	6,508,000

Current Municipal Demands

The Metro Region baseline water demands were largely based on water provider-reported data and had the highest representation of 1051 data for any basin or region in the state. The Republican Basin baseline water demands were largely estimated, and the remaining South Platte Basin baseline demands were largely based on water provider-reported data (see figures below).

Figure 4.8.5 Sources of Water Demand Data in the Metro Region

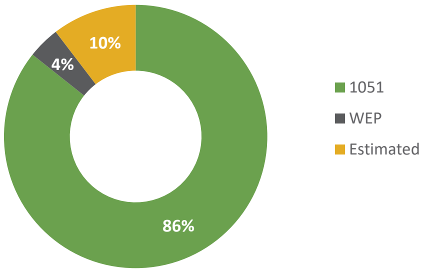


Figure 4.8.6 Sources of Water Demand Data in the Republican Basin

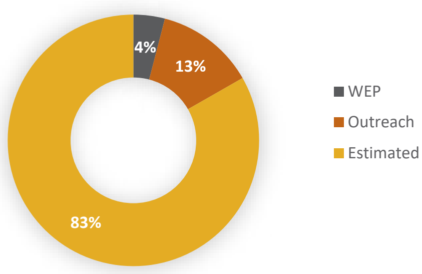


Figure 4.8.7 Sources of Water Demand Data in the Remaining South Platte Basin

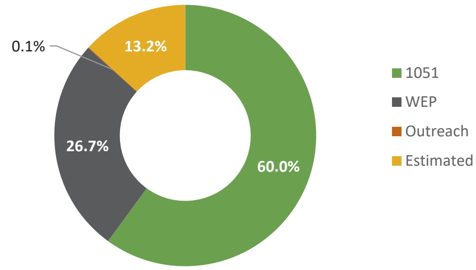
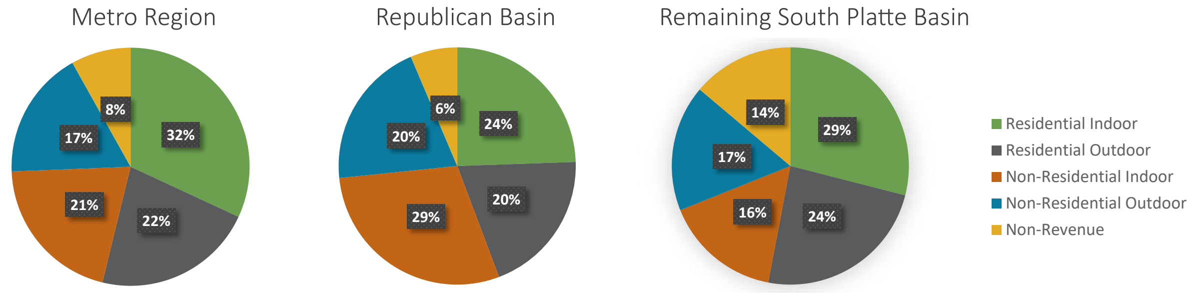


Figure 4.8.8 summarizes the categories of municipal, baseline water usage in the Metro Region, Republican Basin, and the remaining South Platte Basin. In the Metro Region and Republican Basin, non-revenue water as a percentage of systemwide demands is among the lowest in the state (with the Republican Basin being the lowest). Usage percentages in the Metro Region have a significant impact on statewide average, because a significant portion of the state population is located in the Metro Region.

Figure 4.8.8 Categories of Water Usage in the South Platte Basin



Projected Municipal Demands

Figures 4.8.9 through 4.8.11 provide summaries of per capita baseline and projected water demands for the Metro Region, Republican Basin, and the remaining South Platte Basin, respectively. In each basin, systemwide projected per capita demands decrease relative to the baseline except for *Hot Growth*. Additionally, the assumption of a hot and dry climate in *Hot Growth* is projected to cause a significant increase in outdoor demands in each region. Additional observations regarding the demand categories specific to each region are described below:

Metro Region

Consistently across all scenarios, residential indoor demand is the greatest individual demand category; non-revenue water is the lowest.

Republican Basin

Non-residential indoor demand is the greatest individual demand category; non-revenue water is the lowest in all of the scenarios.

Remaining South Platte Basin

The residential indoor demand is the greatest demand category in the baseline, but the residential outdoor demand is projected to exceed the residential indoor demand in *Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth*.

DECREASING GPCD

The Metro Region average baseline per capita systemwide demand has decreased from 155 gpcd in SWSI 2010 to approximately 141 gpcd. Other areas of the South Platte cannot be directly compared because of differences in reporting.

Figure 4.8.9 Metro Region Municipal Baseline and Projected Per Capita Demands by Water Demand Category

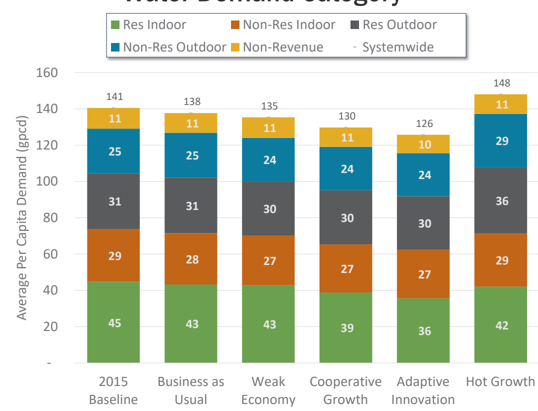


Figure 4.8.10 Republican Basin Municipal Baseline and Projected Per Capita Demands by Water Demand Category

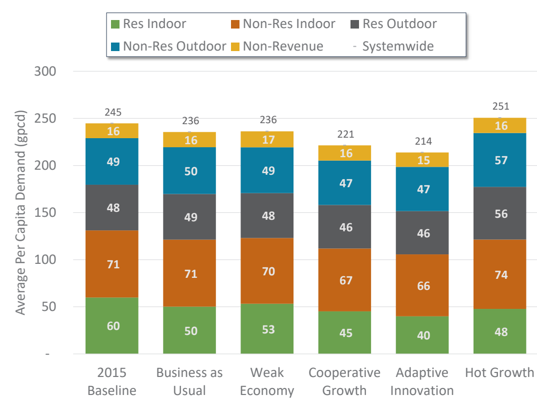
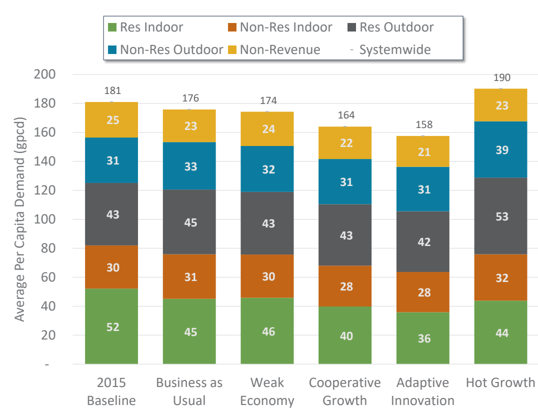


Figure 4.8.11 Remaining South Platte Basin Municipal Baseline and Projected Per Capita Demands by Water Demand Category



The South Platte Basin municipal baseline and projected demands are provided in Table 4.8.7, which shows the combined effect of population and per capita demands. Municipal demands are projected to grow from approximately 653,000 AFY in 2015 to between 897,000 and 1,185,000 AFY in 2050.

Table 4.8.7 South Platte Basin Municipal Baseline and Projected Demands (AFY)

Sub-basin	Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Metro Region	436,000	627,000	579,000	570,000	586,000	716,000
Republican Basin	9,000	9,000	8,000	8,000	9,000	12,000
Remaining South Platte Basin	209,000	366,000	310,000	354,000	405,000	458,000
Total South Platte Basin	653,000	1,002,000	897,000	933,000	1,000,000	1,185,000

The baseline and projected demand distributions for each region and for the South Platte Basin as a whole are shown in Figures 4.8.12 through 4.8.15.

Figure 4.8.12 Metro Region Baseline and Projected Population and Municipal Demands

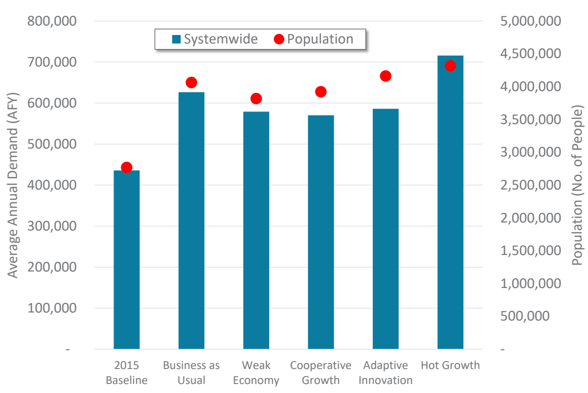


Figure 4.8.13 Republican Baseline and Projected Population and Municipal Demands

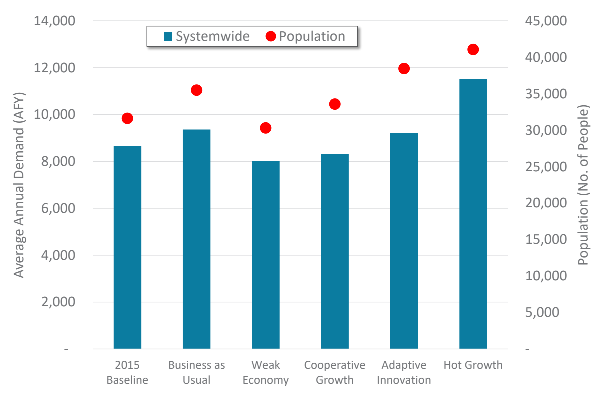


Figure 4.8.14 Remaining South Platte Baseline and Projected Population and Municipal Demands

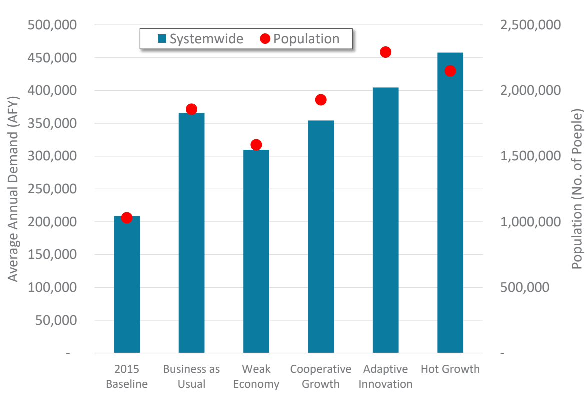
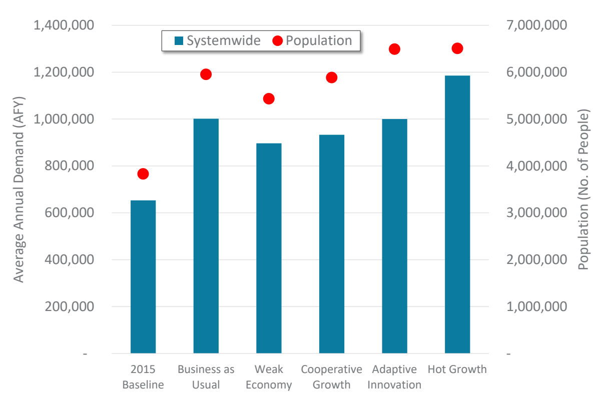


Figure 4.8.15 Total South Platte Basin Baseline and Projected Population and Municipal Demands



Below are some observations on the projected demands and population projections:

Table 4.8.8 Observations on South Platte Basin M&I Demands

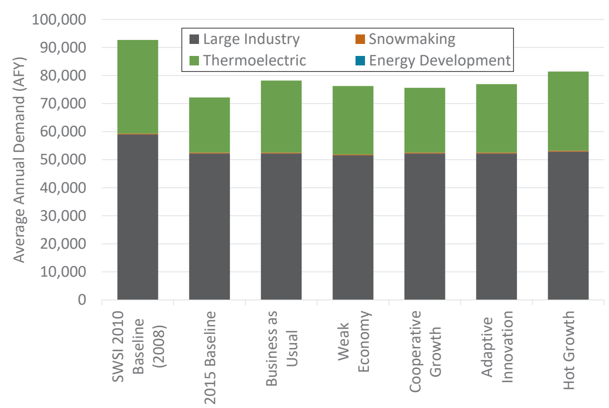
Metro Region	Republican Basin	Remaining South Platte Basin	South Platte Basin/Basin-wide
• All of the planning scenarios result in an increase relative to the baseline. • Projected demand for *Weak Economy, Cooperative Growth, and Adaptive Innovation* are all within 3% of each other, even though each scenario has a different population projection.	• Demands are projected to decrease relative to the baseline in *Weak Economy and Cooperative Growth*.	• All of the planning scenarios result in an increase relative to the baseline. • Projected demands tend to follow population trends, except for *Adaptive Innovation* in which the population exceeds *Hot Growth* but the systemwide demand projection is lower, which shows the influence of projected per capita demands for this basin.	• All of the projection scenarios result in an increase relative to the baseline. • Projected demands in *Business as Usual* and *Adaptive Innovation* are similar, although population projected for *Adaptive Innovation* is about 10% higher.

Self-Supplied Industrial Demands

The South Platte Basin includes about 40 percent of the statewide SSI demand. Approximately 67 percent of the baseline SSI demands are in the Metro Region and 33 percent are in the remaining South Platte Basin. There are no SSI demands in the Republican Basin. SSI demands in the South Platte Basin are associated with the Large Industry, Snowmaking, and Thermoelectric sub-sectors. No demands were projected for the Energy Development sub-sector because no reliable data were available. Basin-scale SSI demands are shown on Figure 4.8.16 and Table 4.8.9.

Large Industry demands in this basin are located in three counties. Baseline demands in Jefferson County were based on data from an existing hydrologic model, and projected demands were not varied by scenario at the direction of the water user. Large Industry demands in Morgan and Weld counties were based on SWSI 2010. The baseline demand has decreased relative to SWSI 2010 due to reductions in Jefferson County.

Figure 4.8.16 Total South Platte Basin Self-Supplied Industrial Demands



The baseline snowmaking demand is 300 AFY (slightly less than in SWSI 2010 due to a reduction in snowmaking acres). Projected demands are 320 AFY and were not varied by scenario.

Thermoelectric demands are related to eight facilities in seven counties. Baseline demands for seven of the eight facilities were updated based on information from Xcel Energy.

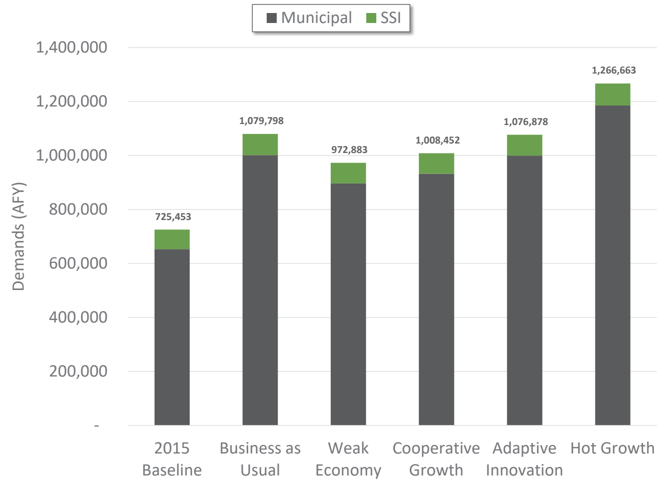
Table 4.8.9 Total South Platte Basin SSI Baseline and Projected Demands (AFY)

	Sub-sector	Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Metro Region	Large Industry	45,630	45,630	45,630	45,630	45,630	45,630
	Snowmaking	0	0	0	0	0	0
	Thermoelectric	3,040	3,040	2,890	2,740	2,890	3,350
	Energy Development	0	0	0	0	0	0
	Sub-Basin Total	48,670	48,670	48,520	48,370	48,520	48,980
Remaining South Platte Basin	Large Industry	6,600	6,600	5,940	6,600	6,600	7,260
	Snowmaking	300	320	320	320	320	320
	Thermoelectric	16,630	22,630	21,500	20,370	21,500	24,890
	Energy Development	0	0	0	0	0	0
	Sub-Basin Total	23,530	29,550	27,760	27,290	28,420	32,470
	Basin Total	**72,200**	**78,220**	**76,280**	**75,660**	**76,940**	**81,450**

Total M&I Diversion Demands

South Platte Basin combined M&I demand projections for 2050 range from approximately 970,000 AFY in *Weak Economy* to 1.27 million AFY in *Hot Growth*, as shown in Figure 4.8.17. SSI demands account for 6 to 10 percent of the M&I demands. On a basin scale, the demand projections do not follow the statewide sequence of the scenario rankings described in the CWP, with *Adaptive Innovation* falling out of sequence.

Figure 4.8.17 South Platte Basin Municipal and Self-Supplied Industrial Demands



4.8.6 Water Supply Gaps

Water supply gap estimates for the five planning scenarios were calculated differently for the South Platte and Republican basins as described in Section 2 and are, therefore, presented separately. In addition, while the CDSS water allocation models used for the water supply gap analysis in the South Platte Basin are able to generate a rich set of demand, supply, and gap data, it is difficult to parse results according to the boundaries of the Metro Region and remaining South Platte Basin. As a result, water supply gaps are described for the combined Metro Region and remaining South Platte Basin.

The agricultural and M&I diversion demands were compared against available water supply modeled for current conditions and the five planning scenarios. Gaps were calculated when water supply was insufficient to meet demands.

South Platte Basin Gaps

Agricultural

The South Platte Basin agricultural diversion demands, demand gaps, and consumptive use gaps for the baseline and planning scenarios are presented in Table 4.8.10 and illustrated in Figure 4.8.18. An annual time series of gaps in terms of percent of demand that was unmet is shown in Figure 4.8.19.

Table 4.8.10 South Platte Basin Agricultural Gap Results (AFY)

		Scenario					
		Scenario	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand	2,465,800	1,988,700	1,988,700	2,157,400	1,696,500	2,063,100
	Average Annual Gap	506,700	404,900	402,100	402,100	378,300	444,000
	Average Annual Gap Increase from Baseline	-	-	-	-	-	-
	Average Annual Percent Gap	21%	20%	20%	19%	22%	22%
	Average Annual CU Gap	278,000	220,400	218,700	220,300	237,800	247,600
Maximum	Demand in Maximum Gap Year	2,982,300	2,411,200	2,411,200	2,419,700	2,006,200	2,360,900
	Gap in Maximum Gap Year	1,206,100	978,400	960,700	901,900	824,800	1,064,000
	Percent Gap in Maximum Gap Year	-	-	-	-	-	-
	Increase from Baseline Gap	40%	41%	40%	37%	41%	45%

Study period for Water Supply Analysis is 1975-2013, reflecting different baseline demand than described in Agricultural Diversion Demands section.

Figure 4.8.18 Projected Average Annual Agricultural Diversion Demand, Demand Met, and Gaps in the South Platte Basin

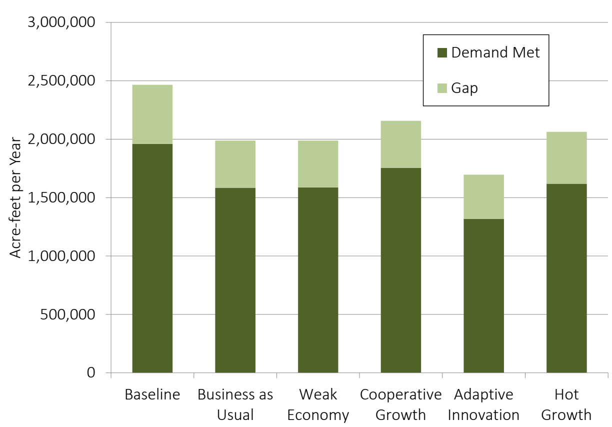
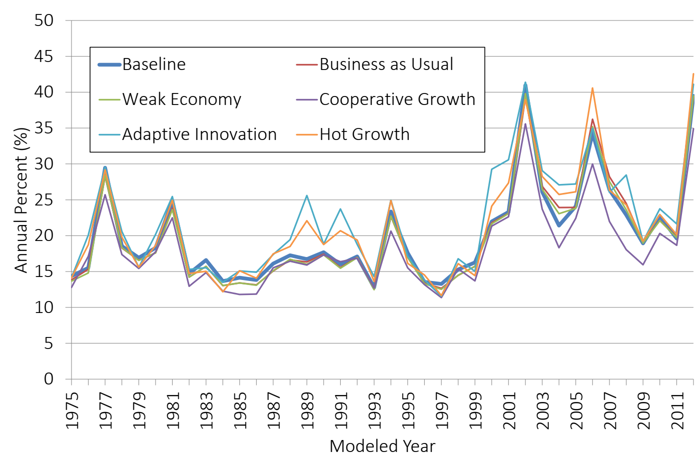


Figure 4.8.19 Annual Agricultural Gaps (expressed as a percentage of demand) for Each Planning Scenario



The following are observations on the agricultural diversion demand and gap results:

- In the South Platte Basin, the current agricultural gap is significant but is not projected to increase greatly in the future as a percentage of demand.
- On a volumetric basis, gaps are projected to decrease as agricultural diversion demands decrease, primarily from urbanization and potential conversion of agricultural water rights to municipal use.
- As shown in Figure 4.8.18, current and future agricultural gap simulation results hovered at around 15 percent of total demand in normal to wetter periods but increased during dry periods.
- In many years, the agricultural gaps in *Adaptive Innovation* and *Hot Growth* are projected to be higher than in other scenarios because of higher irrigation demands and lower supplies associated with the hot and dry future climate assumption. Overall, however, gaps in *Adaptive Innovation* are lower than *Hot Growth* because of the adoption of emerging technologies that lower demand.

M&I

The diversion demand and gap results for M&I uses in the South Platte Basin are summarized in Table 4.8.11 and illustrated in Figure 4.8.20. An annual time series of gaps in terms of percent of demand that was unmet is shown in Figure 4.8.21.

Table 4.8.11 South Platte Basin M&I Gap Results (AFY)

		Scenario					
		Scenario	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand	718,700	1,073,000	968,900	1,002,800	1,070,100	1,257,700
	Average Annual Gap	0*	192,800	136,600	159,800	221,400	390,600
	Average Annual Percent Gap	0%	18%	14%	16%	21%	31%
Maximum	Demand in Maximum Gap Year	720,000	1,074,300	970,200	1,004,100	1,070,200	1,257,700
	Gap in Maximum Gap Year	0*	256,300	184,500	213,300	333,200	540,700
	Percent Gap in Maximum Gap Year	0%	24%	19%	21%	31%	43%

**CDSS water allocation model in this basin calculates small baseline M&I gaps, but they are either due to calibration issues or they are reflective of infrequent, dry-year shortages that are typically managed with temporary demand reductions, such as watering restrictions.*

Study period for Water Supply Analysis is 1975-2013, which reflects a different baseline demand than described in M&I Demand section. Baseline demand also may vary slightly from previous section due to differences in geographic distribution of demand for counties that lie in multiple basins.

Figure 4.8.20 Projected Maximum Annual M&I Diversion Demand, Demand Met, and Gaps in the South Platte Basin

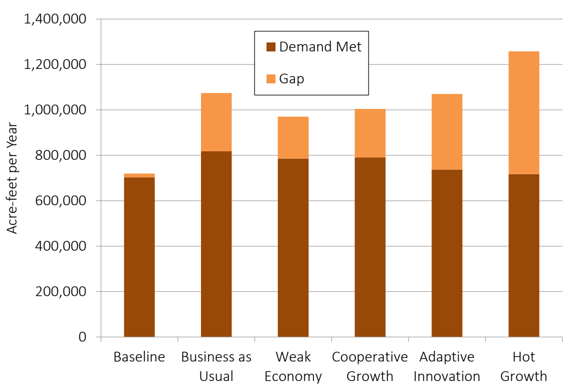
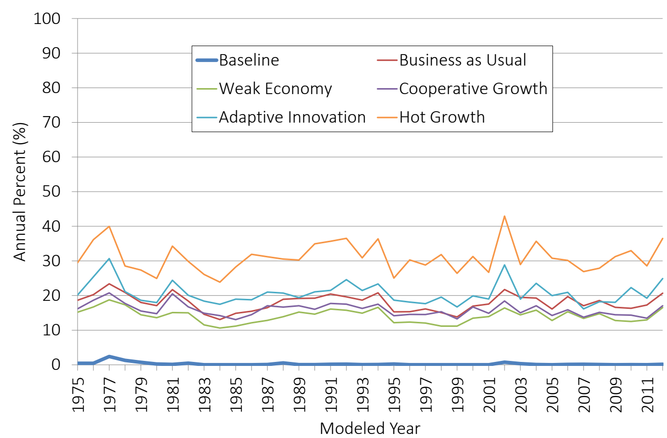


Figure 4.8.21 Annual M&I Gaps (expressed as a percentage of demand) for Each Planning Scenario



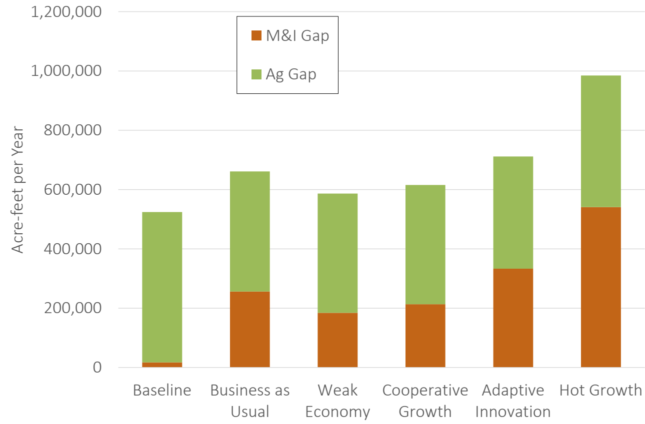
The following are observations on the M&I diversion demand and gap results:

- Gaps under *Hot Growth* are projected to be significantly higher than in other scenarios.
- *Adaptive Innovation* includes similar assumptions to *Hot Growth* in terms of future climate conditions and population projections; however, annual gaps and maximum gaps (as shown in Figure 4.8.19) are projected to be much less, which demonstrates the value of conservation. In addition, the gaps for *Business as Usual* and *Adaptive Innovation* are projected to be very similar even though *Adaptive Innovation* incorporates high population growth and a hot and dry future climate condition. The similarity in gaps suggests that additional conservation on a basinwide scale will help offset additional demands from population growth and climate change. Nonetheless, gaps in *Adaptive Innovation* are projected to be significant and point to the need for developing additional water supplies.
- The persistent nature of the time series of gaps in Figure 4.8.20 points to the need for projects that will provide firm yield.
- Figure 4.8.20 also shows that gaps can increase significantly during dry periods, especially in *Adaptive Management* and *Hot Growth* (the scenarios most severely impacted by future climate assumptions). Projects and water management strategies will be needed to meet periodic maximum M&I gaps.

Total Gap

Figure 4.8.22 illustrates the total combined agricultural and M&I diversion demand gap in the South Platte Basin. The figure combines the average annual agricultural gaps and the maximum M&I gap. Note that agricultural gaps are projected to decrease in the future, and therefore an incremental gap is not shown in the figure.

Figure 4.8.22 Projected Average Annual Agricultural Gaps and Maximum M&I Diversion Demand Gaps in the South Platte Basin.



Supplies from Urbanized Lands and Planned Transfers

The planning scenarios assumed between 127,100 and 169,600 acres of irrigated agricultural land will be urbanized or no longer irrigated because of planned water right transfers from agricultural to municipal use in the South Platte Basin. Irrigation supplies for urbanized lands could potentially be used for M&I needs in the future (subject to a variety of unknowns such as seniority and type of water supply, willingness to change the use of water through water court, etc.). Acreage associated with planned transfers was derived based on stakeholder input.

The average annual historical consumptive use associated with potentially urbanized acreage and planned water right transfers for each scenario is reflected in Table 4.8.12. The data in Table 4.8.12 represents planning-level estimates of this potential supply and has not been applied to the M&I gaps. The data in the table do not represent supplies from permanent water transfers that may be considered by a basin roundtable as a future strategy to meet gaps (note that SWSI 2010 included estimates of permanent transfers beyond those currently planned as a strategy for meeting potential future M&I gaps).

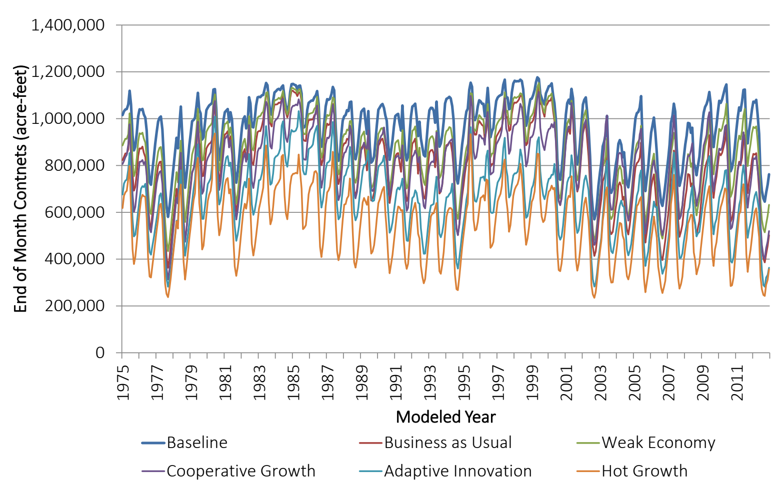
Table 4.8.12 Estimated Consumptive Use from Lands Projected to be Urbanized by 2050 and Planned Transfers in the South Platte Basin

	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Urbanized Acreage and Lands Subject to Planned Transfers (acres)	148,400	148,400	127,100	127,100	169,600
Estimated Consumptive Use (AFY)	209,800	210,200	179,400	172,700	238,600

Storage

Total reservoir storage output from the South Platte water allocation model is shown on Figure 4.8.23. Baseline conditions show the highest levels of water in storage (in general) and the lowest is in *Hot Growth*. *Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth* show lower amounts of water in storage than the two scenarios that do not include the impacts of a drier climate. The results indicate that, without new projects, higher demands will draw storage down to lower levels. Concurrent drier conditions will impede full recovery of reservoirs. Lower demands in *Adaptive Innovation* help reservoir levels stay somewhat higher than in *Hot Growth*. It should be noted that the water allocation model allows reservoirs to be drawn down to the full extent water rights and storage amounts allow. Water providers would likely not be comfortable operating with chronically lower amounts of water in storage and would seek to acquire additional supplies or build new projects to boost reserves.

Figure 4.8.23 South Platte Basin Total Reservoir Storage (not including Water District 3)



Republican Basin Gaps

Agricultural

The Republican Basin agricultural diversion demands, demand gaps, and consumptive use gaps for the baseline and planning scenarios are presented in Table 4.8.13 and illustrated in Figure 4.8.24.

Table 4.8.13 Republican Basin Agricultural Gap Results (AFY)

		Scenario					
		Scenario	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand	1,067,200	805,500	807,500	835,300	797,200	885,800
	Average Annual Gap	266,800	201,400	201,900	208,800	199,300	221,400
	Average Annual Gap Increase from Baseline	-	-	-	-	-	-
	Average Annual Percent Gap	25%	25%	25%	25%	25%	25%
	Average Annual CU Gap	211,400	159,800	160,200	165,700	161,600	179,600
Maximum	Demand in Maximum Gap Year	1,445,200	1,113,000	1,114,700	1,113,200	1,014,400	1,127,100
	Gap in Maximum Gap Year	361,300	278,300	278,700	278,300	253,600	281,800
	Increase from Baseline Gap	-	-	-	-	-	-
	Percent Gap in Maximum Gap Year	25%	25%	25%	25%	25%	25%

Study period for Water Supply Analysis is 1975-2013, reflecting different baseline demand than described in Agricultural Diversion Demands section.

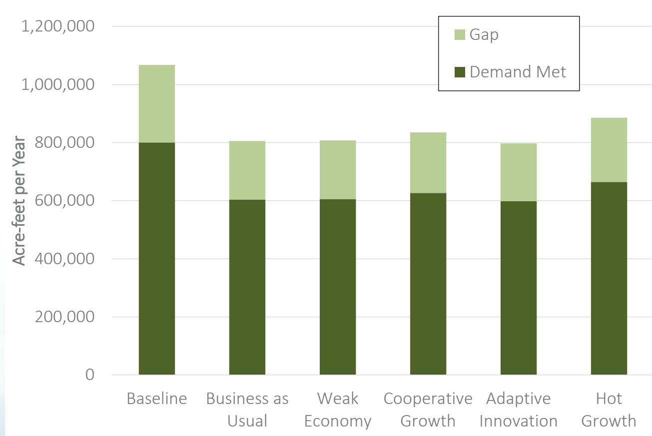
The following are observations on agricultural diversion demands and gaps:

- Both diversion demands and gaps will likely decrease in the future due to reduction of irrigated lands in order to comply with the Republican River Compact and also as a result of declining water levels in the High Plains Aquifer.
- Even with reduced demand, reduced supplies will result in a fairly consistent gap in the future of approximately 25 percent of demand.

INCREMENTAL GAP

The incremental agricultural gap quantifies the degree to which the gap could increase beyond what agriculture has historically experienced under water shortage conditions.

Figure 4.8.24 Projected Average Annual Agricultural Diversion Demand, Demand Met, and Gaps in the Republican Basin



M&I

The diversion demand and gap results for M&I uses in the Republican Basin are summarized Table 4.8.14 and illustrated in Figure 4.8.25.

Table 4.8.14 Republican Basin M&I Gap Results (AFY)

		Scenario					
		Scenario	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand	8,400	9,200	7,900	8,100	8,900	11,200
	Average Annual Gap	-	1,300	-	-	1,100	3,300
	Average Annual Percent Gap	0%	14%	0%	0%	12%	30%
Maximum	Demand in Maximum Gap Year	8,400	9,200	7,900	8,100	8,900	11,200
	Gap in Maximum Gap Year	-	1,300	-	-	1,100	3,300
	Percent Gap in Maximum Gap Year	0%	14%	0%	0%	12%	30%

Total Gap

Figure 4.8.26 illustrates the total combined agricultural and M&I diversion demand gap in the Republican Basin. The figure combines the average annual agricultural gaps and the maximum M&I gap. Note that agricultural gaps are projected to decrease in the future, and therefore an incremental gap is not shown in the figure.

Supplies from Urbanized Lands

The planning scenarios assumed 1,400 acres of irrigated agricultural land will be urbanized in the Republican Basin. Irrigation supplies for these lands could potentially be used for M&I needs in the future (subject to a variety of unknowns such as seniority and type of water supply, willingness to change the use of water through water court, etc.). The average annual historical consumptive use associated with potentially urbanized acreage for each scenario is reflected in Table 4.8.15. The data in Table 4.8.15 represents planning-level estimates of this potential supply and has not been applied to the M&I gaps.

Figure 4.8.25 Projected Maximum Annual M&I Demand Met and Gaps in the Republican Basin

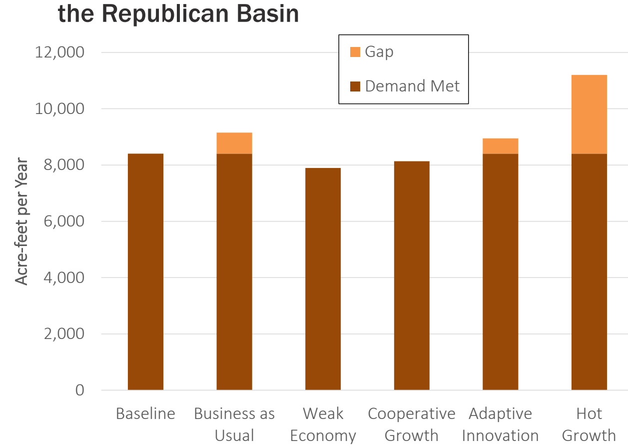


Figure 4.8.26 Projected Average Annual Agricultural Gaps and Maximum M&I Diversion Demand Gaps in the Republican Basin.

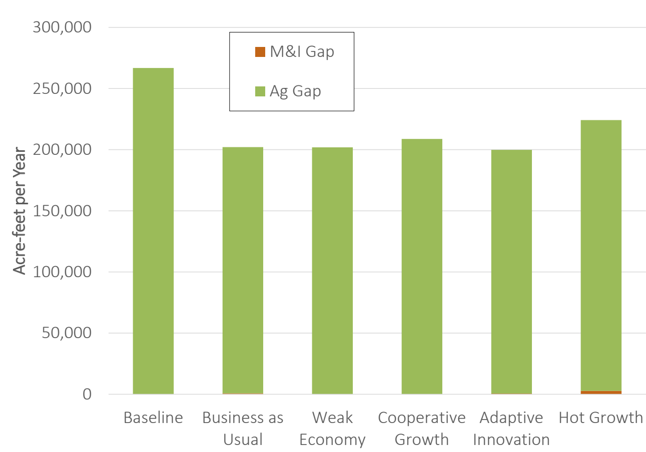


Table 4.8.15 Estimated Consumptive Use from Lands Projected to be Urbanized by 2050 in the Republican Basin

	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Urbanized Acreage (acres)	1,400	-	1,400	1,400	1,400
Estimated Consumptive Use (AFY)	1,500	-	1,600	1,600	1,700

Combined South Platte and Republican Basin Gaps

Table 4.8.16 summarizes the total M&I and agricultural demands in the South Platte and Republican Basins along with a summary of gaps. It should be noted that the South Platte and Republican basins were assessed independently; some of the results from each basin may not be wholly additive in some circumstances. For example, the maximum M&I gap may not occur in the same year in each sub-basin. As a result, the basin as a whole may not experience a year in the future when the total maximum M&I gap corresponds to the sum of the maximum gaps in both sub-basins; however, the sum of the maximum sub-basin gaps does describe the total amount of water that would be needed to fully satisfy all M&I demands in each individual sub-basin, even if the gaps do not simultaneously occur in the sub-basins.

Table 4.8.16 Summary of Total South Platte and Republican Basin Demands and Gaps

	Current (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average Annual Diversion Demand						
Agricultural (AFY)	3,533,000	2,794,200	2,796,100	2,992,700	2,493,700	2,948,900
M&I (AFY)	727,100	1,082,200	976,800	1,010,900	1,079,100	1,268,900
Gaps						
Ag (avg %)	22%	22%	22%	20%	23%	23%
Ag (incremental-AFY)	-	-	-	-	-	-
Ag (incremental gap as % of current demand)	-	-	-	-	-	-
M&I (max %)	0%	24%	19%	21%	31%	43%
M&I (max-AF)	0*	257,100	184,500	213,300	333,700	543,500

**CDSS water allocation model in this basin calculates small baseline M&I gaps, but they are either due to calibration issues or they are reflective of infrequent, dry-year shortages that are typically managed with temporary demand reductions, such as watering restrictions.*

4.8.7 Available Supply

Figures 4.8.27 through 4.8.30 show simulated available at two locations on the South Platte River, the South Platte River at Denver and South Platte River at Kersey. The Denver location, upstream of the Burlington Ditch, is the primary calling right on the mainstem of the Upper South Platte River. The Kersey gage reflects the impact to available flow downstream of the confluence, with the Cache La Poudre River and the Lower South Platte River calling rights for storage and irrigation. Available flow at both locations is generally only available during high flow years and for relatively short periods of time. In scenarios with impacts of climate change, available flows are projected to diminish, and peak flows are projected to occur earlier in the runoff season.

Figure 4.8.27 Simulated Hydrographs of Available Flow at South Platte River at Denver

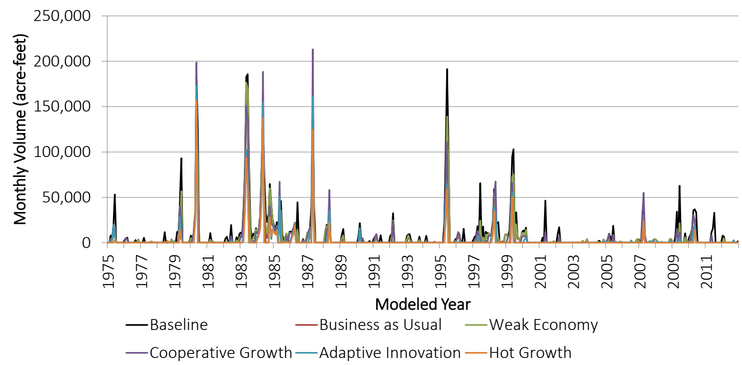


Figure 4.8.28 Average Monthly Simulated Hydrographs of Available Flow at South Platte River at Denver

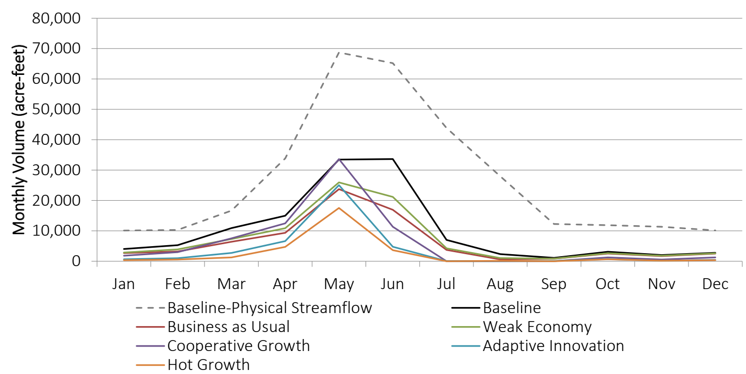


Figure 4.8.29 Simulated Hydrographs of Available Flow at South Platte River at Kersey, CO

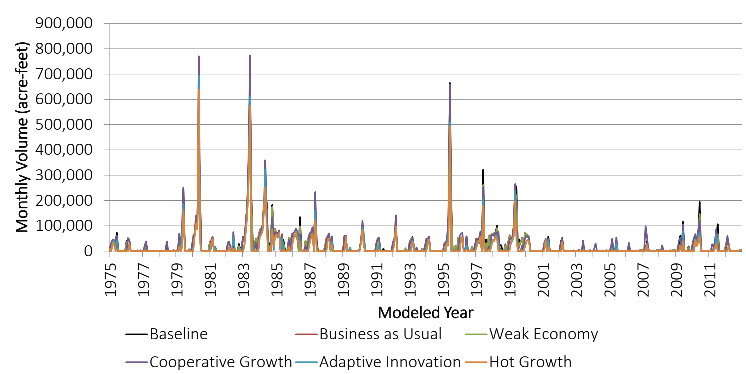
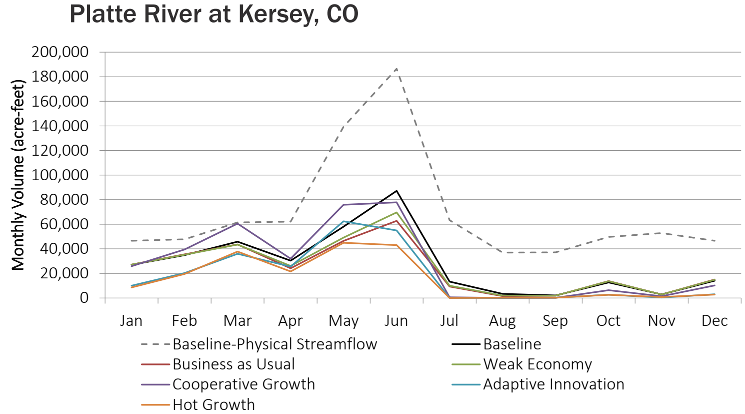


Figure 4.8.30 Average Monthly Simulated Hydrographs of Available Flow at South Platte River at Kersey, CO



4.8.8 Environment and Recreation

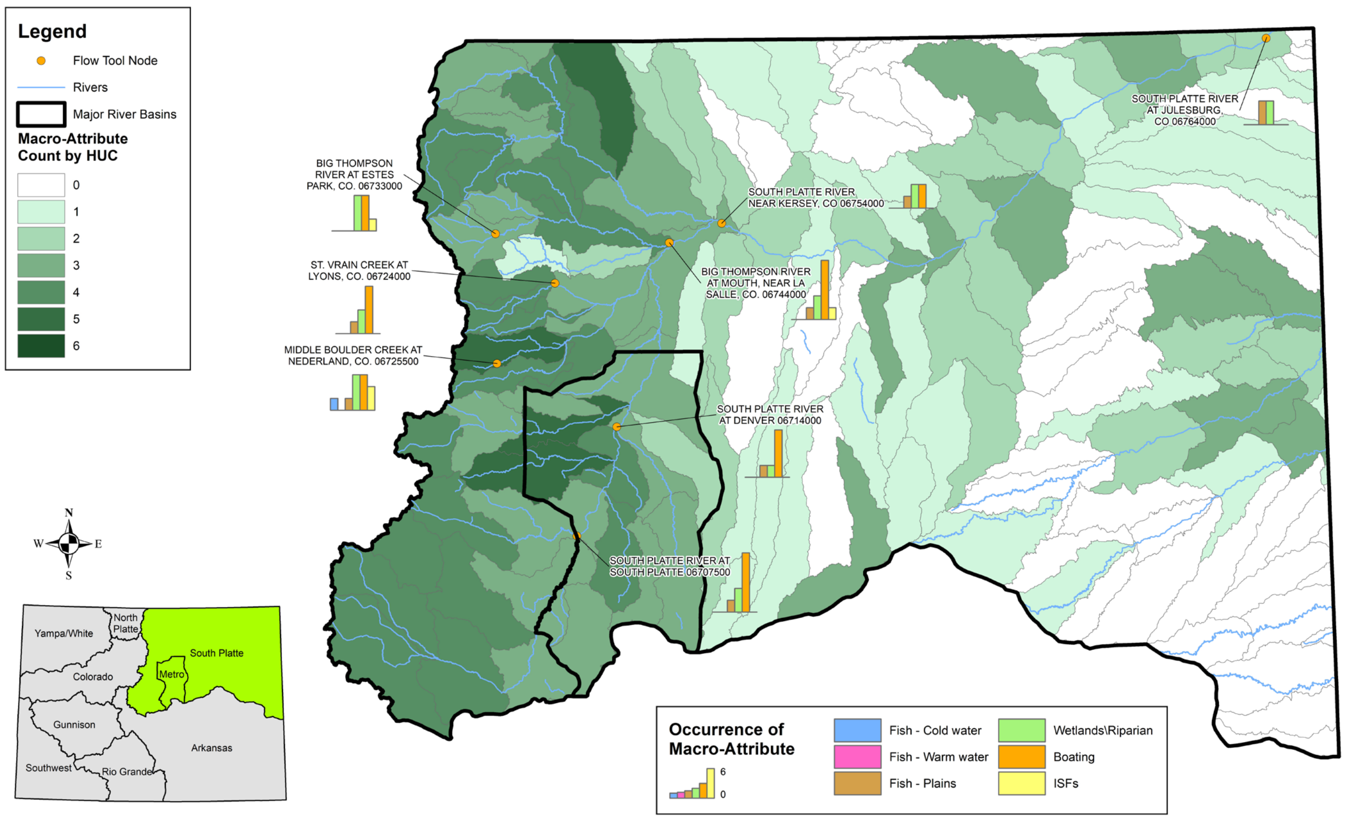
A total of eight water allocation model nodes were selected for the Flow Tool within the South Platte Basin (see list below and Figure 4.8.31). Figure 4.8.31 also shows subwatersheds (at the 12-digit HUC level) and the relative number of E&R attributes located in each subwatershed.

- South Platte River at South Platte (06707500)
- South Platte River at Denver (06714000)
- St Vrain Creek at Lyons, Colorado (06724000)
- Middle Boulder Creek at Nederland, Colorado (06725500)
- Big Thompson River at Estes Park, Colorado (06733000)
- Big Thompson River at Mouth, near La Salle, Colorado (06744000)
- South Platte River near Kersey, Colorado (06754000)
- South Platte River at Julesburg, Colorado (06764000)

NATURALIZED FLOW

Naturalized flows reflect conditions that would occur in the absence of human activities. Baseline flows reflect current conditions as influenced by existing infrastructure and river operations. While observations regarding naturalized flows may be informative, baseline flows reflect actual conditions and the diverse operations of a river's many users.

Figure 4.8.31 Flow Tool Nodes Selected for the South Platte Basin



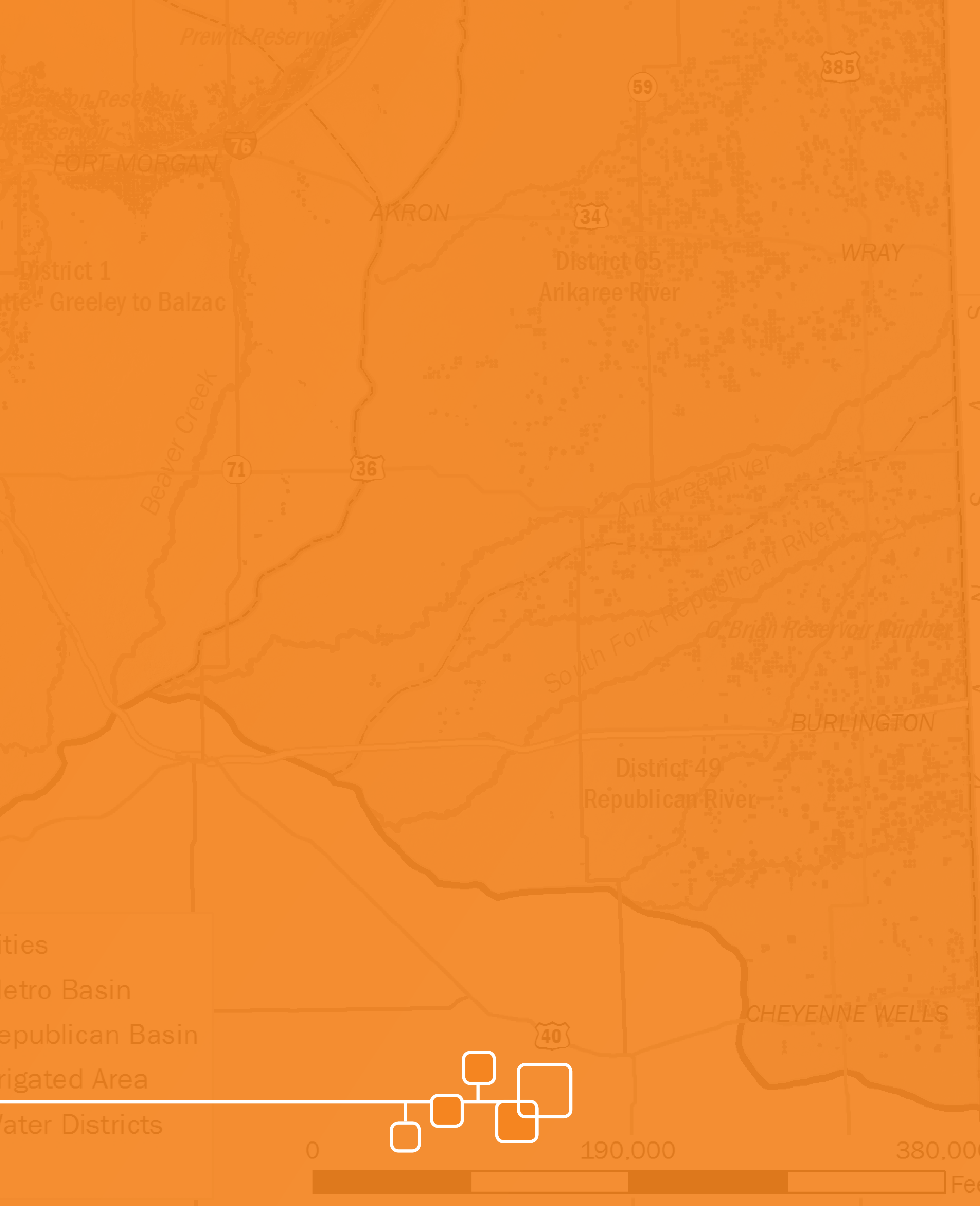
Results and observations from Flow Tool analyses using flow data developed in the water supply and gap analyses for baseline conditions and the planning scenarios are described in Table 4.8.17 below.

Table 4.8.17 Summary of Flow Tool Results in the South Platte Basin

Category	Observation
Projected Flows	Patterns of peak flows are highly variable across locations in the basin.
	Baseline flow patterns diverge the most from naturalized conditions in the Foothills and on the Plains.
	The magnitude of flows on the South Platte in Denver in May and June (historically the months of peak runoff) under baseline conditions are reduced from naturalized conditions, and the divergence from naturalized conditions increases as the South Platte flows through Julesburg. In these locations, peak flow magnitude under the various future scenarios is projected to increase, stay the same, or decrease further depending on location.
	In the mountains (e.g., South Platte River at South Platte, Middle Boulder Creek at Nederland), baseline peak flow magnitudes are only minimally below naturalized peak flow magnitude. Projected changes to peak flow magnitude in these mountain locations also vary depending on location, with minimal changes to peak flow magnitude in some locations and larger declines elsewhere.
	Mountain locations demonstrate a projected pattern under the climate change scenarios where the timing of peak flows shifts earlier in the year, from June to May. The change in timing for peak flows may result in mismatches between peak flow timing and species' needs.
	Mid- and late-summer flows are also highly variable across locations in the basin. On the plains, baseline low flows vary in range below naturalized conditions.
	Under future scenarios, this range is expected to further departed from naturalized conditions in climate-impacted scenarios (*Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth*) causing the greatest decline in flows.
	In the mountains, climate change scenarios may cause a decline in low flows (e.g., Middle Boulder Creek at Nederland), while in other areas (e.g., South Platte River at South Platte) declines may be less pronounced due to transbasin imports and releases of stored water.
Ecological Risk	In the Foothills and on the Plains, especially east of Interstate 25, decreased peak flow magnitudes under baseline conditions and all future scenarios may put many aspects of ecosystem function (e.g., over-bank flooding to support riparian plants, sediment transport to maintain fish habitat) at risk. Projected changes to mid- and late-summer flows may also create risk for plains fishes.
	In the mountains, peak flow and low flows generally create low to moderate risk for riparian plants and fish, although these risks may increase under climate change scenarios.
ISFs and RICDs	There are numerous ISF reaches in the mountains and foothills, and several RICDs in the South Platte Basin. The location of modeled flow points does not allow specific insight into what future scenarios imply for these locations, but the general pattern of diminished flows, especially diminished flows under climate change scenarios, suggests that the flow targets for ISFs and RICDs may be met less often.
E&R Attributes	Increasing risk to E&R attributes arise from several sources. Changes in flow timing through water management (e.g., storage of peak flows) can reduce ecosystem functions that are dependent on high flows (e.g., sediment transport) and can reduce boating opportunities. Changes in timing under climate change scenarios (early peak flow) can also increase risk for ecosystems and species.
	Under all scenarios in most locations, ecological and recreational risk may be increased by depletions from increasing human water consumption and decreasing supply under a changing climate. Water management (e.g., reservoir releases) has the potential to mitigate negative impacts.

The San Juan River, Dolores River, and San Miguel River Basins are located in the southwest corner of Colorado and cover an area of approximately 10,169 square miles. The Upper San Juan River and its tributaries flow through two Native American reservations in the southern portion of the basin—the Ute Mountain Ute Reservation and the Southern Ute Indian Reservation. The Southwest Basin is a series of nine sub-basins, eight of which flow out of state before they join the San Juan River in New Mexico or the Colorado River in Utah. The Colorado River Compact, the Colorado Ute Indian Water Rights Settlement, and several Bureau of Reclamation storage projects have shaped the water history of the Southwest Basin.

SOUTHWEST



Prewitt Reservoir
FORT MORGAN
76
AKRON
34
59
385
WRAY
District 1
Greeley to Balzac
District 65
Arikaree River
Beaver Creek
71
36
Arikaree River
South Fork Republican River
BURLINGTON
District 49
Republican River
CHEYENNE WELLS
40
0
190,000

4.9 SOUTHWEST BASIN RESULTS

4.9.1 BASIN CHALLENGES

The Southwest Basin will face several key issues and challenges to balance valued agricultural uses with instream water to support recreational and environmental values, all of which combine to support the economic and aesthetic values that drive settlement and commerce in the Southwest Basin. In addition, water quality is a significant concern in the Southwest Basin. These issues were described in the Colorado Water Plan and are summarized below.

Table 4.9.1 Key Future Water Management Issues in the Southwest Basin

Agriculture	Environment and Recreation	Municipal and Industrial	Compacts and Administration
• The Cortez and Dove Creek area remains strongly agricultural, supplemented by energy production. It is also seeing growth through an increase in retirees moving to the area.	• US Forest Service and Bureau of Land Management have worked with the CWCB Instream Flow Program to secure substantial flow protection at high elevations throughout the basin. As stream-flow protections have increasingly focused on lower elevation streams that are below stored water and communities, instream flow appropriations have become more complex and challenging.	• The Pagosa Springs-Bayfield-Durango corridor is rapidly growing while experiencing areas of localized water shortages. This area is transitioning from oil and gas, mining, and agricultural use to tourism and recreation use, and to a retirement or second-home area. • Another challenge is the development of sufficient infrastructure to deliver M&I water where it is needed. There is also discussion regarding new storage to meet long-term supply requirements in the Pagosa Springs area, as well as in Montrose County.	• In addition to the three compacts governing water use across the broader Colorado Basin, other compacts, settlements, and species-related issues are specific to the San Juan/ Dolores/San Miguel region.
• The San Miguel area shows a mix of recreation and tourism activities, along with a strong desire to maintain agriculture in the western part of the county.			

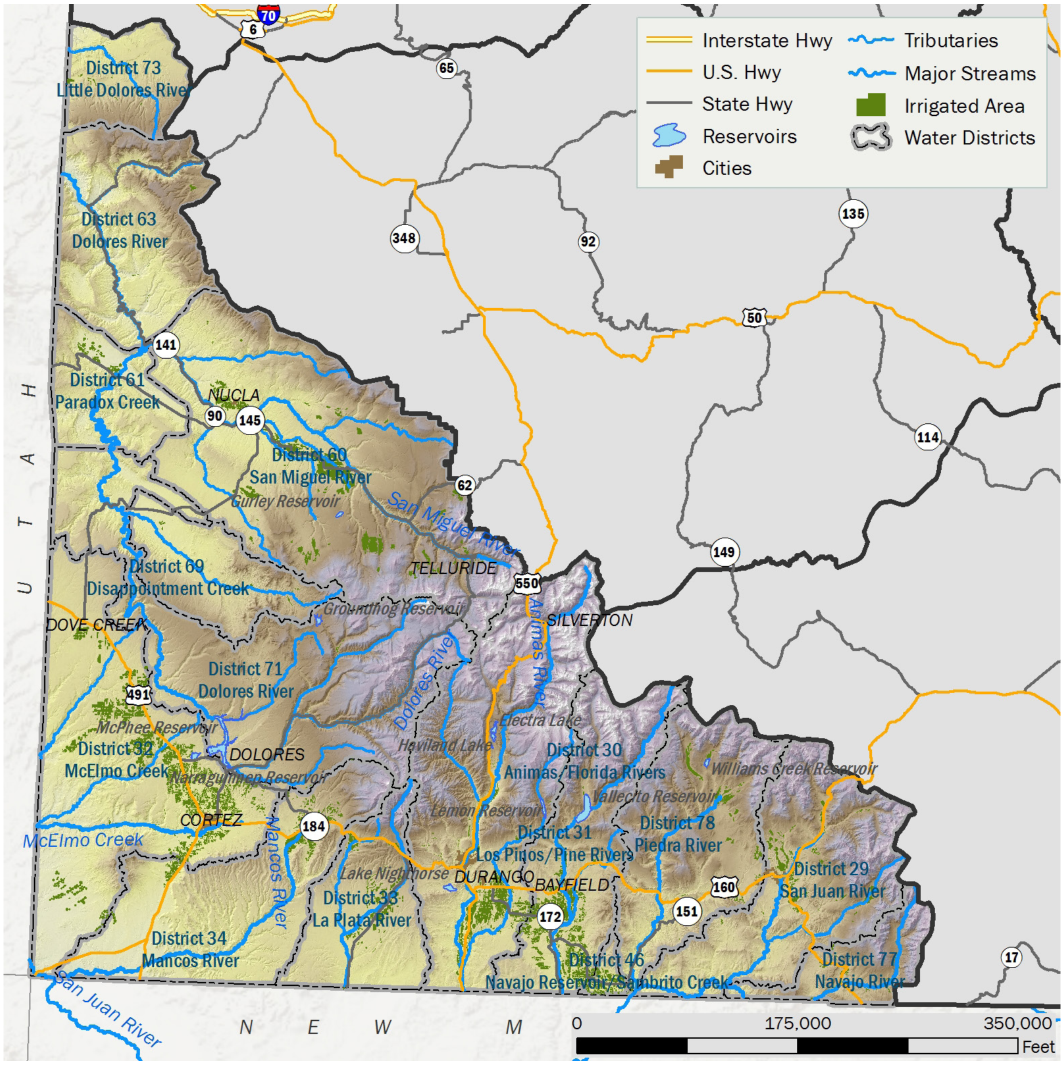


Figure 4.9.1 Map of the Southwest Basin

4.9.2 SUMMARY OF TECHNICAL UPDATE RESULTS

Key results and findings of the Technical Update pertaining to agricultural and M&I demands and gaps as well as findings related to environmental and recreational attributes and future conditions are summarized below.

Table 4.9.2 Summary of Key Results in the Southwest Basin

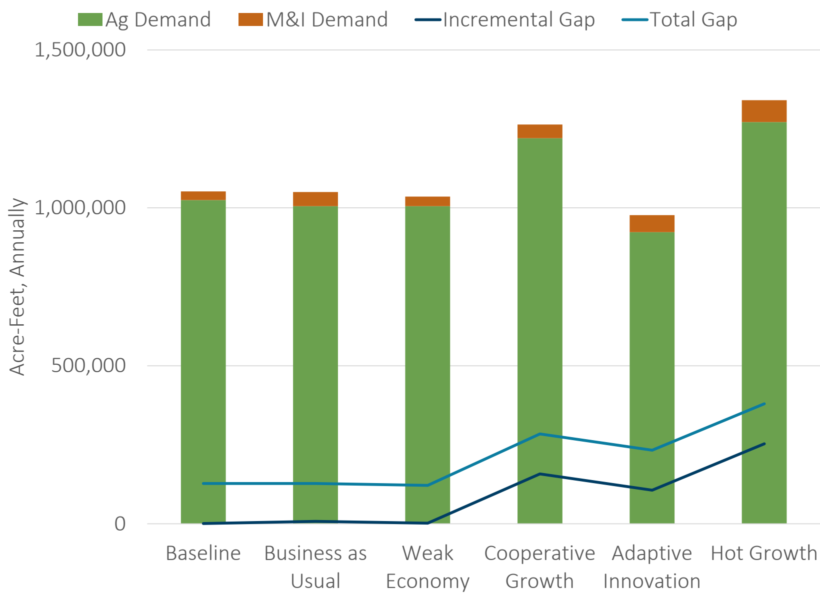
Agriculture	Environment and Recreation	Municipal and Industrial
• Warmer and drier climate conditions in Cooperative Growth, Adaptive Innovation and *Hot Growth* will lead to higher IWR and gaps. • Incorporation of emerging technologies in Adaptive Innovation are projected to help maintain demands and gaps at lower levels than *Hot Growth* despite similar assumptions regarding future climate conditions.	• In locations that are minimally depleted under baseline conditions, peak flows may remain adequate for riparian/ wetlands and fish habitat, but timing mis-matches may occur. • In all locations, mid- and late-summer flows may be substantially reduced, creating high risk for coldwater and warmwater fish.	• Relatively large increases in population could create higher M&I demands and gaps in Adaptive Innovation and *Hot Growth*. • Thermoelectric demands drive a modest increase in SSI demand. • Future per capita demands are projected to decrease in all but *Hot Growth*.

Table 4.9.3 Summary of Diversion Demand and Gap Results in the Southwest River Basin

	Current (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average Annual Demand						
Agricultural (AFY)	1,024,800	1,005,400	1,005,400	1,220,500	923,100	1,271,700
M&I (AFY)	27,200	44,800	30,200	43,300	54,000	69,500
Gaps						
Ag (avg %)	12%	12%	12%	23%	24%	28%
Ag (incremental-AFY)	-	-	-	150,100	92,400	228,400
Ag (incremental gap as % of current demand)	-	-	-	15%	9%	22%
M&I (max %)	0%	17%	6%	18%	26%	36%
M&I (max-AF)	0*	7,500	1,800	7,700	13,800	24,800

* *CDSS water allocation model in this basin calculates small baseline M&I gaps, but they are either due to calibration issues or they are reflective of infrequent, dry-year shortages that are typically managed with temporary demand reductions such as watering restrictions.*

Figure 4.9.2 Summary of Diversion Demand and Gap Results in the Southwest Basin



Summary of Environment and Recreation Findings

- In locations that are minimally depleted under baseline conditions (e.g., the San Miguel River), peak flows may remain adequate for riparian/wetlands and fish habitat, with March-May flows increasing substantially while June flows decrease; possible mis-matches between peak flow timing and species needs may occur.
- In some locations peak flows under baseline conditions indicate high risk to riparian/wetlands and fish habitat, and risk may increase in *Cooperative Growth, Adaptive Innovation*, and *Hot Growth*.
- In all locations, mid- and late-summer flows are projected to be substantially reduced (50 to 80 percent) under *Cooperative Growth, Adaptive Innovation*, and *Hot Growth*, creating high risk for coldwater and warmwater fish. Even on rivers where the baseline condition is low-risk for summer flows, future scenarios may see risks increase substantially. The risk expressed in the coldwater and warmwater fish metrics does not include July because historically July flows are sufficient; however, in some locations, July flows may be reduced (e.g., July flows on the Piedra River near Arboles could be by reduced 84 percent), which could result in much-reduced habitat and high stream temperatures.
- Instream Flow water rights in the Southwest and the Recreational In-Channel Diversion on the Animas River often will likely not be fully met under *Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth*.

4.9.3 NOTABLE BASIN CONSIDERATIONS

Section 4.1 described several analysis assumptions and limitations that apply to all basins and should be considered when reviewing and interpreting analysis results. Additional considerations specific to the Southwest Basin are listed below:

- The full development of tribal reserved water rights is not represented in the models for several reasons. The Tribal Water Study was completed in December of 2018, which was after the agricultural and M&I demands for the Technical Update were completed. In addition, full use of the reserved rights are not projected to occur by 2050, which is the planning time period contemplated in the current Technical Update. It should be noted that Tribal water use through 2050 is included in the M&I projections in each planning scenario; however, similar to other future M&I demands, it has been grouped with other M&I demands and included in the water allocation model at representative locations in each water district. Basin roundtables can take a different look at how tribal rights are used when they update their BIP.
- Water availability in the various sub-basins in the Southwest Basin can be drastically different. The differences in sub-basin water availability and gaps may not be evident at a basinwide scale due to the aggregated reporting of results in the Technical Update; however, models developed for the Technical Update reflect the variation in sub-basin results and are available for sub-basin specific evaluations that could be conducted in the Basin Implementation Plan update.

4.9.4 AGRICULTURAL DIVERSION DEMANDS

Agricultural Setting

The Southwest Basin is made up of a series of nine sub-basins, each with their own unique hydrology and demands. The basin is home to a diverse set of demands; several small towns founded primarily due to either mining or agricultural interests, two Native American reservations (Southern Ute Indian Tribe and Ute Mountain Ute Tribe), one major transbasin diversion (San Juan–Chama Project)[13], and four major Reclamation projects (Pine River, Dolores, Florida and Mancos) that both brought new irrigated acreage under production and provided supplemental supplies to existing lands. For areas outside of the Reclamation rojects, producers generally irrigate grass meadows for cattle operations aligned along the rivers and tributaries and rely on supplies available during the runoff season. Producers under the Reclamation Projects irrigate a wider variety of crops, such as alfalfa and row crops, due to lower elevations, warmer temperatures, and supplemental storage supplies during the later irrigation season.

Planning Scenario Adjustments

Urbanization in the basin will likely have a limited impact on agriculture in the future. Only 4,080 acres of irrigated land basin-wide were estimated to be urbanized by 2050. The larger towns of Durango, Cortez, and Pagosa Springs do not have significant areas of irrigated acreage located within or directly adjacent to the current municipal boundaries, and urbanization of acreage in these areas is projected to be low in the future. Smaller towns in the basin, such as Norwood, Nucla, Bayfield, and Mancos are surrounded by irrigated agriculture, which may lead to some urbanization of irrigated lands by 2050.

Table 4.9.4 summarizes the planning scenario adjustments described above and other adjustments that impact agricultural diversion demands in the various scenarios.

Table 4.9.4 Planning Scenario Adjustments for Agricultural Demands in the Southwest Basin

Adjustment Factor*	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Change in Irrigated Land due to Urbanization	3,800 Acre Reduction	3,800 Acre Reduction	3,800 Acre Reduction	3,800 Acre Reduction	3,800 Acre Reduction
IWR Climate Factor	-	-	26%	34%	34%
Emerging Technologies	-	-	-	10% IWR Reduction 10% System Efficiency Increase	-

** See section 2.2.3 for descriptions of adjustment methodologies and assumptions*

Agricultural Diversion Demand Results

Table 4.9.5 and Figure 4.9.3 summarize the acreage, IWR, and the agricultural diversion demand for surface water supplies in the Southwest Basin for current conditions and the five planning scenarios. Increased demands were projected for *Cooperative Growth* and *Hot Growth*, reflecting the impacts of climate change, without the benefit of increased efficiencies reflected in *Adaptive Innovation*.

Table 4.9.5 Summary of Agricultural Diversion Demand Results in the Southwest Basin

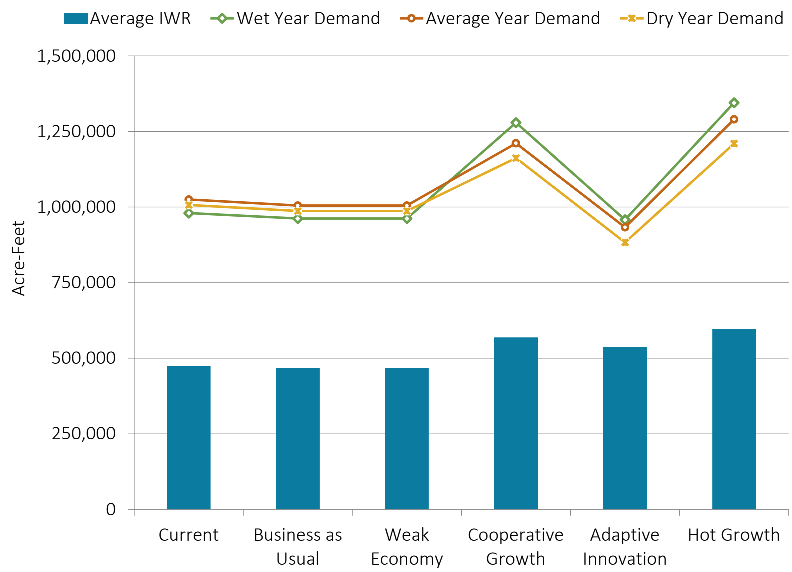
	Current (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Irrigated Acreage (acres)	222,500	218,800	218,800	218,800	218,800	218,800
Average IWR (AFY)	474,900	467,000	467,000	569,000	537,000	597,000
Total Surface and Groundwater Diversion Demand						
Average Year (AFY)	1,025,000	1,005,000	1,005,000	1,211,000	933,000	1,290,000
Wet Yr. Change	-4%	-4%	-4%	6%	3%	4%
Dry Yr Change	-2%	-2%	-2%	-4%	-5%	-6%

Average agricultural diversion demand was calculated using the average hydrologic years (i.e., years classified as neither wet or dry) from 1950-2013

SYSTEM EFFICIENCY

In some cases, diversion demands can be higher in wet years because system efficiency decreases due to the relative abundance of supply.

Figure 4.9.3 Agricultural Diversion Demands and IWR Results in the Southwest Basin



4.9.5 Municipal and Self-Supplied Industrial Diversion Demands

Population Projections

The Southwest Region currently includes about 2 percent of the statewide population. Between the years 2015 and 2050, it is projected to grow from approximately 110,000 to between 130,000 and 280,000 people in the low and high growth projections, respectively, which is an increase in population of 16 to 161 percent. On a percentage basis, the Southwest Basin has the largest projected increase of all basins throughout the state. Table 4.9.6 shows how population growth is projected to vary across the planning scenarios for the Southwest Basin.

Table 4.9.6 Southwest Basin Baseline and Projected Populations

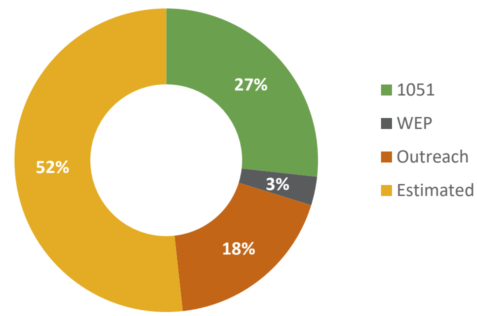
Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
107,999	195,837	125,814	201,010	264,189	282,144

Current Municipal Demands

Sources of water demand data such as 1051 or WEP data made up less than half of the available information in the Southwest Basin, and baseline water demands were largely estimated as shown in Figure 4.9.4.

Figure 4.9.5 summarizes the categories of municipal, baseline water usage in the Southwest Basin. On a basin scale, the non-residential outdoor demand as a percentage of the systemwide demand is one of the lowest reported throughout the state, at approximately 9 percent. Conversely, the baseline non-revenue water demand is one of the highest statewide, at approximately 15 percent of the systemwide demands.

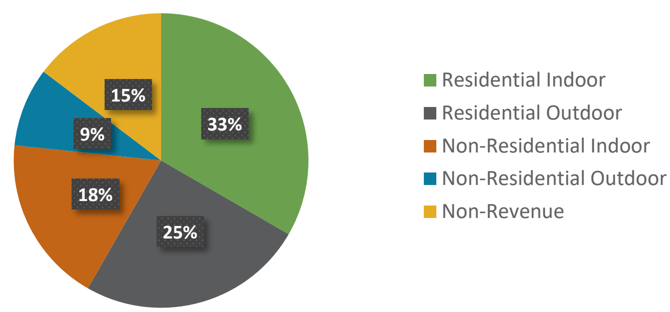
Figure 4.9.4 Sources of Water Demand Data in the Southwest Basin



DECREASING GPCD

The Southwest Region average baseline per capita systemwide demand has increased from 183 gpcd in SWSI 2010 to approximately 198 gpcd.

Figure 4.9.5 Categories of Water Usage in the Southwest Basin



Projected Municipal Demands

Figure 4.9.6 provides a summary of per capita baseline and projected water demands for the Southwest Basin. Systemwide, the projected per capita demands decrease relative to the baseline except for *Hot Growth,* which has a similar systemwide per capita demand as the baseline, but the demand category distributions are different. The residential indoor demand is the greatest demand category in the baseline, but the residential outdoor demand exceeds the residential indoor demand in the all of the projections except for *Weak Economy*. Outdoor demands increased significantly for *Hot Growth* due to an increase in outdoor demands driven by the "Hot and Dry" climate factor (described in Section 2).

The Southwest Basin municipal baseline and projected demands are provided in Table 4.9.7, showing the combined effect of population and per capita demands. Municipal demands are projected to grow from approximately 24,000 AFY in 2015 to between 26,000 and 63,000 AFY in 2050. La Plata County accounts for nearly half of the baseline demand, followed by Montezuma County at just under one-third of the basin demand.

The baseline and projected demand distributions shown in Figure

Figure 4.9.6 Southwest Basin Municipal Baseline and Projected Per Capita Demands by Water Demand Category (gpcd)

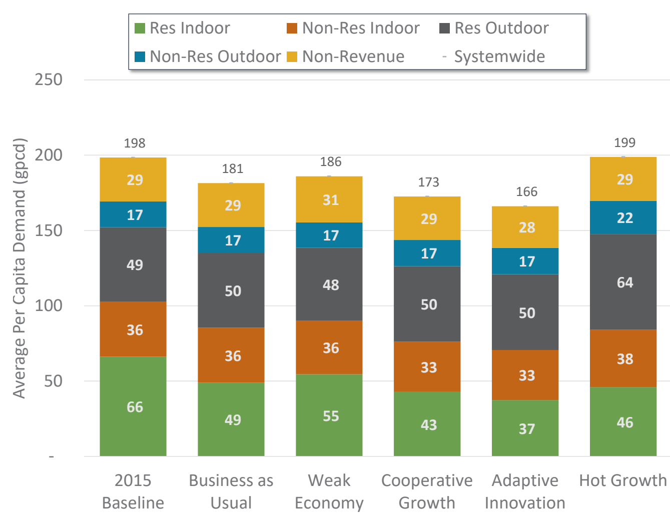


Table 4.9.7 Southwest Basin Municipal Baseline and Projected Demands (AFY)

Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
24,009	39,810	26,214	38,864	49,164	62,851

4.9.7 also show how the population varies between the scenarios. All of the planning scenarios except for *Weak Economy* result in a significant increase relative to the baseline. Demands generally follow the population patterns, however increased outdoor demands for the “Hot and Dry” climate condition have a greater impact on gpcd, resulting in higher demands for *Hot Growth*.

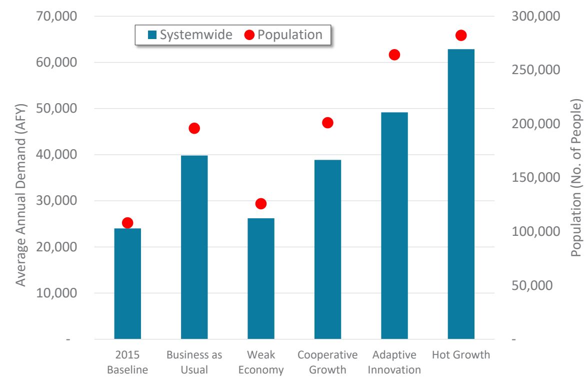


Figure 4.9.7 Southwest Basin Baseline and Projected Population and Municipal Demands

Self-Supplied Industrial Demands

The Southwest Basin currently includes about 1 percent of the statewide SSI demand. SSI demands in this basin are associated with the snowmaking and thermoelectric sub-sectors, with no demands projected for large industry or energy development sub-sectors. Southwest region total SSI demands are shown in Figure 4.9.8 and summarized in Table 4.9.8.

The baseline snowmaking demand is 430 AFY as compared to 410 AFY in SWSI 2010. Projected demands remain at 430 AFY because there is no planned expansion of snowmaking acreage. Projected demands were not varied by scenario.

Thermoelectric demands are related to one facility located in Montrose County and were based on information in SWSI 2010. The baseline demand remains 1,850 AFY as represented in SWSI 2010. Projected thermoelectric demands range from 3,510 AFY to 4,290 AFY.

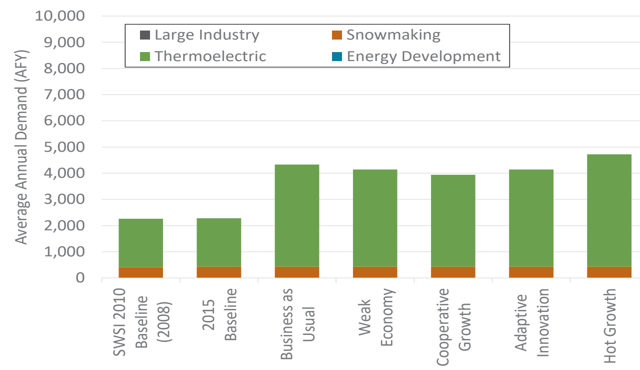


Figure 4.9.8 Southwest Basin Self-Supplied Industrial Demands

Table 4.9.8 Southwest Basin SSI Baseline and Projected Demands (AFY)

Sub-sector	Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Large Industry	-	-	-	-	-	-
Snowmaking	430	430	430	430	430	430
Thermoelectric	1,850	3,900	3,710	3,510	3,710	4,290
Energy Development	-	-	-	-	-	-
Sub-Basin Total	2,280	4,330	4,140	3,940	4,140	4,720

Total M&I Diversion Demands

Southwest Basin combined M&I demand projections for 2050 range from approximately 30,000 AFY in the *Weak Economy* to 68,000 AFY in *Hot Growth*, as shown in Figure 4.9.9. SSI demands account for around 7 to 14 percent of the M&I demands in the Southwest Basin. On a basin scale, the demand projections follow the statewide sequence of the scenario rankings described in the CWP.

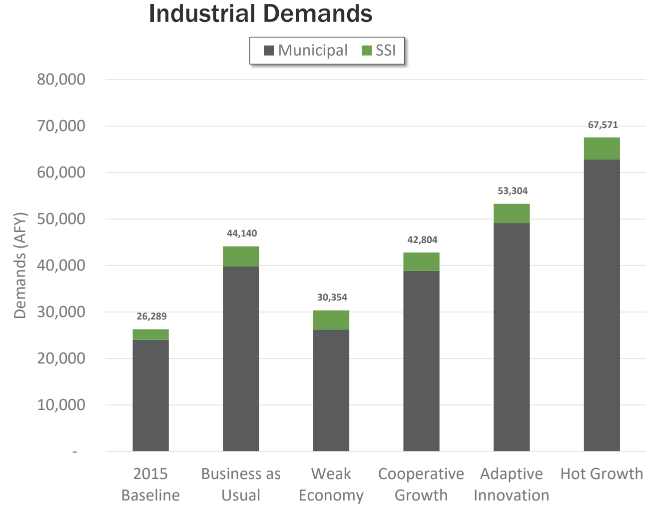


Figure 4.9.9 Southwest Basin Municipal and Self-Supplied Industrial Demands

4.9.6 Water Supply Gaps

The agricultural and M&I diversion demands were compared against available water supply modeled for current conditions and the five planning scenarios. Gaps were calculated when water supply was insufficient to meet demands.

Agricultural

The Southwest Basin agricultural diversion demands, demand gaps, and consumptive use gaps for the baseline and planning scenarios are presented in Table 4.9.9 and illustrated in Figure 4.9.10. An annual time series of gaps in terms of percent of demand that was unmet is shown in Figure 4.9.11.

INCREMENTAL GAP

The incremental agricultural gap quantifies the degree to which the gap could increase beyond what agriculture has historically experienced under water shortage conditions.

Table 4.9.9 Southwest Basin Agricultural Gap Results (AFY)

		Scenario					
		Scenario	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand	1,024,800	1,005,400	1,005,400	1,220,500	923,100	1,271,700
	Average Annual Gap	126,600	120,300	119,800	276,700	219,000	355,100
	Average Annual Gap Increase from Baseline	-	-	-	150,100	92,400	228,400
	Average Annual Percent Gap	12%	12%	12%	23%	24%	28%
	Average Annual CU Gap	72,300	68,700	68,400	158,500	147,200	206,400
Maximum	Demand in Maximum Gap Year	1,153,000	1,131,100	1,131,100	1,215,200	899,300	1,238,200
	Gap in Maximum Gap Year	517,600	507,400	504,900	679,500	474,000	738,100
	Increase from Baseline Gap	-	-	-	161,900	-	220,500
	Percent Gap in Maximum Gap Year	45%	45%	45%	56%	53%	60%

Study period for Water Supply Analysis is 1975-2013, reflecting different baseline demand than described in Agricultural Diversion Demands section.

Figure 4.9.10 Projected Average Annual Agricultural Diversion Demand, Demand Met, and Gaps in the Southwest Basin

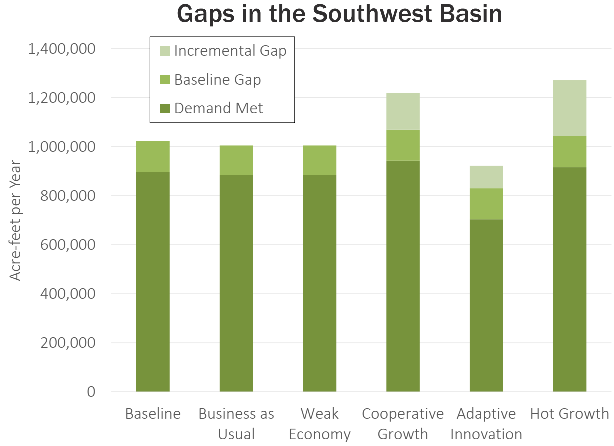
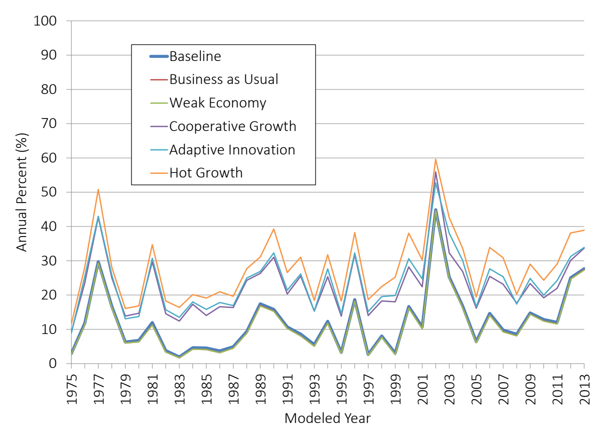


Figure 4.9.11 Annual Agricultural Gaps (expressed as a percentage of demand) for Each Planning Scenario



The following are observations on agricultural demands and gaps:

- Agricultural diversion demands are reduced in three of the five planning scenarios due to urbanization and reduction of irrigated acres.
- Agricultural diversion demand is projected to increase by 11 to 16 percent in *Cooperative Growth* and *Hot Growth* due to climate impacts. The increased demand in these scenarios is exacerbated by reduced water supply, resulting in an increased gap.
- Although *Adaptive Innovation* estimates reduced demand, the reduction in water supply due to climate change could result in an increased gap over baseline.

M&I

The diversion demand and gap results for M&I in the Southwest Basin are summarized in Table 4.9.10 and illustrated in Figure 4.9.12. An annual time series of gaps in terms of percent of demand that was unmet is shown in Figure 4.9.13.

Table 4.9.10 Southwest Basin M&I Gap Results (AFY)

		Scenario					
		Scenario	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand	27,200	44,800	30,200	43,300	54,000	69,500
	Average Annual Gap	0[1]	3,300	400	4,100	7,800	13,400
	Average Annual Percent Gap	0%	7%	1%	9%	14%	19%
Maximum	Demand in Maximum Gap Year	27,200	44,800	30,200	43,300	54,000	69,500
	Gap in Maximum Gap Year	0*	7,500	1,800	7,700	13,800	24,800
	Percent Gap in Maximum Gap Year	0%	17%	6%	18%	26%	36%

** CDSS water allocation model in this basin calculates small baseline M&I gaps, but they are either due to calibration issues or they are reflective of infrequent, dry-year shortages that are typically managed with temporary demand reductions, such as watering restrictions.*

Study period for Water Supply Analysis is 1975-2013, reflecting different baseline demand than described in M&I Demand section. Baseline demand also may vary slightly from previous section due to differences in geographic distribution of demand for counties that lie in multiple basins.

Figure 4.9.12 Projected Maximum Annual M&I Demand Met and Gaps in the Southwest Basin

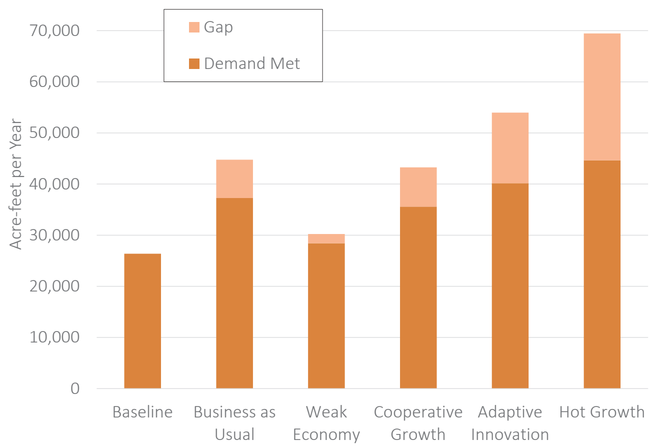
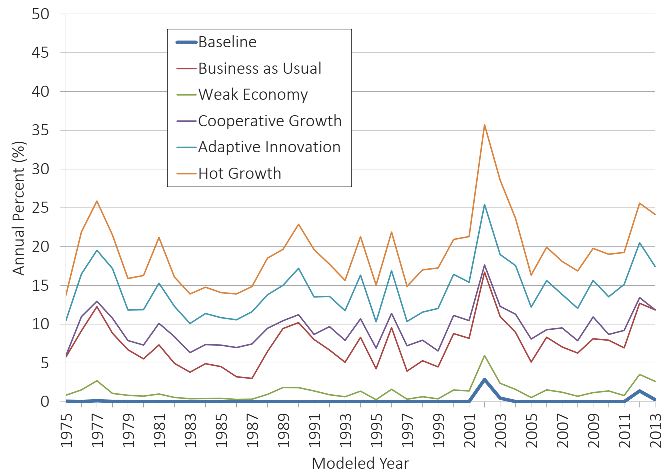


Figure 4.9.13 Annual M&I Gaps (expressed as a percentage of demand) for Each Planning Scenario



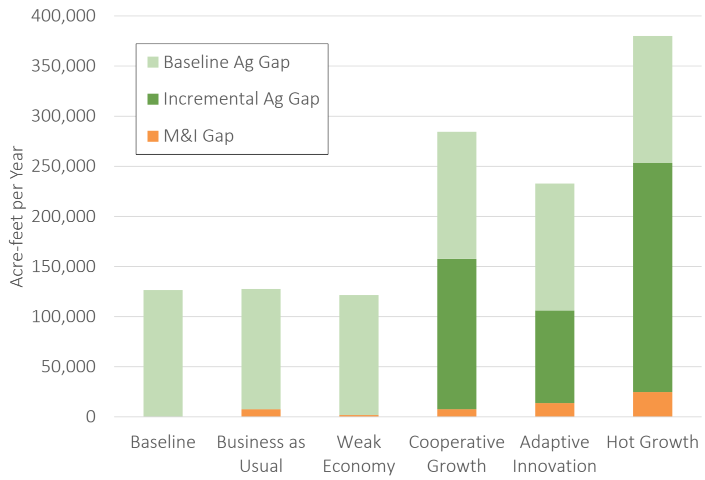
The following are observations on M&I diversion demands and gaps:

- The Southwest Basin is projecting the largest percentage increase in population in the state, which results in increased municipal demand for all future scenarios.
- Thermoelectric demands drive a modest increase in SSI demand.
- Water supply gaps for the planning scenarios range from 1 to 20 percent of demand. The largest gap is projected for *Hot Growth*, which is 36 percent of demand in the maximum gap year.

Total Gap

Figure 4.9.14 illustrates the total combined agricultural and M&I diversion demand gap in the Southwest Basin. The figure combines the average annual baseline and incremental agricultural gaps and the maximum M&I gap. In *Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth*, gaps were driven by agricultural demands, which increase in the "Hot and Dry" climate conditions.

Figure 4.9.14 Projected Average Annual Agricultural Gaps and Maximum M&I Diversion Demand Gaps in the Southwest Basin



Supplies from Urbanized Lands

By 2050, irrigated acreage in the Southwest Basin is projected to decrease by 3,800 acres due to urbanization. Irrigation supplies for these lands could potentially be used for M&I needs in the future (subject to a variety of unknowns such as seniority and type of water supply, willingness to change the use of water through water court, etc.). The average annual historical consumptive use associated with potentially urbanized acreage for each scenario is reflected in Table 4.9.11. The data in the table represent planning-level estimates of this potential supply and has not been applied to the M&I gaps.

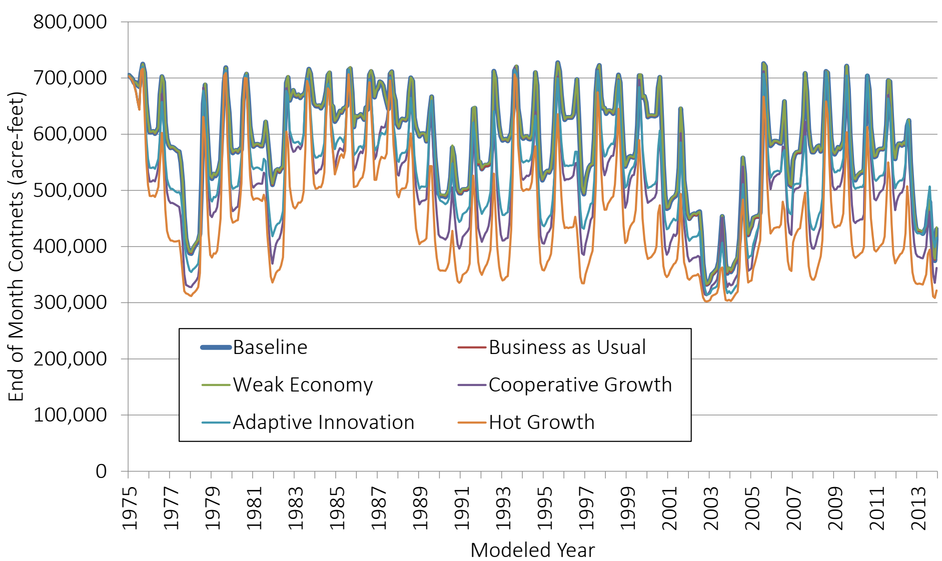
Table 4.9.11 Estimated Consumptive Use from Lands Projected to be Urbanized by 2050 in the Southwest Basin

	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Urbanized Acreage (acres)	3,800	3,800	3,800	3,800	3,800
Estimated Consumptive Use (AFY)	6,900	6,900	7,100	6,800	6,800

Storage

Total simulated reservoir storage from the Southwest Basin water allocation model is shown on Figure 4.9.15. Baseline and *Weak Economy* conditions show the highest levels of water in storage (in general) and the lowest is in *Hot Growth*. A significant spread between storage levels is shown for the various planning scenarios, with as much as 200,000 AF storage difference between *Weak Economy* and *Hot Growth*.

Figure 4.9.15 Southwest Basin Total Simulated Storage



4.9.7 Available Supply

Figures 4.9.16 through 4.9.19 show simulated available flow for the Southwest Basin at two locations to illustrate the difference in hydrology and water availability across the multiple sub-basins. The Animas River at Durango gage is located just upstream of the Durango Boating Park, which is a recreational instream flow demand of 1,400 cfs. Available flow greatly increases downstream of the Boating Park reach.

The La Plata River produces very little runoff and demands on the river chronically experience shortages due to physical flow limitations and curtailment due to the La Plata Compact. At both of the locations, available flows are projected to diminish and peak flows could occur earlier in the runoff season under planning scenarios with climate change impacts.

Figure 4.9.16 Simulated Hydrographs of Available Flow at Animas River at Durango, CO

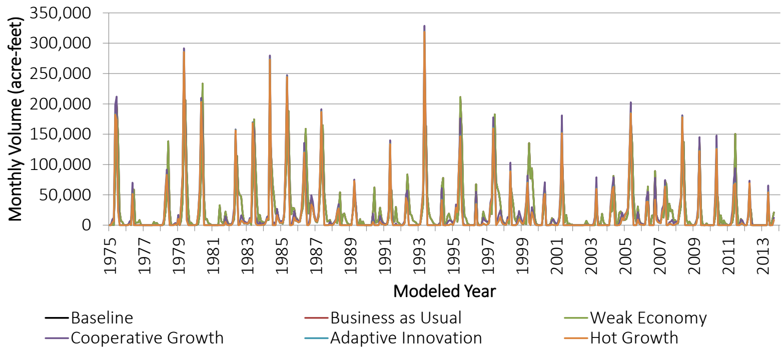


Figure 4.9.17 Average Monthly Simulated Hydrographs of Available Flow at Animas River at Durango, CO

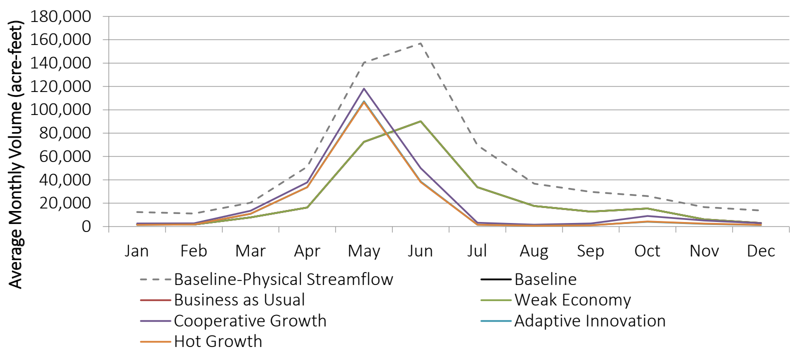


Figure 4.9.18 Simulated Hydrographs of Available Flow at La Plata River at Hesperus, CO

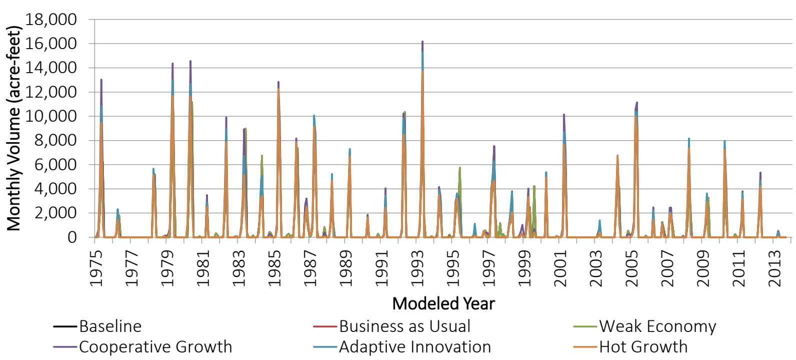
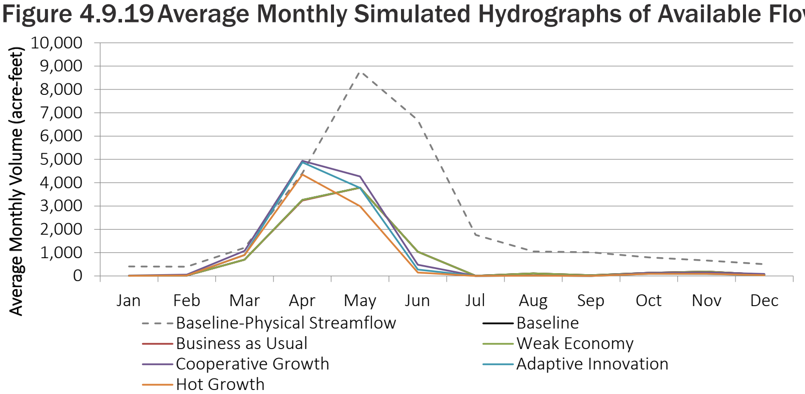


Figure 4.9.19 Average Monthly Simulated Hydrographs of Available Flow at La Plata River at Hesperus, CO



4.9.8 Environment and Recreation

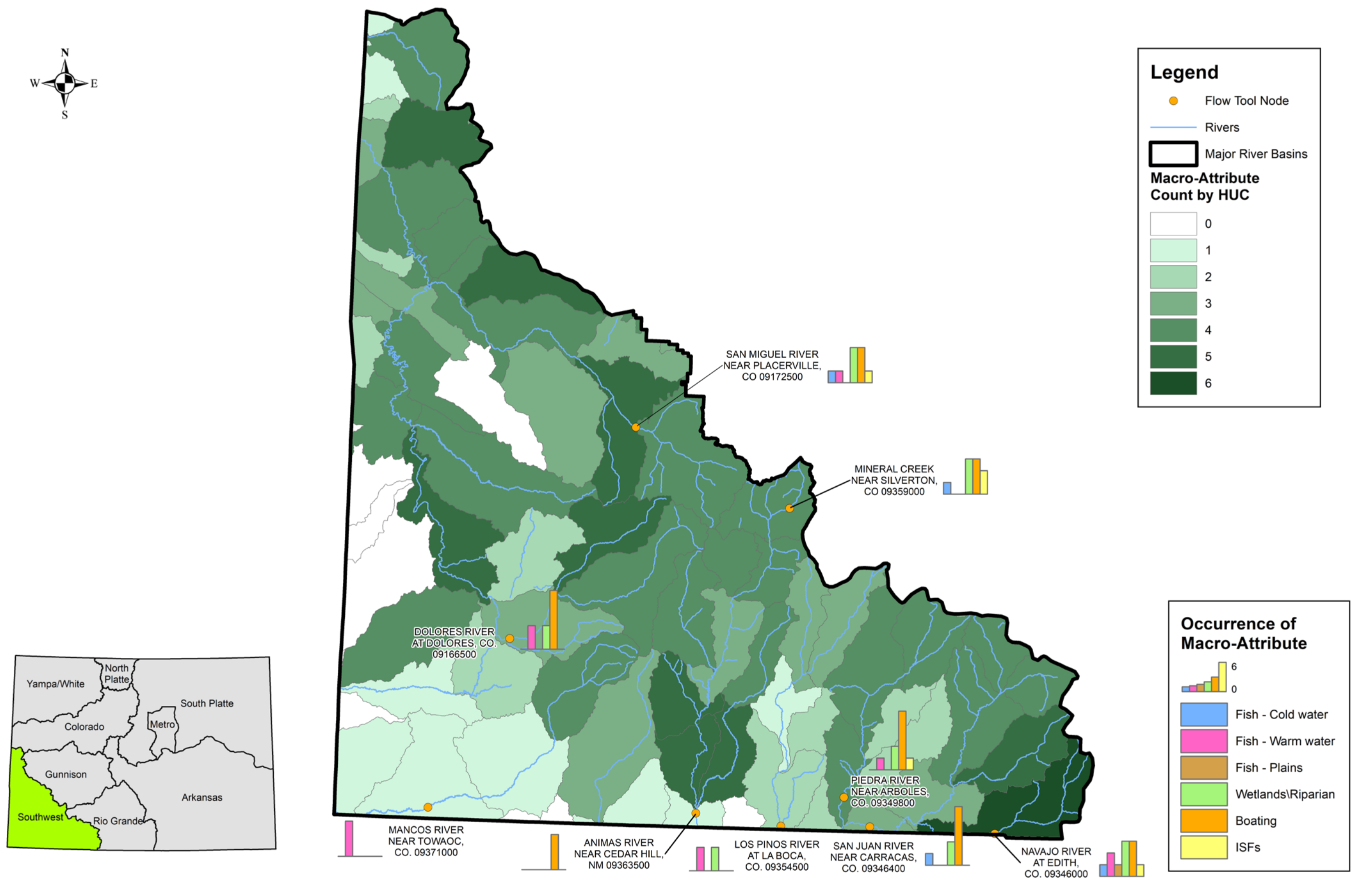
A total of nine water allocation model nodes were selected for the Flow Tool within the Southwest Basin (see list below and Figure 4.9.20). Figure 4.9.20 also shows subwatersheds (at the 12-digit HUC level) and the relative number of E&R attributes located in each subwatershed.

- Dolores River at Dolores, Colorado (09166500)
- San Miguel River near Placerville, Colorado (09172500)
- Navajo River at Edith, Colorado (09346000)
- San Juan River near Carracas, Colorado (09346400)
- Piedra River near Arboles, Colorado (09349800)
- Los Pinos River at La Boca, Colorado (09354500)
- Animas River at Howardsville, Colorado (09357500)
- Animas River near Cedar Hill, New Mexico (09363500)
- Mancos River near Towaoc, Colorado (09371000)

NATURALIZED FLOW

Naturalized flows reflect conditions that would occur in the absence of human activities. Baseline flows reflect current conditions as influenced by existing infrastructure and river operations. While observations regarding naturalized flows may be informative, baseline flows reflect actual conditions and the diverse operations of a river's many users.

Figure 4.9.20 Flow Tool Nodes Selected for the Southwest Basin



Results and observations regarding Flow Tool analyses using flow data developed in the water supply and gap analyses for baseline conditions and the planning scenarios are described below in Table 4.9.12.

Table 4.9.12 Summary of Flow Tool Results in the Southwest Basin

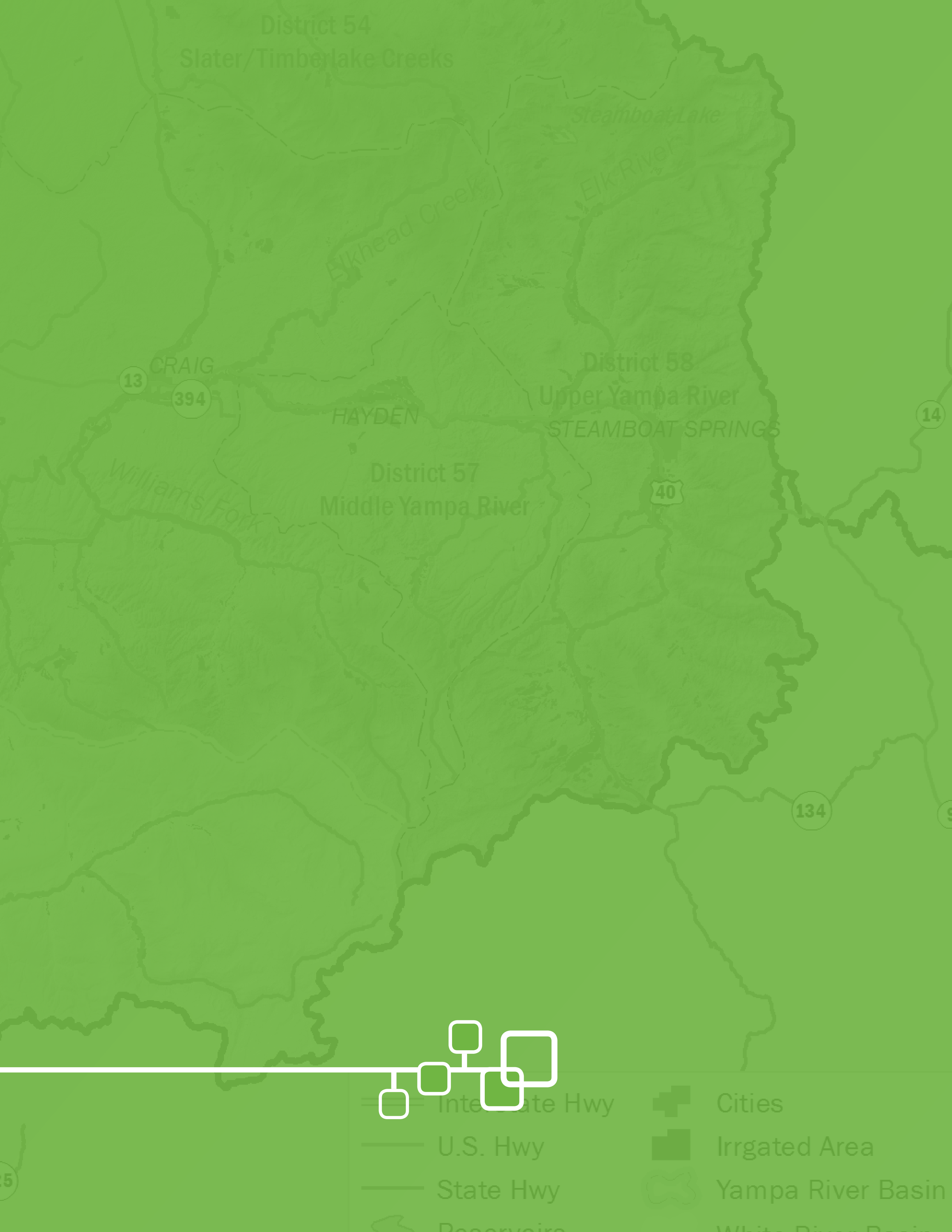
Category	Observation
Projected Flows	In locations where baseline conditions are minimally depleted from naturalized conditions (e.g., the San Miguel River), peak flow magnitude under *Business as Usual* and *Weak Economy* are projected to decline only slightly below baseline. Under climate change scenarios, declines in peak flow magnitude are projected to be further below baseline.
	At all locations, the timing of peak flow is projected to move earlier in the year for all climate change projections (Cooperative Growth, Adaptive Innovation, and Hot and Dry). Under these climate change projections, June flows may decrease the most (e.g., Dolores River at Dolores). Under these same scenarios, April flow may increase, but the increase in April flow magnitude may not offset the decline in June flow magnitude.
Ecological Risk	In all locations, mid- and late-summer flows are projected to decline under *Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth* scenarios, increasing risks for coldwater and warmwater fish.
	In locations where naturalized and baseline conditions are similar, peak flow-related risk to riparian/wetland plants and fish are projected to remain low to moderate under *Business as Usual*, *Weak Economy*, and *Cooperative Growth* scenarios. Under *Adaptive Innovation* and *Hot Growth*, this risk may increase.
	In locations where peak flows under baseline are already substantially less than naturalized conditions, peak flow-related risk to riparian/wetland plants and fish is already high and may increase under climate change scenarios.
	Under all climate change scenarios, runoff and peak flows occur earlier, and possible mis-matches between peak flow timing and species' needs may occur.
	In locations where naturalized and baseline conditions are similar, risk to coldwater fish (mainly trout) may increase under the various planning scenarios because of declines in mid- and late-summer flow. However, the risk remains moderate in most years.
	In locations that experience low summer flows, risk to fish may increase. Note that the Flow Tool risk assessment using coldwater and warmwater fish metrics does not include July because historically July flows are sufficient. In some locations, July flows may be significantly reduced under climate change scenarios (e.g., July flows under *Hot Growth* on the Piedra River near Arboles). The projected reduction will likely result in reduced habitat and increased stream temperatures.
ISFs and RICDs	ISFs throughout the Southwest and the RICD on the Animas River may not be met in many years under *Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth*. For example, flows on the San Miguel River near Placerville are projected to fall short of the 93 cfs summer ISF regularly during mid- and late-summer. In August, this ISF is projected to be unmet during 1 out of 3 years under *Cooperative Growth* and during two out of three years under *Adaptive Innovation* and *Hot Growth*.
	On the Animas River, the 25 cfs RICD near Howardsville is projected to not be met in numerous years during late summer (August) through October, and again in January and February (when the minimum flow is 13 cfs) under the three climate change scenarios.
E&R Attributes	Under baseline, *Business as Usual*, and *Weak Economy*, current flow issues related to E&R attributes arise primarily because of depletions that increase moving downstream.
	In some locations, transbasin diversions reduce and change the timing of flow in the basin of origin while augmenting flows in the receiving basin.
	Under climate change scenarios, the shift in the timing of peak flow, reductions in total runoff, and increasing consumptive demands may contribute to reductions in mid- and late-summer flows.

The Yampa, White, and Green Basins cover approximately 10,500 acres in northwestern Colorado and south-central Wyoming. The basin landscape is diverse and includes steep mountain slopes, high plateaus, canyons, and broad alluvial valleys. Livestock, grazing, and recreation are the predominant land uses. Near the towns of Craig, Hayden, Steamboat Springs, Yampa, and Meeker, much of the land is dedicated to agricultural use, and the mountains are covered by forest. The Steamboat Springs area, featuring a destination ski resort, is likely to experience continued and rapid population growth.

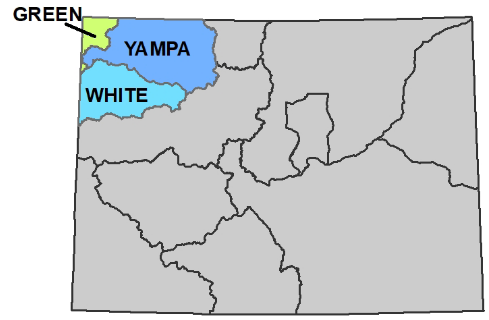
The Technical Update largely keeps the analysis at the basin scale. There are some exceptions where subbasin (river basin) analysis of major waterways was more straightforward. To that end, both the Yampa and the White river basins were explicitly modeled with results that are shown in this section. The combined Yampa-White-Green results are shown where statewide results are described.

Note that tributaries of the Green River have five diversions and one instream flow water right, and these are included in the model for the Yampa Basin. The demands and potential gaps from these structures are included in the Yampa Basin results.

YAMPA WHITE GREEN


District 54
Slater/Timberlake Creeks
Steamboat Lake
Elk River
Elkhead Creek
CRAIG
13
394
HAYDEN
District 58
Upper Yampa River
STEAMBOAT SPRINGS
14
District 57
Middle Yampa River
40
Williams Fork
134
Cities
U.S. Hwy
Irrgated Area
State Hwy
Yampa River Basin

4.10 YAMPA-WHITE-GREEN BASIN RESULTS

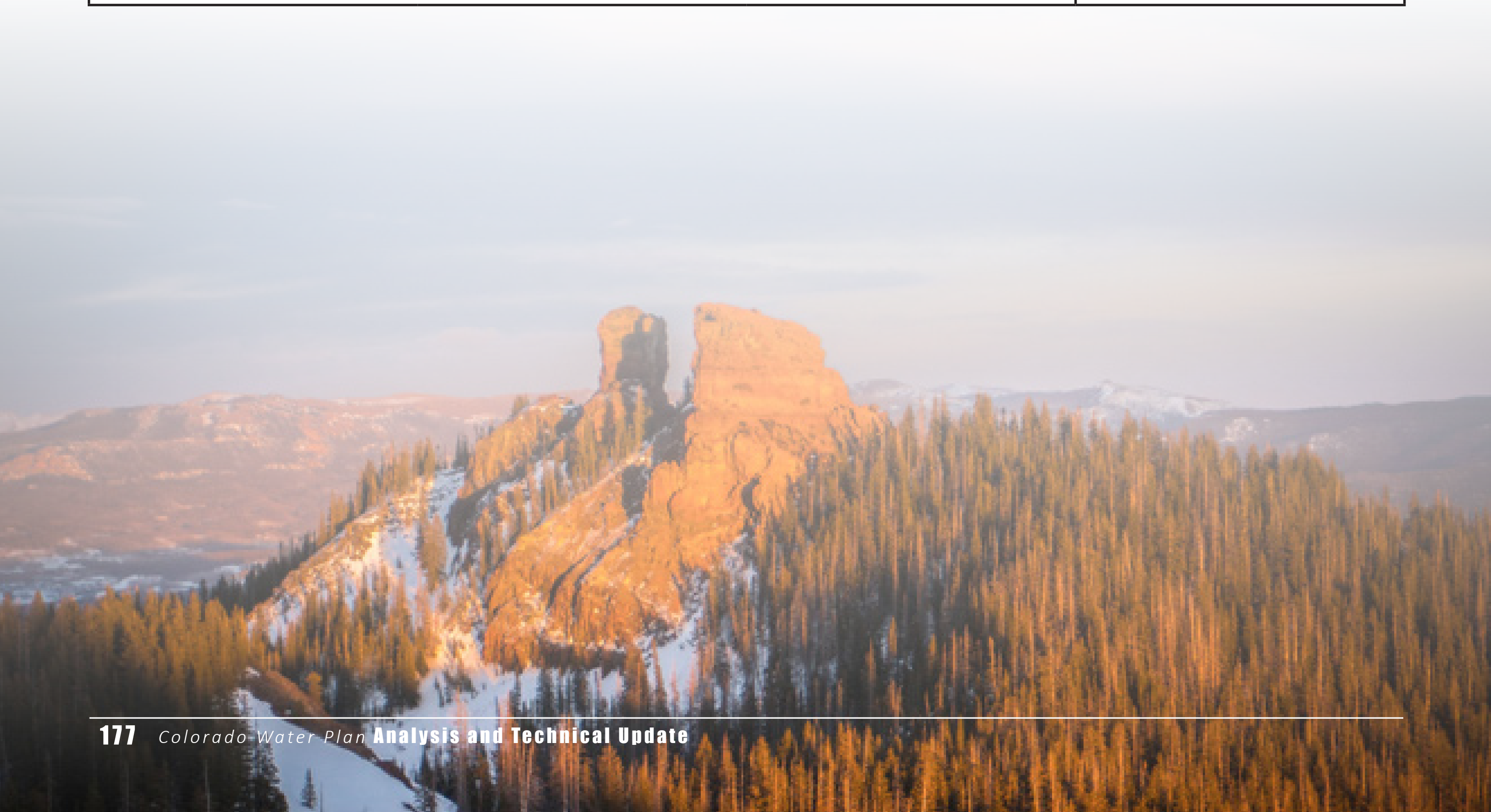


4.10.1 BASIN CHALLENGES

Key future water management issues for this basin include gas and oil shale development and addressing water resources needs for agriculture, tourism and recreation, and protection of endangered species. These challenges are outlined in the Colorado Water Plan and are summarized below.

Table 4.10.1 Key Future Water Management Issues in the Yampa-White-Green Basin

Agriculture	Environment and Recreation	Municipal and Industrial	Compacts and Administration
• Agricultural producers would like to increase irrigated land by 14,000 acres but lack finances to do so.	• Implementation of a successful Upper Colorado River Endangered Fish Recovery Program is vital to ensuring protection of existing and future water uses.	• The emerging development of gas and oil shale resources is affecting water demand, for both direct production and the associated increase in municipal use. • Industrial uses, especially power production, are a major water use. Future energy development is less certain.	• While rapidly growing in the Steamboat Springs area, the basin as a whole is not developing as quickly as other portions of the state. Concerns have arisen that the basin will not get a “fair share” of water under the Colorado River Compact in the event of a compact call.
• Agriculture, tourism, and recreation are vital components of this basin’s economy. As the needs of communities and industry grow, competition among sectors could increase.			



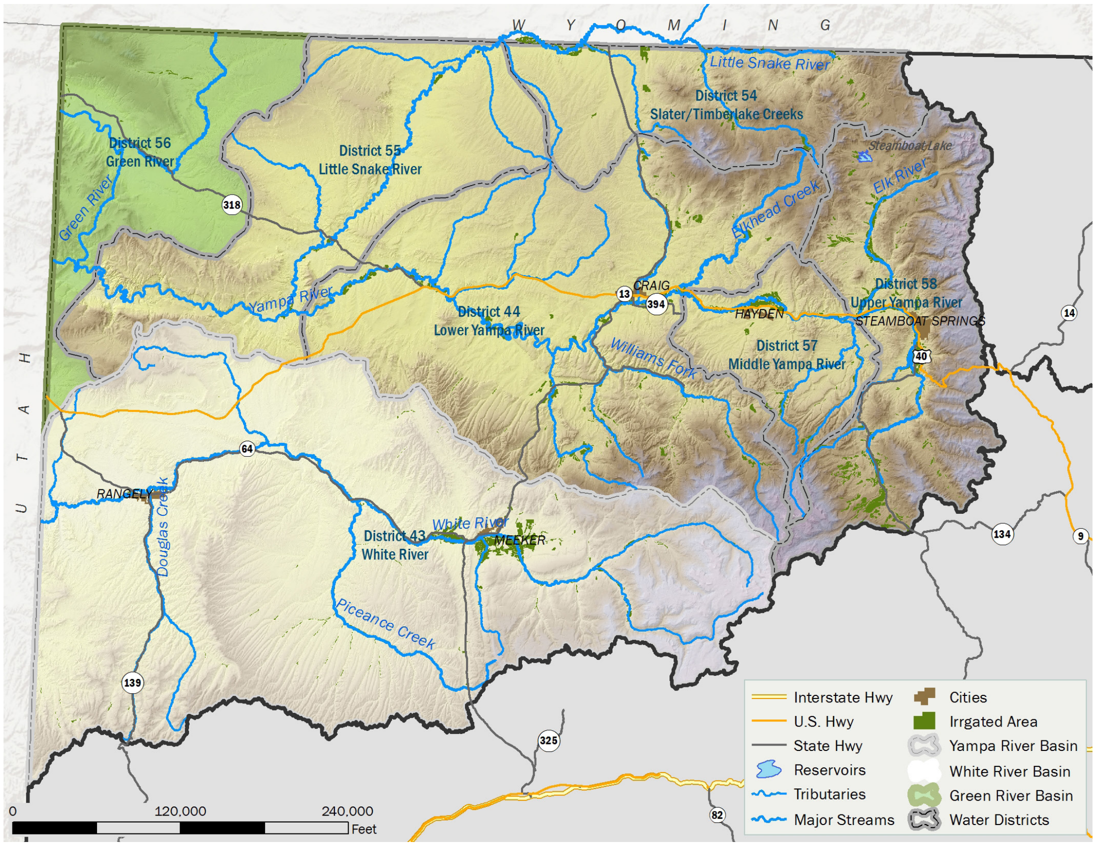


Figure 4.10.1 Map of the Yampa-White-Green Basin

4.10.2 SUMMARY OF TECHNICAL UPDATE RESULTS

Key results and findings of the Technical Update pertaining to agricultural and M&I demands and gaps as well as findings related to environmental and recreational attributes and future conditions are summarized below in Table 4.10.2.

Table 4.10.2 Summary of Key Results in the Yampa-White-Green Basin

Agriculture	Environment and Recreation	Municipal and Industrial
• Agricultural gaps may increase significantly in the Yampa Basin if water demands increase because of new acreage and higher IWR. • Gaps in the Yampa and White basins may also increase if stream flow is diminished via climate change. • Agricultural gaps in the White Basin are not projected to be as significant as in the Yampa	• In most locations, summer flows may be depleted significantly in climate-impacted scenarios, which creates high to very high risk for coldwater and warmwater fish. • Stream flows may be substantially below flow recommendations in some locations under climate-impacted scenarios.	• M&I demand for the combined basin ranges between 6 to 10 percent of agricultural demand. • Water supply gaps in the White Basin show a large increase in *Hot Growth* mainly due to potential increased energy development demand. • Increased population and thermoelectric demand drive increasing M&I gaps in the Yampa Basin.

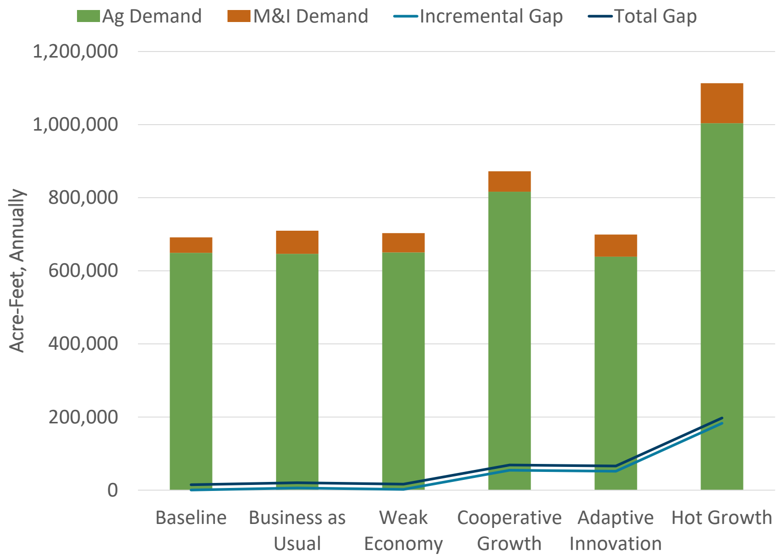
Results describing current and potential future M&I and agricultural demands and gaps are summarized in Table 4.10.3 and in Figure 4.10.2.

Table 4.10.3 Summary of Diversion Demand and Gap Results in the Yampa-White-Green Basin

		Current (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Yampa	**Average Annual Demand**						
	Agricultural (AFY)	402,500	403,600	403,600	522,500	461,000	684,300
	M&I (AFY)	36,900	53,300	46,700	48,900	53,000	68,300
	Gaps						
	Ag (avg %)	3%	3%	3%	12%	13%	22%
	Ag (incremental-AFY)	-	400	300	49,800	45,700	136,800
	Ag (incremental gap as % of current demand)	-	0%	0%	12%	11%	34%
	M&I (max %)	0%	3%	1%	3%	5%	12%
	M&I (max-AF)	0*	1,600	700	1,600	2,500	8,200
White	**Average Annual Demand**						
	Agricultural (AFY)	246,700	242,900	246,700	293,900	177,800	319,700
	M&I (AFY)	5,300	10,000	6,100	6,900	7,700	41,000
	Gaps						
	Ag (avg %)	0%	1%	0%	1%	2%	2%
	Ag (incremental-AFY)	-	-	-	1,900	2,100	4,600
	Ag (incremental gap as % of current demand)	-	0%	0%	1%	1%	2%
	M&I (max %)	0%	39%	15%	13%	17%	82%
	M&I (max-AF)	0	3,900	900	900	1,300	33,500
Total	**Average Annual Demand**						
	Agricultural (AFY)	649,200	646,500	650,400	816,300	638,700	1,004,000
	M&I (AFY)	42,200	63,400	52,800	55,900	60,600	109,300
	Gaps						
	Ag (avg %)	2%	2%	2%	8%	10%	16%
	Ag (incremental-AFY)	-	400	300	51,700	47,800	141,400
	Ag (incremental gap as % of current demand)	-	0%	0%	8%	7%	22%
	M&I (max %)	0%	9%	3%	5%	6%	38%
	M&I (max-AF)	0*	5,600	1,600	2,600	3,800	41,700

** CDSS water allocation model in this basin calculates small baseline M&I gaps, but they are either due to calibration issues or they are reflective of infrequent, dry-year shortages that are typically managed with temporary demand reductions, such as watering restrictions.*

Figure 4.10.2 Summary of Diversion Demand and Gap Results in the Yampa-White-Green Basin



Summary of Environmental and Recreational Findings

- In most stream locations, peak flows may be modestly depleted with low to moderate risk to riparian/wetlands and fish habitat. Peak flows may move earlier in the year, with March, April and May flows increasing substantially and June flows decreasing. Possible mis-matches between peak flow timing and species needs may occur.
- In most stream locations, including those with current low risk during mid- and late-summer, summer flows may be depleted 65 to 90 percent under *Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth*, which could create high to very high risk for coldwater and warmwater fish.
- The recreational in-channel diversion in Steamboat Springs could be at risk of being unmet often in mid- to late-summer, and Instream Flow water rights in most areas could be at greater risk of not being met, especially under *Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth*.
- In critical habitat for endangered species, extremely reduced flows in mid- and late-summer (greater than 90 percent reduction in July on the Yampa River near Maybell; greater than 80 percent reduction in July and August on the White River near Watson) may result in the flows in most years being substantially below flow recommendations. On the Yampa, in addition to loss of habitat for endangered fish, extremely low flows favor non-native fish reproduction and survival.

4.10.3 NOTABLE BASIN CONSIDERATIONS

Section 4.1 described several analysis assumptions and limitations that apply to all basins and should be considered when reviewing and interpreting analysis results. Additional considerations specific to the Yampa-White-Green Basin are listed below:

- The Yampa-White-Green has published a follow-on report to their BIP, which has different results based on different modeling objectives, assumptions, and inputs (e.g., climate assumptions around paleohydrology are different than the assumptions in the Technical Update; see section 2.2.1).
- The Technical Update used water allocation models that reflect a strict application of water administration. In the Yampa-White-Green basin, some water users refrain from placing a call to share the benefit of available supplies.
  - » As an example, in the White Basin, Kenney Reservoir is used for hydropower production. If future water shortages occur that might impact energy development, it is very possible that hydropower operators would choose to reduce generation as opposed to curtailing energy development uses.
- The Yampa-White-Green SSI demands for energy production could be further researched.
- Projected gaps in several scenarios are low relative to other basins. The result is consistent with expectations because supplies in the Yampa-White-Green have historically met demands. The first mainstem call on the Yampa occurred in 2018.
- Current Elkhead Reservoir operations related to the Yampa Programmatic Biological Opinion (PBO) are included in the Yampa model. The White PBO is in progress and was not included in the model. Future water supply projects and strategies were not included in the analysis.

GREEN RIVER DEMANDS

Tributaries of the Green River have five diversions and one instream flow water right, and these are included in the model for the Yampa Basin. The demands and potential gaps from these structures are included in the Yampa Basin results.

4.10.4 AGRICULTURAL DIVERSION DEMANDS

Agricultural Setting

Yampa Basin

Agriculture is a primary focus in the Yampa Basin. Irrigated acreage in the basin consists primarily of high mountain meadows and cattle ranches in the upper reaches of the basin along Elk Creek and the Yampa River. Irrigated acreage is also located along the Little Snake River as it meanders between Colorado and Wyoming.

White Basin

Approximately 60 percent of the irrigated acres in the White Basin are concentrated along the river near the Town of Meeker. The remaining acreage is located along tributaries and spread along the lower mainstem. Grass pasture is the dominant crop in the basin, and alfalfa is also grown. These forage crops support cattle grazing and ranching operations in the basin, which is a major economic driver. Mining and oil and gas extraction are also important elements of the basin's economy.

Planning Scenario Adjustments

Section 2 described ways in which inputs to agricultural diversion demand estimates were adjusted to reflect the future conditions described in the planning scenarios. Adjustments in the Yampa-White-Green Basin focused on urbanization, potential future climate conditions, and implementation of emerging technologies.

Yampa Basin

The Yampa-White-Green basin roundtable completed an Agricultural Water Needs Study in 2010 that identified 14,805 acres of potentially irrigable land in the Yampa Basin. For the Technical Update effort, the Yampa/White/Green basin roundtable contemplated how the irrigable land could be developed under the planning scenarios, recognizing that growth could vary depending on the future demand and economics for hay crops and cattle production. The stakeholders in the basin provided a varying amount of acreage and crops types for planned agricultural projects in each planning scenario in the Yampa Basin as reflected in Table 4.10.4.

Population projections anticipate significant growth in the Yampa Basin. The impact to irrigated areas, however, will be limited because the three largest municipal centers in the basin (Steamboat Springs, Hayden, and Craig) are not surrounded by irrigated agricultural areas.

White Basin

Future urbanization of irrigated lands is expected to be relatively limited in the basin, with 360 acres total in and around the towns of Meeker and Rangely projected to be urbanized. Population projections in Rio Blanco County are expected to decline in *Weak Economy*, and urbanization in this scenario was set to zero. Table 4.10.4 provides a summary of the adjustments to agricultural diversion demand drivers based for each planning scenario.

Table 4.10.4 summarizes the planning scenario adjustments described above and other adjustments that impact agricultural diversion demands in the various scenarios.

SYSTEM EFFICIENCY

In some cases, diversion demands surface water can be higher in wet years because system efficiency decreases due to the relative abundance of supply

Table 4.10.4 Planning Scenario Adjustments for Agricultural Demands in the Yampa and White Basins

Sub-basin	Adjustment Factor*	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Yampa	Change in Irrigated Land due to Urbanization	1,500 Acre Reduction	1,500 Acre Reduction	1,500 Acre Reduction	1,500 Acre Reduction	1,500 Acre Reduction
	Planned Agricultural Development Projects	1,000 Acre Increase 100% Alfalfa	1,000 Acre Increase 100% Alfalfa	5,000 Acre Increase 50/50 Grass Pasture/Alfalfa	14,805 Acre Increase 50/50 Grass Pasture/Alfalfa	14,805 Acre Increase 50/50 Grass Pasture/Alfalfa
	IWR Climate Factor	-	-	19%	34%	34%
	Emerging Technologies	-	-	-	10% IWR Reduction 10% System Efficiency Increase	-
White	Change in Irrigated Land due to Urbanization	360 Acre Reduction	-	360 Acre Reduction	360 Acre Reduction	360 Acre Reduction
	IWR Climate Factor	-	-	22%	37%	37%
	Emerging Technologies	-	-	-	10% IWR Reduction 10% System Efficiency Increase	-

** See section 2.2.3 for descriptions of adjustment methodologies and assumptions*

Agricultural Diversion Demand Results

Table 4.10.5 and Figures 4.10.3 and 4.10.4 summarize the acreage, IWR, and the agricultural diversion demand for surface water supplies in both the White and Yampa Basins for current conditions and the five planning scenarios. The largest variation in the White Basin occurred in *Adaptive Innovation* due to 10 percent reduction in IWR and 10 percent increase to system efficiency. In this basin, the combined impact of *Adaptive Innovation* adjustments resulted in an agricultural diversion demand that is lower than the current demand. The Yampa Basin saw the greatest increase in demand for *Hot Growth*, which assumed a large increase in irrigated acres.

Table 4.10.5 Summary of Agricultural Diversion Demand Results in the Yampa and White Basins

		Current	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Yampa	Irrigated Acreage (acres)	78,900	78,400	78,400	82,400	92,300	92,300
	Average IWR (AFY)	150,600	150,000	150,000	188,000	209,000	232,000
	Diversion Demand						
	Average Year (AFY)	402,000	403,000	403,000	518,000	456,000	679,000
	Wet Yr. Change	-4%	-3%	-3%	0%	1%	2%
	Dry Yr Change	0%	0%	0%	-1%	-2%	-3%
White	Irrigated Acreage (acres)	28,100	27,700	28,000	27,700	27,700	27,700
	Average IWR (AFY)	46,400	45,800	46,400	55,700	55,900	62,100
	Diversion Demand						
	Average Year (AFY)	243,000	239,000	243,000	293,000	180,000	324,000
	Wet Yr. Change	3%	3%	3%	4%	3%	6%
	Dry Yr Change	0%	0%	0%	-5%	-4%	-6%

Average agricultural diversion demand was calculated using the average hydrologic years (i.e., years classified as neither wet or dry) from 1950-2013

Figure 4.10.3 Agricultural Diversion Demands and IWR Results in the Yampa Basin

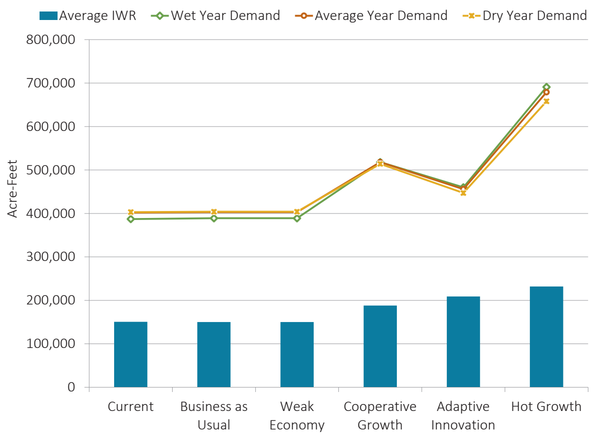
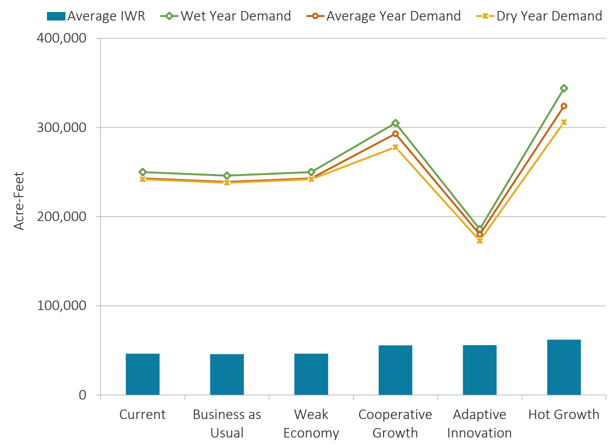


Figure 4.10.4 Agricultural Diversion Demands and IWR Results in the White Basin



4.10.5 Municipal and Self-Supplied Industrial Diversion Demands

Population Projections

The combined Yampa-White Basin currently includes less than 1 percent of the statewide population. Between the years 2015 and 2050, it is projected to change from approximately 44,000 to between 39,000 and 103,000 people in the low and high growth projections, respectively. Table 4.10.6 shows how population growth is projected to vary across the planning scenarios for White and Yampa basins.

Table 4.10.6 Yampa-White Basin 2015 and Projected Populations

Sub-basin	Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Yampa	37,200	59,900	34,400	63,500	86,000	91,900
White	6,500	7,400	4,200	7,000	10,600	11,300
Yampa-White Total	43,700	67,200	38,600	70,400	96,600	103,200

Current Municipal Demands

Sources of water demand data such as 1051 or WEP data were scarce in the Yampa and White Basins, and baseline water demands were largely estimated as shown on Figure 4.10.5.

Figure 4.10.6 summarizes the categories of municipal, baseline water usage in the Yampa and White Basins. In the Yampa Basin, and on a basin-scale, the residential indoor demand as a percentage of the systemwide demands is the highest reported throughout the state, at more than 50 percent. Conversely, the baseline residential outdoor water demand is the lowest statewide, at approximately 15 percent of the systemwide demands.

Figure 4.10.5 Sources of Water Demand Data in the Yampa-White Basin

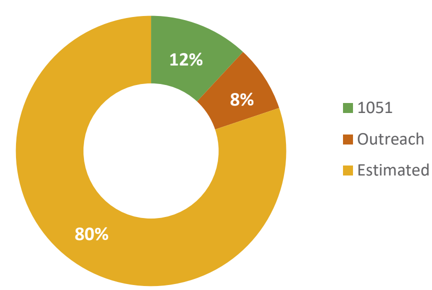
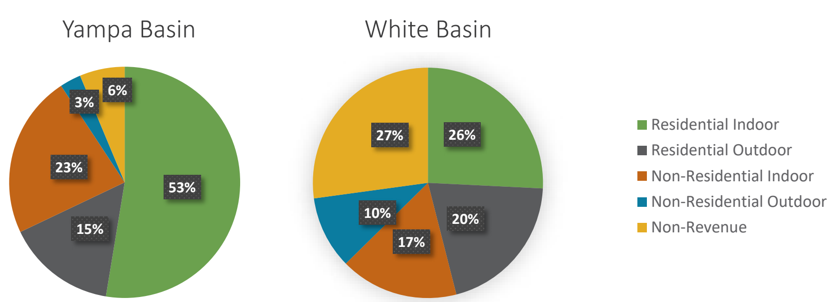


Figure 4.10.6 Categories of Water Usage in the Yampa-White Basin



Projected Municipal Demands

Figure 4.10.7 provides a summary of per capita baseline and projected water demands for the Yampa Basin. Systemwide, the projected per capita demands decrease relative to the baseline under all scenarios.

Figure 4.10.8 shows a summary of per capita baseline and projected water demands for the White Basin. Systemwide, the estimated per capita demands are projected to decrease relative to the baseline except in *Weak Economy* and *Hot Growth*. Consistently across all scenarios, the non-revenue water is the greatest demand category.

DECREASING GPCD

The Yampa-White Basin average baseline per capita systemwide demand has decreased slightly from 230 gpcd in SWSI 2010 to approximately 228 gpcd.

The relative proportions of various demand categories were estimated to be somewhat different in the White and Yampa Basins. Much of the difference is related to lack of representative data. In the White Basin, some usage data was derived from targeted outreach, but most of the data was filled (based on the outreach). In the Yampa Basin, some data were available via 1051 reporting, water efficiency plans, and targeted outreach, but much of the data was filled based on results from the available sources. Basin roundtables could work to acquire better data during the BIP update process.

Figure 4.10.7 Yampa Basin Municipal Baseline and Projected per Capita Demands by Water Demand Category

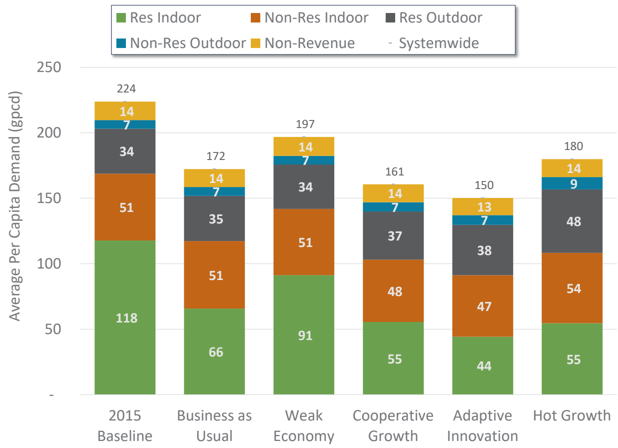


Figure 4.10.8 White Basin Municipal Baseline and Projected per Capita Demands by Water Demand Category

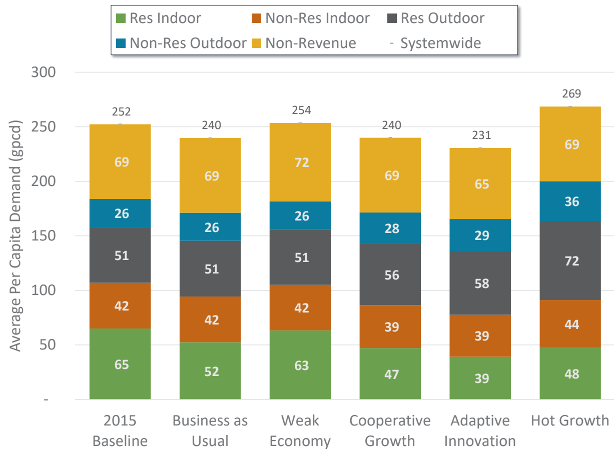


Table 4.10.7 Yampa-White Basin Municipal Baseline and Projected Demands (AFY)

Sub-basin	Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Yampa Basin	9,300	11,600	7,600	11,400	14,500	18,500
White Basin	1,800	2,000	1,200	1,900	2,700	3,400
Yampa-White Basin Total	11,200	13,500	8,800	13,300	17,200	21,900

Figure 4.10.9 Combined Yampa-White Basin Baseline and Projected Population and Municipal Demands

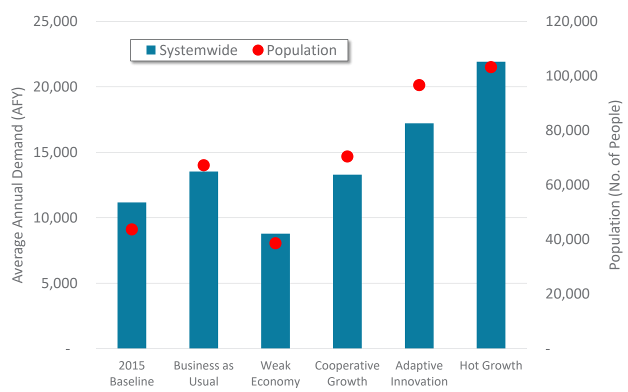
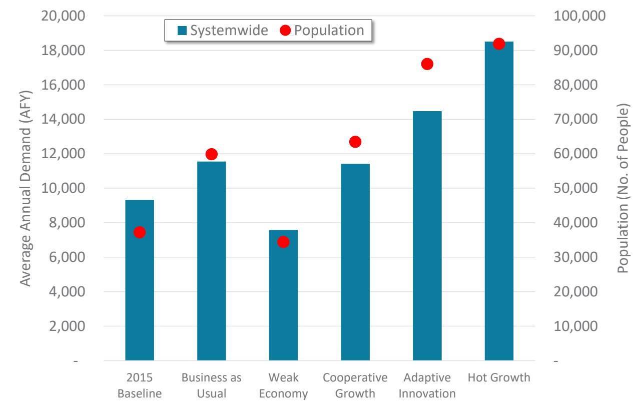


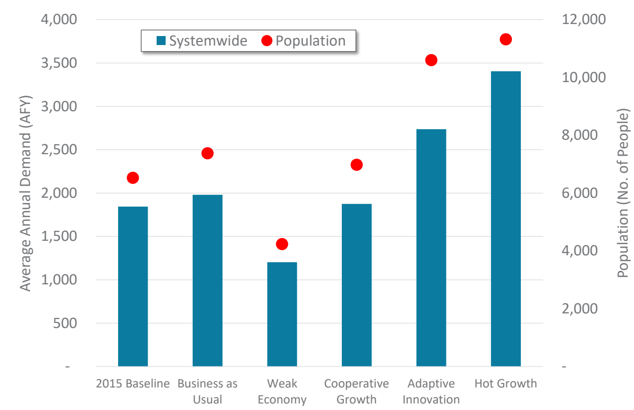
Figure 4.10.10 Yampa Basin Baseline and Projected Population and Municipal Demands



The Yampa-White Basin municipal baseline and projected demands are provided in Table 4.10.7, showing the combined effect of population and per capita demands. Municipal demands are projected to grow from approximately 11,000 AFY in 2015 to between 9,000 and 22,000 AFY in 2050.

The baseline and projected demand distributions are shown on Figures 4.10.9 through 4.10.11. Projected demands in *Business as Usual* and *Cooperative Growth* are nearly identical. All of the projection scenarios except for *Weak Economy* result in an increase relative to the baseline. Demands generally follow the population patterns, which shows the influence that population has within this region. *Adaptive Innovation* demands are an exception to this in that they are lower than *Hot Growth*. *Adaptive Innovation* demands include higher levels of water conservation, which keep demands lower despite similar assumptions of high population growth used in *Hot Growth*. Projected demands and populations in *Business as Usual* and *Cooperative Growth* are similar, with a slightly more noticeable distinction with the White Basin.

Figure 4.10.11 White Basin Baseline and Projected Population and Municipal Demands

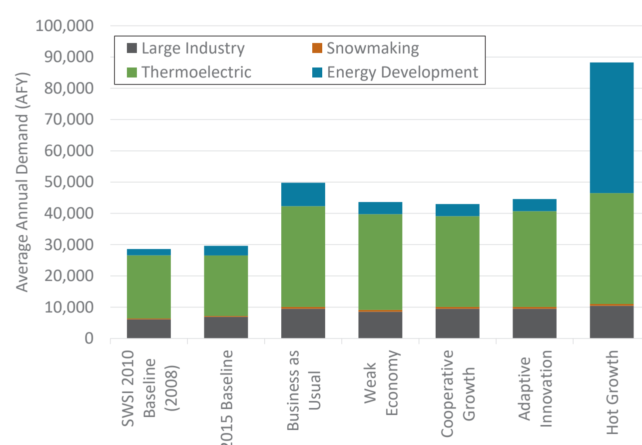


Self-Supplied Industrial Demands

The Yampa-White Basin includes about 17 percent of the statewide SSI demand. Approximately 93 percent of the baseline SSI demands are in the Yampa Basin and 7 percent are in the White Basin. SSI demands in the Yampa-White Basin are associated with all four sub-sectors. Basin-scale SSI demands are shown on Figure 4.10.12 and are summarized in Table 4.10.8.

Large Industry demands in this basin are located in Moffat and Routt counties. All baseline demands were based on SWSI 2010 and are related to mining in Moffat County and mining and golf courses in Routt County.

Figure 4.10.12 Total Yampa-White Basin SSI Baseline and Projected Demands



The baseline snowmaking demand is 290 AFY, which is the same as in SWSI 2010 because there has been no increase in snowmaking acreage. Projected demands are 570 AFY and were not varied by scenario.

Thermoelectric demands are related to two facilities. Baseline demands for the facility on Routt County were updated based on information from Xcel. Baseline demands for the facility in Moffat County were updated based on the BIP.

Table 4.10.8 Yampa-White SSI Baseline and Projected Demands (AFY)

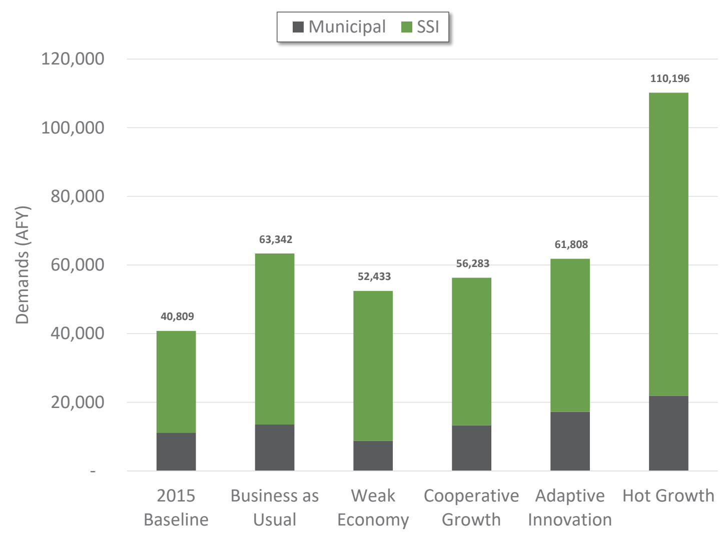
	Sub-sector	Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Yampa Basin	Large Industry	6,900	9,500	8,550	9,500	9,500	10,450
	Snowmaking	290	570	570	570	570	570
	Thermoelectric	19,350	32,240	30,630	29,020	30,630	35,460
	Energy Development	1,500	1,700	900	900	900	3,900
	Sub-Basin Total	28,040	44,010	40,650	39,990	41,600	50,380
White Basin	Large Industry	-	-	-	-	-	-
	Snowmaking	-	-	-	-	-	-
	Thermoelectric	-	-	-	-	-	-
	Energy Development	1,600	5,800	3,000	3,000	3,000	37,900
	Sub-Basin Total	1,600	5,800	3,000	3,000	3,000	37,900
	Basin Total	**29,640**	**49,810**	**43,650**	**42,990**	**44,600**	**88,280**

Energy development demands are located in Moffat, Rio Blanco, and Routt counties. Energy development demands in the White Basin for *Hot Growth* are much higher than for other scenarios but are consistent with high estimates of demands in Rio Blanco County used in SWSI 2010.

Total M&I Diversion Demands

Yampa-White Basin combined M&I demand projections for 2050 range from approximately 52,000 AFY in the *Weak Economy* to 110,000 AFY in *Hot Growth*, as shown on Figure 4.10.13. Under every planning scenario, SSI demands exceed the municipal. This is influenced by SSI use in the Yampa Basin and is the only basin in the state in which SSI demands exceed municipal. Self-supplied industrial demands make up approximately 70 percent to 80 percent of the total M&I demands in the Yampa-White Basin, depending on planning scenario. On a basin scale, the demand projections do not follow the statewide sequence of the scenario rankings described in the CWP, with the *Adaptive Innovation* falling out of sequence.

Figure 4.10.13 Yampa-White Basin Municipal and Self-Supplied Industrial Demands



4.10.6 Water Supply Gaps

The agricultural and M&I diversion demands were compared against available water supply modeled for current conditions and the five planning scenarios. Gaps were calculated when water supply was insufficient to meet demands.

In general, agricultural diversion demands gaps in the Yampa Basin are projected to be relatively low on an average annual basis in *Business as Usual* and *Weak Economy*, but gaps may be more significant in climate-impacted scenarios. Additional observations on the modeling results are summarized below.

Yampa Basin Gaps

Agricultural

The Yampa Basin agricultural diversion demands, demand gaps, and consumptive use gaps for the baseline and planning scenarios are presented in Table 4.10.9 and illustrated on Figure 4.10.14. An annual time series of gaps in terms of percent of demand that was unmet is shown in Figure 4.10.15. Agricultural diversion demand and consumptive use gap estimates were influenced by a number of drivers including climate, urbanization, planned agricultural projects, and emerging technologies.

Table 4.10.9 Yampa Basin Agricultural Gap Results (AFY)

		Scenario					
		Scenario	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand	402,500	403,600	403,600	522,500	461,000	684,300
	Average Annual Gap	13,300	13,600	13,600	63,100	58,900	150,000
	Average Annual Gap Increase from Baseline	-	400	300	49,800	45,700	136,800
	Average Annual Percent Gap	3%	3%	3%	12%	13%	22%
	Average Annual CU Gap	7,400	7,600	7,600	34,400	37,800	81,500
Maximum	Demand in Maximum Gap Year	448,900	450,500	450,500	533,000	463,800	667,500
	Gap in maximum Gap Year	55,600	55,400	55,200	123,400	97,700	246,500
	Increase From Baseline Gap	-	-	-	67,900	42,200	191,000
	Percent Gap in Maximum Gap Year	12%	12%	12%	23%	21%	37%

Study period for Water Supply Analysis is 1975-2013, reflecting different baseline demand than described in Agricultural Diversion Demands section

Figure 4.10.14 Projected Average Annual Agricultural Diversion Demand Met, Baseline Gaps, and Incremental Gaps in the Yampa Basin

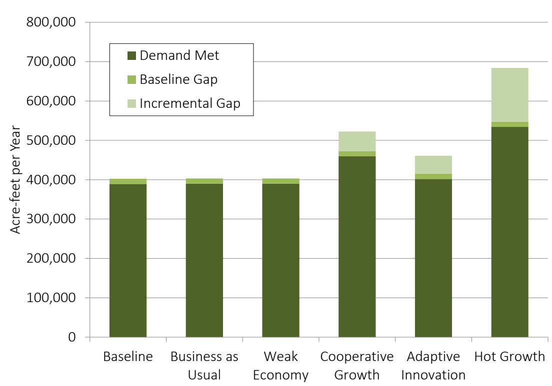
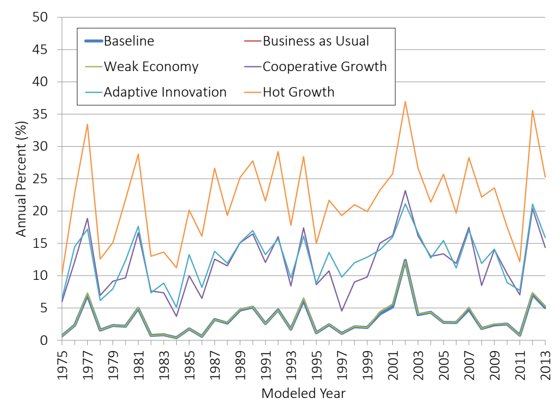


Figure 4.10.15 Annual Agricultural Gaps for Each Planning Scenario



- The Yampa Basin currently experiences an agricultural diversion demand gap, but the gap was not projected to significantly increase under the *Business as Usual* or *Weak Economy* scenarios.
- Agricultural diversion demand gaps increased in *Cooperative Growth*, *Adaptive Innovation* and *Hot Growth* due to additional demand from planned agricultural projects with junior water rights and higher IWR with concurrent lower water supply due to a drier and warmer climate.
- Climate conditions in *Adaptive Innovation* were hotter and drier than the *Cooperative Growth* scenario, but gaps were projected to be similar. Strategies associated with higher system efficiencies and the adoption of emerging technologies such as irrigation schedulings tended to offset climatic and hydrologic drivers that would have otherwise increased gaps in the *Adaptive Innovation* scenario.
- Agricultural water users do not have access to significant reservoir storage in the Yampa Basin. Gaps in *Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth* were impacted by earlier runoff seasons and lower water availability during the latter part of the growing season.

INCREMENTAL GAP

The incremental agricultural gap quantifies the degree to which the gap could increase beyond what agriculture has historically experienced under water shortage conditions.

M&I

The water supply and gap results for M&I in the Yampa Basin are summarized Table 4.10.10 and illustrated on Figure 4.10.16. An annual time series of gaps in terms of percent of demand that was unmet is shown on Figure 4.10.17.

The following are observations on the M&I diversion demands and gaps:

- The modeling suggests M&I gaps occur under baseline conditions, but this result is due to minor model calibration issues and does not currently occur.
- M&I providers and systems with more robust water rights portfolios and access to storage (i.e. systems that were explicitly modeled) will likely have lower gaps than other providers without access to supplemental supplies.
- In general, projected M&I gaps under the scenarios are projected to be relatively modest with the exception of *Hot Growth*.
- Higher M&I diversion demands along with lower water availability due to climate impacts drive higher estimated gaps in the *Hot Growth* scenario

Table 4.10.10 Yampa Basin M&I Gap Results (AFY)

		Scenario					
		Scenario	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand	36,900	53,300	46,700	48,900	53,000	68,300
	Average Annual Gap	0*	600	200	800	1,400	4,800
	Average Annual Percent Gap	0%	1%	0%	2%	3%	7%
Maximum	Demand in Maximum Gap Year	36,900	53,300	46,700	48,900	53,000	68,300
	Gap in Maximum Gap Year	0*	1,600	700	1,600	2,500	8,200
	Percent Gap in Maximum Gap Year	0%	3%	1%	3%	5%	12%

** CDSS water allocation model in this basin calculates small baseline M&I gaps, but they are either due to calibration issues or they are reflective of infrequent, dry-year shortages that are typically managed with temporary demand reductions, such as watering restrictions.*

Study period for Water Supply Analysis is 1975-2013, reflecting different baseline demand than described in M&I Demand section. Baseline demand also may vary slightly from previous section due to differences in geographic distribution of demand for Counties that lie in multiple basins.

Figure 4.10.16 Projected Maximum Annual M&I Diversion Demand, Demand Met, and Gaps in the Yampa Basin

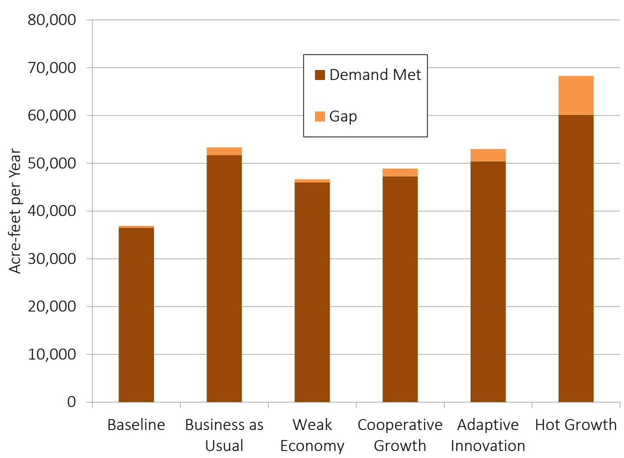
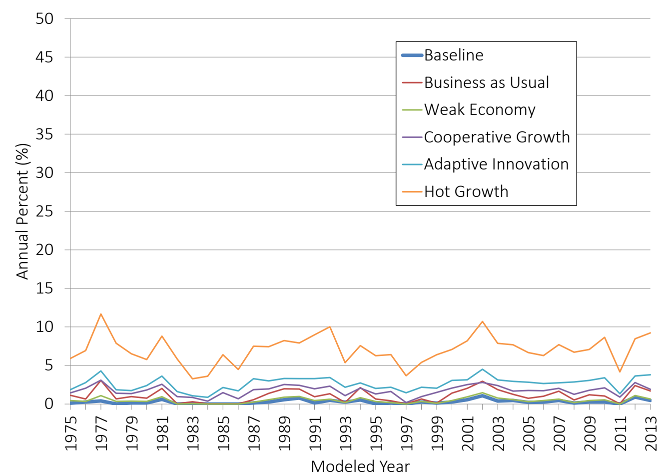


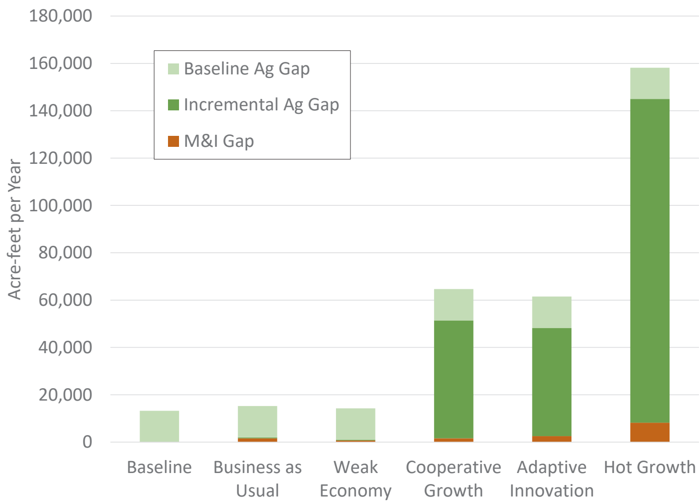
Figure 4.10.17 Annual M&I Gaps for Each Planning Scenario



Total Gap

Figure 4.10.18 illustrates the total combined agricultural and M&I diversion demand gap in the Yampa Basin. The figure combines the average annual baseline and incremental agricultural gap and the maximum M&I gap. Total gaps were driven by agriculture and were projected to be the highest in *Hot Growth*, which includes the highest amount of additional demand from planned agricultural projects and the most severe climate impacts.

Figure 4.10.18 Projected Average Annual Agricultural Gaps and Maximum M&I Diversion Demand Gaps in the Yampa Basin



Supplies from Urbanized Lands

By 2050, irrigated acreage in the Yampa Basin is projected to decrease by 1,500 acres due to urbanization. Irrigation supplies for these lands could potentially be used for M&I needs in the future (subject to a variety of unknowns such as seniority and type of water supply, willingness to change the use of water through water court, etc.). The average annual historical consumptive use associated with potentially urbanized acreage for each scenario is reflected in Table 4.10.11. The data in the table represent planning-level estimates of this potential supply and has not been applied to the M&I gaps.

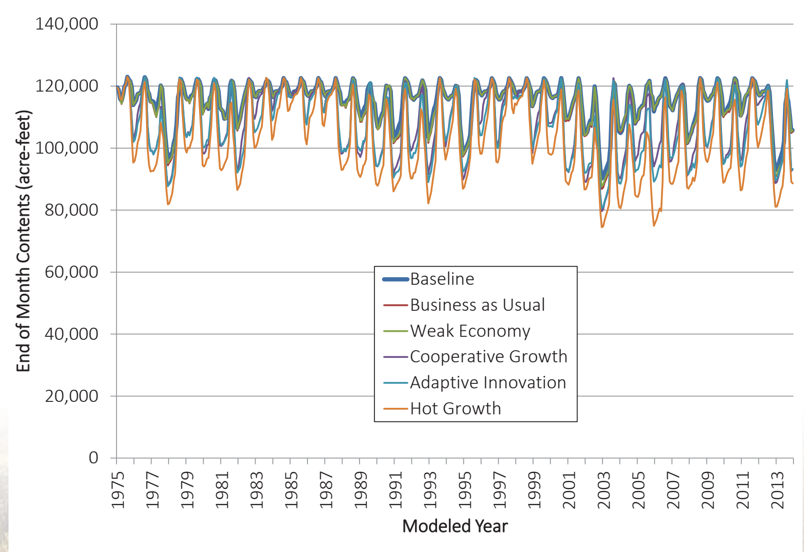
Table 4.10.11 Estimated Consumptive Use from Lands Projected to be Urbanized in the Yampa Basin

	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Urbanized Acreage (acres)	1,500	1,500	1,500	1,500	1,500
Estimated Consumptive Use (AFY)	2,700	2,700	2,800	2,800	2,400

Storage

Total simulated reservoir storage from the Yampa River water allocation model is shown on Figure 4.10.19. Baseline conditions show the highest levels of water in storage (in general), and the lowest is in *Hot Growth*. *Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth* show lower amounts of water in storage during dry periods than the two scenarios that do not include the impacts of a drier climate; however, storage levels generally recover back to baseline levels after dry periods.

Figure 4.10.19 Total Simulated Reservoir Storage in the Yampa Basin



White Basin Gaps

Agricultural

The White Basin agricultural diversion demands, demand gaps, and consumptive use gaps for the baseline and planning scenarios are presented in Table 4.10.12 and illustrated on Figure 4.10.20. An annual time series of gaps in terms of percent of demand that was unmet is shown on Figure 4.10.21.

Table 4.10.12 White Basin Agricultural Gap Results (AFY)

		Scenario					
		Scenario	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand	246,700	242,900	246,700	293,900	177,800	319,700
	Average Annual Gap	1,200	1,200	1,200	3,200	3,400	5,800
	Average Annual Gap Increase from Baseline	-	-	-	1,900	2,100	4,600
	Average Annual Percent Gap	0%	0%	0%	1%	2%	2%
	Average Annual CU Gap	700	700	700	1,700	2,200	3,200
Maximum	Demand in Maximum Gap Year	242,300	238,500	242,300	281,400	174,300	307,600
	Gap in maximum Gap Year	6,000	6,000	6,000	9,500	8,500	12,200
	Increase from Baseline Gap	-	-	-	3,500	2,500	6,200
	Percent Gap in Maximum Gap Year	2%	3%	2%	3%	5%	4%

Study period for Water Supply Analysis is 1975-2013, reflecting different baseline demand than described in Agricultural Diversion Demands section

Figure 4.10.20 Projected Average Annual Agricultural Diversion Demand, Demand Met, and Gaps in the White Basin

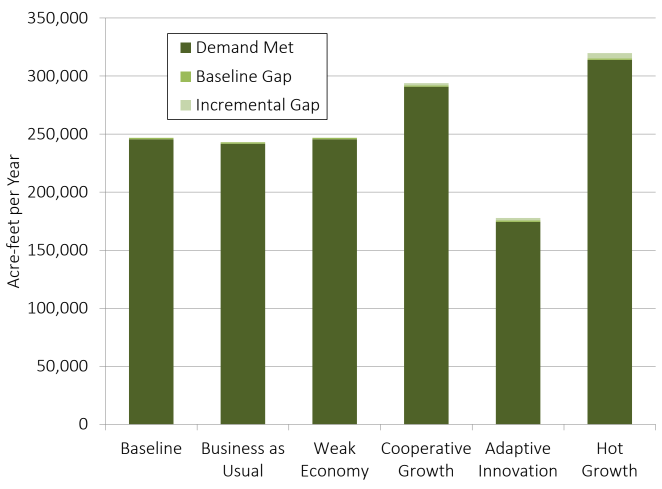
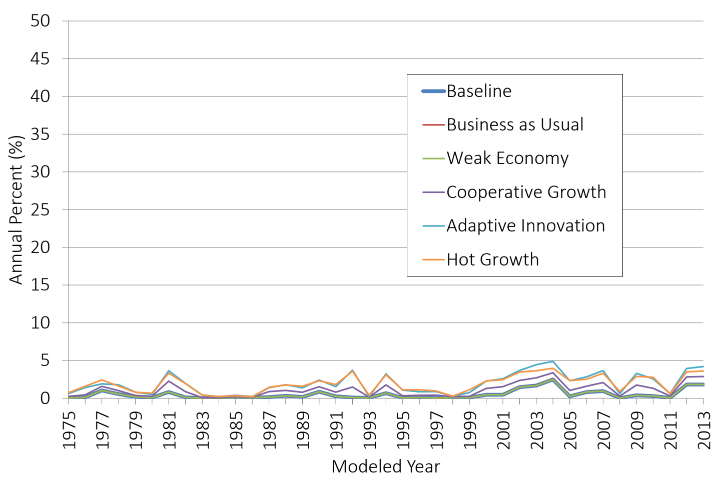


Figure 4.10.21 Annual Agricultural Gaps for Each Planning Scenario



In the White Basin, the current agricultural gap is small, and gaps are not projected to increase greatly in the planning scenarios. Agricultural gaps are greater in dry years. The largest annual, modeled gap occurred in *Hot Growth*, but it was small relative to demands at approximately 4 percent.

M&I

The diversion demand and gap results for M&I uses in the White Basin are summarized Table 4.10.13 and illustrated on Figure 4.10.22. An annual time series of gaps in terms of percent of demand that was unmet is shown in Figure 4.10.23.

Table 4.10.13 White Basin M&I Gap Results (AFY)

		Scenario					
		Scenario	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand	5,300	10,000	6,100	6,900	7,700	41,000
	Average Annual Gap	0	3,000	700	700	800	27,500
	Average Annual Percent Gap	0%	30%	12%	10%	10%	67%
Maximum	Demand in Maximum Gap Year	5,300	10,000	6,100	6,900	7,700	41,000
	Gap in Maximum Gap Year	0	3,900	900	900	1,300	33,500
	Percent Gap in Maximum Gap Year	0%	39%	15%	13%	17%	82%

Figure 4.10.22 Projected Maximum Annual M&I Demand Met and Gaps in the White Basin

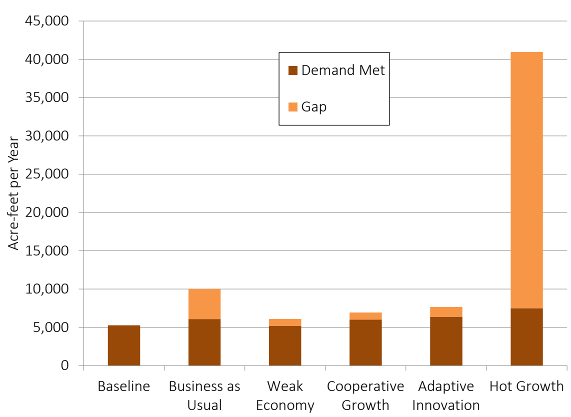
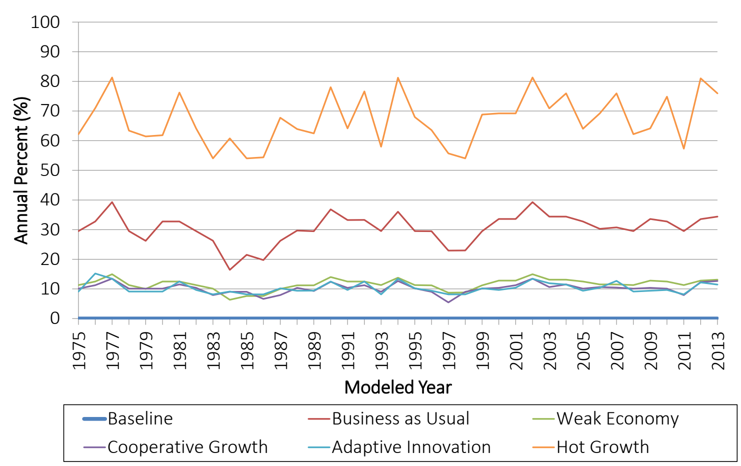


Figure 4.10.23 Annual M&I Gaps for Each Planning Scenario



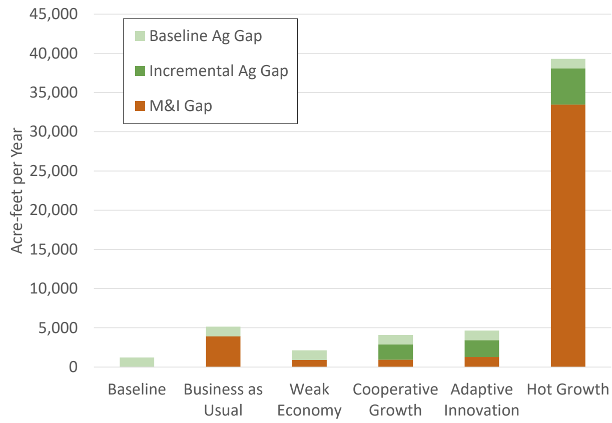
The following are observations on the M&I diversion demands and gaps:

- The average annual M&I gap in the White Basin is greater than the agricultural gap, ranging from about 700 AF for *Weak Economy*, *Cooperative Growth*, and *Adaptive Innovation* up to 27,500 AF for *Hot Growth*.
- The maximum M&I gap for the five planning scenarios ranges from 900 AF to more than 33,000 AF.
- The M&I gaps were modeled to be largest in the *Business as Usual* and *Hot Growth* scenarios and were driven by relatively large energy development demands (especially in *Hot Growth*).

Total Gap

Figure 4.10.24 illustrates the total combined agricultural and M&I diversion demand gap in the White Basin. The figure combines the average annual baseline and incremental agricultural gaps and the maximum M&I gap. In *Business as Usual* and *Hot Growth*, gaps were driven by relatively high SSI demands. In *Weak Economy*, *Cooperative Growth*, and *Adaptive Management*, agricultural gaps were greater than M&I gaps.

Figure 4.10.24 Projected Average Annual Agricultural Gaps and Maximum M&SSI Diversion Demand Gaps in the White Basin



Supplies from Urbanized Lands

By 2050, irrigated acreage in the White Basin is projected to decrease by 360 acres due to urbanization. Irrigation supplies for these lands could potentially be used for M&I needs in the future (subject to a variety of unknowns such as seniority and type of water supply, willingness to change the use of water through water court, etc.). The average annual historical consumptive use associated with potentially urbanized acreage for each scenario is reflected in Table 4.10.14. The data in the table represent planning-level estimates of this potential supply and has not been applied to the M&I gaps.

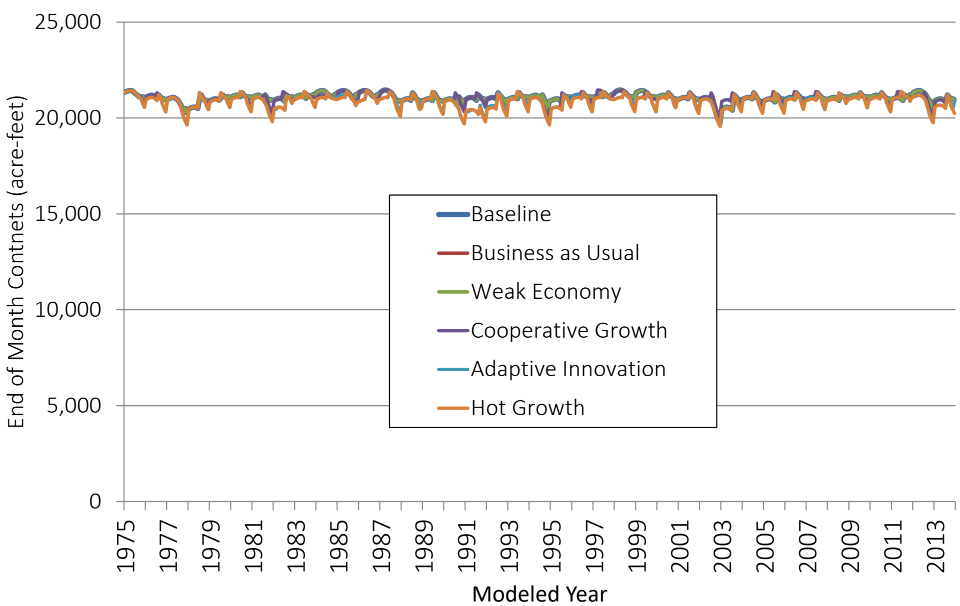
Table 4.10.14 Estimated Consumptive Use from Lands Projected to be Urbanized in the White Basin

	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Urbanized Acreage (acres)	360	-	360	360	360
Estimated Consumptive Use (AFY)	600	-	700	700	800

Storage

Total simulated reservoir storage from the White River water allocation model is shown on Figure 4.10.25. Basinwide storage levels do not significantly change in any of the planning scenarios, because agricultural and municipal water users in the basin do not typically use storage.

Figure 4.10.25 Total Simulated Reservoir Storage in the White Basin



Combined Yampa-White Basin Gaps

Table 4.10.15 summarizes the total M&I and agricultural demands in the Yampa-White Basin along with a summary of gaps. It should be noted that the Yampa and White Basins were modeled independently, and some of the results from each basin may not be wholly additive in some circumstances. For example, the maximum M&I gap may not occur in the same year in each sub-basin. As a result, the Yampa-White Basin as a whole may not experience a year in the future when the total maximum M&I gap corresponds to the sum of the maximum gaps in both sub-basins; however, the sum of the maximum sub-basin gaps does describe the total amount of water that would be needed to fully satisfy all M&I demands in each individual sub-basin, even if the gaps do not simultaneously occur in the sub-basins.

Table 4.10.15 Summary of Total Yampa-White Basin Demands and Gaps

	Current (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average Annual Demand						
Agricultural (AFY)	649,200	646,500	650,400	816,300	638,700	1,004,000
M&I (AFY)	42,200	63,400	52,800	55,900	60,600	109,300
Gaps						
Ag (avg %)	2%	2%	2%	8%	10%	16%
Ag (incremental-AFY)	-	400	300	51,700	47,800	141,400
Ag (incremental gap as % of current demand)	-	0%	0%	8%	7%	22%
M&I (max %)	0%	9%	3%	5%	6%	38%
M&I (max-AF)	01	5,600	1,600	2,600	3,800	41,700

CDSS water allocation model in this basin calculates small baseline M&I gaps, but they are either due to calibration issues or they are reflective of infrequent, dry-year shortages that are typically managed with temporary demand reductions such as watering restrictions.

4.10.7 Available Supply

Figures 4.10.26 and 4.10.27 show simulated monthly available flow for the Yampa Basin near the Maybell Canal, which is typically the senior calling right in the basin. Available flow at this location is very near to the physical flow in the stream, meaning that the Maybell Canal does not have a large impact on the available flow upstream. The figures show that flows are projected to be available each year, though the amounts will vary annually and across scenarios (available flows under the scenarios impacted by climate change are less than in other scenarios). Peak flows are projected to occur earlier in the year under scenarios impacted by climate change.

Figure 4.10.26 Simulated Hydrographs of Available Flow at Yampa River Near Maybell

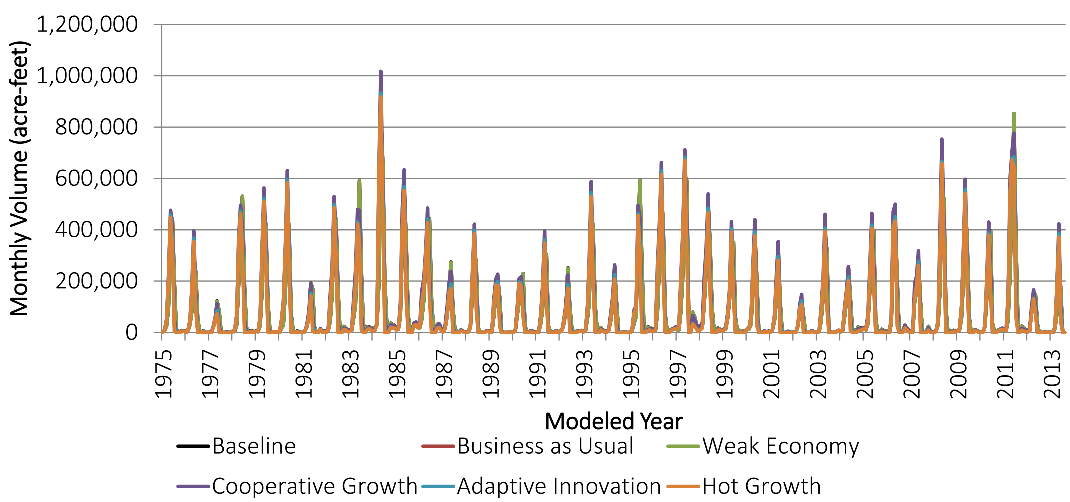
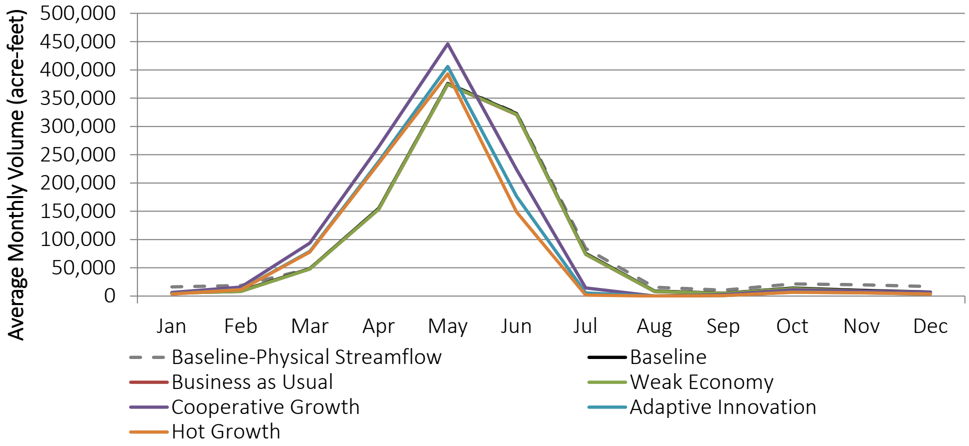


Figure 4.10.27 Average Monthly Simulated Hydrographs of Available Flow at Yampa River near Maybell



Figures 4.10.28 and 4.10.29 show simulated monthly available flow on the White River below Boise Creek, which is just above Kenney Reservoir. The reservoir has a hydropower water right that is not fully satisfied and serves as the calling right in the model. The figures show that flows are projected to be available in most years, though the amounts will vary annually and across scenarios (available flows under the scenarios impacted by climate change are less than in other scenarios). In some years, very little to no flow is available under current and future conditions at this location. Peak flows are projected to occur earlier in the year under scenarios impacted by climate change.

Figure 4.10.28 Simulated Hydrographs of Available Flow at White River Below Boise Creek

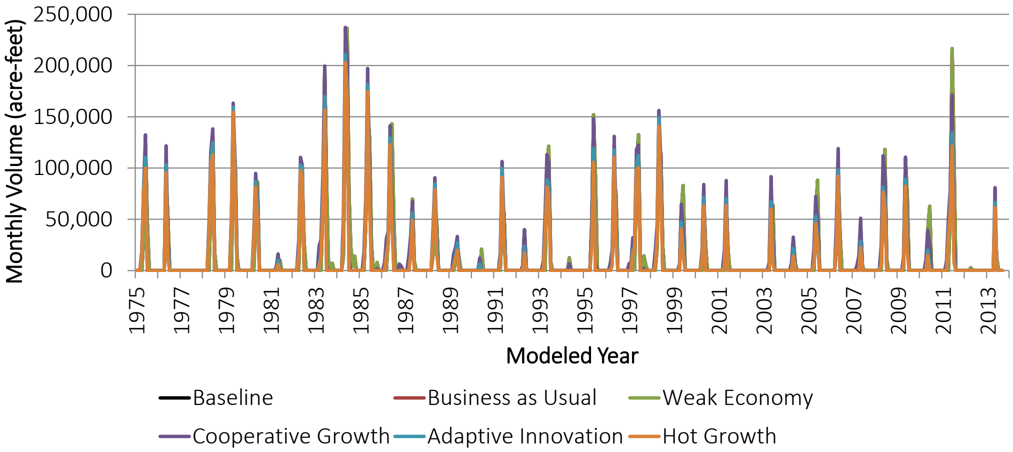
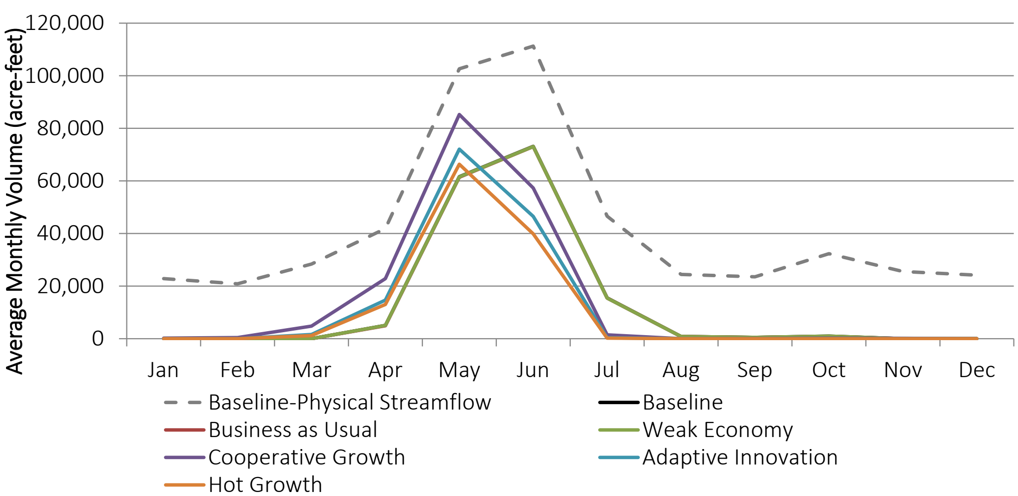


Figure 4.10.29 Average Monthly Simulated Hydrographs of Available Flow at White River Below Boise Creek



4.10.8 Environment and Recreation

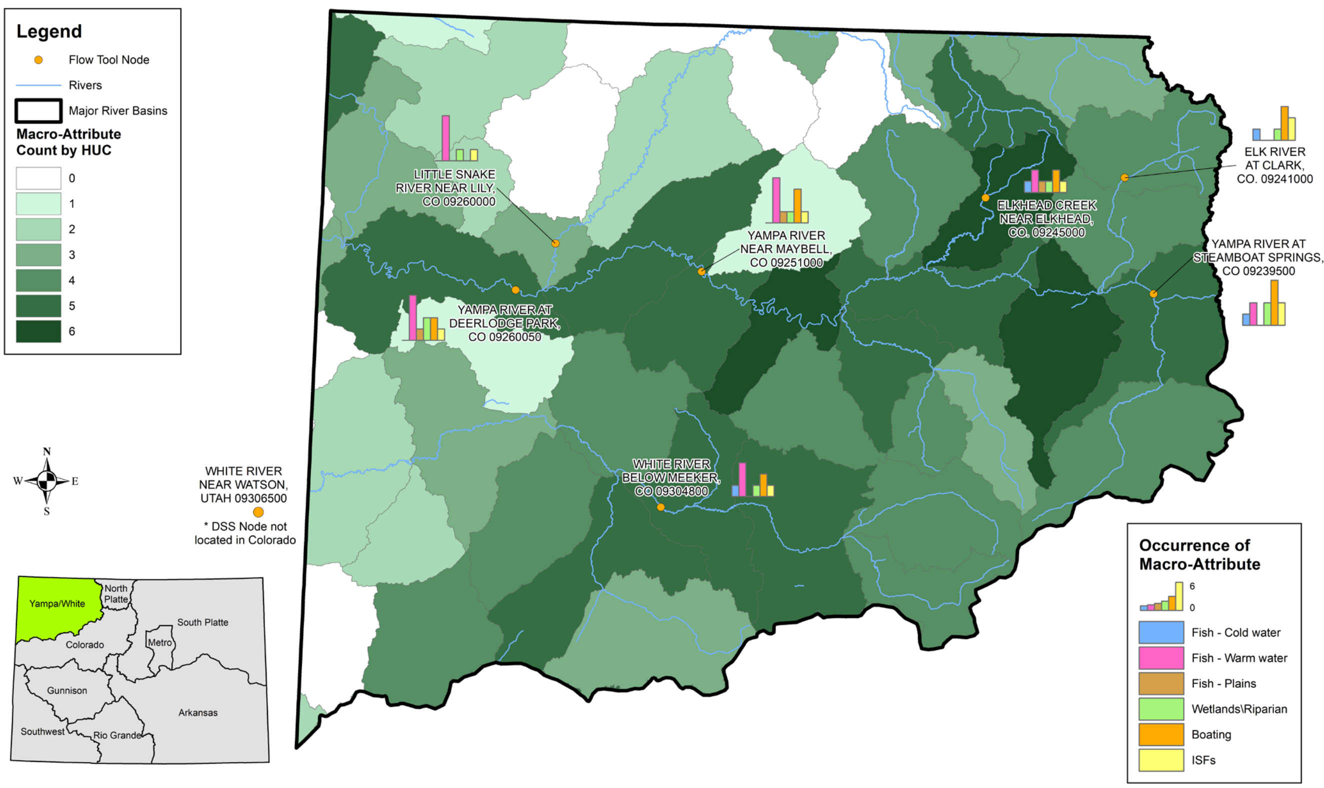
A total of eight water allocation model nodes were selected for the Flow Tool within the Yampa-White-Green Basin (see list below and Figure 4.10.30). Figure 4.10.30 also shows subwatersheds (at the 12-digit HUC level) and the relative number of E&R attributes located in each subwatershed.

- Yampa River at Steamboat Springs, Colorado (09239500)
- Elk River at Clark, Colorado (09241000)
- Elkhead Creek near Elkhead, Colorado (09245000)
- Yampa River near Maybell, Colorado (09251000)
- Little Snake River near Lily, Colorado (09260000)
- Yampa River at Deerlodge Park, Colorado (09260050)
- White River below Meeker, Colorado (09304800)
- White River near Watson, Utah (09306500)

NATURALIZED FLOW

Naturalized flows reflect conditions that would occur in the absence of human activities. Baseline flows reflect current conditions as influenced by existing infrastructure and river operations. While observations regarding naturalized flows may be informative, baseline flows reflect actual conditions and the diverse operations of a river's many users.

Figure 4.10.30 Flow Tool Nodes Selected for the Yampa/White Basin



Results and observations regarding Flow Tool analyses using flow data developed in the water supply and gap analyses for baseline conditions and the planning scenarios are described in Table 4.10.16 below.

Table 4.10.16 Summary of Flow Tool Results in the Yampa-White-Green Basin

Category	Observation
Projected Flows	On the Yampa and White Rivers, peak flow magnitudes under baseline conditions are only slightly reduced (10 percent) from naturalized conditions. A similar status holds for *Business as Usual* and *Weak Economy*. Under *Hot Growth*, total peak flows decline approximately 10 percent.
	At all locations, the timing of peak flow is projected to move earlier in the year under all climate change impacted scenarios (*Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth*). Under these scenarios, June flow may decrease approximately 30 percent at higher elevations (e.g., Elk River at Clark) and continue to decrease more at lower elevations (e.g., Yampa River at Deerlodge Park). Under these same scenarios, April flows may increase at a similar rate. May flows may increase or decrease depending on location and scenario.
	Under baseline conditions, mid- and late-summer flows are minimally depleted at higher elevations under naturalized conditions, are reduced further through mid-elevations (e.g., Steamboat Springs), and continue to decline through low-elevations (e.g., White River below Meeker and Yampa River at Deerlodge Park). Under all climate change scenarios, in most locations, mid- and late-summer flows are projected to have a wide departure from naturalized conditions.
Ecological Risk	Despite declines in peak flow magnitude, flow-related risk to riparian/wetland plants remains low to moderate across the basin. However, flow-related risk to warmwater fish is projected to increase, with the most risk occurring under *Hot Growth*. The change in timing for peak flows may result in mismatches between peak flow timing and species' needs.
	Projected reductions in mid- and late-summer flows may result in increased risks for trout at high and mid-elevations and for warmwater fish at low elevations. Increased risk would be caused by reduction in habitat under reduced flows.
	For trout, increased stream temperatures under low-flow conditions also increases risks, as has been the case in some recent years in Steamboat Springs. Additionally, the projected reductions in flows in mid- and late-summer may result in flows that are below the recommendations for endangered fish. For comparison, flows in August and September of 2018 were among the lowest flows on record and resulted in the first ever call on the Yampa River.
	September flows are projected to be similarly low in nearly one-quarter of all years under *Cooperative Growth* and nearly one-third of all years under *Adaptive Innovation* and *Hot Growth*. These low flows lead to a loss of habitat for endangered fish and favor reproduction and survival of non-native fish that prey upon endangered fish.
ISFs and RICDs	ISFs and RICDs are at risk of being met less often in mid- to late-summer under all future scenarios that include climate change (*Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth*). An example of an ISF at risk is the 65 cfs ISF on the Elk River. This ISF is met in July in every year under the baseline scenario; however, under *Cooperative Growth*, average July flow is projected to drop below 65 cfs in approximately one-third of years and is unmet in approximately half of the modeled years under *Adaptive Innovation* and *Hot Growth*. In August, the Elk River ISF is projected to be unmet in nearly every year under all climate change scenarios.
	The total amount of boating flows during runoff may not change significantly if peak flow magnitude does not decline substantially, but the timing of boating opportunities will shift to earlier in the year under all climate change scenarios. An example of a RICD at risk is for the whitewater park in Steamboat Springs. The August RICD decreed flow of 95 cfs is often not met under baseline conditions. Under *Adaptive Innovation* and *Hot Growth*, the August RICD decree is almost never met.
E&R Attributes	Under baseline conditions and *Business as Usual*, and *Weak Economy*, current flow risk related to E&R attributes arises primarily because of depletions that increase moving downstream.
	Under climate change scenarios, both the projected shift in the timing of peak flow and reductions in total runoff may contribute to reductions in mid- and late-summer flows.

SECTION 5
INSIGHTS, TOOLS, AND RECOMMENDATIONS

In addition to the core analysis of this report, the Technical Update incorporates a set of topic-specific evaluations (insights), supporting tools, and recommendations. These efforts aim to provide insights, assistance and direction to basin roundtables as they update their BIPs and consider solutions for addressing future gaps. Technical memoranda on each of the insights and existing tools are included in Volume 2 (see Appendix A for a full list). An overview of each of these topics is provided in the following subsections and as summarized below:

Insights: Section 5.1 provides a summary of high-level and conceptual analyses on the following focused topics related to implications of supply/demand gaps and key points to consider when developing potential solutions to solving future gaps. Basin roundtables may choose to expand on these analyses if necessary or desirable when updating their BIPs. The analyses focused on the following water-related areas:

- Public values regarding water issues in Colorado
- Overview and case study descriptions of Alternative Transfer Methods (ATM)
- Overview of water reuse mechanism
- Storage opportunities in Colorado
- Economic impacts of failing to solve future projected supply/demand gaps

Tools: Section 5.2 highlights several tools for basin roundtables to use when updating their BIPs. During the Technical Update, the consistency of data across all the existing BIPs was reviewed. The results of this review pointed to a strong need to improve the completeness and uniformity of information on all water supply projects/strategies and related costs. The tools developed in the Technical Update build on prior efforts in the following areas:

- Costing Tool
- E&R Flow Tool
- E&R database
- Projects database

Recommendations: Section 5.3 outlines several recommendations that primarily focus on how to use, enhance, and integrate findings from the Technical Update into the BIP updates. Recommendations stem from multiple stakeholder interactions and divide into five major update areas:

- BIP
- Project
- Technical
- Outreach
- Strategic

5.1 INSIGHTS

5.1.1 Public Perception Insights

In 2012 and 2013, a survey entitled, *Public Opinions, Attitudes and Awareness Regarding Water in Colorado*, was conducted on behalf of the CWCB. In addition, other survey research was documented relevant to understanding social values in the context of the Technical Update planning scenarios and water supply challenges that Colorado will face. Findings from the survey are documented in the technical memorandum, *Observations Regarding Public Perceptions on Water* (included in Volume 2, Section 12) and summarized below.

- Coloradans have varied levels of knowledge regarding water use in the state. Only one in three residents recognizes that agriculture is the largest water user in Colorado. In 2012 and 2013, a large majority of the state's residents were paying more attention to water issues and their own water use than they had in the past. In part, this was likely due to 2012's dry summer conditions. Repeated surveys in other locations found that water awareness rises during droughts and diminishes after the drought recedes.
- Among eight potential water-related concerns, Coloradans identified protecting home water quality, having enough water for Colorado's farms and ranches, and having enough water for Colorado's cities and towns as the most important issues. These were the top three issues in each region of the state, although the ranking order of the issues varied by region.
- Coloradans most frequently described conservation as their preferred approach to addressing Colorado's water issues, followed by prioritizing environmental needs and building new water supply projects. Conservation was the most frequently recommended strategy in every region, and support for prioritizing environmental needs was consistent across Colorado's regions. Support for developing new water supply projects was more varied.
- Coloradans perceive home water service to be affordable compared to other home services, and they are willing to pay more to address Colorado's water issues. On average, Coloradans are willing to pay between $5 and $10 more per month to address water-related concerns. At $5 per month per household, this willingness to pay would correspond to statewide annual financial support of about $125 million.

5.1.2 ATM Insights

Overview

The Technical Update shows that under multiple planning scenarios a growing population, healthy economy, and climate change will lead to increasing municipal and industrial water demands and subsequently intensify pressure to permanently transfer agricultural water rights. In particular, the South Platte and Arkansas basins face significant reductions in irrigated agricultural land due to increasing demand. Other drivers of permanent reductions in irrigated acreage include urbanization, inadequate augmentation water supplies, declining aquifers, and compact compliance.

Across the state, water stakeholders want to minimize permanent reductions in irrigated agricultural land and support a variety of alternative options, such as water banking and interruptible water supply agreements. Colorado's Water Plan sets a goal of achieving 50,000 acre-feet of water transfers through voluntary ATMs by 2030. The Water Plan also sets a goal that ATMs compete with, if not out-perform, traditional transactions in the water market. Through the long-standing ATM Grant Program and other initiatives, the CWCB continues to facilitate the development and implementation of ATM projects across the state

The technical memorandum, *Review of Successful Alternative Transfer Method Programs and Future Implementation* (included in Volume 2, Section 11) reviews select ATM projects that have been successfully implemented and highlights key characteristics of each ATM that provide insight into how future ATMs might also be successfully structured. Additionally, the study provides perspectives on agricultural to municipal transfers, and includes recommendations for monitoring metrics to track the effectiveness of future ATM programs.

ATM projects provide several general benefits when compared to permanent, buy-and-dry water transfers. For municipalities, ATMs may provide a reliable source of dry-year water supplies and can be more cost effective than permanent transfers and other traditional new supply sources. By maintaining some farm operations as part of the ATM program, rural economies that depend on agricultural activities can be sustained, and agricultural users can have access to new income streams for purchasing new equipment and investing in infrastructure improvements or other operational needs. ATMs can also be useful in preserving ecosystem services associated with working agricultural lands, such as open space and wildlife habitat. Additionally, ATMs can be applied to address multiple water supply challenges, including municipal and industrial needs, compact compliance, groundwater management, and non-consumptive needs.

Challenges to ATM implementation include balancing the municipal and industrial user's desire for certainty and permanence of long-term supply with the supplier's desire to maintain profitable agriculture, and potentially high infrastructure costs needed to implement a viable water transfer (potentially high infrastructure costs are a barrier to implementing a permanent transfer and are not necessarily unique to ATMs). Furthermore, high transaction and administration costs common to nearly all transfers can discourage some parties from pursuing an ATM arrangement. Several efforts have been made to address these challenges over recent years, including the continued financing of ATM projects through the CWCB's ATM Grant Program and development of more flexible, administrative ATM project approvals through the HB13-1248 Fallowing-Leasing Pilot Program and Agricultural Water Protection Water Right.

ATM Case Study Examples **(can this just be Case Studies throughout? case study and examples seems redundant)**

ATMs in Colorado are predominantly used to transfer water from agriculture to municipal, industrial, or environmental uses on a temporary basis, but several long-term ATM projects have been developed based on the needs of the parties involved. Case study examples of recently implemented ATMs in Colorado were developed to better understand methods used to overcome challenges and past barriers to implementing ATMs, unique issues between the parties involved, overall benefits, and key lessons learned that can apply to future ATM implementation. The case studies selected represent different ATMs, and are shown below:

Agricultural to Municipal and Industrial

- Little Thompson Farm
- Catlin Canal

Agricultural to Environmental

- McKinley Ditch

Compact Compliance

- Grand Valley Water Users Association Conserved Consumptive Use Pilot Program

Hypothetical Agricultural to Municipal Transfer Considerations

A hypothetical example ATM program was considered to provide context into how a coordinated, large-scale rotational fallowing program could be developed to meet a significant portion of the M&I gap. The example describes a large-scale fallowing program and concluded that a significant portion of irrigated acreage would need to be enrolled in the program to yield significant amounts of supply. Additionally, several infrastructure components may be required to implement a large-scale ATM program, including augmentation and operational storage, pipelines and pump stations, and water treatment systems. This infrastructure may be needed even if traditional agricultural transfers were implemented from the same geographical areas.

ATM Implementation and Effectiveness Monitoring

Following recommendations in the Water Plan concerning ATM data compilation, future ATM monitoring metrics were identified to help give insight to the effectiveness and operation of a single ATM, or a large-scale ATM program across a larger geographic area to gauge regional or basinwide trends. Obtaining this data for a wide variety of implemented ATMs (both geographically and for different ATMs) will provide more information to decision makers to evaluate the effectiveness of proposed ATMs, identify trends, and evaluate pricing. ATMs provide an opportunity to meet increasing water demands of a growing population while lessening the impacts to Colorado agricultural communities. Next steps to be considered include:

- Developing better guidance as to what types of projects and processes further Water Plan goals related to maintaining or enhancing agricultural viability while meeting potential new demands and addressing other water resource management issues
- Assessing institutional support of ATMs and evaluating progress made on addressing the primary barriers to ATM development and implementation
- Developing additional pilot projects for the varying ATM programs and engaging in thoughtful monitoring of their effectiveness
- Working with basin roundtables to consider how ATMs can play a role in addressing basin needs and priorities
- Pursuing further the collection of recommended monitoring data for ATMs as they are developed and sharing this information through existing platforms such as CDSS or new platforms such as an ATM data clearinghouse.

5.1.3 Water Reuse Insights

The Colorado Water Plan notes that various forms of water reuse will be an important component of closing future supply-demand gaps for municipalities; it also encourages water providers to build on the successes of the many reuse projects already implemented in Colorado. To advance these concepts, high-level comparisons of various water reuse mechanisms were compared and contrasted in a fact-sheet style format that summarized hypothetical mass balances of a municipal water system implementing reuse. Benefits, tradeoffs, unintended consequences, treatment requirements, and regulatory considerations pertaining to a particular reuse mechanism were also evaluated. This information was designed to provide guidance on how to define potential municipal reuse projects in future BIP efforts. Evaluated reuse mechanisms included:

- Reuse via. Exchange
- Non-potable reuse
- Indirect potable reuse
- Direct potable reuse
- Graywater reuse

The results of the comparisons are presented in a technical memorandum *Opportunities and Perspectives on Water Reuse* (see Volume 2, Section 13).

Key Findings

In this analysis, particular attention was paid to quantifying and qualifying the impact of a local reuse project on the greater basin and watershed system. The mass balance exercises noted previously identified the following key takeaways to consider when a municipality is evaluating implementation of a particular reuse mechanism:

- *Reuse of Existing Reusable Return Flows:* If a municipality can reuse existing legally reusable return flows, the amount of new supplies needed to meet future demands can be reduced. Indirect, direct, or reuse via exchange methods have the best opportunity to reduce the need for new supplies due to the ability to reuse water year-round. When a municipality begins to reuse return flows that historically have not been reused, a flow reduction to downstream users can result. Coordination between the water provider and downstream water users could help those users plan for this reduction in downstream water availability.
- *Reuse of New Supplies:* If a municipality cannot reuse existing return flows, reusing future, new, legally reusable supplies will reduce the amount of new supplies needed. Reuse of new supplies using indirect, direct, or reuse by exchange methods can be used year-round, which maximizes the benefit of reuse to the municipality and minimizes the amount of new supplies needed.

5.1.4 Storage Opportunity Insights

The CWP states that Colorado must develop additional storage to manage and share conserved water and manage the challenges of a changing climate. It sets a measurable objective of attaining 400,000 acre-feet of innovative water storage by 2050. The technical memorandum, *Opportunities for Increasing Storage* (see Volume 2, Section 10), investigates concepts related to increasing water storage to assist in meeting current and future water supply challenges throughout Colorado.

Conditional Storage Water Rights

To evaluate future storage opportunities in Colorado, the State's current water right database was queried for potential reservoir sites with conditional storage rights greater than 5,000 acre-feet. As shown in Figure 5.5.1, there are more than 6.5 million acre-feet (MAF) of conditional storage rights at reservoir sites with greater than 5,000 AF on file with the State of Colorado.

The 6.5 MAF of conditional storage rights (if constructed) would nearly double the existing surface water storage in Colorado and is more than 15 times the CWP's measurable objective of 400,000 AF of additional storage by 2050. It is not likely that the 6.5 MAF of new surface water storage will occur by 2050; however, if only a portion of the conditional storage sites were ultimately determined to be technically and environmentally feasible, those new surface water storage facilities could become a critical component to a balanced approach to meeting projected water resources gaps throughout Colorado.

Other Storage Opportunities

In addition to considering conditional storage rights, other opportunities for new storage and increasing operational storage in existing reservoirs were evaluated as a means to help solve Colorado's projected water supply and demand gaps. Table 5.5.1 summarizes the key considerations for each type of potential storage discussed in Volume 2, Section 10 titled *Opportunities for Increasing Storage*.

Figure 5.1.1 Sum of Conditional Storage Right Volumes in Various River Basins

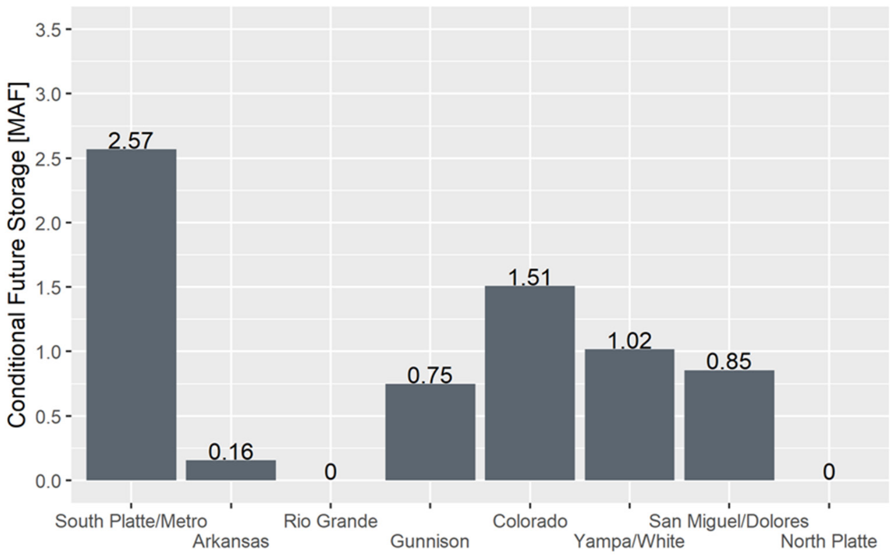
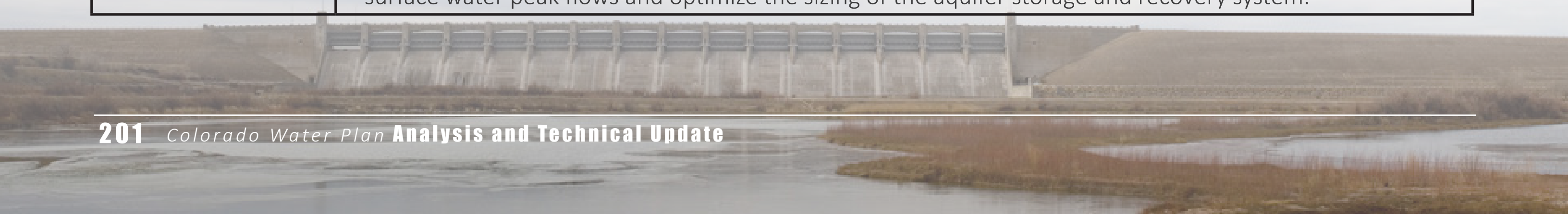


Table 5.1.1 Overview of Water Storage Opportunities

Reallocate Some Flood Storage to Active Storage	• Volume reallocation from flood control to reservoir operations (referred to as the storage delta concept) could be a part of achieving additional storage in existing reservoirs. • Further meteorological and hydrologic analysis could be performed on key reservoirs that have dedicated flood storage to identify the most likely opportunities for implementing the storage delta concept in the future.
Remove Sediment	• Further analysis should be completed on key reservoirs (i.e., reservoirs that have been in operation for a long period or are downstream of wildfire areas) to clarify the degree to which sediment removal could achieve additional operational storage volume.
Rehabilitate Fill Restricted Dams	• Further analysis should be completed on key reservoirs with fill restrictions to determine the degree to which dam rehabilitation and removal of fill restrictions could achieve additional operational storage volume. • Collaborative partnerships between municipal and agricultural water users should be explored as a way to share in the cost of reservoir rehabilitation in some cases.
Enlarge Dams	• In select cases where water is physically and legally available and the reservoir fits into existing system operations, raising the height of a dam could be a feasible option for achieving additional storage in an existing reservoir. • In a dam enlargement situation, significant permitting efforts will be required.
Create New Dam Sites	• Many of the largest of the 6.5 MAF of filed conditional storage water rights greater than 5,000 AF in each basin are decreed for municipal, industrial, and irrigation uses. • When considering future storage options, a larger number of smaller reservoirs do not accomplish the same operational objectives as a mix of larger reservoirs due to significant increases in evaporation losses and the loss of the benefits of economies of scale.
Aquifer Storage and Recovery	• Unconfined/Shallow aquifer storage and recovery projects may be best for near-term or seasonal surface water availability retiming due to potential connections to surface water systems that may limit the duration water can feasibly be stored in the unconfined system. • Confined/Deep aquifer storage and recovery projects may be most applicable for longer-term water storage and can be used in conjunction with a surface water storage system to better enable capture of surface water peak flows and optimize the sizing of the aquifer storage and recovery system.



5.1.5 Economic Impacts Insights

The technical memorandum *Potential Economic Impacts of Not Meeting Projected Gaps* (see Volume 2, Section 9) provides order-of-magnitude estimates of the economic consequences of failing to meet future supply gaps within Colorado and each of its basins. The study was based on data developed for the medium scenario[14] for 2050 M&I gaps from the previous SWSI effort (SWSI 2010), which anticipated a statewide gap for these uses of approximately 390,000 AF per year by 2050[15], and the projected 2050 shortage in water supplies for irrigated agriculture from the previous SWSI study, which was estimated at more than 1.7 MAF per year[16].

The economic analysis conducted for this study was based on a relatively simplified approach consistent with the goal of identifying the general magnitude of the economic consequences of failing to meet future gaps. The analysis focused on the economic implications of projected future gaps for agricultural and M&I uses. There are also significant economic implications for the state and each of its river basins in failing to meet non-consumptive needs for environmental and recreational purposes; however, quantifying the economic implications of shortfalls with respect to non-consumptive needs was beyond the scope of this study.

Three types of economic costs were included:

- Agricultural costs that are already being incurred
- Original costs of a portion of projected future M&I gaps
- Opportunity costs of foregone future economic development

The projected economic impacts of failing to meet the gaps identified in the specific 2010 SWSI demand conditions analyzed in this study provide a number of general insights regarding the importance of Colorado's water planning efforts.

The lack of sufficient supply to meet the full consumptive use requirements for irrigated crops in Colorado already results in an estimated annual loss in potential production value of more than $3 billion and about 28,000 fewer jobs directly and indirectly supported by irrigated agriculture[17]. In many basins, economic impacts on livestock production due to reduced crop and forage output are larger than the economic impacts on the crop producers. Projected gaps in 2050 irrigation water supplies indicate that these reductions in potential agricultural economic activity will continue into the future.

Economic effects of projected M&I gaps depend on the severity of the projected gap in each basin. In areas with smaller M&I gaps relative to projected 2050 demands (less than 10 or 15 percent of projected demand), the primary effects would likely be a substantial reduction in consumer welfare due to greatly reduced water availability for outdoor use and severe effects on the municipal "green industry," involving sectors such as landscape services, nurseries, and car washes. In areas with more severe M&I gaps (greater than 10 or 15 percent of projected future M&I demand), much larger economic impacts are projected due to the opportunity cost of foregone future residential, commercial, and industrial development.

Overall, the potential economic impacts and opportunity costs of the projected gaps in agricultural and M&I water supplies are substantial in every basin in Colorado. From a statewide perspective, failing to meet the gaps identified in the 2010 SWSI demand condition example analyzed in this case study could lead to between 355,000 and 587,000 fewer jobs in Colorado in 2050; $53 to $90 billion fewer dollars in annual economic output; a reduction in gross state product of between $30 and $51 billion per year; $20 to $33 billion in reduced labor income; and $3 to $6 billion fewer dollars in state and local tax revenues. To put these numbers in perspective, the projected economic impacts are equivalent to approximately 9 to 16 percent of current statewide economic output, gross state product, statewide employment, and statewide labor income.

The economic values associated with agricultural water use are substantial but are generally considerably lower than the economic values associated with M&I use. This reality, combined with the flexibility to move water among different uses and locations under Colorado law, implies that there will be continuing economic pressure to shift water from Colorado's farms to its cities and industrial users. Given the importance that the state's residents place on maintaining agriculture in Colorado, as noted in *Observations Regarding Public Perceptions on Water* (Volume 2, Section 12), these economic pressures highlight the need for strategies to mitigate potential future impacts resulting from water transfers that would negatively affect Colorado's agricultural economy. This fact underscores the importance of developing basin-specific water management and supply strategies, and collaborative BIP updates.

5.2 TOOLBOX FOR BASIN ROUNDTABLES

Several tools were developed during the Technical Update that will be useful for basin roundtables during the BIP update process. The tools will be further refined and upgraded in the future as they are used, additional data are gathered, and on-line portals capable of hosting these tools are developed.

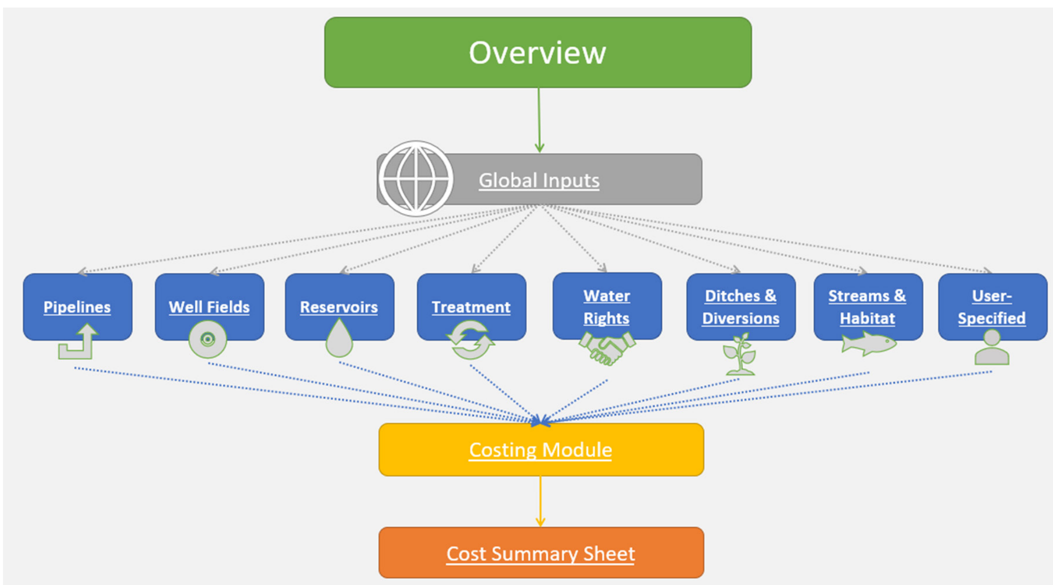
5.2.1 Project Costing Tool

The *Colorado Water Project Cost Estimating Tool* (Cost Estimating Tool) was developed for the Technical Update to provide a common framework for the basin roundtables to develop planning-level project cost estimates. Only 16 percent of the projects and methods listed in previous BIPs included cost estimates. The Cost Estimating Tool provides a baseline cost estimate for use in the planning process and serves as a mechanism to collect useful information for additional planning and tool refinement in future iterations. Its targeted use is for project concepts for which cost estimates have not yet been developed.

Cost Estimating Tool limitations and additional tool functionality recommendations are included in the technical memorandum titled *Colorado Water Project Cost Estimating Tool*, included in Volume 2, Section 5 of the Technical Update.

The Cost Estimating Tool is organized by Project Modules, with each module representing a different type of water supply project. Data from each Project Module is synthesized in the Costing Module and Cost Summary Sheets to develop the overall cost estimate (see Figure 5.2.1).

Figure 5.2.1 Cost Estimating Tool Schematic



Projects Module

The module overview page includes a navigation view of the tool and allows the user to modify global inputs such as project yield, peaking factors, cost indices, and life-cycle and annual costs. Links to each Project Module are also available from the overview page. The Project Modules represent either an entire water project or a component of a large-scale, complex project. The types of projects proposed in BIPs have been pre-loaded into the tool, and users able to customize the parameters associated with their project(s) to reflect a specific design and physical characteristics (see Table 5.2.1). Output from the Project Modules becomes input to the Costing Module.

Table 5.2.1 Project Cost Tool Module Types, Components and Inputs

Project Module	Types	Components	General User Inputs
Pipelines	raw, treated	pipelines, pump stations, storage	project yield and peaking factor, pipeline profile components, pipe size and length, pump type
Well Fields	public supply, aquifer storage and recovery, injection, irrigation wells	wells, booster pumps, pipe network	water table characteristics, project yield and peaking factor, transmission pipeline profile components, number of wells and average production, well depth and capacity, transmission pipe size and length, booster pump capacity
Reservoirs	new reservoir, reservoir expansion, reservoir rehabilitation	reservoir, reservoir rehabilitation, hydropower production	project type, new storage volume, project description, cost of rehabilitation, height of falling water, discharge through hydropower station
Treatment	typical treatment technologies such as direct filtration, conventional, reverse osmosis, etc.	various treatment technologies	average day demand and peaking factor, treatment type
Water Rights	instream flow requirements, recreational in-channel diversion, water supply	cost	total capital cost of water right purchase
Ditches and Diversion	new ditch, ditch rehabilitation	diversion structure, headgate structure, ditch	type of diversion structure, type of headgate structure, maximum diversion discharge/ditch capacity, type of ditch, ditch length
Streams and Habitat	stream restoration, conservation, habitat restoration/species protection, acid mine drainage water treatment	land acquisition, channel improvements, channel structures, channel realignment	stream width range, length of restoration, level of restoration
User-Specified Project	project types not represented by other modules	user-specified	project description, total capital costs, total operations and maintenance costs

Costing Module

The Costing Module brings together information supplied or calculated from the Project Modules to develop planning-level cost estimates. The costs are broken down into construction, project development, and annual costs. Costs are developed based on output from the Project Modules and by applying unit costs or cost curves where available. Unit costs or cost curves are adjustable to account for current market conditions using readily available indices. Other costs are based on industry standard or researched percent values of a direct cost. Values can be adjusted by the user as needed.

The Costing Module provides a final cost summary sheet that includes a summary outline of project costs by type, present-worth calculations, and a normalized cost that can be used for project comparison.

5.2.2 E&R Flow Tool

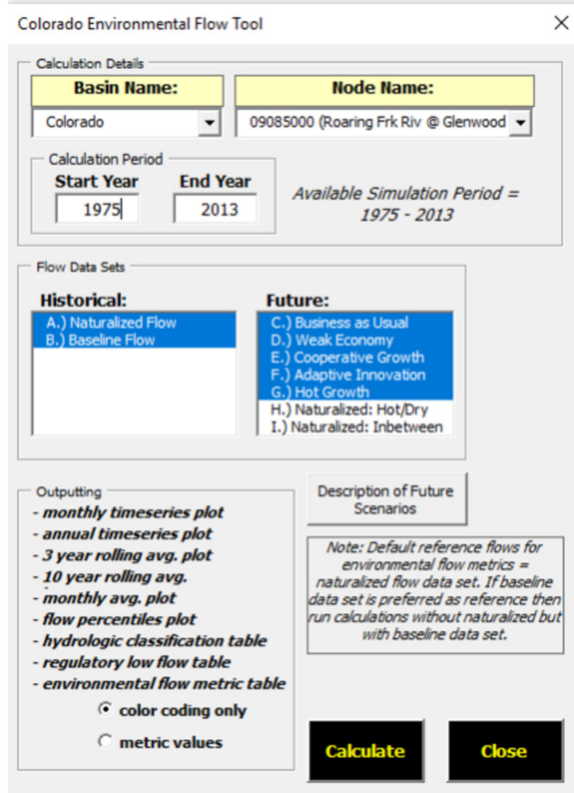
The Technical Update included the development of a Flow Tool designed to assess flow conditions in each basin. The Flow Tool was designed to serve as a resource to help basin roundtables refine, categorize, and prioritize their portfolio of E&R projects and methods through an improved understanding of flow needs and potential flow impairments, both existing and projected. The Flow Tool uses hydrologic data from CDSS, additional modeled hydrologic data for various planning scenarios, and established flow-ecology relationships to assess risks to flows and E&R attribute categories at pre-selected gages across the state.

The Flow Tool was constructed in Microsoft Excel by combining components of the Historical Streamflow Analysis Tool and the Watershed Flow Evaluation Tool. The platform provides a familiar and portable working space for the tool user, and offers standard spreadsheet pre- and post-processing capabilities. User inputs specific to the application of the tool are provided via a user-friendly input form (Figure 5.2.2).

The flow tool provides the following outputs:

- Monthly and annual time series plots
- Three and ten year rolling average time series plots
- Plot of monthly means
- Monthly flow percentile plots
- A tabular summary of annual hydrologic classifications
- A tabular summary of statistical low flow
- A tabular summary of the calculated environmental flow metrics

Table 5.2.2 Example Input Window from Flow Tool



The environmental flows table is generated using the flow-ecology relationships described in Section 2. Numeric output is presented as percent departure from reference flows. Reference flows can be specified as either the naturalized flow dataset (default) or the baseline flow dataset. The table is also color coded based on risk category (from low risk to very high risk). Risk categories are pre-defined by subject matter experts according to percent departure threshold values (compared to reference condition). Risk category thresholds differ for each metric. Flow Tool outputs for all 54 nodes across each of the nine basins are available for review and consideration by basin roundtables. Flow statistics under future planning scenarios can be compared to the timing and magnitude of historical peak and low flows. Risk categories identified through analysis of the environmental flow metrics are also available for review and can inform planning discussion in each basin.

The Flow Tool is easy to use and designed for a range of potential end users; however, adding new stream nodes to the tool is not currently an option available to the user and would require additional programming by the tool developers. While the Flow Tool is intended to provide data for use in planning E&R projects and methods, it is not prescriptive.

The Flow Tool does not:

- Designate any gap values
- Provide the basis for any regulatory actions
- Identify areas where ecological change may be associated with factors other than streamflow
- Provide results as detailed or as accurate as a site-specific analysis

The Flow Tool is intended to be a high-level planning tool that:

- Uses the foundations of the HSAT and Watershed Flow Evaluation Tool to scale to a statewide platform
- Post-processes CDSS projections to provide summaries of changes in monthly flow regime at pre-selected locations under different planning horizons
- Identifies potential risks to E&R attribute categories through flow-ecology calculation projections
- Serves as a complementary tool to CDSS to refine, categorize, and prioritize projects
- Provides guidance during Stream Management Plan development and BIP development

5.2.3 E&R Database

The Nonconsumptive Needs Assessment Database (NCNAdb) was developed in 2010 to help manage nonconsumptive data received by basin roundtables and other stakeholders. The database included information related to nonconsumptive attributes, projects, and protections. A significant focus of the Technical Update has been enhancing the NCNAdb (now referred to as the E&Rdb). The E&Rdb includes an enhanced technical foundation, a more engaging and meaningful user interface, and better integration into the Colorado water planning process.

The E&Rdb is a Microsoft Access database formatted in Microsoft Access 2010 file format. The database contains several tables, queries, and modules. The database uses industry standards such as indexes, keys, referential integrity, normalization, and naming standards for tables and fields.

The core data tables in the E&Rdb are described in Table 5.2.2. A more in-depth data dictionary is provided in the E&Rdb TM included in Volume 2 and is available within the database (tblDataDictionary).

Table 5.2.2 Core Data Tables in the E&Rdb

Table	Description
tblBasin	Contains basin information
tblContact	Contact information such as name, address, phone
tblContactProject	Intermediate table relates contacts to projects
tblDatabaseLog	Used to document modifications to database
tblDataDictionary	Contains all tables/fields and respective attributes within the database
tblProject	Projects
tblProjectProtection	Protections assigned to projects and their attributes
tblSegment	Stream segments
tblSegmentAttributeClass	Attribute classifications for attributes along a given stream segment
tblSegmentProject	List of projects that are related to stream segments, and the length of the segment
tblSegmentIDXRef	Contains cross-reference identification between COMID and GNISID
tblSegmentReach	List of Reaches by COMID

The database contains several tools to help browse, search, and extract data; a project data entry form contains the projects and related information. Predefined reports can be used to view and export data. Querying the database requires experience using Microsoft Access, a solid understanding of the question that is translated to a query, and familiarity with the database design to retrieve the information appropriately. The database includes a Microsoft Excel template that can be used to add or update projects and attributes associated with projects.

5.2.4 Project Database

SWSI 2010 and the BIPs led to the initial development and subsequent revision of project datasets for each basin roundtable. These datasets reflect potential projects and processes identified by stakeholders in each basin that may be developed to meet future water supply needs. Project data across basins are inconsistent in content and format due to the complexity of studies, variation by basin, and number of entities involved. Through the Technical Update, project data were reviewed and formatted to increase the usefulness of data products that can be created and to enhance the consistency of analyses using the data.

Project Dataset Content Standards

After a review of each basin roundtable's project dataset, the principal recommendation for developing a standard project dataset for the Technical Update effort was for the datasets to exist in a Microsoft Excel file (e.g., flat file) format and implement standard dataset fields.

Project Dataset Products

Ultimately, two primary data products were developed through this effort: a consistent standard table reflecting the statewide project dataset and mapping products displaying the project datasets. The original project datasets were inconsistent across each basin, and many of the basins did not provide information that could be represented using standard fields. Original project datasets were converted to the standard project format by interpreting the meaning of project data fields in individual basin's datasets and by using engineering judgement. As reflected in Table 5.2.3, several basins did not have data for all standard fields. In these cases, fields were left blank in the standard project dataset.

Table 5.2.3 Standard Project Data Fields and Presence of Fields in Final Basin Project Datasets

Data Field/Column	Arkansas	Colorado	Gunnison	North Platte	Rio Grande	South Platte / Metro	Southwest	Yampa-White-Green
Project_ID	X	X	X	X	X	X	X	X
Project_Name	X	X	X	X	X	X	X	X
Project_Description	X		X	X			X	X
Project_Keywords								
Status	X	X	X				X	
Lead_Proponent	X	X	X		X	X	X	X
Lead_Contact	X		X	X		X	X	
Municipal_Ind_Need	X	X	X	X	X	X	X	X
Agricultural_Need	X	X	X	X	X		X	X
Envr_Rec_Need	X	X	X	X	X		X	X
Admin_Need					X			
Latitude	X	X	X	X	X	X	X	X
Longitude	X	X	X	X	X	X	X	X
County	X	X	X	X	X	X	X	X
Lat_Long_Flag								
Water_District	X	X	X	X	X	X	X	X
Estimated_Yield	X	X	X			X		
Yield_Units	X	X	X			X		
Estimated_Capacity	X					X		
Capacity_Units	X					X		
Estimated_Cost	X	X	X		X	X		

Uses of Projects Dataset

The availability of required data fields will support several future uses of project datasets:

- **Filtered Lists.** It will be possible to create customized datasets, maps, spreadsheet files, and other formats for use in analysis and visualizations.
- **Maps.** The addition of general location coordinate data for each project allows for all projects to be easily located on maps. A user interested in a particular basin or region can then quickly determine the projects in that area and find more information.

5.3 BIP UPDATES

Recommendations from the Technical Update have been distilled into five "next step" categories: 1) BIP Updates, 2) Project Updates, 3) Technical Updates, 4) Strategic Updates, and 5) Outreach Updates. These recommendations, detailed below, will be used to guide upcoming discussion with Colorado's nine basin roundtables, including future phases of work to update BIPs and the Water Plan.

Each action item is accompanied by a brief background description that provides insight into the history of stakeholder processes and conversations that led to the recommended action. This includes, but is not limited to, input from roundtables; public education, participation and outreach workgroups (known as PEPO); the Interbasin Compact Committee; and the 2018-2019 Implementation Working Group.

The following list of recommendations is intended to provide basin roundtables flexibility in the update process, tailoring approaches to best suit roundtable goals. These recommendations provide a framework for some level of standardization across the BIP updates. This iterative process is meant to support statewide water supply planning, cross-basin dialogue, project funding, enhanced future supply analyses, revised goals, and updated project lists. Integrating Technical Update findings with the BIPs, project lists, and the Colorado Water Plan update ensures state water planning will continue to be informed by the best available data.

5.3.1 BIP Updates

A. Evaluate the scope of BIP updates to integrate Technical Update findings

Basin roundtables will work with the CWCB and their membership to identify how to best update their BIPs. In the first BIP process, the CWCB created a guidance document that each roundtable tailored to suit its own needs. Each roundtable then hired separate contractors to assist with its first plan development. To lighten the level of effort required to update these plans, the CWCB, roundtables, and the IWG reviewed the benefit of hiring a central contractor (selected by the CWCB and roundtable chairs) to support each roundtable and coordinate a path forward. Local expert contractors (selected by each roundtable) will play an important role in supporting the roundtables and the general contractor. A first order of business will be coordinating on the full scope of the BIP update, including an evaluation of core needs (e.g., reviewing project lists) and any additional analysis that may be beneficial to each roundtable.

B. Integrate relevant studies and local plans into BIP updates

Basin roundtables will evaluate which plans and studies should inform and be referenced in their BIPs. As noted by the IWG, several local, regional, and statewide studies are available since the initial BIPs (2015) that may provide important context to basin planning. Examples include stream management plans, conservation plans, forest health studies, climate studies, city/master plans, and resilience plans.

C. Identify opportunities for enhanced data inputs that improve modeling output

Basin roundtables will identify if additional data inputs can support enhanced analysis. In all modeling studies, future projections are only as good as the data that inform the model. In the Technical Update, basin-specific data were limited in certain areas and could likely be refined. For example, municipal irrigated acreage data were not something to which the state had access, which limited the ability to model outdoor municipal water use analysis in more detail; however, municipal providers may have this information, and sharing it could be used to refine the model. Other opportunities exist across municipal, environmental, and agricultural reporting where the Technical Update could likely be enhanced in future iterations with the basin roundtable's help to refine model input data.

5.3.2 Project Updates

A. Enhance planned project data

Basin roundtables will enhance and maintain project data with the help of the contracting team as part of the BIP update. The Technical Update review of basin project lists (previously known as identified projects and processes, or IPPs) recommends 20 data fields to be associated with every project (e.g., project name, location, yield, proponent and cost). The Implementation Working Group reviewed the attribute list and added fields such as water rights and permitting status. While much of the data are not captured in existing project lists, the CWCB is working to develop a project database to assist with consistent data collection and input. This not only helps better support water supply planning needs, but also supports roundtable funding and the refinement of funding needs identified in the Water Plan.

B. Improve project costs in Water Plan

Basin roundtables will update project costs to help confirm Water Plan funding needs. The Water Plan identifies how project cost estimates will be improved upon in the BIP update process. Currently, less than 50 percent of the projects in any BIP have associated costs. To assist in this next step, the Technical Update scope included developing a costing tool to help evaluate project costs. As Water Plan funding is an increasing focus, it is critical to have more accurate cost information to better support how funds would be spent.

C. Assess how to best use project tiers

Basin roundtables will work collectively to help inform simplified and standardized project tiers. To be strategic with limited resources, some level of prioritization is necessary. Three of the eight BIPs already utilize some form of project ranking or tier system. At a minimum, missing data can serve as a de facto tiering system in which projects with clearly listed project proponents, costs, and other data are ranked over those without these data points; however, this needs to be reviewed more carefully as it may not be feasible to have all the data listed based on where a project is in the planning cycle.

To assist with this effort, the IWG reviewed a draft “Project Tier Matrix” that will need to be evaluated further during the BIP updates. The IWG determined that both proof-of-concept and shovel-ready (immediately implementable) projects are equally important to fund. The IWG also saw value in a placeholder category for Projects that may be more conceptual in their current phase but might be fleshed out in the future. This is especially true if the project lists are used establish future funding needs. Similarly, the IWG noted that a tier system should not generate competition in funding between basin roundtables.

5.3.3 Technical Updates

A. Review modeling assumptions + consider refinement

Basin roundtables will review beneficial localized and statewide modeling changes as needed. Every model is based on a set of assumptions. The TAG process reviewed, evaluated, and agreed on baseline model assumptions. However, a number of decision points on additional/refined assumptions arose in later stages of modeling. If roundtables decide additional modeling is desired for their BIP update, roundtables will work with the central contractor to ensure their modeling questions are in-line with baseline model assumptions (to support an “apples-to-apples” analysis). Modeling assumptions cannot be changed in ways that could potentially be used to address sensitive legal issues (local or statewide), conflict with policy, or create divisions across the basins.

B. Consider modeling projects

Basin roundtables will evaluate modeling needs and if/how they choose to model projects. Roundtables may choose to model their own unique variables as appropriate (such as projects). Unlike SWSI 2010, the Technical Update did not include any specific projects (e.g. water savings from planned projects) in the analysis, largely due to insufficient project data. The opportunity remains for roundtables to model their own unique projects to explore offsets to the Technical Update supply gaps. Any modeling would carefully consider potential implications of modeling discrete projects that could conflict with ongoing planning or permitting efforts (or any caveats outlined by the Attorney General’s Office).

C. Review sub-basin modeling needs

Basin roundtables will review need and trade-offs of summarizing more granular subbasin data. Each of the original BIPs divided their basins into tributary regions differently, resulting in regional data and planning at different scales; however, it was unclear if each roundtable found their BIP sub-basin breakouts to be helpful, if they would have done them differently, or if they would potentially need them at all. Additionally, modeling at granular scales is intensive, costly, and complex. The CWCB chose to report modeling findings at the basin level only. If higher resolution data are desirable, regional delineations would require roundtable input.

5.3.4 Strategic Updates

A. Continue to focus on adaptive management strategies through scenario planning

Basin roundtables will evaluate how they can be nimble amidst changing conditions. Adaptive management has been a key component of roundtable and IBCC discussions for many years. This discussion directly informed the adoption of using a scenario planning approach to account for key drivers and uncertainties within the planning horizon (2050). How basin projects and plans can be tested against these variant futures (the five scenarios) or could be shifted to respond to future changes is something that needs to be considered. Projects and basin roundtable planning should be reviewed for impact and responsiveness. This is at the heart of the No-and-Low Regrets Action Plan that comprise not only core strategies in the Water Plan but also received 100 percent consensus by the IBCC and CWCB board. These core strategies aim to establish a set of plans having the highest benefit with the least unintended consequences, regardless of the future condition.

B. Develop signposts with CWCB support

Basin roundtables will work with the CWCB to identify and establish signposts as appropriate. Using signposts, or check-in points, is fundamental to scenario planning. There may be triggers or key indicators that help determine if specific actions are needed and/or there should be a set frequency for review to help determine growth trajectories. A signpost may also be seen as the frequency by which the state and/or basin roundtables look for and review key indicators. Roundtables and the CWCB need to collaborate on the best approach for establishing clear signposts that help provide the necessary review and analysis of current conditions.

C. Evaluate climate extremes for greater integration

Basin roundtables should identify how to best integrate climate change into planning. Climate change factors are incorporated into three of the five scenarios. Beyond temperature, other issues with climate extremes and greater variability are a major concern for acute and chronic impacts. For example, earlier runoff can affect agricultural operations in early and late season. Additionally, the scale of climate extremes, like major floods, may not be reflected in all the current modeling (e.g., the floods of 2013). Issues such as flood, forest fires, invasive species, and drought need to be considered in future planning. Evaluating and planning for climate impacts and extreme weather events with adaptive and resilient management strategies should be a focus that helps with planning for any potential future.

5.3.5 Outreach Updates

A. Enhance water plan goals, messaging and stakeholder engagement

Basin roundtables will work to engage new audiences in water planning and outreach. The Water Plan set education and outreach goals through 2020, which are all on track to be met. Roundtables will review and enhance their Education Action Plans while considering the Statewide Education Action Plan, which is still under development by Water Education Colorado, to further improve coordination and continue the effort to reach beyond the traditional roundtable audience. Each roundtables Education Action Plan will be coordinated with the BIP updates in support of the greater Water Plan goals. The CWCB will need to work across these groups to identify what new outreach goals will need to be established in future plans.

B. Rebrand around the Water Plan for consistency

Basin roundtables will support rebranding that integrates BIPs around the Water Plan. The Technical Update, Basin Implementation Plans, and Water Plan update are all intertwined. Each effort builds on the last and, as such, the collective process informs the comprehensive Water Plan update. Basin roundtables will need to help evaluate creative ways to communicate this comprehensive message using new and innovative strategies. This may include improved data visualization, surveys, statewide events, water-related contests, campaigns, or other means of engaging with and focusing on the Water Plan.

SECTION 6
CITATIONS

[1] Colorado Water Conservation Board, IBCC Annual Report (CWCB, 2012), 78 .

[2] Figure 4.9 in Colorado's Water Plan shows the three composite scenarios selected representing "Hot and Dry", "Between 20th century observed and Hot and Dry" (or "In-Between"), and the current hydrology (or "Baseline Hydrology").

[3] Temperature and precipitation were not attributes that were used in estimates of future hydrologies but are extracted from the datasets to help contextualize what the changes in IWR and runoff relate to. See Technical Update Volume 2 technical memo, "Temperature Offsets and Precipitation Change Factors Implicit in the CRWAS-II Planning Scenarios." A temperature offset (°C) quantifies the predicted temperature change from baseline conditions (1970–1999) to future conditions (2050), summarized as (future = historical + offset). A precipitation change factor (unitless) is the ratio of predicted future (2050) to baseline (1970–1999) precipitation totals, summarized as (future = historical x factor)

[4] The planning scenarios developed for Colorado's Water Plan and this Technical Update were built upon the foundational work of the multiphase Colorado River Water Availability Study, Phase II (CRWAS-II). Detailed methodology and analysis results can be found in CRWAS-II Task 7: Climate Change Approach and Results.

[5] House Bill 2010-1051 requires that the CWCB implement a process for the reporting of water use and conservation data by covered entities. A "covered entity" is defined as each municipality, agency, utility, including any privately owned utility, or other publicly owned entity with a legal obligation to supply, distribute, or otherwise provide water at retail to domestic, commercial, industrial, or public facility customers, and that has a total demand for such customers of two thousand acre-feet or more, per Section 37-60-126(1)(b) of the Colorado Revised Statutes (C.R.S.). 1051 reporting data provided by CWCB for the Technical Update in February 2018.

[6] The adoption rate was applied to all demand categories except for non-revenue water.

[7] Source: https://www.onthesnow.com/colorado/skireport.html

[8] SWSI 2010 did not conduct any surface water modeling but Section 6 of that report provided a cursory review of water availability from existing studies.

[9] Colorado Springs Utilities has water supply to meet additional future demands, and the additional supply was accounted for in gap calculations. Pueblo Board of Water Works did not have an estimate additional future demand that could be met with existing supplies, and gaps were not adjusted.

[10] Source: Contribution of Agricultural to Colorado's Economy (January 2012, Colorado State University Extension)

[11] Source: Rio Grande Basin Implementation Plan (April 2015)

[12] RGDSS represents groups of wells with similar hydraulic characteristics as a "response area", and their combined impact to streams is represented as a "response function". Each Subdistrict represents the geographic area reflected in the RGDSS "response area".

[13] The San Juan Chama Project delivers water from San Juan tributaries to the Rio Grande basin in New Mexico. The baseline and planning scenario models include the current demand and operations, but the project deliveries are not considered a transbasin export for the Technical Update as the project does not operate under a Colorado water right; cannot call out Colorado water users; and the supply is not delivered to a Colorado entity.

[14] Other scenarios examined in the SWSI 2010 analysis projected the 2050 gap in M&I supplies to potentially be as low as 190,000 AFY or as high as 630,000 AFY.

[15] See Table ES-6 from SWSI 2010 Executive Summary.

[16] See Table ES-4 from SWSI 2010 Executive Summary

[17] Based on the estimated existing gap between available water supplies for irrigated agriculture and the full irrigation requirement for current irrigated acres shown in Table ES-3 from SWSI 2010 Executive Summary.

APPENDIX A - *VOLUME II TABLE OF CONTENTS*

CURRENT AND PROJECTED WATER DEMANDS

PROJECTED WATER SUPPLIES AND GAPS

TOOLS FOR BASIN ROUNDTABLES AND WATER STAKEHOLDERS

INSIGHTS FOR BASIN ROUNDTABLES AND WATER STAKEHOLDERS

APPENDIX B - *NARRATIVE TO NUMBERS*

Table 4: Business as Usual Scenario Hydrologic Modeling Inputs

	Relevant Scenario Narrative Language	Key Driver	Water Demand Model Parameter	Input Adjustment (**~no adjustment,** --- large decrease, – moderate **decrease,** - small **decrease,** + small **increase,** ++ moderate **increase,** **+++ large increase)**
M&SSI Demands	By 2050, Colorado's population is close to 9 million people. Single family homes dominate, but there is a slow increase of denser developments in large urban areas. Municipal water conservation efforts slowly increase.	Land Use & Associated Population Growth	Population	~ Per SDO Office Forecast
	The economy goes through regular economic cycles but grows over time.	Economic Growth	Indoor and Outdoor gpcd	~ Economic conditions have similar to historical impact on water use
	The climate is similar to the observed conditions of the 20th century. Municipal water conservation efforts slowly increase.	Climate Conditions	Outdoor gpcd	~ Water use not significantly impacted by climate change
	Social values and regulations remain the same. Regulations are not well coordinated and create increasing uncertainty for local planners and water managers.	Regulations & Technology Change	Indoor and Outdoor gpcd	~ Regulations / technology does not change historic water use
	Social values and regulations remain the same. Willingness to pay for social and environmental mitigation of new water development slowly increases.	Social Values Changes	Indoor and Outdoor gpcd	~ Social values **do not change** historic water use behaviors
Agricultural Demands	Transfer of water from agriculture to urban uses continues. Efforts to mitigate the effects of the transfers slowly increase. Large portions of agricultural land around cities are developed by 2050.	Land Use Changes	Acres of Crops	- - Irrigated agricultural land within and adjacent to city boundaries is converted to housing except in counties with no projected growth
	The climate is similar to the observed conditions of the 20th century.	Climate Conditions	Crop Consumptive Use	~ Similar to recent past
	Agricultural economics continue to be viable, but agricultural water use continues to decline.	Technology Changes	Irrigation Efficiency	~ Similar to recent past
	Social values and regulations remain the same.	Social Values Changes	Crop Types	~ Similar to recent past
Hydrologic	The climate is similar to the observed conditions of the 20th century.	-	Stream Flows	20th century observed
	-	-	Demands	Business as Usual Scenario Demands

APPENDIX B *CONTINUED*

Table 5: Weak Economy Scenario Hydrologic Modeling Inputs

	Relevant Scenario Narrative Language	Key Driver	Water Demand Model Parameter	Input Adjustment (~no adjustment, --- large decrease, -- moderate decrease, - small decrease, + small increase, ++ moderate increase, +++ large increase)
M&SI Demands	Population growth is lower than currently projected, slowing the conversion of agricultural land to housing.	Land Use & Associated Population Growth	Population	- Rural areas have less population decline than SDO forecast & urban areas have less growth than SDO forecast
	The world's economy struggles, and the state's economy is slow to improve. Many sectors of the state's economy, including most water users and water dependent businesses, begin to struggle financially.	Economic Growth	Indoor and Outdoor gpcd	- Poor economy limits water purchases
	Greenhouse gas emissions do not grow as much as currently projected and the climate is similar to the observed conditions of the 20th century.	Climate Conditions	Outdoor gpcd	~ Water use not significantly impact by climate change
	Regulations are not well coordinated and create increasing uncertainty for local planners and water managers. The maintenance of infrastructure, including water facilities, becomes difficult to fund. There is little change in social values, levels of water conservation, urban land use patterns, and environmental regulations.	Regulations & Technology Change	Indoor and Outdoor gpcd	~ Poor economy results in reduced maintenance & increased leakage
	There is little change in social values, levels of water conservation, urban land use patterns, and environmental regulations.	Social Values Changes	Indoor and Outdoor gpcd	~ Social values **do not** change historic water use behaviors
Agricultural Demands	Population growth is lower than currently projected, slowing the conversion of agricultural land to housing. There is little change in social values, levels of water conservation, urban land use patterns, and environmental regulations.	Land Use Changes	Acres of Crops	- Irrigated agricultural land within and adjacent to city boundaries is converted to housing except in counties with no projected growth
	Greenhouse gas emissions do not grow as much as currently projected and the climate is similar to the observed conditions of the 20th century.	Climate Conditions	Crop Consumptive Use	~ Similar to recent past
	There is little change in social values, levels of water conservation, urban land use patterns, and environmental regulations.	Technology Changes	Irrigation Efficiency	~ Similar to recent past
	There is little change in social values, levels of water conservation, urban land use patterns, and environmental regulations.	Social Values Changes	Crop Types	~ Similar to recent past
Hydrologic Modeling Inputs	Greenhouse gas emissions do not grow as much as currently projected and the climate is similar to the observed conditions of the 20th century.	-	Stream Flows	20th century observed
	-	-	Demands	Weak Economy Scenario Demands

APPENDIX B *CONTINUED*

Table 6: Cooperative Growth Scenario Hydrologic Modeling Inputs

	Relevant Scenario Narrative Language	Key Driver	Water Demand Model Parameter	Input Adjustment (~no adjustment, --- large decrease, -- moderate decrease, - small decrease, + small increase, ++ moderate increase, +++ large increase)
M&SSI Demands	Population growth is consistent with current forecasts. Mass transportation planning concentrates more development in urban centers and in mountain resort communities, thereby slowing the loss of agricultural land and reducing the strain on natural resources compared to traditional development.	Land Use & Associated Population Growth	Population	~ Overall urban and rural growth per SDO forecast, but more population in urban areas than suburban areas.
	Broad alliances form to provide for more integrated and efficient planning and development. Eco-tourism thrives.	Economic Growth	Indoor and Outdoor gpcd	~ Economic conditions have similar to historic impact on water use
	There is a moderate warming of the climate, which results in increased water use in all sectors, in turn affecting stream flows and supplies.	Climate Conditions	Outdoor gpcd	+ Moderate warming results in slight increase of outdoor water use
	Coloradans embrace water and energy conservation. New water-saving technologies emerge. Water-development controls are more restrictive and require both high water-use efficiency and environmental and recreation benefits. Environmental regulations are more protective, and include efforts to re-operate water supply projects to reduce effects.	Regulations & Technology Change	Indoor and Outdoor gpcd	- - Water saving technology advancements occur and are required
	Environmental stewardship becomes the norm. Coloradans embrace water and energy conservation. Demand for more water-efficient foods reduces water use. This dynamic reinforces the social value of widespread water efficiency and increased environmental protection.	Social Values Changes	Indoor and Outdoor gpcd	- - Increased conservation behaviors
Agricultural Demands	Population growth is consistent with current forecasts. Mass transportation planning concentrates more development in urban centers and in mountain resort communities, thereby slowing the loss of agricultural land and reducing the strain on natural resources compared to traditional development.	Land Use Changes	Acres of Crops	- Irrigated agricultural land within and adjacent to city boundaries is converted to housing but less dry-up occurs from agricultural water transfers
	There is a moderate warming of the climate, which results in increased water use in all sectors, in turn affecting stream flows and supplies.	Climate Conditions	Crop Consumptive Use	+ Moderate warming
	Coloradans embrace water and energy conservation. New water-saving technologies emerge. Water-development controls are more restrictive and require both high water-use efficiency and environmental and recreation benefits.	Technology Changes	Irrigation Efficiency	~ Agriculture maintains current trends in efficiency improvements
			Crop Types	-
	Environmental stewardship becomes the norm. Coloradans embrace water and energy conservation. Demand for more water-efficient foods reduces water use. This dynamic reinforces the social value of widespread water efficiency and increased environmental protection.	Social Values Changes		Similar to recent past
Hydrologic Modeling Inputs	There is a moderate warming of the climate, which results in increased water use in all sectors, in turn affecting stream flows and supplies.	-	Stream Flows	In-between 20th century observed and hot and dry
		-	Demands	Cooperative Growth Scenario Demands

APPENDIX B *CONTINUED*

Table 7: Adaptive Innovation Scenario Hydrologic Modeling Inputs

	Relevant Scenario Narrative Language	Key Driver	Water Demand Model Parameter	Input Adjustment (~no adjustment, --- large decrease, -- moderate decrease, - small decrease, + small increase, ++ moderate increase, +++ large increase)
M&SSI Demands	The relatively cooler weather in Colorado (due to its higher elevation) and the high-tech job market cause population to grow faster than currently projected. More food is bought locally, increasing local food prices and reducing the loss of agricultural land to urban development. More compact urban development occurs through innovations in mass transit.	Land Use & Associated Population Growth	Population	+ More population growth than forecasted by SDO with greatest growth in urban areas
	Renewable and clean energy become dominant. Colorado is a research hub and has a strong economy. The warmer climate reduces global food production increasing the market for local agriculture and food imports to Colorado	Economic Growth	Indoor and Outdoor gpcd	~ Economic conditions have similar to historic impact on water use
	A much warmer climate causes major environmental problems globally and locally.	Climate Conditions	Outdoor gpcd	++ Significant warming results in increased outdoor water use
	Technological innovation becomes the dominant solution. Strong investments in research lead to breakthrough efficiencies in the use of natural resources, including water. The warmer climate increases demand for irrigation water in agriculture and municipal uses, but innovative technology mitigates the increased demand. The regulations are well defined and permitting outcomes are predictable and expedited.	Regulations & Technology Change	Indoor and Outdoor gpcd	- - Water saving technology advancements occur and are required
	Social attitudes shift to a shared responsibility to address problems	Social Values Changes	Indoor and Outdoor gpcd	- - Increased conservation behaviors
Agricultural Demands	More food is bought locally, increasing local food prices and reducing the loss of agricultural land to urban development.	Land Use Changes	Acres of Crops	- Irrigated agricultural land within and adjacent to city boundaries is converted to housing but less dry-up occurs from agricultural water transfers
	A much warmer climate causes major environmental problems globally and locally.	Climate Conditions	Crop Consumptive Use	++ Much warmer
	The warmer climate increases demand for irrigation water in agriculture and municipal uses, but innovative technology mitigates the increased demand.	Technology Changes	Irrigation Efficiency	+ New technologies increase efficiency
	The warmer climate reduces global food production increasing the market for local agriculture and food imports to Colorado. More food is bought locally, increasing local food prices and reducing the loss of agricultural land to urban development.	Social Values Changes	Crop Types	- Demand for locally grown foods allows for investment in new irrigation efficiency technologies and crops. Increased temperatures and drier conditions lead to crop hybrids that consume less water.
Hydrologic Modeling Inputs	A much warmer climate causes major environmental problems globally and locally. Droughts and floods become more extreme.	-	Stream Flows	Hot and dry
		-	Demands	Adaptive Innovation Scenario Demands

APPENDIX B *CONTINUED*

Table 8: Hot Growth Scenario Hydrologic Modeling Inputs

	Relevant Scenario Narrative Language	Key Driver	Water Demand Model Parameter	Input Adjustment (~no adjustment, --- large decrease, -- moderate decrease, - small decrease, + small increase, ++ moderate increase, +++ large increase)
M&SSI Demands	A vibrant economy fuels population growth and development throughout the state. Families prefer low-density housing and many seek rural properties, ranchettes, and mountain living. Agricultural and other open lands are rapidly developed. A much warmer global climate brings more people to Colorado with its relatively cooler climate.	Land Use & Associated Population Growth	Population	+ More population growth than forecasted by SDO with growth in both urban and suburban areas
	A vibrant economy fuels population growth and development throughout the state. Worldwide demand for agricultural products rises, greatly increasing food prices. Fossil fuel is the dominant energy source, and there is large production of oil shale, coal, natural gas, and oil in the state.	Economic Growth	Indoor and Outdoor gpcd	++ Increased oil and gas production increases water use
	Hot and dry conditions lead to a decline in stream flows and water supplies. A much warmer global climate brings more people to Colorado with its relatively cooler climate.	Climate Conditions	Outdoor gpcd	++ Significant warming results in increased outdoor water use
	Regulations are relaxed in favor of flexibility to promote and pursue business development.	Regulations & Technology Change	Indoor and Outdoor gpcd	+ Regulations are relaxed in favor of business
	Regulations are relaxed in favor of flexibility to promote and pursue business development.	Social Values Changes	Indoor and Outdoor gpcd	~ Social values do not change historic water use behaviors
Agricultural Demands	Agricultural and other open lands are rapidly developed.	Land Use Changes	Acres of Crops	- - - More agricultural land near cities and in rural areas is converted to housing and more irrigated land is dried up for agricultural water transfers
	Hot and dry conditions lead to a decline in stream flows and water supplies. A much warmer global climate brings more people to Colorado with its relatively cooler climate. A hotter climate decreases global food production. Worldwide demand for agricultural products rises, greatly increasing food prices.	Climate Conditions	Crop Consumptive Use	++ Much warmer
	Regulations are relaxed in favor of flexibility to promote and pursue business development.	Technology Changes	Irrigation Efficiency	~ Similar to recent past
	Agricultural and other open lands are rapidly developed.	Social Values Changes	Crop Types	~ Similar to recent past
Hydrologic Modeling Inputs	Hot and dry conditions lead to a decline in stream flows and water supplies. Droughts and floods become more extreme.	-	Stream Flows	Hot and dry
		-	Demands	Hot Growth Scenario Demands

APPENDIX C - *CONSULTANT TEAM*

Technical Update to the Colorado Water Plan Consultant Teams		
Prime Consultant	**Subconsultants**	**Subconsultant Responsibilities**
Brown and Caldwell	CDR Associates	Facilitation (if needed)
	HDR Engineering, Inc.	Facilitation and public relations assistance (if needed), technical advisors related to general water resources
	Lynker Technologies, Inc.	Technical advisors related to general water resources and climate change
CDM Smith	The Nature Conservancy	Technical advisors related to environmental and recreational needs, gaps, etc.
Jacobs	BBC Research & Consulting	Research and calculations related to population estimates and water-related values
	ELEMENT Water Consulting	Research and calculations related to municipal and self-supplied industrial water demands and water conservation
	The Open Water Foundation	IPP information development
	Southwest Water Resource Consulting	Technical advisors related to planning scenarios
	Wilson Water Group	Research and calculations related to water supplies, projects and methods, and gap analyses

APPENDIX D - *TECHNICAL ADVISORY GROUP (TAG) & IMPLEMENTATION WORKING GROUP (IWG) PARTICIPANTS*

Technical Advisory Group Participant List (July 2017)			
NAME	**BASIN**	**ORGANIZATION**	**TAG**
Laurna Kaatz	Metro	Denver Water	Planning Scenario
Joe Frank	South Platte	Lower South Platte WCD	Planning Scenario
Frank Kugel	Gunnison	Upper Gunnison WCD	Planning Scenario
Steve Harris	Southwest	Harris Water Engineering	Planning Scenario
Cary Denison	Gunnison	Trout Unlimited, Gunnison Basin	Planning Scenario
Jim Hall	South Platte	Northern Water Conservancy District	Planning Scenario
Heather Dutton	Rio Grande	San Luis Valley WCD	Planning Scenario
Kevin McBride	Yampa/White	Upper Yampa WCD	Planning Scenario
Jim Broderick	Arkansas	Southeastern WCD	Planning Scenario
John Currier	Colorado	Colorado River WCD	Planning Scenario
David Graf	Gunnison, CO & SW	Colorado Parks and Wildlife	Planning Scenario
Ken Neubecker	Colorado (Enviro Rep)	American Rivers	Environmental & Recreational
Cary Denison	Gunnison (Enviro Rep)	Trout Unlimited	Environmental & Recreational
David Nickum	Metro (Enviro Rep)	Trout Unlimited	Environmental & Recreational
Barbara Vasquez	North Platte (Enviro Rep)	At-large	Environmental & Recreational
Rio de la Vista	Rio Grande (Enviro Rep)	Rio Grande Headwaters Land Trust	Environmental & Recreational
Jason Roudebush	South Platte	Ducks Unlimited	Environmental & Recreational
SeEtta Moss	Arkansas (Rec Rep)	Arkansas Basin Roundtable	Environmental & Recreational
Tim Hunter	Southwest (Rec Rep)	At-large	Environmental & Recreational
Geoff Blakeslee	Yampa White (Enviro Rep)	The Nature Conservancy	Environmental & Recreational
Kent Vertrees	Yampa White (Rec Rep)	Steamboat Powdercats	Environmental & Recreational
Pete Conovitz	Statewide	Colorado Parks and Wildlife	Environmental & Recreational
Mickey O'Hara	Statewide	Colorado Water Trust	Environmental & Recreational
Laura Belanger	Statewide	Western Resource Advocates	Environmental & Recreational
Tammy Allen	Statewide	CDPHE	Environmental & Recreational
Matt Rice	Statewide	American Rivers	Environmental & Recreational
Nathan Fey	Statewide	American Whitewater	Environmental & Recreational
Greg Fisher	Metro	Denver Water	Municipal & Industrial
Lyle Whitney	Metro	Aurora Water	Municipal & Industrial
Rick Marsicek	Metro	South Metro Water Supply Authority	Municipal & Industrial
Liesl Hans	South Platte	City of Fort Collins	Municipal & Industrial
Katie Melander	South Platte	Northern Water	Municipal & Industrial
Ben Moline	South Platte	Molson Coors	Municipal & Industrial
Scott Winter	Arkansas	Colorado Springs Utilities	Municipal & Industrial
Alan Ward	Arkansas	Pueblo Water	Municipal & Industrial

APPENDIX D *CONTINUED*

Technical Advisory Group Participant List (July 2017), continued			
NAME	**BASIN**	**ORGANIZATION**	**TAG**
Maureen Egan	Colorado	Eagle River Water San. Dist.	Municipal & Industrial
Rick Brinkman	Gunnison & Colorado	City of Grand Junction	Municipal & Industrial
Jackie Brown	Yampa/White	Tri State	Municipal & Industrial
Ann Bunting	Rio Grande	Town of Crestone	Municipal & Industrial
Ed Tolin	Southwest	La Plata Archuleta Water District	Municipal & Industrial
Richard Belt	Statewide	Xcel Energy	Municipal & Industrial
Jorge Figueroa	Statewide	Western Resource Advocates	Municipal & Industrial
Kelley Thompson	Statewide	Colorado DWR	Agriculture
Perry Cabot	Statewide	CSU Extension	Agriculture
Cindy Lair	Statewide	Colorado Dept of Agriculture	Agriculture
Tom Trout	Statewide	USDA	Agriculture
Terry Fankhauser	Statewide	Colorado Cattlemen's Association	Agriculture
Eric Wilkinson	South Platte	Northern Water	Agriculture
Mark Sponslor	South Platte	Colorado Corn	Agriculture
Jim Yahn	South Platte	South Platte Roundtable	Agriculture
Joe Frank	South Platte	South Platte Roundtable	Agriculture
T. Wright Dickinson	Yampa/White	Yampa Roundtable	Agriculture
Mary Brown	Yampa/White	Yampa Roundtable	Agriculture
Ty Wattenberg	North Platte	North Platte Roundtable	Agriculture
Travis Smith	Rio Grande	Rio Grande Roundtable	Agriculture
Ken Curtis	Southwest	Southwest Roundtable	Agriculture
Terry Scanga	Arkansas	Arkansas Roundtable	Agriculture
Jack Goble	Arkansas	Arkansas Roundtable	Agriculture
Paul Bruchez	Colorado	Colorado Roundtable	Agriculture
Frank Kugel	Gunnison	Gunnison Roundtable	Agriculture

APPENDIX D *CONTINUED*

Implementation Working Group Participant List (January 2019)	
NAME	**BASIN**
Terry Scanga	Arkansas
Amber Shanklin	Arkansas
Abby Ortega	Arkansas
Jim Pokrandt	Colorado
Ken Neubecker	Colorado
Mike Wageck	Colorado
Joanne Fagan	Gunnison
Frank Kugel	Gunnison
Cary Denison	Gunnison
Lisa Darling	Metro
Casey Davenhill	Metro
Rick Marsicek	Metro
Curran Trick	North Platte
Kent Crowder	North Platte
Barbara Vasquez	North Platte
Ty Wattenberg	North Platte
Heather Dutton	Rio Grande
Emma Reesor	Rio Grande
Daniel Boyes	Rio Grande
Judy Lopez	Rio Grande
Sean Cronin	South
Lisa McVicker	South
Mike Shimmin	South
Mely Whiting	Southwest
Philip Johnson	Southwest
Karen Guglielmone	Southwest
Kevin McBride	Yampa
Alden Brink	Yampa
Jackie Brown	Yampa
Kelly Romero-Heaney	Yampa

COLLABORATING ON COLORADO'S WATER FUTURE

SECTION 1
INTRODUCTION

Clean and reliable water supplies are essential to our way of life. All of us—agricultural producers, urbanites, environmentalists, and recreationalists—depend on it for healthy lifestyles, a vibrant economy, and a beautiful environment. These are the reasons we call Colorado home, the qualities that attract new Colorado residents, and the drivers of the Colorado Water Plan (Water Plan).

Colorado's water supplies are limited, yet our demands on those supplies continue to increase. Throughout Colorado's history, and especially in recent decades, we have experienced severe drought conditions, extreme flooding events, population booms, and economic recessions. These extremes often reflect larger shifts that highlight the importance of resiliency in our water supplies, and the need for thoughtful, collaborative planning.

The Colorado Water Plan provides a framework for developing resilient responses to our water-related challenges. It articulates a vision for collaborative and balanced water solutions led by the Colorado Water Conservation Board (CWCB) and our grassroots basin roundtable structure. The Water Plan's success will be fostered by the development of technical information and robust analysis tools that support informed decision making on how to tackle our State's challenges.

Following the 2015 launch of the Water Plan and BIPs, the CWCB began a process of updating the underlying water supply and demand analyses. The work included collaboration with TAGs, which included diverse basin roundtable representatives from each basin and subject matter experts. The TAGs helped outline the methods to be used in the Analysis and Technical Update to the Colorado Water Plan, hereafter Technical Update (formerly known as the Statewide Water Supply Initiative or SWSI), which establishes a new approach to statewide water analysis and data sharing.

While this effort stems from past water supply and demand projections (SWSI I, SWSI II, and SWSI 2010), it is markedly different in its scope and approach. Key features include more robust modeling, integration of scenario planning, incorporation of climate change, and the development of functional support tools to promote data refinement. With these enhancements, the Technical Update sets the stage for enhanced basin-level planning.

The Technical Update methods and results are described in this report, along with a description of how the study fits into the next phases of Colorado water planning. Designed for accessibility, this document summarizes the findings of the analysis and is supported by additional technical memoranda and data that can be accessed at www.colorado.gov/cowaterplan.

1.1 COLORADO'S STATEWIDE WATER PLANNING CYCLE

1.1.1 Colorado's Statewide Water Planning Cycle & Recent Water Planning Efforts

In the early 2000s, severe statewide drought, combined with increasing water demands, spurred Colorado's General Assembly to undertake long-term water planning initiatives. One key initiative established the nine basin roundtables as well as the creation of the Interbasin Compact Committee (IBCC). A second key action was the initiation of the Statewide Water Supply Initiative (SWSI). The latter, created a statewide technical analysis to quantify future demands and potential gaps in the ability to supply Colorado's water needs. The roundtables formalized a grassroots process to bolster communication and collaboration within and between major river basins.

Since the early 2000s, Colorado's statewide planning process has evolved to include additional planning phases that foster communication, transparency, and action. Updates to the SWSI data sets and analyses provided new and enhanced information for basin roundtables to use in developing strategies and tangible solutions to meet future consumptive and nonconsumptive needs.

In 2015, BIPs were completed to provide basin-focused portfolios of solutions to projected supply gaps. The BIPs provided basin-level details to the Colorado Water Plan, which sets statewide policy and implementation strategies to meet current and future water-related challenges. The timeline on the following page summarizes major water planning efforts since 2003.

2000

2002 — MAJOR DROUGHT

The 2002-2003 drought and the 2002 Hayman Fire (Colorado's largest fire) trigger legislative action that focused on water supply planning and statewide collaboration.

2004 — SWSI I

The first Statewide Water Supply Initiative (SWSI I) provided quantification of current and future water needs through 2030.

2005 — WATER FOR THE 21st CENTURY ACT

The Water for the 21st Century Act created the nine basin roundtables and the Interbasin Compact Committee (IBCC) in an effort to build more collaborative cross-basin water planning.

2007 — SWSI II

The second phase of SWSI (SWSI II) established technical roundtable groups for Conservation, Alternative Agriculture Water Transfers, Environment and Recreation, and Water Supply Gaps.

2010 — SWSI 2010

SWSI 2010 incorporated SWSI II work group findings, analyzed future water needs through 2050, and served as the technical foundation for the Colorado Water Plan.

2015 — THE COLORADO WATER PLAN

The Colorado Water Plan (Water Plan) brought together statewide planning objectives and local implementation activities under a common banner.

2017 — RIPPLE EFFECTS

Provided an update of progress made toward meeting the actions and objectives of the Water Plan.

2019 — TECHNICAL UPDATE

In keeping with goals of the Water Plan to update SWSI efforts, the Technical Update launched in Summer 2019.

2020 — NEXT STEPS

Building on 2018-2019 BIP update scoping, basins will work with the CWCB to use the methodologies, findings and recommendations from the Technical Update to revise BIPs and update the Water Plan.

Moving Forward Under the Colorado Water Plan

Colorado water users understand that making specific predictions of future conditions is impossible. From precipitation to population, there are any number of possible shifts that could significantly impact water availability. Being responsive to these drivers of change requires thoughtful planning and adaptive management. This involves using the best data available to predict a range of variant futures, which helps ensure Colorado's water planning is robust and flexible enough to address future concerns. The five planning scenarios identified in the Colorado Water Plan were born from this effort and were developed through an iterative process with the basin roundtables and the IBCC.

Holistic Planning

Colorado recognizes the evolutionary nature of water resource planning and implementation. The two are not mutually exclusive, and occur simultaneously at several scales. Colorado's cyclical, statewide planning process is made up of three phases:

A **Analysis and Technical Update Phase** – includes the statewide Analysis and Technical Update to the Water Plan with standard tools, datasets, and analyses quantifying future supplies, demands, and resource gaps.

B **Basin Plan Update Phase** – includes local, basin-wide planning conducted through BIP updates that integrate information from the analysis phase and work to identify projects that address gaps and other priority basin needs.

C **Comprehensive Update Phase** – includes the Water Plan update itself with a focus on metrics, goals, timelines, and strategies that honor the values in the Water Plan and work toward implementation.

These phases occur cyclically and are, by design, iterative. To that end, the Water Plan process in its entirety (phases A, B, and C) are constantly being updated, planned for, and implemented. Each phase works in concert to refine the understanding of existing and future gaps in water supply and to identify solutions for addressing these gaps.

1.1.2 Advanced Methodologies and Refined Objectives

Advanced Methodology

The Technical Update addresses a variety of questions using new TAG-supported methodologies and analysis tools. The analysis leverages the State's 25+ year investment in Colorado's Decision Support Systems (CDSS), which has made significant gains in basin modeling since SWSI 2010. Use of CDSS and more robust modeling has been incorporated into the new analysis methodologies.

The new analysis tools help prepare for the future in a more robust manner; however, more in-depth modeling capabilities also help us shed light on new questions that previous SWSI studies were not able to accurately integrate or fully consider, such as potential effects of climate change, variable hydrology, and water rights. At the same time, several new planning concepts are being incorporated into the Technical Update that were not part of prior versions of SWSI. Most notably, incorporating the scenarios in the Water Plan offers a new way of evaluating Colorado's water needs that is significantly different from earlier versions of SWSI. A shortlist of key differences in this Technical Update and SWSI 2010 follows:

- **Scenario planning and adaptive management**

  The Colorado Water Plan developed five plausible water supply/demand year 2050 scenarios that consider varying levels of high-impact drivers such as population increase, agricultural water needs, adoption of conservation measures, social values, and climate conditions. These scenarios are foundational to the analyses and modeling in this Technical Update.

- **Climate change impacts to demand and supply**

  Climate change is a consideration in three of the five planning scenarios described in the Colorado Water Plan. The Technical Update evaluates how potential impacts from climate change affect flows, diversions, crop demand, reservoir storage and more through the use of StateMod water allocation models and StateCU consumptive use models that have been fully developed in most basins. These CDSS modeling tools enable analysis of variable supply and demand conditions and provide a broader view of gaps and how they may vary in response to changing supply and demand drivers.

- **Agricultural diversion demand gaps**

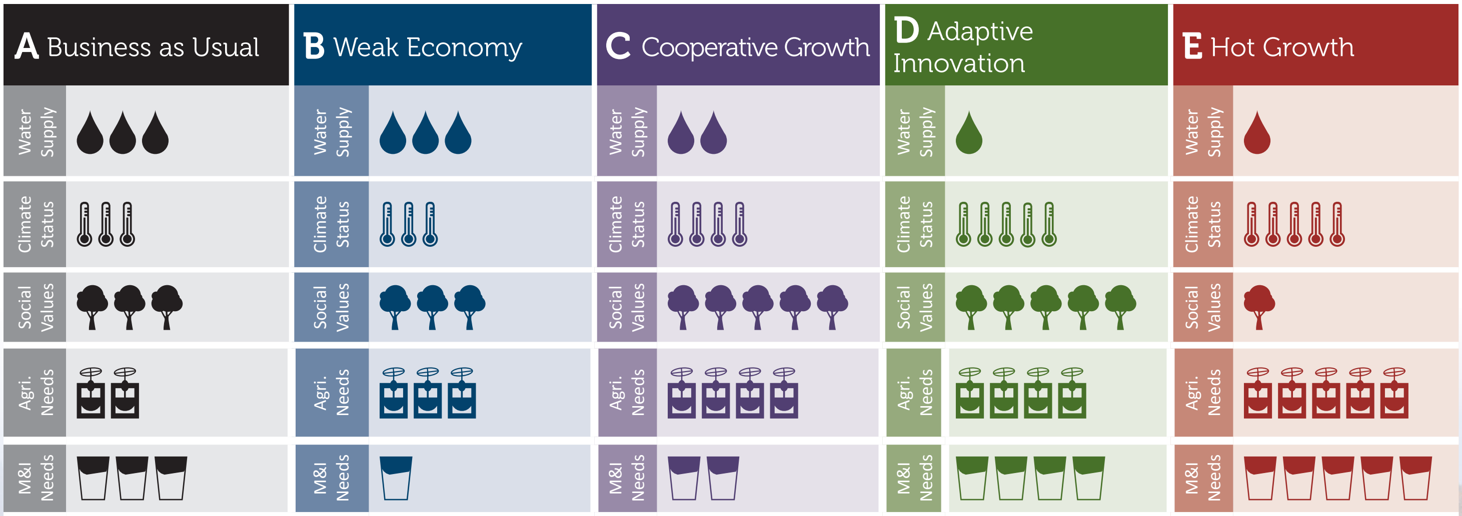
  The SWSI 2010 update quantified historical, field-level agricultural water shortages by comparing crop water demands with historical water deliveries to farms. The Technical Update takes this a step further by using CDSS consumptive use and water allocation models to estimate agricultural gaps in terms of agricultural diversion demands. Diversion demands account for crop demands, application and conveyance efficiencies, and available supply. As a result, agricultural gaps are larger than the field-level shortages quantified in SWSI 2010. The previous methodology was updated to provide basin roundtables with information and tools to use in analyzing "what if" scenarios and for evaluating the effectiveness of future projects, and to provide consistency with estimates of municipal and industrial demands.

Refined Objectives

Given the context and the new planning concepts described above, the primary objectives of the Technical Update report are to:

- Update and recharacterize future gaps and the ability to meet municipal, self-supplied industrial, and agricultural water needs. This recharacterization considers variable hydrology and variable demands in the context of five planning scenarios. The results help basin roundtables account for future uncertainties and develop planning strategies to mitigate future shortages.
- Evaluate environmental and recreational flow needs with new tools. The tools include an enhanced database of E&R attributes and a standardized tool for high-level review of future scenario impacts on streamflows.
- Create user-friendly standardized tools and data products for BIP updates, basin-level project and cost planning, and improved communication and outreach—all aimed at helping basins mitigate future shortages.

Figure 1.1.1 CWP Planning Scenarios and Key Drivers Graphical Summary



1.2 TECHNICAL ADVISORY GROUPS AND OUTREACH

The CWCB enlisted TAGs to develop analysis methodologies and modeling inputs in a collaborative manner. Four TAGs were formed consisting of stakeholders, subject matter experts, and basin roundtable members. The TAGs focused on the following four topics:

- Planning Scenarios
- Environment and Recreation
- Municipal and Self-supplied Demands
- Agricultural Diversion Demands

Each TAG evaluated proposed methodologies through a similar process. First, draft methodologies were distributed to TAG members for review. Comments were discussed at length in the first of two TAG workshops. Consultants updated draft methodologies in response to comments and active discussion and then redistributed the revised drafts to TAG members for re-review. A second meeting was held to describe changes to the methodologies and discuss any final concerns. All final technical memoranda were posted to the CWCB website. A list of TAG members, their organizations, and the basins they represent are included in Appendix D.

In addition to TAG meetings, CWCB staff used the following outreach efforts during the Technical Update process:

- Produced easy-to-read fact sheets that summarized proposed Technical Update methodologies
- Presented progress reports at CWCB board meetings and basin roundtable meetings
- Held targeted stakeholder meetings with basin stakeholders (many of whom were TAG members) to obtain basin-specific information to improve modeling input data
- Hosted webinars to present methodologies and results of various Technical Update components
- Gave presentations at water-related forums such as Colorado Water Congress, farm shows, and conventions
- Conducted live polling and surveys at various intervals to allow for real-time feedback throughout the update process
- Updated and maintained website content, including recordings of various meetings
- Sought feedback from the Implementation Working Group—a group convened by the CWCB that includes basin roundtable and Interbasin Compact Committee members—to help inform Technical Update recommendations and next steps.

SECTION 2
METHODOLOGIES

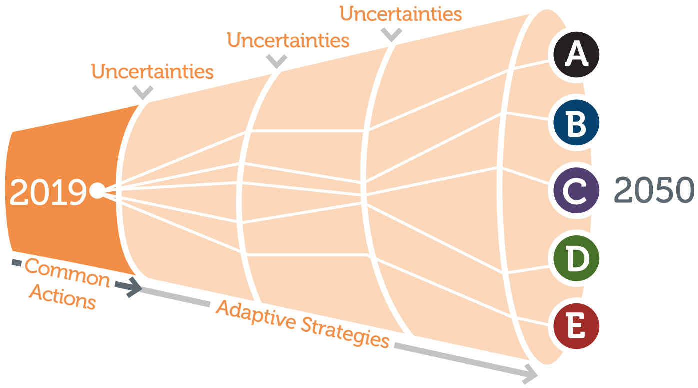
The analysis methodologies used in the Technical Update are summarized in this section. The technical memoranda describing these methodologies can be found in Volume 2. See Appendix A for a comprehensive list of technical memoranda.

2.1 SCENARIO PLANNING

2.1.1 Description of Scenario Planning

Scenario planning is a strategic foresight planning process that acknowledges the future is uncertain. Colorado's Water Plan enlists scenario planning to consider a wide range of possible futures according to the best available science and stakeholder input. The approach embraces inherent uncertainties in future climate conditions, social conditions (such as values and economics), and supply-demand conditions (e.g., energy, agricultural, and municipal needs).

Figure 2.1.1 Illustration of Scenario Planning Concepts



Scenario planning and adaptive management allow decision makers and water users the flexibility to track environmental and social changes over time that provide insights into which future conditions might become more likely as time passes (see Figure 2.1.1). The scenario planning method varies from a more simplistic application of high, medium, and low stress conditions (used in SWSI 2010) by acknowledging that the future holds a degree of uncertainty, depending on a variety of environmental and social drivers.

The scenario planning method includes the following six general steps.

Previous steps conducted by IBCC and described in the Colorado Water Plan	*Steps that are part of this Technical Update*	*Future steps that are to be completed by basin roundtables in BIP updates*
1 Develop expansive list of drivers that can influence future water planning conditions	**4** Quantify future supply and demand conditions for each scenario per identified drivers	**6** Develop projects and strategies that can be used to address gaps for each planning future
2 Identify most uncertain and most important key drivers	**5** Calculate baseline supply versus demand gaps for each scenario without considering future projects or strategies that may address the calculated gap	
3 Develop scenario narratives that define different plausible futures that warrant planning		

2.1.2 Development of the Planning Scenarios

Before developing the Colorado Water Plan, the CWCB initiated a multi-year stakeholder process in conjunction with the nine basin roundtables and the IBCC. Each roundtable developed one or more statewide water supply portfolios to respond to the projected low, medium, or high future water needs of communities. The IBCC subsequently synthesized and reduced the basin roundtable-generated portfolios into a smaller set of 10 representative portfolios to address projected low-, mid-, and high-range M&I water demands. The IBCC then developed a list of the following nine high-impact drivers that could greatly influence the direction of Colorado's water future. Using these drivers, the IBCC developed five scenarios that represent how Colorado's water future might look in 2050, knowing that the future is unpredictable and will contain a mix of multiple scenarios.

1. Population/Economic Growth
2. Social/Environmental Values
3. Climate Change/Water Supply Availability
4. Urban Land Use/Urban Growth Patterns
5. Energy Economics/Water Demand
6. Level of Regulatory Oversight/Constraint
7. Agricultural Economics/Water Demand
8. Municipal and Industrial Water Demands
9. Availability of Water-Efficient Technologies

Signpost Indicators

The adaptive management framework recognizes that the future hinges on how much the drivers (scenario variables) change over time. Major changes in the drivers could tip the still-evolving future toward one scenario or another. The tipping points serve as water management decision points, (i.e., "signposts") that can lead toward the need to implement an alternative portfolio of solutions. Signposts were defined in the Water Plan as decision points that reveal whether past uncertainties now have more clarity. Signposts are a key part of scenario planning, but signpost development was not part of the Technical Update scope. Like project lists, signposts may be unique to regions or specific industries. Signposts could be developed in collaboration with basin planning efforts to identify specific indicators and criteria that signal a need for a new suite of projects or strategies. Alternatively, signposts may be seen as the frequency by which the state and/or basin roundtables evaluate and review key indicators. Section 5 of the Technical Update describes recommendations for the future establishment of signposts.

2.1.3 Description of the Planning Scenarios

The five planning scenarios are summarized in the Water Plan with names portraying each scenario's respective depiction of the future.[1] A summary graphic (see Figure 2.1.2) shows the relative increase and decrease for five main drivers compared to current levels. A full description of each planning scenario follows.

A. Business as Usual. Recent trends continue into the future. Few unanticipated events occur. The economy goes through regular economic cycles but grows over time. By 2050, Colorado's population is close to 9 million people. Single family homes dominate, but there is a slow increase of denser developments in large urban areas. Social values and regulations remain the same, but streamflow and water supplies show increased stress. Regulations are not well coordinated and create increasing uncertainty for local planners and water managers. Willingness to pay for social and environmental mitigation of new water development slowly increases. Municipal water conservation efforts slowly increase. Oil-shale development continues to be researched as an option. Large portions of agricultural land around cities are developed by 2050. Transfer of water from agriculture to urban uses continues. Efforts to mitigate the effects of the transfers slowly increase. Agricultural economics continue to be viable, but agricultural water use continues to decline. The climate is similar to the observed conditions of the 20th century.

B. Weak Economy. The world's economy struggles, and the state's economy is slow to improve. Population growth is lower than currently projected, which is slowing the conversion of agricultural land to housing. The maintenance of infrastructure, including water facilities, becomes difficult to fund. Many sectors of the State's economy, including most water users and water-dependent businesses, begin to struggle financially. There is little change in social values, levels of water conservation, urban land use patterns, and environmental regulations. Regulations are not well coordinated and create increasing uncertainty for local planners and water managers. Willingness to pay for social and environmental mitigation decreases due to economic concerns. Greenhouse gas emissions do not grow as much as projected, and the climate is similar to the observed conditions of the 20th century.

C. Cooperative Growth. Environmental stewardship becomes the norm. Broad alliances form to provide for more integrated and efficient planning and development. Population growth is consistent with current forecasts. Mass transportation planning concentrates more development in urban centers and mountain resort communities, thereby slowing the loss of agricultural land and reducing the strain on natural resources compared to traditional development. Coloradans embrace water and energy conservation. New water-saving technologies emerge. Ecotourism thrives. Water-development controls are more restrictive and require both high water-use efficiency and environmental and recreation benefits. Environmental regulations are more protective and include efforts to reoperate water supply projects to reduce effects. Demand for more water-efficient foods reduces water use. There is a moderate warming of the climate, which results in increased water use in all sectors and in turn, affects streamflow and supplies. This dynamic reinforces the social value of widespread water efficiency and increased environmental protection.

D. Adaptive Innovation. A much warmer climate causes major environmental problems globally and locally. Social attitudes shift to a shared responsibility to address problems. Technological innovation becomes the dominant solution. Strong investments in research lead to breakthrough efficiencies in the use of natural resources, including water. Renewable and clean energy become dominant. Colorado is a research hub and has a strong economy. The relatively cooler weather in Colorado (due to its higher elevation) and the high-tech job market cause population to grow faster than currently projected. The warmer climate increases demand for irrigation water in agriculture and municipal uses, but innovative technology mitigates the increased demand. The warmer climate reduces global food production, which increases the market for local agriculture and food imports to Colorado. More food is bought locally, which increases local food prices and reduces the loss of agricultural land to urban development. Higher water efficiency helps maintain streamflow, even as water supplies decline. The regulations are well defined, and permitting outcomes are predictable and expedited. The environment declines and shifts to becoming habitat for warmer-weather species. Droughts and floods become more extreme. More compact urban development occurs through innovations in mass transit.

E. Hot Growth. A vibrant economy fuels population growth and development throughout the state. Regulations are relaxed in favor of flexibility to promote and pursue business development. A much warmer global climate brings more people to Colorado with its relatively cooler climate. Families prefer low-density housing, and many seek rural properties, ranchettes, and mountain living. Agricultural and other open lands are rapidly developed. A hotter climate decreases global food production. Worldwide demand for agricultural products rises, which increases food prices. Hot and dry conditions lead to a decline in streamflow and water supplies. The environment degrades and shifts to becoming habitat for species adapted to warmer waters and climate. Droughts and floods become more extreme. Communities struggle to provide services needed to accommodate rapid business and population growth. Fossil fuel, the dominant energy source, is supplemented by production of oil shale, coal, natural gas, and oil in the state.

2.1.4 Quantification of High-Impact Drivers in the Scenarios

Quantifying future demands, supplies, gaps, and available water under each of the five scenarios is a foundational task of the Technical Update. While the preceding narrative descriptions provide a qualitative summary, more significant interpretation was needed to determine how technical analyses could quantify the future conditions described in each based on available data and scientific best practices. Figure 2.1.2 summarizes and compares how the drivers varied across the scenarios. A more detailed explanation of how the various drivers were quantified and how the drivers relate to one another and across scenarios is shown in Tables 4 through 8 of Appendix B. The methodology sections and appendices provide more information on specific, quantitative adjustments to the drivers for each scenario and how the adjustments were implemented in various analyses.

Figure 2.1.2 Illustration of High-Impact Drivers Associated with Five Planning Scenarios

Drivers	A Business as Usual	B Weak Economy	C Cooperative Growth	D Adaptive Innovation	E Hot Growth
A. Economy/Population					
B. Urban Land use	No change in density	No change in density	Higher density	Higher density	Lower density
C. Climate Status/Water Supply	Same as 20th century observed	Same as 20th century observed	Between hot and dry and 20th century observed	Hot and dry	Hot and dry
D. Energy Water Needs	Low (no oil shale)	Moderate (no oil shale)	Low (no oil shale)	Low (no oil shale)	High (oil shale)
E. Agricultural Conditions	Total ag water demands decrease • Decrease in irrigated acres due to urbanization • Ag exports and demands lower • Ag is less able to compete with urban areas for water	Total ag water demands slightly decrease • Slight decrease in irrigated acres due to urbanization • Ag exports and demands constant • Ag is less able to compete with urban areas for water	Total ag water demands slightly higher • Slight decrease in irrigated acres due to urbanization • Ag exports down and local demands up • Ag is better able to compete with urban areas for water • Increased ET due to climate change	Total ag water demands slightly higher • Slight decrease in irrigated acres due to urbanization • Ag exports down and local demands up • Ag is better able to compete with urban areas for water • Increased ET due to climate change	Total ag water demands higher • Significant decrease in irrigated acres due to urbanization • Ag exports and demands high • Ag is better able to compete with urban areas for water • Increased ET due to climate change
F. Availability of New Water Efficiency Technology	• M&I Moderate • Ag: Efficiencies are increased	• M&I Moderate • Ag: Efficiencies are increased	• M&I High • Ag: Efficiencies are increased	• M&I High • Ag: Much higher efficiencies are implimented	• M&I Moderate • Ag: Efficiencies are increased
G. Social/Environmental Values	No change	No change	• Increased awareness • Increased willingness to protect environment and stream recreation	• Increased awareness • Increased willingness to protect environment and stream recreation	• Full use of resources • Low willingness to protect environment and stream recreation
H. Regulatory Constraints	Regulation Deregulation No change	Regulation Deregulation No change	Regulation Deregulation Increased	Regulation Deregulation Increased but expedited	Regulation Deregulation Reduced
I. M&I Water Demands	Middle of the five scenarios	Lowest of the five scenarios	Second lowest of the five scenarios	Second highest of the five scenairos	Highest of the five scnarios

2.2 ANALYSIS METHODOLOGIES

TheTechnical Update offers a more scientifically rigorous and robust analysis compared to previous SWSI efforts, which did not include scenario planning, climate change considerations, water rights, or surface water modeling. The Technical Update leverages the state's 25-year investment in CDSS, including StateMod models that connect major waterways and tributaries in Colorado.

Hydrologic modeling allows for detailed temporal (hydrology over time) and spatial (geographic and node-specific) analyses. It incorporates inputs that reflect water availability drivers under a variety of future conditions throughout the state. Additionally, hydrologic modeling provides increased consistency in the representation of municipal and agricultural demand gaps in ways that could not be as equitably modeled in earlier methodologies (i.e., SWSI 2010). The models produce a wealth of time series data and quantifications of "hydrologic gaps" at representative locations under each planning scenario.

2.2.1 Incorporating Climate Change into Scenario Planning

Through an iterative effort with the CWCB, basin roundtables, and the IBCC, three composite climate projections were incorporated into the planning scenarios.[2] Of the five planning scenarios, three include some level of stressed future climate change (*Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth*). The other two planning scenarios (*Business as Usual* and *Weak Economy)* assume similar climate conditions and variability to the observed conditions of the 20th century compared to historical natural flows for the period 1950–2013).

High stress conditions occur when runoff is low and consumptive use is high, whereas low stress conditions occur when runoff is high and consumptive use is low. The consumptive use, in this case, refers to the irrigation need (increased or decreased) for watering crops or other outdoor watering. This is expressed as the irrigation water requirement (IWR), which is synonymous with the term Crop Irrigation Requirement (CIR).

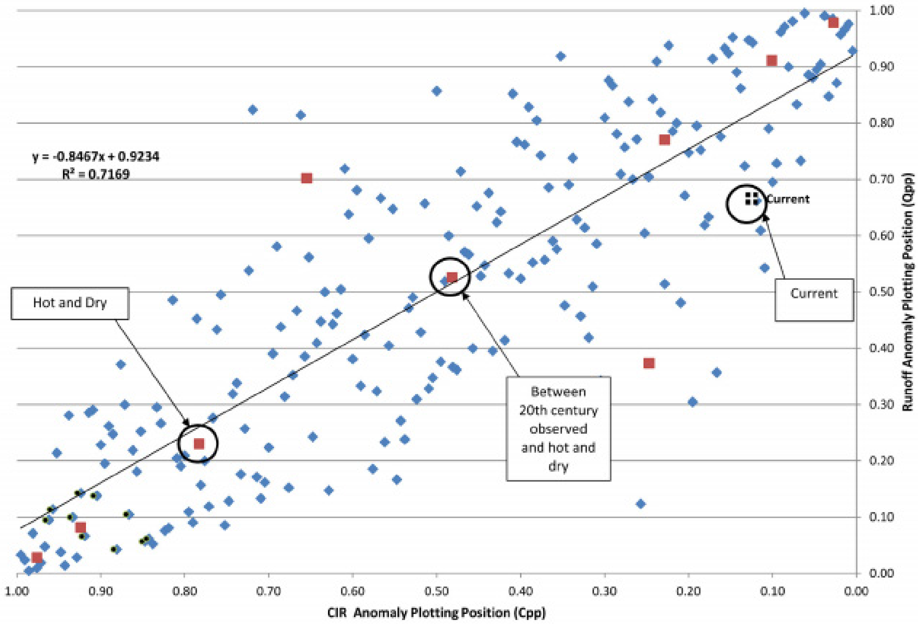
Table 2.2.1 and Figure 2.2.1 map this integration of future climate stress into the Technical Update planning scenarios. More detailed explanations of climate impacts follow and can be found in several documents such as the Colorado Climate Plan, Colorado Water Plan, and the foundational work of the multiphase Colorado River Water Availability Study (CRWAS).

Table 2.2.1 Incorporation of Climate Change into Scenario Planning

CWP Planning Scenario Name	CRWAS Climate Projection Name	Climate Stress Impact on 2050 Future Condition			
		CIR*	Runoff*	Average Annual Temperature[3]	Precipitation Change[3]
Business as Usual	Current	None	None	None	None
Weak Economy	Current	None	None	None	None
Cooperative Growth	In-Between	Moderate (50th percentile)	Moderate (50th percentile)	+ 3.78 °F (+2.0 °C)	5% increase in annual precipitation
Adaptive Innovation	Hot and Dry	High (75th percentile)	Low (25th percentile)	4.15 °F (+2.3 °C)	1% decrease in annual precipitation
Hot Growth	Hot and Dry	High (75th percentile)	(Low (25th percentile)	+ 4.15 °F (+2.3 °C)	1% decrease in annual precipitation

**See Figure 2.3 Plot of Runoff vs. Crop Irrigation Requirement (CIR)*

Figure 2.2.1 Runoff vs CIR Plotting Position



This plot of Runoff vs. CIR uses the Bureau of Reclamation's 200 composite climate scenarios. "Hot and dry" is defined as the 75th percentile of climate projections for crop irrigation requirements (water use), and the 25th percentile for natural flows. In other words, only 25 percent of projections have lower natural flows and 25 percent of projections have higher crop irrigation requirements. "Between 20th century-observed and hot and dry" is defined as the 50th percentile for both natural flows and crop irrigation requirements. This scenario represents the middle of the range in terms of severity. Baseline, or "Current" conditions, which represents no change in runoff or in crop irrigation requirements, fall at roughly the 9th and 67th percentiles; this means that 91 percent of model runs show increases in crop irrigation requirements and about two-thirds show reductions in runoff.

Turning Narrative into Numbers

Understanding how climate change could affect Colorado is key to understanding how to translate climate themes in scenario narratives into quantitative model inputs. In the Technical Update, climate stress is modeled from two dominant perspectives:

1) Supply Perspective: Output from the CRWAS-II project[4] included an extended time series of "natural flow" data developed for numerous locations throughout the state's basins (more than 300 streamflow gage locations statewide). "Natural flow" is the amount of water in the river absent the effect of humans, and serves as the foundational water supply data in the StateMod water allocation models. Although the impacts of climate projections vary across the state, natural flows under the climate projections generally show overall declines and temporal shifts to reflect earlier runoff periods. CRWAS-II project output also included a time series of climate-adjusted hydrology for both the moderate and high climate stress projections (respectively, "In-Between" and "Hot and Dry"). These datasets, also unique at more than 300 gage locations, reflect the relative change streamflow under each climate projection.

2) Demand Perspective: The runoff and IWR factors (jointly "climate factors") from both the "In-Between" and "Hot and Dry" projections reflect increased outdoor evapotranspiration (ET) rates and, therefore, increased IWR. In the Agricultural Diversion Demand methodology (Section 2.2.3) this is represented by IWR numbers that vary monthly, for every model year, for every water district. In the M&I Demand methodology (Section 2.2.4), IWR factors were applied at the county level to represent the average annual change in outdoor municipal demands. It was assumed that indoor demands and non-revenue water are not affected by climate factors.

2.2.2 CDSS Tools

The technical analyses make extensive use of CDSS modeling tools. CDSS is a water management system developed by the CWCB and the Colorado Division of Water Resources. The primary CDSS components used for the Technical Update are as follows:

- **HydroBase:** HydroBase contains historical and current water resources data, including streamflow records, historical climate data, diversion records, and water rights.
- **Geographic information system data:** Spatial data includes geographic information system (GIS) layers of diversion locations, irrigated acreage by ditch and crop type, streamflow measurement points, rivers, climate station locations, and ditch locations.
- **Surface water allocation models:** StateMod, the state's water allocation simulation program, analyzes water supplies and water demands and allocates available supply based on water rights, locations of demands, operational protocols, etc. Shortages (gaps) are calculated if supplies cannot fully meet demands. StateMod model datasets are available in most, but not all, of the river basins in the state.

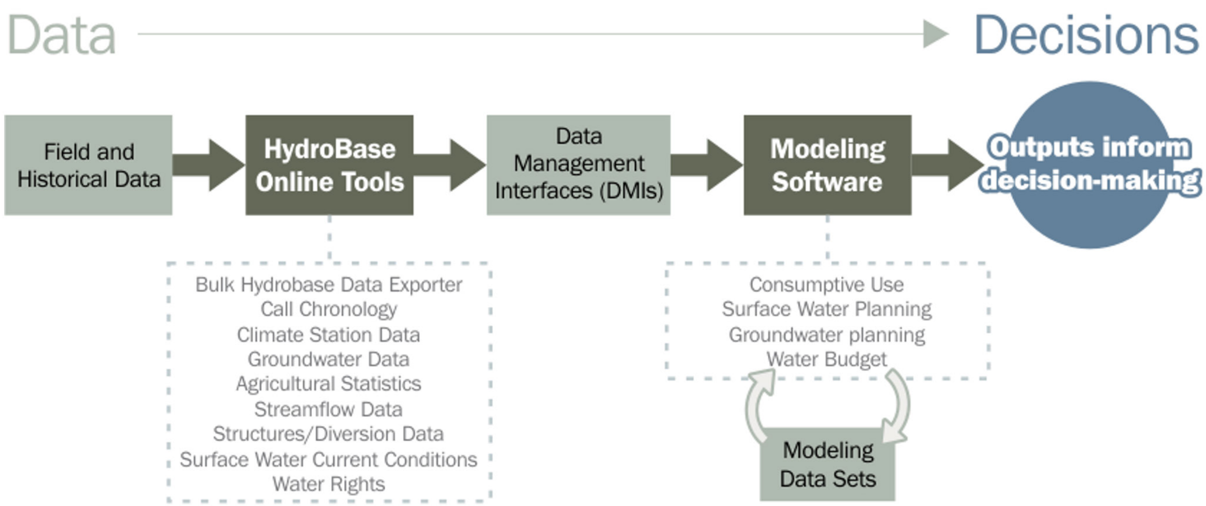
BASIN MODELING TOOLS

Many of the CDSS tools described here were not available for use when SWSI 2010 was being developed. The Technical Update has leveraged Colorado's investment in the CDSS to create a more comprehensive picture of supplies, demands, and gaps under each of the scenarios and under variable hydrologic conditions. The resulting analyses and tools are available for basin roundtables to use in updating their BIPs.

- **Consumptive use models:** StateCU, the state's crop consumptive use model, estimates the amount of water consumed by agriculture. It uses climate data (primarily temperature and precipitation), information on crop types and acreages, and water supply data to generate estimates of irrigation water requirements, consumptive use, irrigation system efficiencies, and agricultural diversion demand. StateCU model datasets are available in most, but not all, of the river basins in the state.

CDSS is foundational for statewide and basinwide water supply planning and establishes a common and accepted framework of information and tools to facilitate informed decision making. CDSS datasets and tools have been developed for use in the West Slope (Colorado; Yampa/White; Gunnison; San Juan/Dolores), North Platte, Rio Grande (consumptive use datasets only), and South Platte basins, and are being developed for the Arkansas Basin. State agencies, water users, and managers in these basins increasingly rely on CDSS as a common and efficient means for organizing, accessing, and evaluating a wide range of information and alternative water management strategies and decisions. Figure 2.2.2 illustrates the types of data and models available in CDSS and how data are incorporated and flow through the tools to facilitate informed decision making.

Figure 2.2.2 How Data and CDSS Tools Foster Informed Decision Making



2.2.3 Agricultural Diversion Demands

Agricultural demands in SWSI 2010 primarily reflected the consumptive use for crop irrigation at the field level. SWSI 2010 agricultural demands did not consider irrigation inefficiencies and ditch losses that occur as surface water diversions and/or pumped groundwater supplies are conveyed and applied to the crop. The Technical Update methodology, by accounting for crop consumptive needs plus irrigation inefficiencies, reflects the total amount of water needed to meet agricultural demands and allows for direct comparison between agricultural and municipal demands in the modeling. The updated methodology also provides information and tools for basin roundtables to use in evaluating the effectiveness of future agriculture projects. The Technical Update methodology described below was used to estimate diversion demands to meet the full irrigation needs of crops.

The Technical Update defines the current agricultural diversion demand as the amount of water that needs to be diverted or pumped to meet the full crop irrigation water requirements associated with the current levels of irrigated acreage, assuming historical climate conditions continue. In other words, the methodology assumes that irrigators will, regardless of a given delivery method's efficiency level, seek to divert enough water to meet their crops' full ET need (noting that under a range of climate patterns in water-short systems, the amount of water irrigators seek to divert is not always available). Current demand serves as the "baseline" for the Technical Update analysis and can be used to estimate the change from current to future conditions. To estimate potential future diversion demands, irrigated acreage, climate conditions, and efficiencies associated with the current agricultural diversion demand were adjusted by various factors to estimate the demands associated with the five planning scenarios that serve as the basis for the Technical Update analyses.

The results of the analyses are projected agricultural diversions and pumping required to meet the full crop requirement for each planning scenario (referred to as agricultural diversion demand). Agricultural diversion demands were incorporated into the water allocation models, which were used to determine how much water is available to meet the demands. Shortages to the agricultural diversion demands in the model are defined as an "agricultural gap".

Current Agricultural Diversion Demand

The approach used to develop the current agricultural diversion demand for the Technical Update varied based on the available data and the type of supplies (groundwater or surface water) used to meet the demand in each basin. The CWCB has developed crop consumptive use datasets using CDSS's StateCU modeling platform for most basins in the state. Two consumptive use datasets have been created for basins with full CDSS development:

> **ONGOING AGRICULTURAL SHORTAGES**
>
> Irrigators in many basins have historically operated under shortage conditions and currently experience a water supply gap in many or most years.

- **Historical Dataset.** This dataset reflects historical conditions and considers historical irrigated acreage, cropping, and climate variability. It also includes estimates of IWR associated with historical agricultural diversion demand using average system efficiency.
- **Baseline Dataset.** This dataset reflects current conditions assuming that variability in climate and hydrologic drivers will be similar to what has occurred in the past. This dataset considers current irrigated acreage and historical climate variability, and includes estimates of IWR associated with current agricultural diversion demand using average system efficiency.

For basins with both historical and baseline datasets, the following approach was used to develop the irrigated acreage, IWR, system efficiencies, and current agricultural demand:

Step	Calculation
1	Extract IWR, reflecting current acreage and crop types, from the most recent Baseline StateCU datasets
2	Develop a representative set of monthly system efficiency values for wet, dry, and average year types for each structure using information from the Historical StateCU datasets
3	Divide the monthly Baseline IWR by either the wet, dry, or average monthly system efficiency values depending on the indicator gage year type to develop the current agricultural diversion demand

The above approach was used for all basins with full CDSS datasets, though some required developing the necessary historical and/or baseline datasets, as summarized below. An additional complication pertained to the use of both surface water and groundwater supplies for irrigation in some basins. In these basins, it was necessary to partition the total agricultural diversion demand into surface diversion demand and groundwater demand. Historical groundwater demands were used to estimate current and future groundwater diversion demand patterns, assuming that the current level of groundwater pumping would likely remain the same or decrease in the future.

The basins for which full CDSS datasets are available include the West Slope basins (Colorado; Yampa/White; Gunnison; San Juan/Dolores) and the North Platte Basin (see Figure 2.2.4). In other basins, the approach was modified, or a different approach was needed based on available datasets and modeling tools. Methodologies are described in detail in Volume 2 of the Technical Update. Methodologies used in basins without full CDSS datasets are briefly summarized below:

- **South Platte and Rio Grande Basins:** Only the historical consumptive use datasets were available from CDSS. Baseline datasets were developed prior to modeling.
- **Republican Basin:** Historical and baseline StateCU models have not been developed in this basin; however, agricultural diversion demand information reflecting groundwater pumping, the source of irrigation in the Republican Basin, was available from the most recent Republican River Compact Administration (RRCA) accounting and model.
- **Arkansas Basin:** Neither historical or baseline StateCU models were available in the Arkansas Basin when the technical analysis began; however, the models are being created as a part of the Arkansas River DSS development project. Historical and baseline StateCU models were developed concurrently with the Technical Update effort and used to estimate agricultural diversion demands.

Projected Agricultural Diversion Demands in the Planning Scenarios

The Technical Update focused on several factors that can be consistently and quantitatively applied to adjust the agricultural diversion demand in each planning scenario. While there are many different factors that can impact the future of agriculture in Colorado (changing climatic conditions, new irrigation technologies, innovative crop hybrids, market fluctuations), the impact of these factors is difficult to quantify or predict with reasonable certainty. The agricultural factors that were quantified in the Technical Update are described as follows.

- **Urbanization.** Urbanization of irrigated agricultural lands will reduce agricultural demands. The approach to evaluating the impact of urbanization relied on mapping current irrigated lands, current municipal boundaries, and basinwide population projections to determine the amount of irrigated acreage that would likely be dried up and urbanized within each basin by 2050. The analysis assumed if mapped irrigated lands fall within or are directly adjacent to mapped municipal boundaries, the irrigated lands will be urbanized by 2050; however, if population projections suggested that no local increase in population will occur in a scenario, then it was assumed that irrigated lands would not be urbanized in those locations in that basin for that scenario.
- **Planned Agricultural Development Projects.** The BIPs developed by each of the basin roundtables described their current agricultural needs as well as each basin's future agricultural goals and approaches to meeting those goals. The North Platte and Yampa basins included a goal to increase agriculture in their basins by putting new lands under production. Irrigated acreage in these basins was projected to increase based on their planned agricultural projects.
- **Groundwater Acreage Sustainability.** A large portion of irrigated acreage in Colorado relies on groundwater supplies, primarily in the South Platte, Republican, Arkansas, and Rio Grande basins. Sustaining these groundwater supplies, both in terms of physical and legal availability, is necessary for preserving groundwater-irrigated acreage. If groundwater levels or augmentation supplies cannot be sustained, irrigated acreage served by groundwater in these basins will likely decrease in the future.
- **Climate.** Factors reflecting increases in IWR due to a potentially warmer and drier future climate were applied in *Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth*. Background on climate adjustments are provided in Section 2.2.1.

POTENTIAL FOR BUY & DRY

In addition to urbanization, irrigated acreage in the South Platte and Arkansas basins is anticipated to decline resulting from permanent agricultural-to-urban water right transfers (widely known as "Buy and Dry"). Meetings were held with stakeholders to estimate these future declines in the five planning scenarios.

- **Emerging Technologies.** Emerging agricultural technologies will play a significant role in future water use. Instrumentation, automation, and telemetry have improved irrigation efficiency and scheduling in many areas of Colorado and will likely continue to improve. Efficiency improvements in delivery and application of water through drip irrigation, more efficient sprinklers, ditch lining, or enclosing open ditches (or additional adoption of these technologies) may reduce water supply shortages and/or reduce the amount of water diverted or pumped. Innovations in crop hybrids have resulted in more drought tolerance while preserving or increasing yields. Two adjustments were made to provide perspective on the potential effect of these emerging technologies in the five planning scenarios:
  - *Sprinkler Development.* The South Platte and Arkansas basins have experienced significant conversion of flood irrigation (less water efficient) practices to center-pivot sprinklers and drip irrigation systems (more water efficient) for the past several decades. Discussions with stakeholders in the basin indicated a continued likelihood of this development to varying degrees in the five planning scenarios.
  - *Technological Innovations.* The *Adaptive Innovation* planning scenario narrative contemplates future technological innovations that mitigate potential climate-change-related increases in irrigation demand and decreases in supply. To implement this narrative in the agricultural diversion demand methodology, the impact of contemplated technological innovations was translated as reductions to IWR and improved water delivery efficiencies.

Agricultural Diversion Demand Calculation Process

In general, the adjustment factors discussed in the previous section impact either the acreage, IWR, or efficiency components of the agricultural diversion demand analyses. The following general approach was used to integrate the planning scenario factors and develop the planning scenario agricultural demand.

STEP	ADJUSTMENT	DETAILS
1	Adjust acreage by the urbanization, planned agricultural projects, and groundwater acreage sustainability factors	Using the current irrigated acreage as a starting point, irrigated acreage was increased or decreased in each basin using the acreage values associated with each factor.
2	Calculate adjusted IWR	Revise the consumptive use datasets developed for the current agricultural diversion demand effort with the adjusted acreage and simulate the models to calculate the adjusted IWR for each planning scenario in each basin.
3	Adjust the IWR by the Climate factor	Multiply the adjusted IWR from Step 2 by the adjustment factors associated with the climate change projection pertaining to each planning scenario.
4	Adjust the system efficiency by the Emerging Technologies factor	Using the historical wet, dry, and average monthly system efficiencies as a starting point, increase the system efficiency of each irrigation ditch by 10 percent. This occurs only in the *Adaptive Innovation* scenario.
5	Develop the agricultural diversion demand for the five planning scenarios	Divide the climate-adjusted IWR from Step 3 by system efficiency values to develop the agricultural diversion demand for each planning scenario.

Assumptions and Limitations

The following assumptions and limitations should be considered when reviewing the agricultural diversion demand methodologies and results:

- **Comparison to Historical Diversions.** The current agricultural diversion demands are not directly comparable to historical diversions, because historical diversions reflect changing irrigation practices, crop types, and acreage, as well as physical and legal water availability shortages.
- **Irrigated Acreage Assessments.** The current agricultural diversion demand analysis relies on the irrigated acreage assessments developed by the CWCB and DWR, generally performed every five years. While the assessments are being continually improved, some acreage delineation inconsistencies and incorrect assignment of water supplies remain.

■ CROP TYPE CONSIDERATIONS

Note that future crop types were not adjusted in the planning scenarios but could be during the BIP update process if roundtables would like to evaluate changes in diversion demand from different cropping patterns.

- **Recharge Demands.** A small number of irrigation systems in the Rio Grande Basin have decrees allowing preferential use of groundwater supplies while diverting surface water for on-farm aquifer recharge. Although the structures are legally allowed to use either surface or groundwater supplies on their acreage, designating their agricultural diversion demand as a groundwater demand for the Technical Update efforts is consistent with their current irrigation practices.
- **Shoulder Season Irrigation Practices.** The agricultural diversion demand approach relies on IWR and historical system efficiencies from wet, dry, and average year types to capture the variability of irrigation practices across changing hydrologic conditions. Although this approach allows for estimating demands that can vary based on IWR, it may not fully capture the agricultural diversion demand associated with irrigation practices during months when the IWR is very low or zero (e.g., early-season diversions associated with "wetting up" a ditch).
- **Agricultural Diversion Demands.** The agricultural diversion demand is defined as the amount of water that would need to be diverted or pumped to meet the full crop irrigation demand but does not reflect nor consider the common practice of re-diverting irrigation return flows many times within a river basin. As such, it is not appropriate to assume the total demand reflects the amount of native streamflow that would need to be diverted to meet the full crop irrigation demand.
- **Pumping Estimates.** Groundwater withdrawals have been metered and recorded in recent years, but records are generally not available over a long historical period. As a result, it was necessary to estimate groundwater-only and supplemental irrigation (co-mingled) supplies. In basins with CDSS models, pumping was initially estimated based on IWR in the StateCU datasets and then adjusted to account for historical restrictions to pumping. This approach holds supplemental/co-mingled pumping to current levels, which leaves any change of agricultural diversion demand (positive or negative) in the five planning scenarios a change in surface water agricultural diversion demand.
- **Planning Scenario Adjustments.** The five planning scenarios describe plausible futures with characteristics that require several adjustments to agricultural diversion demands; however, some of the agricultural drivers in the scenario narratives were not explicitly represented in the analyses as they could not be defensibly quantified (examples include narrative commentary on food security, crop type, and future agricultural economies). It is difficult to isolate the impact of a specific adjustment because the adjustments tend to compound and overlap within a planning scenario. If water resources planners are interested in the impact of an individual adjustment, they are encouraged to obtain the consumptive use datasets and implement the adjustments in a stepwise fashion, analyzing the results after each adjustment is implemented.

2.2.4 M&I Demands

The M&I demands were prepared on a spatial and temporal scale in ways that could be incorporated into the hydrologic modeling of future demand and supply scenarios. As with SWSI 2010, the methods used in this approach are for general statewide and basinwide planning and are not intended to replace demand projections prepared by local entities or for project-specific purposes.

Where the Technical Update uses M&I demands across five scenarios and a much more robust calculation, SWSI 2010 used a more simplistic approach that is worth explaining for context. In SWSI 2010, municipal/industrial demands were defined as water uses typical of municipal systems (including residential, commercial, light industrial, non-agricultural irrigation, non-revenue water, and firefighting) and a baseline was developed by multiplying the Colorado State Demography Office (SDO) population projections by per-capita rate of use.

Like SWSI 2010, the Technical Update uses population multiplied by per-capita rate of use (in terms of gallons per capita per day or "gpcd") in preparing a range of possibilities that reflect the uncertainties in future municipal demands.

Municipal Demand = (population) x (gallons per capita per day)

Unlike SWSI 2010, the Technical Update provides projected demands in the year 2050 for five future scenarios that each include a different level of conservation and water management that is characteristic of the scenario as defined in the Water Plan. The potential impact from drivers of climate, urban land use, technology, regulations, and social values are incorporated into the municipal demand projections through adjustments to the current gpcd rate of use.

2050 PROJECTIONS

Projected M&I demands reflect anticipated conditions in the year 2050. Demands for time periods between now and 2050 were not estimated. See Section 3 for more explanation.

The Water Plan provides relative rankings of M&I water use in the planning scenario narratives (see Figure 1.1.1 in Section 1.1.2). These rankings influenced the municipal demand projections. The rankings provide direction for how the combinations of M&I drivers affect the future volumetric demands under each scenario. They were interpreted to apply to average annual statewide volumetric demands rather than per capita demands. The rankings heavily influenced, and in some cases constrained, the combinations of drivers and population used in each scenario.

Description of Municipal Demand Methodology

Municipal diversion demands were calculated based on the factors described below.

Population

A unique population and growth pattern projection for the year 2050 was prepared for each planning scenario, as further described in the *Updated Population Projections for Water Plan Scenarios* (see Volume 2) and summarized in Table 2.2.2. The population projections were informed by the planning scenario narratives in the Water Plan.

The SDO forecast was adopted as the "medium" projection in Table 2.2.2. The variances around the SDO forecast assumed for other scenarios were estimated from the historical population growth experience of the state and each of its basins. Three sets of initial projections, with some modifications to the distribution of growth within the state, were then used to develop population forecasts consistent with the five planning scenarios.

Table 2.2.2 2050 Population Projections used for Five Planning Scenarios

	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Population Projection	Medium	Low	Medium, Adjusted	High, Adjusted	High

Only three pieces of information were required to develop probabilistic estimates of the potential range surrounding the "median" population projections produced by the SDO. The information requirements were:

- The compound average annual growth rate implied by the SDO forecast
- The historical standard deviation in population growth rates by decade
- The historical compound average annual growth rate for the area being projected

The following sequence of steps was used to implement the analysis:

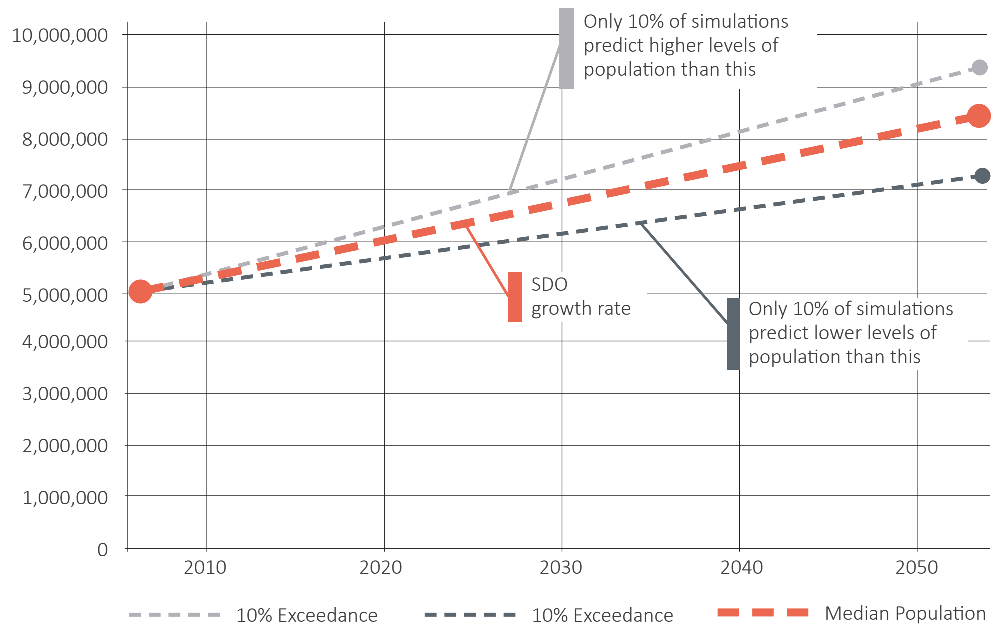
STEP	CALCULATION	DETAILS
1	Calculate median compound average annual growth rate	Calculated for the state and each basin based on the 2017 SDO projections through 2050.
2	Estimate the standard deviation in future growth rates	Based on historical standard deviation and historical and projected compound growth rates.
3	Use Monte Carlo techniques to simulate alternative future populations for each area based on baseline compound average annual growth rate and estimated standard deviation in growth rates by decade	Simulations result in thousands of alternative future populations derived from above for the state and each basin in 2050.
4	Select "High Growth" and "Low Growth" projections	CWCB selected the 10 percent exceedance probability for the "high growth" projections and the 90 percent exceedance probability for the "low growth" projections (see Figure 2.2.3).

Baseline Water Demands

Baseline municipal water demands were prepared by county, on a per-capita and volumetric basis. One of the key objectives for the Technical Update was to maximize the use of new data that were not available for SWSI 2010. The baseline (circa 2015) demands were prepared for each county using the following four data sources:

1. Data reported to the CWCB by water providers pursuant to House Bill 2010-1051[5]
2. Municipal water efficiency plans (WEP)
3. Targeted water provider outreach
4. Basin Implementation Plans

Figure 2.2.3 Projected Population Growth Through 2050



Per Capita Water Demand Projections. Projected future per capita rates of water demand in gpcd were calculated for each county by adjusting the baseline gpcd values by future demand drivers representing urban land use, technology, regulations, and social values. The potential future impact of these drivers on each of the five water demand categories was evaluated and values were developed that considered the planning scenario descriptions in the Water Plan and with input from the M&I TAG.

The residential indoor demand category was adjusted for each planning scenario to a fixed gpcd value, while percentage adjustments were applied to the other demand categories (positive values created an increase in gpcd and negative values a decrease in gpcd). The adjustment values are shown in Table 2.2.3. The adjusted future indoor and outdoor gpcd rates[6] were used to represent all new population (associated with new construction) and a portion of the existing population reflected by the adoption rates shown in Table 2.2.4 (associated with retrofits); the remainder of the existing population continues at the baseline gpcd rate. The resulting future gpcd rates used in demand modeling, therefore, include the combined effects of active and passive conservation.

Table 2.2.3 Municipal Per Capita Rate Adjustments for Planning Scenarios

Demand Category	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Residential Indoor (gpcd)	42.4	42.4	36.4	33.3	42.4
Non-Residential Indoor	0%	-5%	-10%	-10%	+5%
Outdoor	0%	-5%	-15%	-20%	+5%
Non-Revenue Water	0%	+5%	0%	-5%	0%

Table 2.2.4 Municipal Adoption Rates Applied to Indoor and Outdoor Demand Categories for Planning Scenarios

	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Adoption Rate	50%	40%	60%	70%	60%

Climate

Changes in climate primarily influence outdoor aspects of municipal demands due to impacts on landscape vegetation irrigation water needs. These impacts are typically associated with warmer temperatures that increase evapotranspiration (ET) rates and lengths of growing seasons, which increase the landscape irrigation water demand and consumptive use. For the Technical Update, it was assumed that indoor demands and non-revenue water are not affected by climate changes. ET change factors developed under the CRWAS Phase II (See Section 2.2.1) were used to estimate the impacts of changing climate on future outdoor demands for the Technical Update. These factors were applied to outdoor demands at a county level to represent the average annual change in outdoor demand in the year 2050 due to the climate status.

Municipal Demand Calculation Process

The calculation process for developing current and future municipal demands for the five planning scenarios is summarized below:

STEP	CALCULATION
1	Using water provider population, distributed water and customer water use data, prepare one population-weighted average current gpcd for each county
2	Disaggregate the representative current gpcd value into the appropriate sectoral uses
3	Adjust the current disaggregated gpcd values using the methodologies described in the sections above to prepare future gpcd values for each county under each of the five planning scenarios
4	Apply climate change factors to the 2050 outdoor municipal demand projections in *Cooperative Growth*, *Adaptive Innovation* and *Hot Growth*

Description of Industrial Demand Methodology

The Water Plan provides some narrative guidance regarding effects on self-supplied industrial (industrial) demands under the five planning scenarios, although less specific than for the municipal demands. New and updated information related to current and projected industrial demands is limited. Based on published references and data collected through outreach with the M&I TAG, SWSI 2010 values were updated where possible and appropriate as follows:

- Large Industry: Baseline large-industry demands for facilities represented in SWSI 2010 were updated using either BIP data, recent data from existing hydrologic models, or interpolated values between 2008 and 2035 in SWSI 2010. Technical Update values vary by scenario as shown in Table 2.2.5. Large industry demands in Jefferson County were not varied by scenario.

CLIMATE SHIFTS

Climate change could impact SSI water needs like thermoelectric generation, snow making, etc. Analyzing the potential impacts of climate change on the various sectors of SSI water demands would require a more complex evaluation than could be conducted in this round of Technical Update work but could be considered in future iterations or BIP updates.

- Snowmaking: Baseline demands were updated based on current snowmaking acres for each resort[7] and water use factors from SWSI 2010 and are in line with the linear increase from 2008 through 2050 reported in SWSI 2010. SWSI 2010 projections represent the best available information for *Business as Usual* demands in 2050. As with SWSI 2010, snowmaking demands are not varied by scenario for the Technical Update, in part, due to uncertainty regarding the effects of climate change.
- Thermoelectric: Baseline and *Business as Usual* thermoelectric demands for 10 of the thirteen facilities included were updated using data provided by M&I TAG participants. Baseline and *Business as Usual* demands for one facility were based on information from the Yampa-White-Green BIP. SWSI 2010 values were used to define Baseline and *Business as Usual* demands for the remaining two facilities where no updated information was available. Thermoelectric demands for all facilities were varied by scenario according to the factors in Table 2.2.5.
- Energy Development: Baseline energy development demands were updated using either BIP data or interpolating between 2008 and 2035 values used in SWSI 2010. Demand projections in the Rio Grande Basin were based on information from the BIP and did not vary by scenario. Demands in all other basins were based on low, medium, and high projections from SWSI 2010.

Table 2.2.5 Adjustments to SSI Demands for Each Planning Scenario

SSI Category	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Large Industry	-	-10%	0%	0%	10%
Snowmaking	-	0%	0%	0%	0%
Thermoelectric	-	-5%	10%	-5%	10%
Energy Development	SWSI 2010- Medium	SWSI 2010- Medium	SWSI 2010- Low	SWSI 2010- Low	SWSI 2010- High

Assumptions and Limitations

- The projected demands represent potential demands under conditions described for each scenario; however, they do not necessarily represent the full potential for water management strategies under each scenario (e.g., more aggressive active conservation programs). Basins may continue to develop water conservation efforts as part of existing and future projects that reduce consumption.
- Erroneous or suspect reported non-revenue water loss values were adjusted, using stakeholder input where possible, to provide a reasonable range of planning values for several water providers. An emphasis should continue to be placed on improving this data and understanding the associated real and apparent losses.
- Aside from the climate driver described above, per capita drivers were not modified by basin or county. Drivers were applied using the same values and methodology for each county and are intended to prepare a scenario planning approach that can be further customized at the basin level.
- Planning scenarios do not include acute drought response efforts like imposing restrictions, so comparing to other areas of the country (e.g., Southern California) is not appropriate if their current demands reflect not only aggressive active conservation, but also imposed restrictions.
- Demand projections were prepared using the same adoption rate for indoor and outdoor demands and for residential and non-residential demands. The adoption rate should be further investigated at a local level because it is highly influenced by new construction and active water conservation programs. The adoption rate also encompasses effects from the persistence of demand reductions associated with indoor and outdoor uses.
- The per capita gpcd metric is being used as a projection tool for this statewide planning project, even in areas with a significant influence from non-permanent residents, such as mountain resort communities, and is not applicable as a comparison tool between communities. It is not appropriate to compare a gpcd value from areas that have a significant influence from tourism and non-permanent residents to areas that have a primarily year-round, residential type of population. Specific characteristics about each community need to be understood when interpreting per-capita demand data.
- Urban land use changes have the potential to significantly affect future municipal (primarily outdoor) and agricultural demands. The range of impacts may not be fully reflected in the Technical Update municipal and agricultural demand projections, primarily due to a lack of information available for use in statewide planning projections. Future demand projections may be improved by collecting service area delineations and density information regarding developed and irrigated, landscaped areas under current conditions and anticipated for the future planning year (i.e., 2050).

- The climate factor adjustments described above represent the average annual change in 2050 for the climate represented in each scenario. Outdoor demands will vary annually and monthly, and this type of annual variability is not included in the hydrologic modeling for the Technical Update. This could be incorporated into future technical updates.
- The adjustments assume that amount and type of vegetative cover and irrigation methods and management remain the same in the future as today.
- The methodology assumes that the percentage reduction of current to future outdoor use found from existing programs (20 to 30 percent) remains possible and representative of the potential percentage reductions under scenarios that include climate change; however, some communities are already struggling to support healthy landscapes in response to utility rate increases. Active management will likely be required to maintain healthy landscapes in a hotter and drier future or landscapes may need to change.

2.2.5 Hydrologic Modeling and Analysis

The water supply modeling focused on physical streamflow, water available to meet projected or new demands, and the agricultural and M&I gap under a variety of hydrological conditions. While surface water availability in SWSI 2010[8] represented the amount of unappropriated streamflow that may be developed in the future in basins with available streamflow, it also found that the groundwater supplies were generally declining, and the discussion regarding these supplies focused on sustainability (as opposed to supplies that may be developed in the future). The Technical Update provides more in-depth analyses of current and climate-adjusted hydrology and analyses of water availability to meet future projected agricultural and municipal diversion demands. The analyses, discussed in more detail below, relies primarily on water allocation models to simulate how climate-adjusted hydrology will impact the existing demands, supplies and gaps, and what unappropriated supplies may be available to meet the future projected demands.

Modeling Period

The hydrologic models use 1975 to current-year (models vary in the most recent year of data depending on the basin) as the reference modeling time period, because existing transbasin diversion projects were, in general, fully operational by the mid-1970s. In addition, record keeping and data describing diversions (of all kinds) in years prior to the 1970s are of relatively low quality in some basins. Models simulating the planning scenarios use 1975 to current-year water supplies (in some scenarios, adjusted for climate change impacts), current administrative practices and infrastructure, and projected demands. The 1975 to current-year period of record provides a robust variety of hydrological conditions (i.e., high flow years and extended droughts) over which the planning scenarios can be analyzed.

Methodology to Develop Current Water Supply

Current water supply information consists of physical streamflow and water availability at key locations throughout the modeled basin. The bulk of the analysis of current water supplies relies on models and data developed under the CDSS program. In basins where the CDSS program has not been fully implemented, the methodology for those basins was modified to use available water supply information. The sections below discuss the specific methodologies that were used to evaluate current water supplies for each basin.

CDSS Basin Water Supply

StateMod water allocation models are available for several of the basins through the CDSS program (see Figure 2.2.4). For basins with full CDSS model development, two water allocation datasets were developed:

- Historical Dataset. Historical model datasets allocate water to meet historical agricultural and municipal diversion demands in each basin. They contain historical diversions and pumping that reflect administrative and operational constraints on water supply as they occurred over time. The historical models were calibrated by comparing historical measured diversions, reservoir contents, and streamflow to simulated results. Model adjustments were made until there was adequate correlation between the measured and simulated data. They are an appropriate dataset to assess historical conditions in basins over an extended period of time.
- Baseline Dataset. Baseline model datasets allocate water to meet current agricultural and municipal diversion demands assuming recent historical climatic and hydrologic conditions will continue into the future. Baseline models reflect current administrative, infrastructure, and operational conditions overlaid on the hydrology of the entire study period. For example, the model could include the operation of an existing reservoir constructed in 1985, but it would be simulated using hydrology reflective of 1975 to 2013 conditions. Baseline datasets and models are appropriate to use for "what if" planning scenarios.

For basins with both historical and baseline datasets, the following approach was used to develop the current water supply information:

Step	Procedure
1	Incorporate current agricultural diversion demands into the Baseline models.
2	Incorporate current M&I diversion demands.
3	Simulate the models.
4	Extract the monthly physical streamflow and water availability at key locations in each basin.
5	Summarize the agricultural gap and crop demand gap by Water District and by basin for on average and for critically dry years. No M&I gaps occur under current conditions.
6	Summarize total storage by water district and by basin over the modeled period.

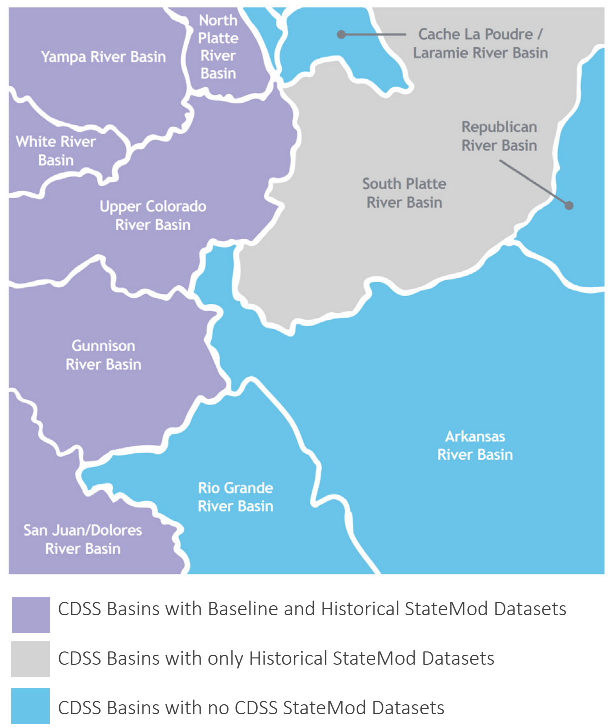
Non-CDSS Basin Water Supply

As shown in Figure 2.2.4, StateMod water allocation models have not yet been developed for the Arkansas, Republican, Rio Grande, and Cache La Poudre/Laramie basins. As these regions are generally water supply limited, a water allocation model may not be necessary to understand future water availability in the basin. Historical data can be used to estimate current water supplies in the basin at a level sufficient for the Technical Update planning effort. Current water supply information in these basins was developed primarily using historical data:

- Current physical streamflow was based on historical data from key streamflow gages.
- Current water availability was set to zero.
- Current agricultural gap was based on historical consumptive use analyses and estimated as the difference between the current agricultural diversion demand and the historical pumping (in the Republican Basin) or the historical diversions and pumping (in the Arkansas and Rio Grande basins) on average and for critically dry years.
- Current M&I gap was set to zero, assuming the M&I demands are fully satisfied under current conditions.

Although the methodologies for estimating current water supplies in each of these basins differs from the basins with CDSS models and datasets, they provide appropriate estimates of physical streamflow, water availability, and gaps for current conditions for comparison to the five planning scenario results.

Figure 2.2.4 CDSS and Basin Modeling Map



Methodology to Develop Planning Scenario Water Supply

The planning scenario water supplies were estimated using an approach similar to that used to estimate the current water supplies. For planning scenario water supplies, agricultural and municipal diversion demands reflective of 2050 conditions specific to each of the five planning scenarios were used as was, in some scenarios, climate-adjusted hydrology. Once the planning scenario datasets were developed, results were compared to the current water supply to assess the impact of the projected demands and hydrology.

CDSS Basin Methodologies

The baseline StateMod datasets developed for the current water supply analysis served as the starting point for the planning scenario datasets. The following steps were taken to develop the planning scenario StateMod datasets and ultimately the water supply information:

Step	Procedure
1	Incorporate the appropriate planning scenario agricultural diversion demands into the planning scenario models.
2	Incorporate the appropriate planning scenario M&I diversion demands into the planning scenario models.
3	Incorporate the appropriate climate-adjusted natural flow into *Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth*. Note that *Business as Usual* and *Weak Economy* reflect current (or recent historical) hydrology.
4	Run the planning scenario models.
5	Extract the monthly physical streamflow and water availability at key locations in each basin.
6	Summarize the M&I gap by water district and by basin on average and for very dry years.
7	Summarize the agricultural gap and crop demand gap by water district and by basin on average and for very dry years.
8	Summarize total storage by water district and by basin over the modeled period.
9	Estimate the amount of water available from changed irrigation water rights associated with land undergoing urbanization
10	Estimate the transbasin import reductions due to changes in physical or legally available supply in the exporting basin.

The planning scenario StateMod datasets incorporate the projected hydrology and demands with the baseline representation of the basins' infrastructure and operations. Adjustments to other modeling parameters, such as order of supplies used to meet municipal diversion demands or alternative methods for conveying water, were not made in the planning scenario datasets under this effort. In addition, the models utilize existing infrastructure to the full operational potential, and no adjustments were made to limit those operations. For example, in planning scenarios that contemplate lower water supplies, simulated reservoir storage may be drawn down to lower levels and on a more frequent basis than has occurred historically. While reservoirs are being simulated within their existing operational constraints in the models, it is possible that water providers would obtain additional storage or other water rights in a drier future rather than consistently operating existing facilities at low levels.

Non-CDSS Basin Methodologies

The absence of basinwide planning models in some basins limited the options to evaluate the projected demands and hydrology. As a result, the existing analysis tools are not conducive to implementing the "what-if" planning scenario conditions; however, they do provide information on the basin operations which were used in developing the planning scenario water supply information. Various qualitative and quantitative methods were used to develop the planning scenario water supply information in these basins as described:

- **Republican Basin.** For the Republican Basin, the current level of appropriated groundwater supplies serves as the maximum available water supply in the basin into the future and assumes that no unappropriated surface or groundwater supplies will be available. Projected water supplies in the Republican Basin were estimated as follows:
  - » Current irrigation practices, in which irrigators pump less than the full amount needed by the crops, was assumed to continue into the future based on discussions with stakeholders in the basin. The current agricultural gap percentage was used to estimate the planning scenario gaps, and associated crop demand gaps, on average and for critically dry years.
  - » Planning scenario water availability was set to zero.

FREE RIVER

Some water users (primarily agriculture) have historically supplemented their water rights with additional diversions under free river conditions. The modeling assumes this will continue. As a result, available free river is first allocated to agriculture and then to other water rights. Basin roundtables could propose future projects to allocate available free river to meet M&I needs.

  - Any projected planning scenario M&I demand greater than current M&I demand was assumed to be a gap due to lack of future water availability. Planning scenario M&I gaps were estimated as the difference between the planning scenario M&I demand and the current M&I demand on average and for very dry years.

- **Arkansas and Rio Grande Basins.** The *Business as Usual* and *Weak Economy* scenarios do not include climate-adjusted hydrology or demands, therefore the anticipated changes in these scenarios result from changes in M&I demands and irrigated acreage, respectively. The approach to develop water supply information in these basins included the following assumptions:
  - Water availability was set to zero.
  - Historical agricultural shortages are expected to continue into the future, exacerbated by reduced supplies under climate-adjusted hydrology.
  - Current pumping levels serve as the maximum groundwater supply available to meet projected demands.
  - Any groundwater supplies associated with the removal of irrigated acreage due to groundwater sustainability adjustments remain in the aquifers and are not available to offset gaps experienced by other demands in the basin.
  - Any projected planning scenario M&I demand greater than current M&I demand was assumed to be a gap, due to lack of future water availability.[9]

  In general, the current agricultural gap was used as the basis for the planning scenario agricultural gap, and further reductions in supplies due to climate-adjusted hydrology were applied to gaps. In each planning scenario, the average reduction in streamflow at indicator gages throughout the basin was used to increase the agricultural gap in *Cooperative Growth, Adaptive Innovation*, and *Hot Growth*. The M&I gap was based on the difference between the current M&I demand and the planning scenario M&I demand, assuming no additional supplies are available to meet the increased demand. Simulated streamflow under the planning scenarios with climate-adjusted hydrology was not available; however, the change in runoff (i.e., natural flow), both magnitude and timing, between current conditions and climate-adjusted conditions is provided to reflect the general impact of these projected hydrology adjustments.

- **Cache la Poudre and Laramie Basins.** Although these basins do not have the full suite of CDSS modeling tools available, model results from neighboring sub-basins with similar levels of irrigated acreage, M&I demands, storage, and transbasin supplies were used to inform and adjust the results in these basins. The planning scenario agricultural gaps in these basins were based on the current agricultural gap and then adjusted based on the gap results from neighboring sub-basins in each planning scenario. The planning scenario M&I gap in these basins was assumed to be similar to M&I gaps experienced in neighboring sub-basins, particularly in sub-basins where municipal supplies are generally similar and consist of sources like Colorado-Big Thompson supplies, changed water rights, and storage. The outflow from the Cache La Poudre River to the South Platte River was based on historical streamflow for *Business as Usual* and *Weak Economy* and adjusted with the hydrology factors in planning scenarios with climate-adjusted hydrology. The planning scenario water supply information from the Cache La Poudre and Laramie basins was then incorporated into the overall South Platte and North Platte Basin results, respectively.

Assumptions and Limitations

- Basinwide Planning Model: A primary objective of CDSS is to develop water allocation models that can be used to evaluate potential future planning issues or management alternatives based on Colorado water law at a regional level. The level of detail regarding representation of hydrology, operations, and demands in the model is appropriate for the Technical Update efforts. The models operate on a monthly time-step and, therefore, do not capture daily changes in streamflow, routing of reservoir releases, or daily accretions or depletions to the river system. One hundred percent of the consumptive use demands are represented in the model, and many are represented with their individual water rights and operations. Smaller streams are not individually represented in the model; rather the demands and contributing inflow from those tributaries are grouped and represented on larger tributaries in the model. Information used in the modeling datasets is based on available data collected and developed through CDSS, including information recorded by the State Engineer's Office. The model datasets and results are intended for basinwide planning purposes.
- Model Calibration: Each water allocation model undergoes calibration, in which the model developer adjusts model inputs to achieve better agreement between the simulated and measured streamflow, diversions, and reservoir contents. The model builds on historical water supply information, and if information is missing, errant, or there are data inconsistencies, the model cannot be well calibrated and cannot accurately predict future conditions. The models are only as good as the input.
- Representation of Water Supplies and Operations: The baseline models reflect one representation of waer users' operations associated with their current infrastructure. The representation in the model is intended to capture their typical operations; however, they are simplified and do not reflect the full suite of operations generally available to larger water providers. This representation may not capture operational adjustments or agreements implemented during drought conditions, or the maximum operational flexibility of using water supplies from multiple sources. In addition, the model allocates water according to prior appropriation, and non-decreed "gentlemen's agreements" are generally not represented in the models.

- Groundwater Pumping Levels/ Transbasin Diversions: The models reflect current levels of groundwater pumping and transbasin diversions. Noting that administration of groundwater pumping shifted due to the mid-2000s drought, post-drought groundwater pumping levels were used in the baseline and planning scenario models. Similarly, the historical transbasin diversions were used in the baseline and planning scenario models. Transbasin diversions are based on many factors, including water availability and storage in both the source and destination basins, demands, other water supplies available to the water provider, and other operational considerations like water quality. Projecting how these factors may change under the 2050 planning scenarios was beyond the Technical Update scope; therefore, transbasin diversions were set to historical levels.
- Interstate Compacts. The Technical Update modeling only takes into account Compact administration where a Compact is currently being actively administered. It does not account for or make assumptions relating to how potential future administration could occur where a Compact is not currently being administered.
- Solutions/Projects: The Technical Update is intended to develop water supply and gap information that can be used by basin roundtables for future planning efforts, including the development of potential solutions to mitigate gaps. The models can be used to evaluate the effectiveness of a future solution, though future projects and/or solutions are not currently included in the models.
- Urbanization: As agricultural lands are urbanized, the irrigation supplies on those lands could potentially be transferred to other uses, such as municipal or industrial; however, the transfer of these supplies is subject to a variety of unknowns such as seniority, type of water supply, location of supply relative to the demand, and willingness to change the use of water through water court. Potentially available supplies from urbanized agricultural lands were quantified after gap calculations were conducted and are not considered in the gap; however, the supply potentially available from these lands is described in each basin (see Section 4) and can be applied to gaps at the discretion of basin roundtables in their BIP updates.

2.2.6 Environment and Recreation

The methodologies described in this section informed the development of tools to help basin roundtables update their BIPs and evaluate and prioritize future environment and recreation projects.

NONCONSUMPTIVE USES

In prior SWSIs, the term “nonconsumptive” referred to “environment and recreation” data sets and analyses. For the purposes of the Technical Update these two terms can be viewed as interchangeable; however, the phrase “environment and recreation” (or E&R) will be used moving forward.

Background on E&R Database and Enhancements for Technical Update

Beginning with the original SWSI phases and continuing through and beyond the SWSI 2010 process, the basin roundtables first identified E&R needs, then developed and refined mapping and evaluation tools, and subsequently identified projects to address those needs. The evolution of addressing E&R issues in the state is described in the graphic below. The Technical Update advances the development of tools that can be utilized by the basin roundtables in identifying E&R needs and providing support for E&R projects and methods.

SWSI I & II		SWSI 2010		Post-SWSI 2010
Developed E&R mapping tools.	→	BRTs used E&R mapping tools to develop maps for each basin showing E&R focus areas. BRTs identified projects and methods to meet E&R needs and developed maps showing: location of projects/methods, status of projects/methods, E&R focus areas that have projects/methods completed or in progress.	→	Developed nonconsumptive needs assessment database (NCNAdb), which contains nonconsumptive attributes, projects and associated protections.

Technical Update Enhancements for E&R Database

The Technical Update focused on enhancing the Nonconsumptive Needs Assessment database (NCNAdb, now referred to as the E&Rdb). The E&Rdb was updated and will allow the CWCB and basin roundtables to better leverage E&R data, streamline data entry and reporting, and promote collaboration based upon common, consistent and reliable technology and processes. Building on the technical foundation of the existing NCNAdb, several improvements were implemented that serve to accomplish the goals described in Table 2.2.6.

Table 2.2.6 Enhancement Goals and Actions for the E&Rdb

Overall Goal	Action and Results
Enhanced Technical Foundation	Data loading processes are consistent and streamlined to add efficiency and improve data quality.
	Implement the Source Water Route Framework as a common spatial unit to provide statewide consistency.
Engaging and Meaningful User Experience	Develop Excel-based templates for data entry to improve uniformity of data and add efficiency.
	Develop standard reports to enhance consistency of data retrieval.
	Provide mapping data on the CDSS MapViewer to increase ease of use and enable visualization of database content.
	Develop a user manual and identify potential improvements through user feedback.
Integration into Colorado Water Planning Process	Improve database content and expand to include project identification, project descriptions, dates, etc. making it more useful and meaningful for planning purposes.

Updating the spatial unit of analysis was an important aspect of enhancing the technical foundation of the E&Rdb. The update occurred because of the retirement of the USGS stream segment-based spatial unit called the common ID (COMID), which had been used in the NCNAdb. The Source Water Route Framework (SWRF), a Colorado-specific spatial dataset, was included as a spatial unit of analysis for the updated E&Rdb. The updated E&Rdb also relies on the USGS's National Hydrography Dataset (NHD). Data in the database can be queried by hydrologic unit code (HUC) and/or stream segment.

Improvements were also made to the data in the E&Rdb. The prior NCNAdb included more than 100 E&R attributes compiled through stakeholder outreach in each basin. The original attributes were reviewed and quality checked to identify repetitive or unreliable data sources and datasets. Closely related attributes that provided repetitive or overlapping data were consolidated into a single attribute. Additionally, previous attributes that did not have public data sources or datasets available to confirm spatial data were archived and not included in the updated attribute list. Several attributes were also renamed to better reflect the dataset and simplify database development. The final 58 attributes were grouped into several "macro" categories that help increase organization of the E&Rdb and provide a foundational set of attributes for the E&R Flow Tool (described below).

Background on Flow Tool and Enhancements for Technical Update

In addition to the updated E&Rdb, the Technical Update includes an E&R Flow Tool (Flow Tool) designed to assess flow conditions and associated ecological health at selected nodes in each basin. The Flow Tool will serve as a resource to help basin roundtables refine, categorize, and prioritize their current portfolio of E&R projects and methods and to better understand risks to ecological attributes based on possible future flow conditions under each planning scenario.

Prior to the Technical Update, the CWCB funded the development and testing of a tool known as the Watershed Flow Evaluation Tool (WFET). To date, the WFET has been applied in the Colorado and Yampa-White-Green basins. The WFET offers an approach to conducting a watershed-scale, science-based assessment of flow-related ecological risk throughout a basin, particularly when site-specific studies are sparse.

Also prior to the Technical Update, the Historical Streamflow Analysis Tool (HSAT) was developed and made available for use in the first round of BIPs and emphasized the evaluation of hydrologic variability at gage locations across Colorado. The user interface includes a simple dropdown menu and the output included automatically generated tables and plots. Many of the basic flow summaries included in the HSAT were carried forward into the Flow Tool.

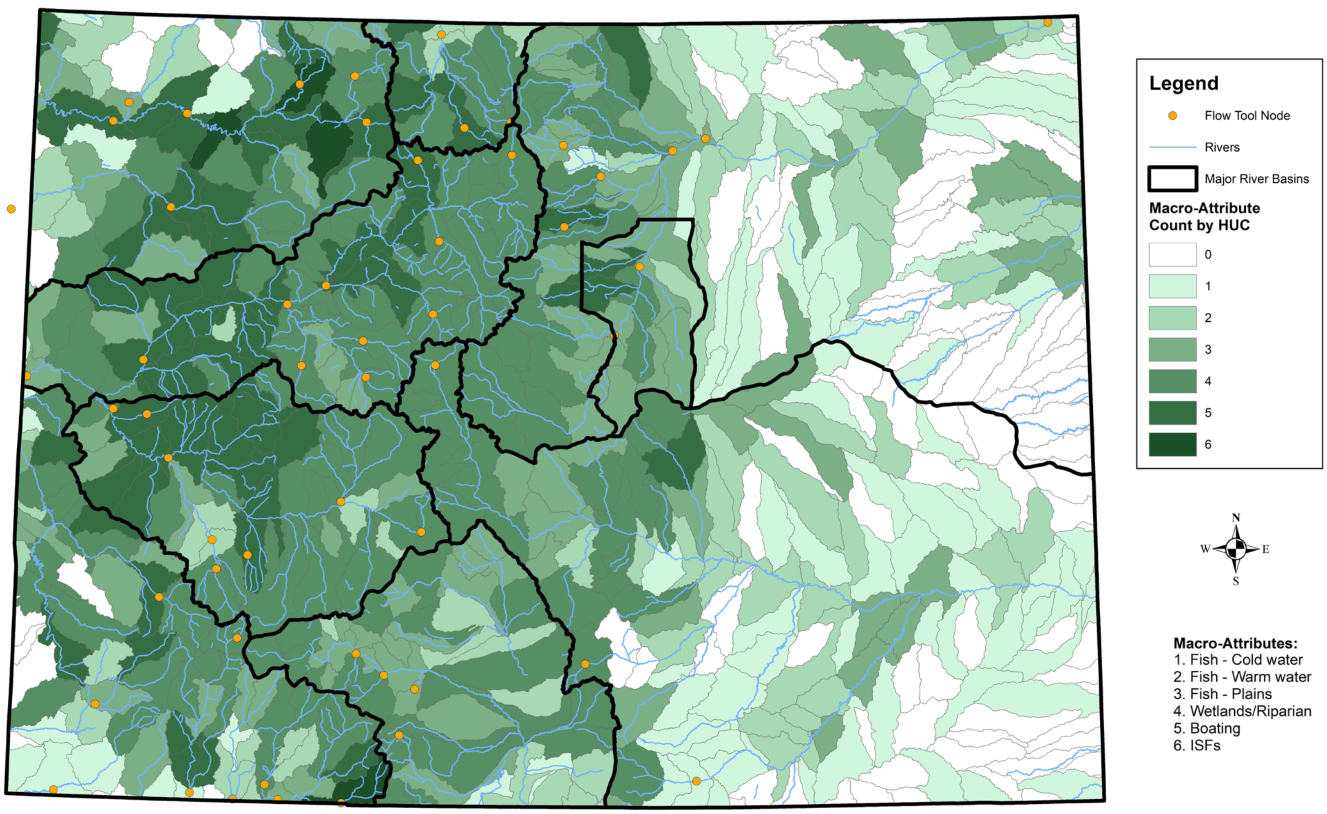
Methodology Description

The Flow Tool is built on a legacy of stakeholder involvement and was created through a methodology that was developed collaboratively with the E&R TAG and builds on the previous E&R tools described above. The Flow Tool was designed to incorporate and compare modeling output from the five planning scenarios against baseline (existing) and naturalized (unimpaired) flow condition scenarios. Key outputs include a comparison of monthly flow regimes relative to ecological-flow indicators, building off the WFET.

The Flow Tool uses monthly streamflow output from CDSS water allocation models. The Excel-based tool was designed to incorporate and compare modeling output from the five planning scenarios against historical gage data and the baseline/current conditions scenario. Key outputs include a comparison of monthly flow regimes relative to ecological-flow indicators.

The Flow Tool analyzes and produces data for 54 pre-selected model nodes corresponding to stream gages (see Figure 2.2.5). The nodes included in the Flow Tool were selected for inclusion based on a number of factors. Gages were reviewed to determine available attribute data (where key E&R attributes were located and concentrated within a basin [darker shaded HUCs in Figure 2.2.5]), to consider spatial coverage across basins, and to assess data availability.

Figure 2.2.5 Nodes in Flow Tool



The Flow Tool estimates the response of E&R attributes in rivers under various hydrologic scenarios. The flow-ecology relationships in the Flow Tool were first developed as part of the WFET and were patterned after similar relationships that have been developed across the globe to inform water management. Flow-ecology quantifies the relationship between specific flow statistics (e.g., average magnitude of peak flow, the ratio of flow in August and September to mean annual flow) and the risk status (low to very high) for E&R attributes under the flow scenario being analyzed. Data-derived relationships have been developed for riparian/wetland plants (cottonwoods), coldwater fish (trout), warmwater fish (bluehead sucker, flannelmouth sucker, and roundtail chub), and Plains fish. Other metrics were developed with basic, well-established relationships between hydrology and stream ecology. Relationships for recreational boating were developed with stakeholders during WFET development.

The Flow Tool compares historical gage records to current-conditions-modeling-output and planning-scenario-modeling-output. The comparison provides insights on where and how much monthly flow regimes are expected to change relative to ecological flow indicators related to macro-attribute categories discussed above. This comparison also highlights areas where future E&R projects and protections could be beneficial. Basin roundtables will then be able to apply their own analysis (and preferences) to determine the best way to meet these E&R needs.

Flow Tool Limitations

While the Flow Tool is intended to provide data for use in planning E&R projects and methods, it should be noted that it is not prescriptive. Tool output is currently limited to monthly timesteps, and does not designate gap values nor provide basis for any regulatory actions. The Flow Tool does not identify areas where ecological change may be associated with factors other than streamflow, nor detail results as accurately as a site-specific analysis. The tool does not evaluate potential shifts in flooding magnitude and frequency that could result from climate change.

SECTION 3
REVISITING THE GAPS

The Colorado Water Plan set an adaptive management framework for future water planning activities, and described five planning scenarios under which demands, supplies, and gaps were to be estimated. The planning scenarios included new considerations, such as climate change, that were not a part of prior SWSI analyses. The CWCB and Division of Water Resources have developed new consumptive use and surface water allocation models that were not previously available for use in prior SWSI phases. As a result of these factors, the Technical Update takes a different and more robust approach to estimating potential future gaps.

3.1 SWSI 2010 GAP METHODOLOGY

Gaps in SWSI 2010 were focused on municipal and self-supplied industrial water users and were defined as a "future water supply need for which a project or method to meet that need is not presently identified." The gaps accounted for new future water needs and also anticipated yields from Identified Projects and Processes (IPPs) projected to provide future supply. Gaps were calculated using the following formulas:

M&I Water Supply Gap = 2050 net new water needs – 2050 projects

Where:

> 2050 Net New Water Needs = (2050 low/medium/high M&I baseline demands – high passive conservation – current M&I use) + (2050 low/medium/high SSI demands – current SSI use)
>
> 2050 IPPs = Water Provider Anticipated Yield from: Agricultural Transfers + Reuse + Growth into Existing Supplies + Regional In-basin Projects + New Transbasin Projects + Firming In-basin Water Rights + Firming Transbasin Water Rights

Information on specific IPPs and estimated yields were obtained from CWCB interviews and data collected from water providers throughout the State in 2009 and 2010, the original SWSI effort in 2004, and information from basin roundtables from 2008 to 2010. The overall IPP "success" was then adjusted to create varying levels of M&I gap based on the likelihood that a specific IPP would produce its full yield

Agricultural shortages were estimated in SWSI 2010. The shortages were estimated by calculating the difference between the amount of water consumed by a full-irrigated crop and the amount of water actually consumed by crops under water short conditions. The shortages were field-based, meaning that they did not account for water needed for conveyance and other losses. Agricultural shortages were not described as gaps, in part because they were conceptually different than the infrastructure gaps calculated for M&I water uses.

CALCULATING THE GAP

Gaps calculated in SWSI 2010 were based on future water demands and accounted for the degree to which future projects might meet future demands. Gap projections in the Technical Update do not include estimates of basin-identified project yields. This is primarily due to the lack of specific project data that would allow projects to be modeled. Forthcoming basin plan updates will reevaluate projects and consider strategies to address gaps.

REGARDING PROJECTS

IPPs in SWSI 2010 referenced "Identified Projects and Processes" that were being pursued by water providers to meet future demands. The Technical Update refers to these simply as "projects."

3.2 GAP METHODOLOGY IN THE TECHNICAL UPDATE

The methodology for calculating gaps in the Technical Update is very different from that used in prior SWSIs. The new methodology was necessary to address new analysis needs, to provide basin roundtables with the tools to develop implementation strategies within the adaptive management framework, and to take advantage of new models and data sets.

New Analysis Needs

The Technical Update estimates future available water supplies and gaps under the five different planning scenarios described in the Colorado Water Plan. Previous SWSIs were conducted prior to the Water Plan and, therefore, did not consider the scenarios. The planning scenarios incorporate water supply and demand drivers associated with the potential effects of climate change, population growth, and many other factors.

New Planning Process

In the BIPs, the basin roundtables cataloged various projects and methods to mitigate future water supply gaps. The Technical Update focuses on developing tools and more detailed datasets to help the basin roundtables update their portfolios of projects and methods for meeting future water needs in a targeted manner, with forthcoming updates to their BIPs.

New Models and Data Sets

New analysis tools and data sets have been developed since SWSI 2010. Consumptive use and surface water allocation models developed through the CDSS are now available in most river basins. The CDSS tools allow the evaluation of gaps under a variety of hydrologic conditions. Municipal water demand and conservation data is available via HB10-1051 reporting. The availability of these new tools and data sets allows for a more robust approach to assessing future water availability and potential gaps.

The new gap methodology uses the CDSS tools to evaluate demands and supplies available to meet demands over a range of time and under a variety of hydrologic conditions. As a result, time series of gaps were developed to help examine how gaps change in wet, average/normal, and dry conditions at key locations in each basin (see illustration in Figure 3.2.1). In addition, the CDSS tools were used to estimate M&I and agricultural gaps on the same platform, which creates uniformity in how the respective gaps were estimated. In short, the analyses and data sets are more consistent and robust than what the CWCB was able to achieve in the past.

3.2.1 Important Considerations and General Differences

The new gap methodology has some important differences from SWSI 2010 that need to be understood and considered by basin roundtable members and others who use the findings, tools, and data from the Technical Update. Differences are summarized in Table 3.2.1 on the following page.

Figure 3.2.1 Example Time Series of Gaps

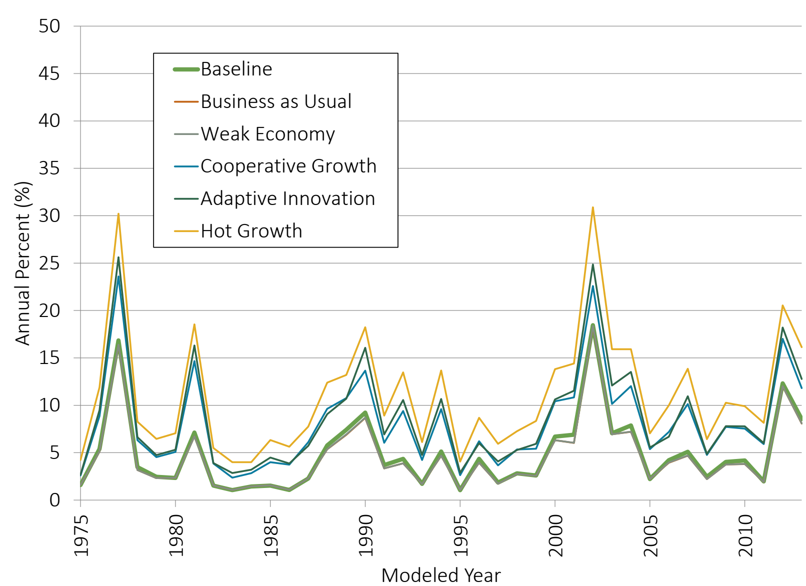


Table 3.2.1 Summary of Differences Between SWSI 2010 and Technical Update

Item	SWSI 2010	Technical Update
Consideration of alternative future conditions	✓	✓
Inclusion of yield from projects (or IPPs) in gap	✓	
Variability in future conditions (2050)		✓
Agricultural gaps using surface water modeling		✓
Quantification of livestock water demands [*]	✓	
Simultaneous consideration of active and passive municipal water conservation [**]		✓
Consideration of climate change		✓
Use of water allocation models reflecting variable supplies, demands, and river operations		✓
Simulation of existing reservoirs		✓
SDO population projections to the year 2050 [***]		✓

[*] Livestock water demands are relatively small on a basin scale and are not simulated in the CDSS tools used in the Technical Update
[**] SWSI 2010 considered active and passive conservation separately, but the Technical Update considers them jointly
[***] SWSI 2010 used complex projections to extend estimates to 2050 because SDO 2050 projections were not available at that time

Results represent 2050 conditions: The planning scenarios in the Water Plan describe assumed future conditions, but they do not contemplate the progression of changes that will occur between now and 2050. As a result, the Technical Update models and data sets represent conditions in the year 2050 and do not depict how drivers of future conditions change between now and then. For example, M&I water demands reflect the needs of Colorado's population in the year 2050 and not prior years. It should be noted that demands and supplies vary in the models, but the variation is reflective of typical ups and downs in future supplies and demands under stable hydrologic cycles, amounts of irrigated land, and population.

Climate change is considered in the Technical Update: Projections of future climate conditions were not a part of SWSI 2010 and have a significant influence on estimated gaps. Planning scenarios that consider a hotter and drier future climate have higher agricultural and municipal diversion demands (for outdoor uses) combined with lower amounts of available water supply—factors that both tend to drive larger gaps.

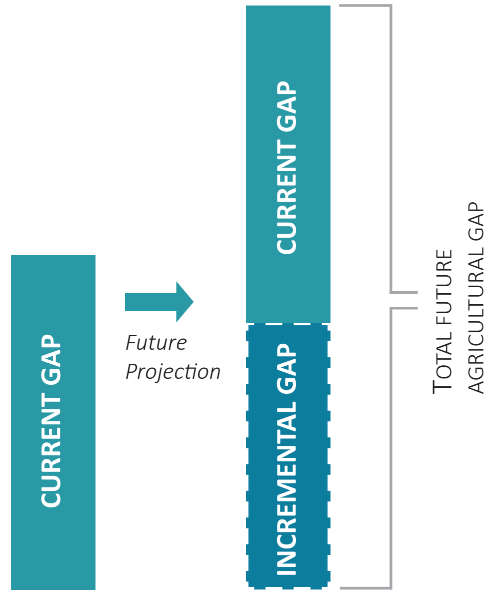
Agricultural gaps are based on diversion demands and described in new ways: The Technical Update quantifies and describes agricultural gaps differently than 2010.

- Agricultural gaps based on diversion demand: As explained in Section 2, water demands in the agricultural sector are based on diversion demands at a river headgate or wellhead. Unlike SWSI 2010, irrigation conveyance and on-farm efficiencies were considered in the agricultural demands and gaps in the Technical Update. As a result, the agricultural gap in the Technical Update will be significantly larger than the agricultural shortages described in SWSI 2010.
- Total and "incremental" agricultural gaps are provided**:** It is anticipated that basin roundtables may want to understand both the total agricultural gap and the degree to which existing agricultural gaps may increase under various scenarios. To meet this need, total and incremental gaps are provided in the Technical Update, and they are described in more detail below.
    - *Total Gap*: The total agricultural gap reflects the overall shortage of agricultural water supplies to meet diversion demands required to fully irrigated crops.
    - *Incremental Gap*: The incremental gap quantifies the degree to which the gap could increase beyond what agriculture has historically experienced under water shortage conditions.

- Total and incremental gaps are quantified as averages. Shortages in agriculture vary across irrigators depending on the seniority of their water rights and based upon hydrologic conditions and their source of supply (tributaries, main steam rivers, groundwater or surface water, etc.). Because of this variability, agricultural gap reporting focuses on averages, though maximum gaps are also presented in Section 4 results tables.

Municipal gaps focus on maximum shortages:

Water providers generally consider and plan for worst-case scenarios. As a result, M&I gaps described in the Technical Update focus on maximum annual shortages or gaps. For perspective, average gaps are presented as well.



Conservation is incorporated into the scenarios:

In SWSI 2010, active and passive conservation measures were considered separately. In the Technical Update, they were jointly considered in the context of the scenario narratives in the Water Plan. Additional levels of conservation beyond what was described in the scenario narratives would be considered a project that a basin roundtable could pursue to help eliminate future gaps.

Water allocation models provide for more robust analyses:

Water allocation models not readily available for use in SWSI 201 are used extensively in the Technical Update. The water allocation models reflect variable supplies, demands, and river operations using existing infrastructure and therefore provide for more robust analyses than prior SWSIs. Using models can lead to different gap results due to the wide variety of additional considerations that influence how supplies are used to meet demands.

3.2.2 Differences in Foundational Municipal Demand Data

In addition to the factors above, two foundational data inputs for estimating municipal water demands have changed since the publication of SWSI 2010—population projections and per capita demand. The changes in both of these data inputs tend to result in lower municipal water demands in the Technical Update than in SWSI 2010.

Population Projections

SWSI 2010 needed to extend the then-current SDO projections for 2035 out to the year 2050 using complex analyses. As noted in Table 3.2.1, the Technical Update was able to rely on newly developed SDO projections for 2050, and estimated high and low ranges based on historical growth statistics.

Figure 3.2.2 provides a comparison of the population projections between SWSI 2010 and the Technical Update. Note that results of population projections are described further in Section 4, but statewide results are shown here for comparison purposes. All of the Technical Update planning scenario projections for 2050 anticipate lower population than the SWSI 2010 high population projection. The Technical Update medium growth projection that is used for *Business as Usual* and *Cooperative Growth* is similar to the SWSI 2010 low population projection (within about 2 percent). The Technical Update high growth projection that is used for *Adaptive Innovation* and *Hot Growth* is similar to the SWSI 2010 medium population projection. Basin-level population projections vary from the comparison above due to the variable distributions under the scenario planning methodology, but mimic similar patterns of lower projections than were developed for SWSI 2010.

BASIN MODELING

In general, modeling was conducted at the basin scale. Due to model availability, some basins were more easily broken out into sub-basins. This was done for the following regions:

- YAMPA-WHITE-GREEN BASIN
  Individual models were available for the Yampa (which includes Green River operations) and White basins. Results of basin analyses were preseted for individual sub-basins and the combined Yampa-Green Basin.

- SOUTH PLATTE BASIN
  A model exists for the South Platte Basin but not the Republican Basin. The results of basin analysis were presented for the South Platte and Republican basins both separately and combined. In addition, the South Plate Basin model does not specifically represent the Metro Basin Roundtable region, and gap results for the Metro region are incorporated in the South Platte Basin Gap results; however, Metro-region M&I demands are specifically quantified and are presented individually (as well as combined with Republican and the remaining South Platte Basin regions).

Per capita and overall municipal demands. The statewide baseline per capita system-wide demand has decreased from 172 gpcd in SWSI 2010 to approximately 164 gpcd, which is nearly a 5 percent reduction in demands between 2008 and 2015. The reduction is associated with improved data availability, conservation efforts, and ongoing behavioral changes. Per capita demand reductions combined with lower population projections compared with SWSI 2010 resulted in lower overall municipal water demands in the Technical Update.

Figure 3.2.3 provides a comparison of the Technical Update results with the SWSI 2010 projected demands for 2050. Note that it is challenging to directly compare the municipal demand projections due to differences in the methodologies. The SWSI 2010 projections selected for Figure 3.2.3 are intended to show a range of the spread in the SWSI 2010 projections relative to the Technical Update projections.

The Technical Update demand projections for all planning scenarios fall within the spread of the SWSI 2010 high population demands with passive-conservation savings and the SWSI 2010 medium population growth with passive and high active-conservation savings. This result was anticipated with the Technical Update methodology, considering that the updated projections represent potential demands under conditions described for each scenario and do not necessarily represent the full potential for conservation programs under each scenario. All of the planning scenarios, with the exception of *Hot Growth*, project municipal water demands that are below the SWSI 2010 low population demands with passive conservation savings.

Figure 3.2.2 Comparison of SWSI 2010 and Technical Update Statewide Population Projections

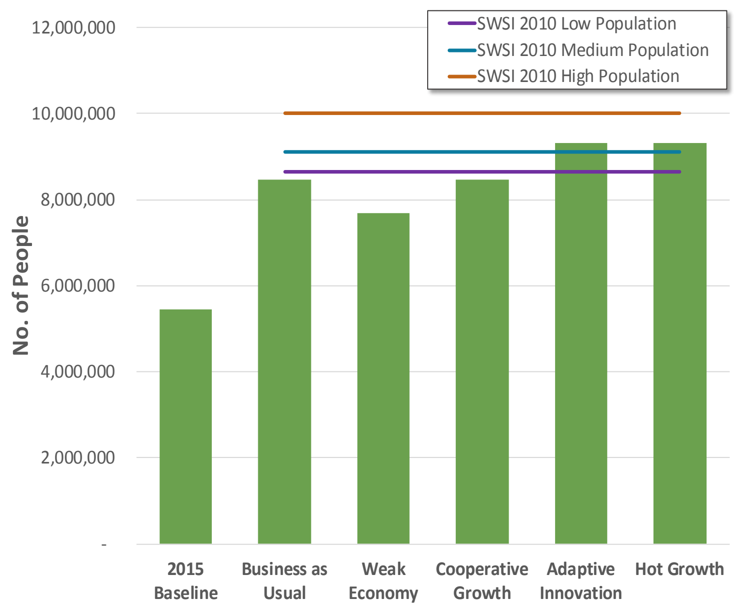


Figure 3.2.3 Comparison of SWSI 2010 and Technical Update Statewide Municipal Diversion Demands

The Arkansas River originates in the central mountains of Colorado near Leadville, then travels eastward through the southeastern part of Colorado toward the Kansas border. The Arkansas Basin is spatially the largest river basin in Colorado, covering slightly less than one-third of the state's land area. A large amount of land is devoted to agriculture, with one-third of agricultural lands requiring irrigation. Increasing urbanization is occurring throughout portions of the Arkansas Basin, and in the recent past, persistent drought has heavily affected the basin.

The Arkansas River Compact of 1948 apportions the waters of the Arkansas River between Colorado and Kansas, while providing for the operation of John Martin Reservoir. Since the early 20th century, Colorado and Kansas have litigated claims concerning Arkansas River water, which has led to the development of rules and regulations to administer the basin's water resources for compliance with the compact.

ARKANSAS


LIMON
KIT CARSON
Big Sandy Creek
Rush Creek
Nee Noshe Reservoir
Adobe Creek Reservoir
District 17
Arkansas - Fowler to Las Animas
District 67
Arkansas - Las Animas to Stateline
Meredith Lake
Horse Creek Reservoir
LAMAR
ROCKY FORD
LA JUNTA
Apishapa River
Timpas Creek
Purgatoire River
Two Butte Creek
District 19
Purgatoire River
PRITCHETT
District 66
Cimarron River

4.3 ARKANSAS BASIN RESULTS

4.3.1 BASIN CHALLENGES

The Arkansas Basin will face several key opportunities and challenges pertaining to water management issues and needs in the future. These were described in Colorado's Water Plan and are summarized below.

Table 4.3.1 Key Future Water Management Issues in the Arkansas Basin

<table>
<tr><th>Agriculture</th><th>Environment and Recreation</th><th>Municipal and Industrial</th><th>Compacts and Administration</th></tr>
<tr>
<td>• Concerns over permanent agricultural transfers and the effects on rural economies are substantial in the lower portion of the basin downstream of Pueblo Reservoir.</td>
<td>• As the most rafted river in the world, the Arkansas River Voluntary Flow Agreement provides a benchmark for cooperative integration of municipal, agricultural, and recreational solutions in support of recreational boating and a gold-medal fishery.</td>
<td>• Replacement of municipal water supplies that depend on the non-renewing Denver Basin aquifer and declining water levels in designated basins is becoming critical, exacerbated by continued growth in groundwater-dependent urban areas.
• Rural areas within the Arkansas Basin have identified water needs but face challenges in marshalling resources to identify and implement solutions.</td>
<td rowspan="2">• All new uses require augmentation. Increasing irrigation efficiency, i.e., conversion from flood to center-pivot irrigation for labor and cost savings, will require 30,000 to 50,000 AF of augmentation water in the coming years.
• Regional solutions are emerging, like the Southeastern Colorado Water Conservancy District (SECWCD) Regional Water Conservation Plan, which can serve as a model for future regional initiatives to address the needs of the Arkansas Basin.</td>
</tr>
<tr>
<td colspan="3">• Collaborative solutions, as demonstrated in the Super Ditch and alternative transfer methods pilot projects, are needed to forestall or minimize loss of irrigated acreage in agriculture.
• Concerns over water quality include drinking water in the Lower Valley and the impact of fires and floods in the Fountain Creek watershed.
• The great majority of surface storage reservoirs in the Arkansas Basin were constructed between 1890 and 1930. Many of these facilities are in need of repair or restoration.</td>
</tr>
</table>

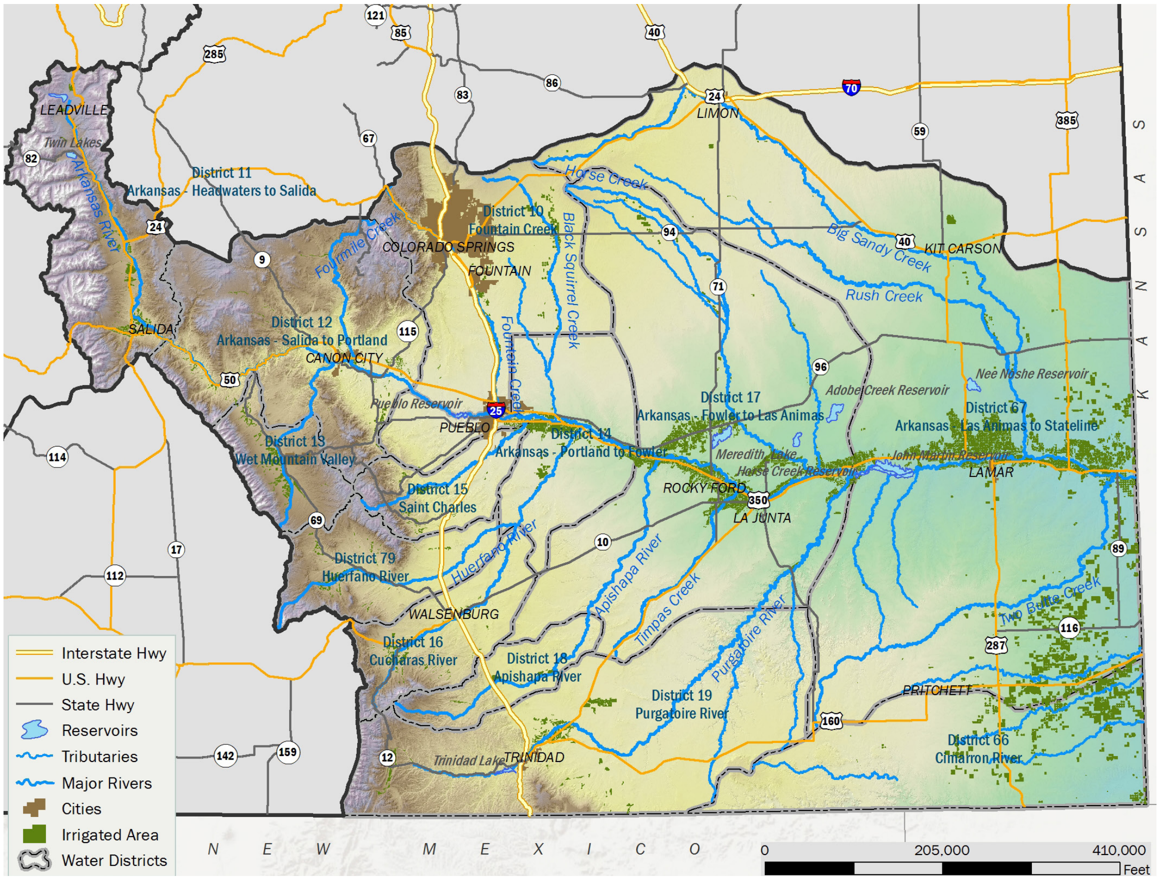


Figure 4.3.1 Map of Arkansas Basin

4.3.2 Summary of Technical Update Results

Key results and findings of the Technical Update pertaining to agricultural and M&I demands and gaps as well as findings related to environment and recreation attributes and future conditions are summarized in Table 4.3.2 below.

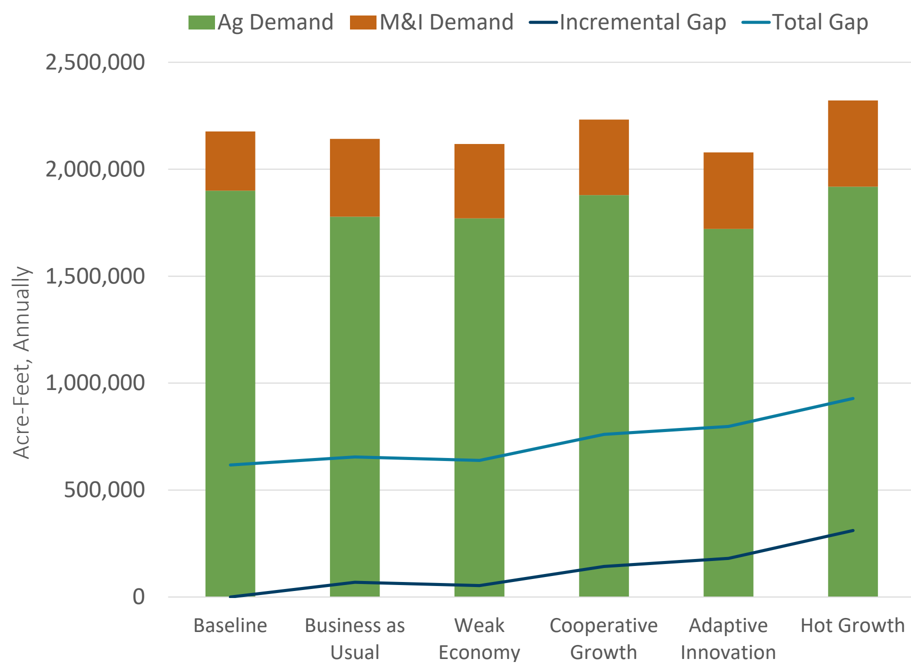
Table 4.3.2 Summary of Key Results in the Arkansas Basin

Agriculture	Environment and Recreation	Municipal and Industrial
• Agricultural demand will remain steady or be slightly reduced due to urbanization (20,000 acres), additional reduction of acres in the Southern High Plains Groundwater Basin, and increased sprinkler use (note that return flow reductions from increased sprinkler use would need to be mitigated). • Agricultural diversion demand gaps may increase due to a warmer climate as much as 10 percent.	• At high elevations, flow magnitude is not projected to significantly change under climate-impacted scenarios, but the annual hydrograph may shift with earlier snowmelt. Risks to riparian and fish habitat would remain low to moderate. • At montane elevations (between 5,500 and 8,500 feet), flow magnitude in climate-impacted scenarios is projected to drop significantly, creating high risk for riparian and fish habitat during the runoff season.	• M&I demand in this basin will grow to become a higher percentage of overall demand (from 13 to 17 percent). At the same time, municipal per capita use is projected to decline by various amounts depending on the scenario. • Municipal demand is driven by population growth in the Colorado Springs and Pueblo area, as well as modest increases in large industry and thermoelectric demand. • Gaps may be exacerbated by reductions in West Slope supplies.

Table 4.3.3 Summary of Diversion Demand and Gap Results in the Arkansas Basin

	Current (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average Annual Demand						
Agricultural (AFY)	1,899,900	1,778,300	1,770,200	1,878,900	1,721,200	1,918,000
M&I (AFY)	276,700	363,300	347,900	353,200	357,600	403,500
Gaps						
Ag (avg %)	32%	33%	33%	37%	43%	43%
Ag (incremental- AFY)	-	-	-	84,400	117,500	202,200
Ag (incremental gap as % of current demand)	-	-	-	4%	6%	11%
M&I (max %)	0%	19%	15%	17%	18%	27%
M&I (max-AF)	0	68,500	53,100	58,500	62,900	108,700

Figure 4.3.2 Summary of Diversion Demand and Gap Results in the Arkansas Basin



Summary of Environmental and Recreational Findings

- A surface water allocation model was not available in the Arkansas Basin, so the available flow dataset only includes natural flows and natural flows as impacted by climate drivers; no management drivers are factored in. Management drivers impact river flows in the eastern plains. Because a water allocation model that incorporates management is not available, no data-based insights into flow change and risk to non-consumptive attributes in the eastern plains could be developed.
- At high elevation locations (e.g., near Leadville), peak flow magnitude is not projected to change substantially, but April and May streamflow may increase, and June flows may decrease under "In-Between" and "Hot and Dry" climate projections. Subsequent risk for riparian/wetland plants and fish habitat would remain low or moderate. Mid- to late-summer streamflow is projected to decrease by 30 to 40 percent, and risk for trout could change from low (current) to moderate (under all climate-driven scenarios).
- At montane locations (elevation approximately 5,500 ft to 8,500 ft), peak flow magnitude is projected to drop 40 to 60 percent under "In-Between" and "Hot and Dry" climate projections, putting riparian/wetland plants and fish habitat at high to very high risk. Mid- to late-summer flows are projected to drop 25 to 45 percent, keeping cold water fish risk low or moderate, although the risk may be higher in July and/or during dry years.

4.3.3 Notable Basin Considerations

Section 4.1 described several analysis assumptions and limitations that apply to all basins and should be considered when reviewing and interpreting analysis results. Additional considerations specific to the Arkansas Basin are listed below:

- Agricultural and M&I gaps in the Arkansas Basin could increase due to reductions in transbasin imports. The gap increase could be more than the reduction in transmountain imports because return flows from transmountain imports are used to extinction within the Arkansas Basin (by either the importing entity or by downstream agricultural and M&I water users).
- Water allocation models were not available in the Arkansas Basin; however, the StateCU portion of the ArkDSS was used to estimate agricultural diversion demands. The ArkDSS is being developed and will allow more robust modeling in the future.
- The analysis assumed that there is no unappropriated water available for new uses. As a result, increased demands in various scenarios contributed directly to the gap. Because of this, increases in demand in one sector will lead to decreases in supply in another sector.
- Agricultural diversion demands were calculated based on irrigated acreage and crop water needs. Because no unappropriated water is available in the basin, the gap evaluation focused on historical water shortages and additional future demands. In other words, given the lack of additional supply, the analysis focused on physical shortages and did not need to consider the presence of junior water rights and whether those rights were fulfilled. Additional future diversion demands contribute directly to the gap because no unappropriated supplies are available in the basin.
- Basin stakeholders have cautioned that large reductions in irrigated land could result in socio-economic impacts that cause a reduction of municipal population in rural areas.
- The analysis does not consider specific alternative crops that may be grown in the future under the different scenarios; however, it accounts for future changes in crop types in a general sense in *Adaptive Innovation* and assumed that future crops would have 10 percent lower IWR.

4.3.4 Agricultural Diversion Demands

Agricultural Setting

Producers irrigate more than 472,000 acres in the Arkansas Basin, with nearly half of these acres located along the river between Pueblo Reservoir and the state line. The fertile soils in the river valley support a wide variety of crops, including pasture grass, alfalfa, corn, grains, wheat, fruits, vegetables, and melons. Many of the large irrigation systems in this area rely on surface water diversions from the mainstem Arkansas River, supplemented with groundwater and Fryingpan-Arkansas Project deliveries. Pasture grass is the primary crop grown outside of the Arkansas River Valley, with concentrated areas of irrigated acreage under the Trinidad Project on the Purgatoire River, along Fountain Creek downstream of Colorado Springs, and in the southeastern corner in the Southern High Plains Ground Water Management District.

The basin also provides water to three of the fastest growing municipalities in the state—Colorado Springs, Aurora, and Pueblo—and competition for water is high. An over-appropriated basin, coupled with the constraints of developing new water supplies under the Arkansas River Compact, have historically led municipalities to purchase and transfer irrigation water rights to municipal uses to meet their growing needs. Beginning in the 1970s, large transfers of irrigation water rights in the Colorado Canal (including Twin Lake shares) resulted in the dry up of 45,000 acres in Crowley County alone, which contributed to socioeconomic and environmental impacts in the Lower Arkansas River Valley. More recently, however, the basin has been proactive at looking for solutions to share water supplies and has been one of the front runners in developing alternative transfer methods such as lease/fallow pilot projects and interruptible supply agreements in which irrigation rights can be temporarily leased to municipalities for a limited number of years (e.g., three years out of every 10 years).

Planning Scenario Adjustments

Section 2 described ways in which inputs to agricultural diversion demand estimates were adjusted to reflect the future conditions described in the planning scenarios. Discussions with stakeholders in the Arkansas Basin regarding what agriculture in the basin may look like by 2050 focused on three major areas: additional dry up of acreage for municipal purposes, declining groundwater aquifer levels in the Southern High Plains region, and irrigation practices. As discussed in more detail below, dry up of acreage and declining aquifer levels impact the amount of projected 2050 irrigated acreage. In addition, irrigation practices affect projected 2050 efficiencies.

Population projections by 2050 in the basin reflect significant increases for Colorado Springs and Pueblo. With limited acreage in close proximity, smaller amounts of irrigated acreage are expected to be urbanized by their growth compared to urbanization that may occur around smaller agricultural towns such as Salida, Canon City, and Lamar. Portions of two irrigation ditches, Fort Lyon Canal and Bessemer Ditch, have been purchased by municipalities, and their water rights are in the process of being transferred for municipal uses. It is anticipated that portions of these ditches, totaling 12,600 irrigated acres, will be dried up by 2050. Although additional purchase of irrigation water rights is expected, the stakeholders in the basin are hopeful that leasing agreements or other solutions may limit the permanent dry up of irrigated acreage in the future.

From a groundwater sustainability perspective in the basin, more than 85,000 acres in the southeast corner of the basin are irrigated by groundwater pumped from a series of deep aquifers, including the Ogallala, Dakota/Cheyenne, and Dockum aquifers. This area is largely disconnected from the mainstem of the Arkansas River and is managed as the Southern High Plains Designated Groundwater Basin (SHPDGWB). After review of groundwater reports documenting downward trends in groundwater levels, discussions with stakeholders, and conversations with landowners in the area, the acreage in this area was reduced between 10 and 33 percent across the planning scenarios. This range reflects the uncertainty associated with estimating the future water availability in the basin and the potential for increased pumping as projected climate change increases crop demands in the area.

Table 4.3.4 summarizes the planning scenario adjustments described above and other adjustments that impact agricultural diversion demands in the various scenarios, including constraints on improved irrigation efficiencies in the lower basin.

Table 4.3.4 Planning Scenario Adjustments to for Agricultural Demands in the Arkansas Basin

Adjustment Factor*	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Change in Irrigated Land due to Urbanization & Municipal Transfers	19,840 Acre Reduction	19,840 Acre Reduction	19,840 Acre Reduction	19,840 Acre Reduction	19,840 Acre Reduction
GW Acreage Sustainability	10% Acre Reduction (SHPDGWB)	15% Acre Reduction (SHPDGWB)	20% Acre Reduction (SHPDGWB)	33% Acre Reduction (SHPDGWB)	33% Acre Reduction (SHPDGWB)
IWR Climate Factor	-	-	18%	26%	26%
Emerging Technologies	20% Increased Sprinkler Use (H-I Area)	20% Increased Sprinkler Use (H-I Area)	20% Increased Sprinkler Use (H-I Area) 100% use of Sprinklers (SHPDGWB)	20% Increased Sprinkler Use (H-I Area) 100% use of Sprinklers (SHPDGWB) 10% IWR Reduction	20% Increased Sprinkler Use (H-I Area) 100% use of Sprinklers (SHPDGWB)

** See Section 2.2.3 for descriptions of adjustment methodologies and assumptions*

Agricultural Diversion Demand Results

Table 4.3.5 and Figure 4.3.3 summarize the acreage, IWR, and the agricultural diversion demand for surface water supplies in the Arkansas Basin for current conditions and the five planning scenarios. The largest variation in the basin occurred in *Adaptive Innovation* due to a 10 percent reduction in IWR and a 10 percent increase to system efficiency, both of which reduce diversion demands. In this basin, several planning scenarios projected less agricultural demand than the current demand, mainly due to reduced irrigated acres and resulting decreased IWR. Only *Hot Growth* had a slightly increased demand over baseline.

SYSTEM EFFICIENCY

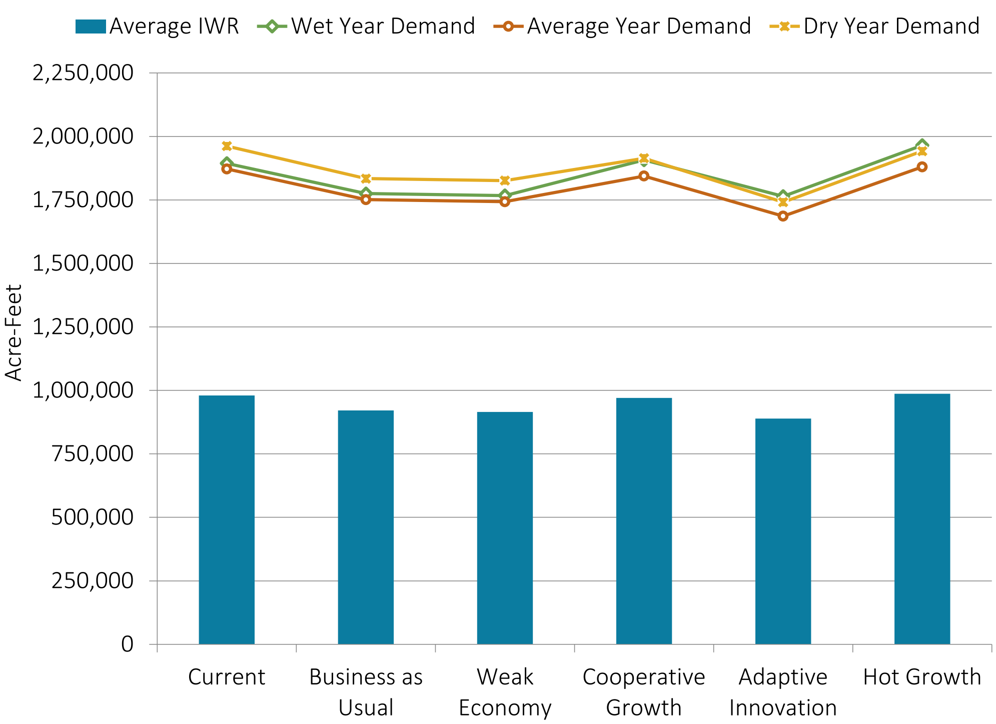
In some cases, diversion demands can be higher in wet years because system efficiency decreases due to the relative abundance of supply.

Table 4.3.5 Summary of Agricultural Diversion Demand Results in the Arkansas Basin

	Current (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Irrigated Acreage (acres)	445,000	417,700	413,600	409,500	398,900	398,900
Average IWR (AFY)	980,000	921,000	915,000	970,000	889,000	987,000
Diversion Demand						
Average Year (AFY)	1,872,000	1,751,000	1,743,000	1,844,000	1,686,000	1,880,000
Wet Yr. Change	1%	1%	1%	3%	5%	5%
Dry Yr Change	5%	5%	5%	4%	3%	3%

Average agricultural diversion demand was calculated using the average hydrologic years (i.e., years classified as neither wet or dry) from 1950-2013

Figure 4.3.3 Agricultural Diversion Demands and IWR Results in the Arkansas Basin



4.3.5 Municipal and Industrial Demands

Population Projections

The Arkansas Basin includes about 19 percent of the statewide population. Between the years 2015 and 2050, it is projected to grow from approximately 1.0 million to between 1.46 million and 1.63 million people in the low and high growth projections, respectively, which is an increase in population of 45 to 61 percent. Table 4.3.6 shows how population growth is projected to vary across the planning scenarios for the Arkansas Basin.

Table 4.3.6 Arkansas Basin 2015 and Projected Populations

2015 Population	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
1,008,400	1,509,500	1,462,800	1,544,400	1,626,000	1,568,000

Current Municipal Demands

In the Arkansas Basin, baseline water demands were largely based on 1051 data as shown on Figure 4.3.4.

Figure 4.3.5 summarizes the categories of municipal, baseline water usage in the Arkansas Basin. On a basin scale, the residential outdoor demand as a percentage of the systemwide demands is one of the lowest reported throughout the state, at approximately 17 percent. Conversely, the baseline non-revenue water demand is one of the highest statewide, at approximately 18 percent of the systemwide demands.

Figure 4.3.4 Sources of Water Demand Data in the Arkansas Basin

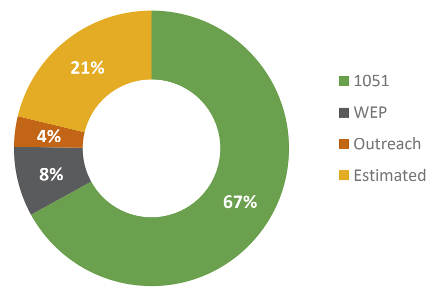
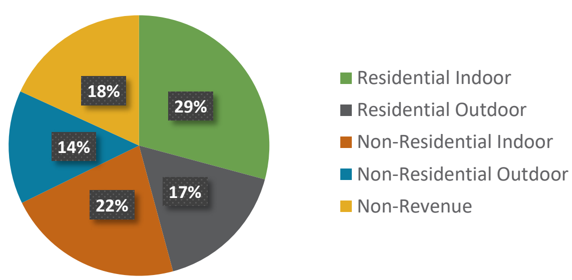


Figure 4.3.5 Categories of Water Usage in the Arkansas Basin



DEMANDS

The Arkansas Basin average baseline per capita system wide demand has increased from 185 gpcd in SWSI 2010 to approximately 194 gpcd.

Projected Municipal Demands

Figure 4.3.6 provides a summary of per capita baseline and projected water demands for the Arkansas Basin. Systemwide, all of the projected per capita demands decrease relative to the baseline. Th *Hot Growth* is projected to be nearly as high as the baseline, with lower residential indoor but higher residential and non-residential outdoor demands that are significantly influenced by hotter and drier climate conditions.

The Arkansas Basin municipal baseline and projected diversion demands in Table 4.3.7 show the combined effect of population and per capita demands. Municipal demands are projected to grow from approximately 219,000 AFY in 2015 to between 294,000 and 337,000 AFY in 2050. El Paso County accounts for around half of the baseline demand, followed by Pueblo County at about one-third of basin demand.

Figure 4.3.6 Arkansas Basin Municipal Baseline and Projected Per Capita Demands by Water Demand Category

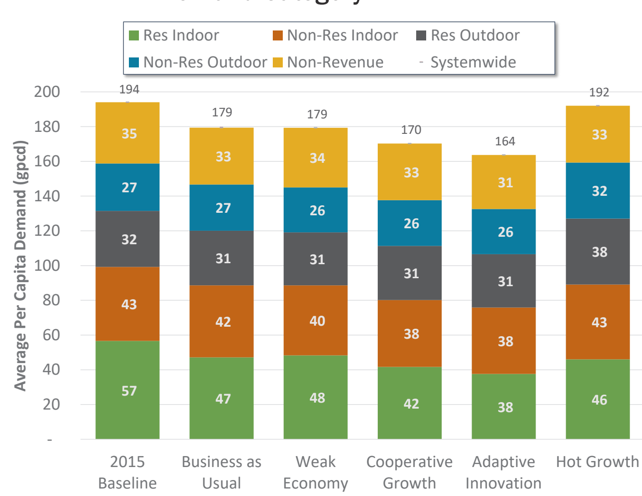


Table 4.3.7 Arkansas Basin Municipal Baseline and Projected Demands (AFY)

Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
219,200	303,400	293,800	294,500	298,100	337,200

The baseline and projected demand distributions are shown on Figure 4.3.7, which also shows how the population varies between the scenarios. All of the planning scenarios result in an increase relative to the baseline. Except *Hot Growth*, the systemwide demand projections are similar, which demonstrates how the pairing of drivers and population can offset each other and narrow the range of results. Higher levels of conservation associated with *Adaptive Innovation* help limit the impacts of the "Hot and Dry" climate projection and higher population.

Self-Supplied Industrial Demands

The Arkansas Basin includes about 33 percent of the statewide SSI demand. SSI demands in this basin are associated with the large industry and thermoelectric sub-sectors, with no demands projected for snowmaking or energy development sub-sectors. Basin-scale SSI demands are shown on Figure 4.3.8 and summarized in Table 4.3.8.

Total M&I Diversion Demands

Arkansas Basin combined M&I demand projections for 2050 range from approximately 350,000 AFY in *Weak Economy* to 405,000 AFY in *Hot Growth*, as shown on Figure 4.3.9. SSI demands account for 16 to 17 percent of the projected M&I demands. On a basin scale, the demand projections do not follow the statewide sequence of the scenario rankings described in the CWP, with *Adaptive Innovation* falling out of sequence.

Figure 4.3.7 Arkansas Basin Baseline and Projected Population and Municipal Demands

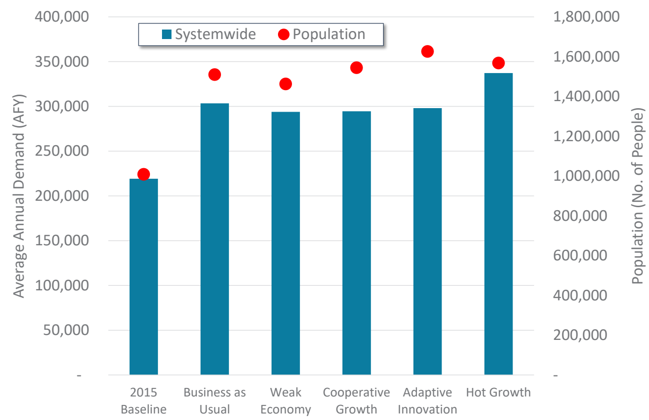


Figure 4.3.8 Arkansas Basin Self-Supplied Industrial Demands

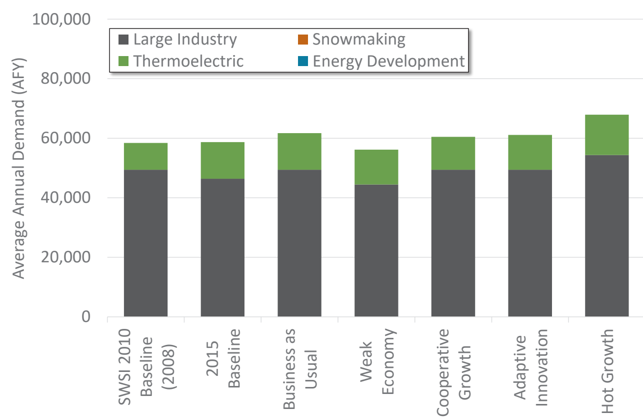


Figure 4.3.9 Arkansas Basin Municipal and Self-Supplied Industrial Demands

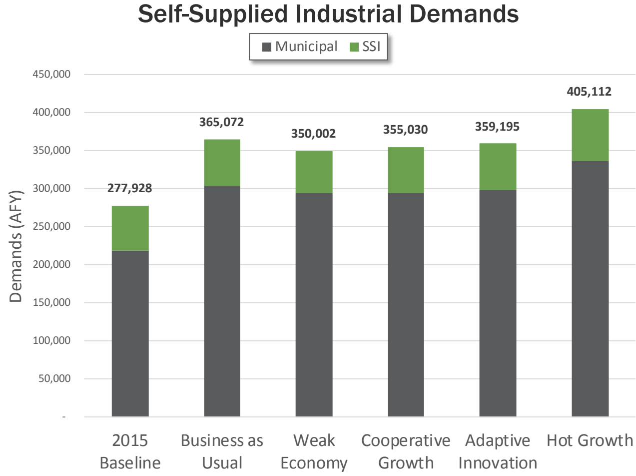


Table 4.3.8 Arkansas SSI Baseline and Projected Demands (AFY)

Sub-sector	Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Large Industry	46,400	49,400	44,460	49,400	49,400	54,340
Snowmaking	-	-	-	-	-	-
Thermoelectric	12,320	12,320	11,700	11,090	11,700	13,550
Energy Development	-	-	-	-	-	-
Sub-Basin Total	58,720	61,720	56,160	60,490	61,100	67,890

4.3.6 Water Supply Gaps

The agricultural and M&I diversion demands were compared against available water supply modeled for current conditions and the five planning scenarios. Gaps were calculated when water supply was insufficient to meet demands.

Agricultural

The Arkansas Basin agricultural diversion demands, demand gaps, and consumptive use gaps for the baseline and planning scenarios are presented in Table 4.3.9 and illustrated on Figure 4.3.10. An annual time series of gaps in terms of percent of demand that was unmet is shown on Figure 4.3.11.

> **INCREMENTAL GAP**
>
> The incremental agricultural gap quantifies the degree to which the gap could increase beyond what agriculture has historically experienced under water shortage conditions.

Table 4.3.9 Arkansas Basin Agricultural Gap Results (AFY)

		Scenario					
		Scenario	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand	1,899,900	1,778,300	1,770,200	1,878,900	1,721,200	1,918,000
Average	Average Annual Gap	617,300	586,400	585,200	701,700	734,800	819,500
Average	Average Annual Gap Increase from Baseline	-	-	-	84,400	117,500	202,200
Average	Average Annual Percent Gap	32%	33%	33%	37%	43%	43%
Average	Average Annual CU Gap	313,100	297,100	296,400	362,500	381,500	425,300
Maximum	Demand in Maximum Gap Year	2,303,900	2,152,100	2,141,500	2,149,300	1,932,700	2,157,900
Maximum	Gap in Maximum Gap Year	1,446,400	1,369,600	1,366,600	1,532,000	1,566,100	1,749,800
Maximum	Increase from Baseline Gap	-	-	-	85,600	119,700	303,400
Maximum	Percent Gap in Maximum Gap Year	63%	64%	64%	71%	81%	81%

Study period for Water Supply analysis is 1975-2013, reflecting different baseline demand than described in Agricultural Diversion Demands section.

Figure 4.3.10 Projected Averages Annual Agricultural Diversion Demand, Demand Met, and Gaps in the Arkansas Basin

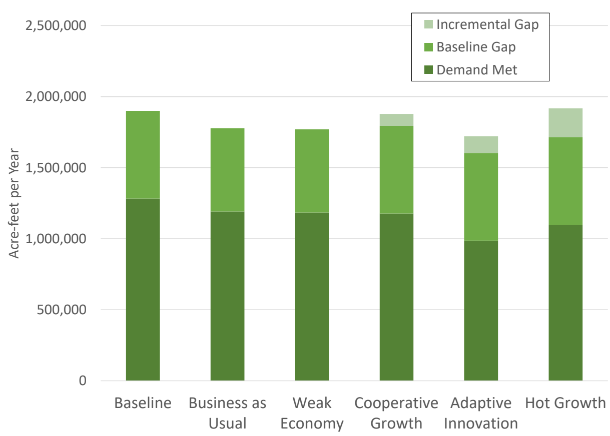
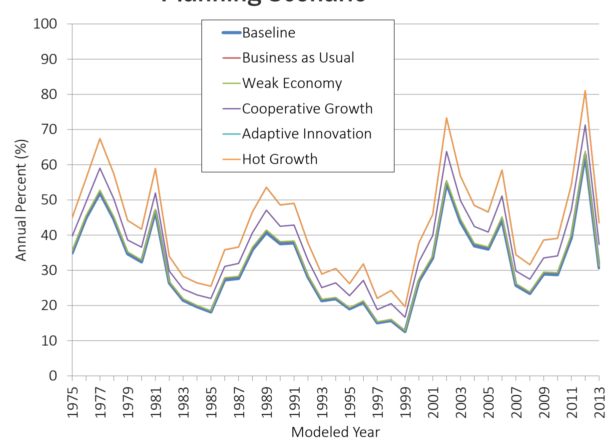


Figure 4.3.11 Annual Agricultural Gaps (expressed as a percentage of demand) for Each Planning Scenario



The following are observations on agricultural diversion demands and gaps:

- Agricultural diversion demands are projected to be similar or even reduced as compared to baseline in all five planning scenarios due to urbanization, transfers of agricultural water rights to municipal uses, and declining aquifer levels in the Southern High Plains, all resulting in reduced irrigated acres.
- The agricultural gap as a percent of demand is relatively large in this basin (32 to 43 percent). Current farming practices help to minimize this gap, which is projected to remain consistent in *Business as Usual* and *Weak Economy*; however, climate changes reflected in *Cooperative Growth*, *Adaptive Innovation* and *Hot Growth* are projected to increase water supply gaps up to 40 percent of demand.

M&I

The diversion demand and gap results for M&I uses in the Arkansas Basin are summarized in Table 4.3.10 and illustrated on Figure 4.3.12. Note that annual time series of M&I gaps are not available for the Arkansas Basin due to the lack of available CDSS tools.

The following are observations on M&I diversion demands and gaps:

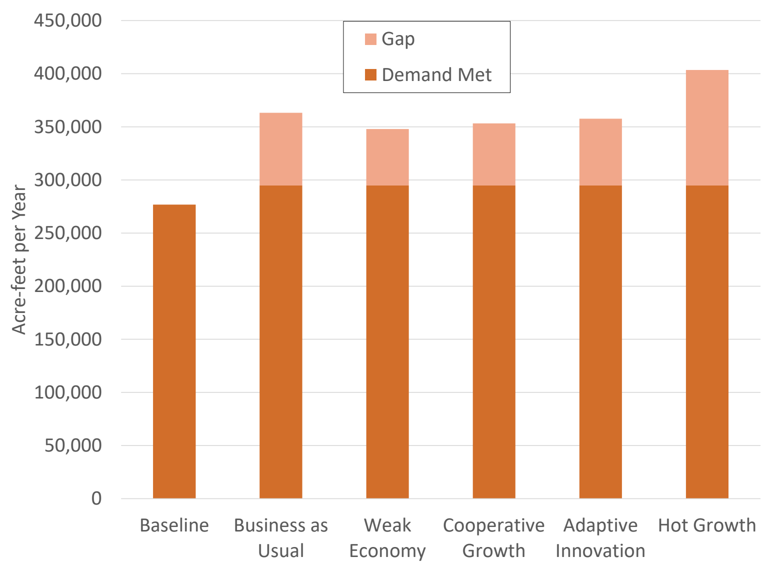
- M&I diversion demand in this basin is projected to grow to become a higher percentage of overall demand (from 13 to 17 percent).
- Municipal demand is driven by population growth in the Colorado Springs and Pueblo area, as well as modest increases in large industry and thermoelectric demand.
- The M&I gap in *Adaptive Innovation* is projected to be less than in *Business as Usual* even with high levels of projected population growth and increased outdoor water demands due to a hotter and drier climate.
- M&I gaps may be exacerbated by reductions in transbasin imports in planning scenarios that include considerations of climate change.

Table 4.3.10 Arkansas Basin M&I Gap Results

		Scenario					
		Scenario	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand	276,700	363,300	347,900	353,200	357,600	403,500
Average	Average Annual Gap	0	68,500	53,100	58,500	62,900	108,700
Average	Average Annual Percent Gap	0%	19%	15%	17%	18%	27%
Maximum	Demand in Maximum Gap Year	276,700	363,300	347,900	353,200	357,600	403,500
Maximum	Gap in Maximum Gap Year	0	68,500	53,100	58,500	62,900	108,700
Maximum	Percent Gap in Maximum Gap Year	0%	19%	15%	17%	18%	27%

Study period for Water Supply Analysis is 1975-2013, reflecting different baseline demand than described in M&I Demand section.
Baseline demand also may vary slightly from previous section due to differences in geographic distribution of demand for counties that lie in multiple basins.

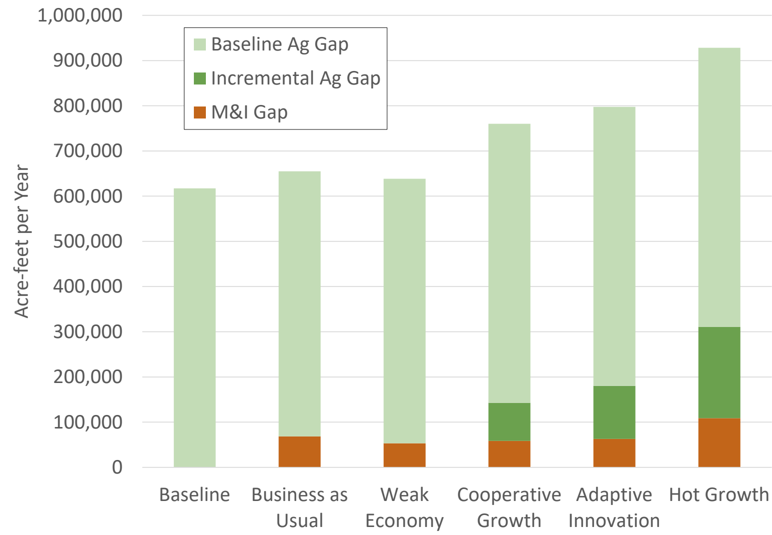
Figure 4.3.12 Projected Maximum Annual M&I Demand Met and Gaps in the Arkansas Basin



Total Gap

Figure 4.3.13 illustrates the total combined agricultural and M&I diversion demand gap in the Arkansas Basin. The figure combines the average annual baseline and incremental agricultural gap and the maximum M&I gap. In *Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth*, gaps are driven by both agricultural and municipal demands, which increase in the "Hot and Dry" climate projection.

Figure 4.3.13 Projected Average Annual Agricultural Gaps and Maximum M&I Diversion Demand Gaps in the Arkansas Basin



Supplies from Urbanized Lands

By 2050, irrigated acreage in the Arkansas Basin is projected to decrease by more than 19,000 acres due to urbanization or lands that are no longer irrigated because of planned water right transfers from agricultural to municipal use in the Arkansas Basin. Irrigation supplies for these lands could potentially be used for M&I needs in the future (subject to a variety of unknowns such as seniority and type of water supply, willingness to change the use of water through water court, etc.). Acreage associated with planned transfers was derived based on stakeholder input.

The average annual historical consumptive use associated with potentially urbanized acreage and planned water right transfers for each scenario is reflected in Table 4.3.11. The data in the table represent planning-level estimates of this potential supply and has not been applied to the M&I gaps. The data in the table do not represent supplies from permanent water transfers that may be considered by a basin roundtable as a future strategy to meet gaps (note that SWSI 2010 included estimates of permanent transfers beyond those currently planned as a strategy for meeting potential future M&I gaps).

Table 4.3.11 Estimated Consumptive Use from Lands Projected to be Urbanized by 2050 and Planned Transfers in the Arkansas Basin

	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Urbanized Acreage and Lands Subject to Planned Transfers (acres)	19,800	19,800	19,800	19,800	19,800
Estimated Consumptive Use (AFY)	29,600	29,700	29,400	25,200	27,900

4.3.7 Available Supply

For the purposes of the Technical Update, it was assumed that due to compact constraints, there are no available water supplies now or in the future that can meet new demands.

4.3.8 Environment and Recreation

A surface water allocation model is not currently available in the Arkansas Basin. As a result, hydrologic datasets in the Flow Tool include only naturalized flows and naturalized flows as impacted by climate change. A total of three water allocation model nodes were selected for the Flow Tool within the Arkansas Basin (Figure 4.3.14). The figure also shows subwatersheds (at the 12-digit HUC level) and the relative number of E&R attributes located in each subwatershed.

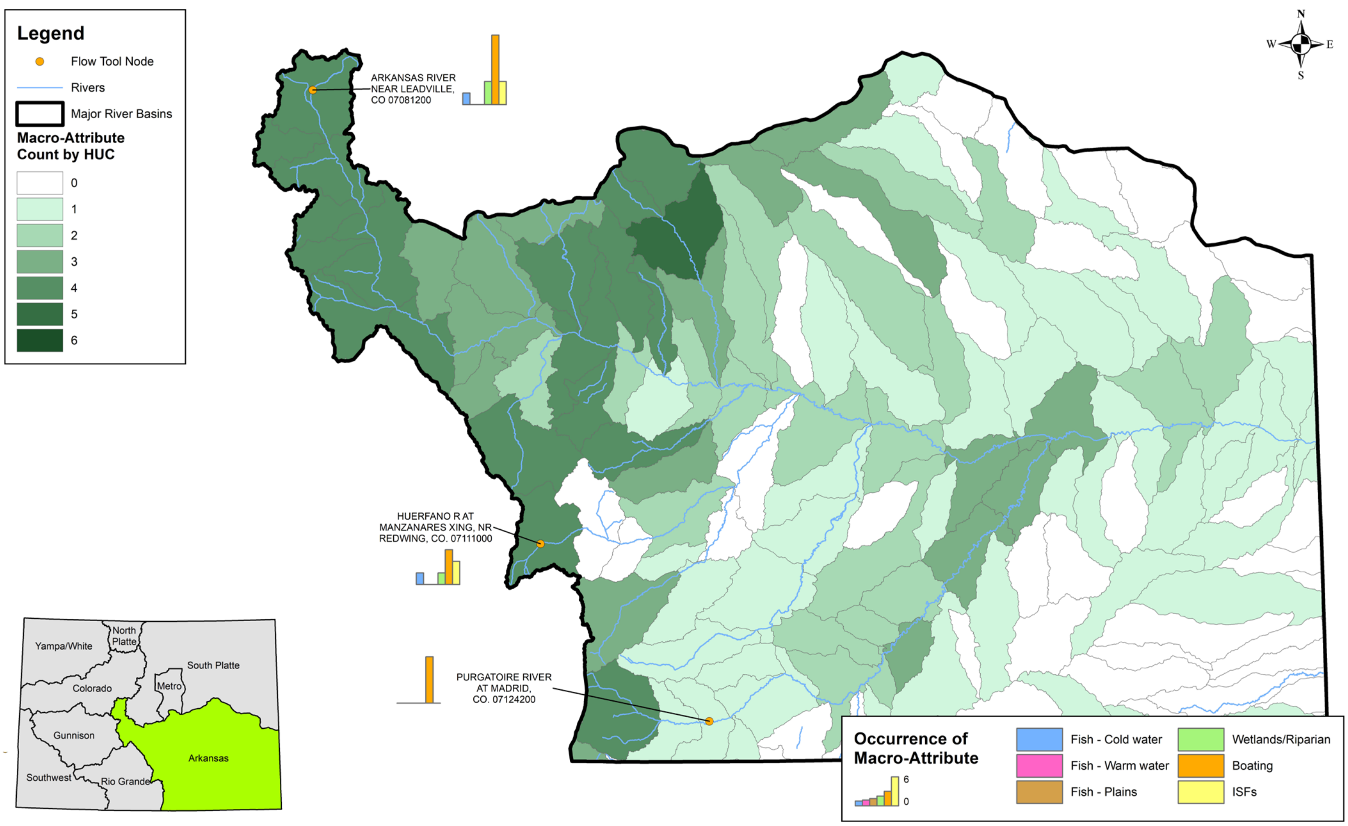
- Arkansas River near Leadville, Colorado (07081200)
- Huerfano River at Manzanares Crossing, near Redwing, Colorado (07111000)
- Purgatoire River at Madrid, Colorado (07124200)

The sites were selected because they are above major supply and demand drivers, and because future flow changes would likely be associated only with climate-change factors. Management drivers impact river flows on the eastern plains. Because a water allocation model that incorporates management is not available, no data-based insights into potential flow changes and risks to E&R attributes could be developed at this time. The Flow Tool results for the Arkansas Basin include only naturalized flows and naturalized flows as impacted by climate change factors ("In-Between" and "Hot and Dry" climate projections). These data do not represent changes in flow due to irrigation, transbasin imports, and/or storage.

NATURALIZED FLOW

Naturalized flows reflect conditions that would occur in the absence of human activities. Baseline flows reflect current conditions as influenced by existing infrastructure and river operations. While observations regarding naturalized flows may be informative, baseline flows reflect actual conditions and the diverse operations of the river's many users.

Figure 4.3.14 Flow Tool Nodes Selected for The Arkansas Basin



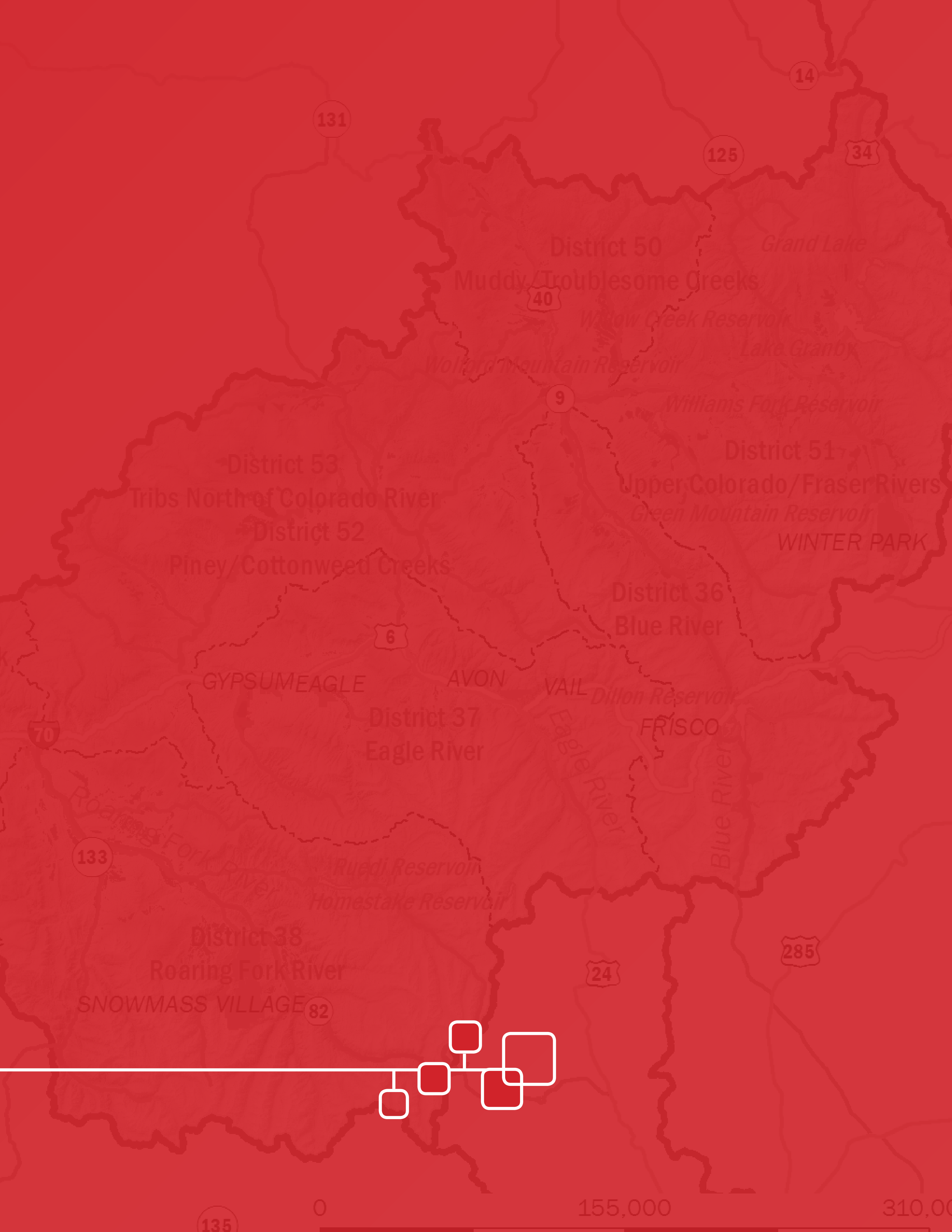
Results and observations from Flow Tool analyses using flow data developed in the water supply and gap analyses for baseline conditions and the planning scenarios are described in Table 4.3.12.

Table 4.3.12 Summary of Flow Tool Results in the Arkansas Basin

Category	Observation
Projected Flows	At high elevation locations (e.g., near Leadville), peak flow magnitude are not projected to change substantially. However, the timing of peak flow may shift to earlier in the year, with April and May flow magnitudes rising and June flows decreasing under the In-Between and Hot and Dry climate change projections.
	At montane and foothills locations (elevation range from approximately 5,500 feet to 8,500 feet), peak flow magnitude will likely drop under the In-Between and Hot and Dry climate change projections.
	Across all locations, mid- and late-summer streamflow is projected to decrease due to climate change.
Ecological Risk	At high elevations, peak-flow related risk for riparian/wetland plants and fish habitat remains low or moderate under future climate change projections.
	At lower elevations, the decline in peak flow magnitude is projected to increase the risk status for riparian/wetland plants and fish habitat. The reduction in peak flow may also adversely affect recreational boating.
	Metrics for coldwater fish (trout) indicate that even with climate-induced changes to mid- and late-summer flows, flows are projected to be sufficient to keep risk low or moderate, though risk may be higher in July and/or during dry years.
E&R Attributes	Because future flows under the five scenarios were not modeled in the Arkansas Basin, projected changes to flow at the selected nodes and the associated changes in risk to E&R attributes are entirely attributable to projected changes in climate. These climate-induced changes are similar to the general pattern seen in many parts of Colorado: earlier peak flow and reduced mid- and late-summer flows, with reduced peak flow magnitudes in some locations.

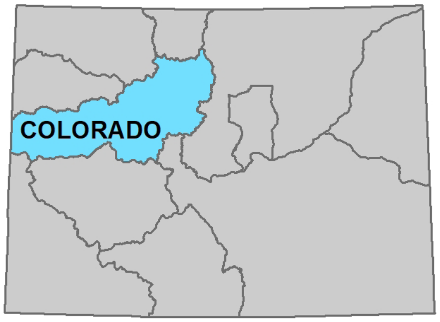
The mainstem Colorado Basin in Colorado encompasses approximately 9,830 square miles and extends from Rocky Mountain National Park to the Colorado-Utah state line. Elevations range from more than 14,000 feet to about 4,300 feet. Snowpack in the high country is an important water source to both sides of the Continental Divide, as the state's largest transbasin diversions are here. Ranching and livestock production typify agriculture in the upper reaches, while the Grand Valley has a long history of fruit and vegetable production. With major ski areas as well as boating and fishing opportunities, water drives a robust recreation and tourism economy throughout the basin.

COLORADO



131
14
125
34
District 50
Muddy/Troublesome Creeks
Grand Lake
40
Willow Creek Reservoir
Lake Granby
Wolford Mountain Reservoir
9
Williams Fork Reservoir
District 51
Upper Colorado/Fraser Rivers
Green Mountain Reservoir
WINTER PARK
District 53
Tribs North of Colorado River
District 52
Piney/Cottonwood Creeks
District 36
Blue River
6
GYPSUM
EAGLE
AVON
VAIL
Dillon Reservoir
FRISCO
District 37
Eagle River
70
Eagle River
Blue River
Roaring Fork River
133
Ruedi Reservoir
Homestake Reservoir
District 38
Roaring Fork River
285
24
SNOWMASS VILLAGE
82
0
155,000
310,00
135

4.4 COLORADO BASIN RESULTS

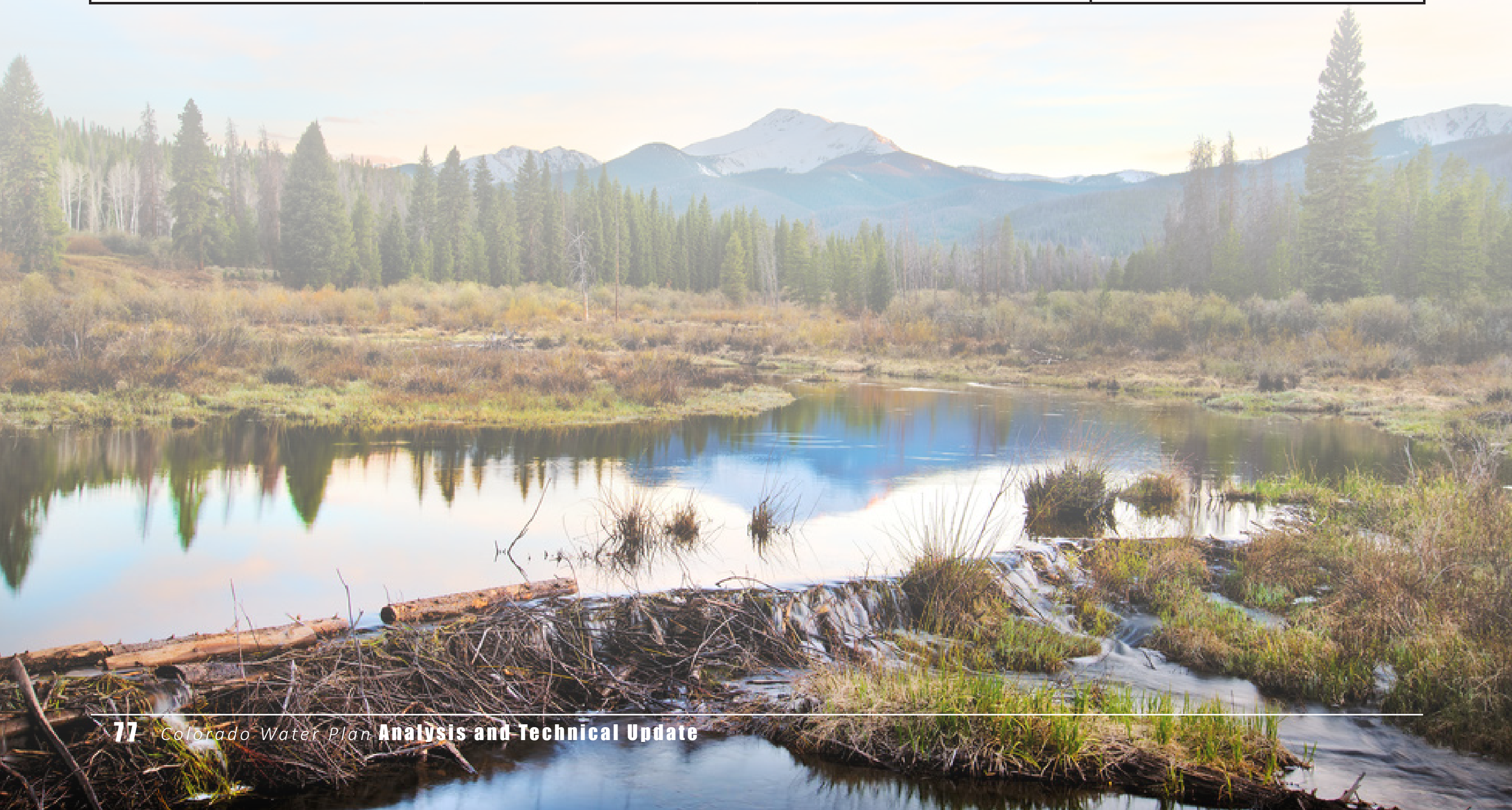


4.4.1 BASIN CHALLENGES

Key future water management issues in this basin include competing resources for agriculture, tourism and recreation, protection of endangered species, and the threat of a Colorado River Compact call. These challenges are described in Colorado's Water Plan and summarized below in Table 4.4.1.

Table 4.4.1 Key Future Water Management Issues in the Colorado Basin

Agriculture	Environment and Recreation	Municipal and Industrial	Compacts and Administration
• Despite the importance of agriculture, continued urbanization of agricultural lands could reduce irrigated acres in the basin.	• Success of the Upper Colorado River Endangered Fish Recovery Program is vital to the river's future. The program is designed to address the needs of endangered fish while protecting existing and future use of Colorado River water. • Recreational use and environmental conservation are major drivers in the basin and are important for economic health and quality of life.	• Development of conditional transbasin water rights is a concern, and Colorado must consider the effect on in-basin supplies.	• There is concern over a potential compact shortage during severe and sustained drought and the potential effects to in-basin supplies. Demand management to conserve water per the recently signed Drought Contingency Plan is a pressing issue.
• Selenium and salinity are of concern in parts of the basin.			



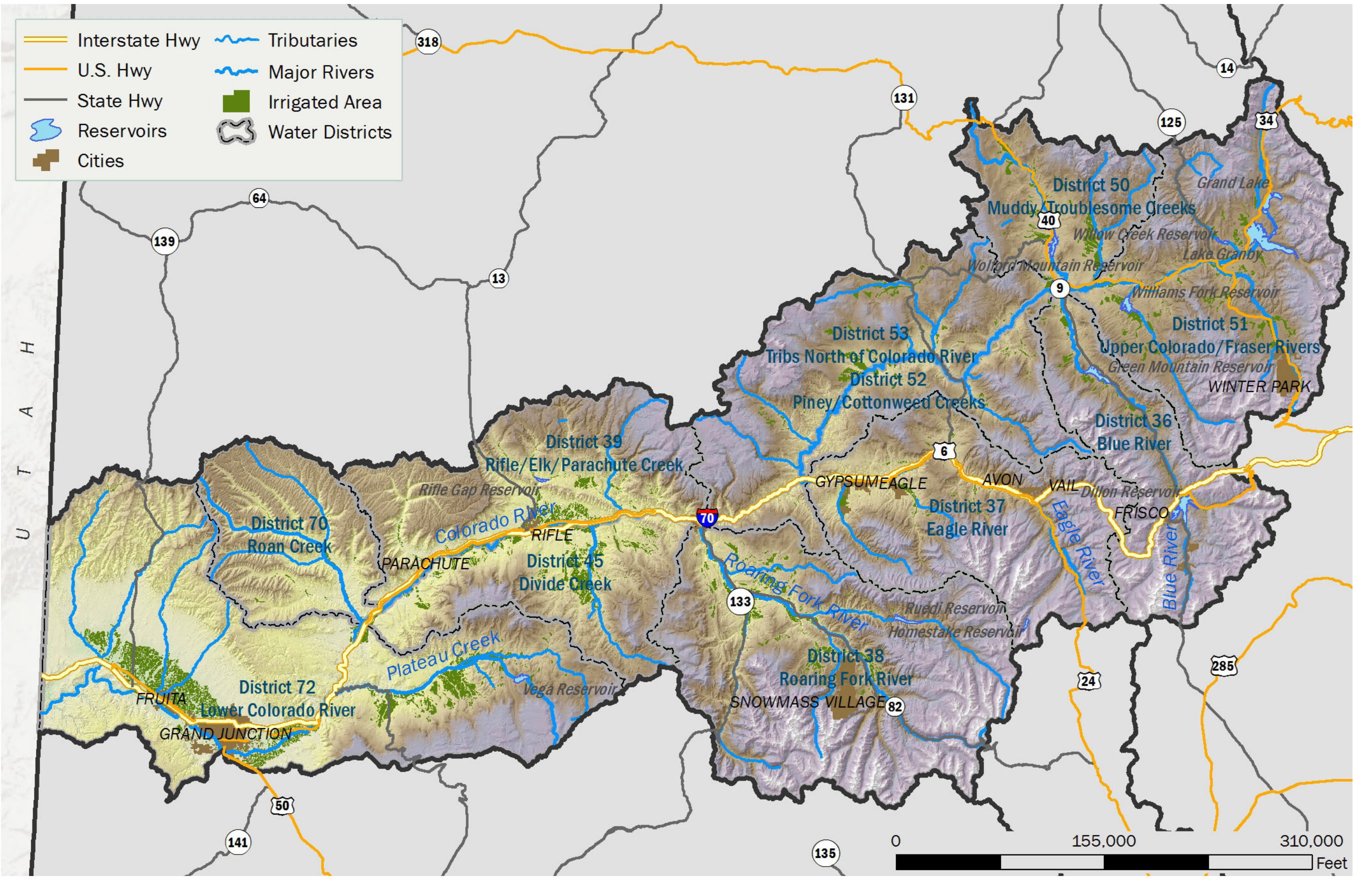


Figure 4.4.1 Map of the Colorado Basin

4.4.2 SUMMARY OF TECHNICAL UPDATE RESULTS

Key results and findings of the Technical Update pertaining to agricultural and M&I demands and gaps, as well as findings related to environmental and recreational attributes and future conditions, are summarized below in Table 4.4.2.

Table 4.4.2 Summary of Key Results in the Colorado Basin

Agriculture	Environment and Recreation	Municipal and Industrial
• Although irrigated area is estimated to decrease by 13,600 acres as cities expand onto irrigated land, IWR may increase in a warmer future climate. • Emerging technology, including adoption of higher system efficiencies, may mitigate climate impacts and reduce demand below baseline. • The future incremental gap ranges from 0 to 4 percent of baseline demand • Scenarios that assume current climate conditions (Business as Usual and Weak Economy) have agricultural gaps around 3 percent of demand. Gaps (as a percentage of demand) increase in scenarios that assume a warmer and drier future climate.	• In climate-impacted scenarios, peak flow generally moves earlier in the year. • Aquatic and riparian attributes may be affected differently based on location and potential changes in stream flow magnitude and timing.	• Per capita municipal usage is projected to decrease in the future. • Municipal demand is projected to increase for all scenarios due to increased population; however, except for Hot Growth, the systemwide demand projections for all future scenarios are similar, showing that pairing of drivers and population can offset each other and even out the results. • Increases in SSI demands in Business as Usual and Hot Growth represent anticipated energy development.

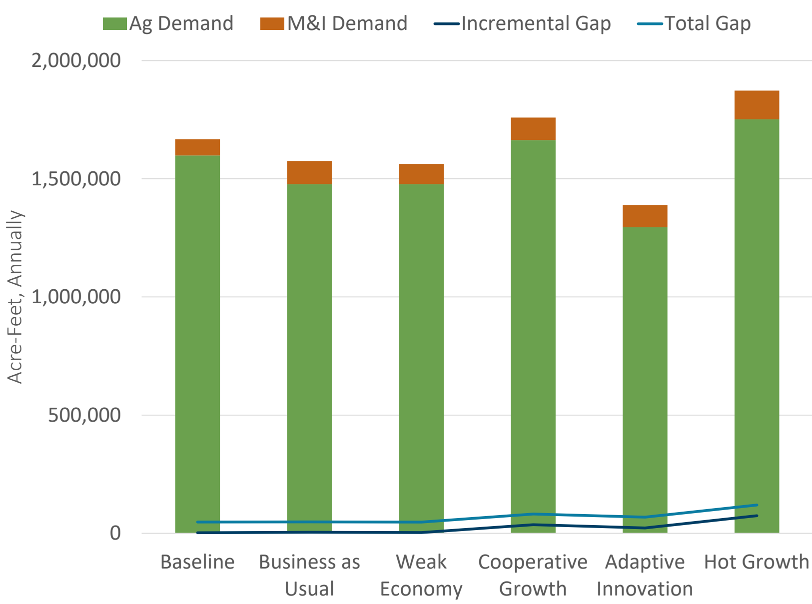
Results describing current and potential future M&I and agricultural demands and gaps are summarized in Table 4.4.3 and in Figure 4.4.2.

Table 4.4.3 Summary of Diversion Demand and Gap Results in the Colorado Basin

	Current (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average Annual Demand						
Agricultural (AFY)	1,598,900	1,476,800	1,476,800	1,663,800	1,294,900	1,751,600
M&I (AFY)	68,500	98,400	85,800	95,400	94,500	121,400
Gaps						
Ag (avg %)	3%	3%	3%	5%	5%	6%
Ag (incremental-AFY)	-	-	-	30,900	16,200	58,500
Ag (incremental gap as % of current demand)	-	0%	0%	2%	1%	4%
M&I (max %)	0%	4%	4%	6%	7%	13%
M&I (max-AF)	0*	4,200	3,300	5,300	6,600	15,800

**CDSS water allocation model in this basin calculates small baseline M&I gaps, but they are either due to calibration issues or they are reflective of infrequent, dry-year shortages that are typically managed with temporary demand reductions, such as watering restrictions.*

Figure 4.4.2 Summary of Diversion Demand and Gap Results in the Colorado Basin



Summary of Environmental and Recreational Findings

- In climate-impacted scenarios, peak flow is projected to move earlier in the year, with March, April and May flows increasing substantially and June flows decreasing; possible mis-matches between peak flow timing and species' needs may occur. Flow magnitude could decrease some, but peak-flow risk for plants and fish is projected to remain moderate.
- In some areas (e.g., Crystal River above Avalanche Creek near Redstone), peak flow magnitude is projected to increase substantially, potentially over-widening the creek channel and causing habitat issues during low-flow periods.
- Under *Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth*, mid- and late-summer flows may be reduced by 60 to 70 percent and create high risk for fish from loss of habitat and, in trout regions, high water temperatures.
- Downstream from major reservoirs (e.g., Frying Pan, Green Mountain), diminished peak flows could create high to very high risk for riparian/wetland vegetation and fish habitat if sediment is not flushed, while consistent mid- and late-summer flows could keep risk to fish low to moderate.

- Several recreational in-channel diversions and Instream Flow water rights may be unmet more often with diminished June to August flows.
- In critical habitat for endangered species, highly reduced flows in mid- and late-summer will make it more difficult to meet flow recommendations.

4.4.3 NOTABLE BASIN CONSIDERATIONS

Section 4.1 described several analysis assumptions and limitations that apply to all basins and should be considered when reviewing and interpreting analysis results. Additional considerations specific to the Colorado Basin are listed below:

- The Colorado River Model includes operations that allow Ruedi Reservoir, Wolford Mountain Reservoir, and Green Mountain Reservoir to make releases from their contract accounts to meet M&I demands aggregated by location throughout the basin. In most years, these contract supplies are sufficient to meet the projected M&I demands in the planning scenarios.
- Historical transbasin diversions from the Colorado Basin are included in the model as an export demand. In certain planning scenarios, the export demand cannot be fully met as a result of changed hydrology or increased agricultural demands of senior water users. When this occurs, the export demand is shorted in the Colorado Basin model, and that shortage is reflected on the East Slope as reduction in transbasin imports.
- Water demands for energy development were based primarily on SWSI 2010 data and were varied based on the language in each scenario. The demand data were not updated per Technical Advisory Group input because estimates of water needs have varied substantially, and defendable updated datasets are not currently available.

4.4.4 AGRICULTURAL DIVERSION DEMANDS

The irrigated agriculture industry across the Colorado Basin is highly diverse. Large ranching operations dominate agriculture in the basin's higher elevations, particularly around the towns of Kremmling, Collbran, and Rifle. Farming regions focused on the cultivation of fruits, vegetables, and alfalfa are more prevalent in the lower basin due to a longer growing season and warmer summer temperatures. The largest of these farming operations, the Grand Valley Project, irrigates about a quarter of the 206,700 acres irrigated in the entire basin. Mixed between these agricultural operations are many growing municipalities, such as Grand Junction.

Planning Scenario Adjustments

Section 2 described ways in which inputs to agricultural diversion demand estimates were adjusted to reflect the future conditions described in the planning scenarios. Adjustments in the Colorado Basin focused on urbanization, potential future climate conditions, and implementation of emerging technologies.

2050 population projections reflect significant increases for counties across the Colorado Basin. The impact of urbanization, however, is tied to the proximity of existing municipalities to agricultural operations. The impact of urbanization to resort communities, such as the towns of Winter Park, Breckenridge, Glenwood Springs, Snowmass Village, Vail and Avon, is limited due to lack of adjacent irrigated acreage to urbanize. The impact of urbanization is expected to be much larger in agricultural-based communities, such as Fruita, Grand Junction, Palisade, Eagle, and Rifle. In total, nearly 14,000 acres of irrigated land are expected to be urbanized, with one-third of that expected to occur in municipalities located within the Grand Valley Project and Grand Valley Irrigation Company service areas.

IWR could increase in this basin due to climate change by 20 percent and 31 percent on average in the "In-Between" and "Hot and Dry" climate projections, respectively.

In *Adaptive Innovation*, in addition to assuming reduced IWR, the average irrigation efficiency was assumed to increase by 10 percent. Irrigation systems efficiencies vary across the Colorado Basin depending upon irrigation infrastructure and practices, averaging just under 30 percent basinwide. System efficiencies were increased by 10 percent for ditches that provide water solely for irrigation purposes in *Adaptive Innovation*. Structures that carry water both for irrigation and for other purposes (e.g., power operations) were not adjusted.

Table 4.4.4 summarizes the planning scenario adjustments described above and other adjustments that impact agricultural diversion demands in the various scenarios.

Table 4.4.4 Planning Scenario Adjustments for Agricultural Demands in the Colorado Basin

Adjustment Factor	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Change in Irrigated Land due to Urbanization	13,600 Acre Reduction	13,600 Acre Reduction	13,600 Acre Reduction	13,600 Acre Reduction	13,600 Acre Reduction
IWR Climate Factor	-	-	20%	31%	31%
Emerging Technologies	-	-	-	10% IWR Reduction 10% System Efficiency Increase	-

See section 2.2.3 for descriptions of adjustment methodologies and assumptions.

Agricultural Diversion Demand Results

Table 4.4.5 and Figure 4.4.3 summarize the acreage, IWR, and the agricultural diversion demand for surface water supplies in the Colorado Basin for current conditions and the five planning scenarios. Demand is lower than current conditions in *Business as Usual* and *Weak Economy*, because irrigated acreage is projected to be urbanized. Although *Cooperative Growth* and *Hot Growth* feature the same reduction in irrigated acres, higher IWR could drive demand above current levels. In *Adaptive Innovation*, the reduction in IWR, increase in system efficiency, and reduction in acreage results in the lowest demand among all scenarios even with the potential effects of a hotter and drier climate.

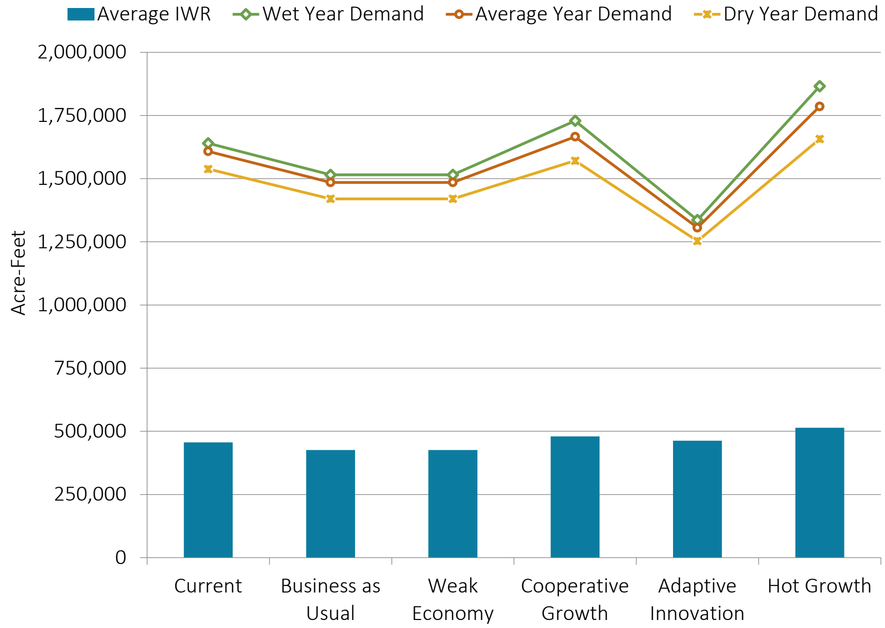
SYSTEM EFFICIENCY

In some cases, diversion demands can be higher in wet years because system efficiency decreases due to the relative abundance of supply.

Table 4.4.5 Summary of Agricultural Diversion Demand Results in the Colorado Basin

	Current (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Irrigated Acreage (acres)	206,700	193,100	193,100	193,100	193,100	193,100
Average IWR (AFY)	456,500	426,000	426,000	480,000	463,000	514,000
Diversion Demand						
Average Year (AFY)	1,608,000	1,485,000	1,485,000	1,666,000	1,306,000	1,786,000
Wet Yr. Change	2%	2%	2%	4%	2%	4%
Dry Yr. Change	-4%	-4%	-4%	-6%	-4%	-7%

Figure 4.4.3 Agricultural Diversion Demands and IWR Results in the Colorado Basin



4.4.5 Municipal and Self-Supplied Industrial Diversion Demands

Population Projections

The Colorado Basin includes about 6 percent of the statewide population. Between the years 2015 and 2050, it is projected to grow from approximately 310,000 to between 460,000 and 580,000 people in the low and high growth projections, respectively. Using the specific numbers, this is an increase in population of 48 percent to 88 percent. Table 4.4.6 shows how population growth is projected to vary across the planning scenarios for the Colorado Basin.

Table 4.4.6 Colorado Basin 2015 and Projected Populations

Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
307,600	515,500	456,300	549,200	572,900	577,800

Current Municipal Demands

The Colorado Basin baseline water demands were largely based on water-provider-reported data, with approximately 43 percent of the baseline population demands represented by WEPs, 25 percent from 1051 data, and 9 percent from BIPs. The remaining baseline water demand had to be estimated. Figure 4.4.4 shows the proportions of each data source among all sources.

Figure 4.4.4 Sources of Water Demand Data in the Colorado Basin

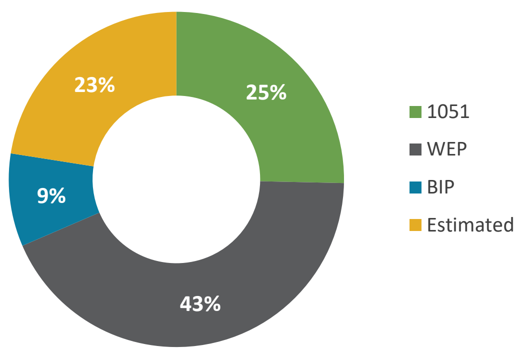


Figure 4.4.5 shows the proportion of each category of municipal baseline water usage in the Colorado Basin. On a basin scale, the residential indoor demand as a percentage of the systemwide demands are relatively high, at 44 percent of the systemwide demands.

Figure 4.4.5 Categories of Municipal Water Usage in the Colorado Basin

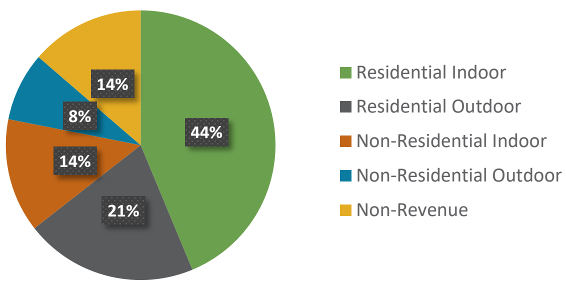
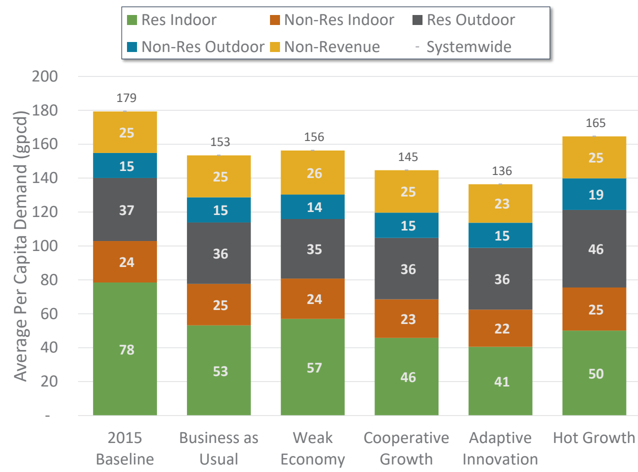


Figure 4.4.6 Colorado Basin Municipal Baseline and Projected per Capita Demands by Water Demand Category



Projected Municipal Demands

Figure 4.4.6 provides a summary of per capita baseline and projected water demands for the Colorado Basin.

Systemwide, all of the projected total per capita demands are projected to decrease relative to the baseline. Consistently across all scenarios, residential indoor demand is the greatest individual demand category while non-residential outdoor is the lowest. Aside from *Hot Growth*, there is minimal variation in outdoor demands across scenarios. This is due to the scenario pairing of water demand reductions and climate drivers, particularly for *Adaptive Innovation,* which has high outdoor reductions coupled with the "Hot and Dry" climate. Outdoor demands increased significantly for the *Hot Growth* scenario, due to an increase in outdoor demands coupled with the "Hot and Dry" climate.

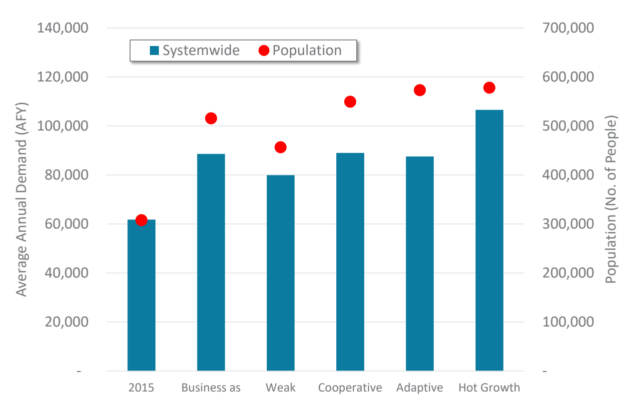
The Colorado Basin municipal baseline and projected diversion demands provided in Table 4.4.7 show the combined effect of population and per capita demands. Municipal demands are projected to grow from approximately 62,000 AFY in 2015 to between 80,000 and 107,000 AFY in 2050. Mesa County accounts for about 28 percent of the baseline demand, followed by Garfield County at about 23 percent of the basin demand.

Table 4.4.7 Colorado Basin Municipal Baseline and Projected Demands (AFY)

Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
61,800	88,600	79,900	89,000	87,500	106,600

Figure 4.4.7 shows baseline and projected diversion demand by scenario, as well as population for each scenario. All projection scenarios result in an increase relative to the baseline. Except for *Hot Growth*, the systemwide demand projections for all the Colorado Basin scenarios are similar, which demonstrates how the pairing of drivers and population can offset each other and even out the results.

Figure 4.4.7 Colorado Basin Baseline and Projected Population and Municipal Demands



Self-Supplied Industrial Demands

The Colorado Basin currently includes about 4 percent of the statewide SSI demand. SSI demands in this basin are associated with the large industry, snowmaking, and energy development sub-sectors, with no demands projected for the thermoelectric sub-sector. Basin-scale SSI demands are shown on Figure 4.4.8 and summarized in Table 4.4.8.

Large-industry demands are related to a mining facility in Grand County. This facility was not represented in SWSI 2010 but was added because it is a significant use. Projected large-industry demands range from 1,530 AFY to 1,870 AFY.

The baseline snowmaking demand is 4,340 AFY as compared to 3,180 AFY in SWSI 2010. Projected demands increase to 5,890 AFY under all scenarios.

Energy development demands are located in Garfield and Mesa counties. The baseline energy development demand in the Colorado Basin has been updated to 1,800 AFY from 2,300 AFY in SWSI 2010. Projected demands range from 200 AFY to 10,700 AFY.

Figure 4.4.8 Colorado Basin Self-Supplied Industrial Demands

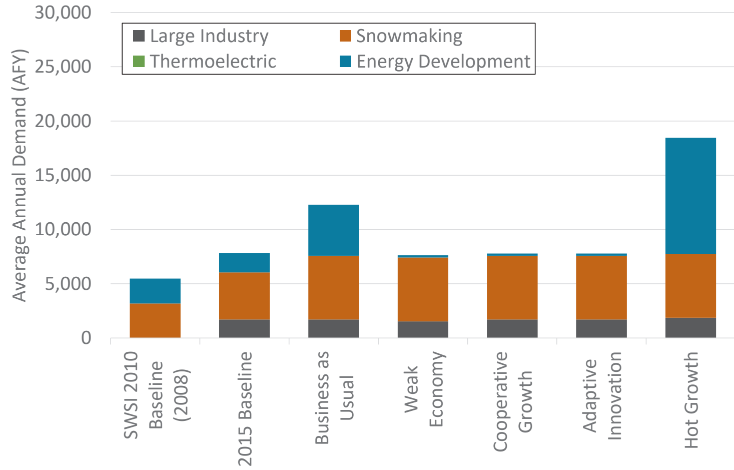


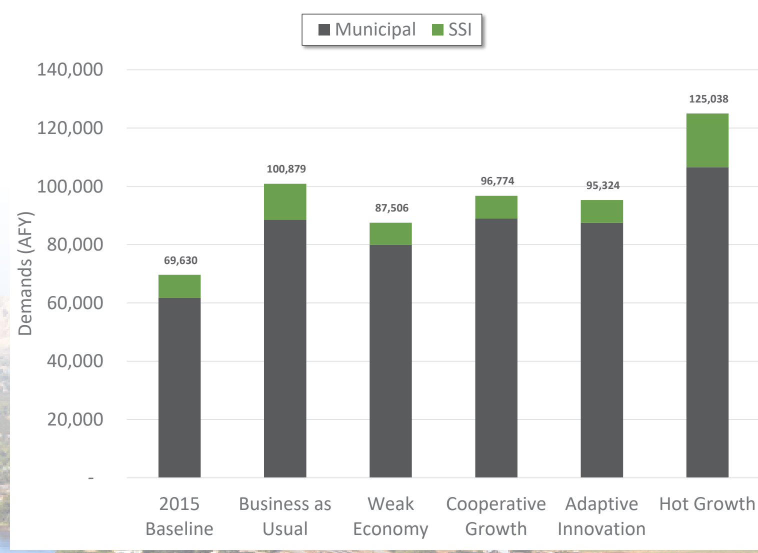
Table 4.4.8 Colorado Basin SSI Baseline and Projected Demands (AFY)

Sub-sector	Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Large Industry	1,700	1,700	1,530	1,700	1,700	1,870
Snowmaking	4,340	5,890	5,890	5,890	5,890	5,890
Thermoelectric	0	0	0	0	0	0
Energy Development	1,800	4,700	200	200	200	10,700
Sub-Basin Total	7,840	12,290	7,620	7,790	7,790	18,460

Total M&I Diversion Demands

Colorado Basin combined M&I diversion demand projections for 2050 range from approximately 88,000 AFY in *Weak Economy* to 125,000 AFY in *Hot Growth*, as shown in Figure 4.4.9. SSI demands account for between 8 and 15 percent of M&I demands. On a basin scale, the demand projections do not follow the statewide sequence of the scenario rankings described in the Water Plan, with *Adaptive Innovation* falling out of sequence.

Figure 4.4.9 Colorado Basin Municipal and Self-Supplied Industrial Demands



4.4.6 Water Supply Gaps

The agricultural and M&I diversion demands were compared against available water supply modeled for current conditions and the five planning scenarios. Gaps were calculated when water supply was insufficient to meet demands.

INCREMENTAL GAP

The incremental agricultural gap quantifies the degree to which the gap could increase beyond what agriculture has historically experienced under water shortage conditions.

Agricultural

The Colorado Basin agricultural diversion demands, demand gaps, and consumptive use gaps for the baseline and planning scenarios are presented in Table 4.4.9 and illustrated on Figure 4.4.10. An annual time series of gaps in terms of percent of demand that was unmet is shown on Figure 4.4.11.

Table 4.4.9 Colorado Basin Agricultural Gap Results (AFY)

		Scenario					
		Scenario	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand	1,598,900	1,476,800	1,476,800	1,663,800	1,294,900	1,751,600
Average	Average Annual Gap	45,300	44,994	43,000	76,200	61,500	103,800
Average	Average Annual Gap Increase from Baseline	-	-	-	30,900	16,200	58,500
Average	Average Annual Percent Gap	3%	3%	3%	5%	5%	6%
Average	Average Annual CU Gap	25,100	24,400	24,400	42,400	40,400	57,800
Maximum	Demand in Maximum Gap Year	1,598,800	1,477,500	1,477,500	1,587,200	1,258,000	1,668,300
Maximum	Gap in Maximum Gap Year	148,000	141,100	141,000	166,500	131,400	210,400
Maximum	Increase from Baseline Gap	-	-	-	18,500	-	62,400
Maximum	Percent Gap in Maximum Gap Year	9%	10%	10%	10%	10%	13%

Study period for Water Supply analysis is 1975-2013, reflecting different baseline demand than described in Agricultural Diversion Demands section.

Figure 4.4.10 Projected Average Annual Agricultural Diversion Demand, Demand Met, and Gaps in the Colorado Basin

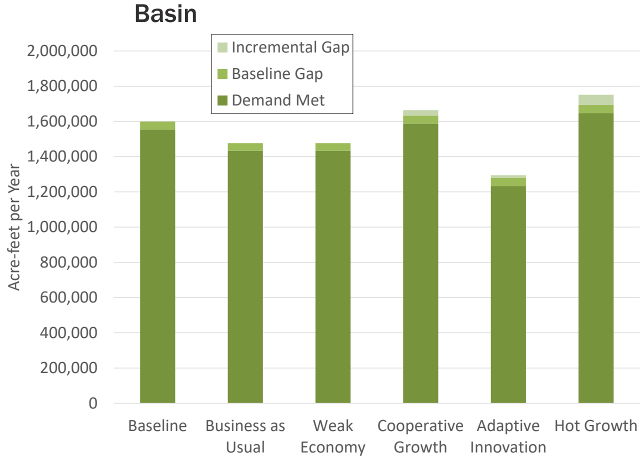
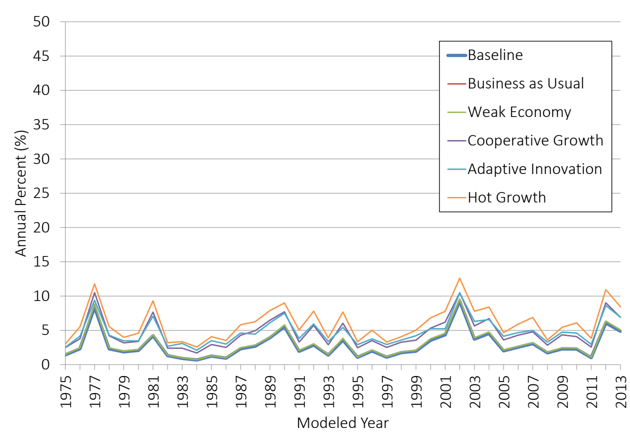


Figure 4.4.11 Annual Agricultural Gaps (expressed as a percentage of demand) for Each Planning Scenario



The following are observations on agricultural diversion demands and gaps:

- Although irrigated area is estimated to decrease by 13,600 acres as cities expand onto irrigated land, basin-wide IWR and diversion demand may increase in a warmer future climate.
- Emerging technologies, including the adoption of more efficient irrigation practices, modernizing irrigation infrastructure (e.g., automation) and crops with lower irrigation requirements, may mitigate climate impacts and reduce demand below baseline.
- The future incremental gap ranges from 0 to 4 percent of baseline demand.
- Scenarios that assume current climate conditions (*Business as Usual* and *Weak Economy*) have agricultural gaps around 3 percent of demand. Gaps (as a percentage of demand) increase in scenarios that assume a warmer and drier future climate.

M&I

The diversion demand and gap results for M&I uses in the Colorado Basin are summarized in Table 4.4.10 and illustrated in Figure 4.4.12. An annual time series of gaps in terms of percent of demand that was unmet is shown in Figure 4.4.13.

Table 4.4.10 Colorado Basin M&I Gap Results (AFY)

		Scenario					
		Scenario	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand	68,500	98,400	85,800	95,400	94,500	121,400
	Average Annual Gap	0*	1,200	800	1,900	2,300	4,700
	Average Annual Percent Gap	0%	1%	1%	2%	2%	4%
Maximum	Demand in Maximum Gap Year	68,500	98,400	85,800	95,400	94,500	121,400
	Gap in Maximum Gap Year	0*	4,200	3,300	5,300	6,600	15,800
	Percent Gap in Maximum Gap Year	0%	4%	4%	6%	7%	13%

**CDSS water allocation model in this basin calculates small baseline M&I gaps, but they are either due to calibration issues or they are reflective of infrequent, dry-year shortages that are typically managed with temporary demand reductions such as watering restrictions.*

Figure 4.4.12 Projected Maximum Annual M&I Demand Met and Gaps in the Colorado Basin

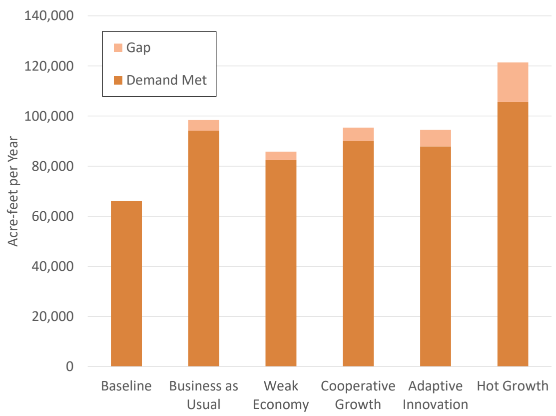
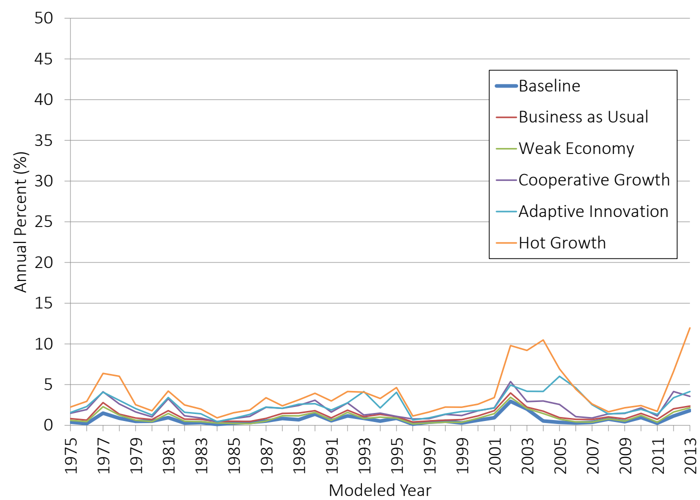


Figure 4.4.13 Annual M&I Gaps (expressed as a percentage of demand) for Each Planning Scenario



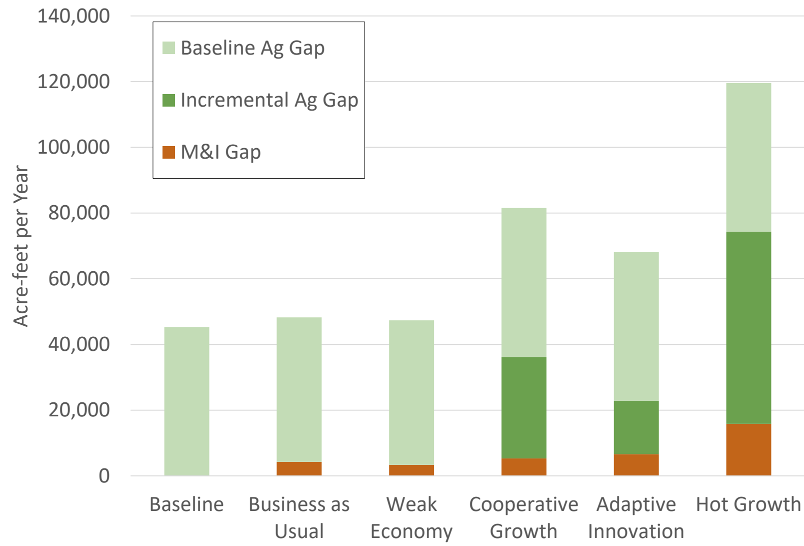
The following are observations on the M&I diversion demands and gaps:

- Average annual M&I gap in the Colorado Basin is far less than the agricultural gap, ranging from 500 AF to more than 4,700 AF.
- The maximum M&I gap for the five planning scenarios ranges from 2,300 AF to nearly 16,000 AF.
- Per capita municipal usage is projected to decrease.
- Overall municipal demand is projected to increase for all scenarios due to increased population; however, except for *Hot Growth*, the systemwide demand projections for all future scenarios are similar.
- Increase in SSI demand in *Business as Usual* and *Hot Growth* represent anticipated energy development.

Total Gap

Figure 4.4.14 illustrates the total combined agricultural and M&I diversion demand gap in the Colorado Basin. The figure combines average annual baseline and incremental agricultural gap and the maximum M&I gap. In *Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth*, gaps were driven by agricultural demands, which increase in the "In Between" and "Hot and Dry" climate projections.

Figure 4.4.14 Projected Average Annual Agricultural Gaps and Maximum M&I Diversion Demand Gaps in the Colorado Basin



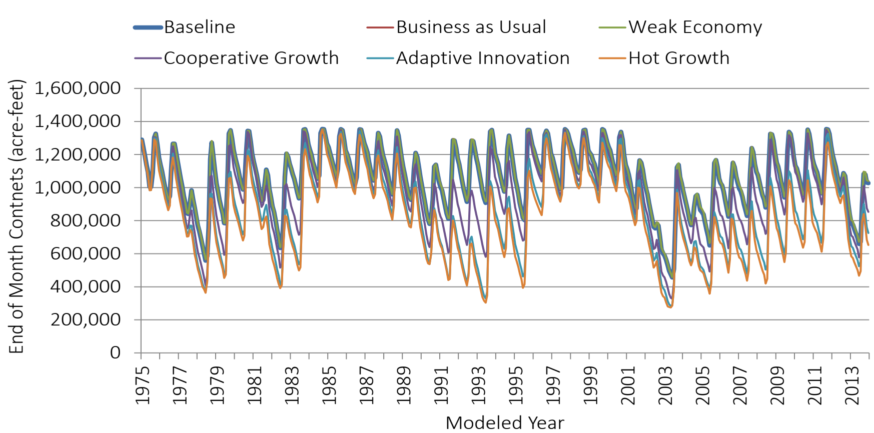
Supplies from Urbanized Lands

By 2050, irrigated acreage in the Colorado Basin is projected to decrease by 13,600 acres due to urbanization. Irrigation supplies for these lands could potentially be used for M&I needs in the future (subject to a variety of unknowns such as seniority and type of water supply, willingness to change the use of water through water court, etc.). The average annual historical consumptive use associated with potentially urbanized acreage for each scenario is reflected in Table 4.4.11. The data in the table represent planning-level estimates of this potential supply and has not been applied to the M&I gaps.

Table 4.4.11 Estimated Consumptive Use from Lands Projected to be Urbanized by 2050 in the Colorado Basin

	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Urbanized Acreage (acres)	13,600	13,600	13,600	13,600	13,600
Estimated Consumptive Use (AFY)	28,300	28,300	30,800	29,700	32,100

Figure 4.4.15. Total Simulated Reservoir Storage in the Colorado Basin



Storage

Total simulated reservoir storage from the Colorado water allocation model is shown on Figure 4.4.15. Baseline conditions show the highest levels of water in storage (in general) and the lowest is in *Hot Growth*. *Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth* show lower amounts of water in storage during dry periods than the two scenarios that do not include the impacts of a drier climate; however, storage levels generally recover from dry periods back to baseline levels. Storage in the Colorado Basin is critical to minimizing gaps as described in Section 4.4.3 and as demonstrated by the large degree of fluctuation in basin-wide storage amount.

4.4.7 Available Supply

Figures 4.4.16 through 4.4.19 show simulated monthly available flow for the Colorado Basin at locations representative of the Shoshone Power Plant diversion (near Dotsero) and the “Cameo Call”, which are generally the controlling rights on the mainstem of the Colorado River. Streamflow and available flow nearly double between the upstream and downstream locations due to inflows from the Roaring Fork, Parachute Creek, and Rifle Creek. The figures show that flows are projected to be available each year, though the amounts will vary annually and across scenarios (available flows under the scenarios impacted by climate change are less than in other scenarios). Peak flows are projected to occur earlier in the year under scenarios impacted by climate change.

Figure 4.4.16 Simulated Hydrographs of Available Flow at Colorado River near Dotsero, CO

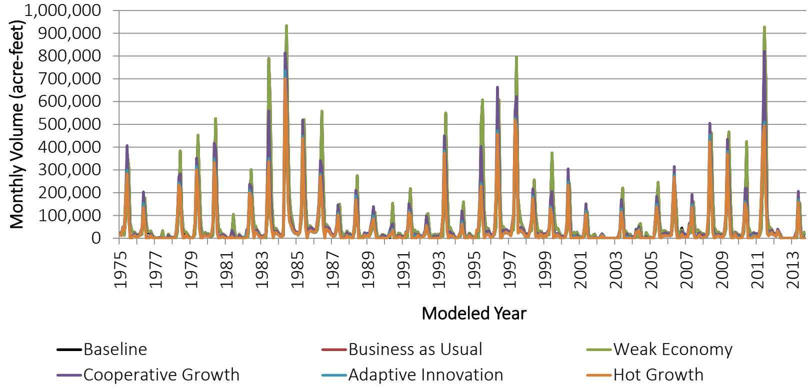


Figure 4.4.17 Average Monthly Simulated Hydrographs of Available Flow at Colorado River near Dotsero, CO

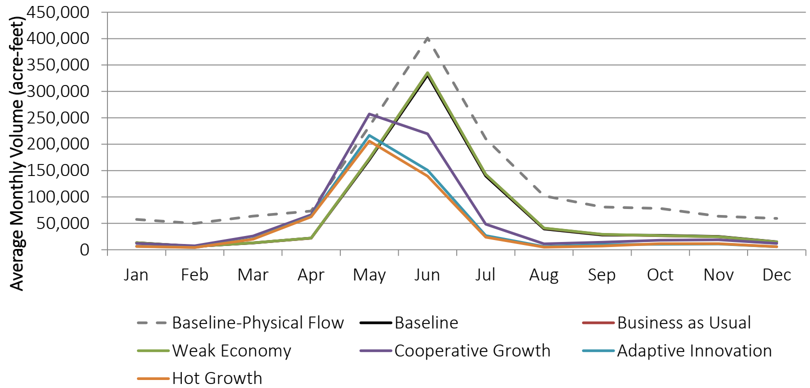


Figure 4.4.18 Simulated Hydrographs of Available Flow at Colorado River near Cameo, CO

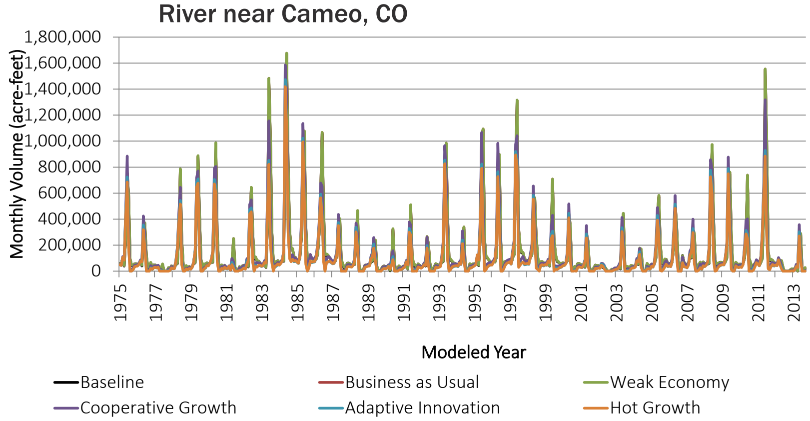
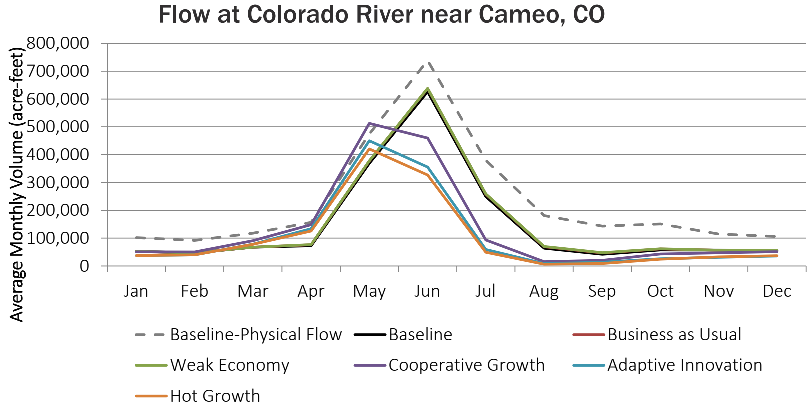


Figure 4.4.19 Average Monthly Simulated Hydrographs of Available Flow at Colorado River near Cameo, CO



4.4.8 Environment and Recreation

A total of eleven water allocation model nodes were selected for the Flow Tool within the Colorado Basin (see Figure 4.4.20). In addition to nodes, Figure 4.4.20 also shows subwatersheds (at the 12-digit HUC level) and the relative number of E&R attributes located in each subwatershed.

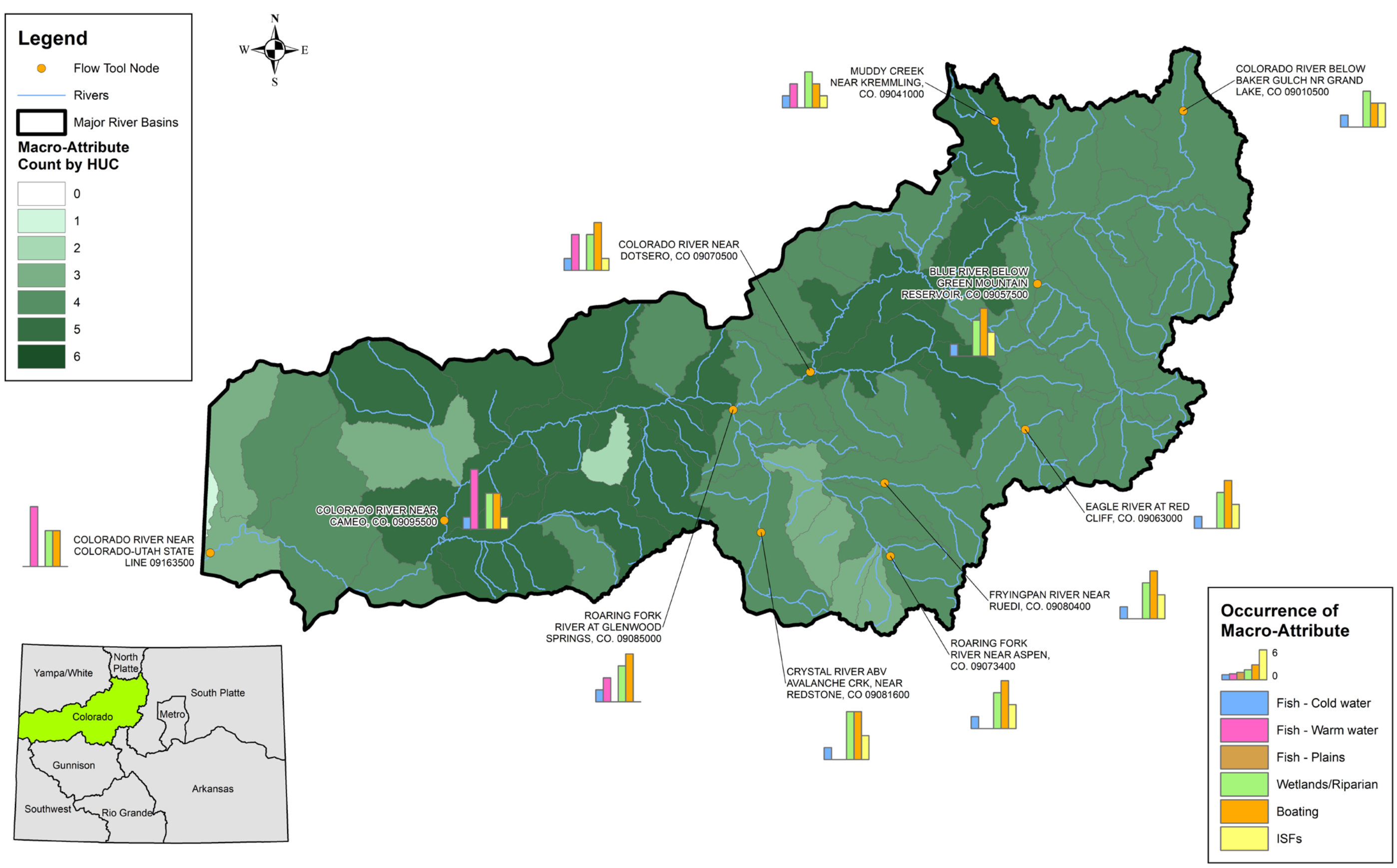
Nodes include:

- Colorado River below Baker Gulch near Grand Lake, Colorado (09010500)
- Muddy Creek near Kremmling, Colorado (09041000)
- Blue River below Green Mountain Reservoir, Colorado (09057500)
- Eagle River at Red Cliff, Colorado (09063000)
- Colorado River near Dotsero, Colorado (09070500)
- Roaring Fork River near Aspen, Colorado (09073400)
- Fryingpan River near Ruedi, Colorado (09080400)
- Crystal River above Avalanche Creek, near Redstone, Colorado (09081600)
- Roaring Fork River at Glenwood Springs, Colorado (09085000)
- Colorado River near Cameo, Colorado (09095500)
- Colorado River near Colorado-Utah State Line (09163500)

NATURALIZED FLOW

Naturalized flows reflect conditions that would occur in the absence of human activities. Baseline flows reflect current conditions as influenced by existing infrastructure and river operations. While observations regarding naturalized flows may be informative, baseline flows reflect actual conditions and the diverse operations of a river's many users.

Figure 4.4.20 Flow Tool Nodes Selected for the Colorado Basin



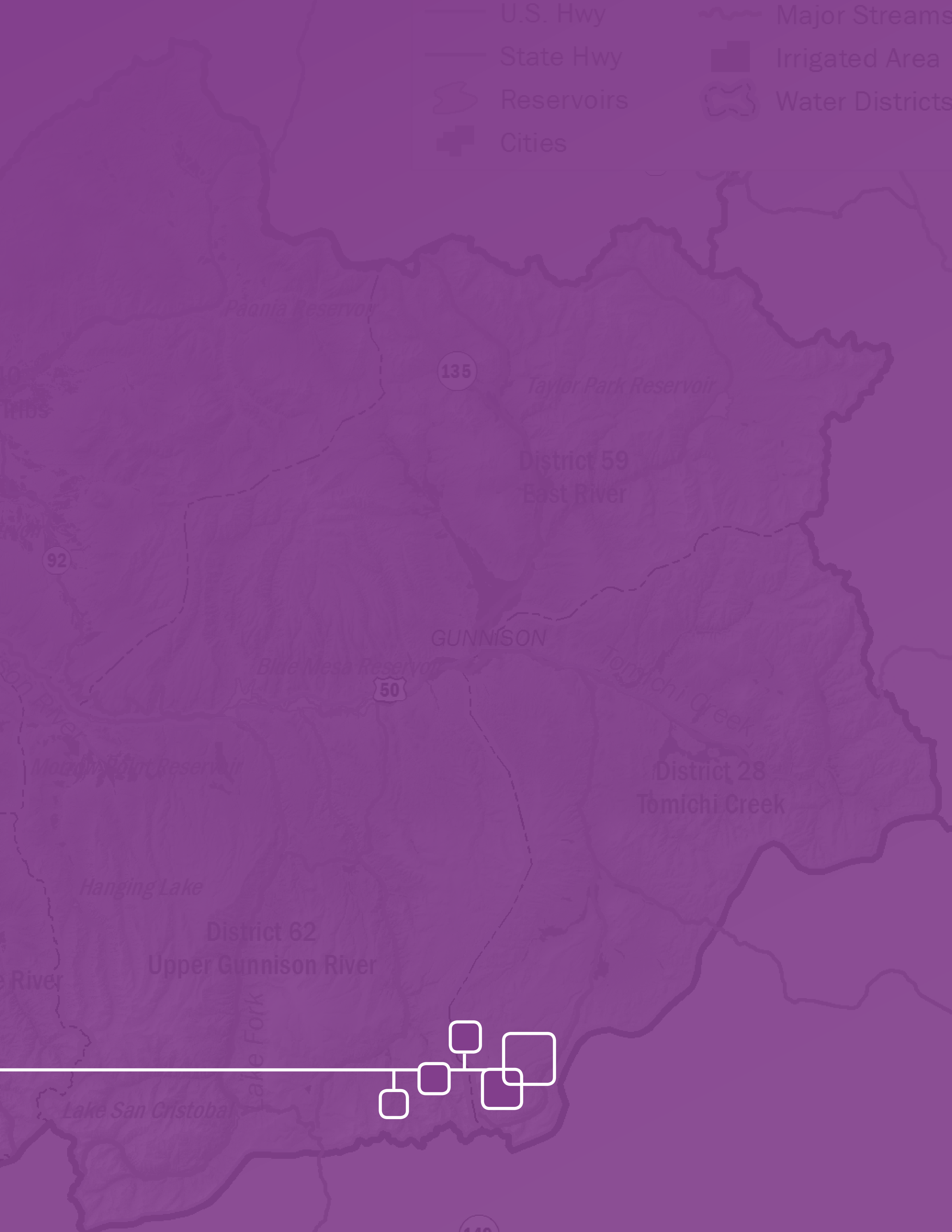
Results of Flow Tool analyses using flow data developed in the water supply and gap analyses for baseline conditions and the planning scenarios are described below.

Table 4.4.12 Summary of Flow Tool Results in Colorado Basin

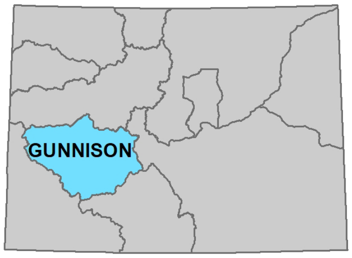
Category	Observation
Projected Flows	Annual flow in headwaters (Colorado River below Baker's Gulch) under baseline conditions is below natural conditions, and this departure increases under climate change scenarios. Moving downstream through Dotsero, Cameo, and to the state line, annual flow under baseline conditions rebounds slightly closer to naturalized conditions.
	Under climate change scenarios (*Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth*), annual depletions are projected to increase from headwaters to the state line.
	Similar to the alterations in annual flows, peak flow magnitudes on the Colorado River under baseline conditions are below natural conditions from the headwaters through Dotsero, and are closer to natural conditions at lower elevations (Cameo and State Line).
	Under climate change scenarios (*Collaborative Growth*, *Adaptive Innovation*, and *Hot Growth*), peak flow magnitudes on the Colorado River are projected to decrease further below natural conditions. Decreases in peak flows (from naturalized to baseline) are more pronounced at locations below large reservoirs (e.g., Blue River below Green Mountain Reservoir, Fryingpan River below Reudi Reservoir). This dampening of peak flows is projected to worsen under climate driven scenarios. In some locations (notably, Crystal River above Avalanche Creek), peak flow magnitude is projected to increase under some scenarios.
	Under the scenarios with climate change influences, snowmelt and timing of peak flow is projected to shift earlier in the year. In many areas from headwaters to lower elevations, June flows are projected to decrease well below naturalized conditions, while April and May flows could similar to baseline or increase slightly.
	Under baseline conditions, mid- and late-summer flows in headwaters subject to transbasin exports are currently depleted compared to naturalized conditions. The difference between baseline and naturalized conditions lessens farther downstream.
	Under scenarios with climate change, mid- and late-summer flows in headwaters are projected to drop well below naturalized, but farther downstream, this drop is projected to be less pronounced. In many locations, mid- and late-summer flows under climate change scenarios are projected to be well below naturalized. The Fryingpan below Reudi Reservoir is an exception to the large projected decreases in mid- and late-summer flows, because releases are made steadily from the reservoir.
Ecological Risk	Decreased peak flows that are prevalent across the basin under baseline conditions create risk for riparian/wetland plants and fish habitat.
	This risk increases under climate change scenarios. Projected decreases in mid- and late-summer flows create risk for fish from loss of habitat and, in trout regions, increased water temperatures. Downstream from major reservoirs (e.g., Fryingpan, Green Mountain), projected diminished peak flows create increased risk for riparian/wetland vegetation and fish habitat if sediment is not flushed, while projected consistent mid- and late-summer flows keep risk to fish low to moderate.
ISFs and RICDs	Several Instream Flows (ISFs) throughout the basin and Recreational In-channel Diversion (RICD) are likely to be regularly unmet if June-August flows decrease as projected under climate change scenarios.
	In critical habitat for endangered species, projected reduced flows in mid- and late-summer will make it more difficult to meet flow recommendations. For example, projected August flows under climate change scenarios on the Colorado River at Cameo suggest that flow recommendations for endangered fish will not be met during August in approximately one-third of years.
E&R Attributes	Under baseline, *Business as Usual*, and *Weak Economy*, current flow issues related to E&R attributes arise from timing/water delivery issues.
	Under climate change scenarios, the shift in the timing of peak flow, reductions in total runoff, and increasing demands for consumptive uses contribute to reductions in mid- and late-summer flows. Several water management programs implemented in the context of the Upper Colorado Endangered Fish Program (e.g., Coordinated Reservoir Operations Program) have demonstrated that flow timing and magnitude, along with stream temperature, can be improved through water management that explicitly considers the needs of E&R attributes.

The Gunnison Basin stretches across more than 8,000 square miles of western Colorado, extending from the Continental Divide to the confluence of the Gunnison and Colorado rivers near Grand Junction. The basin is largely forested, with forest covering approximately 52 percent of the total basin area. About 5.5 percent of the basin is classified as planted or cultivated land, and these lands are primarily concentrated in the Uncompahgre River Valley between Montrose and Delta with additional pockets near Gunnison and Hotchkiss. Key future water management issues in this basin as described in The Colorado Water Plan include agricultural water shortages and increased growth and tourism in the headwaters region.

GUNNISON


U.S. Hwy
State Hwy
Reservoirs
Cities
Major Streams
Irrigated Area
Water Districts
Paonia Reservoir
135
Taylor Park Reservoir
District 59
East River
92
GUNNISON
Blue Mesa Reservoir
50
Tomichi Creek
District 28
Tomichi Creek
Hanging Lake
District 62
Upper Gunnison River
Lake Fork
Lake San Cristobal

4.5 GUNNISON BASIN RESULTS

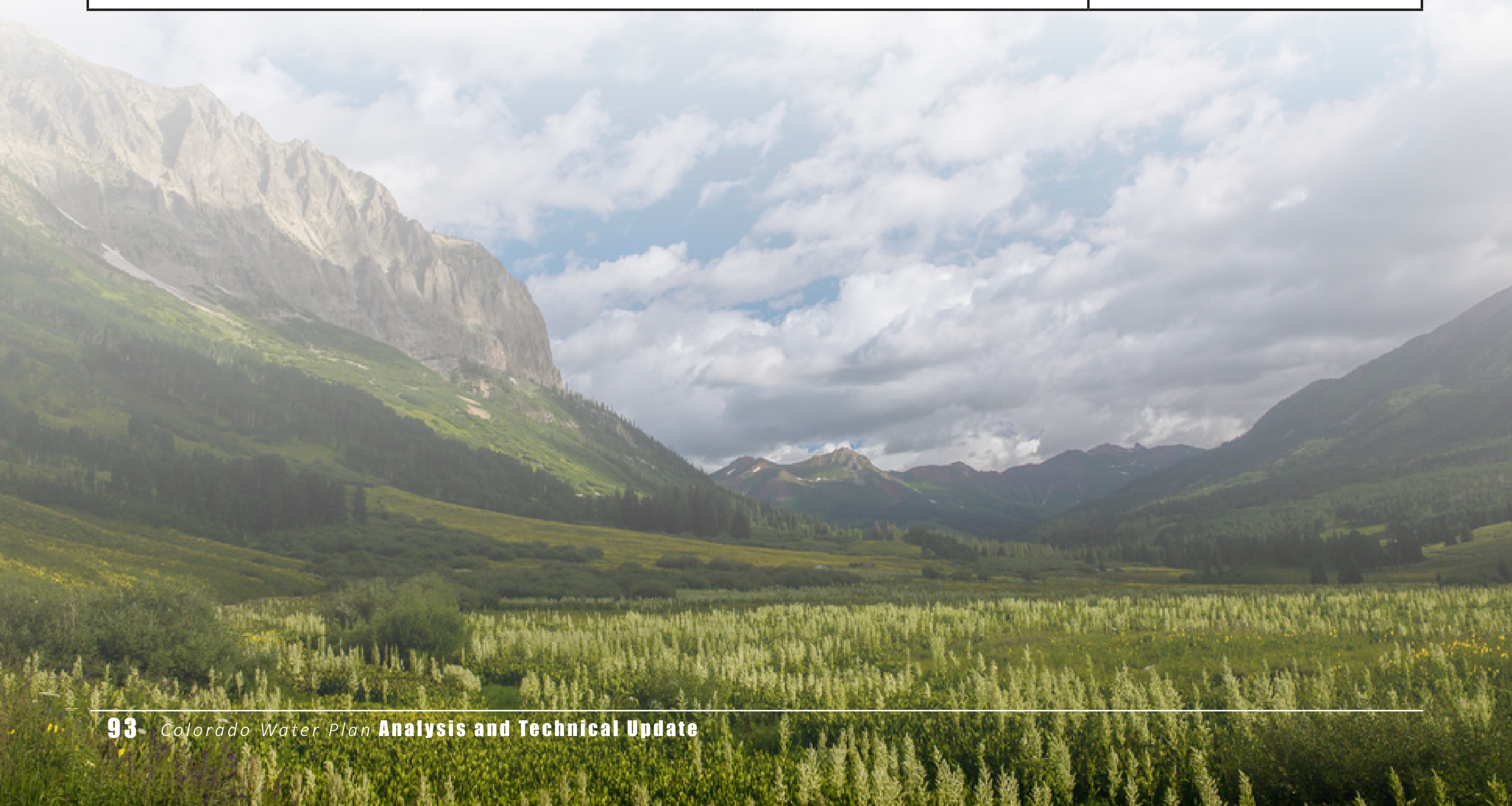


4.5.1 BASIN SUMMARY

Key future water management issues in this basin as described in The Colorado Water Plan include agricultural water shortages and increased growth and tourism in the headwaters region.

Table 4.5.1 Key Future Water Management Issues in the Gunnison Basin

<table>
<tr><th>Agriculture</th><th>Environment and Recreation</th><th>Municipal and Industrial</th><th>Compacts and Administration</th></tr>
<tr><td>• Addressing agricultural water shortages in the upper portion of the basin is an important goal of the community. Lack of financial resources is an impediment.</td><td>• The Gunnison River Basin faces a complex set of environmental issues associated with water quality, water quantity and associated impacts to fish and wildlife habitat in the context of regulatory drivers associated with the Endangered Species Act (ESA) and the Clean Water Act (CWA).</td><td>• Growth in the headwaters region will require additional water management strategies.</td><td rowspan="2">• Possible future transbasin diversions have been a concern, along with the potential effect this might have on existing uses within the basin.</td></tr>
<tr><td colspan="3">• The area between Ouray and Montrose is rapidly growing. Tourism is important in the headwaters areas, but agriculture is dominant in the Uncompahgre Valley. A rapid influx of retirees and growth in the Uncompahgre Valley may dramatically change agricultural uses and other land uses in the area.</td></tr>
</table>



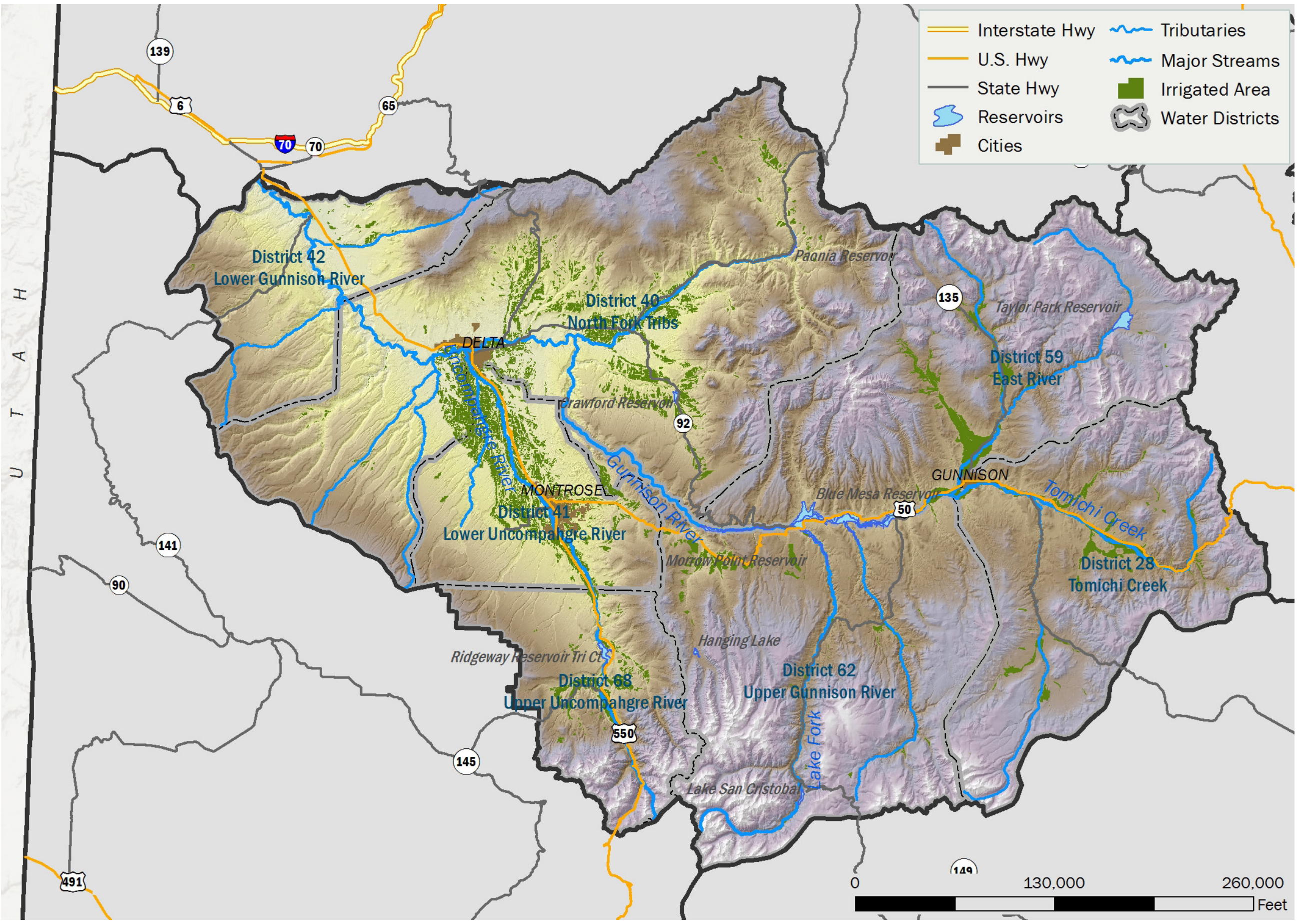


Figure 4.5.1 Map of the Gunnison Basin

4.5.2 SUMMARY OF TECHNICAL UPDATE RESULTS

Key results and findings of the Technical Update pertaining to agricultural and M&I demands and gaps as well as findings related to environmental and recreational attributes and future conditions are summarized below in Table 4.5.2.

Table 4.5.2 Summary of Key Results in the Gunnison Basin

Agriculture	Environment and Recreation	Municipal and Industrial
• Agricultural demand is a major factor in this basin and represents 99% of the total water demand. • Increases in agricultural demand and gaps will occur with a warmer and drier climate. • Increases in system efficiency and reductions in irrigation water requirements significantly reduce diversion demand and the gap in Adaptive Innovation.	• Aquatic and riparian attributes may be affected differently based on location and potential changes in streamflow magnitude and timing. • Flow recommendations, Instream Flow water rights, and recreational in-channel diversions may be met less often in climate-impacted scenarios.	• Population increases are the main driver for increased M&I demands in the planning scenarios, as per capita water use decreased for every scenario except Hot Growth. • Growth in Montrose County accounts for 50% of the M&I demand. • The only SSI use in the basin is snow-making, and it is a relatively small proportion of demands.

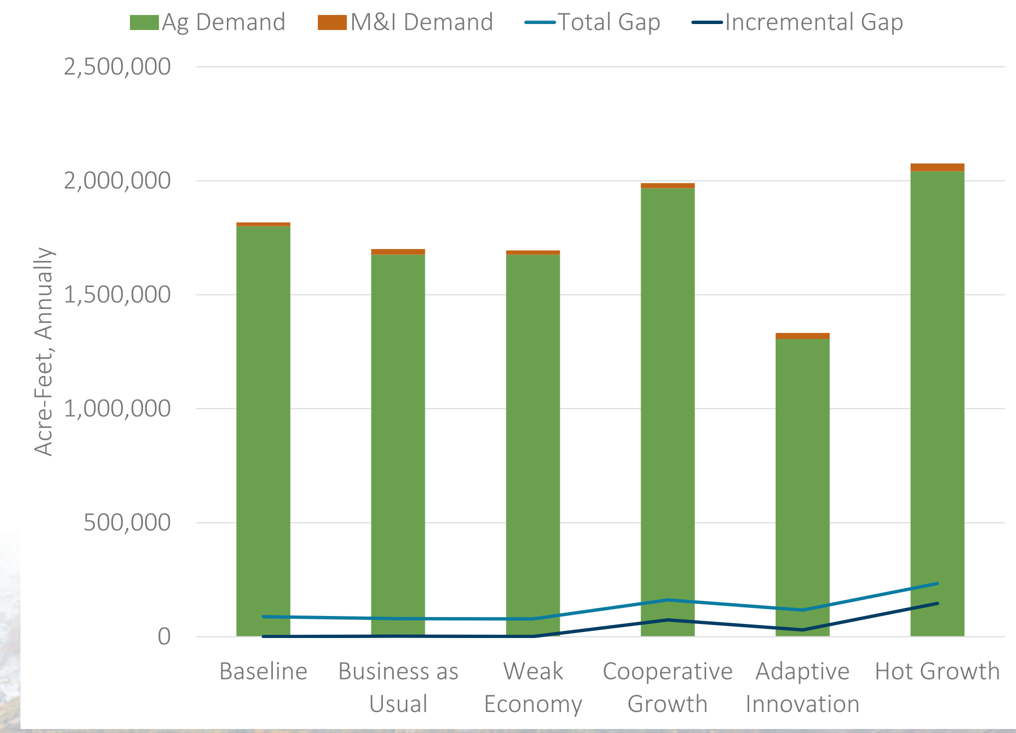
Results describing current and potential future M&I and agricultural demands and gaps are summarized in Table 4.5.3 and in Figure 4.5.2.

Table 4.5.3 Summary of Diversion Demand and Gap Results in the Gunnison Basin

	Current (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average Annual Demand						
Agricultural (AFY)	1,800,200	1,675,500	1,675,500	1,967,200	1,305,700	2,041,500
M&I (AFY)	17,000	24,800	19,100	22,900	26,400	34,100
Gaps						
Ag (avg %)	5%	5%	5%	8%	9%	11%
Ag (incremental-AFY)	-	-	-	70,300	25,300	134,700
Ag (incremental gap as % of current demand)	-	-	-	4%	1%	7%
M&I (max %)	0%	9%	4%	15%	16%	34%
M&I (max-AF)	0*	2,300	700	3,500	4,300	11,500

*CDSS water allocation model in this basin calculates small baseline M&I gaps, but they are either due to calibration issues, or they are reflective of infrequent, dry-year shortages that are typically managed with temporary demand reductions such, as watering restrictions.

Figure 4.5.2 Summary of Diversion Demand and Gap Results in the Gunnison Basin



Summary of Environmental and Recreational Findings

- Reduced peak flows below major reservoirs on the Uncompahgre and Gunnison mainstems under baseline conditions create high risk to riparian/wetland habitat and may not support sediment dynamics needed to maintain fish habitat.
- Across most locations, mid- and late-summer flows drop, but risk to fish remains moderate; however, the metric used to assess risk for fish does not include the month of July because historically July flows have been sufficient. Under *Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth*, July flows drop substantially, which increases the risk for fish.
- In several locations, Instream Flow water rights may be met less often. At least one RICD may be met less often.
- In critical habitat for endangered species, much reduced flows in mid- and late-summer will make it more difficult to meet flow recommendations.
- In at least one location (Cimarron River), winter flows become extremely low and puts fish at risk.

4.5.3 NOTABLE BASIN CONSIDERATIONS

Section 4.1 described several analysis assumptions and limitations that apply to all basins and should be considered when reviewing and interpreting analysis results. An additional consideration with respect to the Gunnison Basin is that agricultural system efficiencies in this basin are generally lower than in other basins due to factors described in the next section. The associated return flows, however, become the supplies for downstream irrigators and are reused.

4.5.4 AGRICULTURAL DIVERSION DEMANDS

Agricultural Setting

Agriculture in the Upper Gunnison Basin, above Blue Mesa Reservoir, is dominated by large cattle ranches located along the tributaries and mainstem river. Ranchers generally rely on flood irrigation to fill the alluvial aquifer during the runoff season, as supplies are typically scarce later in the irrigation season. Agricultural diversion demands are higher in this basin due to the presence of gravelly soils, which leads to generally lower irrigation efficiencies than in other basins.

Several Bureau of Reclamation Projects provide supplemental irrigation supplies for much of the irrigated acreage in the Lower Gunnison Basin. The most notable irrigation projects in the area include the Uncompahgre, Paonia, Smith Fork, Fruitland Mesa, Bostwick Park, and the Fruitgrowers Dam projects. Lower elevations and warmer temperatures in the Lower Gunnison Basin provide conditions to grow a variety of fruits, vegetables, corn grain, and root crops on more than 185,000 acres of the total 234,000 irrigated acres in the basin.

Planning Scenario Adjustments

Section 2 described ways in which inputs to agricultural diversion demand estimates were adjusted to reflect the future conditions described in the planning scenarios. Adjustments in the Gunnison Basin focused on urbanization, potential future climate conditions, and implementation of emerging technologies.

Many of the municipalities in the basin are surrounded by or near irrigated lands, and many counties in the basin are projected to have significant population increases by 2050. The resulting urbanization of irrigated acreage from this growth was estimated to be approximately 14,600 acres, primarily around Gunnison, Montrose, Delta, and the corridor between Cedaredge and Orchard City.

Table 4.5.4 summarizes the planning scenario adjustments described above and other adjustments that impact agricultural diversion demands in the scenarios.

Table 4.5.4 Planning Scenario Adjustments for Agricultural Demands in the Gunnison Basin

Adjustment Factor*	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Change in Irrigated Land due to Urbanization	14,600 Acre Reduction	14,600 Acre Reduction	14,600 Acre Reduction	14,600 Acre Reduction	14,600 Acre Reduction
Increase in IWR due to Climate	-	-	22%	30%	30%
Emerging Technologies	-	-	-	10% IWR Reduction; 10% System Efficiency Increase	-

**See Section 2.2.3 for descriptions of adjustment methodologies and assumptions.*

Agricultural Diversion Demand Results

Table 4.5.5 and Figure 4.5.3 summarize the acreage, IWR, and the agricultural diversion demand for surface water supplies in the Gunnison Basin for current conditions and the five planning scenarios. The largest variation in the basin occurred in the *Adaptive Innovation* scenario due to 10 percent reduction in IWR and 10 percent increase to system efficiency, both of which reduce diversion demands. The combined effect of the *Adaptive Innovation* scenario adjustments resulted in an agricultural diversion demand that is lower than the current demand. Diversion demands increased in *Cooperative Growth* and *Hot Growth* due to higher IWR resulting from a warmer and drier future climate.

SYSTEM EFFICIENCY

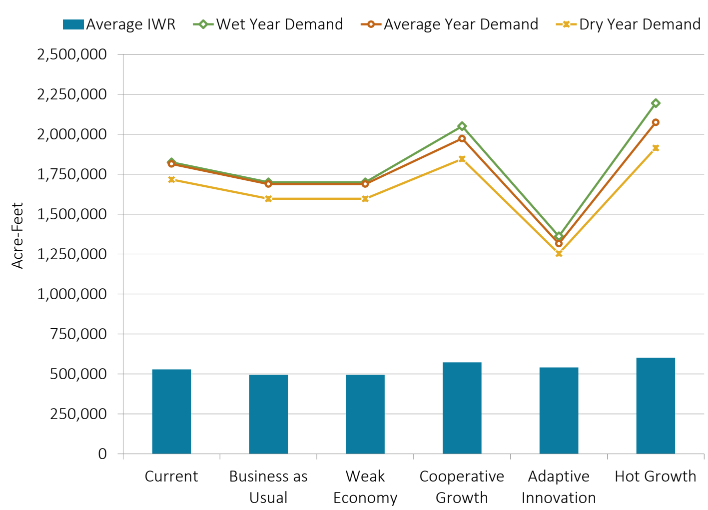
In some cases, diversion demands can be higher in wet years because system efficiency decreases due to the relative abundance of supply.

Table 4.5.5 Summary of Agricultural Diversion Demand Results in the Gunnison Basin

	Current (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Irrigated Acreage (acres)	234,400	219,800	219,800	219,800	219,800	219,800
Average IWR (AFY)	528,200	494,000	494,000	573,000	541,000	601,000
Diversion Demand						
Average Year (AFY)	1,814,000	1,688,000	1,688,000	1,973,000	1,315,000	2,074,000
Wet Yr. Change	1%	1%	1%	4%	3%	6%
Dry Yr Change	-5%	-5%	-5%	-6%	-5%	-8%

Average agricultural diversion demand was calculated using the average hydrologic years (i.e., years classified as neither wet or dry) from 1950-2013

Figure 4.5.3 Agricultural Diversion Demands and IWR Results in the Gunnison Basin



Municipal and Self-Supplied Industrial Diversion Demands

Population Projections

The Gunnison Basin includes about 2 percent of the statewide population. Between the years 2015 and 2050, it is projected to grow from approximately 100,000 to between 120,000 and 200,000 people in the low and high growth projections, respectively, which is an increase in population of 19 to 99 percent. Table 4.5.6 shows how population growth is projected to vary across the planning scenarios for the Gunnison Basin.

Table 4.5.6 Gunnison Basin 2015 and Projected Populations

Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
103,100	162,600	123,100	158,600	196,000	204,900

Current Municipal Demands

Sources of water demand data such as 1051 or WEP data made up less than 50 percent of the available information in the Gunnison Basin, and baseline water demands were largely estimated as shown on Figure 4.5.4.

Figure 4.5.5 summarizes the categories of municipal, baseline water usage in the Gunnison Basin. On a basin scale, the residential indoor demand as a percentage of the systemwide demands are relatively high, at almost 40 percent of the systemwide demands.

Figure 4.5.4 Sources of Water Demand Data in the Gunnison Basin

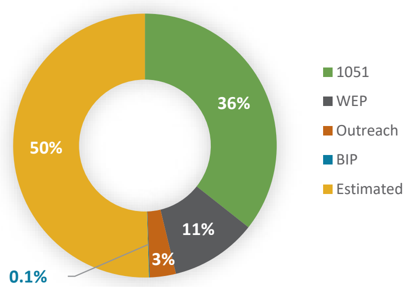
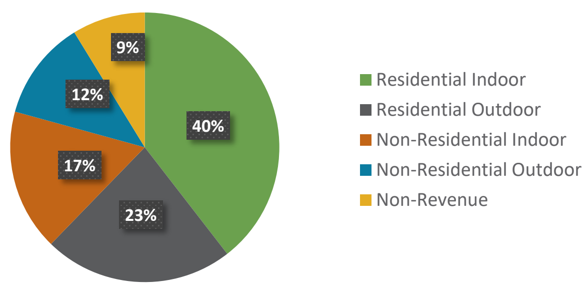


Figure 4.5.5 Categories of Water Usage in the Gunnison Basin



Projected Municipal Demands

Figure 4.5.6 provides a summary of per capita baseline and projected water demands for the Gunnison Basin. Systemwide, the per capita demands are projected to decrease relative to the baseline except for *Hot Growth*. Outdoor demands are projected to increase significantly for *Hot Growth* due to hotter and drier climate conditions.

The Gunnison Basin municipal baseline and projected diversion demands provided in Table 4.5.7 show the combined effect of population and per capita demands. Municipal demands are projected to grow from approximately 18,000 AFY in 2015 to between 21,000 and 37,000 AFY in 2050. Montrose County accounts for almost half of the baseline demand, followed by Delta County at about one-fifth of the basin demand.

Figure 4.5.6 Gunnison Basin Municipal Baseline and Projected per Capita Demands by Water Demand Category

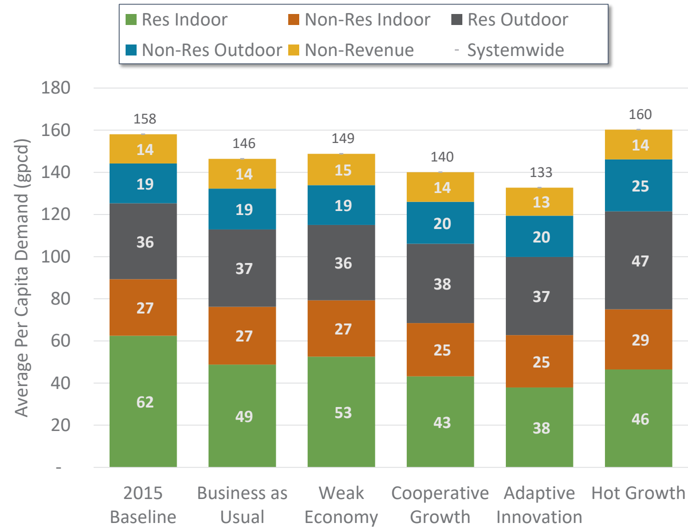
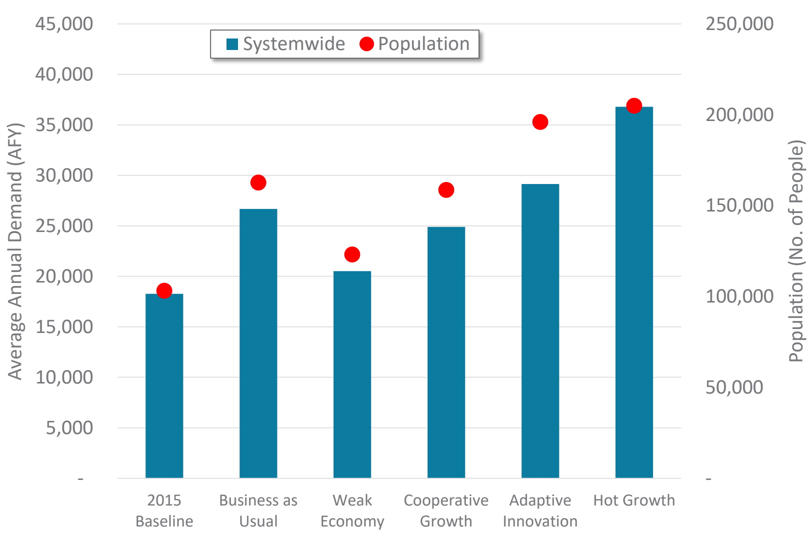


Table 4.5.7 Gunnison Basin Municipal Baseline and Projected Demands (AFY)

Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
18,300	26,700	20,500	24,900	29,100	36,800

The baseline and projected demand distributions are shown on Figure 4.5.7, which also shows how the population varies between the scenarios. All of the planning scenarios show an increase relative to the baseline. Demands generally follow the population patterns; however, increased outdoor demands for the "Hot and Dry" climate projection have a greater impact on gpcd, resulting in higher demands for *Hot Growth*. Higher levels of conservation associated with *Adaptive Innovation* help limit the impacts of the "Hot and Dry" climate projection and higher population.

Figure 4.5.7 Gunnison Basin Baseline and Projected Population and Municipal Demands



Self-Supplied Industrial Demands

The Gunnison Basin currently includes less than one percent of the statewide SSI demand. SSI demands in this basin are associated exclusively with the snowmaking sub-sector. There are no demands projected for the large industry, thermoelectric, or energy development sub-sectors. Basin-scale SSI demands are shown on Figure 4.5.8 and summarized in Table 4.5.8.

The baseline snowmaking demand is 270 AFY as compared to 260 AFY in SWSI 2010. All snowmaking occurs in Gunnison County. Projected SSI demands increase to 650 AFY under all scenarios.

Figure 4.5.8 Gunnison Basin Self-Supplied Industrial Demands

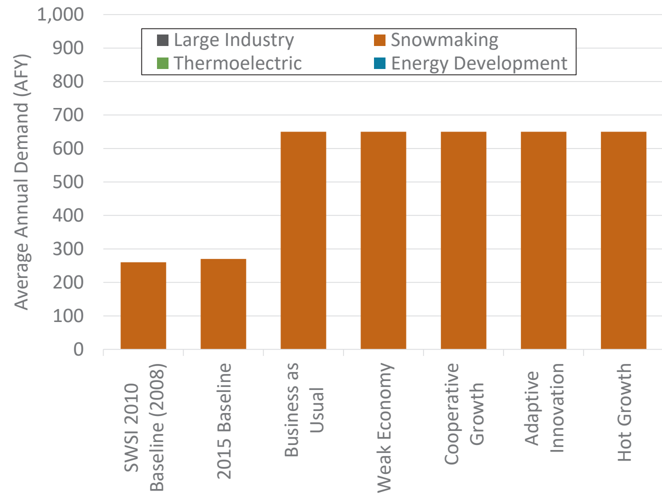


Table 4.5.8 Gunnison SSI Baseline and Projected Demands (AFY).

Sub-sector	Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Large Industry	-	-	-	-	-	-
Snowmaking	270	650	650	650	650	650
Thermoelectric	-	-	-	-	-	-
Energy Development	-	-	-	-	-	-
Sub-Basin Total	**270**	**650**	**650**	**650**	**650**	**650**

Total M&I Diversion Demands

Gunnison Basin combined M&I demand projections for 2050 range from approximately 21,000 AFY in *Weak Economy* to more than 37,000 AFY in *Hot Growth* as shown on Figure 4.5.9. Under every planning scenario, municipal demands are the majority (at least 97 percent) of the total M&I demands. On a basin scale, the demand projections follow the statewide sequence of the scenario rankings described in the CWP.

Figure 4.5.9 Gunnison Basin Municipal and Self-Supplied Industrial Demands

4.5.5 Water Supply Gaps

The agricultural and M&I diversion demands were compared against available water supply modeled for current conditions and the five planning scenarios. Gaps were calculated when water supply was insufficient to meet demands.

Agricultural

The Gunnison Basin agricultural diversion demands, demand gaps, and consumptive use gaps for the baseline and planning scenarios are presented in Table 4.5.9 and illustrated in Figure 4.5.10. An annual time series of gaps in terms of percent of demand that was unmet is shown on Figure 4.5.11.

INCREMENTAL GAP

The incremental agricultural gap quantifies the degree to which the gap could increase beyond what agriculture has historically experienced under water shortage conditions.

Table 4.5.9 Gunnison Basin Agricultural Gap Results (AFY)

		Scenario					
		Scenario	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand	1,800,200	1,675,500	1,675,500	1,967,200	1,305,700	2,041,500
	Average Annual Gap	87,300	77,200	77,300	157,600	112,600	222,000
	Average Annual Gap Increase from Baseline	-	-	-	70,300	25,300	134,700
	Average Annual Percent Gap	5%	5%	5%	8%	9%	11%
	Average Annual CU Gap	43,200	38,200	38,300	74,800	64,700	104,000
Maximum	Demand in Maximum Gap	1,841,100	1,713,900	1,713,900	1,833,600	1,247,600	1,912,700
	Gap in Maximum Gap Year	339,700	313,500	314,800	432,600	319,600	590,800
	Increase from Baseline Gap	-	-	-	93,000	-	251,100
	Percent Gap in Maximum Gap Year	18%	18%	18%	24%	26%	31%

Study period for Water Supply analysis is 1975-2013, reflecting different baseline demand than described in Agricultural Diversion Demands section

Figure 4.5.10 Projected Average Annual Agricultural Diversion Demand, Demand Met, and Gaps in the Gunnison Basin

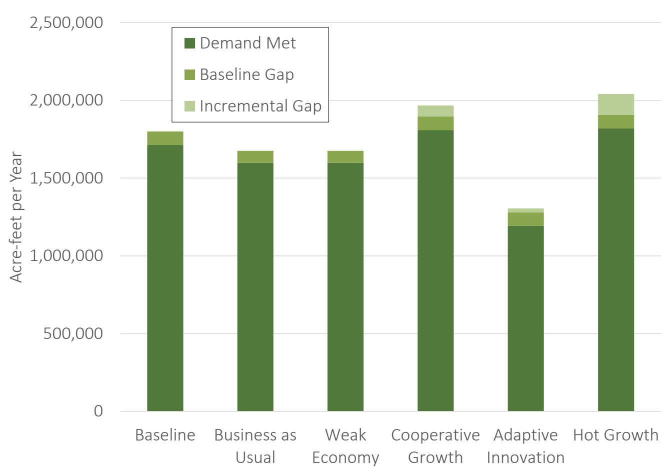
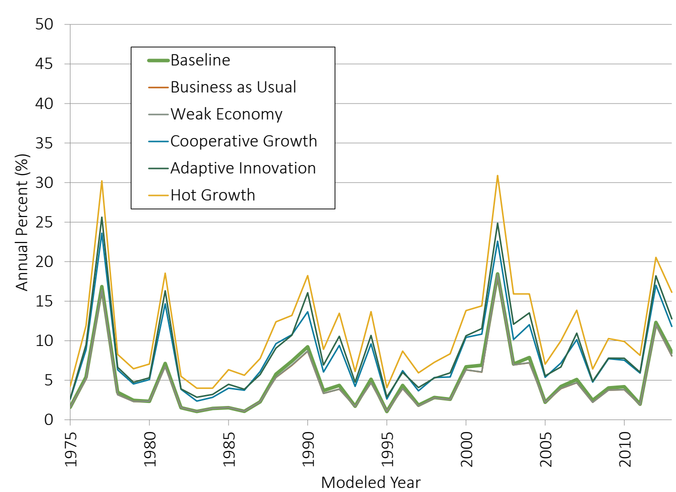


Figure 4.5.11 Annual Agricultural Gaps (expressed as a percentage of demand) for Each Planning Scenario



The following are observations on agricultural diversion demands and gaps:

- Agricultural diversion demands are projected to decrease in three of the five planning scenarios due to urbanization and the associated reduction of irrigated acres and the adoption of emerging agricultural technologies (in *Adaptive Innovation*).
- Agricultural diversion demands are projected to increase by 9 to 13 percent above current in *Cooperative Growth* and *Hot Growth* due to climate impacts.
- Agricultural gaps are projected to increase beyond existing gaps in the climate-impacted planning scenarios.
- While the gap as a percent of demand is projected to be relatively small in average years (5 to 11 percent), it may nearly triple (in terms of percent of demand) in maximum gap years.

M&I

The diversion demand and gap results for M&I uses in the Gunnison Basin are summarized in Table 4.5.10 and illustrated on Figure 4.5.12. An annual time series of gaps in terms of percent of demand that was unmet is shown on Figure 4.5.13.

Table 4.5.10 Gunnison Basin M&I Gap Results (AFY)

		Scenario					
		Scenario	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand	17,000	24,800	19,100	22,900	26,400	34,100
	Average Annual Gap	0*	1,000	200	1,400	2,200	5,000
	Average Annual Percent Gap	0%	4%	1%	6%	8%	16%
Maximum	Demand in Maximum Gap Year	17,000	24,800	19,100	22,900	26,400	34,100
	Gap in Maximum Gap Year	0*	2,300	700	3,500	4,300	11,500
	Percent Gap in Maximum Gap Year	0%	9%	4%	15%	16%	34%

**CDSS water allocation model in this basin calculates small baseline M&I gaps, but they are either due to calibration issues or they are reflective of infrequent, dry-year shortages that are typically managed with temporary demand reductions, such as watering restrictions.*

Study period for Water Supply Analysis is 1975-2013, reflecting different baseline demand than described in M&I Demand section. Baseline demand also may vary slightly from previous section due to differences in geographic distribution of demand for counties that lie in multiple basins.

Figure 4.5.12 Projected Maximum Annual M&I Demand Met and Gaps in the Gunnison Basin

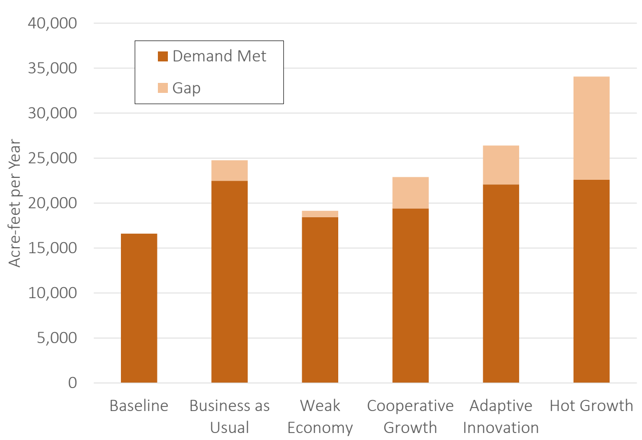
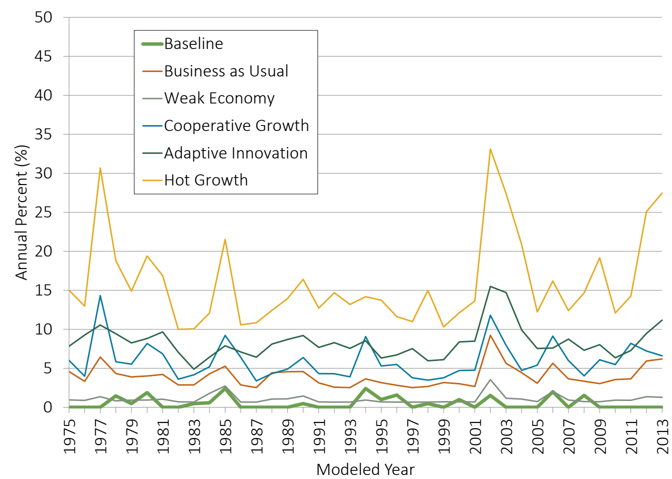


Figure 4.5.13 Annual M&I Gaps (expressed as a percentage of demand) for Each Planning Scenario



The following are observations on M&I diversion demands and gaps:

- The average annual M&I gap in the Gunnison Basin is projected to be less than the agricultural gap, ranging from 200 AF to over 5,000 AF.
- The maximum M&I gap for the five planning scenarios is projected to range from 700 AF to more than 11,000 AF.
- Population increases are the primary driver for increased M&I demands in the planning scenarios, as per capita water use is projected to decrease for every scenario except *Hot Growth*.
- The only SSI use in the basin is snowmaking, which is not projected to increase over baseline.
- For *Hot Growth*, the maximum M&I gap is much larger than other scenarios (at 34 percent of demand), which reflects lower supplies, large population growth, and less conservation.

Total Gap

Figure 4.5.14 illustrates the total combined agricultural and M&I diversion demand gap in the Gunnison Basin. The figure combines the average annual baseline and incremental agricultural gaps and the maximum M&I gap. In *Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth*, gaps were driven by agricultural demands, which increase in the *"Hot and Dry"* climate projection.

Supplies from Urbanized Lands

By 2050, irrigated acreage in the Gunnison Basin is projected to decrease by 14,600 acres due to urbanization. Irrigation supplies for these lands could potentially be used for M&I needs in the future (subject to a variety of unknowns such as seniority and type of water supply, willingness to change the use of water through water court, etc.). The average annual historical consumptive use associated with potentially urbanized acreage for each scenario is reflected in Table 4.5.11. The data in the table represent planning-level estimates of this potential supply and has not been applied to the M&I gaps.

Figure 4.5.14 Projected Average Annual Agricultural Gaps and Maximum M&I Diversion Demand Gaps in the Gunnison Basin

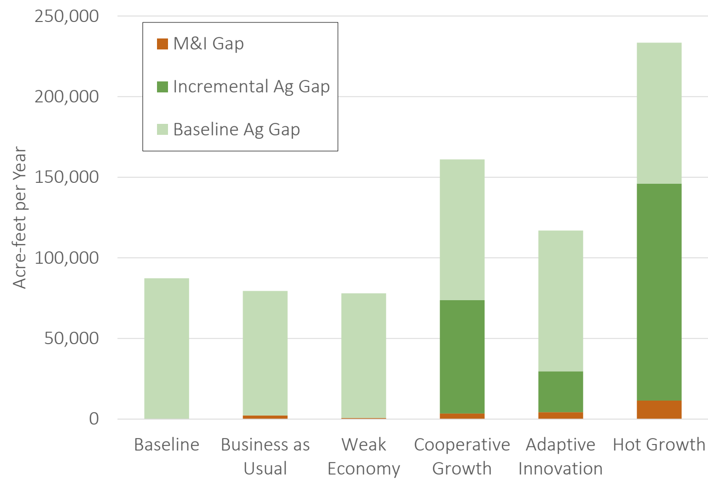


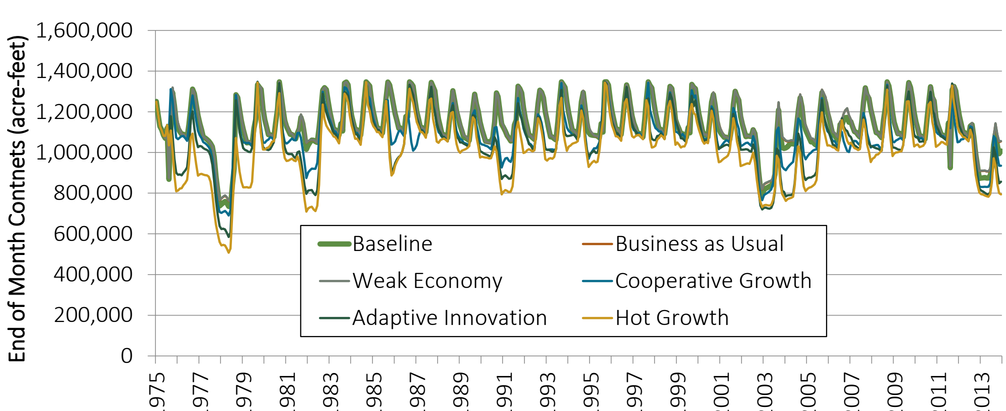
Table 4.5.11 Estimated Consumptive Use from Lands Projected to be Urbanized by 2050 in the Gunnison Basin

	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Urbanized Acreage (acres)	14,600	14,600	14,600	14,600	14,600
Estimated Consumptive Use (AFY)	30,300	30,300	33,100	31,600	33,000

Storage

Total simulated reservoir storage from the Gunnison River water allocation model is shown in Figure 4.5.15. Baseline conditions show the highest levels of water in storage (in general), and the lowest is in *Hot Growth*. *Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth* show lower amounts of water in storage during dry periods than the two scenarios that do not include the impacts of a drier climate; however, storage levels generally recover back to baseline levels after dry periods.

Figure 4.5.15 Total Simulated Reservoir Storage in the Gunnison Basin



4.5.6 Available Supply

Figures 4.5.16 and 4.5.17 show estimated simulated monthly available flow in the Gunnison River at a location below the Aspinall Unit and Gunnison Tunnel diversions but upstream of the Redlands Canal, which is the primary calling right in the lower basin. The canal diverts for power and irrigation, and return flows accrue to the Colorado Basin, which reflects a total depletion to the Gunnison River.

The figures show that flows are projected to be available in many years, though the amounts will vary greatly on an annual basis and across scenarios (available flows under the scenarios impacted by climate change are less than in other scenarios). In *Hot Growth* and *Adaptive Innovation*, very little flow may be available at this location for long periods of time during dry times. Peak flows are projected to occur earlier in the year under scenarios impacted by climate change.

Figure 4.5.16 Simulated Hydrographs of Available Flow at Gunnison River Below Gunnison Tunnel

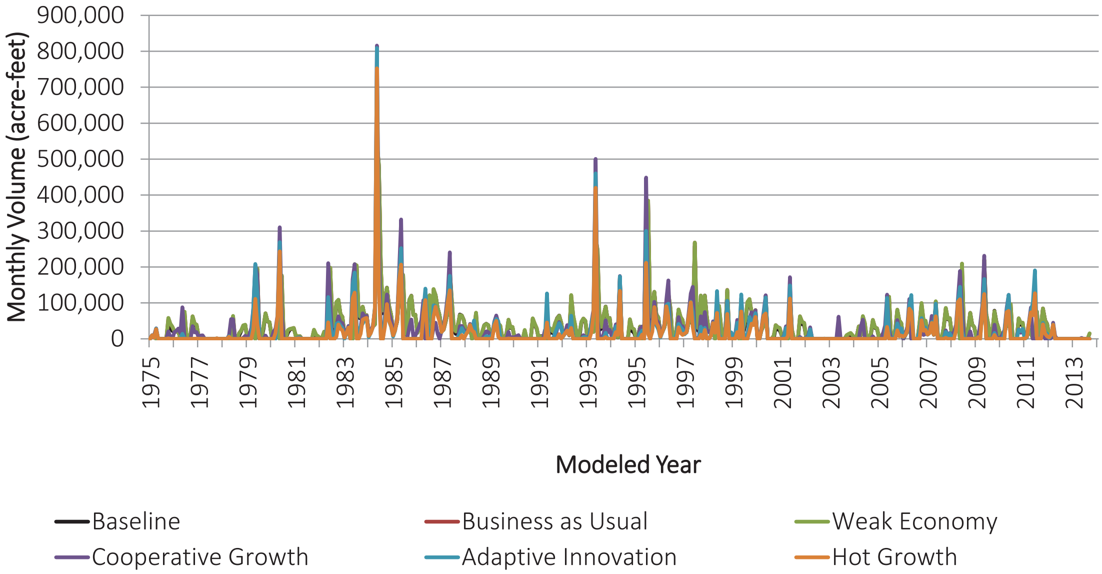
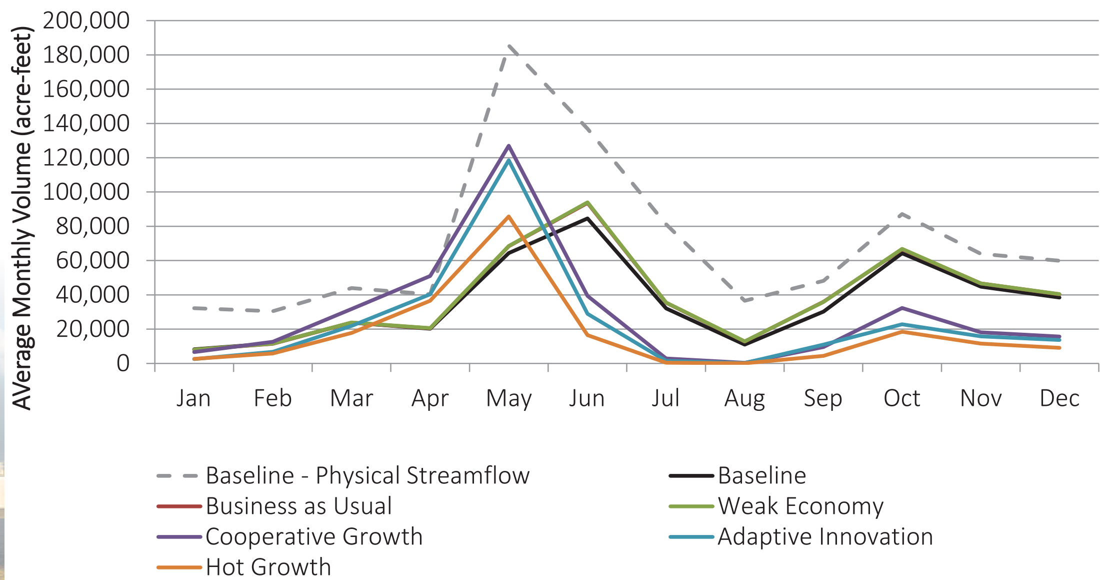


Figure 4.5.17 Average Monthly Simulated Hydrographs of Available Flow at Gunnison River Below Gunnison Tunnel



4.5.7 Environment and Recreation

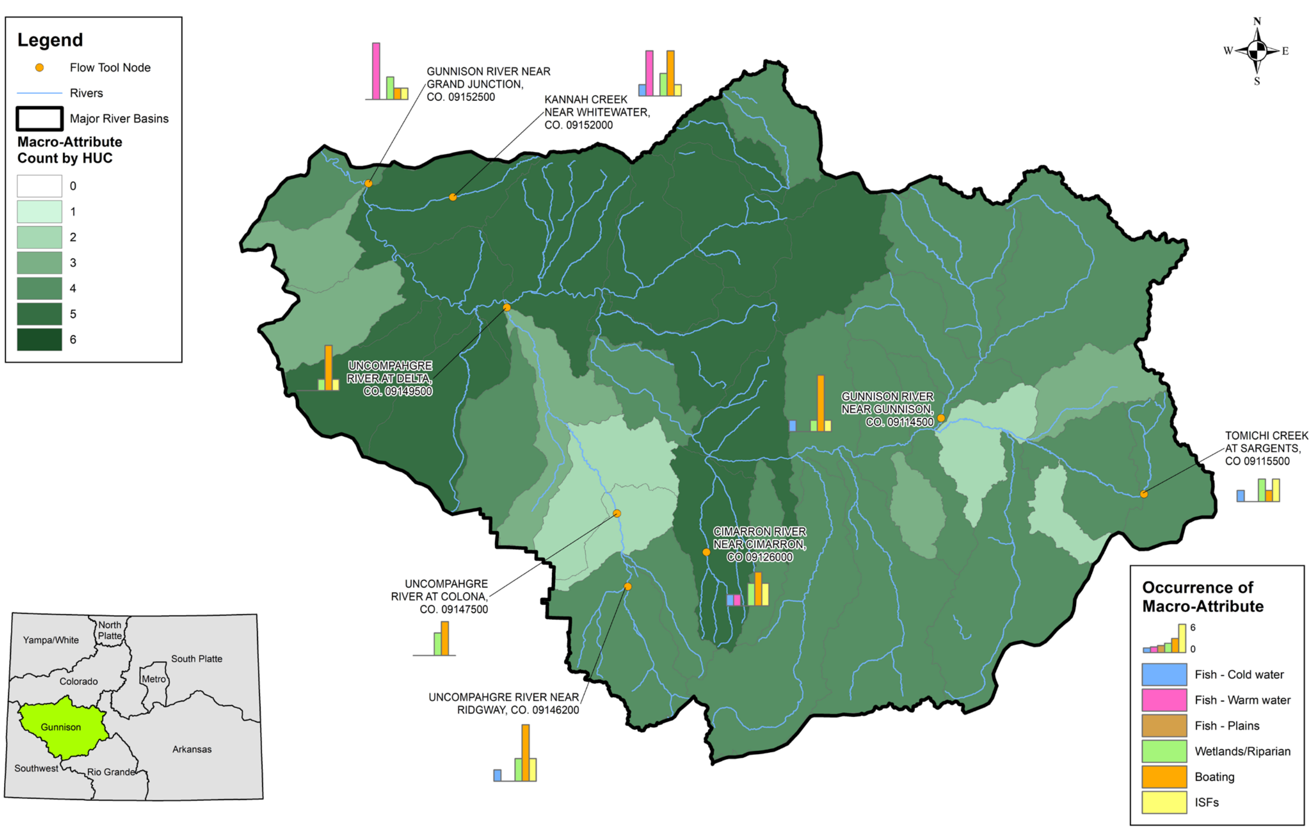
A total of eight water allocation model nodes were selected for the Environmental Flow Tool in the Gunnison Basin (see list below and Figure 4.5.18). Figure 4.5.18 also shows subwatersheds (at the 12-digit HUC level) and the relative number of E&R attributes located in each watershed.

- Gunnison River near Gunnison, Colorado (09114500)
- Tomichi Creek at Sargents, Colorado (09115500)
- Cimarron River near Cimarron, Colorado (09126000)
- Uncompahgre River near Ridgway, Colorado (09146200)
- Uncompahgre River at Colona, Colorado (09147500)
- Uncompahgre River at Delta, Colorado (09149500)
- Kannah Creek near Whitewater, Colorado (09152000)
- Gunnison River near Grand Junction, Colorado (90152500)

NATURALIZED FLOW

Naturalized flows reflect conditions that would occur in the absence of human activities. Baseline flows reflect current conditions as influenced by existing infrastructure and river operations. While observations regarding naturalized flows may be informative, baseline flows reflect actual conditions and the diverse operations of a river's many users.

Figure 4.5.18 Flow Tool Nodes Selected for the Gunnison Basin



Results of Flow Tool analyses using flow data developed in the water supply and gap analyses for baseline conditions and the planning scenarios are described below.

In the Gunnison Basin, pattern of flow varies as a function of elevation, major diversions, and location relative to reservoir storage. Observations related to projected changes in flow, potential ecological risks, etc. are provided in Table 4.5.12.

Table 4.5.12 Summary of Flow Tool Results in the Gunnison Basin

Category	Observation
Projected Flows	At higher elevations (e.g., Gunnison River at Gunnison), mean annual flow under baseline conditions are close to naturalized conditions. Under climate-impacted scenarios (*Cooperative Growth*, *Adaptive Innovation*, *Hot Growth*), annual flows are projected to decrease.
	At locations lower in the basin (e.g., Gunnison River near Grand Junction), baseline annual flows are further depleted, and under climate change scenarios, depletions continue to grow.
	In some locations (e.g., Gunnison River at Gunnison), peak flow magnitude under baseline conditions is below naturalized conditions, but under climate change scenarios, peak flow magnitudes increase. As a general rule, however, peak flows change little from baseline under *Business as Usual* and *Weak Economy* scenarios but decrease more substantially under climate change scenarios.
	Below major reservoirs on the Uncompahgre and Gunnison mainstems, peak flow under baseline conditions can be half of the naturalized condition. Peak flows continue to decrease from naturalized under climate change scenarios.
	Under all climate change scenarios in all locations, runoff and peak flows occur earlier, with June flows decreasing and April and May flows increasing. This change in peak flow timing may cause mis-matches between flow dynamics and the flows needed to support species.
	At higher locations in the Gunnison Basin, mid- and late-summer flows under baseline conditions are 0 to 20 percent depleted from naturalized conditions. Under climate change scenarios, these flows drop further below naturalized.
	At lower elevations on mainstem rivers (e.g., Uncompahgre at Delta; Gunnison River near Grand Junction), mid- and late-summer flows under baseline conditions are 30 to 50 percent below naturalized. Under climate change scenarios, these flows are also projected to fall further below naturalized.
Ecological Risk	Ecological risk (riparian/wetland plants and fish habitat) related to projected changes in peak flow magnitude is generally low to moderate at higher elevations. Under climate change scenarios this risk is projected to increase at most locations.
	At lower elevations and on mainstems, peak flows are already reduced in general and reductions are projected to increase under climate change scenarios.
	Mid- and late-summer flows are projected to decline under climate change scenarios, though flow-related risk to coldwater fish (trout) is projected to remain moderate. However, the metric used to assess risk for fish does not include the month of July because historically, July flows are sufficient. Under *Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth*, July flows are predicted to drop, increasing risk for fish by reducing habitat and increasing stream temperatures. In at least one location (Cimarron River), winter flows are projected to become low, also putting fish at risk.
ISFs and RICDs	In several locations, ISFs may be met less often, and at least one RICD (in Gunnison), may be met less often. In critical endangered species habitat, lower mean annual flows and reduced flows in mid- and late-summer will make it more difficult to meet flow recommendations.
E&R Attributes	Under baseline conditions and the *Business as Usual* and *Weak Economy* scenarios, current flow issues related to E&R attributes arise from in-basin diversions and storage of peak flows in reservoirs.
	Under climate change scenarios, the shift in the timing of peak flow, reductions in total runoff, and increasing consumptive demands are projected to contribute to reductions in mid- and late-summer flows. Several water management programs implemented in the context of the Upper Colorado Endangered Fish Program, including on the Gunnison River below the Apsinall Unit, have demonstrated that flow timing and magnitude can be planned in a way that better meets the needs of E&R attributes.

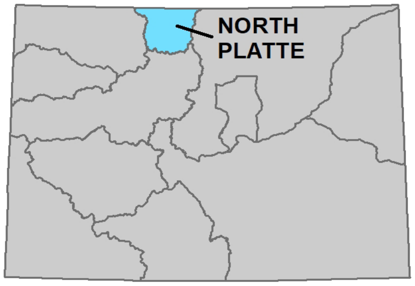
The North Platte Basin, also known as North Park, is a high-altitude valley covering about 2,000 square miles in north-central Colorado. It includes all of Jackson County and the small portion of Larimer County that contains the Laramie River watershed. Both the North Platte and Laramie Rivers flow north into Wyoming and are subject to use-limitations described in Supreme Court decrees.

The basin is also affected by the Platte River Recovery Implementation Program (PRRIP), which was developed to manage endangered species recovery efforts on the Platte River in Central Nebraska. Water use in the basin is dominated by irrigated pastures associated with ranching operations. The basin also has a major wildlife refuge in addition to numerous public lands and recreational opportunities. The basin exports a portion of North Platte water—approximately 4,500 AFY—to the Front Range.

NORTH PLATTE


127
District 76
Sand Creek
Sand Creek
District 48
Laramie River
Laramie River
Lost Lake
Barnes Meadow Reservoir
Chambers Lake
14
34
36

4.6 NORTH PLATTE BASIN RESULTS



4.6.1 BASIN CHALLENGES

The North Platte Basin will face several key issues and challenges pertaining to water management, endangered species, and resource development in the future. These are described in The Colorado Water Plan and summarized below.

Table 4.6.1 Key Future Water Management Issues in the North Platte Basin

<table>
<tr><th>Agriculture</th><th>Environment and Recreation</th><th>Municipal and Industrial</th><th>Compacts and Administration</th></tr>
<tr><td>• Gaining knowledge of the basin's consumptive uses and high-altitude crop coefficients.</td><td>• Maintaining healthy rivers through the strategic implementation of projects that meet prioritized nonconsumptive needs.
• Enhancing forest health and management efforts for wildfire protection and beetle-kill effects.</td><td>• Increasing economic development and diversification through strategic water use and development.</td><td rowspan="2">• Maintaining compliance with the equitable apportionment decrees on the North Platte* and Laramie** rivers that quantify the amount of available water and lands that can be irrigated.
• Successfully resolving endangered species issues on the Platte River in Central Nebraska through the PRRIP in a manner that does not put pressure on water users to reduce existing uses.
• Promoting water-rights protection and management through improved streamflow-gaging data.</td></tr>
<tr><td colspan="3">• Continuing to restore, maintain, and modernize critical water infrastructure to preserve current uses and increase efficiencies.
• Quantifying and strategically developing available unappropriated waters within the basin.</td></tr>
</table>

**The North Platte decree limits total irrigation in Jackson County to 145,000 acres and allows 17,000 AF reservoir storage annually during the irrigation season. In addition, the decree limits exports from the basin within Colorado to 60,000 AF over 10 years.*
***The Laramie River decree limits Colorado's total diversions and exports from the Laramie River to 39,750 AFY, divided among specific water facilities.*

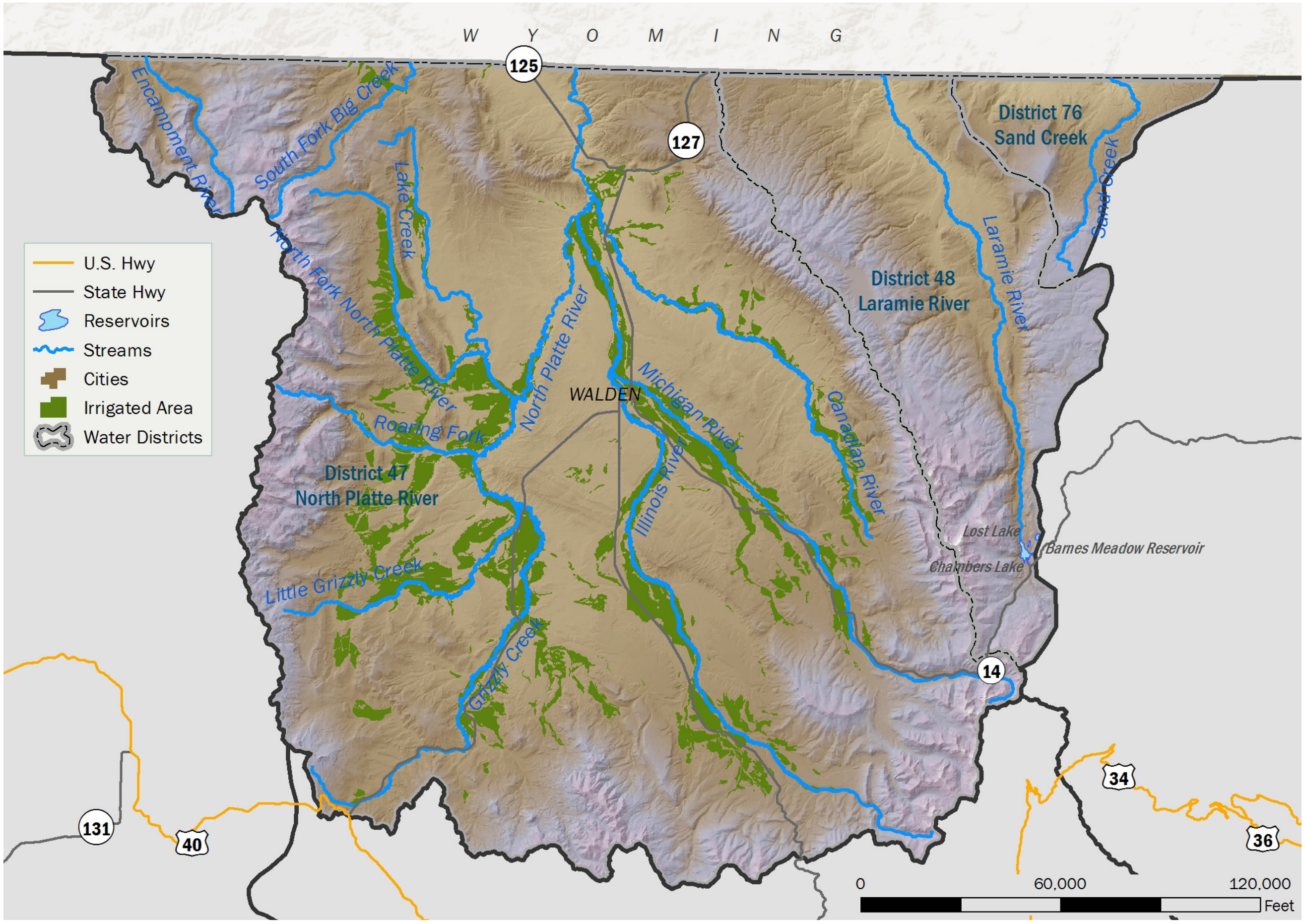


Figure 4.6.1 Map of the North Platte Basin

4.6.2 SUMMARY OF TECHNICAL UPDATE RESULTS

Key results and findings of the Technical Update pertaining to agricultural and M&I demands and gaps, as well as findings related to environmental and recreational attributes and future conditions, are summarized in Table 4.6.2 below.

Table 4.6.2 Summary of Key Results in the North Platte Basin

Agriculture	Environment and Recreation	Municipal and Industrial
• An additional 10,600 acres will increase agricultural demand in the future. • Although some technology improvements may occur, climate impacts may increase the agricultural demands and gap by 8 to 14 percent.	• In climate-impacted scenarios, peak flow generally moves earlier in the year. • Risks for trout increase in climate-impacted scenarios.	• Relatively small M&I demands are a reflection of the rural nature of this basin. There is little anticipated municipal growth, and no SSI water demand now or projected for the future.

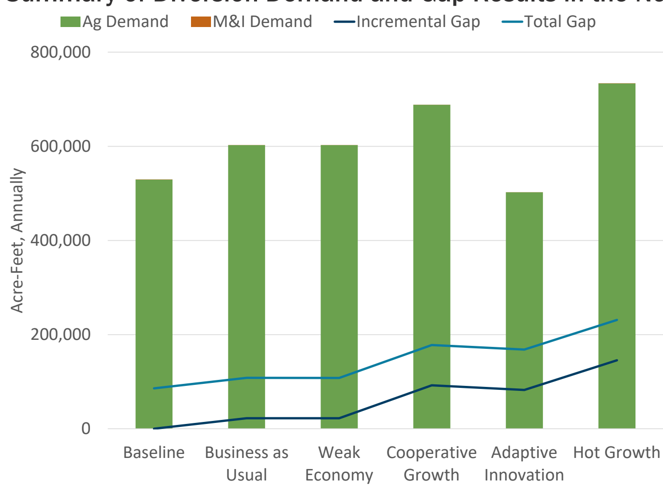
Results describing current and potential future M&I and agricultural demands and gaps are summarized in Table 4.6.3 and in Figure 4.6.2.

Table 4.6.3 Summary of Diversion Demand and Gap Results in the North Platte Basin

	Current (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average Annual Demand						
Agricultural (AFY)	529,200	602,400	602,400	688,300	502,300	733,500
M&I (AFY)	400	400	300	300	400	500
Gaps						
Ag (avg %)	16%	18%	18%	26%	33%	32%
Ag (incremental-AFY)	-	22,200	22,200	92,100	82,400	145,400
Ag (incremental gap as % of current demand)	-	4%	4%	17%	16%	27%
M&I (max %)	0%	4%	4%	4%	5%	10%
M&I (max-AF)	0*	20	10	10	20	50

**CDSS water allocation model in this basin calculates small baseline M&I gaps, but they are either due to calibration issues or they are reflective of infrequent, dry-year shortages that are typically managed with temporary demand reductions, such as watering restrictions.*

Figure 4.6.2 Summary of Diversion Demand and Gap Results in the North Platte Basin



Environmental and Recreational Findings

- Peak flows are projected to shift earlier in the year (April and May flows increase, offsetting June flow decreases) while magnitude may remain similar, keeping riparian/wetland and risk to fish habitat low to moderate. Possible mis-matches between peak flow timing and species needs may occur.
- Mid- and late-summer flows in North Park are moderate risk for trout under natural conditions, moderate to high risk under baseline conditions, and are projected to become high and very high risk for trout under *Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth.*

4.6.3 NOTABLE BASIN CONSIDERATIONS

- Irrigation demands reflect full season demand, but basin irrigators generally end irrigation earlier in the season. In general, North Platte Basin irrigators tend to get a first cutting of grass/hay around mid-July; falling stream flow conditions in late summer and, in some years, early frosts can make it difficult to get a second cutting. In addition, many farmers do not have access to supplemental storage that would provide late-season supplies. If this trend continues, agricultural gaps may not be as large as projected.
- The Technical Update used water allocation models that reflect a strict application of water administration. In the North Platte Basin, some water users refrain from placing a call to share the benefit of available supplies, but these practices are not reflected in the models
- SSI water demands for fracking are not included in the overall M&I diversion demands. Water demand data for fracking was researched, but reliable sources of data were not found. The M&I diversion demands technical memorandum includes a recommendation to improve this dataset.

4.6.4 AGRICULTURAL DIVERSION DEMANDS

Agricultural Setting

Ranchers in the North Platte River and Laramie River basins irrigate more than 113,000 acres of grass and hay to support numerous cow-calf operations throughout the basin. These high mountain meadows are generally flood irrigated, and with limited storage in the basin irrigators rely on diversions of spring and summer runoff for supplies. With low population projections for the basin, future agricultural diversion demands in the basin will be most impacted by the ability to maintain and even increase irrigated acreage and potential impacts from climate change.

Planning Scenario Adjustments

Section 2 described ways in which inputs to agricultural diversion demand estimates were adjusted to reflect the future conditions described in the planning scenarios. The North Platte BIP identifies parcels of historically irrigated or potentially irrigable land that may be irrigated in the future if infrastructure improvements are made and water rights secured. Altogether, the North Platte BIP identified seven planned agricultural development projects throughout the basin that totalled a potential increase of 10,576 irrigable acres. Due to a short growing season and the prevalence of irrigated pasture grass related to ranching operations in the basin, it is reasonable to assume that these planned agricultural projects will also be operated for hay and cattle ranching. The North Platte basin roundtable consistently emphasizes the importance of maintaining and increasing irrigated acreage in the basin allowable under the Nebraska v. Wyoming Equitable Apportionment Decree and foresees implementing the planned agricultural projects in all planning scenarios.

Table 4.6.4 summarizes the planning scenario adjustments described above and other adjustments that impact agricultural diversion demands in the various scenarios, including increased irrigated acres.

Table 4.6.4 Planning Scenario Adjustments for Agricultural Demands in the North Platte Basin

Adjustment Factor*	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Change in Irrigated Land due to Urbanization	-	-	-	40 Acre Reduction	40 Acre Reduction
Planned Agricultural Development Projects	10,576 Acre Increase	10,576 Acre Increase	10,576 Acre Increase	10,576 Acre Increase	10,576 Acre Increase
IWR Climate Factor	-	-	25%	39%	39%
Emerging Technologies	-	-	-	10% IWR Reduction 10% System Efficiency Increase	-

** See Section 2.2.3 for descriptions of adjustment methodologies and assumptions*

Agricultural Diversion Demand Results

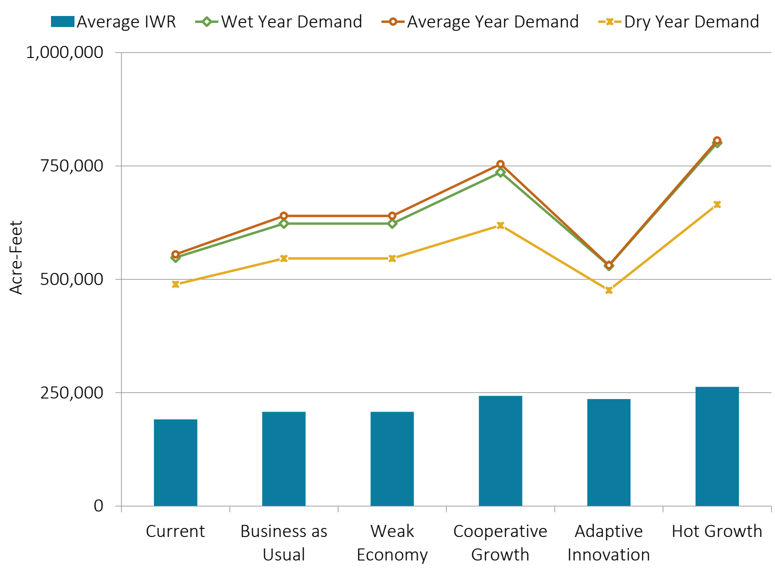
Table 4.6.5 and Figure 4.6.3 summarize the acreage, IWR, and the agricultural diversion demand for surface water supplies in the North Platte Basin for current conditions and the five planning scenarios. Agricultural diversion demands are projected to increase by 2050 due to additional irrigated acres; however, despite increased irrigated acres, *Adaptive Innovation* projects decreased demands as compared to baseline due to 10 percent reduction in IWR and 10 percent increase to system efficiency. *Hot Growth* projected the largest increase in demand due to higher IWR resulting from a warmer and drier future climate.

Table 4.6.5 Summary of Agricultural Diversion Demand Results in the North Platte Basin

	Current (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Irrigated Acreage (acres)	113,600	124,200	124,200	124,200	124,200	124,200
Average IWR (AFY)	191,100	208,000	208,000	243,000	236,000	263,000
Diversion Demand						
Average Year (AFY)	555,000	640,000	640,000	754,000	531,000	806,000
Wet Yr. Change	-1%	-3%	-3%	-2%	0%	-1%
Dry Yr Change	12%	15%	15%	18%	10%	17%

Average agricultural demand is calculated from the average of the "average" hydrologic years from 1950-2013

Figure 4.6.3 Summary of Agricultural Diversion Demand Results in the North Platte Basin



4.6.5 Municipal and Self-Supplied Industrial Diversion Demands

Population Projections

The North Platte Basin includes about 0.02 percent of the statewide population. Between the years 2015 and 2050, it is projected to change from approximately 1,400 to between 1,100 and 1,500 people in the low and high growth projections, respectively. This ranges from a 22 percent decrease in population to an increase of 8 percent. On a basin scale, the North Platte Basin represents the lowest baseline population and the lowest basinwide growth in the state. Table 4.6.6 shows how population growth is projected to vary for the North Platte Basin under each planning scenario.

Table 4.6.6 North Platte Basin 2015 and Projected Populations

Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
1,353	1,279	1,055	1,210	1,364	1,457

Current Municipal Demands

The North Platte Basin baseline demands relied entirely on estimated data from neighboring counties. No municipal data were available for utilities within Jackson County, which is the only county in the North Platte Basin.

Figure 4.6.4 summarizes the categories of municipal, baseline water usage in the North Platte Basin. Because there was no water provider-reported data available for Jackson County, the statewide weighted average demand category distribution was used for the North Platte Basin.

Projected Municipal Demands

Figure 4.6.5 provides a summary of per capita baseline and projected water demands for the North Platte Basin. Systemwide, the projected per capita demands are projected to decrease relative to the baseline except for *Hot Growth*. The residential indoor demand is the greatest demand category in the baseline, but the residential outdoor demand exceeds the residential indoor demand in *Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth*. Outdoor demands increased significantly for *Hot Growth* due to an increase in outdoor demands driven by the "Hot and Dry" climate factor (described in Section 2).

The North Platte Basin municipal baseline and projected demands provided in Table 4.6.7 show the combined effect of population and per capita demands. Municipal demands are projected to grow from approximately 400 AFY in 2015 to between 300 and 440 AFY in 2050.

The baseline and projected municipal demands are shown in Figure 4.6.6, which also shows how the population varies between the scenarios. *Hot Growth* is the only planning scenario in which the projected demands increase from the baseline; all other planning scenarios show an overall decrease in demands by 2050.

DECREASING GPCD

The North Platte Basin average baseline per capita systemwide demand has decreased from 310 gpcd in SWSI 2010 to approximately 264 gpcd.

Figure 4.6.4 Categories of Water Usage in the North Platte Basin

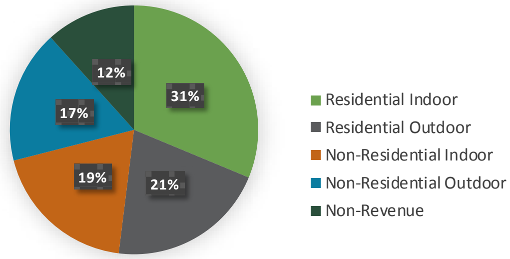


Figure 4.6.5 North Platte Basin Municipal Baseline and Projected Per Capita Demands by Water Demand Category

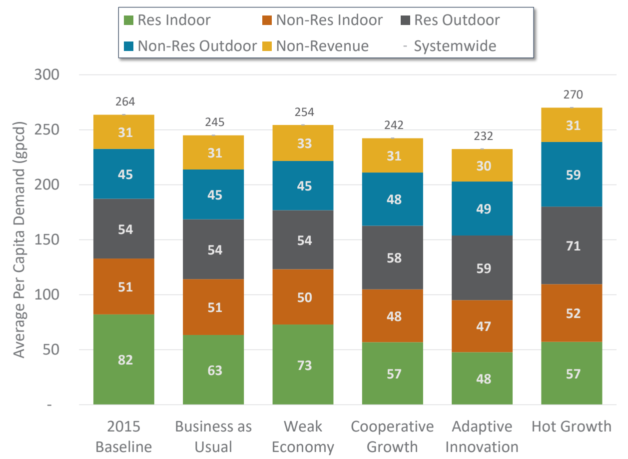


Figure 4.6.6 North Platte Basin Baseline and Projected Population and Municipal Demands

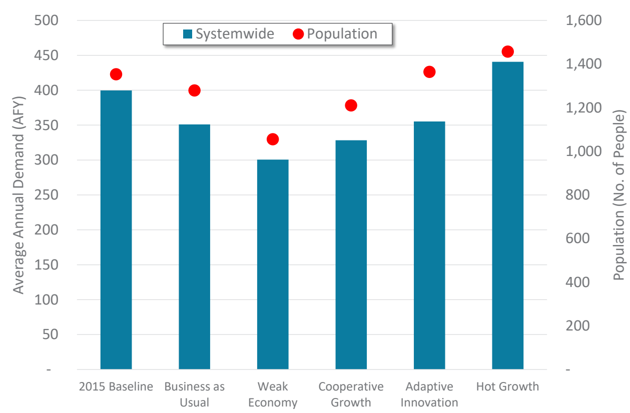


Table 4.6.7 North Platte Basin Municipal Baseline and Projected Demands (AFY)

Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
400	350	300	330	360	440

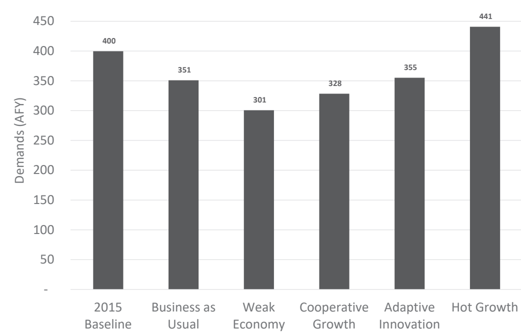
Self-Supplied Industrial Demands

The analysis does not include baseline and projected industrial demands in the North Platte Basin. Water demands for fracking occur in the basin, but no reliable sources of data were identified that could be used to quantify the water demands.

Total M&I Diversion Demands

North Platte Basin combined M&I demand projections for 2050 range from approximately 300 AFY under *Weak Economy* to 440 AFY in *Hot Growth*, as shown in Figure 4.6.7. On a basin scale, the demand projections follow the statewide sequence of the scenario rankings described in the CWP.

Figure 4.6.7 North Platte Basin Municipal and Self-Supplied Industrial Demands



4.6.6 Water Supply Gaps

The agricultural and M&I diversion demands were compared against available water supply modeled for current conditions and the five planning scenarios. Gaps were calculated when water supply was insufficient to meet demands.

Agricultural

The North Platte Basin agricultural diversion demands, demand gaps, and consumptive use gaps for the baseline and planning scenarios are presented in Table 4.6.8 and illustrated on Figure 4.6.8. An annual time series of gaps in terms of percent of demand that was unmet is shown on Figure 4.6.9.

INCREMENTAL GAP

The incremental agricultural gap quantifies the degree to which the gap could increase beyond what agriculture has historically experienced under water shortage conditions.

Table 4.6.8 North Platte Basin Agricultural Gap Results (AFY)

		Scenario					
		Scenario	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand	529,200	602,400	602,400	688,300	502,300	733,500
	Average Annual Gap	85,700	108,000	107,900	177,900	168,100	231,100
	Average Annual Gap Increase from Baseline	-	22,200	22,200	92,100	82,400	145,400
	Average Annual Percent Gap	16%	18%	18%	26%	33%	32%
	Average Annual CU Gap	40,300	50,800	50,800	83,600	92,000	108,500
Maximum	Demand in Maximum Gap Year	521,600	582,400	582,400	659,400	494,900	694,000
	Gap in Maximum Gap Year	296,900	336,700	336,700	394,800	320,800	441,000
	Increase from Baseline Gap	-	39,800	39,700	97,900	23,800	144,100
	Percent Gap in Maximum Gap Year	57%	58%	58%	60%	65%	64%

Study period for Water Supply Analysis is 1975-2013, reflecting different baseline demand than described in Agricultural Diversion Demands section

Figure 4.6.8 Projected Average Annual Agricultural Diversion Demand, Demand Met, and Gaps in the North Platte Basin

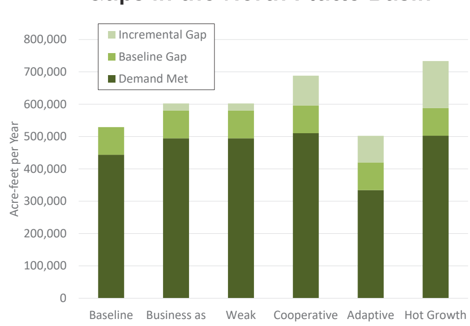
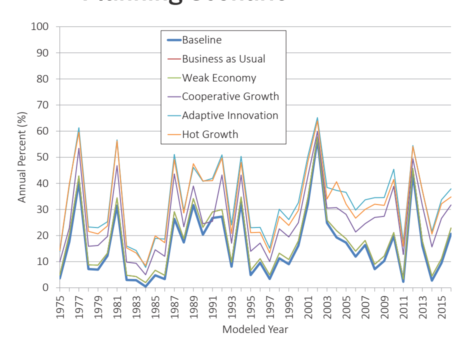


Figure 4.6.9 Annual Agricultural Gaps (expressed as a percentage of demand) for Each Planning Scenario



Observations on agricultural demands and gaps include:

- An additional 10,600 acres will increase agricultural diversion demand in the future.
- Although some technology improvements may occur, climate impacts will serve to increase the agricultural gap by 8 to 16 percent.
- Annual agricultural gaps can vary significantly and are more pronounced in dry years.

M&I

The diversion demand and gap results for M&I in the North Platte Basin are summarized in Table 4.6.9 and illustrated on Figure 4.6.10. An annual time series of gaps in terms of percent of demand that was unmet is shown on Figure 4.6.11.

Table 4.6.9 North Platte Basin M&I Gap Results (AFY)

		Scenario					
		Scenario	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand	400	370	310	350	380	460
	Average Annual Gap	0	0	0	1	2	21
	Average Annual Percent Gap	0%	0%	0%	0%	1%	5%
Maximum	Demand in Maximum Gap Year	400	370	310	350	380	460
	Gap in Maximum Gap Year	0*	15	13	13	18	45
	Percent Gap in Maximum Gap Year	0%	4%	4%	4%	5%	10%

* *CDSS water allocation model in this basin calculates small baseline M&I gaps, but they are either due to calibration issues or they are reflective of infrequent, dry-year shortages that are typically managed with temporary demand reductions, such as watering restrictions.*
Study period for Water Supply Analysis is 1975-2013, reflecting different baseline demand than described in M&I Demand section.

Figure 4.6.10 Projected Maximum Annual M&I Demand Met and Gaps in the North Platte Basin

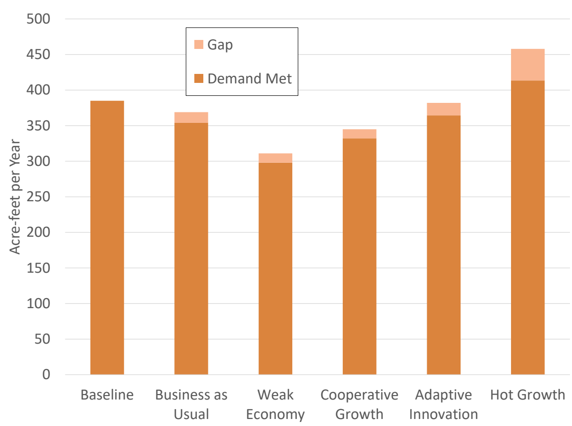
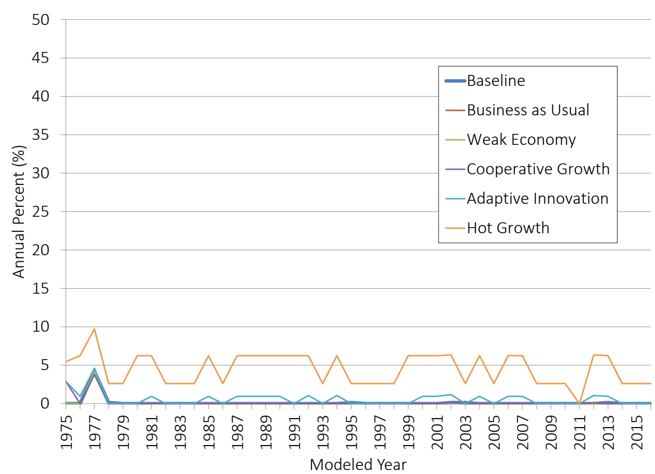


Figure 4.6.11 Annual M&I Gaps (expressed as a percent of demand) for Each Planning Scenario



The following are observations on M&I diversion demands and gaps:

- Relatively small M&I demands are a reflection of the rural nature of this basin. There is little anticipated municipal growth.
- Consistent M&I gaps are only present in *Hot Growth*.

Total Gap

Figure 4.6.12 illustrates the total combined agricultural and M&I diversion demand gap in the North Platte Basin. The figure combines the average annual baseline and incremental agricultural gaps and the maximum M&I gap. In all future scenarios, gaps are driven by agricultural demands, which increase due to more irrigated acres and climate impacts.

Supplies from Urbanized Lands

By 2050, irrigated acreage in the North Platte Basin is projected to decrease by only 40 acres due to urbanization, reflecting the rural nature of the basin. These decreases are only projected to occur in *Adaptive Innovation* and *Hot Growth*. Irrigation supplies for these lands could potentially be used for M&I needs in the future (subject to a variety of unknowns such as seniority and type of water supply, willingness to change the use of water through water court, etc.). The average annual historical consumptive use associated with potentially urbanized acreage for each scenario is reflected in Table 4.6.10. The data in the table represent planning-level estimates of this potential supply and has not been applied to the M&I gaps.

Figure 4.6.12 Projected Average Annual Agricultural Gaps and Maximum M&I Diversion Demand Gaps in the North Platte Basin (AFY)

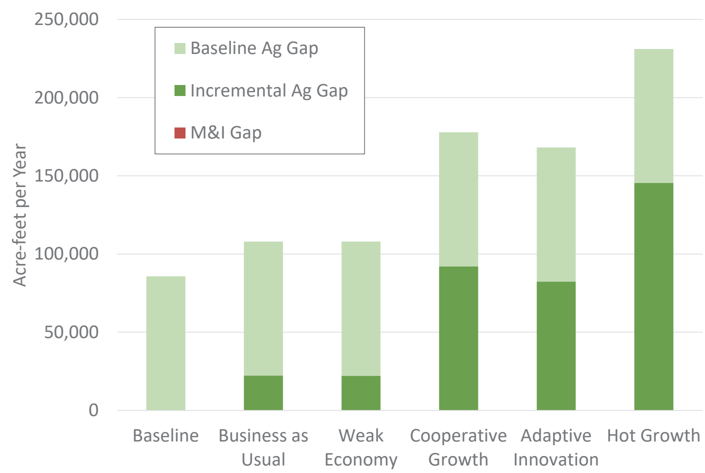


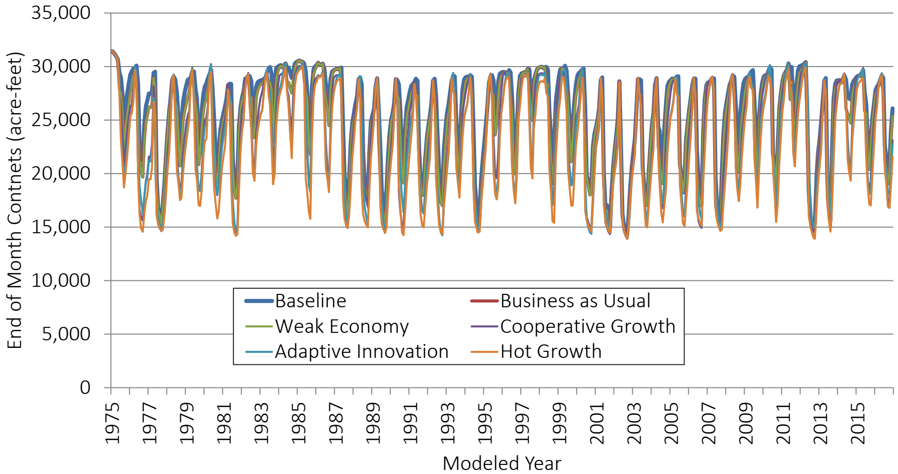
Table 4.6.10 Estimated Consumptive Use from Lands Projected to Be Urbanized by 2050 in the North Platte Basin

	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Urbanized Acreage (acres)	-	-	-	40	40
Estimated Consumptive Use (AFY)	-	-	-	50	50

Storage

Total simulated reservoir storage from the North Platte River water allocation model is shown in Figure 4.6.13. Baseline and *Weak Economy* scenarios show the highest levels of water in storage (in general) and the lowest is in *Hot Growth*; however, storage levels for all future scenarios track closely with baseline throughout the study period.

Figure 4.6.13 North Platte Basin Total Simulated Storage



4.6.7 Available Supply

Figures 4.6.14 and 4.6.15 show simulated available flow at a location on the Lower Michigan River upstream of the confluence with the North Platte River. The location represents water availability near the senior calling rights, which include the Hiho Ditch, Kiwa Ditch, and diversions to storage in Carlstrom Reservoir. Water availability is only moderately impacted by the calling rights, and flows are projected to be available in most years (but vary greatly on an annual basis). Peak flows are projected to increase at this location but could diminish in the late summer in climate-impacted scenarios.

Figure 4.6.14 Simulated Hydrograph of Available Flow at Michigan River at Cumberland Ditch

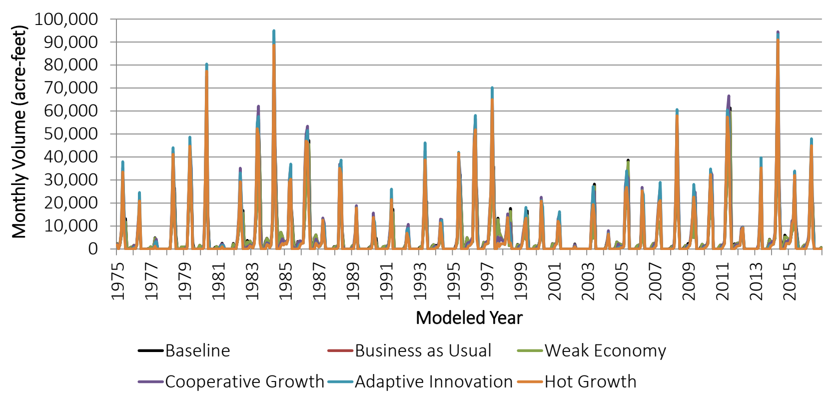
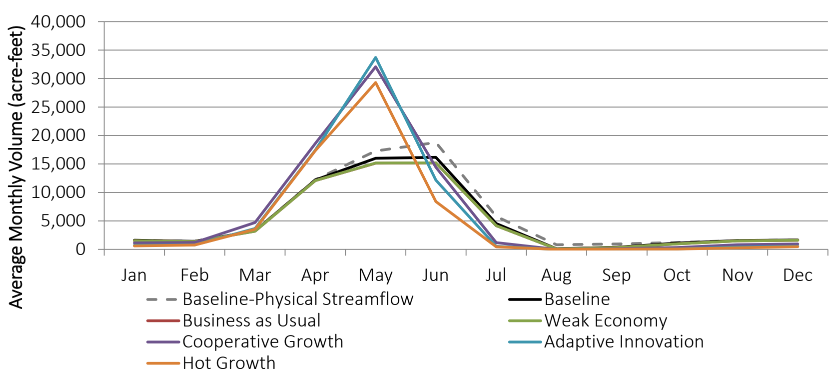


Figure 4.6.15 Average Monthly Simulated Hydrographs of Available Flow at Michigan River at Cumberland Ditch



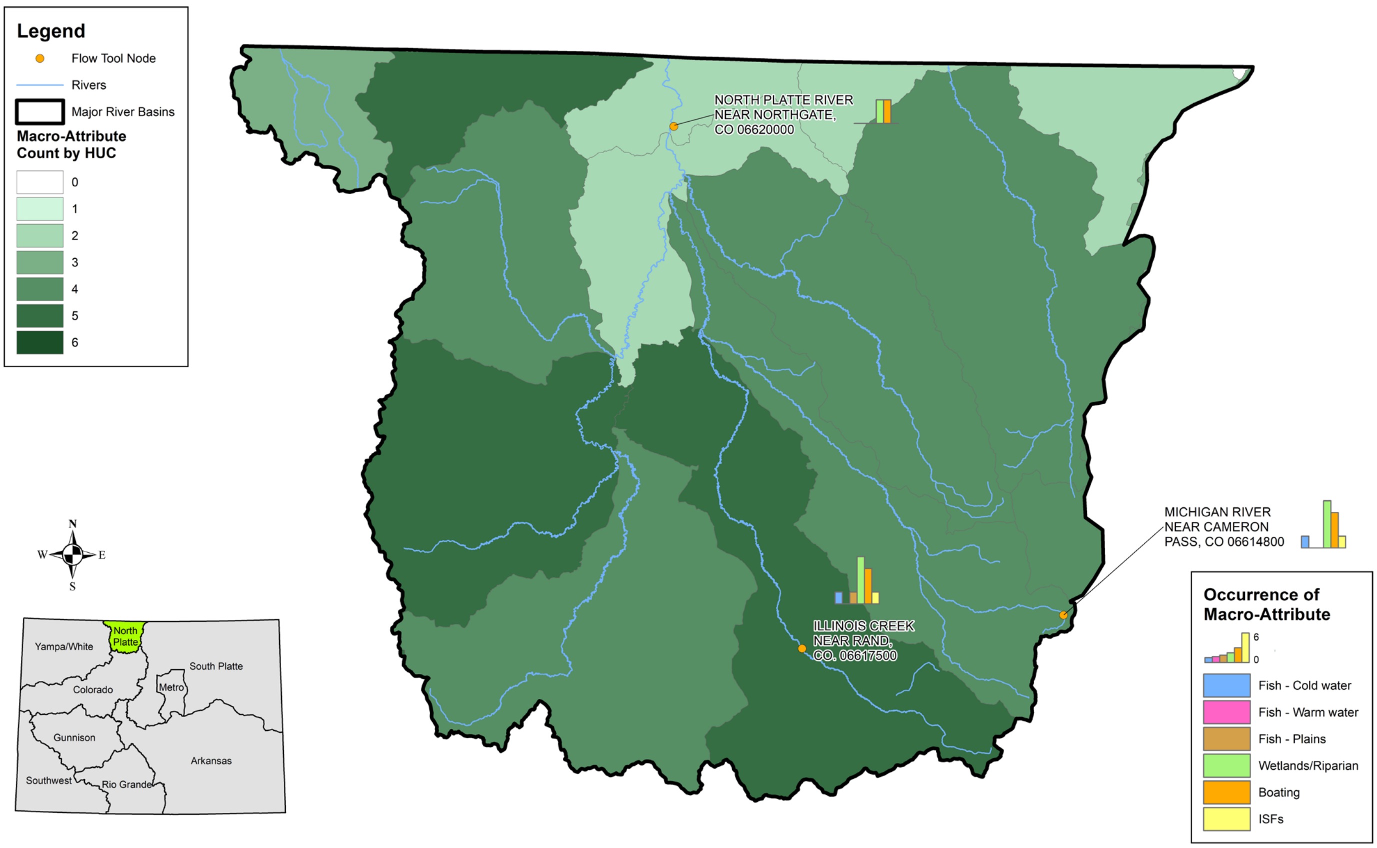
4.6.8 Environment and Recreation

A total of three water allocation model nodes were selected for the Flow Tool within the North Platte Basin (see list below and Figure 4.6.16). Figure 4.6.16 also shows subwatersheds (at the 12-digit HUC level) and the relative number of E&R attributes located in each subwatershed.

- Michigan River near Cameron Pass, Colorado (06614800)
- Illinois Creek near Rand, Colorado (06617500)
- North Platte River near Northgate, Colorado (06620000)

> **NATURALIZED FLOW**
>
> Naturalized flows reflect conditions that would occur in the absence of human activities. Baseline flows reflect current conditions as influenced by existing infrastructure and river operations. While observations regarding naturalized flows may be informative, baseline flows reflect actual conditions and the diverse operations of a river's many users.

Figure 4.6.16 Flow Tool Nodes Selected in the North Platte Basin



Results and observations describing Flow Tool analyses using flow data developed in the water supply and gap analyses for baseline conditions and the planning scenarios are described in Table 4.6.11.

Table 4.6.11 Summary of Flow Tool Results in the North Platte Basin

Category	Observation
Projected Flows	Mean annual flows in North Platte Basin under baseline conditions are 20 to 35 percent below naturalized conditions.
	Unlike all other basins analyzed, mean annual flow changes little under all scenarios, including climate change scenarios.
	Although there is little projected change in mean annual flow in future scenarios compared to baseline, peak flows do change. Peak flow magnitude under baseline conditions are approximately 15 percent below naturalized conditions at higher elevations and decrease further below naturalized conditions where the North Platte leaves Colorado near North Gate.
	Under *Business as Usual* and *Weak Growth*, projected peak flows change little. Under scenarios with climate change, peak flow magnitude may increase slightly. The timing of peak flows is also projected to change, shifting earlier in the year (April and May flows increase, offsetting June flow decreases).
	Under baseline conditions, mid- and late-summer flows in North Park are 30 to 60 percent below naturalized conditions, depending on location. This condition may not be as ideal for trout as many other locations in Colorado at similar elevation. Under climate change scenarios, mid- and late-summer flows are likely to decline further.
Ecological Risk	Baseline peak flow magnitudes create some risk for maintaining riparian/wetland plants and fish habitat, but this risk may lessen under climate change scenarios as peak flow magnitude increases. However, earlier and larger peak flows may lead to lower mid- and late-summer flows, and these lower flows could increase risk for trout under *Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth*. Also, the change in peak flow timing under climate change scenarios may lead to mis-matches between peak flows and species' needs.

The Rio Grande drainage basin in Colorado is bound by the San Juan Mountains to the west, the Sangre de Cristo Range to the north and east, the Culebra Range to the southeast, and the Colorado-New Mexico state line to the south. Between the mountains lies the San Luis Valley, an expansive, generally flat area with an average elevation of 7,500 feet and precipitation of less than eight inches per year. Despite the low precipitation, agriculture has long been the basis of the Rio Grande basin economy. Principal crops are potatoes, followed by alfalfa, native hay, barley, wheat, and small vegetables like lettuce, spinach and carrots. Mountainous areas of the basin are forested and sparsely populated.

The northern third of the valley is a closed basin, meaning runoff from the surrounding mountains and diversions from the Rio Grande recharge the basin's two stacked aquifers, known as the unconfined and confined aquifers, rather than contributing or returning to the Rio Grande. Irrigated agriculture in the Rio Grande Basin relies on well pumping from the aquifers as well as surface deliveries from the Rio Grande and Conejos River. These diversions are both applied directly to crops and, in the closed basin, recharged into the unconfined aquifer.

The Rio Grande Compact establishes Colorado's obligations to ensure water delivery at the New Mexico state line with some allowance for credits and debits via accounts in Elephant Butte Reservoir. The compact dictates that Colorado calculate its delivery obligation based on the flow at indexed stations, which effectively caps Colorado's allowable consumptive use even in wet years. Key future water management issues in this basin center around sustainability of the groundwater supply, but also include maintaining and providing domestic supply for new growth and operating within the constraints of the Rio Grande Compact.

RIO GRANDE


285
District 25
San Luis Creek
69
MOFFAT
Saguache Creek
17
San Luis Creek
112
150
MONTE VISTA
15
ALAMOSA
District 35
Trinchera Creek
370
Terrace Reservoir
District 21
Alamosa La Jara
SAN LUIS
District 24
Culebra Creek
District 22
Conejos River

4.7 RIO GRANDE BASIN RESULTS

4.7.1 BASIN CHALLENGES

Key future water management issues in this basin center around sustainability of the groundwater supply, but also include maintaining and providing domestic supply for new growth and operating within the constraints of the Rio Grande Compact. These challenges are described in the Colorado Water Plan and are summarized below.

Table 4.7.1 Key Future Water Management Issues in the Rio Grande Basin

Agriculture	Environment and Recreation	Municipal and Industrial	Compacts and Administration
• Groundwater use for agriculture is currently at unsustainable levels. • Community-based solutions offer best hope of minimizing effects of reducing irrigated acres.	• The Rio Grande Basin has an abundance of terrestrial and aquatic wildlife populations, rare and important habitats, diverse ecosystems, and exceptional recreational opportunities; however, the increasingly water-short nature of the Basin makes sustaining these attributes challenging.	• All cities and towns are supplied by groundwater wells and must comply with the State Engineer's Well Rules and Regulations. • Growth of commercial uses throughout the basin, new homes near Alamosa, and second homes in the surrounding mountains are creating a need for additional water supplies and well augmentation.	• The Rio Grande Compact and sustained drought make the objective of groundwater sustainability difficult.
• Groundwater is a key component of water supply in the basin for both M&I and agriculture. Groundwater management presents an ongoing challenge.			

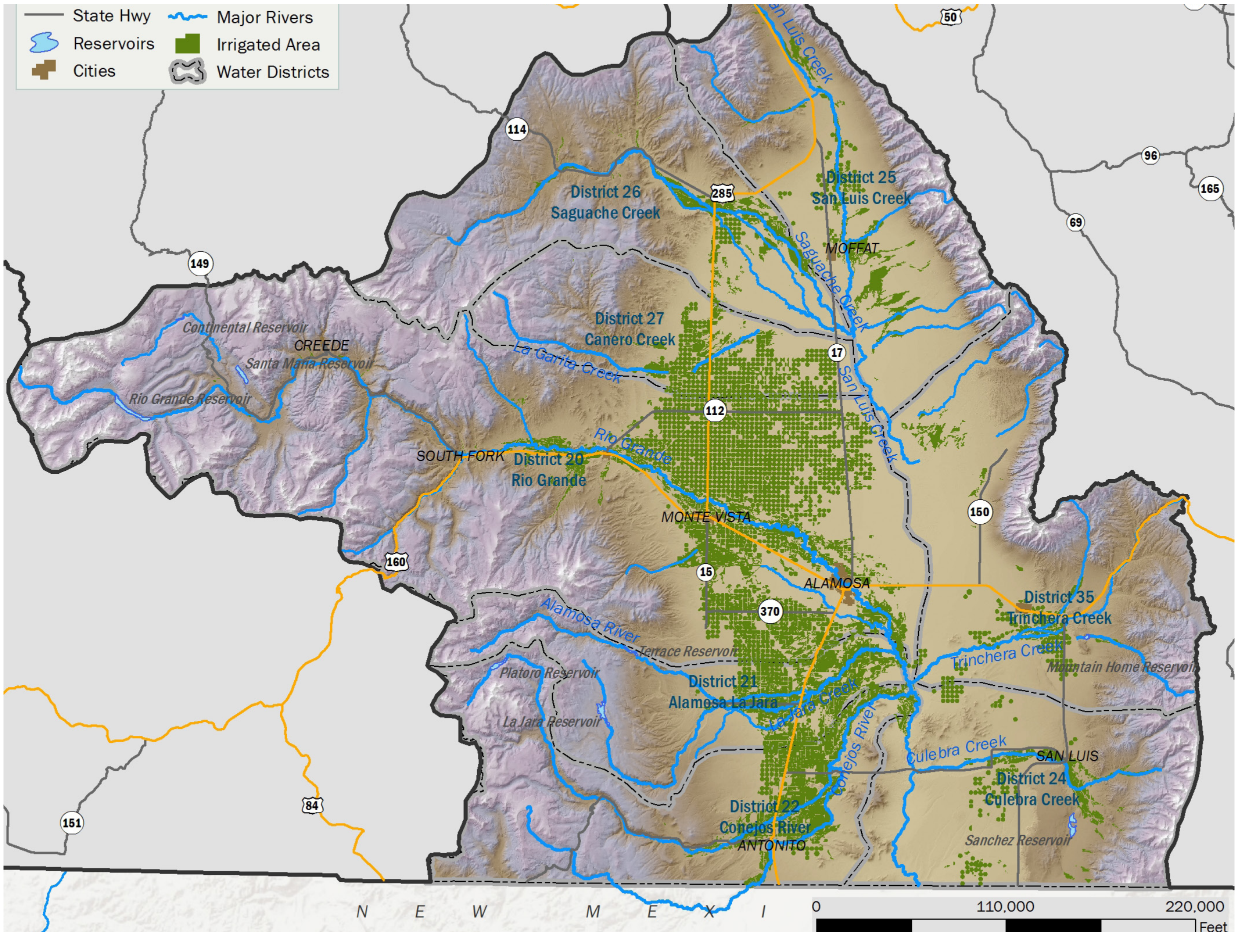


Figure 4.7.1 Map of the Rio Grande Basin

4.7.2 SUMMARY OF TECHNICAL UPDATE RESULTS

Key results and findings of the Technical Update pertaining to agricultural and M&I demands and gaps, as well as findings related to environmental and recreational attributes and future conditions, are summarized below in Table 4.7.2.

Table 4.7.2 Summary of Key Results in the Rio Grande Basin

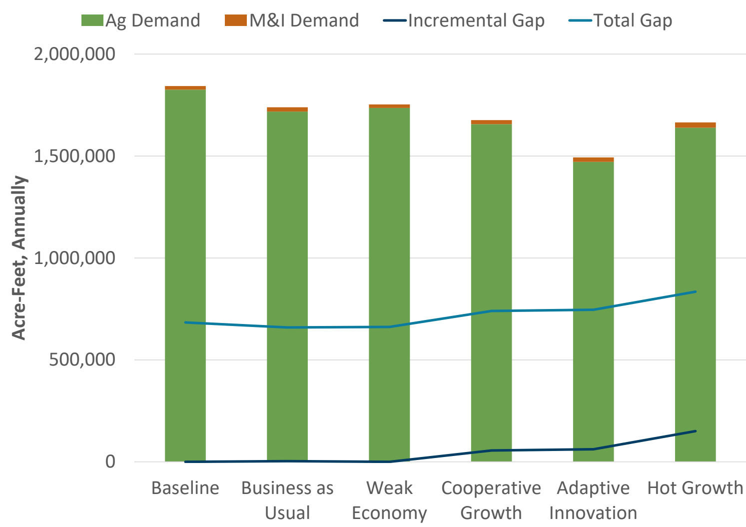
Agriculture	Environment and Recreation	Municipal and Industrial
• Future agricultural demand is lower than baseline, based on current and future acreage reductions due to groundwater administration and need to restore and sustain aquifer levels. • Agricultural demand in the scenarios is related to acreage reductions to offset climate-induced increases in IWR. Demand under Adaptive Innovation is lower than other scenarios, reflecting a higher system efficiency and reduction in IWR from emerging technologies. • As a percentage of demand, the gap is similar for Baseline, Business as Usual, and Weak Economy but larger larger for remaining scenarios despite lower demand.	• Flow magnitude in mountainous areas is not projected to significantly change under climate-impacted scenarios, but the annual hydrograph may shift with earlier snowmelt. Risks to riparian and fish habitat would remain low to moderate in most cases.Mid- and late-summer streamflow is projected to drop substantially in mountainous regions represented in the Flow Tool. Risk to cold water fish may remain moderate but increase in July and/or dry years.	• Both per capita use and total demand are significantly lower in the Technical Update baseline than in the SWSI 2010 baseline. • Aside from *Hot Growth*, outdoor demands are similar for all scenarios. This is due to the scenario pairing of water demand reductions and climate drivers.

Results describing current and potential future M&I and agricultural demands and gaps are summarized in Table 4.7.3 and in Figure 4.7.2.

Table 4.7.3 Summary of Diversion Demand and Gap Results in the Rio Grande Basin

	Current (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average Annual Demand						
Agricultural (AFY)	1,825,200	1,717,800	1,735,700	1,656,300	1,471,400	1,638,900
M&I (AFY)	17,700	21,100	17,700	20,100	21,700	25,800
Gaps						
Ag (avg %)	37%	38%	38%	45%	50%	50%
Ag (incremental-AFY)	-	-	-	53,500	58,000	142,500
Ag (incremental gap as % of current demand)	-	-	-	3%	3%	8%
M&I (max %)	-	16%	0%	12%	18%	31%
M&I (max-AF)	0	3,400	0	2,400	4,000	8,100

Figure 4.7.2 Summary of Diversion Demand and Gap Results in the Rio Grande Basin



Summary of Environmental and Recreational Findings

- A surface water allocation model was not available in the Rio Grande Basin, so the available flow dataset only includes natural flows and natural flows as impacted by climate drivers in mountainous areas; no management drivers are factored in.
  - » Management drivers impact river flows in areas downstream of mountainous areas in the Rio Grande and Conejos basins. Because a water allocation model that incorporates management is not available, no data-based insights into flow change and risk to non-consumptive attributes could be developed.
- In general, overall peak flow magnitude is not projected to change substantially under climate-impacted scenarios, but the peak may shift to earlier in the year (April/May streamflow magnitude may increase and June streamflow magnitude may decrease). Subsequent risk for riparian/wetland and fish habitat may remain low or moderate in most cases, although there are some indications that risk could increase in smaller streams.
- Mid- and late-summer streamflow is projected to drop substantially in all locations, with July streamflow decreasing 40 to 60 percent on the Rio Grande and tributaries and up to 70 percent on the Conejos River under the “In-Between” and “Hot and Dry” climate projections. Risk to cold water fish due to decreasing streamflow may remain moderate in most years but could be higher in July and/or during dry years.

4.7.3 NOTABLE BASIN CONSIDERATIONS

Section 4.1 described several analysis assumptions and limitations that apply to all basins and should be considered when reviewing and interpreting analysis results. Additional considerations specific to the Rio Grande Basin are listed below:

- The analysis assumed that there is no available water for meeting new uses. As a result, additional future M&I demands contribute directly to gaps.
- Basin stakeholders have cautioned that large reductions in irrigated land could result in socio-economic impacts that cause a reduction of municipal population.
- Stakeholder input was the basis of projected decreases in irrigated land due to groundwater sustainability and climate change.
- The Rio Grande Basin average baseline per capita systemwide demand has decreased significantly from 314 gpcd in SWSI 2010 to approximately 207 gpcd. The BIP was the primary source of water demand data.
- Aquifer sustainability will be a primary focus of future water management strategies and activities in this basin.
- The analysis did not consider specific different types of crops that may be grown in the future under the different scenarios; however, it accounted for future changes in crop types in a general sense in *Adaptive Innovation* and assumed that future crops would have 10 percent lower IWR. This is in line with the Rio Grande BIP recommendation to explore opportunities to reduce pumping through alternative cropping rather than drying up productive farm ground.

4.7.4 AGRICULTURAL DIVERSION DEMANDS

Agricultural Setting

Irrigated acreage in the Rio Grande Basin, particularly in the San Luis Valley, is inherently tied to the basin's unique surface and groundwater supplies. Surface water supplies diverted from streams fed by snowmelt are highly variable from year to year, with annual runoff in high flow years yielding up to eight times[11] more than in drought years. Groundwater from the upper unconfined aquifer and the deeper confined aquifer provides a more consistent irrigation supply. Although recharge to the unconfined aquifer occurs relatively quickly, decades of withdrawals greater than recharge have severely depleted it. Although the deeper confined aquifer supplies fewer wells than the unconfined aquifer due to its depth, it also experiences withdrawals that exceed recharge. Daily administration of the Rio Grande Compact, which primarily restricts surface water diversions through curtailment to meet compact deliveries, further impacts water availability in the basin. Surface and groundwater supplies combined support the irrigation of approximately 515,000 acres in the basin, predominantly in potatoes, grass, alfalfa, and small grains; however, the future of agriculture in the basin is threatened by more frequent periods of drought and declining aquifer levels.

Spurred by the drought in the early 2000s, declining levels of the unconfined aquifer in the Closed Basin, reduced confined aquifer pressure valleywide, and passage of Senate Bill 04-222 mandating the promulgation of groundwater rules and regulations by the Division of Water Resources (DWR), the Rio Grande Water Conservation District (RGWCD) created the first Special Improvement District of the Rio RGWCD (Subdistrict No. 1). Subdistrict No. 1 operates to replace injurious stream depletions caused by the subdistrict wells, recover aquifer levels, and maintain a sustainable irrigation water supply in the unconfined aquifer. The impacts to streams covered by the subdistricts are derived from a basin-wide groundwater model, developed through the Rio Grande Decision Support System (RGDSS).[12]

Subdistrict No. 1 began operations in 2012 and includes approximately 174,000 irrigated acres in the Closed Basin area. Subdistrict No. 2 covering the Rio Grande Alluvium and Subdistrict No. 3 covering the Conejos area began operating in 2019. Subdistricts No. 4, No. 5 and No. 6 covering the San Luis Creek, Saguache, and Alamosa/La-Jara Creek areas, respectively, are under development.

Due to the large amount of acreage in the subdistrict areas, management of these subdistricts will likely shape how irrigated agriculture will look by 2050.

Planning Scenario Adjustments

Section 2 described ways in which inputs to estimates of agricultural diversion demands were adjusted to reflect the future conditions described in the planning scenarios. Adjustments in the Rio Grande Basin focused on urbanization, groundwater sustainability, potential future climate conditions, and implementation of emerging technologies.

Population projections for the basin indicate that under all scenarios except *Weak Economy*, the basin's population will increase modestly and municipal water demands will grow. Irrigated acreage surrounding small towns in the basin is vulnerable to urbanization. For all scenarios other than *Weak Economy*, approximately 4,010 acres were estimated to come out of production due to urbanization of irrigated lands in the basin.

Much more significant are reductions in irrigated acreage to reach water use levels that the aquifers can sustainably support. In total, 40,000 irrigated acres were removed from the Subdistrict No.1 area, and 5,000 irrigated acres were removed across the basin in all planning scenarios.

IWR in the Rio Grande Basin is projected to increase on average by 15 percent under the *In-Between* climate projection and 18 percent on average under the "Hot and Dry" climate projection. Faced with this information, stakeholders in the basin discussed what the ultimate effects on the basin may be if IWR increases to these levels, particularly in light of the Rio Grande Compact. The group decided that as the compact will continue to limit surface water availability, any increase in IWR would likely lead to irrigated acreage being taken out of production because there would not be sufficient surface water supplies to meet these increased demands.

To account for this future potential outcome, it was assumed that the percent increase in IWR by Water District would result in the same percent decrease in irrigated acreage. With basinwide unit IWR historically averaging 2 AF per year and crop consumptive use in the basin historically averaging 1.3 AF per year, this is potentially an underestimate of the total acreage that may come out of production under potential future climate conditions. This approach, however, resulted in the removal of approximately 70,000 acres in *Cooperative Growth* and approximately 81,000 acres in *Adaptive Innovation* and *Hot Growth* across the basin. Note that IWR is reduced by 10 percent in *Adaptive Innovation* to account for technological innovations that may mitigate the increased IWR due to climate adjustments.

Table 4.7.4 summarizes the planning scenario adjustments described above and other adjustments that impact agricultural diversion demands in the various scenarios.

Table 4.7.4 Planning Scenario Adjustments for Agricultural Demands in the Rio Grande Basin

Adjustment Factor*	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Change in Irrigated Land due to Urbanization	4,010 Acre Reduction	-	4,010 Acre Reduction	4,010 Acre Reduction	4,010 Acre Reduction
Change in Irrigated Land for Groundwater Sustainability	45,000 Acre Reduction	45,000 Acre Reduction	45,000 Acre Reduction	45,000 Acre Reduction	45,000 Acre Reduction
IWR Climate Factor	-	-	15% 70,000 Acre Reduction	18% 81,000 Acre Reduction	18% 81,000 Acre Reduction
Emerging Technologies	-	-	-	10% IWR Reduction	-

**See section 2.2.3 for descriptions of adjustment methodologies and assumptions*

Agricultural Diversion Demand Results

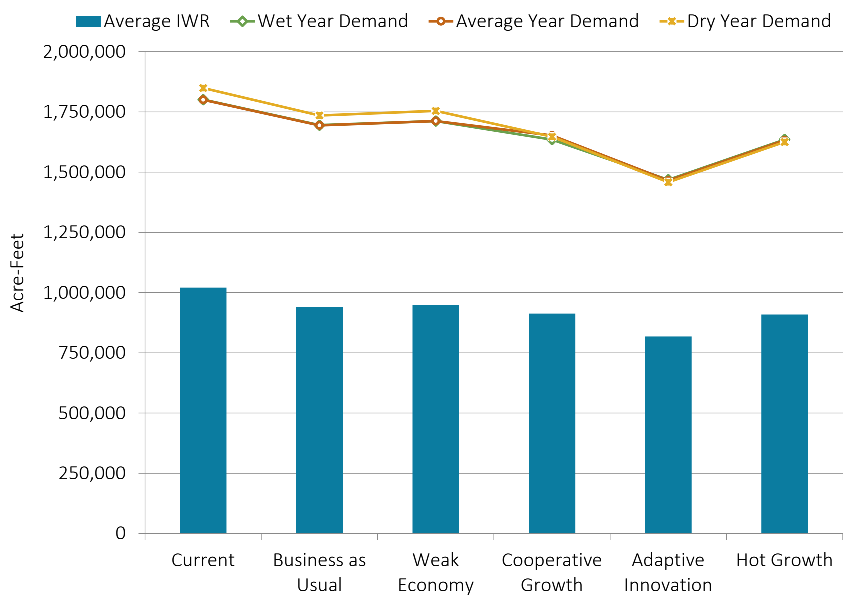
Table 4.7.5 and Figure 4.7.3 summarize the acreage, IWR, and the agricultural diversion demand for surface water supplies in the Rio Grande Basin for current conditions and the five planning scenarios. All scenario demands are lower than Baseline, because of irrigated acreage reduction to better manage the aquifer. Demand in climate impacted scenarios (*Cooperative Growth*, *Adaptive Innovation* and *Hot Growth*) is no higher than in *Business as Usual* and *Weak Economy* because compensating reductions in irrigated acreage are assumed to be implemented.

Table 4.7.5 Summary of Agricultural Diversion Demand Results in the Rio Grande Basin

	Current (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Irrigated Acreage (acres)	515,300	466,300	470,300	396,500	385,200	385,200
Average IWR (AFY)	1,021,000	940,000	949,000	913,000	818,000	909,000
Total Surface and Groundwater Diversion Demand						
Average Year (AFY)	1,800,000	1,694,000	1,712,000	1,652,000	1,465,000	1,632,000
Wet Yr. Change	0%	0%	0%	-1%	0%	0%
Dry Yr Change	3%	2%	3%	0%	-1%	0%

Average agricultural diversion demand was calculated using the average hydrologic years (i.e. years classified as neither wet or dry) from 1950-2013

Figure 4.7.3 Agricultural Diversion Demands and IWR Results in the Rio Grande Basin



4.7.5 Municipal and Self-Supplied Industrial Diversion Demands

Population Projections

The Rio Grande Basin currently includes less than 1 percent of the statewide population. Between the years 2015 and 2050, it is projected to change from approximately 46,000 people to between 42,000 and 67,000 people in the low and high growth projections, respectively. This ranges from an 8 percent decrease in population to an increase of 46 percent. Table 4.7.6 shows how population growth is projected to vary across planning scenarios.

Table 4.7.6 Rio Grande Basin 2015 and Projected Populations

Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
46,000	55,100	42,300	52,100	63,000	67,300

Current Municipal Demands

Approximately 79 percent of the baseline municipal demands were derived from BIP data, which represents the highest reliance on BIP data for any basin in the state. Data from WEPs represent demands for another 9 percent of the population, requiring about 12 percent of the basin's baseline population demands to be estimated (see Figure 4.7.4).

The BIP data did not include breakdowns of water use by demand category. Because there was insufficient demand category data available to apply county-specific distributions, the statewide weighted average demand category distribution was used for the Rio Grande Basin, as shown on Figure 4.7.5.

Figure 4.7.4 Sources of Water Demand Data in the Rio Grande Basin

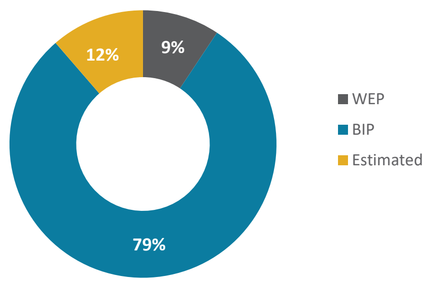
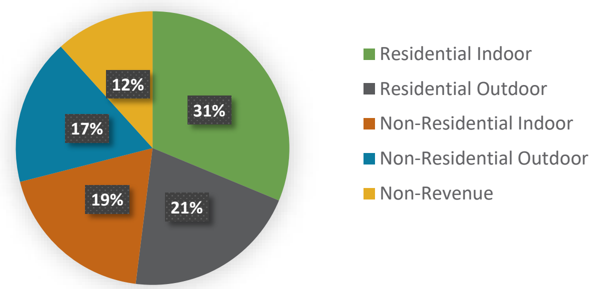


Figure 4.7.5 Categories of Municipal Water Usage in the Rio Grande Basin



Projected Municipal Demands

Figure 4.7.6 provides a summary of per capita baseline and projected water demands for the Rio Grande Basin. Systemwide, projected per capita demands decrease relative to the baseline except for *Hot Growth*. Residential indoor demand is generally the greatest demand. Outdoor demands increased significantly for *Hot Growth*, due to a general increase in outdoor demands coupled with the "Hot and Dry" climate.

The Rio Grande Basin municipal baseline and projected diversion demands provided in Table 4.7.7 show the combined effect of population and per capita demands. Municipal demands are projected to change from approximately 11,000 AFY in 2015 to between 9,000 and 16,000 AFY in 2050. Alamosa County accounts for around one-third of the baseline demand, followed by Conejos and Rio Grande counties, each at about one-quarter of the basin demand.

Figure 4.7.6 Rio Grande Basin Municipal Baseline and Projected Per Capita Demands by Water Demand Category (pgcd)

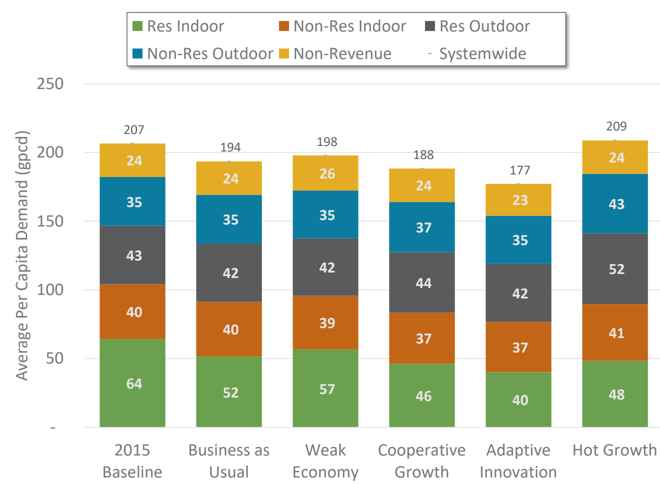
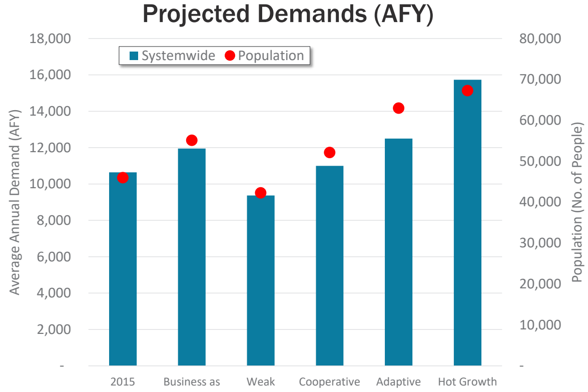


Table 4.7.7 Rio Grande Basin Municipal Baseline and Projected Demands (AFY)

Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
10,600	11,900	9,400	11,000	12,500	15,700

Figure 4.7.7 Rio Grande Basin Municipal Baseline and Projected Demands (AFY)



The baseline and projected demand distributions are shown in Figure 4.7.7, which also shows how the population varies across scenarios. All of the projection scenarios except for the *Weak Economy* result in an increase in systemwide demand relative to the baseline.

DECREASING GPCD

The Rio Grande Basin average baseline per capita systemwide demand decreased from 314 gpcd in SWSI 2010 to approximately 207 gpcd.

Self-Supplied Industrial Demands

The Rio Grande Basin includes about 4 percent of the statewide SSI diversion demand. SSI demands in this basin are associated with Large Industry (fish and aquaculture, agricultural product processing) and Energy Development (solar power generation and future oil and gas development), with no demands projected for the thermoelectric sub-sector. A minor amount of snowmaking occurs in the basin, but the required amount of water is insignificant compared to other SSI demands, and it was not considered in the demand analysis. Basin-scale SSI demands are shown in Figure 4.7.8 and tabulated in Table 4.7.8.

Figure 4.7.8 Rio Grande Basin SSI Baseline and Projected Demands (AFY)

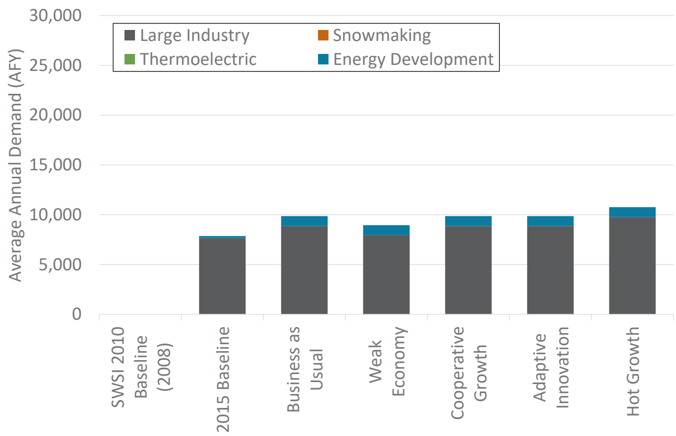


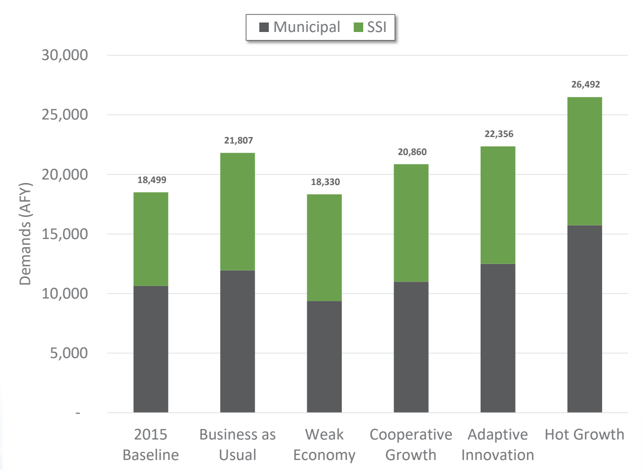
Table 4.7.8 Rio Grande Basin SSI Baseline and Projected Demands (AFY)

Sub-sector	Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Large Industry	7,660	8,860	7,960	8,860	8,860	9,760
Snowmaking	0	0	0	0	0	0
Thermoelectric	0	0	0	0	0	0
Energy Development	200	1,000	1,000	1,000	1,000	1,000
Sub-Basin Total	7,860	9,860	8,960	9,860	9,860	10,760

Total M&I Diversion Demands

Rio Grande Basin combined M&I demand projections for 2050 range from approximately 18,000 AFY in *Weak Economy* to 26,000 AFY in *Hot Growth*, as shown in Figure 4.7.9. SSI demands account for about 40 to 50 percent of the M&I demands. On a basin scale, the demand projections follow the statewide sequence of the scenario rankings described in the CWP.

Figure 4.7.9 Rio Grande Basin Municipal and Self-Supplied Industrial Demands



4.7.6 Water Supply Gaps

The agricultural and M&I diversion demands were compared against available water supply for current conditions and the five planning scenarios.

Agricultural

Because the Rio Grande Compact limits agricultural water use and because the system is over appropriated, current water supply was assumed to be equal to historical diversions and pumping, with no additional supply available. The current agricultural gap was estimated as the difference between the current agricultural diversion demand and historical diversions and pumping for wet, dry, and average years.

INCREMENTAL GAP

The incremental agricultural gap quantifies the degree to which the gap could increase beyond what agriculture has historically experienced under water shortage conditions.

The Rio Grande Basin agricultural diversion demands, demand gaps, and consumptive use gaps for the baseline and planning scenarios are presented in Table 4.7.9 and illustrated in Figure 4.7.10. An annual time series of gaps in terms of percent of demand that was unmet is shown in Figure 4.7.11.

Table 4.7.9 Rio Grande Basin Agricultural Gap Results (AFY)

		Scenario					
		Scenario	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand	1,825,200	1,717,800	1,735,700	1,656,300	1,471,400	1,638,900
	Average Annual Gap	683,900	655,800	661,500	737,400	741,900	826,400
	Average Annual Gap Increase from Baseline	-	-	-	53,500	58,000	142,500
	Average Annual Percent Gap	37%	38%	38%	45%	50%	50%
	Average Annual CU Gap	348,300	333,400	336,300	374,600	376,900	419,800
Maximum	Demand in Maximum Gap Year	2,058,800	1,935,400	1,956,200	1,814,100	1,605,700	1,789,700
	Gap in Maximum Gap Year	1,059,702	1,017,391	1,026,351	1,112,661	1,110,956	1,238,485
	Increase from Baseline Gap	-	-	-	52,959	51,254	178,783
	Percent Gap in Maximum Gap Year	51%	53%	52%	61%	69%	69%

Study period for Water Supply Analysis is 1975-2013, reflecting different baseline demand than described in Agricultural Diversion Demands section

Figure 4.7.10 Projected Average Annual Agricultural Diversion Demand, Demand Met, and Gaps in the Rio Grande Basin

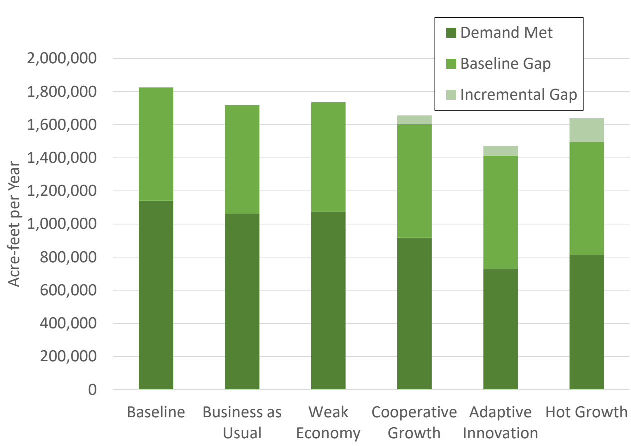
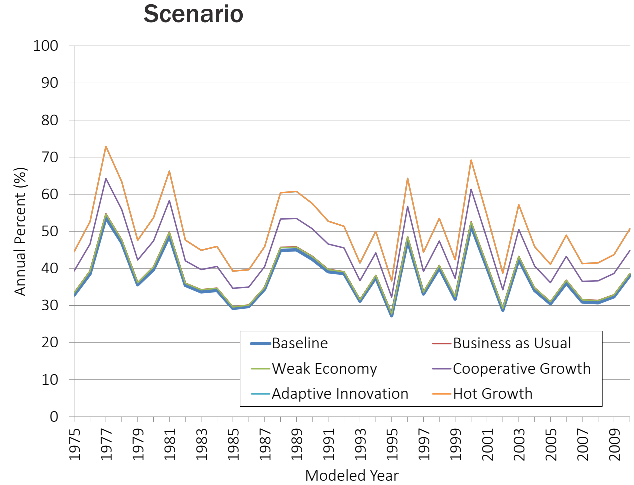


Figure 4.7.11 Annual Agricultural Gaps (expressed as a percentage of demand) for Each Planning Scenario



The following are observations on agricultural diversion demands and gaps:

- *Business as Usual* and *Weak Economy* do not include climate-adjusted hydrology or demands; therefore, changes in these scenarios relative to baseline are related strictly to changes in irrigated acreage and their impact on diversion demands.
- The inclusion of climate-adjusted hydrology and demands in *Cooperative Growth*, *Adaptive Innovation* and *Hot Growth* complicates the analyses for these scenarios. The analysis looked at the projected water supply under different year types available to senior and junior water rights in the basin and identified water rights that may no longer have constant supplies under the projected hydrology.
- Agricultural diversion demand is a major factor in this basin, with M&I demand only 1 to 1.5 percent of agricultural demand.
- Although agricultural diversion demand is expected to fall, gaps in excess of 650,000 AFY persist regardless of the planning scenario. Between 38 and 50 percent of agricultural demand is projected to be unmet in the planning scenarios.
- Despite reduced demand, the size of the gap is projected to increase relative to baseline in the three scenarios that are climate-impacted, because the available supply is forecast to be reduced.

M&I

The M&I gap for each scenario was estimated as the difference between the projected diversion demands and the current levels of municipal diversions and pumping. The diversion demand and gap results for M&I uses in the Rio Grande Basin are summarized in Table 4.7.10 and illustrated in Figure 4.7.12. Time series of M&I gaps were not developed in the Rio Grande Basin, because a CDSS water allocation model is not available at this time.

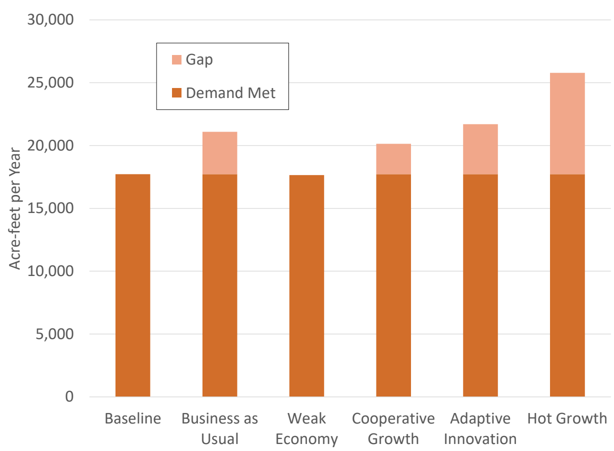
Table 4.7.10 Rio Grande Basin M&I Gap Results (AFY)

		Scenario					
		Scenario	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand	17,700	21,100	17,700	20,100	21,700	25,800
	Average Annual Gap	-	3,400	-	2,400	4,000	8,100
	Average Annual Percent Gap	-	16%	-	12%	18%	31%
Maximum	Demand in Maximum Gap Year	17,700	21,100	17,700	20,100	21,700	25,800
	Gap in Maximum Gap Year	-	3,400	-	2,400	4,000	8,100
	Percent Gap in Maximum Gap Year	-	16%	-	12%	18%	31%

The following are observations on the M&I diversion demands and gaps:

- Average annual M&I gap in the Rio Grande Basin ranges from 0 AF to more than 8,100 AF.
- Municipal diversion demand and SSI diversion demand contribute nearly evenly to total M&I diversion demand, with municipal accounting for just a little more than half. This is unique among Colorado's river basins.
- Population growth is the main driver for the modest increases in M&I demands in the planning scenarios, as per capita water use decreased for every scenario except *Hot Growth*.
- For *Hot Growth*, the M&I gap is much larger than other scenarios, at 31 percent of demand.

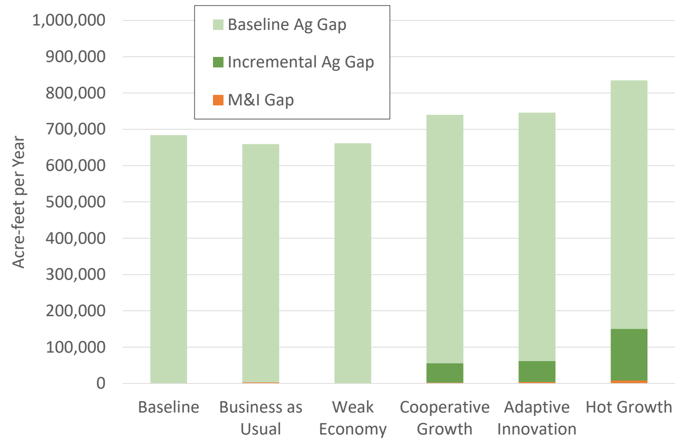
Figure 4.7.12 Projected Maximum Annual M&I Demand Met and Gaps in the Rio Grande Basin



Total Gap

Figure 4.7.13 illustrates the total combined agricultural and M&I diversion demand gap in the Rio Grande Basin. The figure combines the average annual baseline and incremental agricultural gap and the maximum M&I gap. In *Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth*, gaps were driven by agricultural demands, which increase in the "Hot and Dry" climate conditions.

Figure 4.7.13 Projected Average Annual Agricultural Gaps and Maximum M&I Diversion Demand Gaps in the Rio Grande Basin



Supplies from Urbanized Lands

By 2050, irrigated acreage in the Rio Grande Basin is projected to decrease by 4,000 acres due to urbanization. Irrigation supplies for these lands could potentially be used for M&I needs in the future (subject to a variety of unknowns such as seniority and type of water supply, willingness to change the use of water through water court, etc.). The average annual historical consumptive use associated with potentially urbanized acreage for each scenario is reflected in Table 4.7.11. The data in the table represent planning-level estimates of this potential supply and has not been applied to the M&I gaps.

Table 4.7.11 Estimated Consumptive Use from Lands Projected to be Urbanized by 2050 in the Rio Grande Basin

	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Urbanized Acreage (acres)	4,000	-	4,000	4,000	4,000
Estimated Consumptive Use (AFY)	5,300	-	5,400	4,600	5,100

4.7.7 Available Supply

For the purposes of the Technical Update, it was assumed that due to compact constraints, there are no available water supplies now or in the future that can meet new demands.

4.7.8 Environment and Recreation

A surface water allocation model is not currently available in the Rio Grande Basin. As a result, hydrologic datasets in the Flow Tool include only naturalized flows and naturalized flows as impacted by climate change. A total of four water allocation model nodes, all in the mountains and foothills west of the San Luis Valley, were selected for the Flow Tool within the Rio Grande Basin (see list below and Figure 4.7.14). Figure 4.7.14 also shows subwatersheds (at the 12-digit HUC level) and the relative number of E&R attributes located in each subwatershed.

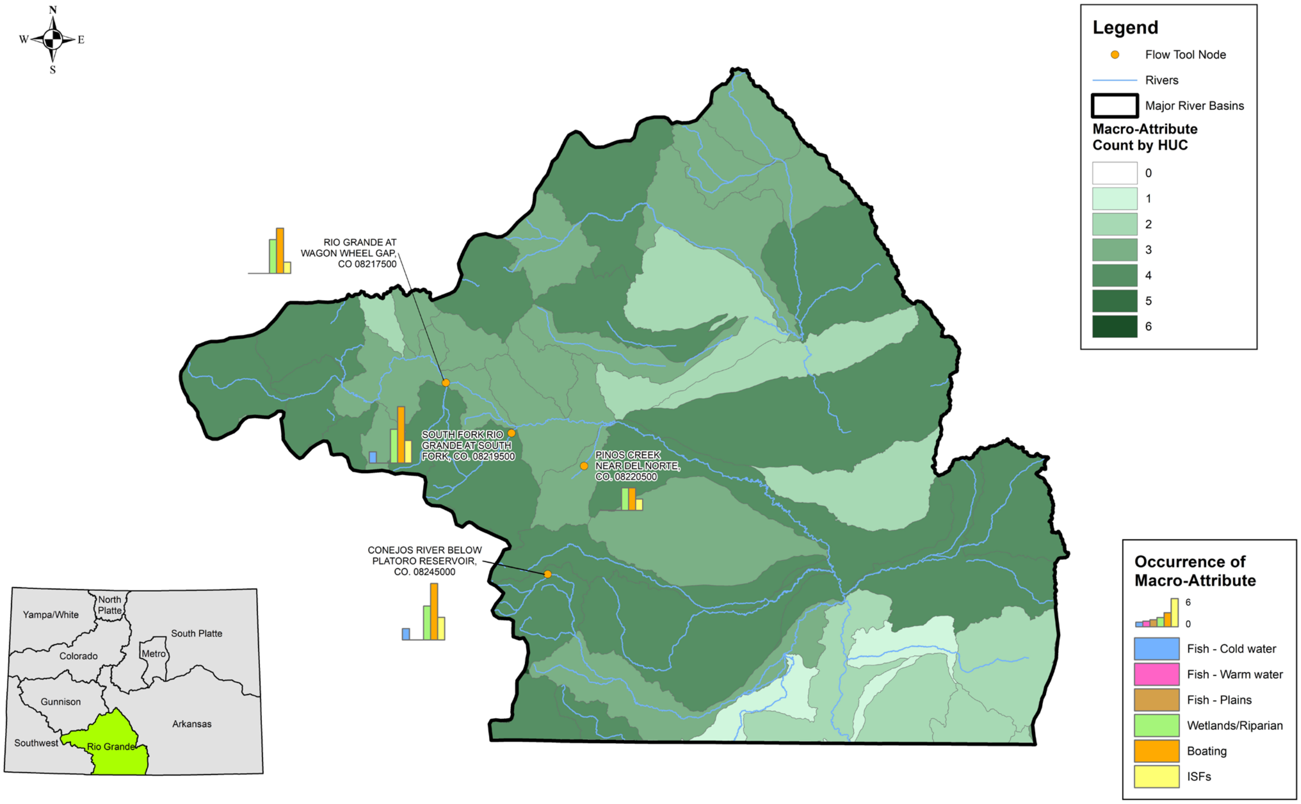
- Rio Grande at Wagon Wheel Gap, Colorado (08217500)
- South Fork Rio Grande at South Fork, Colorado (08219500)
- Pinos Creek near Del Norte, Colorado (08220500)
- Conejos River below Platoro Reservoir, Colorado (08245000)

These sites were selected because they are above major supply and demand drivers where future flow changes would likely be associated with only climate change factors. Management drivers impact river flows in areas downstream of mountainous areas in the Rio Grande and Conejos basins. Because a water allocation model that incorporates management is not available, the Flow Tool results for the Rio Grande Basin include only naturalized conditions and naturalized conditions as impacted by climate drivers ("In-Between" and "Hot and Dry" climate change projections) to illustrate a representative potential change in flow due to climate. These data do not represent changes in flow due to irrigation, transmountain imports, and/or storage.

NATURALIZED FLOW

Naturalized flows reflect conditions that would occur in the absence of human activities. Baseline flows reflect current conditions as influenced by existing infrastructure and river operations. While observations regarding naturalized flows may be informative, baseline flows reflect actual conditions and the diverse operations of a river's many users.

Figure 4.7.14 Flow Tool Nodes Selected in the Rio Grande Basin



Results and observations from Flow Tool analyses using flow data developed in the water supply and gap analyses for baseline conditions and the planning scenarios are described below in Table 4.7.11.

Table 4.7.12 Summary of Flow Tool Results in the Rio Grande Basin

Category	Observation
Projected Flows	For the selected locations, overall peak flow magnitude is not projected to change substantially under climate change projections; however, the timing of peak flow may shift to earlier in the year, with April and May flow magnitudes rising and June flows decreasing under the "In-Between" and "Hot and Dry" climate change projections.
	Mid- and late-summer flow may be reduced in all locations under the "In-Between" and "Hot and Dry" climate change projections, with July streamflow decreasing by roughly half on the Rio Grande and tributaries and even more on the Conejos River.
Ecological Risk	Peak flow related risk for riparian/wetland and fish habitat is projected to remain low or moderate in most cases, although there are some indications that risk could increase in smaller streams.
	Risk to trout due to decreasing mid- and late-summer streamflow may remain moderate in most years but could be higher in July and/or during dry years.
E&R Attributes	Because future flows under the five scenarios have not been modeled in the Rio Grande Basin, projected changes to flow and associated changes in risk to E&R attributes within the Flow Tool are attributable only to projected changes in climate. These climate-induced changes—earlier peak flow and reduced mid- and late-summer flows—are similar to the general pattern seen in many parts of Colorado.

The South Platte Basin is the most populous basin in the state. Approximately 85 percent of Colorado's population resides in the South Platte Basin, and the Front Range area of the basin is Colorado's economic and social engine. The basin also has the greatest concentration of irrigated agricultural lands in Colorado.

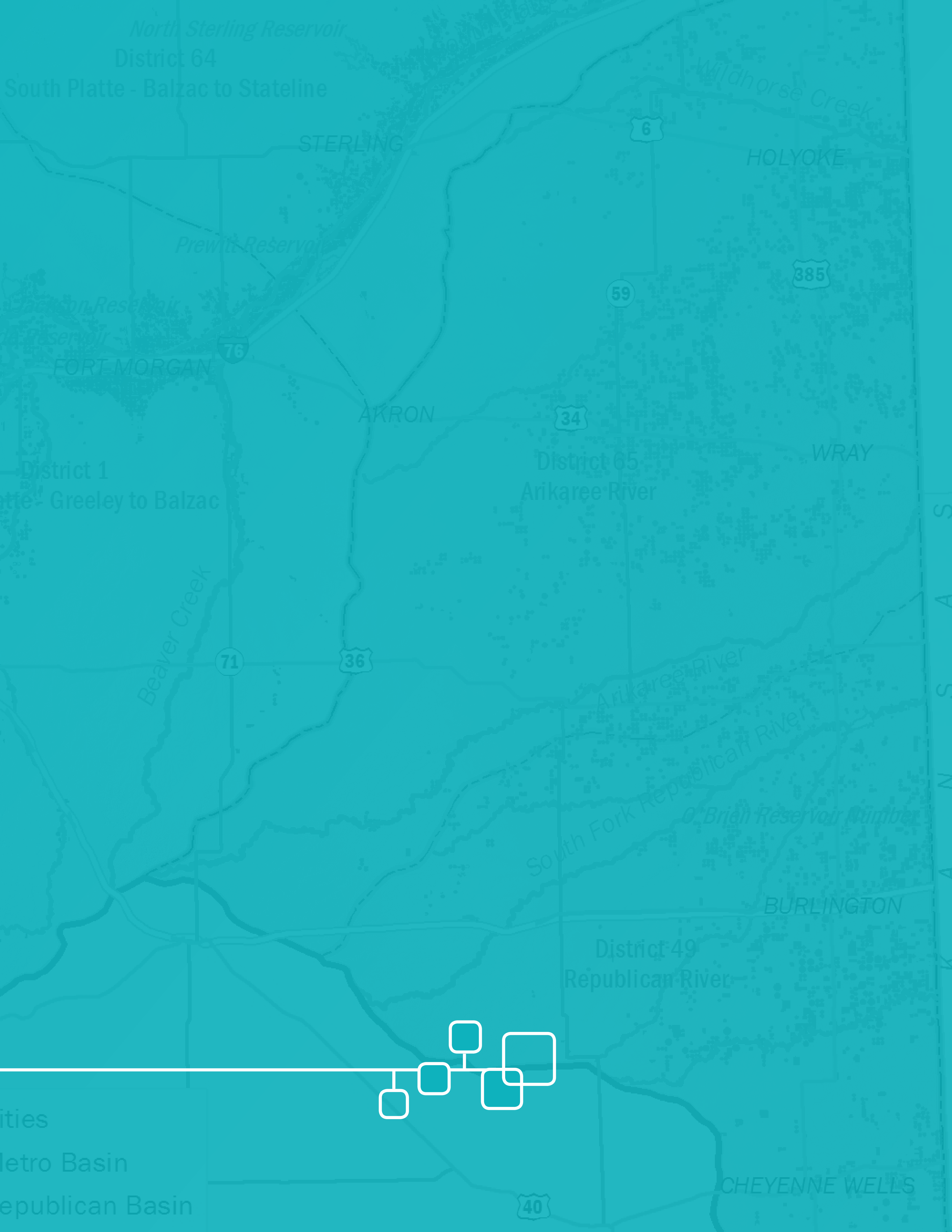
The topographic characteristics of the South Platte Basin are diverse. The western portions of the basin and its mountainous and subalpine areas are mostly forested, while the High Plains region is mainly grassland and planted or cultivated land.

The hydrology of the South Platte Basin is highly variable, with an approximate average annual native flow volume of 1.4 million AF About 400,000 AF of transmountain imports and 30,000 AF from nontributary groundwater aquifers supplement the water supply in the South Platte Basin. Yet, surface-water diversions in the South Platte Basin average about 4 million AF annually, with groundwater withdrawals totaling an additional annual 500,000 AF on average. The amount of diversion in excess of native flow highlights the return flow-dependent nature of the basin's hydrology, and the basinwide efficient use and reuse of water supplies.

The Republican Basin in Colorado is located on the Northeastern High Plains. Land uses in the basin are primarily agricultural. The topographic characteristics of the Republican Basin, which are similar to the High Plains region of the South Platte Basin, consist mainly of grassland and planted or cultivated land. The Republican Basin in Colorado is underlain by the High Plains or Ogallala aquifer, which is one of the largest aquifer systems in the United States, extending from South Dakota to Texas.

The Technical Update largely keeps the analysis at the basin scale. There are some exceptions where subbasin (river basin) analysis of major waterways was more straightforward. To that end, both the South Platte, Metro and Republican basins were explicitly analyzed where possible. Those results are shown in the following sections. In other sections, of this report where statewide analysis is shown, the entire South Platte Basin (with values from the South Platte, Metro and Republican combined) are shown.

SOUTH PLATTE / METRO


North Sterling Reservoir
District 64
South Platte - Balzac to Stateline
STERLING
Wildhorse Creek
6
HOLYOKE
Prewitt Reservoir
59
385
76
FORT MORGAN
AKRON
34
District 65
Arikaree River
WRAY
District 1
tte - Greeley to Balzac
Beaver Creek
71
36
Arikaree River
South Fork Republican River
O Brien Reservoir Number
BURLINGTON
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ities
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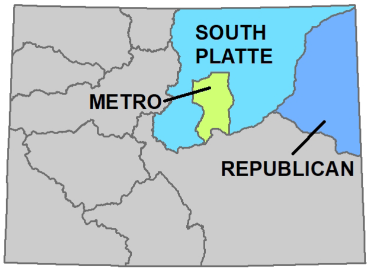
CHEYENNE WELLS
40

4.8 SOUTH PLATTE BASIN RESULTS



4.8.1 BASIN CHALLENGES

Key future water management issues in this basin will be focused on meeting future water supply demands for a variety of sectors while complying with interstate compacts and maintaining Coloradans' quality of life. These challenges are described in the Colorado Water Plan and are summarized below.

Table 4.8.1 Key Future Water Management Issues in the South Platte Basin

Agriculture	Environment and Recreation	Municipal and Industrial	Compacts and Administration
• Agriculture is the dominant water use in the basin, but agricultural water transfers are likely to have negative effects on rural communities and the environment. • Depletions to the Ogallala Aquifer and long-term impacts to water supplies are a concern to agricultural viability.	• Environmental and recreational features in the basin are important to Colorado's quality of life and tourism economy.	• Competition for additional M&I supplies is substantial and increases costs to customers. • Lack of new storage projects has led to reliance on non-renewable groundwater supplies in quickly-urbanizing areas of the South Metro region. • Value judgements regarding irrigated landscaping complicate discussions about water development.	• A significant amount of the South Platte Basin's supply originates in the Colorado Basin and is subject to compact compliance. • Aquifer storage, while promising, poses control and administrative issues. • Republican River Compact compliance. • Coordination among water authorities in the Republican Basin is a challenge.
• Water quality will continue to be a challenge for all segments of water use. • Increases in M&I water use efficiency is critical but will reduce the quantity of water available for agriculture and the environment.			

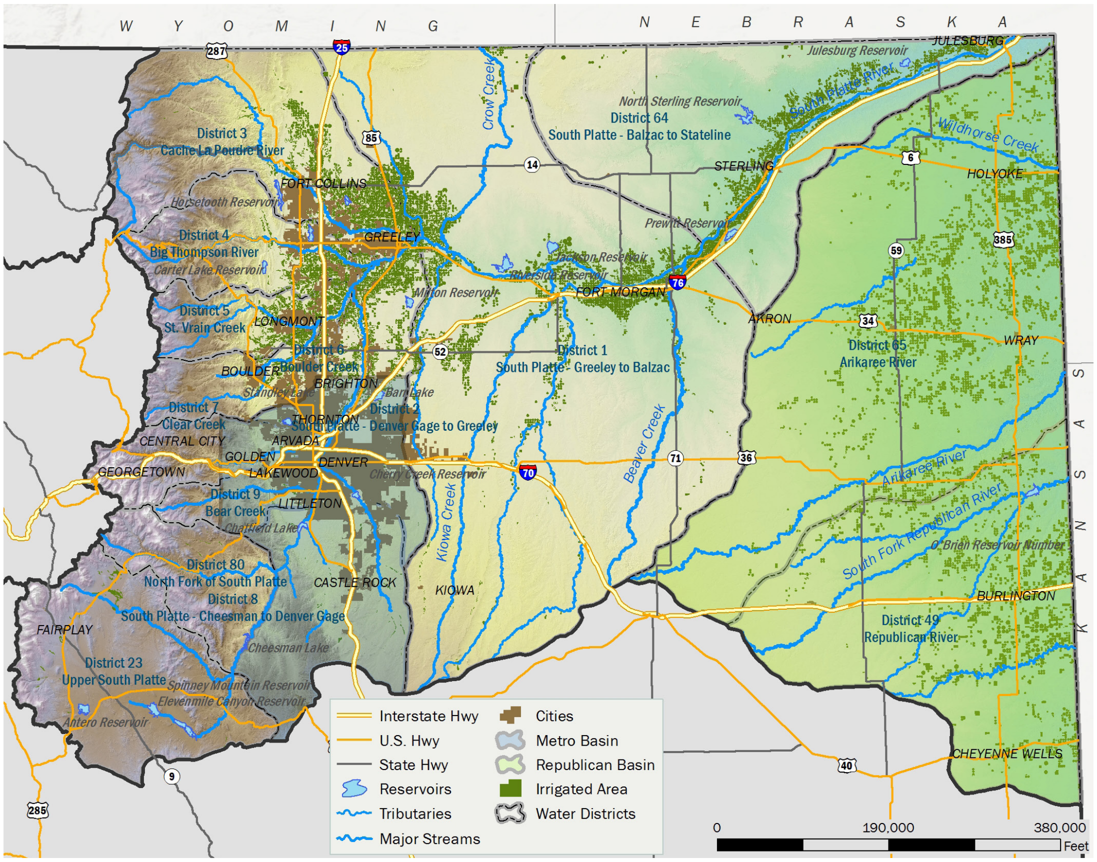


Figure 4.8.1 Map of the South Platte Basin

4.8.2 SUMMARY OF TECHNICAL UPDATE RESULTS

Key results and findings of the Technical Update pertaining to agricultural and M&I demands and gaps as well as findings related to environment and recreation attributes and future conditions are summarized below in Table 4.8.2.

Table 4.8.2 Summary of Key Results in the South Platte and Republican Basins

Agriculture	Environment and Recreation	Municipal and Industrial
• Future agricultural demands in the South Platte Basin are projected to decrease due to loss of irrigated lands from lack of groundwater sustainability. • Future agricultural demands in the South Platte Basin are projected to decrease due to loss of irrigated lands from urbanization and agricultural water transfers. • Agricultural gaps as a percentage of total demand in the South Platte Basin are not projected to greatly increase.	• In several locations in the mountains and foothills, climate-impacted scenarios show variable responses in peak flows. • On the plains, especially east of Interstate 25, flow conditions are projected to be poor for all aspects of ecosystem health. • In the mountains and foothills, climate-impacted scenarios show diminished mid- and late-summer flows.	• M&I demands in Adaptive Innovation are projected to be very similar to Business as Usual despite higher population and hotter/drier climate assumptions in Adaptive Innovation. This result demonstrates the value of higher levels of conservation. • Significant future gaps are estimated for each planning scenario, and they could be exacerbated by reductions in West Slope supplies.

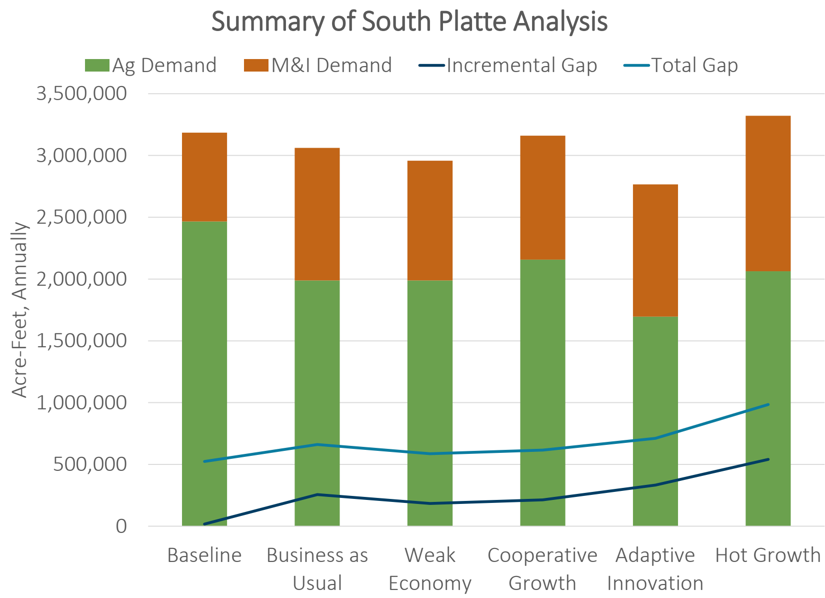
Results describing current and potential future M&I and agricultural demands and gaps are summarized in Table 4.8.3 and Figure 4.8.2.

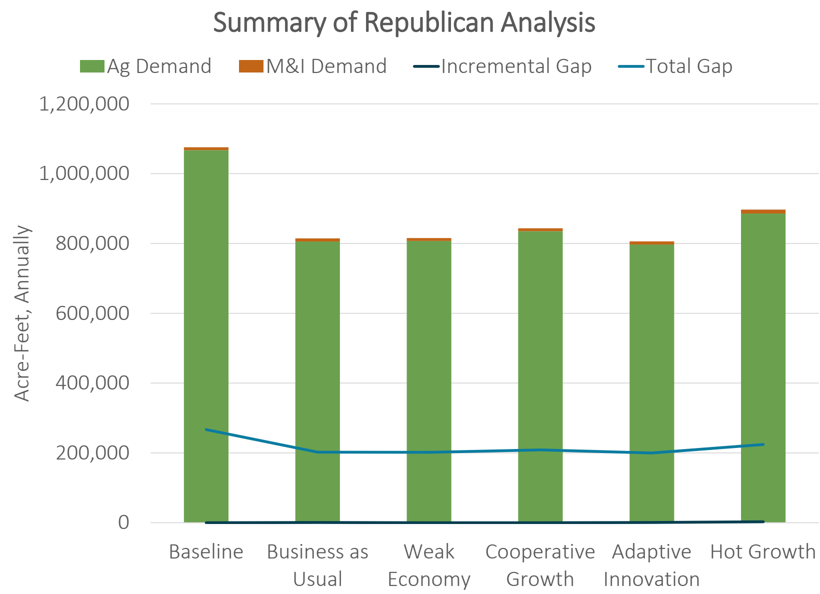
Table 4.8.3 Summary of Diversion Demand and Gap Results in the South Platte and Republican Basins

		Current (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
South Platte	**Average Annual Demand**						
	Agricultural (AFY)	2,465,800	1,988,700	1,988,700	2,157,400	1,696,500	2,063,100
	M&I (AFY)	718,700	1,073,000	968,900	1,002,800	1,070,100	1,257,700
	Gaps						
	Ag (avg %)	21%	20%	20%	19%	22%	22%
	Ag (incremental-AFY)	-	-	-	-	-	-
	Ag (incremental gap as % of current demand)	-	-	-	-	-	-
	M&I (max %)	0%	24%	19%	21%	31%	43%
	M&I (max-AF)	0*	256,300	184,500	213,300	333,200	540,700
Republican	**Average Annual Demand**						
	Agricultural (AFY)	1,067,200	805,500	807,500	835,300	797,200	885,800
	M&I (AFY)	8,400	9,200	7,900	8,100	8,900	11,200
	Gaps						
	Ag (avg %)	25%	25%	25%	25%	25%	25%
	Ag (incremental-AFY)	-	-	-	-	-	-
	Ag (incremental gap as % of current demand)	-	-	-	-	-	-
	M&I (max %)	0%	8%	0%	0%	6%	25%
	M&I (max-AF)	-	700	-	-	500	2,800
Total	**Average Annual Demand**						
	Agricultural (AFY)	3,533,000	2,794,200	2,796,100	2,992,700	2,493,700	2,948,900
	M&I (AFY)	727,100	1,082,200	976,800	1,010,900	1,079,100	1,268,900
	Gaps						
	Ag (avg %)	22%	22%	22%	20%	23%	23%
	Ag (incremental-AFY)	-	-	-	-	-	-
	Ag (incremental gap as % of current demand)	-	-	-	-	-	-
	M&I (max %)	0%	24%	19%	21%	31%	43%
	M&I (max-AF)	0*	257,100	184,500	213,300	333,700	543,500

**CDSS water allocation model in this basin calculates small baseline M&I gaps, but they are either due to calibration issues or they are reflective of infrequent, dry-year shortages that are typically managed with temporary demand reductions, such as watering restrictions.*

Figure 4.8.2 Summary of Diversion Demand and Gap Results in the South Platte and Republican Basins





Summary of Environment and Recreation Findings

- In several locations in the mountains and foothills, *Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth* project variable responses to peak flows, in some cases increasing peak flow (thus improving or maintaining risk to plants and fish habitat) and in other cases diminishing peak flows and increasing risk to riparian/wetlands and fish habitat to high or very high.
- In the mountains and foothills, *Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth* project diminished mid- and late-summer flows, increasing risk to fish. This risk may remain moderate; however, the metric used to assess risk for fish does not include the month of July because historically July flows are sufficient. Under *Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth*, July flows may drop substantially, increasing risk for fish.
- On the plains, especially east of Interstate 25, flow conditions are projected to be poor for all aspects of ecosystem health. Peak flows for riparian/wetlands are high risk under baseline conditions and are projected to remain so under all scenarios. Mid- and late-summer flows are very high risk for plains fishes and risk is projected to increase under all future scenarios.
- The recreational in-channel diversions may be met less often in the future.

4.8.3 NOTABLE BASIN CONSIDERATIONS

Section 4.1 described several analysis assumptions and limitations that apply to all basins and should be considered when reviewing and interpreting analysis results. Additional considerations specific to the South Platte Basin are listed below:

- Imports from transmountain diversion projects were set at historical levels and reflect historical operations. In climate-impacted scenarios, transmountain imports are projected to decrease, which could increase agricultural and M&I gaps. Gaps in the South Platte Basin would likely increase more than the reduction in transmountain imports because return flows from transmountain imports are used to extinction within the South Platte Basin by either the importing entity or by downstream agricultural and M&I water users.
- Stakeholders in the South Platte Basin suggested that purchase and transfer of senior irrigation water rights resulting in permanent reductions in irrigated acreage to municipal uses will continue through 2050 even though alternative water transfers have the potential to reduce reliance on transfers resulting in permanent dry up. Stakeholder estimates of acreage associated with these transfers were accounted for in the agricultural diversion demand and the modeling effort the same way urbanized lands were considered. Acreage purchased, transferred, and/or urbanized was quantified, but was not modeled as a future water supply strategy in this effort as it was unknown what municipal entity may benefit from resulting supply.
- Aquifer sustainability will be a primary focus of future water management strategies and activities in the Republican Basin.
- Due to on-going permitting efforts in the basin, the Cache La Poudre basin (Water District 3) was excluded from the CDSS surface water allocation model. Shortages to agriculture and M&I demands within the basin were informed by the results from nearby basins with similar characteristics (e.g. storage, C-BT supplies) to reflect the impact of climate adjustments on hydrology.
- No groundwater modeling was performed in either the South Platte or Republican basin. Groundwater pumping in the planning scenarios was estimated based on the premise that current groundwater pumping would either stay the same or be reduced in the future based on sustainability of groundwater supplies. Groundwater pumping was effectively reduced to account for sustainability concerns by removing acreage served by groundwater supplies.

4.8.4 AGRICULTURAL DIVERSION DEMANDS

Agricultural Setting

South Platte Basin

Approximately 854,000 acres are irrigated in the South Platte Basin. It is the highest producing basin in the state in terms of the value of agricultural products sold. Irrigated lands are located along and adjacent to the South Platte River and its tributaries and stretch to the state line.

Farmers divert surface water and pump groundwater. In many cases, both sources of supply are available to irrigate South Platte Basin farms. Much of the surface water supply in the basin is generated via return flows as an upstream irrigators' inefficiencies become the water supply for downstream irrigators.

The amount of irrigated land in the basin is anticipated to decrease in the future. Urbanization will impact irrigated lands in and around the basin's municipalities by 2050. The majority of urbanization of irrigated land (60 percent) is projected to occur in the St. Vrain River, Big Thompson River, and Cache La Poudre River basins. These basins have some of the highest concentrations of irrigated land adjacent to municipalities that are projected to increase in population. Although large population increases are also anticipated in and around the Denver Metropolitan area, the concentration of irrigated land that could be urbanized is less. Acquisition of senior water rights by "buy and dry" methods is also expected to reduce the amount of irrigated land in the basin.

Republican Basin

The Republican Basin has nearly 580,000 irrigated acres, making it one of the highest producing basins of irrigated crops in the state. The basin has very limited surface water supplies. As a result, irrigators rely on groundwater supplies from the High Plains Aquifer (also known as the Ogallala Aquifer). Approximately 10 percent of total pumping is subject to the Republican River Compact, with the remaining 90 percent pumped from "storage" in the High Plains Aquifer. Groundwater pumping is managed by several groundwater management districts in the basin.

The current amount of irrigated land in the basin is expected to decline in the future. Absent the development of an alternative means to reduce consumptive use, irrigated lands will need to be retired to maintain compliance with the Republican River Compact. In addition, declining saturated thickness in the High Plains Aquifer will also lead to the retirement of groundwater-irrigated lands.

Planning Scenario Adjustments

South Platte Basin

The South Platte Basin is expected to experience the largest municipal growth in the state by 2050, straining already limited water supplies and increasing competition among municipal, industrial, agricultural, environmental and recreation users in the basin. The planning scenarios contemplate various pressures that may affect basin agriculture and consider increased urbanization of irrigated lands, increased municipal conversions of agricultural water supplies, limited augmentation supplies, and higher irrigation demands due to a warmer climate.

Adjustments to agricultural diversion demands were made to reflect the above considerations. Stakeholder outreach was conducted to estimate the amount of irrigated land that could be lost from transfers of water from agriculture to municipal providers and the loss of groundwater-irrigated land due to insufficient augmentation supplies. In addition, the Agricultural Technical Advisory Group provided input on the level of future increases in irrigation efficiency and reductions in future IWR due to advances in agronomic technologies. Table 4.8.4 summarizes the adjustments that were made in each of the planning scenarios to reflect assumed future conditions in agriculture.

Republican Basin

The sustainability of groundwater supplies will be the primary source of future pressure to irrigated agriculture in the Republican Basin. As described previously, irrigated lands are likely going to be retired to comply with the Republican River Compact and also as a result of declining water levels in the High Plains Aquifer. Stakeholder outreach informed the assumptions that were used to reduce irrigated acreage under each of the planning scenarios. Table 4.8.4 summarizes the planning scenario adjustments used to reflect these conditions and other adjustments that impact agricultural diversion demands basin

Table 4.8.4 Planning Scenario Adjustments for Agricultural Demands in the South Platte and Republican Basins

Sub-basin	Adjustment Factor*	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
South Platte	Change in Irrigated Land due to Urbanization & Municipal Transfers	105,900 Acre Reduction	105,900 Acre Reduction 20% SW Acre Reduction (WD 1 & 64)	105,900 Acre Reduction 20% SW Acre Reduction (WD 1 & 64)	105,900 Acre Reduction 20% SW Acre Reduction (WD 1 & 64)	105,900 Acre Reduction 20% SW Acre Reduction (WD 1 & 64)
	Groundwater Acreage Sustainability	20% GW-Only Acre Reduction (Central)	20% GW-Only Acre Reduction (Central)	20% GW-Only Acre Reduction (Central)	20% GW-Only Acre Reduction (Central)	20% GW-Only Acre Reduction (Central)
	IWR Climate Factor	-	-	15%	24%	24%
	Emerging Technologies	85% GW Only Acreage in Sprinkler	85% GW Only Acreage in Sprinkler	90% GW Only Acreage in Sprinkler	90% GW Only Acreage in Sprinkler 10% IWR Reduction 10% System Efficiency Increase	90% GW Only Acreage in Sprinkler
Republican	Change in Irrigated Land due to Urbanization	1,410 Acre Reduction	-	1,410 Acre Reduction	1,410 Acre Reduction	1,410 Acre Reduction
	Groundwater Acreage Sustainability	135,420 Acre Reduction	135,420 Acre Reduction	135,420 Acre Reduction	135,420 Acre Reduction	135,420 Acre Reduction
	IWR Climate Factor	-	-	4%	11%	11%
	Emerging Technologies	-	-	-	10% IWR Reduction	-

**See section 2.2.3 for descriptions of adjustment methodologies and assumptions*

Agricultural Diversion Demand Results

Table 4.8.5 and Figures 4.8.3 and 4.8.4 summarize the acreage, IWR, and agricultural diversion demand in both the South Platte and Republican basins for current conditions and the five planning scenarios. Note that in the South Platte Basin, surface water and groundwater sources are used for irrigation, and a breakout of diversion demand for these sources is included in the technical memorandum *Current and Projected Planning Scenario Agricultural Diversion Demands* (see Volume 2). All agricultural diversion demands in the Republican Basin were from groundwater sources.

SYSTEM EFFICIENCY

In some cases, diversion demands surface water can be higher in wet years because system efficiency decreases due to the relative abundance of supply.

Future agricultural diversion demands in both the South Platte and Republican Basins are anticipated to be lower in the future due primarily to the loss of irrigated land. While assumptions of a warmer climate increase IWR in *Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth*, the loss of irrigated land may offset the additional IWR demand, resulting in lower future demands. Projected increases in IWR due to a warmer climate are the same in *Adaptive Innovation* and *Hot Growth*, but the agricultural diversion demand is lower in *Adaptive Innovation* due to the assumed 10 percent reduction in IWR from emerging technologies and a 10 percent increase in system efficiency. Agricultural diversion demands in the South Platte are relatively consistent in wet, average, and dry years due to surface water irrigation system efficiencies that fluctuate in differing hydrologic conditions. Republican Basin irrigation is provided from groundwater, and system efficiencies of wells do not fluctuate. As a result, agricultural diversion demands in the Republican Basin change to a greater degree in response to hydrologic conditions.

Table 4.8.5 Summary of Agricultural Diversion Demand Results in the South Platte and Republican Basins

		Current	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
South Platte	Irrigated Acreage (acres)	854,300	701,100	701,100	722,400	722,400	679,900
	Average IWR (AFY)	1,500,000	1,225,000	1,225,000	1,341,000	1,264,000	1,323,000
	Total Surface Water and Groundwater Diversion Demand						
	Average Year (AFY)	2,589,000	2,081,000	2,081,000	2,268,000	1,771,000	2,202,000
	Wet Yr. Change	-6%	-6%	-6%	-4%	-4%	-4%
	Dry Yr Change	2%	2%	2%	1%	2%	-1%
Republican	Irrigated Acreage (acres)	578,800	442,000	443,400	442,000	442,000	442,000
	Average IWR (AFY)	837,000	635,000	636,000	661,000	649,000	721,000
	Groundwater Diversion Demand						
	Average Year (AFY)	1,056,000	800,000	802,000	833,000	799,000	888,000
	Wet Yr. Change	-14%	-15%	-15%	-14%	-13%	-13%
	Dry Yr Change	20%	21%	21%	18%	14%	14%

Figure 4.8.3 Agricultural Diversion Demands and IWR Results in the South Platte Basin

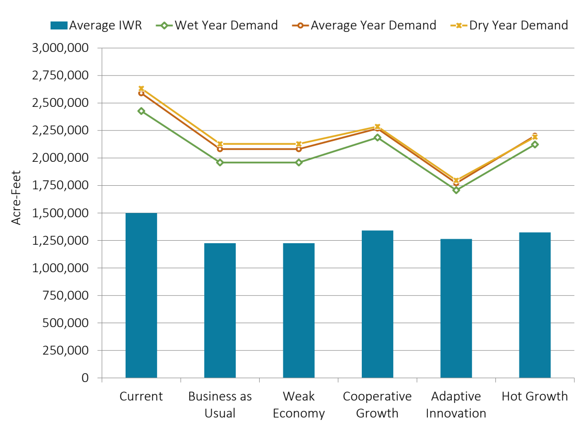
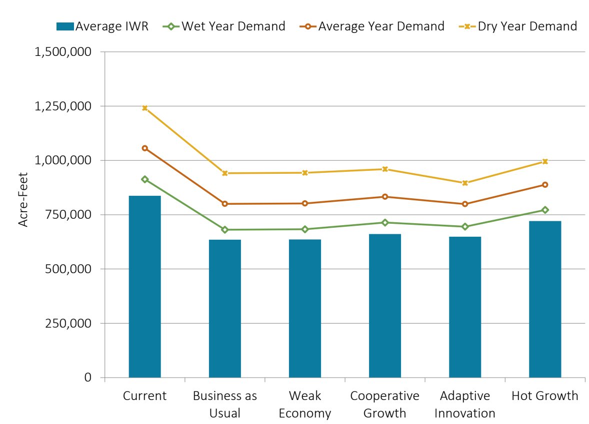


Figure 4.8.4 Agricultural Diversion Demands and IWR Results in the Republican Basin



4.8.5 Municipal and Self-Supplied Industrial Diversion Demands

For purposes of the M&I demand reporting, the South Platte Basin includes three sub-basins—the Metro Region as defined by the basin roundtables, the Republican Basin, and the remainder of the South Platte Basin. SWSI 2010 included the Republican Basin demands in the reporting of the South Platte Basin demands, but separately reported M&I demands for the Metro Region. The Republican Basin was evaluated separately in the water supply and gap analysis in the Technical Update, and the Metro Region demands were analyzed in the South Platte Basin modeling of water supplies and gaps. The three sub-basins are each summarized in the following subsections, along with the combined South Platte Basin.

Population Projections

The South Platte Basin as a whole is currently the most populous basin and includes about 70 percent of the statewide population. The Metro Region holds the majority of the population at 51 percent of the statewide total. The remaining portion of the South Platte Basin has 19 percent of the statewide population, and the Republican Basin has less than 1 percent.

Between the years 2015 and 2050, the South Platte Basin as a whole is projected to grow from approximately 3.8 million people to between 5.4 million and 6.5 million people in the low and high growth scenarios, respectively, which represents an increase in population of 42 to 70 percent. Table 4.8.6 shows how population growth is projected to vary across the planning scenarios for the South Platte Basin.

Table 4.8.6 South Platte Basin 2015 and Projected Populations

Sub-basin	Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Metro Region	2,768,000	4,062,000	3,817,000	3,922,000	4,162,000	4,318,000
Republican Basin	32,000	35,000	30,000	34,000	38,000	41,000
Remaining South Platte Basin	1,030,000	1,857,000	1,586,000	1,929,000	2,292,000	2,149,000
Total South Platte Basin	3,830,000	5,954,000	5,433,000	5,884,000	6,492,000	6,508,000

Current Municipal Demands

The Metro Region baseline water demands were largely based on water provider-reported data and had the highest representation of 1051 data for any basin or region in the state. The Republican Basin baseline water demands were largely estimated, and the remaining South Platte Basin baseline demands were largely based on water provider-reported data (see figures below).

Figure 4.8.5 Sources of Water Demand Data in the Metro Region

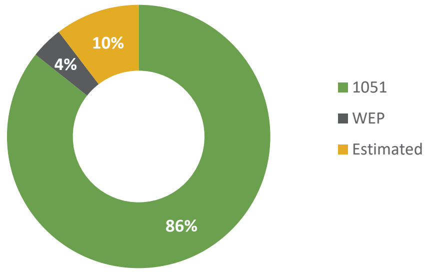


Figure 4.8.6 Sources of Water Demand Data in the Republican Basin

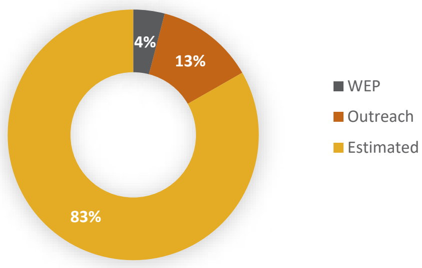


Figure 4.8.7 Sources of Water Demand Data in the Remaining South Platte Basin

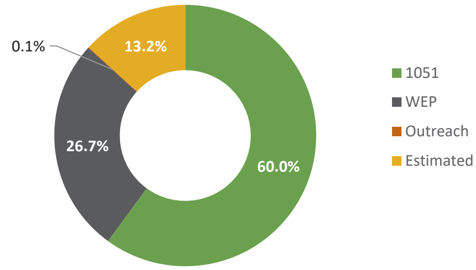
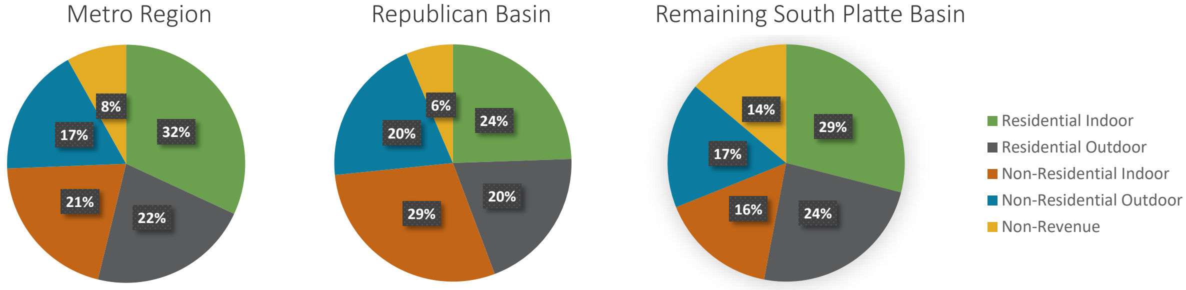


Figure 4.8.8 summarizes the categories of municipal, baseline water usage in the Metro Region, Republican Basin, and the remaining South Platte Basin. In the Metro Region and Republican Basin, non-revenue water as a percentage of systemwide demands is among the lowest in the state (with the Republican Basin being the lowest). Usage percentages in the Metro Region have a significant impact on statewide average, because a significant portion of the state population is located in the Metro Region.

Figure 4.8.8 Categories of Water Usage in the South Platte Basin



Projected Municipal Demands

Figures 4.8.9 through 4.8.11 provide summaries of per capita baseline and projected water demands for the Metro Region, Republican Basin, and the remaining South Platte Basin, respectively. In each basin, systemwide projected per capita demands decrease relative to the baseline except for *Hot Growth*. Additionally, the assumption of a hot and dry climate in *Hot Growth* is projected to cause a significant increase in outdoor demands in each region. Additional observations regarding the demand categories specific to each region are described below:

Metro Region

Consistently across all scenarios, residential indoor demand is the greatest individual demand category; non-revenue water is the lowest.

Republican Basin

Non-residential indoor demand is the greatest individual demand category; non-revenue water is the lowest in all of the scenarios.

Remaining South Platte Basin

The residential indoor demand is the greatest demand category in the baseline, but the residential outdoor demand is projected to exceed the residential indoor demand in *Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth*.

Figure 4.8.9 Metro Region Municipal Baseline and Projected Per Capita Demands by Water Demand Category

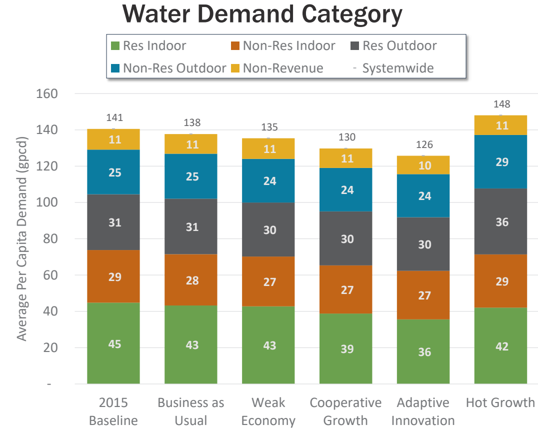


Figure 4.8.10 Republican Basin Municipal Baseline and Projected Per Capita Demands by Water Demand Category

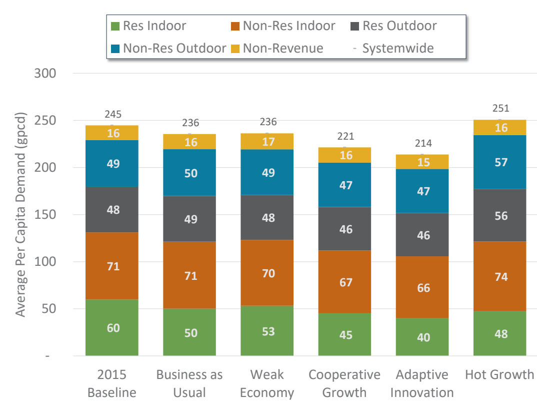
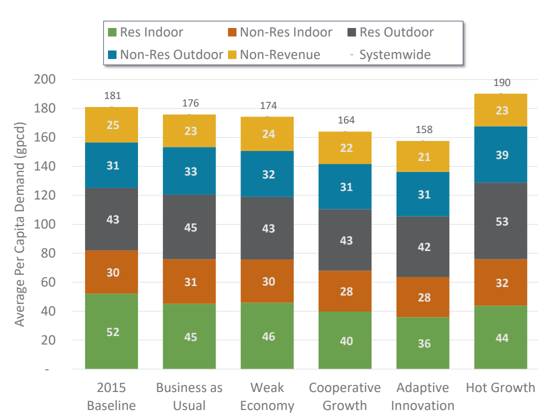


Figure 4.8.11 Remaining South Platte Basin Municipal Baseline and Projected Per Capita Demands by Water Demand Category



DECREASING GPCD

The Metro Region average baseline per capita systemwide demand has decreased from 155 gpcd in SWSI 2010 to approximately 141 gpcd. Other areas of the South Platte cannot be directly compared because of differences in reporting.

The South Platte Basin municipal baseline and projected demands are provided in Table 4.8.7, which shows the combined effect of population and per capita demands. Municipal demands are projected to grow from approximately 653,000 AFY in 2015 to between 897,000 and 1,185,000 AFY in 2050.

Table 4.8.7 South Platte Basin Municipal Baseline and Projected Demands (AFY)

Sub-basin	Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Metro Region	436,000	627,000	579,000	570,000	586,000	716,000
Republican Basin	9,000	9,000	8,000	8,000	9,000	12,000
Remaining South Platte Basin	209,000	366,000	310,000	354,000	405,000	458,000
Total South Platte Basin	653,000	1,002,000	897,000	933,000	1,000,000	1,185,000

The baseline and projected demand distributions for each region and for the South Platte Basin as a whole are shown in Figures 4.8.12 through 4.8.15.

Figure 4.8.12 Metro Region Baseline and Projected Population and Municipal Demands

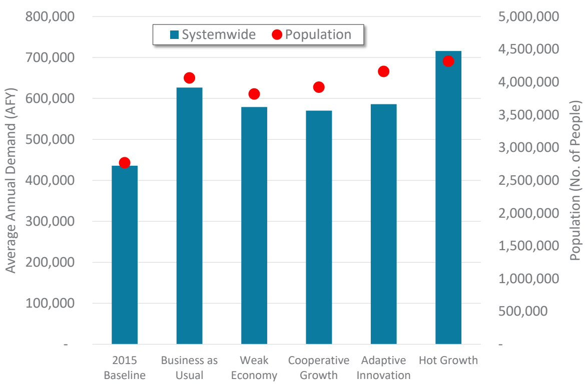


Figure 4.8.13 Republican Baseline and Projected Population and Municipal Demands

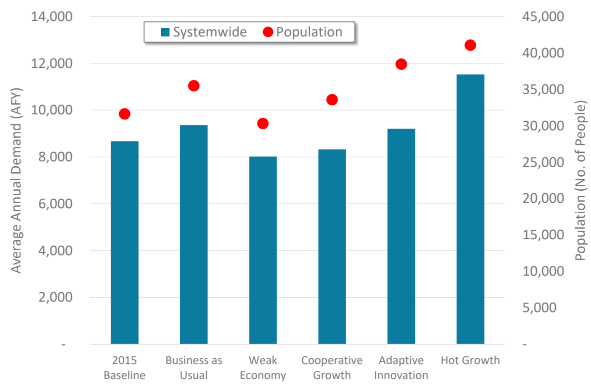


Figure 4.8.14 Remaining South Platte Baseline and Projected Population and Municipal Demands

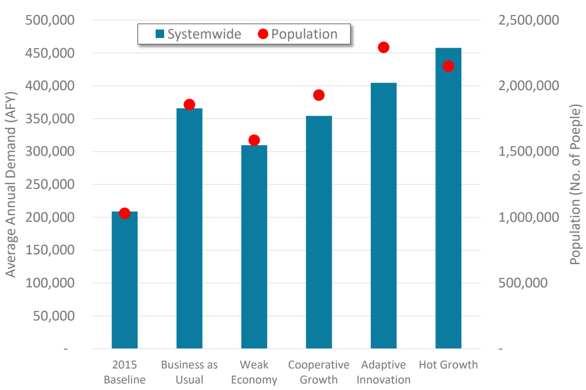
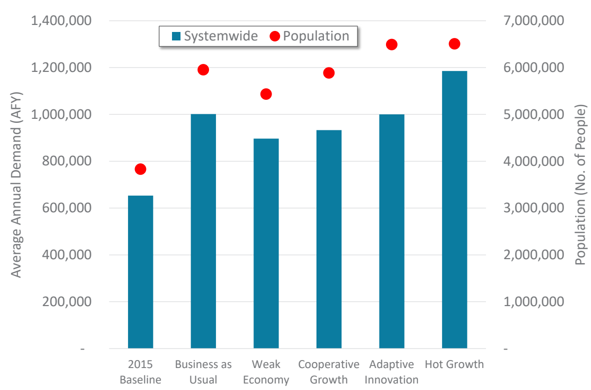


Figure 4.8.15 Total South Platte Basin Baseline and Projected Population and Municipal Demands



Below are some observations on the projected demands and population projections:

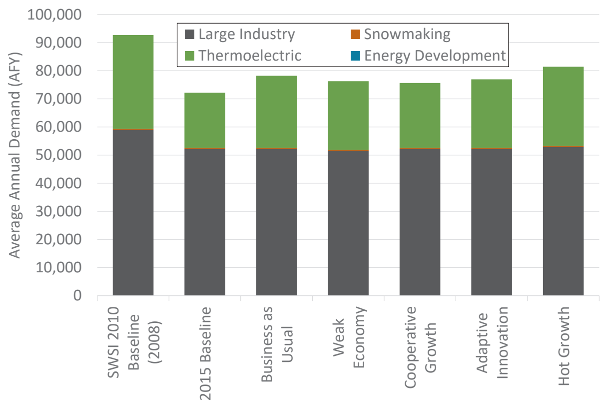
Table 4.8.8 Observations on South Platte Basin M&I Demands

Metro Region	Republican Basin	Remaining South Platte Basin	South Platte Basin/Basin-wide
• All of the planning scenarios result in an increase relative to the baseline. • Projected demand for *Weak Economy, Cooperative Growth, and Adaptive Innovation* are all within 3% of each other, even though each scenario has a different population projection.	• Demands are projected to decrease relative to the baseline in *Weak Economy and Cooperative Growth*.	• All of the planning scenarios result in an increase relative to the baseline. • Projected demands tend to follow population trends, except for *Adaptive Innovation* in which the population exceeds *Hot Growth* but the systemwide demand projection is lower, which shows the influence of projected per capita demands for this basin.	• All of the projection scenarios result in an increase relative to the baseline. • Projected demands in *Business as Usual* and *Adaptive Innovation* are similar, although population projected for *Adaptive Innovation* is about 10% higher.

Self-Supplied Industrial Demands

The South Platte Basin includes about 40 percent of the statewide SSI demand. Approximately 67 percent of the baseline SSI demands are in the Metro Region and 33 percent are in the remaining South Platte Basin. There are no SSI demands in the Republican Basin. SSI demands in the South Platte Basin are associated with the Large Industry, Snowmaking, and Thermoelectric sub-sectors. No demands were projected for the Energy Development sub-sector because no reliable data were available. Basin-scale SSI demands are shown on Figure 4.8.16 and Table 4.8.9.

Figure 4.8.16 Total South Platte Basin Self-Supplied Industrial Demands



Large Industry demands in this basin are located in three counties. Baseline demands in Jefferson County were based on data from an existing hydrologic model, and projected demands were not varied by scenario at the direction of the water user. Large Industry demands in Morgan and Weld counties were based on SWSI 2010. The baseline demand has decreased relative to SWSI 2010 due to reductions in Jefferson County.

The baseline snowmaking demand is 300 AFY (slightly less than in SWSI 2010 due to a reduction in snowmaking acres). Projected demands are 320 AFY and were not varied by scenario.

Thermoelectric demands are related to eight facilities in seven counties. Baseline demands for seven of the eight facilities were updated based on information from Xcel Energy.

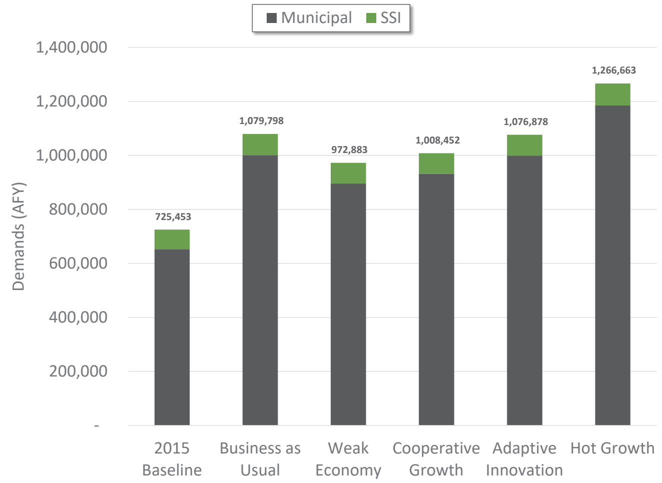
Table 4.8.9 Total South Platte Basin SSI Baseline and Projected Demands (AFY)

	Sub-sector	Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Metro Region	Large Industry	45,630	45,630	45,630	45,630	45,630	45,630
	Snowmaking	0	0	0	0	0	0
	Thermoelectric	3,040	3,040	2,890	2,740	2,890	3,350
	Energy Development	0	0	0	0	0	0
	Sub-Basin Total	48,670	48,670	48,520	48,370	48,520	48,980
Remaining South Platte Basin	Large Industry	6,600	6,600	5,940	6,600	6,600	7,260
	Snowmaking	300	320	320	320	320	320
	Thermoelectric	16,630	22,630	21,500	20,370	21,500	24,890
	Energy Development	0	0	0	0	0	0
	Sub-Basin Total	23,530	29,550	27,760	27,290	28,420	32,470
	Basin Total	**72,200**	**78,220**	**76,280**	**75,660**	**76,940**	**81,450**

Total M&I Diversion Demands

South Platte Basin combined M&I demand projections for 2050 range from approximately 970,000 AFY in *Weak Economy* to 1.27 million AFY in *Hot Growth*, as shown in Figure 4.8.17. SSI demands account for 6 to 10 percent of the M&I demands. On a basin scale, the demand projections do not follow the statewide sequence of the scenario rankings described in the CWP, with *Adaptive Innovation* falling out of sequence.

Figure 4.8.17 South Platte Basin Municipal and Self-Supplied Industrial Demands



4.8.6 Water Supply Gaps

Water supply gap estimates for the five planning scenarios were calculated differently for the South Platte and Republican basins as described in Section 2 and are, therefore, presented separately. In addition, while the CDSS water allocation models used for the water supply gap analysis in the South Platte Basin are able to generate a rich set of demand, supply, and gap data, it is difficult to parse results according to the boundaries of the Metro Region and remaining South Platte Basin. As a result, water supply gaps are described for the combined Metro Region and remaining South Platte Basin.

The agricultural and M&I diversion demands were compared against available water supply modeled for current conditions and the five planning scenarios. Gaps were calculated when water supply was insufficient to meet demands.

South Platte Basin Gaps

Agricultural

The South Platte Basin agricultural diversion demands, demand gaps, and consumptive use gaps for the baseline and planning scenarios are presented in Table 4.8.10 and illustrated in Figure 4.8.18. An annual time series of gaps in terms of percent of demand that was unmet is shown in Figure 4.8.19.

Table 4.8.10 South Platte Basin Agricultural Gap Results (AFY)

		Scenario					
		Scenario	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand	2,465,800	1,988,700	1,988,700	2,157,400	1,696,500	2,063,100
	Average Annual Gap	506,700	404,900	402,100	402,100	378,300	444,000
	Average Annual Gap Increase from Baseline	-	-	-	-	-	-
	Average Annual Percent Gap	21%	20%	20%	19%	22%	22%
	Average Annual CU Gap	278,000	220,400	218,700	220,300	237,800	247,600
Maximum	Demand in Maximum Gap Year	2,982,300	2,411,200	2,411,200	2,419,700	2,006,200	2,360,900
	Gap in Maximum Gap Year	1,206,100	978,400	960,700	901,900	824,800	1,064,000
	Percent Gap in Maximum Gap Year	-	-	-	-	-	-
	Increase from Baseline Gap	40%	41%	40%	37%	41%	45%

Study period for Water Supply Analysis is 1975-2013, reflecting different baseline demand than described in Agricultural Diversion Demands section.

Figure 4.8.18 Projected Average Annual Agricultural Diversion Demand, Demand Met, and Gaps in the South Platte Basin

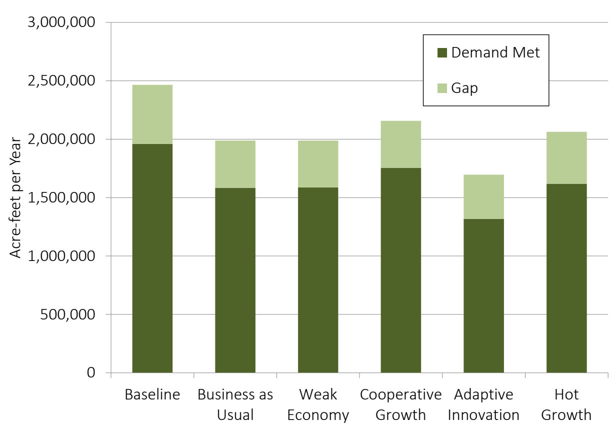
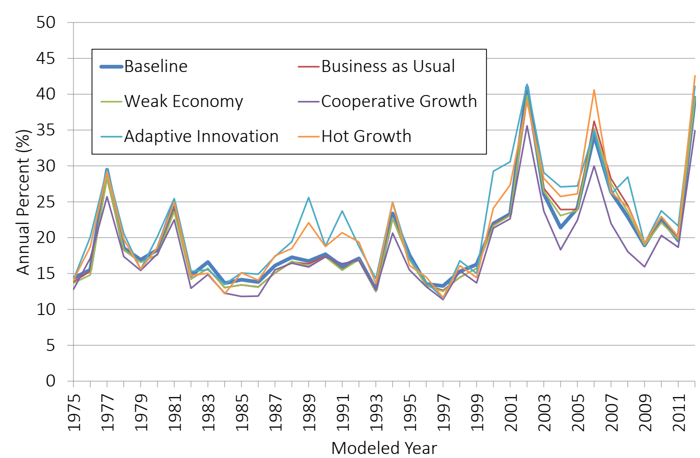


Figure 4.8.19 Annual Agricultural Gaps (expressed as a percentage of demand) for Each Planning Scenario



The following are observations on the agricultural diversion demand and gap results:

- In the South Platte Basin, the current agricultural gap is significant but is not projected to increase greatly in the future as a percentage of demand.
- On a volumetric basis, gaps are projected to decrease as agricultural diversion demands decrease, primarily from urbanization and potential conversion of agricultural water rights to municipal use.
- As shown in Figure 4.8.18, current and future agricultural gap simulation results hovered at around 15 percent of total demand in normal to wetter periods but increased during dry periods.
- In many years, the agricultural gaps in *Adaptive Innovation* and *Hot Growth* are projected to be higher than in other scenarios because of higher irrigation demands and lower supplies associated with the hot and dry future climate assumption. Overall, however, gaps in *Adaptive Innovation* are lower than *Hot Growth* because of the adoption of emerging technologies that lower demand.

M&I

The diversion demand and gap results for M&I uses in the South Platte Basin are summarized in Table 4.8.11 and illustrated in Figure 4.8.20. An annual time series of gaps in terms of percent of demand that was unmet is shown in Figure 4.8.21.

Table 4.8.11 South Platte Basin M&I Gap Results (AFY)

		Scenario					
		Scenario	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand	718,700	1,073,000	968,900	1,002,800	1,070,100	1,257,700
	Average Annual Gap	0*	192,800	136,600	159,800	221,400	390,600
	Average Annual Percent Gap	0%	18%	14%	16%	21%	31%
Maximum	Demand in Maximum Gap Year	720,000	1,074,300	970,200	1,004,100	1,070,200	1,257,700
	Gap in Maximum Gap Year	0*	256,300	184,500	213,300	333,200	540,700
	Percent Gap in Maximum Gap Year	0%	24%	19%	21%	31%	43%

**CDSS water allocation model in this basin calculates small baseline M&I gaps, but they are either due to calibration issues or they are reflective of infrequent, dry-year shortages that are typically managed with temporary demand reductions, such as watering restrictions.*

Study period for Water Supply Analysis is 1975-2013, which reflects a different baseline demand than described in M&I Demand section. Baseline demand also may vary slightly from previous section due to differences in geographic distribution of demand for counties that lie in multiple basins.

Figure 4.8.20 Projected Maximum Annual M&I Diversion Demand, Demand Met, and Gaps in the South Platte Basin

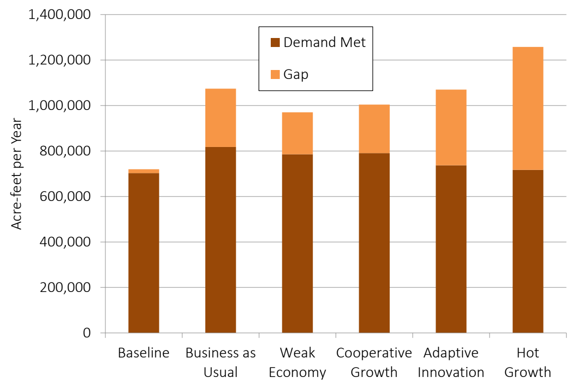
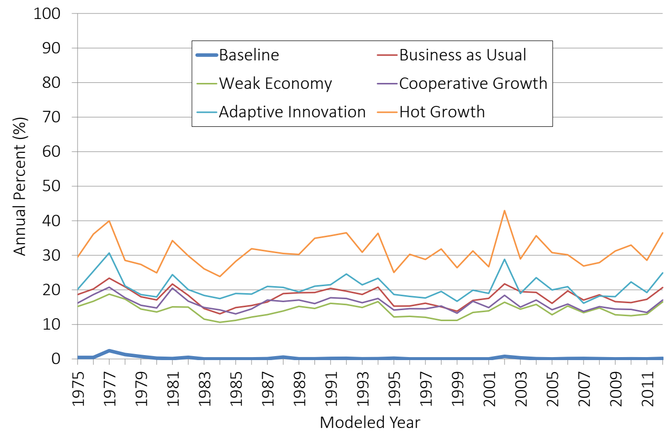


Figure 4.8.21 Annual M&I Gaps (expressed as a percentage of demand) for Each Planning Scenario



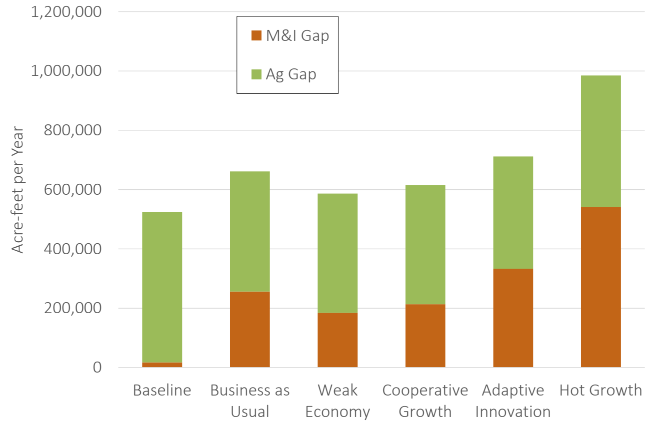
The following are observations on the M&I diversion demand and gap results:

- Gaps under *Hot Growth* are projected to be significantly higher than in other scenarios.
- *Adaptive Innovation* includes similar assumptions to *Hot Growth* in terms of future climate conditions and population projections; however, annual gaps and maximum gaps (as shown in Figure 4.8.19) are projected to be much less, which demonstrates the value of conservation. In addition, the gaps for *Business as Usual* and *Adaptive Innovation* are projected to be very similar even though *Adaptive Innovation* incorporates high population growth and a hot and dry future climate condition. The similarity in gaps suggests that additional conservation on a basinwide scale will help offset additional demands from population growth and climate change. Nonetheless, gaps in *Adaptive Innovation* are projected to be significant and point to the need for developing additional water supplies.
- The persistent nature of the time series of gaps in Figure 4.8.20 points to the need for projects that will provide firm yield.
- Figure 4.8.20 also shows that gaps can increase significantly during dry periods, especially in *Adaptive Management* and *Hot Growth* (the scenarios most severely impacted by future climate assumptions). Projects and water management strategies will be needed to meet periodic maximum M&I gaps.

Total Gap

Figure 4.8.22 illustrates the total combined agricultural and M&I diversion demand gap in the South Platte Basin. The figure combines the average annual agricultural gaps and the maximum M&I gap. Note that agricultural gaps are projected to decrease in the future, and therefore an incremental gap is not shown in the figure.

Figure 4.8.22 Projected Average Annual Agricultural Gaps and Maximum M&I Diversion Demand Gaps in the South Platte Basin.



Supplies from Urbanized Lands and Planned Transfers

The planning scenarios assumed between 127,100 and 169,600 acres of irrigated agricultural land will be urbanized or no longer irrigated because of planned water right transfers from agricultural to municipal use in the South Platte Basin. Irrigation supplies for urbanized lands could potentially be used for M&I needs in the future (subject to a variety of unknowns such as seniority and type of water supply, willingness to change the use of water through water court, etc.). Acreage associated with planned transfers was derived based on stakeholder input.

The average annual historical consumptive use associated with potentially urbanized acreage and planned water right transfers for each scenario is reflected in Table 4.8.12. The data in Table 4.8.12 represents planning-level estimates of this potential supply and has not been applied to the M&I gaps. The data in the table do not represent supplies from permanent water transfers that may be considered by a basin roundtable as a future strategy to meet gaps (note that SWSI 2010 included estimates of permanent transfers beyond those currently planned as a strategy for meeting potential future M&I gaps).

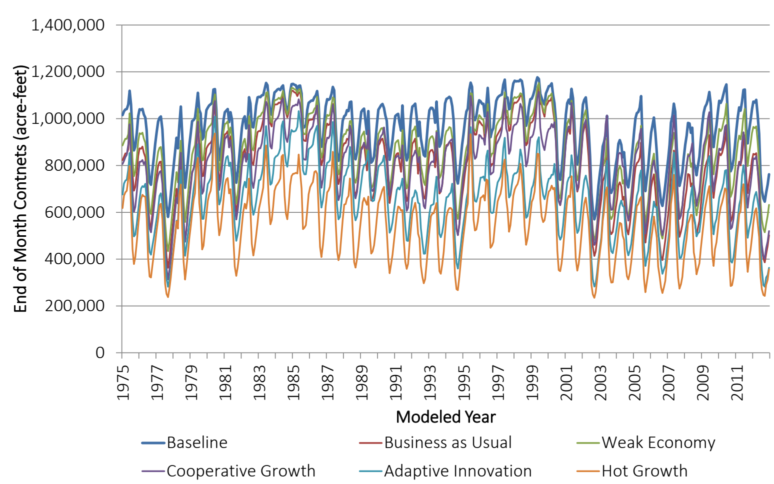
Table 4.8.12 Estimated Consumptive Use from Lands Projected to be Urbanized by 2050 and Planned Transfers in the South Platte Basin

	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Urbanized Acreage and Lands Subject to Planned Transfers (acres)	148,400	148,400	127,100	127,100	169,600
Estimated Consumptive Use (AFY)	209,800	210,200	179,400	172,700	238,600

Storage

Total reservoir storage output from the South Platte water allocation model is shown on Figure 4.8.23. Baseline conditions show the highest levels of water in storage (in general) and the lowest is in *Hot Growth*. *Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth* show lower amounts of water in storage than the two scenarios that do not include the impacts of a drier climate. The results indicate that, without new projects, higher demands will draw storage down to lower levels. Concurrent drier conditions will impede full recovery of reservoirs. Lower demands in *Adaptive Innovation* help reservoir levels stay somewhat higher than in *Hot Growth*. It should be noted that the water allocation model allows reservoirs to be drawn down to the full extent water rights and storage amounts allow. Water providers would likely not be comfortable operating with chronically lower amounts of water in storage and would seek to acquire additional supplies or build new projects to boost reserves.

Figure 4.8.23 South Platte Basin Total Reservoir Storage (not including Water District 3)



Republican Basin Gaps

Agricultural

The Republican Basin agricultural diversion demands, demand gaps, and consumptive use gaps for the baseline and planning scenarios are presented in Table 4.8.13 and illustrated in Figure 4.8.24.

Table 4.8.13 Republican Basin Agricultural Gap Results (AFY)

		Scenario					
		Scenario	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand	1,067,200	805,500	807,500	835,300	797,200	885,800
	Average Annual Gap	266,800	201,400	201,900	208,800	199,300	221,400
	Average Annual Gap Increase from Baseline	-	-	-	-	-	-
	Average Annual Percent Gap	25%	25%	25%	25%	25%	25%
	Average Annual CU Gap	211,400	159,800	160,200	165,700	161,600	179,600
Maximum	Demand in Maximum Gap Year	1,445,200	1,113,000	1,114,700	1,113,200	1,014,400	1,127,100
	Gap in Maximum Gap Year	361,300	278,300	278,700	278,300	253,600	281,800
	Increase from Baseline Gap	-	-	-	-	-	-
	Percent Gap in Maximum Gap Year	25%	25%	25%	25%	25%	25%

Study period for Water Supply Analysis is 1975-2013, reflecting different baseline demand than described in Agricultural Diversion Demands section.

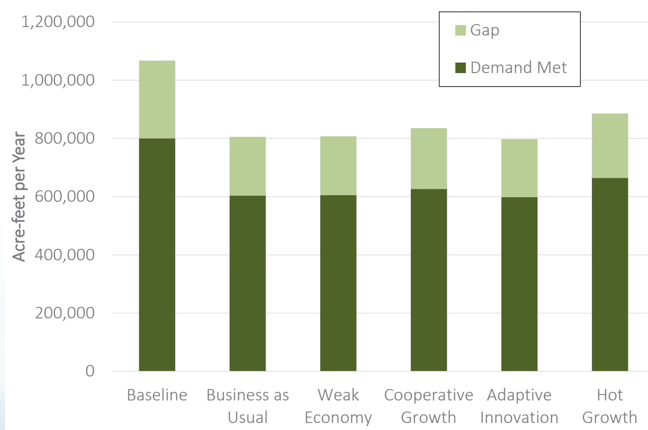
The following are observations on agricultural diversion demands and gaps:

- Both diversion demands and gaps will likely decrease in the future due to reduction of irrigated lands in order to comply with the Republican River Compact and also as a result of declining water levels in the High Plains Aquifer.
- Even with reduced demand, reduced supplies will result in a fairly consistent gap in the future of approximately 25 percent of demand.

INCREMENTAL GAP

The incremental agricultural gap quantifies the degree to which the gap could increase beyond what agriculture has historically experienced under water shortage conditions.

Figure 4.8.24 Projected Average Annual Agricultural Diversion Demand, Demand Met, and Gaps in the Republican Basin



M&I

The diversion demand and gap results for M&I uses in the Republican Basin are summarized Table 4.8.14 and illustrated in Figure 4.8.25.

Table 4.8.14 Republican Basin M&I Gap Results (AFY)

		Scenario					
		Scenario	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand	8,400	9,200	7,900	8,100	8,900	11,200
Average	Average Annual Gap	-	1,300	-	-	1,100	3,300
Average	Average Annual Percent Gap	0%	14%	0%	0%	12%	30%
Maximum	Demand in Maximum Gap Year	8,400	9,200	7,900	8,100	8,900	11,200
Maximum	Gap in Maximum Gap Year	-	1,300	-	-	1,100	3,300
Maximum	Percent Gap in Maximum Gap Year	0%	14%	0%	0%	12%	30%

Total Gap

Figure 4.8.26 illustrates the total combined agricultural and M&I diversion demand gap in the Republican Basin. The figure combines the average annual agricultural gaps and the maximum M&I gap. Note that agricultural gaps are projected to decrease in the future, and therefore an incremental gap is not shown in the figure.

Supplies from Urbanized Lands

The planning scenarios assumed 1,400 acres of irrigated agricultural land will be urbanized in the Republican Basin. Irrigation supplies for these lands could potentially be used for M&I needs in the future (subject to a variety of unknowns such as seniority and type of water supply, willingness to change the use of water through water court, etc.). The average annual historical consumptive use associated with potentially urbanized acreage for each scenario is reflected in Table 4.8.15. The data in Table 4.8.15 represents planning-level estimates of this potential supply and has not been applied to the M&I gaps.

Figure 4.8.25 Projected Maximum Annual M&I Demand Met and Gaps in the Republican Basin

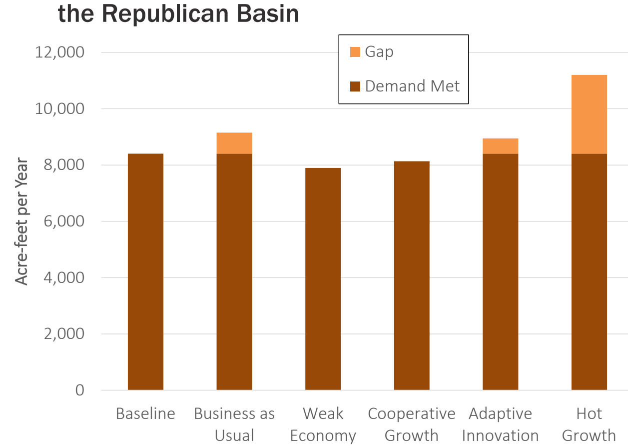


Figure 4.8.26 Projected Average Annual Agricultural Gaps and Maximum M&I Diversion Demand Gaps in the Republican Basin.

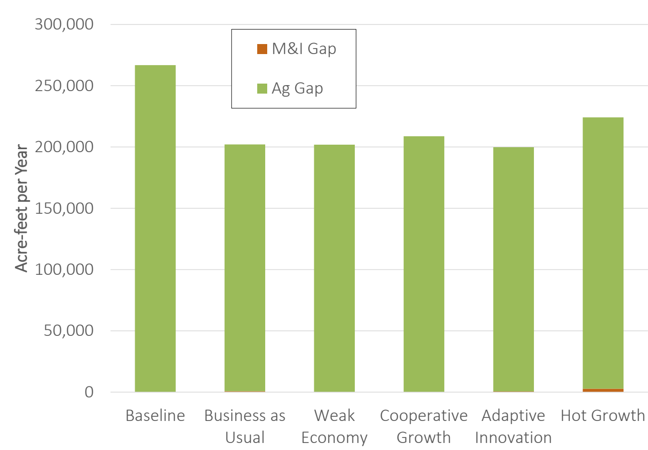


Table 4.8.15 Estimated Consumptive Use from Lands Projected to be Urbanized by 2050 in the Republican Basin

	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Urbanized Acreage (acres)	1,400	-	1,400	1,400	1,400
Estimated Consumptive Use (AFY)	1,500	-	1,600	1,600	1,700

Combined South Platte and Republican Basin Gaps

Table 4.8.16 summarizes the total M&I and agricultural demands in the South Platte and Republican Basins along with a summary of gaps. It should be noted that the South Platte and Republican basins were assessed independently; some of the results from each basin may not be wholly additive in some circumstances. For example, the maximum M&I gap may not occur in the same year in each sub-basin. As a result, the basin as a whole may not experience a year in the future when the total maximum M&I gap corresponds to the sum of the maximum gaps in both sub-basins; however, the sum of the maximum sub-basin gaps does describe the total amount of water that would be needed to fully satisfy all M&I demands in each individual sub-basin, even if the gaps do not simultaneously occur in the sub-basins.

Table 4.8.16 Summary of Total South Platte and Republican Basin Demands and Gaps

	Current (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average Annual Diversion Demand						
Agricultural (AFY)	3,533,000	2,794,200	2,796,100	2,992,700	2,493,700	2,948,900
M&I (AFY)	727,100	1,082,200	976,800	1,010,900	1,079,100	1,268,900
Gaps						
Ag (avg %)	22%	22%	22%	20%	23%	23%
Ag (incremental-AFY)	-	-	-	-	-	-
Ag (incremental gap as % of current demand)	-	-	-	-	-	-
M&I (max %)	0%	24%	19%	21%	31%	43%
M&I (max-AF)	0*	257,100	184,500	213,300	333,700	543,500

**CDSS water allocation model in this basin calculates small baseline M&I gaps, but they are either due to calibration issues or they are reflective of infrequent, dry-year shortages that are typically managed with temporary demand reductions, such as watering restrictions.*

4.8.7 Available Supply

Figures 4.8.27 through 4.8.30 show simulated available at two locations on the South Platte River, the South Platte River at Denver and South Platte River at Kersey. The Denver location, upstream of the Burlington Ditch, is the primary calling right on the mainstem of the Upper South Platte River. The Kersey gage reflects the impact to available flow downstream of the confluence, with the Cache La Poudre River and the Lower South Platte River calling rights for storage and irrigation. Available flow at both locations is generally only available during high flow years and for relatively short periods of time. In scenarios with impacts of climate change, available flows are projected to diminish, and peak flows are projected to occur earlier in the runoff season.

Figure 4.8.27 Simulated Hydrographs of Available Flow at South Platte River at Denver

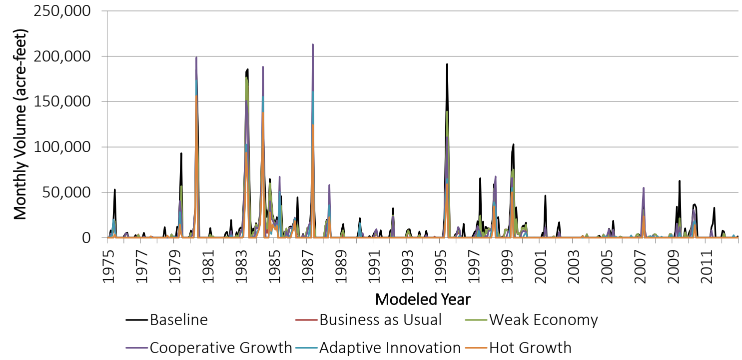


Figure 4.8.28 Average Monthly Simulated Hydrographs of Available Flow at South Platte River at Denver

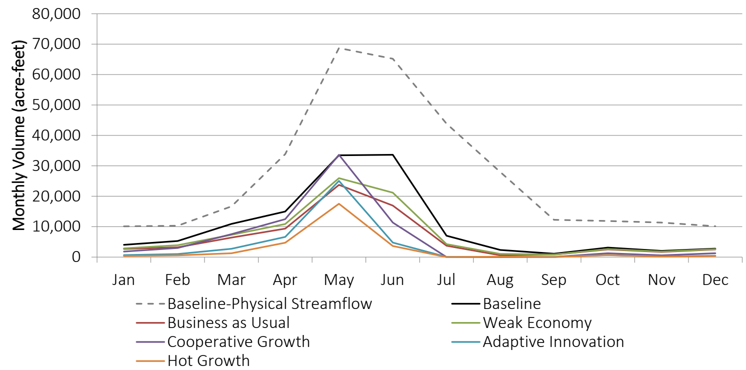


Figure 4.8.29 Simulated Hydrographs of Available Flow at South Platte River at Kersey, CO

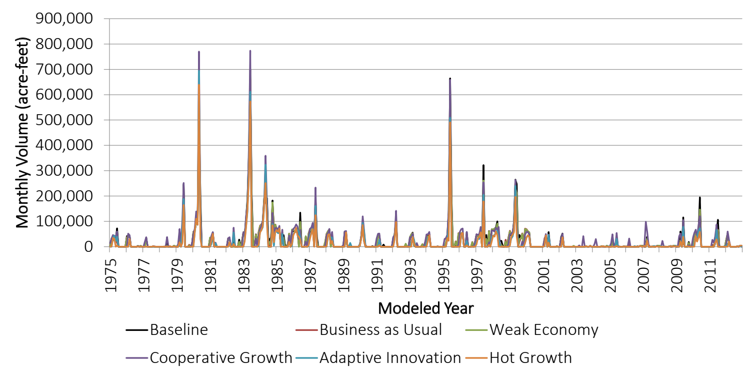
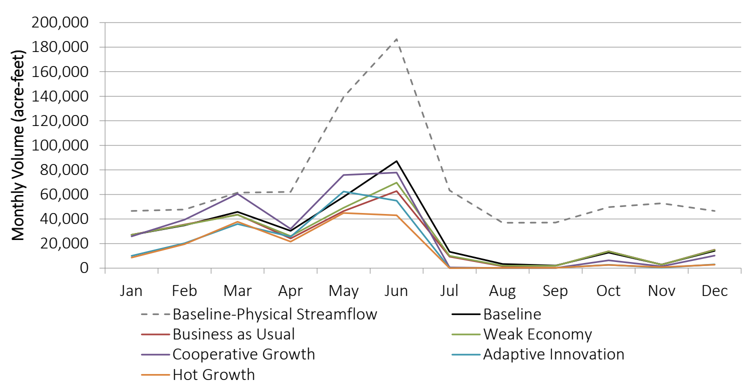


Figure 4.8.30 Average Monthly Simulated Hydrographs of Available Flow at South Platte River at Kersey, CO



4.8.8 Environment and Recreation

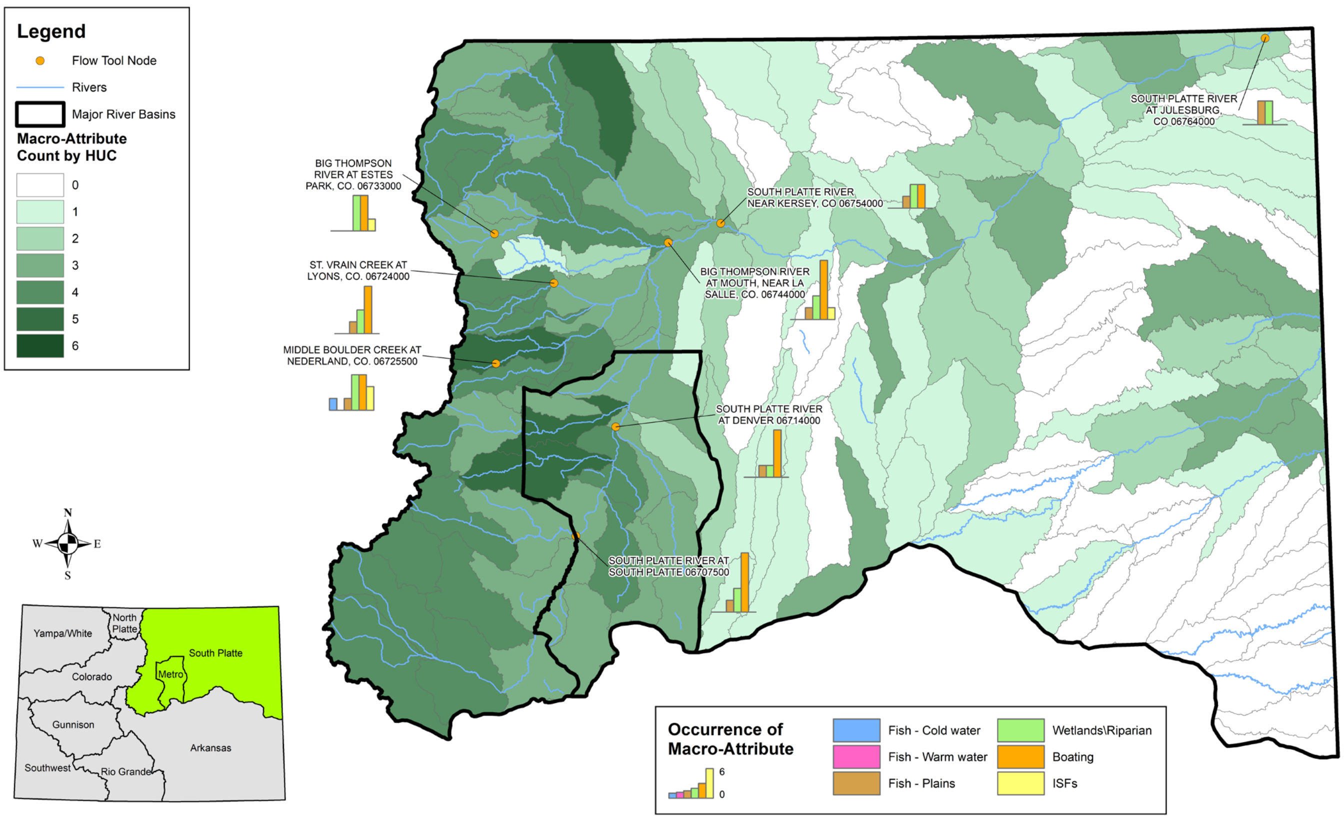
A total of eight water allocation model nodes were selected for the Flow Tool within the South Platte Basin (see list below and Figure 4.8.31). Figure 4.8.31 also shows subwatersheds (at the 12-digit HUC level) and the relative number of E&R attributes located in each subwatershed.

- South Platte River at South Platte (06707500)
- South Platte River at Denver (06714000)
- St Vrain Creek at Lyons, Colorado (06724000)
- Middle Boulder Creek at Nederland, Colorado (06725500)
- Big Thompson River at Estes Park, Colorado (06733000)
- Big Thompson River at Mouth, near La Salle, Colorado (06744000)
- South Platte River near Kersey, Colorado (06754000)
- South Platte River at Julesburg, Colorado (06764000)

NATURALIZED FLOW

Naturalized flows reflect conditions that would occur in the absence of human activities. Baseline flows reflect current conditions as influenced by existing infrastructure and river operations. While observations regarding naturalized flows may be informative, baseline flows reflect actual conditions and the diverse operations of a river's many users.

Figure 4.8.31 Flow Tool Nodes Selected for the South Platte Basin



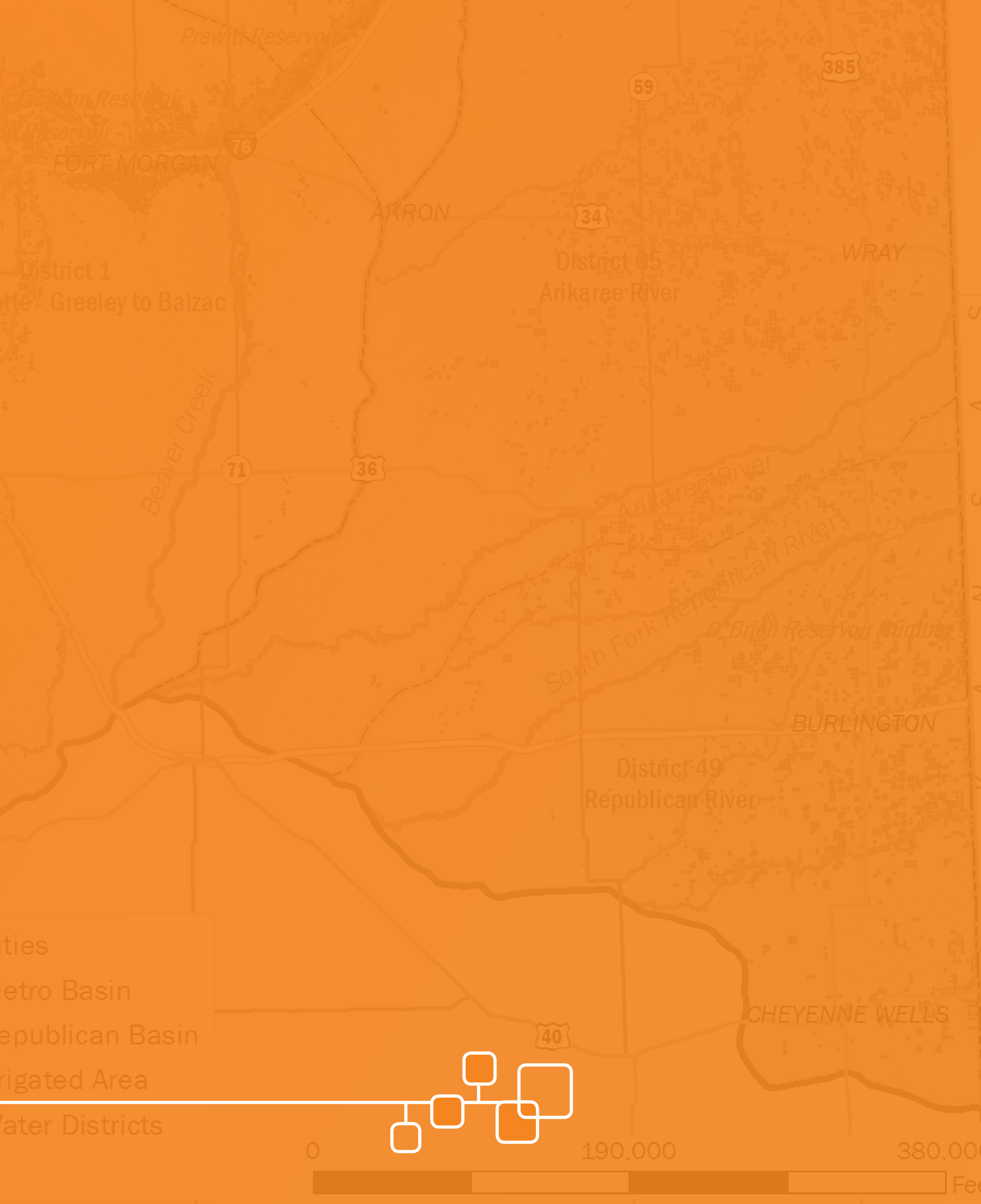
Results and observations from Flow Tool analyses using flow data developed in the water supply and gap analyses for baseline conditions and the planning scenarios are described in Table 4.8.17 below.

Table 4.8.17 Summary of Flow Tool Results in the South Platte Basin

Category	Observation
Projected Flows	Patterns of peak flows are highly variable across locations in the basin.
	Baseline flow patterns diverge the most from naturalized conditions in the Foothills and on the Plains.
	The magnitude of flows on the South Platte in Denver in May and June (historically the months of peak runoff) under baseline conditions are reduced from naturalized conditions, and the divergence from naturalized conditions increases as the South Platte flows through Julesburg. In these locations, peak flow magnitude under the various future scenarios is projected to increase, stay the same, or decrease further depending on location.
	In the mountains (e.g., South Platte River at South Platte, Middle Boulder Creek at Nederland), baseline peak flow magnitudes are only minimally below naturalized peak flow magnitude. Projected changes to peak flow magnitude in these mountain locations also vary depending on location, with minimal changes to peak flow magnitude in some locations and larger declines elsewhere.
	Mountain locations demonstrate a projected pattern under the climate change scenarios where the timing of peak flows shifts earlier in the year, from June to May. The change in timing for peak flows may result in mismatches between peak flow timing and species' needs.
	Mid- and late-summer flows are also highly variable across locations in the basin. On the plains, baseline low flows vary in range below naturalized conditions.
	Under future scenarios, this range is expected to further departed from naturalized conditions in climate-impacted scenarios (*Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth*) causing the greatest decline in flows.
	In the mountains, climate change scenarios may cause a decline in low flows (e.g., Middle Boulder Creek at Nederland), while in other areas (e.g., South Platte River at South Platte) declines may be less pronounced due to transbasin imports and releases of stored water.
Ecological Risk	In the Foothills and on the Plains, especially east of Interstate 25, decreased peak flow magnitudes under baseline conditions and all future scenarios may put many aspects of ecosystem function (e.g., over-bank flooding to support riparian plants, sediment transport to maintain fish habitat) at risk. Projected changes to mid- and late-summer flows may also create risk for plains fishes.
	In the mountains, peak flow and low flows generally create low to moderate risk for riparian plants and fish, although these risks may increase under climate change scenarios.
ISFs and RICDs	There are numerous ISF reaches in the mountains and foothills, and several RICDs in the South Platte Basin. The location of modeled flow points does not allow specific insight into what future scenarios imply for these locations, but the general pattern of diminished flows, especially diminished flows under climate change scenarios, suggests that the flow targets for ISFs and RICDs may be met less often.
E&R Attributes	Increasing risk to E&R attributes arise from several sources. Changes in flow timing through water management (e.g., storage of peak flows) can reduce ecosystem functions that are dependent on high flows (e.g., sediment transport) and can reduce boating opportunities. Changes in timing under climate change scenarios (early peak flow) can also increase risk for ecosystems and species.
	Under all scenarios in most locations, ecological and recreational risk may be increased by depletions from increasing human water consumption and decreasing supply under a changing climate. Water management (e.g., reservoir releases) has the potential to mitigate negative impacts.

The San Juan River, Dolores River, and San Miguel River Basins are located in the southwest corner of Colorado and cover an area of approximately 10,169 square miles. The Upper San Juan River and its tributaries flow through two Native American reservations in the southern portion of the basin—the Ute Mountain Ute Reservation and the Southern Ute Indian Reservation. The Southwest Basin is a series of nine sub-basins, eight of which flow out of state before they join the San Juan River in New Mexico or the Colorado River in Utah. The Colorado River Compact, the Colorado Ute Indian Water Rights Settlement, and several Bureau of Reclamation storage projects have shaped the water history of the Southwest Basin.

SOUTHWEST


FORT MORGAN
AKRON
WRAY
District 65
Arikaree River
District 1
Greeley to Balzac
Beaver Creek
Arikaree River
South Fork Republican River
BURLINGTON
District 49
Republican River
CHEYENNE WELLS
0
190,000

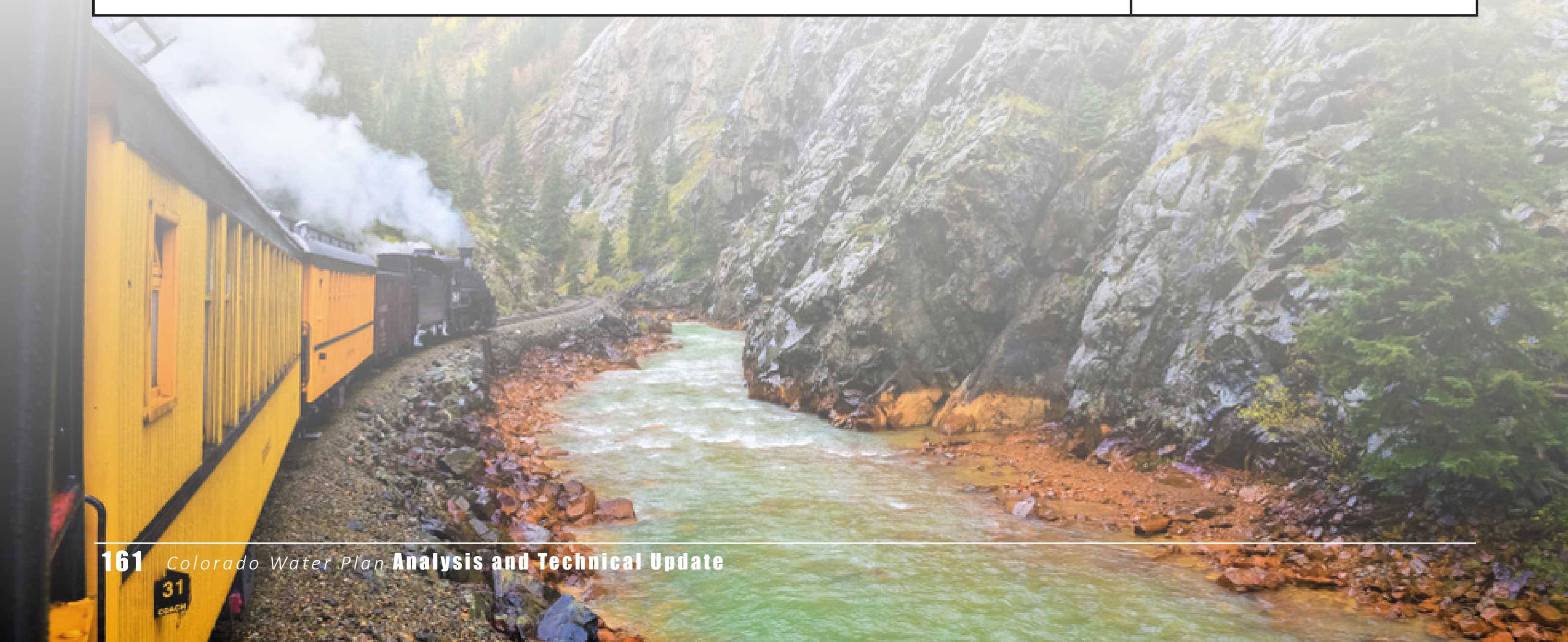
4.9 SOUTHWEST BASIN RESULTS

4.9.1 BASIN CHALLENGES

The Southwest Basin will face several key issues and challenges to balance valued agricultural uses with instream water to support recreational and environmental values, all of which combine to support the economic and aesthetic values that drive settlement and commerce in the Southwest Basin. In addition, water quality is a significant concern in the Southwest Basin. These issues were described in the Colorado Water Plan and are summarized below.

Table 4.9.1 Key Future Water Management Issues in the Southwest Basin

Agriculture	Environment and Recreation	Municipal and Industrial	Compacts and Administration
• The Cortez and Dove Creek area remains strongly agricultural, supplemented by energy production. It is also seeing growth through an increase in retirees moving to the area.	• US Forest Service and Bureau of Land Management have worked with the CWCB Instream Flow Program to secure substantial flow protection at high elevations throughout the basin. As stream-flow protections have increasingly focused on lower elevation streams that are below stored water and communities, instream flow appropriations have become more complex and challenging.	• The Pagosa Springs-Bayfield-Durango corridor is rapidly growing while experiencing areas of localized water shortages. This area is transitioning from oil and gas, mining, and agricultural use to tourism and recreation use, and to a retirement or second-home area. • Another challenge is the development of sufficient infrastructure to deliver M&I water where it is needed. There is also discussion regarding new storage to meet long-term supply requirements in the Pagosa Springs area, as well as in Montrose County.	• In addition to the three compacts governing water use across the broader Colorado Basin, other compacts, settlements, and species-related issues are specific to the San Juan/ Dolores/San Miguel region.
• The San Miguel area shows a mix of recreation and tourism activities, along with a strong desire to maintain agriculture in the western part of the county.			



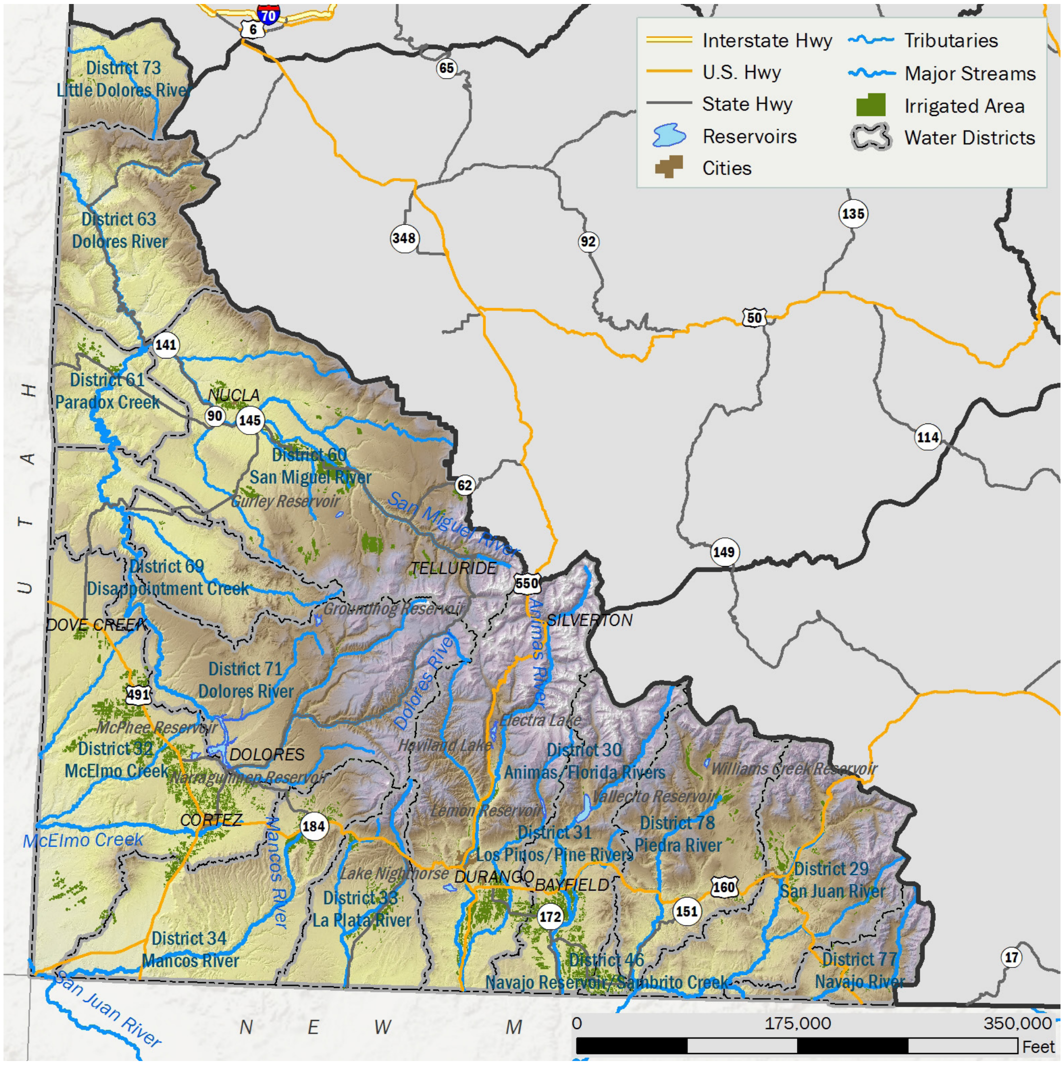


Figure 4.9.1 Map of the Southwest Basin

4.9.2 SUMMARY OF TECHNICAL UPDATE RESULTS

Key results and findings of the Technical Update pertaining to agricultural and M&I demands and gaps as well as findings related to environmental and recreational attributes and future conditions are summarized below.

Table 4.9.2 Summary of Key Results in the Southwest Basin

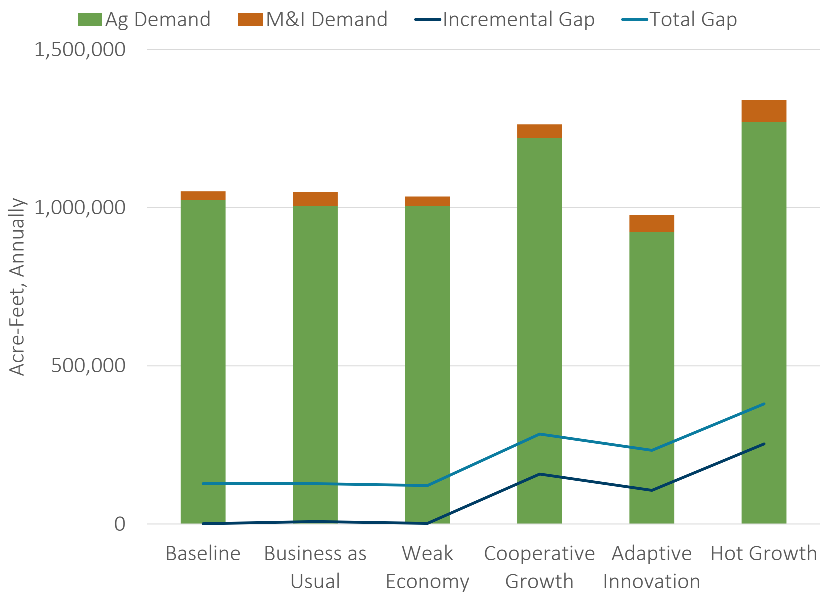
Agriculture	Environment and Recreation	Municipal and Industrial
• Warmer and drier climate conditions in Cooperative Growth, Adaptive Innovation and *Hot Growth* will lead to higher IWR and gaps. • Incorporation of emerging technologies in Adaptive Innovation are projected to help maintain demands and gaps at lower levels than *Hot Growth* despite similar assumptions regarding future climate conditions.	• In locations that are minimally depleted under baseline conditions, peak flows may remain adequate for riparian/ wetlands and fish habitat, but timing mis-matches may occur. • In all locations, mid- and late-summer flows may be substantially reduced, creating high risk for coldwater and warmwater fish.	• Relatively large increases in population could create higher M&I demands and gaps in Adaptive Innovation and *Hot Growth*. • Thermoelectric demands drive a modest increase in SSI demand. • Future per capita demands are projected to decrease in all but *Hot Growth*.

Table 4.9.3 Summary of Diversion Demand and Gap Results in the Southwest River Basin

	Current (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average Annual Demand						
Agricultural (AFY)	1,024,800	1,005,400	1,005,400	1,220,500	923,100	1,271,700
M&I (AFY)	27,200	44,800	30,200	43,300	54,000	69,500
Gaps						
Ag (avg %)	12%	12%	12%	23%	24%	28%
Ag (incremental-AFY)	-	-	-	150,100	92,400	228,400
Ag (incremental gap as % of current demand)	-	-	-	15%	9%	22%
M&I (max %)	0%	17%	6%	18%	26%	36%
M&I (max-AF)	0*	7,500	1,800	7,700	13,800	24,800

* *CDSS water allocation model in this basin calculates small baseline M&I gaps, but they are either due to calibration issues or they are reflective of infrequent, dry-year shortages that are typically managed with temporary demand reductions such as watering restrictions.*

Figure 4.9.2 Summary of Diversion Demand and Gap Results in the Southwest Basin



Summary of Environment and Recreation Findings

- In locations that are minimally depleted under baseline conditions (e.g., the San Miguel River), peak flows may remain adequate for riparian/wetlands and fish habitat, with March-May flows increasing substantially while June flows decrease; possible mis-matches between peak flow timing and species needs may occur.
- In some locations peak flows under baseline conditions indicate high risk to riparian/wetlands and fish habitat, and risk may increase in *Cooperative Growth, Adaptive Innovation*, and *Hot Growth*.
- In all locations, mid- and late-summer flows are projected to be substantially reduced (50 to 80 percent) under *Cooperative Growth, Adaptive Innovation*, and *Hot Growth*, creating high risk for coldwater and warmwater fish. Even on rivers where the baseline condition is low-risk for summer flows, future scenarios may see risks increase substantially. The risk expressed in the coldwater and warmwater fish metrics does not include July because historically July flows are sufficient; however, in some locations, July flows may be reduced (e.g., July flows on the Piedra River near Arboles could be by reduced 84 percent), which could result in much-reduced habitat and high stream temperatures.
- Instream Flow water rights in the Southwest and the Recreational In-Channel Diversion on the Animas River often will likely not be fully met under *Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth*.

4.9.3 NOTABLE BASIN CONSIDERATIONS

Section 4.1 described several analysis assumptions and limitations that apply to all basins and should be considered when reviewing and interpreting analysis results. Additional considerations specific to the Southwest Basin are listed below:

- The full development of tribal reserved water rights is not represented in the models for several reasons. The Tribal Water Study was completed in December of 2018, which was after the agricultural and M&I demands for the Technical Update were completed. In addition, full use of the reserved rights are not projected to occur by 2050, which is the planning time period contemplated in the current Technical Update. It should be noted that Tribal water use through 2050 is included in the M&I projections in each planning scenario; however, similar to other future M&I demands, it has been grouped with other M&I demands and included in the water allocation model at representative locations in each water district. Basin roundtables can take a different look at how tribal rights are used when they update their BIP.
- Water availability in the various sub-basins in the Southwest Basin can be drastically different. The differences in sub-basin water availability and gaps may not be evident at a basinwide scale due to the aggregated reporting of results in the Technical Update; however, models developed for the Technical Update reflect the variation in sub-basin results and are available for sub-basin specific evaluations that could be conducted in the Basin Implementation Plan update.

4.9.4 AGRICULTURAL DIVERSION DEMANDS

Agricultural Setting

The Southwest Basin is made up of a series of nine sub-basins, each with their own unique hydrology and demands. The basin is home to a diverse set of demands; several small towns founded primarily due to either mining or agricultural interests, two Native American reservations (Southern Ute Indian Tribe and Ute Mountain Ute Tribe), one major transbasin diversion (San Juan–Chama Project)[13], and four major Reclamation projects (Pine River, Dolores, Florida and Mancos) that both brought new irrigated acreage under production and provided supplemental supplies to existing lands. For areas outside of the Reclamation rojects, producers generally irrigate grass meadows for cattle operations aligned along the rivers and tributaries and rely on supplies available during the runoff season. Producers under the Reclamation Projects irrigate a wider variety of crops, such as alfalfa and row crops, due to lower elevations, warmer temperatures, and supplemental storage supplies during the later irrigation season.

Planning Scenario Adjustments

Urbanization in the basin will likely have a limited impact on agriculture in the future. Only 4,080 acres of irrigated land basin-wide were estimated to be urbanized by 2050. The larger towns of Durango, Cortez, and Pagosa Springs do not have significant areas of irrigated acreage located within or directly adjacent to the current municipal boundaries, and urbanization of acreage in these areas is projected to be low in the future. Smaller towns in the basin, such as Norwood, Nucla, Bayfield, and Mancos are surrounded by irrigated agriculture, which may lead to some urbanization of irrigated lands by 2050.

Table 4.9.4 summarizes the planning scenario adjustments described above and other adjustments that impact agricultural diversion demands in the various scenarios.

Table 4.9.4 Planning Scenario Adjustments for Agricultural Demands in the Southwest Basin

Adjustment Factor*	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Change in Irrigated Land due to Urbanization	3,800 Acre Reduction	3,800 Acre Reduction	3,800 Acre Reduction	3,800 Acre Reduction	3,800 Acre Reduction
IWR Climate Factor	-	-	26%	34%	34%
Emerging Technologies	-	-	-	10% IWR Reduction 10% System Efficiency Increase	-

** See section 2.2.3 for descriptions of adjustment methodologies and assumptions*

Agricultural Diversion Demand Results

Table 4.9.5 and Figure 4.9.3 summarize the acreage, IWR, and the agricultural diversion demand for surface water supplies in the Southwest Basin for current conditions and the five planning scenarios. Increased demands were projected for *Cooperative Growth* and *Hot Growth*, reflecting the impacts of climate change, without the benefit of increased efficiencies reflected in *Adaptive Innovation*.

Table 4.9.5 Summary of Agricultural Diversion Demand Results in the Southwest Basin

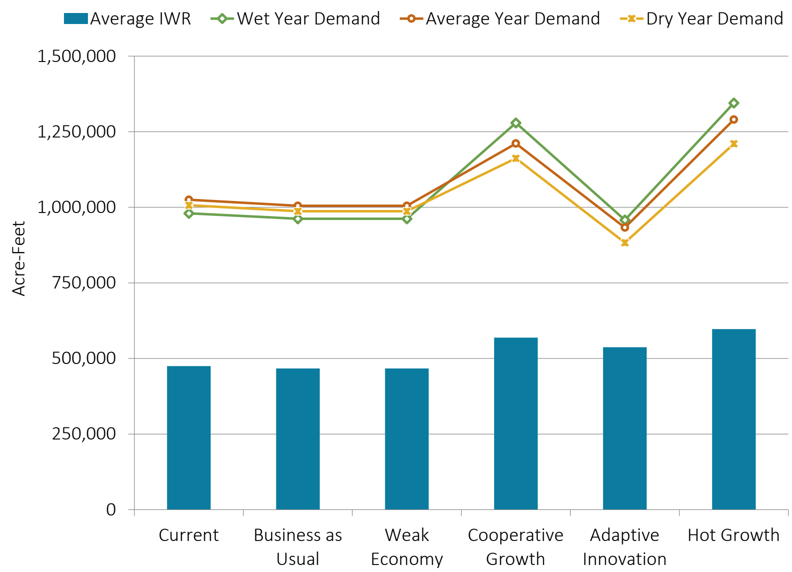
	Current (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Irrigated Acreage (acres)	222,500	218,800	218,800	218,800	218,800	218,800
Average IWR (AFY)	474,900	467,000	467,000	569,000	537,000	597,000
Total Surface and Groundwater Diversion Demand						
Average Year (AFY)	1,025,000	1,005,000	1,005,000	1,211,000	933,000	1,290,000
Wet Yr. Change	-4%	-4%	-4%	6%	3%	4%
Dry Yr Change	-2%	-2%	-2%	-4%	-5%	-6%

Average agricultural diversion demand was calculated using the average hydrologic years (i.e., years classified as neither wet or dry) from 1950-2013

SYSTEM EFFICIENCY

In some cases, diversion demands can be higher in wet years because system efficiency decreases due to the relative abundance of supply.

Figure 4.9.3 Agricultural Diversion Demands and IWR Results in the Southwest Basin



4.9.5 Municipal and Self-Supplied Industrial Diversion Demands

Population Projections

The Southwest Region currently includes about 2 percent of the statewide population. Between the years 2015 and 2050, it is projected to grow from approximately 110,000 to between 130,000 and 280,000 people in the low and high growth projections, respectively, which is an increase in population of 16 to 161 percent. On a percentage basis, the Southwest Basin has the largest projected increase of all basins throughout the state. Table 4.9.6 shows how population growth is projected to vary across the planning scenarios for the Southwest Basin.

Table 4.9.6 Southwest Basin Baseline and Projected Populations

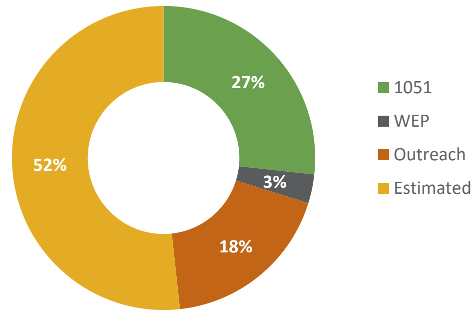
Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
107,999	195,837	125,814	201,010	264,189	282,144

Current Municipal Demands

Sources of water demand data such as 1051 or WEP data made up less than half of the available information in the Southwest Basin, and baseline water demands were largely estimated as shown in Figure 4.9.4.

Figure 4.9.5 summarizes the categories of municipal, baseline water usage in the Southwest Basin. On a basin scale, the non-residential outdoor demand as a percentage of the systemwide demand is one of the lowest reported throughout the state, at approximately 9 percent. Conversely, the baseline non-revenue water demand is one of the highest statewide, at approximately 15 percent of the systemwide demands.

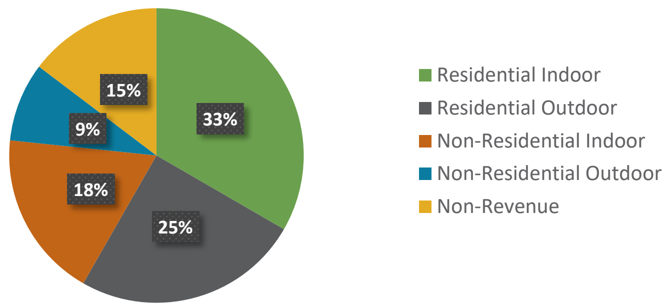
Figure 4.9.4 Sources of Water Demand Data in the Southwest Basin



DECREASING GPCD

The Southwest Region average baseline per capita systemwide demand has increased from 183 gpcd in SWSI 2010 to approximately 198 gpcd.

Figure 4.9.5 Categories of Water Usage in the Southwest Basin



Projected Municipal Demands

Figure 4.9.6 provides a summary of per capita baseline and projected water demands for the Southwest Basin. Systemwide, the projected per capita demands decrease relative to the baseline except for *Hot Growth,* which has a similar systemwide per capita demand as the baseline, but the demand category distributions are different. The residential indoor demand is the greatest demand category in the baseline, but the residential outdoor demand exceeds the residential indoor demand in the all of the projections except for *Weak Economy*. Outdoor demands increased significantly for *Hot Growth* due to an increase in outdoor demands driven by the "Hot and Dry" climate factor (described in Section 2).

The Southwest Basin municipal baseline and projected demands are provided in Table 4.9.7, showing the combined effect of population and per capita demands. Municipal demands are projected to grow from approximately 24,000 AFY in 2015 to between 26,000 and 63,000 AFY in 2050. La Plata County accounts for nearly half of the baseline demand, followed by Montezuma County at just under one-third of the basin demand.

The baseline and projected demand distributions shown in Figure

Figure 4.9.6 Southwest Basin Municipal Baseline and Projected Per Capita Demands by Water Demand Category (gpcd)

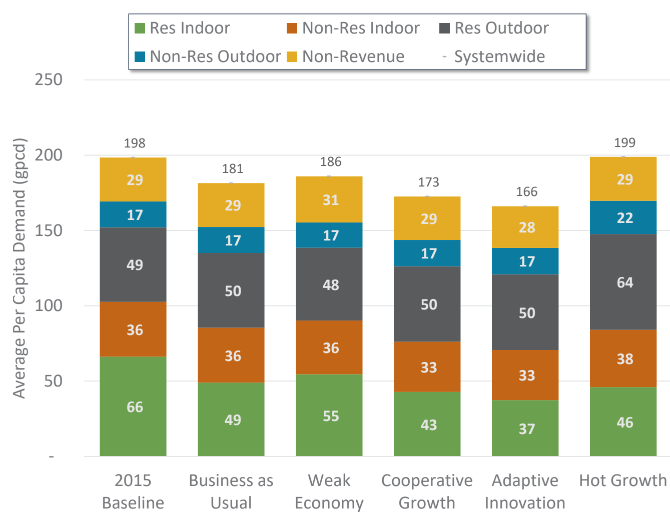
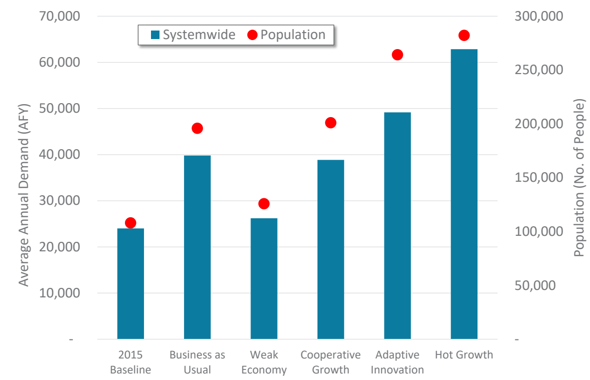


Table 4.9.7 Southwest Basin Municipal Baseline and Projected Demands (AFY)

Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
24,009	39,810	26,214	38,864	49,164	62,851

4.9.7 also show how the population varies between the scenarios. All of the planning scenarios except for *Weak Economy* result in a significant increase relative to the baseline. Demands generally follow the population patterns, however increased outdoor demands for the "Hot and Dry" climate condition have a greater impact on gpcd, resulting in higher demands for *Hot Growth*.

Figure 4.9.7 Southwest Basin Baseline and Projected Population and Municipal Demands



Self-Supplied Industrial Demands

The Southwest Basin currently includes about 1 percent of the statewide SSI demand. SSI demands in this basin are associated with the snowmaking and thermoelectric sub-sectors, with no demands projected for large industry or energy development sub-sectors. Southwest region total SSI demands are shown in Figure 4.9.8 and summarized in Table 4.9.8.

The baseline snowmaking demand is 430 AFY as compared to 410 AFY in SWSI 2010. Projected demands remain at 430 AFY because there is no planned expansion of snowmaking acreage. Projected demands were not varied by scenario.

Thermoelectric demands are related to one facility located in Montrose County and were based on information in SWSI 2010. The baseline demand remains 1,850 AFY as represented in SWSI 2010. Projected thermoelectric demands range from 3,510 AFY to 4,290 AFY.

Figure 4.9.8 Southwest Basin Self-Supplied Industrial Demands

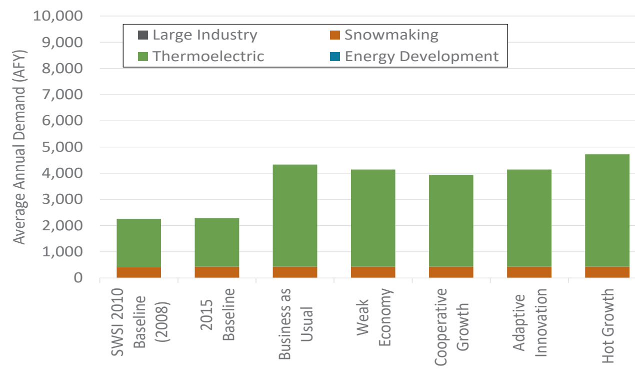


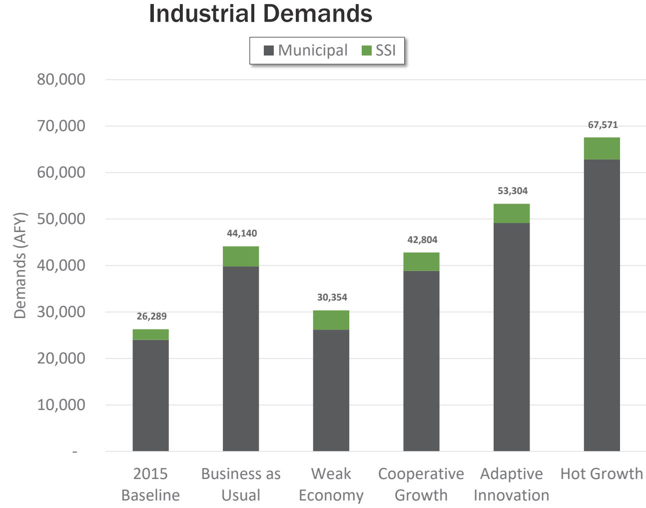
Table 4.9.8 Southwest Basin SSI Baseline and Projected Demands (AFY)

Sub-sector	Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Large Industry	-	-	-	-	-	-
Snowmaking	430	430	430	430	430	430
Thermoelectric	1,850	3,900	3,710	3,510	3,710	4,290
Energy Development	-	-	-	-	-	-
Sub-Basin Total	2,280	4,330	4,140	3,940	4,140	4,720

Total M&I Diversion Demands

Southwest Basin combined M&I demand projections for 2050 range from approximately 30,000 AFY in the *Weak Economy* to 68,000 AFY in *Hot Growth*, as shown in Figure 4.9.9. SSI demands account for around 7 to 14 percent of the M&I demands in the Southwest Basin. On a basin scale, the demand projections follow the statewide sequence of the scenario rankings described in the CWP.

Figure 4.9.9 Southwest Basin Municipal and Self-Supplied Industrial Demands



4.9.6 Water Supply Gaps

The agricultural and M&I diversion demands were compared against available water supply modeled for current conditions and the five planning scenarios. Gaps were calculated when water supply was insufficient to meet demands.

Agricultural

The Southwest Basin agricultural diversion demands, demand gaps, and consumptive use gaps for the baseline and planning scenarios are presented in Table 4.9.9 and illustrated in Figure 4.9.10. An annual time series of gaps in terms of percent of demand that was unmet is shown in Figure 4.9.11.

INCREMENTAL GAP

The incremental agricultural gap quantifies the degree to which the gap could increase beyond what agriculture has historically experienced under water shortage conditions.

Table 4.9.9 Southwest Basin Agricultural Gap Results (AFY)

		Scenario					
		Scenario	**Business as Usual**	**Weak Economy**	**Cooperative Growth**	**Adaptive Innovation**	**Hot Growth**
Average	Average Annual Demand	1,024,800	1,005,400	1,005,400	1,220,500	923,100	1,271,700
	Average Annual Gap	126,600	120,300	119,800	276,700	219,000	355,100
	Average Annual Gap Increase from Baseline	-	-	-	150,100	92,400	228,400
	Average Annual Percent Gap	12%	12%	12%	23%	24%	28%
	Average Annual CU Gap	72,300	68,700	68,400	158,500	147,200	206,400
Maximum	Demand in Maximum Gap Year	1,153,000	1,131,100	1,131,100	1,215,200	899,300	1,238,200
	Gap in Maximum Gap Year	517,600	507,400	504,900	679,500	474,000	738,100
	Increase from Baseline Gap	-	-	-	161,900	-	220,500
	Percent Gap in Maximum Gap Year	45%	45%	45%	56%	53%	60%

Study period for Water Supply Analysis is 1975-2013, reflecting different baseline demand than described in Agricultural Diversion Demands section.

Figure 4.9.10 Projected Average Annual Agricultural Diversion Demand, Demand Met, and Gaps in the Southwest Basin

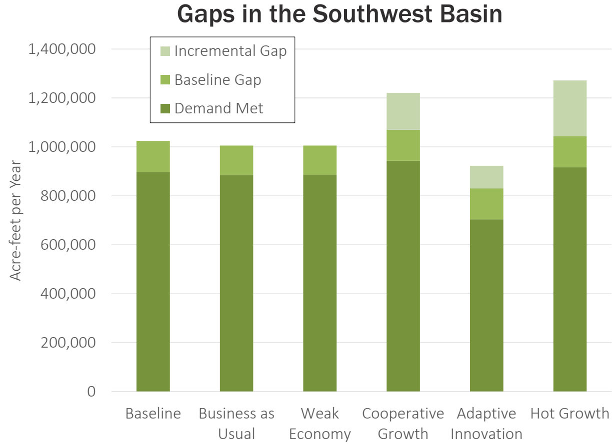
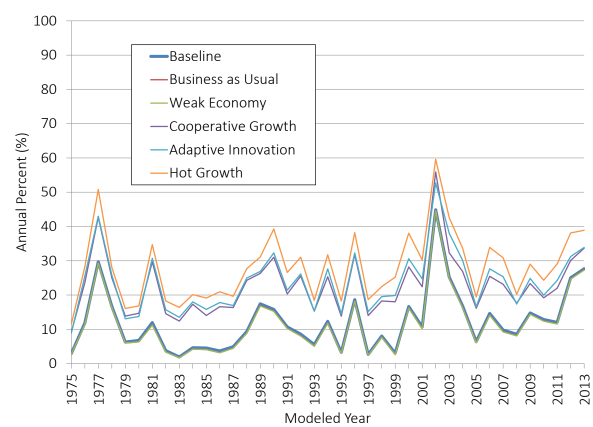


Figure 4.9.11 Annual Agricultural Gaps (expressed as a percentage of demand) for Each Planning Scenario



The following are observations on agricultural demands and gaps:

- Agricultural diversion demands are reduced in three of the five planning scenarios due to urbanization and reduction of irrigated acres.
- Agricultural diversion demand is projected to increase by 11 to 16 percent in *Cooperative Growth* and *Hot Growth* due to climate impacts. The increased demand in these scenarios is exacerbated by reduced water supply, resulting in an increased gap.
- Although *Adaptive Innovation* estimates reduced demand, the reduction in water supply due to climate change could result in an increased gap over baseline.

M&I

The diversion demand and gap results for M&I in the Southwest Basin are summarized in Table 4.9.10 and illustrated in Figure 4.9.12. An annual time series of gaps in terms of percent of demand that was unmet is shown in Figure 4.9.13.

Table 4.9.10 Southwest Basin M&I Gap Results (AFY)

		Scenario					
		Scenario	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand	27,200	44,800	30,200	43,300	54,000	69,500
	Average Annual Gap	0[1]	3,300	400	4,100	7,800	13,400
	Average Annual Percent Gap	0%	7%	1%	9%	14%	19%
Maximum	Demand in Maximum Gap Year	27,200	44,800	30,200	43,300	54,000	69,500
	Gap in Maximum Gap Year	0*	7,500	1,800	7,700	13,800	24,800
	Percent Gap in Maximum Gap Year	0%	17%	6%	18%	26%	36%

** CDSS water allocation model in this basin calculates small baseline M&I gaps, but they are either due to calibration issues or they are reflective of infrequent, dry-year shortages that are typically managed with temporary demand reductions, such as watering restrictions.*

Study period for Water Supply Analysis is 1975-2013, reflecting different baseline demand than described in M&I Demand section. Baseline demand also may vary slightly from previous section due to differences in geographic distribution of demand for counties that lie in multiple basins.

Figure 4.9.12 Projected Maximum Annual M&I Demand Met and Gaps in the Southwest Basin

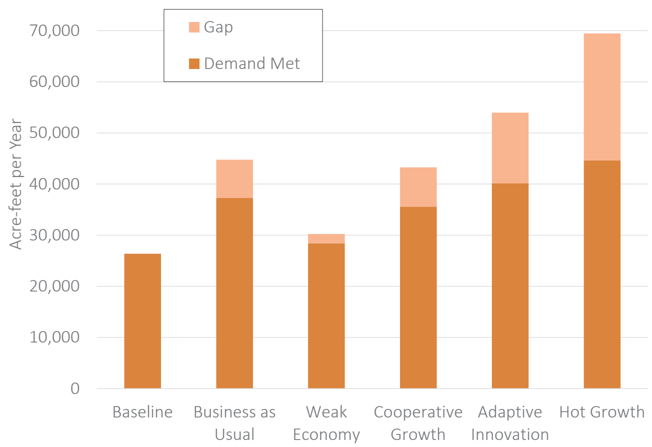
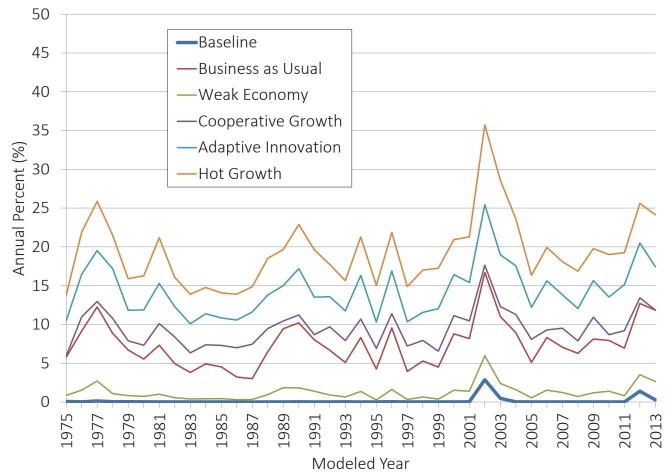


Figure 4.9.13 Annual M&I Gaps (expressed as a percentage of demand) for Each Planning Scenario



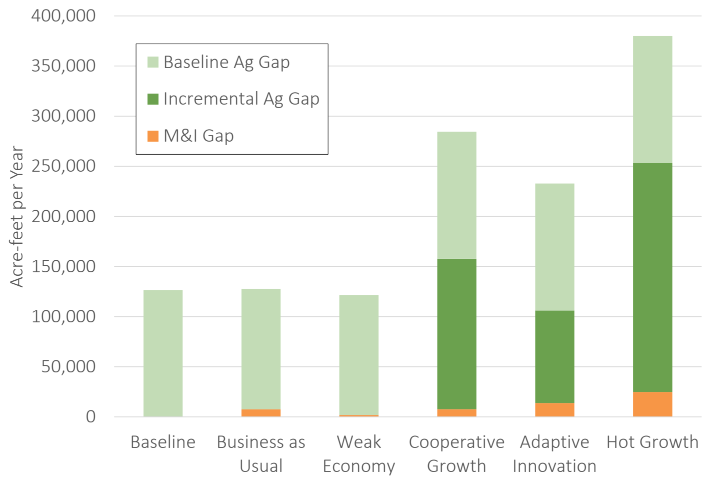
The following are observations on M&I diversion demands and gaps:

- The Southwest Basin is projecting the largest percentage increase in population in the state, which results in increased municipal demand for all future scenarios.
- Thermoelectric demands drive a modest increase in SSI demand.
- Water supply gaps for the planning scenarios range from 1 to 20 percent of demand. The largest gap is projected for *Hot Growth*, which is 36 percent of demand in the maximum gap year.

Total Gap

Figure 4.9.14 illustrates the total combined agricultural and M&I diversion demand gap in the Southwest Basin. The figure combines the average annual baseline and incremental agricultural gaps and the maximum M&I gap. In *Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth*, gaps were driven by agricultural demands, which increase in the "Hot and Dry" climate conditions.

Figure 4.9.14 Projected Average Annual Agricultural Gaps and Maximum M&I Diversion Demand Gaps in the Southwest Basin



Supplies from Urbanized Lands

By 2050, irrigated acreage in the Southwest Basin is projected to decrease by 3,800 acres due to urbanization. Irrigation supplies for these lands could potentially be used for M&I needs in the future (subject to a variety of unknowns such as seniority and type of water supply, willingness to change the use of water through water court, etc.). The average annual historical consumptive use associated with potentially urbanized acreage for each scenario is reflected in Table 4.9.11. The data in the table represent planning-level estimates of this potential supply and has not been applied to the M&I gaps.

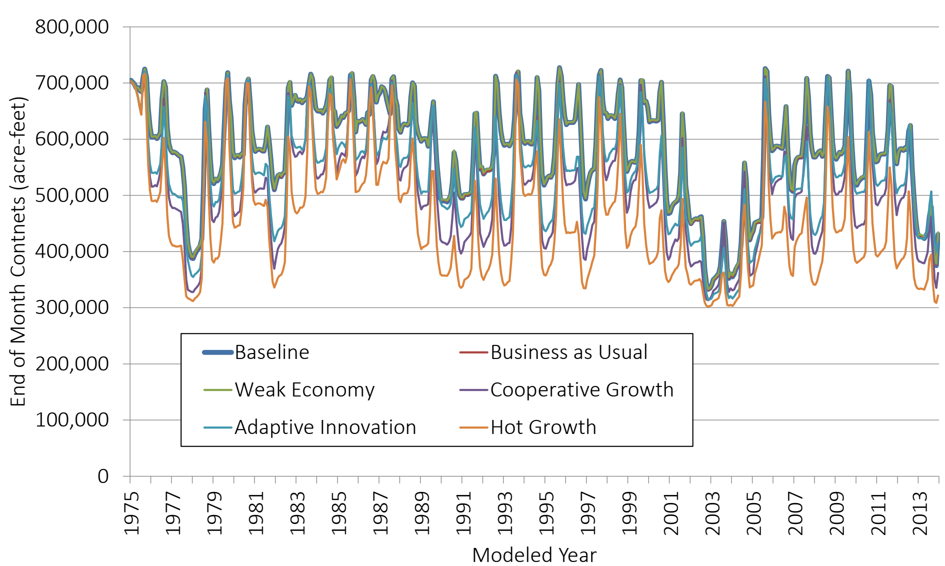
Table 4.9.11 Estimated Consumptive Use from Lands Projected to be Urbanized by 2050 in the Southwest Basin

	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Urbanized Acreage (acres)	3,800	3,800	3,800	3,800	3,800
Estimated Consumptive Use (AFY)	6,900	6,900	7,100	6,800	6,800

Storage

Total simulated reservoir storage from the Southwest Basin water allocation model is shown on Figure 4.9.15. Baseline and *Weak Economy* conditions show the highest levels of water in storage (in general) and the lowest is in *Hot Growth*. A significant spread between storage levels is shown for the various planning scenarios, with as much as 200,000 AF storage difference between *Weak Economy* and *Hot Growth*.

Figure 4.9.15 Southwest Basin Total Simulated Storage



4.9.7 Available Supply

Figures 4.9.16 through 4.9.19 show simulated available flow for the Southwest Basin at two locations to illustrate the difference in hydrology and water availability across the multiple sub-basins. The Animas River at Durango gage is located just upstream of the Durango Boating Park, which is a recreational instream flow demand of 1,400 cfs. Available flow greatly increases downstream of the Boating Park reach.

The La Plata River produces very little runoff and demands on the river chronically experience shortages due to physical flow limitations and curtailment due to the La Plata Compact. At both of the locations, available flows are projected to diminish and peak flows could occur earlier in the runoff season under planning scenarios with climate change impacts.

Figure 4.9.16 Simulated Hydrographs of Available Flow at Animas River at Durango, CO

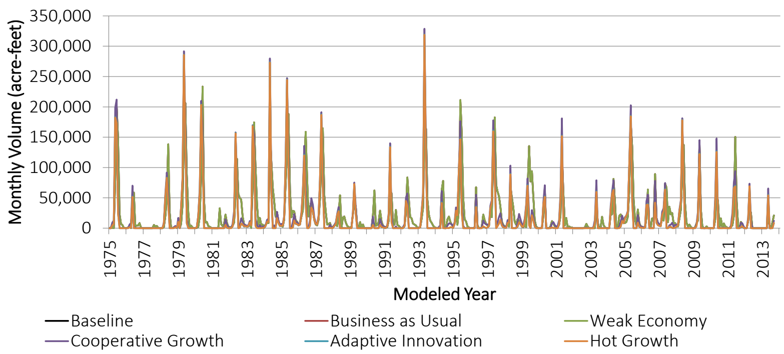


Figure 4.9.17 Average Monthly Simulated Hydrographs of Available Flow at Animas River at Durango, CO

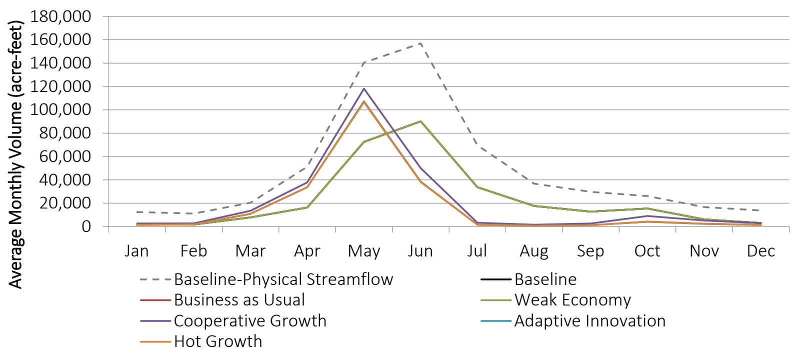


Figure 4.9.18 Simulated Hydrographs of Available Flow at La Plata River at Hesperus, CO

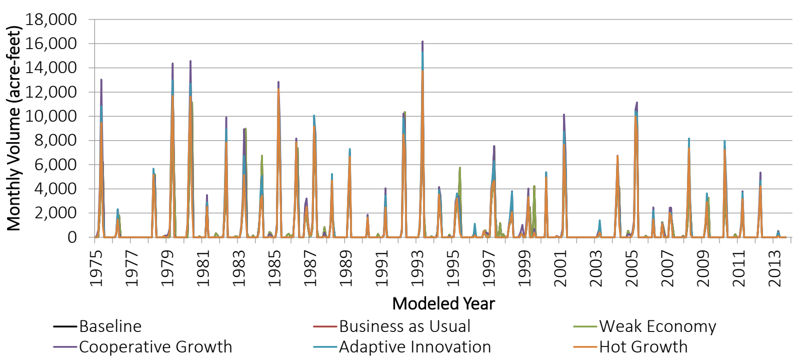
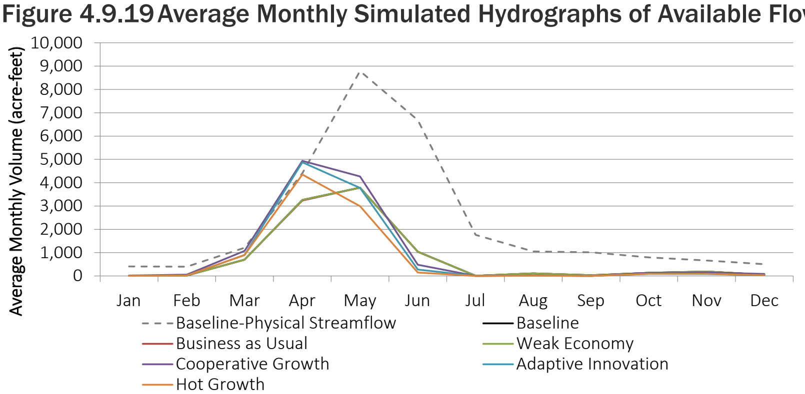


Figure 4.9.19 Average Monthly Simulated Hydrographs of Available Flow at La Plata River at Hesperus, CO



4.9.8 Environment and Recreation

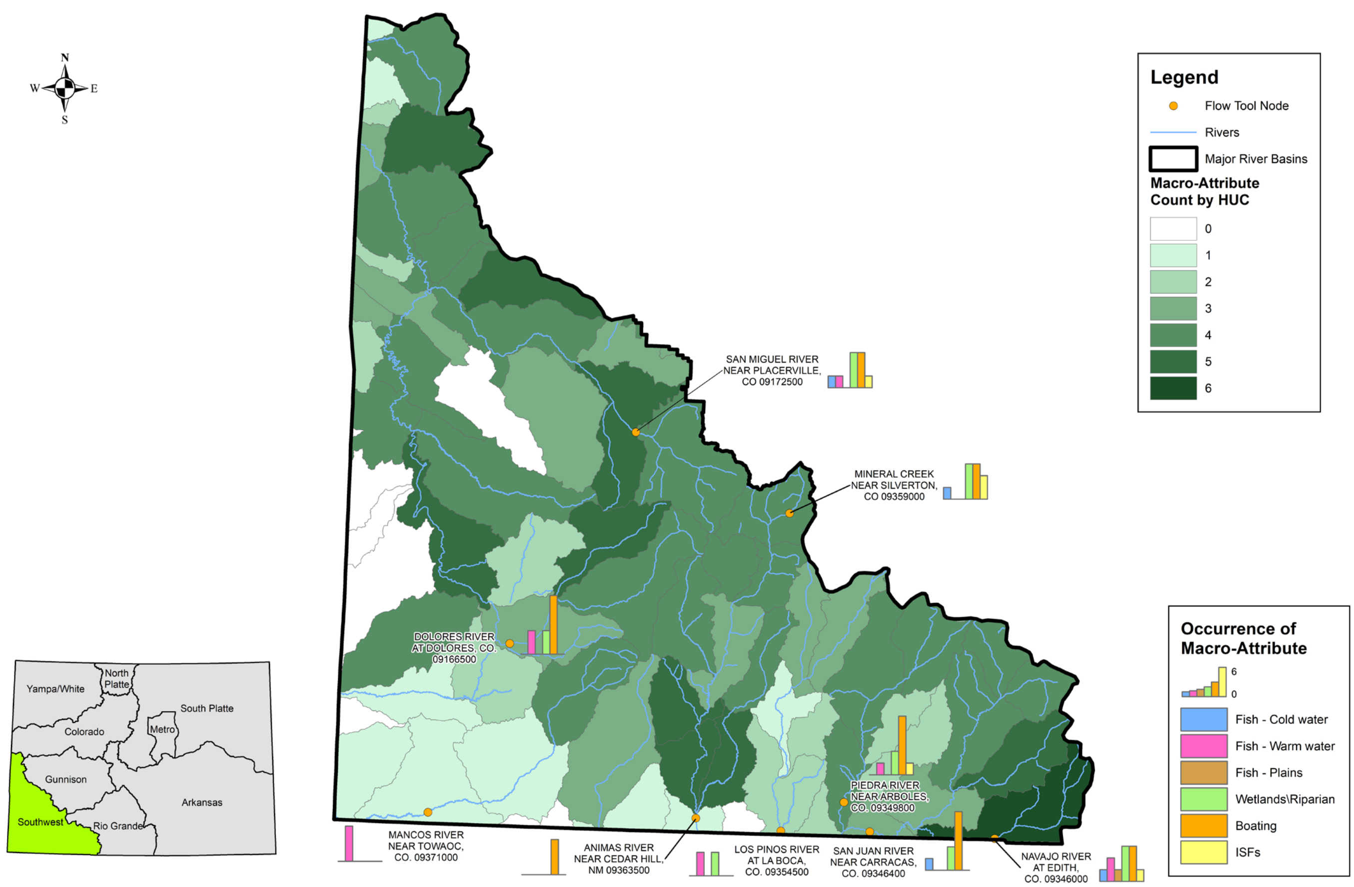
A total of nine water allocation model nodes were selected for the Flow Tool within the Southwest Basin (see list below and Figure 4.9.20). Figure 4.9.20 also shows subwatersheds (at the 12-digit HUC level) and the relative number of E&R attributes located in each subwatershed.

- Dolores River at Dolores, Colorado (09166500)
- San Miguel River near Placerville, Colorado (09172500)
- Navajo River at Edith, Colorado (09346000)
- San Juan River near Carracas, Colorado (09346400)
- Piedra River near Arboles, Colorado (09349800)
- Los Pinos River at La Boca, Colorado (09354500)
- Animas River at Howardsville, Colorado (09357500)
- Animas River near Cedar Hill, New Mexico (09363500)
- Mancos River near Towaoc, Colorado (09371000)

NATURALIZED FLOW

Naturalized flows reflect conditions that would occur in the absence of human activities. Baseline flows reflect current conditions as influenced by existing infrastructure and river operations. While observations regarding naturalized flows may be informative, baseline flows reflect actual conditions and the diverse operations of a river's many users.

Figure 4.9.20 Flow Tool Nodes Selected for the Southwest Basin



Results and observations regarding Flow Tool analyses using flow data developed in the water supply and gap analyses for baseline conditions and the planning scenarios are described below in Table 4.9.12.

Table 4.9.12 Summary of Flow Tool Results in the Southwest Basin

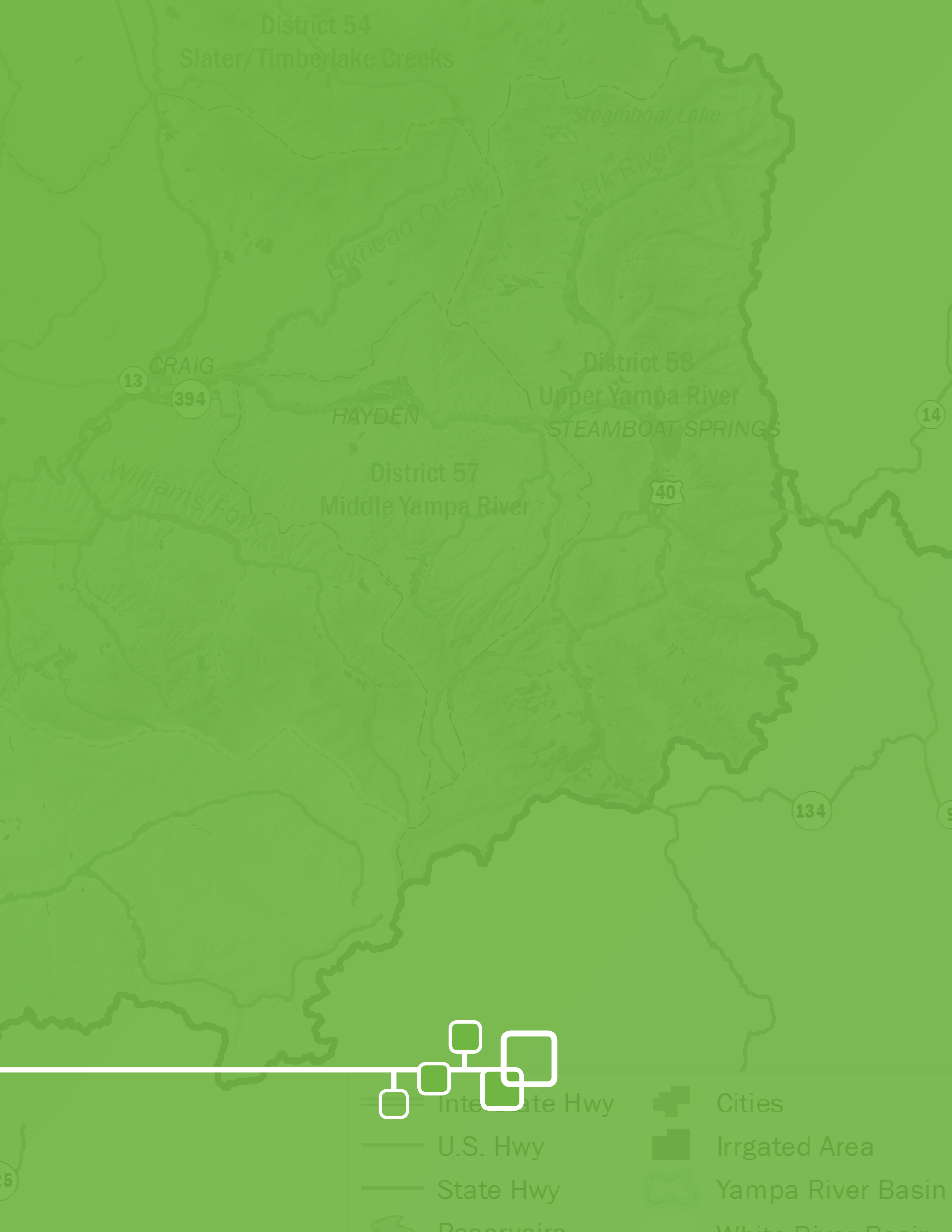
Category	Observation
Projected Flows	In locations where baseline conditions are minimally depleted from naturalized conditions (e.g., the San Miguel River), peak flow magnitude under *Business as Usual* and *Weak Economy* are projected to decline only slightly below baseline. Under climate change scenarios, declines in peak flow magnitude are projected to be further below baseline.
	At all locations, the timing of peak flow is projected to move earlier in the year for all climate change projections (Cooperative Growth, Adaptive Innovation, and Hot and Dry). Under these climate change projections, June flows may decrease the most (e.g., Dolores River at Dolores). Under these same scenarios, April flow may increase, but the increase in April flow magnitude may not offset the decline in June flow magnitude.
Ecological Risk	In all locations, mid- and late-summer flows are projected to decline under *Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth* scenarios, increasing risks for coldwater and warmwater fish.
	In locations where naturalized and baseline conditions are similar, peak flow-related risk to riparian/wetland plants and fish are projected to remain low to moderate under *Business as Usual*, *Weak Economy*, and *Cooperative Growth* scenarios. Under *Adaptive Innovation* and *Hot Growth*, this risk may increase.
	In locations where peak flows under baseline are already substantially less than naturalized conditions, peak flow-related risk to riparian/wetland plants and fish is already high and may increase under climate change scenarios.
	Under all climate change scenarios, runoff and peak flows occur earlier, and possible mis-matches between peak flow timing and species' needs may occur.
	In locations where naturalized and baseline conditions are similar, risk to coldwater fish (mainly trout) may increase under the various planning scenarios because of declines in mid- and late-summer flow. However, the risk remains moderate in most years.
	In locations that experience low summer flows, risk to fish may increase. Note that the Flow Tool risk assessment using coldwater and warmwater fish metrics does not include July because historically July flows are sufficient. In some locations, July flows may be significantly reduced under climate change scenarios (e.g., July flows under *Hot Growth* on the Piedra River near Arboles). The projected reduction will likely result in reduced habitat and increased stream temperatures.
ISFs and RICDs	ISFs throughout the Southwest and the RICD on the Animas River may not be met in many years under *Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth*. For example, flows on the San Miguel River near Placerville are projected to fall short of the 93 cfs summer ISF regularly during mid- and late-summer. In August, this ISF is projected to be unmet during 1 out of 3 years under *Cooperative Growth* and during two out of three years under *Adaptive Innovation* and *Hot Growth*.
	On the Animas River, the 25 cfs RICD near Howardsville is projected to not be met in numerous years during late summer (August) through October, and again in January and February (when the minimum flow is 13 cfs) under the three climate change scenarios.
E&R Attributes	Under baseline, *Business as Usual*, and *Weak Economy*, current flow issues related to E&R attributes arise primarily because of depletions that increase moving downstream.
	In some locations, transbasin diversions reduce and change the timing of flow in the basin of origin while augmenting flows in the receiving basin.
	Under climate change scenarios, the shift in the timing of peak flow, reductions in total runoff, and increasing consumptive demands may contribute to reductions in mid- and late-summer flows.

The Yampa, White, and Green Basins cover approximately 10,500 acres in northwestern Colorado and south-central Wyoming. The basin landscape is diverse and includes steep mountain slopes, high plateaus, canyons, and broad alluvial valleys. Livestock, grazing, and recreation are the predominant land uses. Near the towns of Craig, Hayden, Steamboat Springs, Yampa, and Meeker, much of the land is dedicated to agricultural use, and the mountains are covered by forest. The Steamboat Springs area, featuring a destination ski resort, is likely to experience continued and rapid population growth.

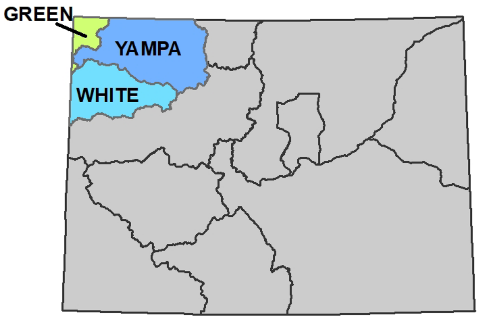
The Technical Update largely keeps the analysis at the basin scale. There are some exceptions where subbasin (river basin) analysis of major waterways was more straightforward. To that end, both the Yampa and the White river basins were explicitly modeled with results that are shown in this section. The combined Yampa-White-Green results are shown where statewide results are described.

Note that tributaries of the Green River have five diversions and one instream flow water right, and these are included in the model for the Yampa Basin. The demands and potential gaps from these structures are included in the Yampa Basin results.

YAMPA WHITE GREEN


District 54
Slater/Timberlake Creeks
Steamboat Lake
Elk River
Elkhead Creek
CRAIG
13
394
HAYDEN
District 58
Upper Yampa River
STEAMBOAT SPRINGS
14
District 57
Middle Yampa River
Williams Fork
40
134
U.S. Hwy
State Hwy
Cities
Irrgated Area
Yampa River Basin

4.10 YAMPA-WHITE-GREEN BASIN RESULTS



4.10.1 BASIN CHALLENGES

Key future water management issues for this basin include gas and oil shale development and addressing water resources needs for agriculture, tourism and recreation, and protection of endangered species. These challenges are outlined in the Colorado Water Plan and are summarized below.

Table 4.10.1 Key Future Water Management Issues in the Yampa-White-Green Basin

<table>
<tr><th>Agriculture</th><th>Environment and Recreation</th><th>Municipal and Industrial</th><th>Compacts and Administration</th></tr>
<tr><td>• Agricultural producers would like to increase irrigated land by 14,000 acres but lack finances to do so.</td><td>• Implementation of a successful Upper Colorado River Endangered Fish Recovery Program is vital to ensuring protection of existing and future water uses.</td><td>• The emerging development of gas and oil shale resources is affecting water demand, for both direct production and the associated increase in municipal use.
• Industrial uses, especially power production, are a major water use. Future energy development is less certain.</td><td rowspan="2">• While rapidly growing in the Steamboat Springs area, the basin as a whole is not developing as quickly as other portions of the state. Concerns have arisen that the basin will not get a “fair share” of water under the Colorado River Compact in the event of a compact call.</td></tr>
<tr><td colspan="3">• Agriculture, tourism, and recreation are vital components of this basin’s economy. As the needs of communities and industry grow, competition among sectors could increase.</td></tr>
</table>

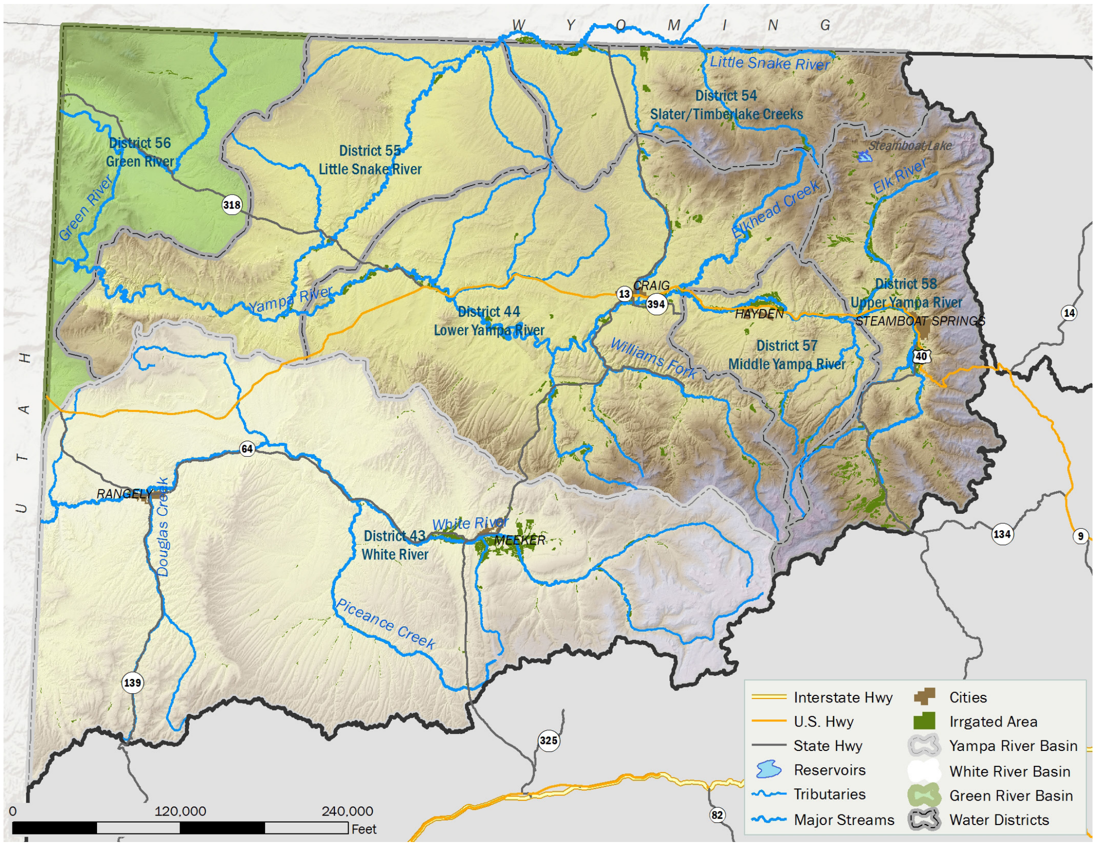


Figure 4.10.1 Map of the Yampa-White-Green Basin

4.10.2 SUMMARY OF TECHNICAL UPDATE RESULTS

Key results and findings of the Technical Update pertaining to agricultural and M&I demands and gaps as well as findings related to environmental and recreational attributes and future conditions are summarized below in Table 4.10.2.

Table 4.10.2 Summary of Key Results in the Yampa-White-Green Basin

Agriculture	Environment and Recreation	Municipal and Industrial
• Agricultural gaps may increase significantly in the Yampa Basin if water demands increase because of new acreage and higher IWR. • Gaps in the Yampa and White basins may also increase if stream flow is diminished via climate change. • Agricultural gaps in the White Basin are not projected to be as significant as in the Yampa	• In most locations, summer flows may be depleted significantly in climate-impacted scenarios, which creates high to very high risk for coldwater and warmwater fish. • Stream flows may be substantially below flow recommendations in some locations under climate-impacted scenarios.	• M&I demand for the combined basin ranges between 6 to 10 percent of agricultural demand. • Water supply gaps in the White Basin show a large increase in *Hot Growth* mainly due to potential increased energy development demand. • Increased population and thermoelectric demand drive increasing M&I gaps in the Yampa Basin.

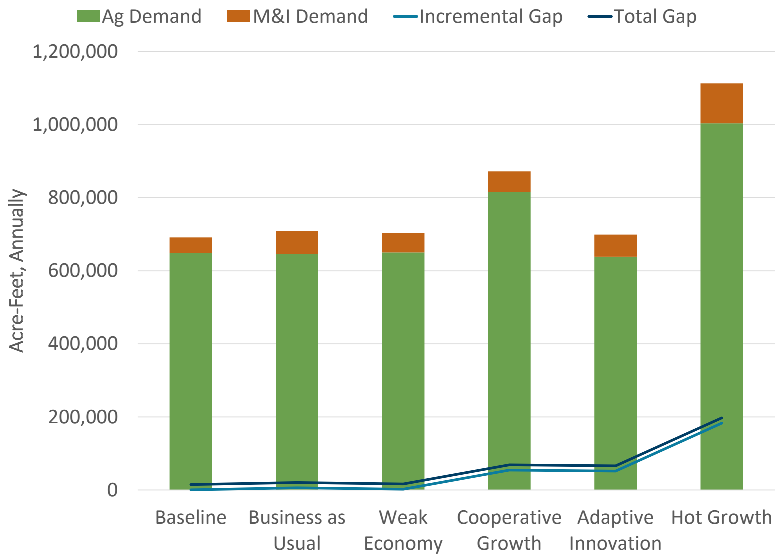
Results describing current and potential future M&I and agricultural demands and gaps are summarized in Table 4.10.3 and in Figure 4.10.2.

Table 4.10.3 Summary of Diversion Demand and Gap Results in the Yampa-White-Green Basin

		Current (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Yampa	**Average Annual Demand**						
	Agricultural (AFY)	402,500	403,600	403,600	522,500	461,000	684,300
	M&I (AFY)	36,900	53,300	46,700	48,900	53,000	68,300
	Gaps						
	Ag (avg %)	3%	3%	3%	12%	13%	22%
	Ag (incremental-AFY)	-	400	300	49,800	45,700	136,800
	Ag (incremental gap as % of current demand)	-	0%	0%	12%	11%	34%
	M&I (max %)	0%	3%	1%	3%	5%	12%
	M&I (max-AF)	0*	1,600	700	1,600	2,500	8,200
White	**Average Annual Demand**						
	Agricultural (AFY)	246,700	242,900	246,700	293,900	177,800	319,700
	M&I (AFY)	5,300	10,000	6,100	6,900	7,700	41,000
	Gaps						
	Ag (avg %)	0%	1%	0%	1%	2%	2%
	Ag (incremental-AFY)	-	-	-	1,900	2,100	4,600
	Ag (incremental gap as % of current demand)	-	0%	0%	1%	1%	2%
	M&I (max %)	0%	39%	15%	13%	17%	82%
	M&I (max-AF)	0	3,900	900	900	1,300	33,500
Total	**Average Annual Demand**						
	Agricultural (AFY)	649,200	646,500	650,400	816,300	638,700	1,004,000
	M&I (AFY)	42,200	63,400	52,800	55,900	60,600	109,300
	Gaps						
	Ag (avg %)	2%	2%	2%	8%	10%	16%
	Ag (incremental-AFY)	-	400	300	51,700	47,800	141,400
	Ag (incremental gap as % of current demand)	-	0%	0%	8%	7%	22%
	M&I (max %)	0%	9%	3%	5%	6%	38%
	M&I (max-AF)	0*	5,600	1,600	2,600	3,800	41,700

** CDSS water allocation model in this basin calculates small baseline M&I gaps, but they are either due to calibration issues or they are reflective of infrequent, dry-year shortages that are typically managed with temporary demand reductions, such as watering restrictions.*

Figure 4.10.2 Summary of Diversion Demand and Gap Results in the Yampa-White-Green Basin



Summary of Environmental and Recreational Findings

- In most stream locations, peak flows may be modestly depleted with low to moderate risk to riparian/wetlands and fish habitat. Peak flows may move earlier in the year, with March, April and May flows increasing substantially and June flows decreasing. Possible mis-matches between peak flow timing and species needs may occur.
- In most stream locations, including those with current low risk during mid- and late-summer, summer flows may be depleted 65 to 90 percent under *Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth*, which could create high to very high risk for coldwater and warmwater fish.
- The recreational in-channel diversion in Steamboat Springs could be at risk of being unmet often in mid- to late-summer, and Instream Flow water rights in most areas could be at greater risk of not being met, especially under *Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth*.
- In critical habitat for endangered species, extremely reduced flows in mid- and late-summer (greater than 90 percent reduction in July on the Yampa River near Maybell; greater than 80 percent reduction in July and August on the White River near Watson) may result in the flows in most years being substantially below flow recommendations. On the Yampa, in addition to loss of habitat for endangered fish, extremely low flows favor non-native fish reproduction and survival.

4.10.3 NOTABLE BASIN CONSIDERATIONS

Section 4.1 described several analysis assumptions and limitations that apply to all basins and should be considered when reviewing and interpreting analysis results. Additional considerations specific to the Yampa-White-Green Basin are listed below:

- The Yampa-White-Green has published a follow-on report to their BIP, which has different results based on different modeling objectives, assumptions, and inputs (e.g., climate assumptions around paleohydrology are different than the assumptions in the Technical Update; see section 2.2.1).
- The Technical Update used water allocation models that reflect a strict application of water administration. In the Yampa-White-Green basin, some water users refrain from placing a call to share the benefit of available supplies.
  - As an example, in the White Basin, Kenney Reservoir is used for hydropower production. If future water shortages occur that might impact energy development, it is very possible that hydropower operators would choose to reduce generation as opposed to curtailing energy development uses.
- The Yampa-White-Green SSI demands for energy production could be further researched.
- Projected gaps in several scenarios are low relative to other basins. The result is consistent with expectations because supplies in the Yampa-White-Green have historically met demands. The first mainstem call on the Yampa occurred in 2018.
- Current Elkhead Reservoir operations related to the Yampa Programmatic Biological Opinion (PBO) are included in the Yampa model. The White PBO is in progress and was not included in the model. Future water supply projects and strategies were not included in the analysis.

GREEN RIVER DEMANDS

Tributaries of the Green River have five diversions and one instream flow water right, and these are included in the model for the Yampa Basin. The demands and potential gaps from these structures are included in the Yampa Basin results.

4.10.4 AGRICULTURAL DIVERSION DEMANDS

Agricultural Setting

Yampa Basin

Agriculture is a primary focus in the Yampa Basin. Irrigated acreage in the basin consists primarily of high mountain meadows and cattle ranches in the upper reaches of the basin along Elk Creek and the Yampa River. Irrigated acreage is also located along the Little Snake River as it meanders between Colorado and Wyoming.

White Basin

Approximately 60 percent of the irrigated acres in the White Basin are concentrated along the river near the Town of Meeker. The remaining acreage is located along tributaries and spread along the lower mainstem. Grass pasture is the dominant crop in the basin, and alfalfa is also grown. These forage crops support cattle grazing and ranching operations in the basin, which is a major economic driver. Mining and oil and gas extraction are also important elements of the basin's economy.

Planning Scenario Adjustments

Section 2 described ways in which inputs to agricultural diversion demand estimates were adjusted to reflect the future conditions described in the planning scenarios. Adjustments in the Yampa-White-Green Basin focused on urbanization, potential future climate conditions, and implementation of emerging technologies.

Yampa Basin

The Yampa-White-Green basin roundtable completed an Agricultural Water Needs Study in 2010 that identified 14,805 acres of potentially irrigable land in the Yampa Basin. For the Technical Update effort, the Yampa/White/Green basin roundtable contemplated how the irrigable land could be developed under the planning scenarios, recognizing that growth could vary depending on the future demand and economics for hay crops and cattle production. The stakeholders in the basin provided a varying amount of acreage and crops types for planned agricultural projects in each planning scenario in the Yampa Basin as reflected in Table 4.10.4.

Population projections anticipate significant growth in the Yampa Basin. The impact to irrigated areas, however, will be limited because the three largest municipal centers in the basin (Steamboat Springs, Hayden, and Craig) are not surrounded by irrigated agricultural areas.

White Basin

Future urbanization of irrigated lands is expected to be relatively limited in the basin, with 360 acres total in and around the towns of Meeker and Rangely projected to be urbanized. Population projections in Rio Blanco County are expected to decline in *Weak Economy*, and urbanization in this scenario was set to zero. Table 4.10.4 provides a summary of the adjustments to agricultural diversion demand drivers based for each planning scenario.

Table 4.10.4 summarizes the planning scenario adjustments described above and other adjustments that impact agricultural diversion demands in the various scenarios.

SYSTEM EFFICIENCY

In some cases, diversion demands surface water can be higher in wet years because system efficiency decreases due to the relative abundance of supply

Table 4.10.4 Planning Scenario Adjustments for Agricultural Demands in the Yampa and White Basins

Sub-basin	Adjustment Factor*	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Yampa	Change in Irrigated Land due to Urbanization	1,500 Acre Reduction	1,500 Acre Reduction	1,500 Acre Reduction	1,500 Acre Reduction	1,500 Acre Reduction
	Planned Agricultural Development Projects	1,000 Acre Increase 100% Alfalfa	1,000 Acre Increase 100% Alfalfa	5,000 Acre Increase 50/50 Grass Pasture/Alfalfa	14,805 Acre Increase 50/50 Grass Pasture/Alfalfa	14,805 Acre Increase 50/50 Grass Pasture/Alfalfa
	IWR Climate Factor	-	-	19%	34%	34%
	Emerging Technologies	-	-	-	10% IWR Reduction 10% System Efficiency Increase	-
White	Change in Irrigated Land due to Urbanization	360 Acre Reduction	-	360 Acre Reduction	360 Acre Reduction	360 Acre Reduction
	IWR Climate Factor	-	-	22%	37%	37%
	Emerging Technologies	-	-	-	10% IWR Reduction 10% System Efficiency Increase	-

** See section 2.2.3 for descriptions of adjustment methodologies and assumptions*

Agricultural Diversion Demand Results

Table 4.10.5 and Figures 4.10.3 and 4.10.4 summarize the acreage, IWR, and the agricultural diversion demand for surface water supplies in both the White and Yampa Basins for current conditions and the five planning scenarios. The largest variation in the White Basin occurred in *Adaptive Innovation* due to 10 percent reduction in IWR and 10 percent increase to system efficiency. In this basin, the combined impact of *Adaptive Innovation* adjustments resulted in an agricultural diversion demand that is lower than the current demand. The Yampa Basin saw the greatest increase in demand for *Hot Growth*, which assumed a large increase in irrigated acres.

Table 4.10.5 Summary of Agricultural Diversion Demand Results in the Yampa and White Basins

		Current	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Yampa	Irrigated Acreage (acres)	78,900	78,400	78,400	82,400	92,300	92,300
	Average IWR (AFY)	150,600	150,000	150,000	188,000	209,000	232,000
	Diversion Demand						
	Average Year (AFY)	402,000	403,000	403,000	518,000	456,000	679,000
	Wet Yr. Change	-4%	-3%	-3%	0%	1%	2%
	Dry Yr Change	0%	0%	0%	-1%	-2%	-3%
White	Irrigated Acreage (acres)	28,100	27,700	28,000	27,700	27,700	27,700
	Average IWR (AFY)	46,400	45,800	46,400	55,700	55,900	62,100
	Diversion Demand						
	Average Year (AFY)	243,000	239,000	243,000	293,000	180,000	324,000
	Wet Yr. Change	3%	3%	3%	4%	3%	6%
	Dry Yr Change	0%	0%	0%	-5%	-4%	-6%

Average agricultural diversion demand was calculated using the average hydrologic years (i.e., years classified as neither wet or dry) from 1950-2013

Figure 4.10.3 Agricultural Diversion Demands and IWR Results in the Yampa Basin

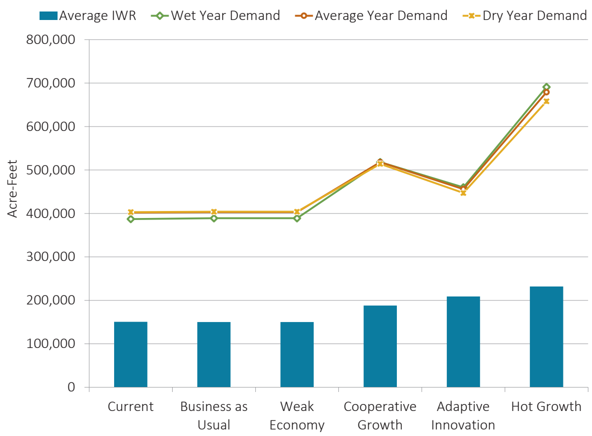
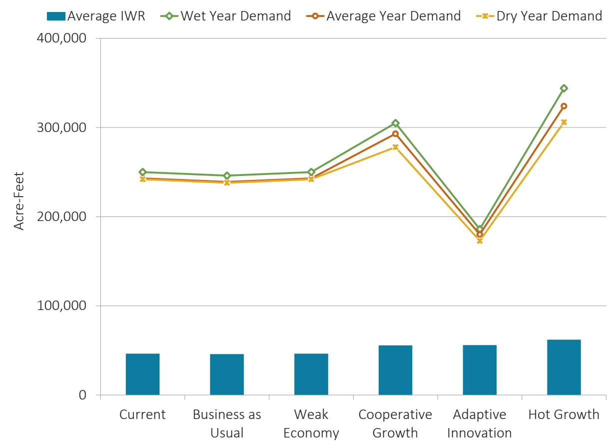


Figure 4.10.4 Agricultural Diversion Demands and IWR Results in the White Basin



4.10.5 Municipal and Self-Supplied Industrial Diversion Demands

Population Projections

The combined Yampa-White Basin currently includes less than 1 percent of the statewide population. Between the years 2015 and 2050, it is projected to change from approximately 44,000 to between 39,000 and 103,000 people in the low and high growth projections, respectively. Table 4.10.6 shows how population growth is projected to vary across the planning scenarios for White and Yampa basins.

Table 4.10.6 Yampa-White Basin 2015 and Projected Populations

Sub-basin	Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Yampa	37,200	59,900	34,400	63,500	86,000	91,900
White	6,500	7,400	4,200	7,000	10,600	11,300
Yampa-White Total	43,700	67,200	38,600	70,400	96,600	103,200

Current Municipal Demands

Sources of water demand data such as 1051 or WEP data were scarce in the Yampa and White Basins, and baseline water demands were largely estimated as shown on Figure 4.10.5.

Figure 4.10.6 summarizes the categories of municipal, baseline water usage in the Yampa and White Basins. In the Yampa Basin, and on a basin-scale, the residential indoor demand as a percentage of the systemwide demands is the highest reported throughout the state, at more than 50 percent. Conversely, the baseline residential outdoor water demand is the lowest statewide, at approximately 15 percent of the systemwide demands.

Figure 4.10.5 Sources of Water Demand Data in the Yampa-White Basin

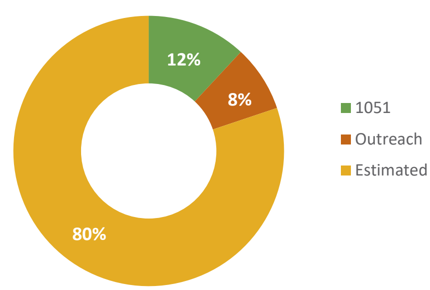
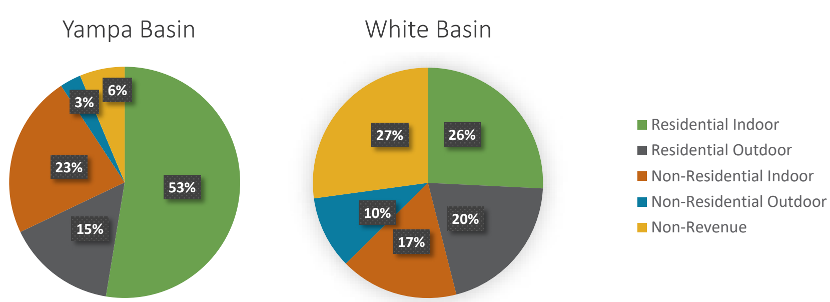


Figure 4.10.6 Categories of Water Usage in the Yampa-White Basin



Projected Municipal Demands

Figure 4.10.7 provides a summary of per capita baseline and projected water demands for the Yampa Basin. Systemwide, the projected per capita demands decrease relative to the baseline under all scenarios.

Figure 4.10.8 shows a summary of per capita baseline and projected water demands for the White Basin. Systemwide, the estimated per capita demands are projected to decrease relative to the baseline except in *Weak Economy* and *Hot Growth*. Consistently across all scenarios, the non-revenue water is the greatest demand category.

DECREASING GPCD

The Yampa-White Basin average baseline per capita systemwide demand has decreased slightly from 230 gpcd in SWSI 2010 to approximately 228 gpcd.

The relative proportions of various demand categories were estimated to be somewhat different in the White and Yampa Basins. Much of the difference is related to lack of representative data. In the White Basin, some usage data was derived from targeted outreach, but most of the data was filled (based on the outreach). In the Yampa Basin, some data were available via 1051 reporting, water efficiency plans, and targeted outreach, but much of the data was filled based on results from the available sources. Basin roundtables could work to acquire better data during the BIP update process.

Figure 4.10.7 Yampa Basin Municipal Baseline and Projected per Capita Demands by Water Demand Category

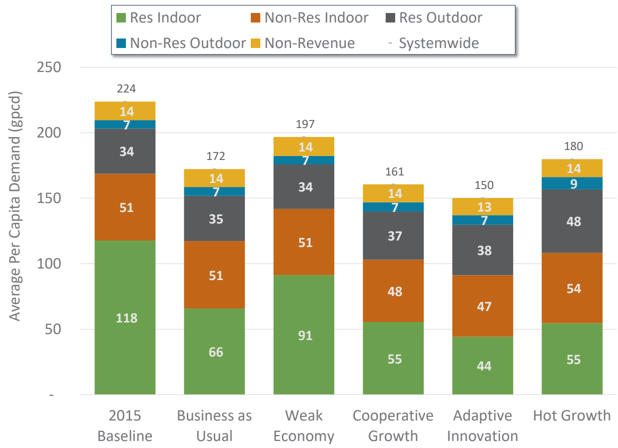


Figure 4.10.8 White Basin Municipal Baseline and Projected per Capita Demands by Water Demand Category

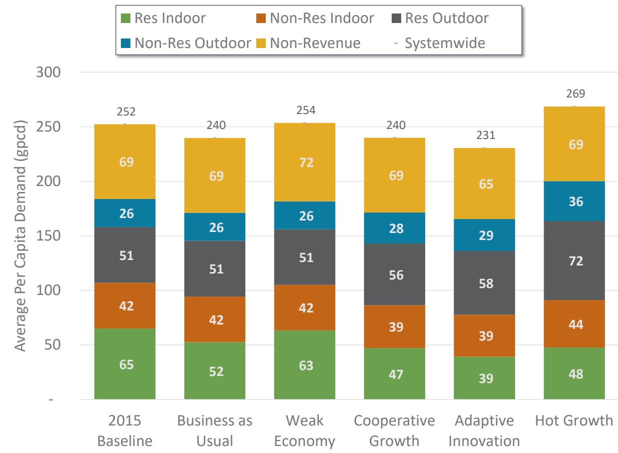


Table 4.10.7 Yampa-White Basin Municipal Baseline and Projected Demands (AFY)

Sub-basin	Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Yampa Basin	9,300	11,600	7,600	11,400	14,500	18,500
White Basin	1,800	2,000	1,200	1,900	2,700	3,400
Yampa-White Basin Total	11,200	13,500	8,800	13,300	17,200	21,900

Figure 4.10.9 Combined Yampa-White Basin Baseline and Projected Population and Municipal Demands

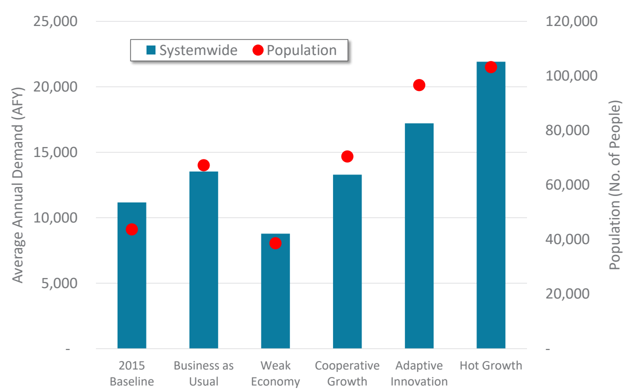
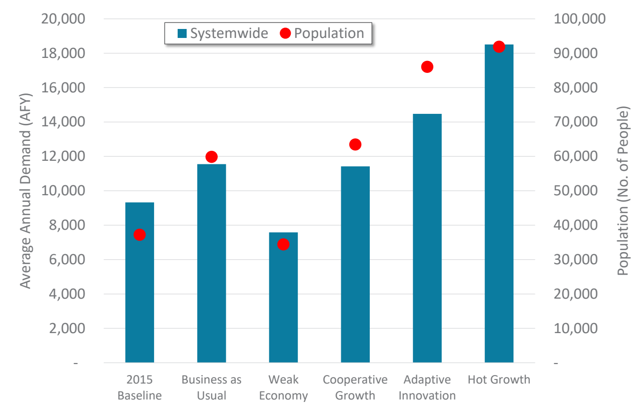


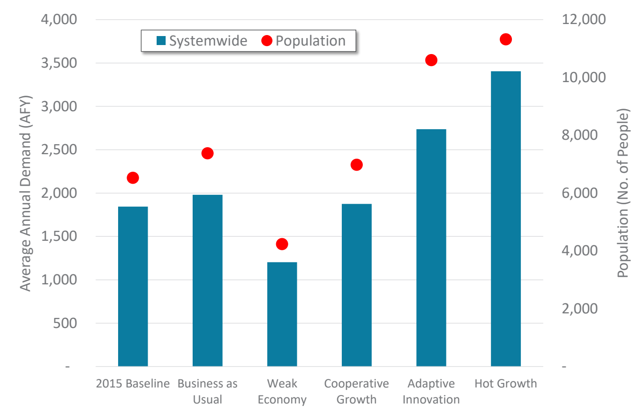
Figure 4.10.10 Yampa Basin Baseline and Projected Population and Municipal Demands



The Yampa-White Basin municipal baseline and projected demands are provided in Table 4.10.7, showing the combined effect of population and per capita demands. Municipal demands are projected to grow from approximately 11,000 AFY in 2015 to between 9,000 and 22,000 AFY in 2050.

The baseline and projected demand distributions are shown on Figures 4.10.9 through 4.10.11. Projected demands in *Business as Usual* and *Cooperative Growth* are nearly identical. All of the projection scenarios except for *Weak Economy* result in an increase relative to the baseline. Demands generally follow the population patterns, which shows the influence that population has within this region. *Adaptive Innovation* demands are an exception to this in that they are lower than *Hot Growth*. *Adaptive Innovation* demands include higher levels of water conservation, which keep demands lower despite similar assumptions of high population growth used in *Hot Growth*. Projected demands and populations in *Business as Usual* and *Cooperative Growth* are similar, with a slightly more noticeable distinction with the White Basin.

Figure 4.10.11 White Basin Baseline and Projected Population and Municipal Demands

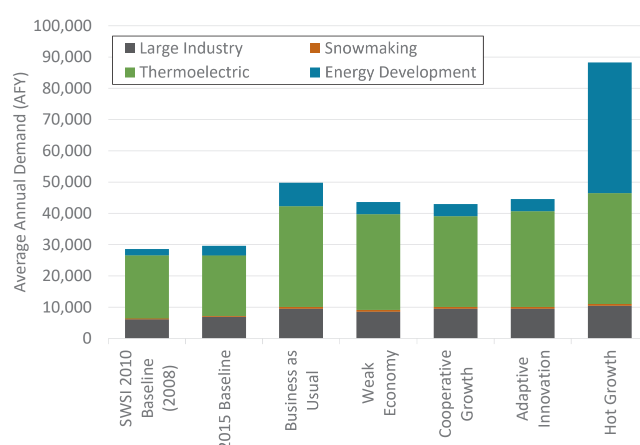


Self-Supplied Industrial Demands

The Yampa-White Basin includes about 17 percent of the statewide SSI demand. Approximately 93 percent of the baseline SSI demands are in the Yampa Basin and 7 percent are in the White Basin. SSI demands in the Yampa-White Basin are associated with all four sub-sectors. Basin-scale SSI demands are shown on Figure 4.10.12 and are summarized in Table 4.10.8.

Large Industry demands in this basin are located in Moffat and Routt counties. All baseline demands were based on SWSI 2010 and are related to mining in Moffat County and mining and golf courses in Routt County.

Figure 4.10.12 Total Yampa-White Basin SSI Baseline and Projected Demands



The baseline snowmaking demand is 290 AFY, which is the same as in SWSI 2010 because there has been no increase in snowmaking acreage. Projected demands are 570 AFY and were not varied by scenario.

Thermoelectric demands are related to two facilities. Baseline demands for the facility on Routt County were updated based on information from Xcel. Baseline demands for the facility in Moffat County were updated based on the BIP.

Table 4.10.8 Yampa-White SSI Baseline and Projected Demands (AFY)

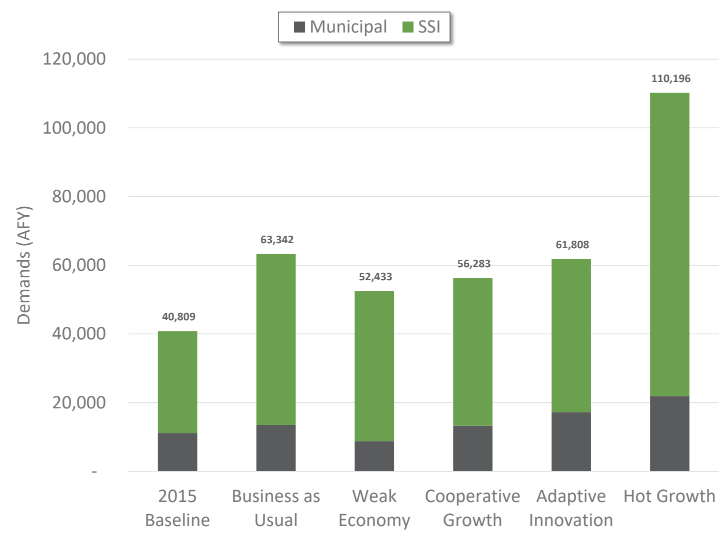
	Sub-sector	Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Yampa Basin	Large Industry	6,900	9,500	8,550	9,500	9,500	10,450
	Snowmaking	290	570	570	570	570	570
	Thermoelectric	19,350	32,240	30,630	29,020	30,630	35,460
	Energy Development	1,500	1,700	900	900	900	3,900
	Sub-Basin Total	28,040	44,010	40,650	39,990	41,600	50,380
White Basin	Large Industry	-	-	-	-	-	-
	Snowmaking	-	-	-	-	-	-
	Thermoelectric	-	-	-	-	-	-
	Energy Development	1,600	5,800	3,000	3,000	3,000	37,900
	Sub-Basin Total	1,600	5,800	3,000	3,000	3,000	37,900
	Basin Total	**29,640**	**49,810**	**43,650**	**42,990**	**44,600**	**88,280**

Energy development demands are located in Moffat, Rio Blanco, and Routt counties. Energy development demands in the White Basin for *Hot Growth* are much higher than for other scenarios but are consistent with high estimates of demands in Rio Blanco County used in SWSI 2010.

Total M&I Diversion Demands

Yampa-White Basin combined M&I demand projections for 2050 range from approximately 52,000 AFY in the *Weak Economy* to 110,000 AFY in *Hot Growth*, as shown on Figure 4.10.13. Under every planning scenario, SSI demands exceed the municipal. This is influenced by SSI use in the Yampa Basin and is the only basin in the state in which SSI demands exceed municipal. Self-supplied industrial demands make up approximately 70 percent to 80 percent of the total M&I demands in the Yampa-White Basin, depending on planning scenario. On a basin scale, the demand projections do not follow the statewide sequence of the scenario rankings described in the CWP, with the *Adaptive Innovation* falling out of sequence.

Figure 4.10.13 Yampa-White Basin Municipal and Self-Supplied Industrial Demands



4.10.6 Water Supply Gaps

The agricultural and M&I diversion demands were compared against available water supply modeled for current conditions and the five planning scenarios. Gaps were calculated when water supply was insufficient to meet demands.

In general, agricultural diversion demands gaps in the Yampa Basin are projected to be relatively low on an average annual basis in *Business as Usual* and *Weak Economy*, but gaps may be more significant in climate-impacted scenarios. Additional observations on the modeling results are summarized below.

Yampa Basin Gaps

Agricultural

The Yampa Basin agricultural diversion demands, demand gaps, and consumptive use gaps for the baseline and planning scenarios are presented in Table 4.10.9 and illustrated on Figure 4.10.14. An annual time series of gaps in terms of percent of demand that was unmet is shown in Figure 4.10.15. Agricultural diversion demand and consumptive use gap estimates were influenced by a number of drivers including climate, urbanization, planned agricultural projects, and emerging technologies.

Table 4.10.9 Yampa Basin Agricultural Gap Results (AFY)

		Scenario					
		Scenario	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand	402,500	403,600	403,600	522,500	461,000	684,300
	Average Annual Gap	13,300	13,600	13,600	63,100	58,900	150,000
	Average Annual Gap Increase from Baseline	-	400	300	49,800	45,700	136,800
	Average Annual Percent Gap	3%	3%	3%	12%	13%	22%
	Average Annual CU Gap	7,400	7,600	7,600	34,400	37,800	81,500
Maximum	Demand in Maximum Gap Year	448,900	450,500	450,500	533,000	463,800	667,500
	Gap in maximum Gap Year	55,600	55,400	55,200	123,400	97,700	246,500
	Increase From Baseline Gap	-	-	-	67,900	42,200	191,000
	Percent Gap in Maximum Gap Year	12%	12%	12%	23%	21%	37%

Study period for Water Supply Analysis is 1975-2013, reflecting different baseline demand than described in Agricultural Diversion Demands section

Figure 4.10.14 Projected Average Annual Agricultural Diversion Demand Met, Baseline Gaps, and Incremental Gaps in the Yampa Basin

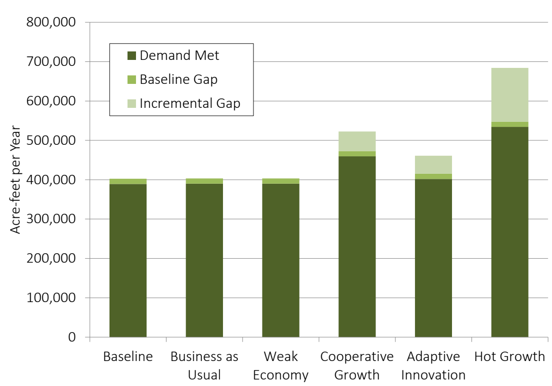
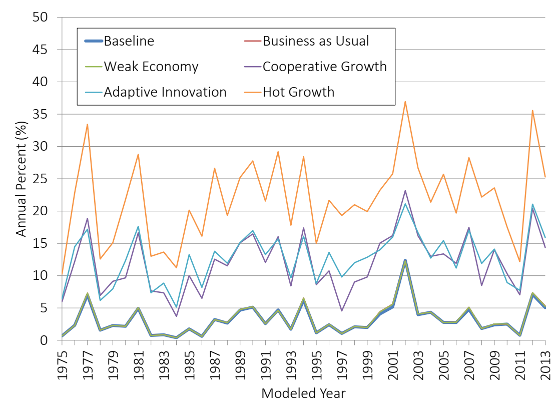


Figure 4.10.15 Annual Agricultural Gaps for Each Planning Scenario



- The Yampa Basin currently experiences an agricultural diversion demand gap, but the gap was not projected to significantly increase under the *Business as Usual* or *Weak Economy* scenarios.
- Agricultural diversion demand gaps increased in *Cooperative Growth*, *Adaptive Innovation* and *Hot Growth* due to additional demand from planned agricultural projects with junior water rights and higher IWR with concurrent lower water supply due to a drier and warmer climate.
- Climate conditions in *Adaptive Innovation* were hotter and drier than the *Cooperative Growth* scenario, but gaps were projected to be similar. Strategies associated with higher system efficiencies and the adoption of emerging technologies such as irrigation schedulings tended to offset climatic and hydrologic drivers that would have otherwise increased gaps in the *Adaptive Innovation* scenario.
- Agricultural water users do not have access to significant reservoir storage in the Yampa Basin. Gaps in *Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth* were impacted by earlier runoff seasons and lower water availability during the latter part of the growing season.

INCREMENTAL GAP

The incremental agricultural gap quantifies the degree to which the gap could increase beyond what agriculture has historically experienced under water shortage conditions.

M&I

The water supply and gap results for M&I in the Yampa Basin are summarized Table 4.10.10 and illustrated on Figure 4.10.16. An annual time series of gaps in terms of percent of demand that was unmet is shown on Figure 4.10.17.

The following are observations on the M&I diversion demands and gaps:

- The modeling suggests M&I gaps occur under baseline conditions, but this result is due to minor model calibration issues and does not currently occur.
- M&I providers and systems with more robust water rights portfolios and access to storage (i.e. systems that were explicitly modeled) will likely have lower gaps than other providers without access to supplemental supplies.
- In general, projected M&I gaps under the scenarios are projected to be relatively modest with the exception of *Hot Growth*.
- Higher M&I diversion demands along with lower water availability due to climate impacts drive higher estimated gaps in the *Hot Growth* scenario

Table 4.10.10 Yampa Basin M&I Gap Results (AFY)

		Scenario					
		Scenario	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand	36,900	53,300	46,700	48,900	53,000	68,300
Average	Average Annual Gap	0*	600	200	800	1,400	4,800
Average	Average Annual Percent Gap	0%	1%	0%	2%	3%	7%
Maximum	Demand in Maximum Gap Year	36,900	53,300	46,700	48,900	53,000	68,300
Maximum	Gap in Maximum Gap Year	0*	1,600	700	1,600	2,500	8,200
Maximum	Percent Gap in Maximum Gap Year	0%	3%	1%	3%	5%	12%

** CDSS water allocation model in this basin calculates small baseline M&I gaps, but they are either due to calibration issues or they are reflective of infrequent, dry-year shortages that are typically managed with temporary demand reductions, such as watering restrictions.*

Study period for Water Supply Analysis is 1975-2013, reflecting different baseline demand than described in M&I Demand section. Baseline demand also may vary slightly from previous section due to differences in geographic distribution of demand for Counties that lie in multiple basins.

Figure 4.10.16 Projected Maximum Annual M&I Diversion Demand, Demand Met, and Gaps in the Yampa Basin

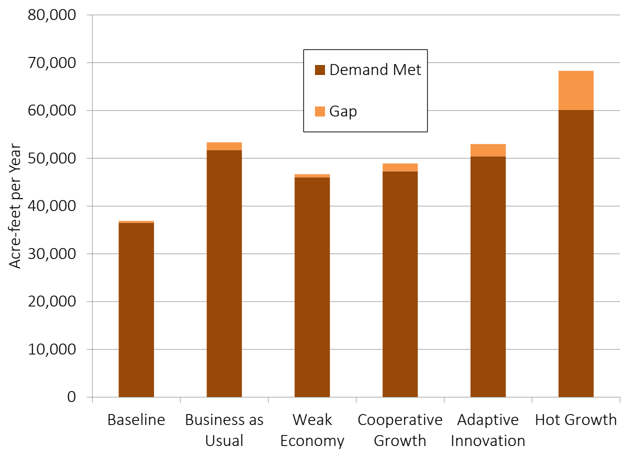
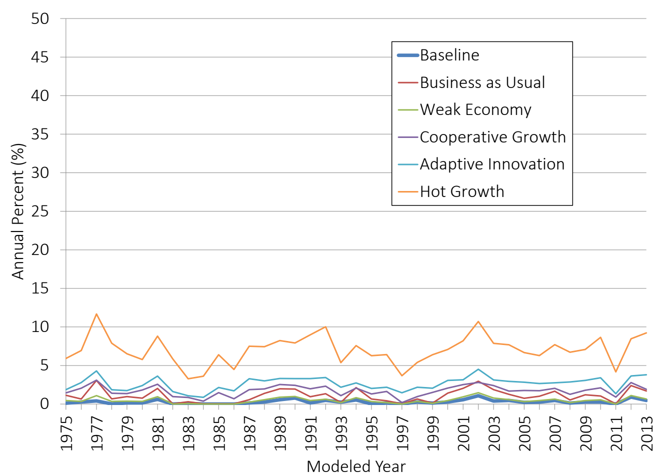


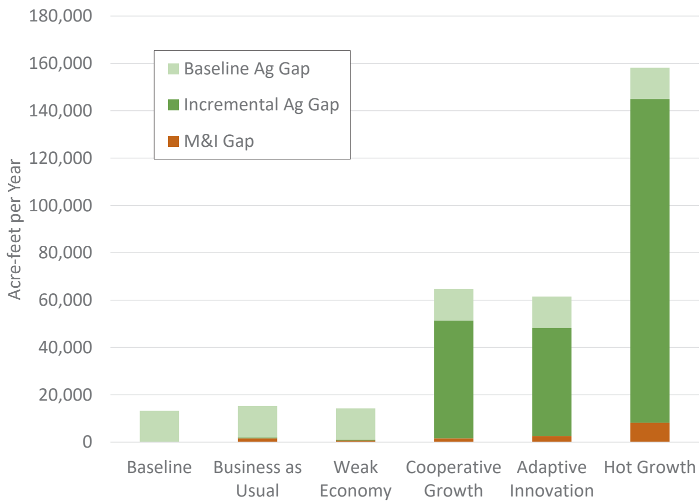
Figure 4.10.17 Annual M&I Gaps for Each Planning Scenario



Total Gap

Figure 4.10.18 illustrates the total combined agricultural and M&I diversion demand gap in the Yampa Basin. The figure combines the average annual baseline and incremental agricultural gap and the maximum M&I gap. Total gaps were driven by agriculture and were projected to be the highest in *Hot Growth*, which includes the highest amount of additional demand from planned agricultural projects and the most severe climate impacts.

Figure 4.10.18 Projected Average Annual Agricultural Gaps and Maximum M&I Diversion Demand Gaps in the Yampa Basin



Supplies from Urbanized Lands

By 2050, irrigated acreage in the Yampa Basin is projected to decrease by 1,500 acres due to urbanization. Irrigation supplies for these lands could potentially be used for M&I needs in the future (subject to a variety of unknowns such as seniority and type of water supply, willingness to change the use of water through water court, etc.). The average annual historical consumptive use associated with potentially urbanized acreage for each scenario is reflected in Table 4.10.11. The data in the table represent planning-level estimates of this potential supply and has not been applied to the M&I gaps.

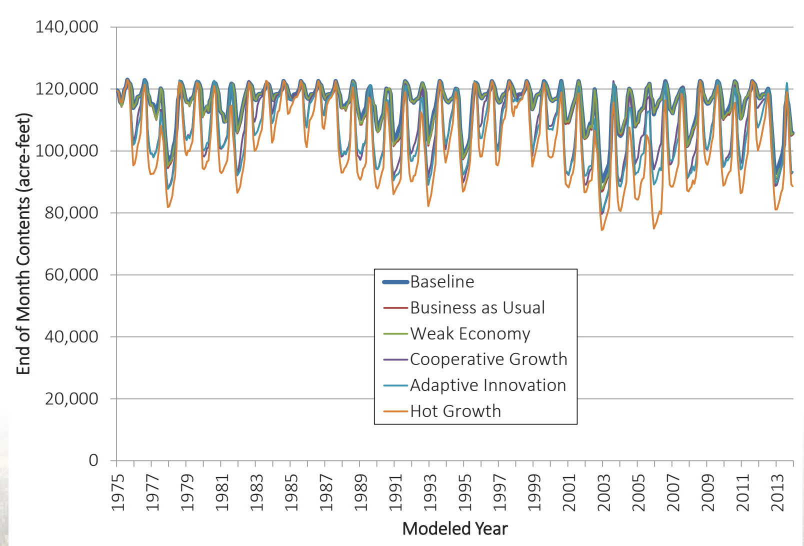
Table 4.10.11 Estimated Consumptive Use from Lands Projected to be Urbanized in the Yampa Basin

	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Urbanized Acreage (acres)	1,500	1,500	1,500	1,500	1,500
Estimated Consumptive Use (AFY)	2,700	2,700	2,800	2,800	2,400

Storage

Total simulated reservoir storage from the Yampa River water allocation model is shown on Figure 4.10.19. Baseline conditions show the highest levels of water in storage (in general), and the lowest is in *Hot Growth*. *Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth* show lower amounts of water in storage during dry periods than the two scenarios that do not include the impacts of a drier climate; however, storage levels generally recover back to baseline levels after dry periods.

Figure 4.10.19 Total Simulated Reservoir Storage in the Yampa Basin



White Basin Gaps

Agricultural

The White Basin agricultural diversion demands, demand gaps, and consumptive use gaps for the baseline and planning scenarios are presented in Table 4.10.12 and illustrated on Figure 4.10.20. An annual time series of gaps in terms of percent of demand that was unmet is shown on Figure 4.10.21.

Table 4.10.12 White Basin Agricultural Gap Results (AFY)

		Scenario					
		Scenario	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand	246,700	242,900	246,700	293,900	177,800	319,700
	Average Annual Gap	1,200	1,200	1,200	3,200	3,400	5,800
	Average Annual Gap Increase from Baseline	-	-	-	1,900	2,100	4,600
	Average Annual Percent Gap	0%	0%	0%	1%	2%	2%
	Average Annual CU Gap	700	700	700	1,700	2,200	3,200
Maximum	Demand in Maximum Gap Year	242,300	238,500	242,300	281,400	174,300	307,600
	Gap in maximum Gap Year	6,000	6,000	6,000	9,500	8,500	12,200
	Increase from Baseline Gap	-	-	-	3,500	2,500	6,200
	Percent Gap in Maximum Gap Year	2%	3%	2%	3%	5%	4%

Study period for Water Supply Analysis is 1975-2013, reflecting different baseline demand than described in Agricultural Diversion Demands section

Figure 4.10.20 Projected Average Annual Agricultural Diversion Demand, Demand Met, and Gaps in the White Basin

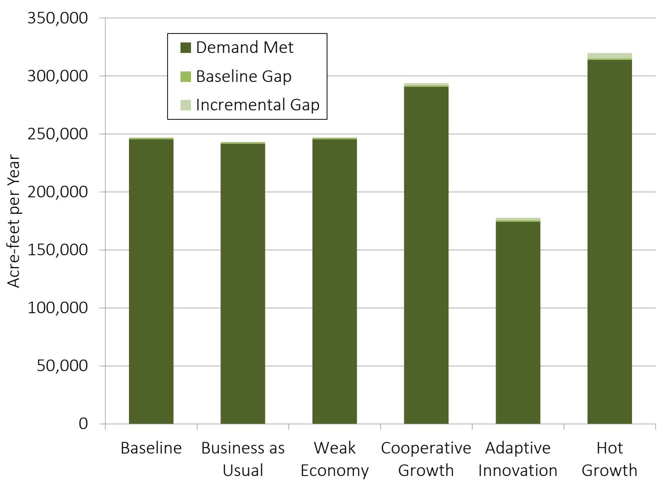
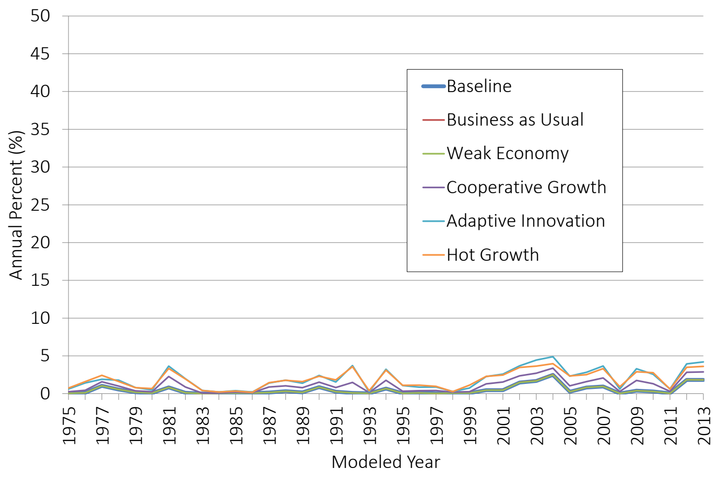


Figure 4.10.21 Annual Agricultural Gaps for Each Planning Scenario



In the White Basin, the current agricultural gap is small, and gaps are not projected to increase greatly in the planning scenarios. Agricultural gaps are greater in dry years. The largest annual, modeled gap occurred in *Hot Growth*, but it was small relative to demands at approximately 4 percent.

M&I

The diversion demand and gap results for M&I uses in the White Basin are summarized Table 4.10.13 and illustrated on Figure 4.10.22. An annual time series of gaps in terms of percent of demand that was unmet is shown in Figure 4.10.23.

Table 4.10.13 White Basin M&I Gap Results (AFY)

		Scenario					
		Scenario	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand	5,300	10,000	6,100	6,900	7,700	41,000
	Average Annual Gap	0	3,000	700	700	800	27,500
	Average Annual Percent Gap	0%	30%	12%	10%	10%	67%
Maximum	Demand in Maximum Gap Year	5,300	10,000	6,100	6,900	7,700	41,000
	Gap in Maximum Gap Year	0	3,900	900	900	1,300	33,500
	Percent Gap in Maximum Gap Year	0%	39%	15%	13%	17%	82%

Figure 4.10.22 Projected Maximum Annual M&I Demand Met and Gaps in the White Basin

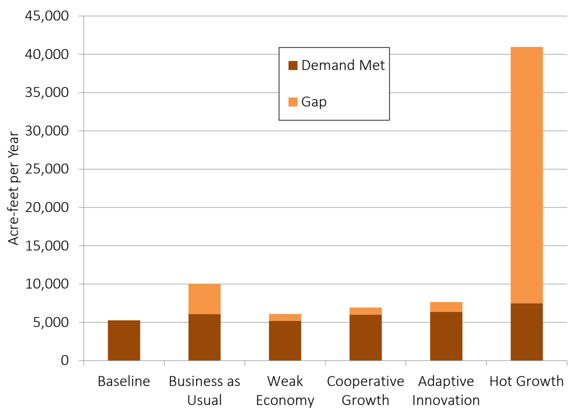
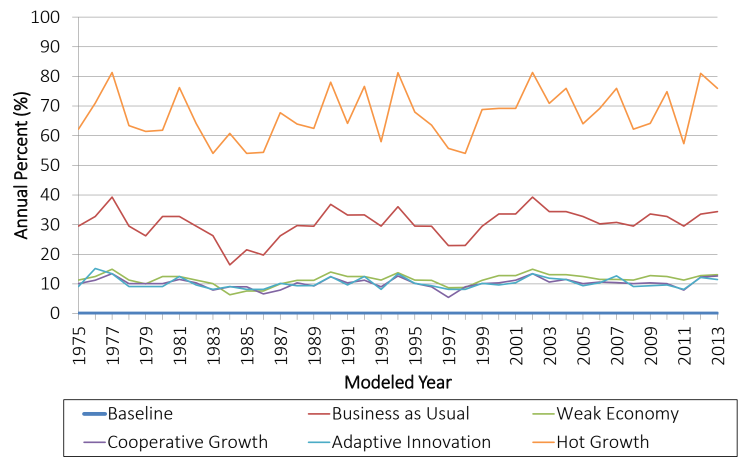


Figure 4.10.23 Annual M&I Gaps for Each Planning Scenario



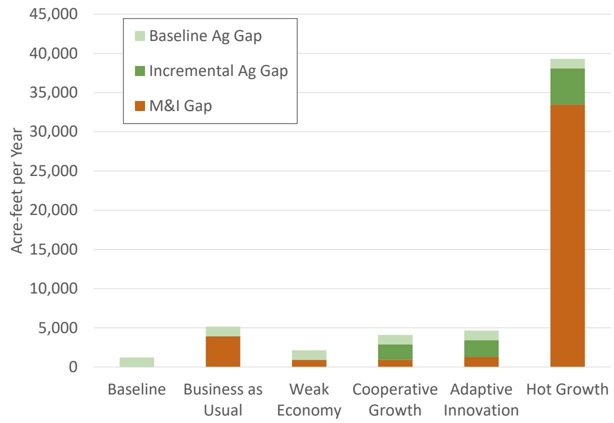
The following are observations on the M&I diversion demands and gaps:

- The average annual M&I gap in the White Basin is greater than the agricultural gap, ranging from about 700 AF for *Weak Economy*, *Cooperative Growth*, and *Adaptive Innovation* up to 27,500 AF for *Hot Growth*.
- The maximum M&I gap for the five planning scenarios ranges from 900 AF to more than 33,000 AF.
- The M&I gaps were modeled to be largest in the *Business as Usual* and *Hot Growth* scenarios and were driven by relatively large energy development demands (especially in *Hot Growth*).

Total Gap

Figure 4.10.24 illustrates the total combined agricultural and M&I diversion demand gap in the White Basin. The figure combines the average annual baseline and incremental agricultural gaps and the maximum M&I gap. In *Business as Usual* and *Hot Growth*, gaps were driven by relatively high SSI demands. In *Weak Economy*, *Cooperative Growth*, and *Adaptive Management*, agricultural gaps were greater than M&I gaps.

Figure 4.10.24 Projected Average Annual Agricultural Gaps and Maximum M&SSI Diversion Demand Gaps in the White Basin



Supplies from Urbanized Lands

By 2050, irrigated acreage in the White Basin is projected to decrease by 360 acres due to urbanization. Irrigation supplies for these lands could potentially be used for M&I needs in the future (subject to a variety of unknowns such as seniority and type of water supply, willingness to change the use of water through water court, etc.). The average annual historical consumptive use associated with potentially urbanized acreage for each scenario is reflected in Table 4.10.14. The data in the table represent planning-level estimates of this potential supply and has not been applied to the M&I gaps.

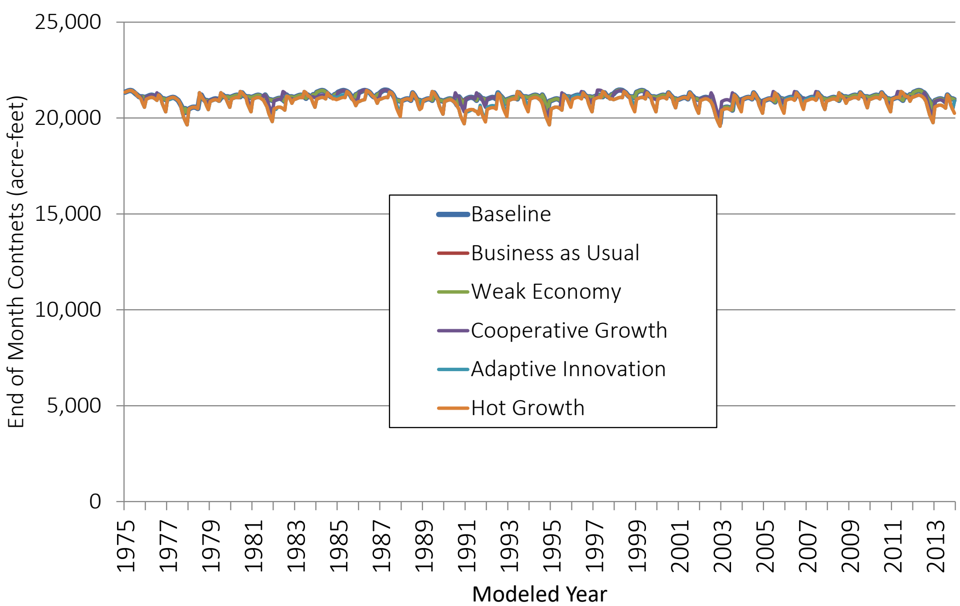
Table 4.10.14 Estimated Consumptive Use from Lands Projected to be Urbanized in the White Basin

	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Urbanized Acreage (acres)	360	-	360	360	360
Estimated Consumptive Use (AFY)	600	-	700	700	800

Storage

Total simulated reservoir storage from the White River water allocation model is shown on Figure 4.10.25. Basinwide storage levels do not significantly change in any of the planning scenarios, because agricultural and municipal water users in the basin do not typically use storage.

Figure 4.10.25 Total Simulated Reservoir Storage in the White Basin



Combined Yampa-White Basin Gaps

Table 4.10.15 summarizes the total M&I and agricultural demands in the Yampa-White Basin along with a summary of gaps. It should be noted that the Yampa and White Basins were modeled independently, and some of the results from each basin may not be wholly additive in some circumstances. For example, the maximum M&I gap may not occur in the same year in each sub-basin. As a result, the Yampa-White Basin as a whole may not experience a year in the future when the total maximum M&I gap corresponds to the sum of the maximum gaps in both sub-basins; however, the sum of the maximum sub-basin gaps does describe the total amount of water that would be needed to fully satisfy all M&I demands in each individual sub-basin, even if the gaps do not simultaneously occur in the sub-basins.

Table 4.10.15 Summary of Total Yampa-White Basin Demands and Gaps

	Current (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average Annual Demand						
Agricultural (AFY)	649,200	646,500	650,400	816,300	638,700	1,004,000
M&I (AFY)	42,200	63,400	52,800	55,900	60,600	109,300
Gaps						
Ag (avg %)	2%	2%	2%	8%	10%	16%
Ag (incremental-AFY)	-	400	300	51,700	47,800	141,400
Ag (incremental gap as % of current demand)	-	0%	0%	8%	7%	22%
M&I (max %)	0%	9%	3%	5%	6%	38%
M&I (max-AF)	01	5,600	1,600	2,600	3,800	41,700

CDSS water allocation model in this basin calculates small baseline M&I gaps, but they are either due to calibration issues or they are reflective of infrequent, dry-year shortages that are typically managed with temporary demand reductions such as watering restrictions.

4.10.7 Available Supply

Figures 4.10.26 and 4.10.27 show simulated monthly available flow for the Yampa Basin near the Maybell Canal, which is typically the senior calling right in the basin. Available flow at this location is very near to the physical flow in the stream, meaning that the Maybell Canal does not have a large impact on the available flow upstream. The figures show that flows are projected to be available each year, though the amounts will vary annually and across scenarios (available flows under the scenarios impacted by climate change are less than in other scenarios). Peak flows are projected to occur earlier in the year under scenarios impacted by climate change.

Figure 4.10.26 Simulated Hydrographs of Available Flow at Yampa River Near Maybell

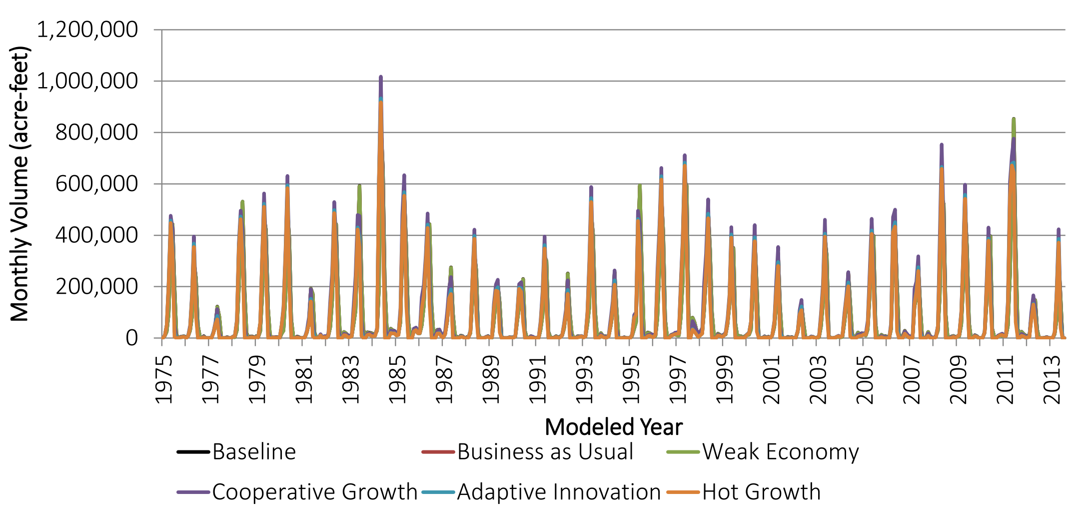
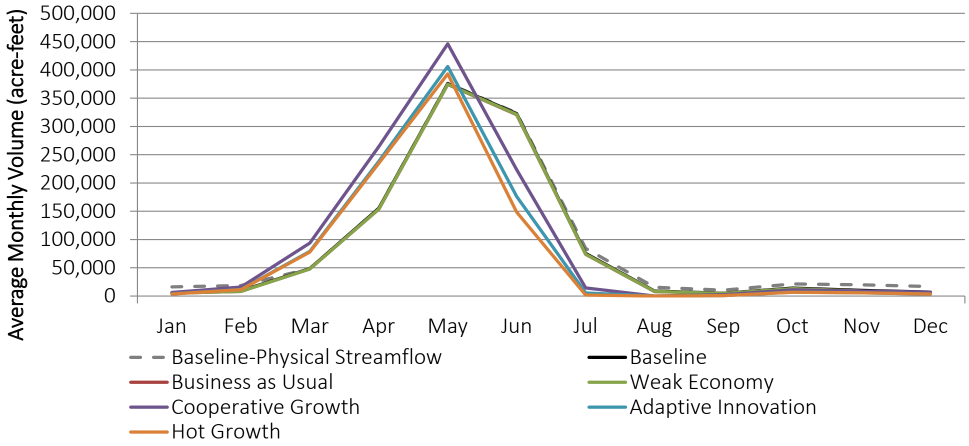


Figure 4.10.27 Average Monthly Simulated Hydrographs of Available Flow at Yampa River near Maybell



Figures 4.10.28 and 4.10.29 show simulated monthly available flow on the White River below Boise Creek, which is just above Kenney Reservoir. The reservoir has a hydropower water right that is not fully satisfied and serves as the calling right in the model. The figures show that flows are projected to be available in most years, though the amounts will vary annually and across scenarios (available flows under the scenarios impacted by climate change are less than in other scenarios). In some years, very little to no flow is available under current and future conditions at this location. Peak flows are projected to occur earlier in the year under scenarios impacted by climate change.

Figure 4.10.28 Simulated Hydrographs of Available Flow at White River Below Boise Creek

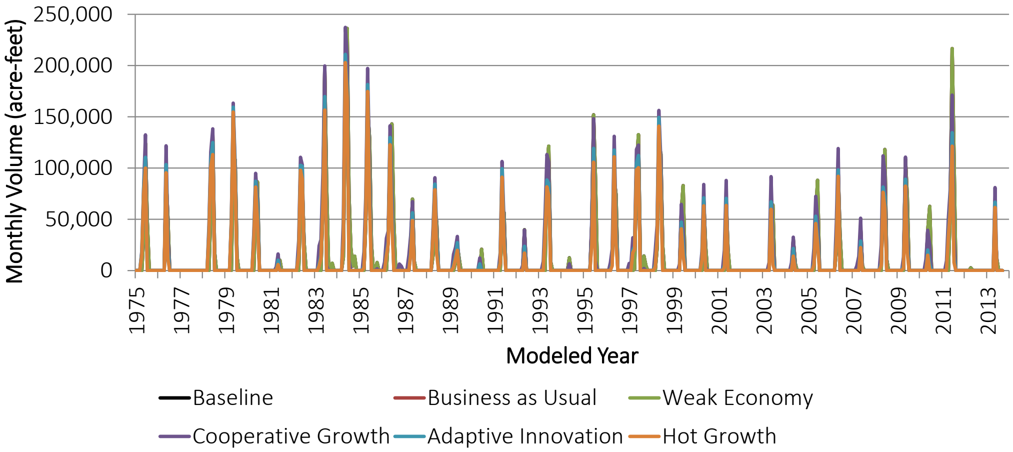
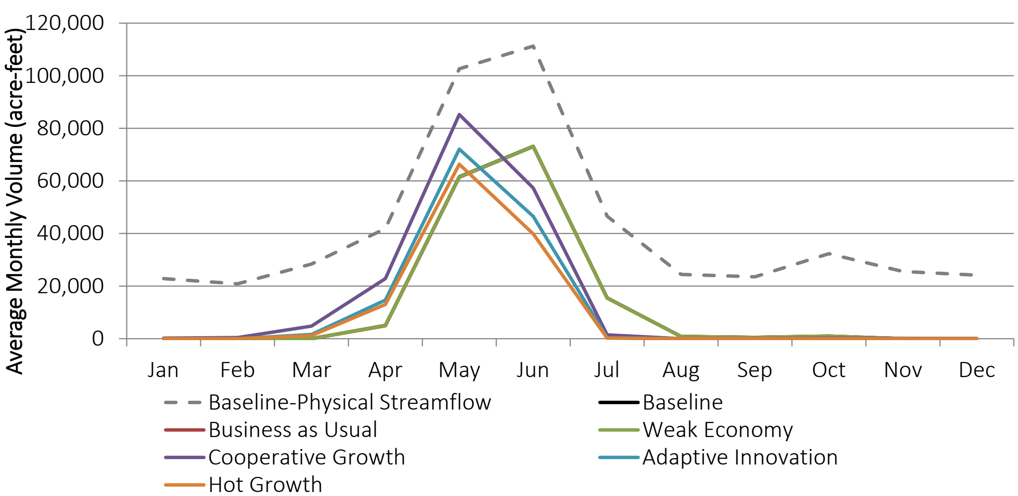


Figure 4.10.29 Average Monthly Simulated Hydrographs of Available Flow at White River Below Boise Creek



4.10.8 Environment and Recreation

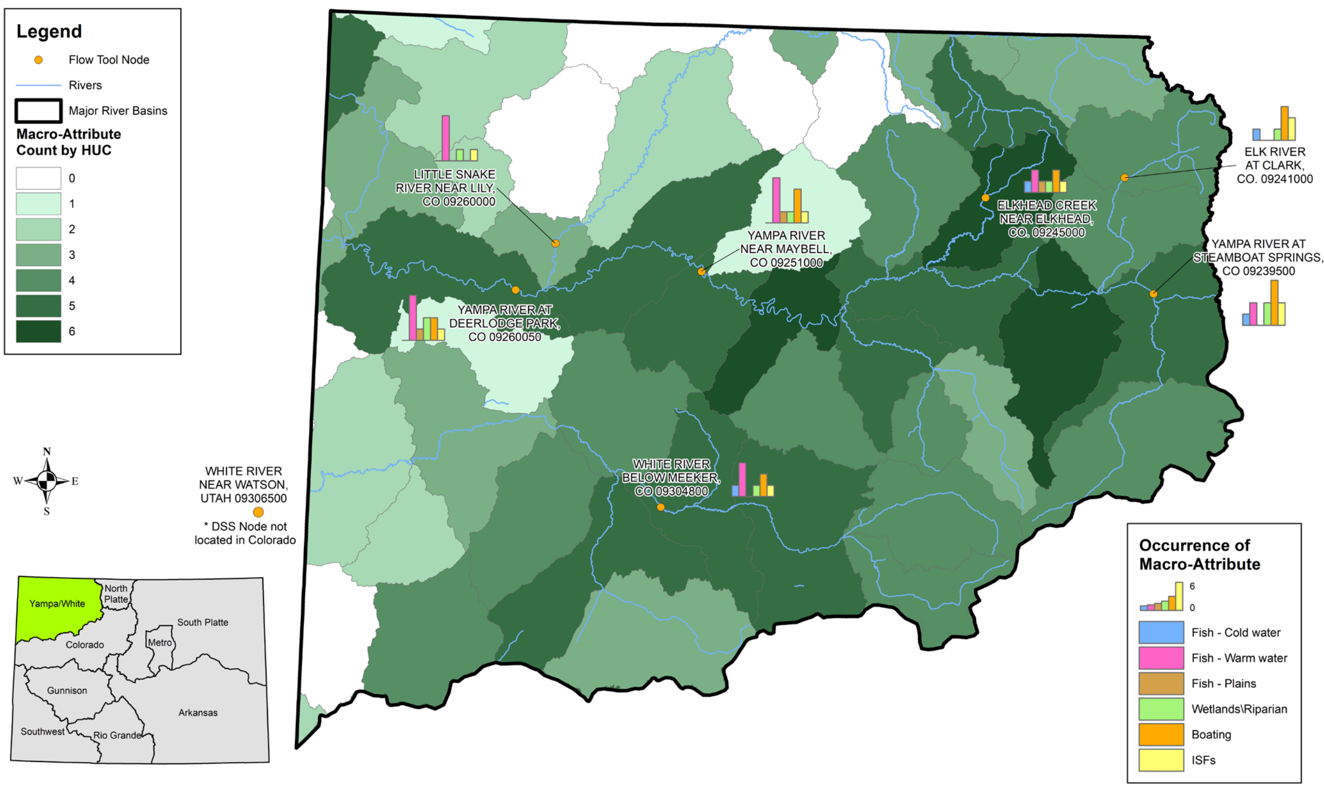
A total of eight water allocation model nodes were selected for the Flow Tool within the Yampa-White-Green Basin (see list below and Figure 4.10.30). Figure 4.10.30 also shows subwatersheds (at the 12-digit HUC level) and the relative number of E&R attributes located in each subwatershed.

- Yampa River at Steamboat Springs, Colorado (09239500)
- Elk River at Clark, Colorado (09241000)
- Elkhead Creek near Elkhead, Colorado (09245000)
- Yampa River near Maybell, Colorado (09251000)
- Little Snake River near Lily, Colorado (09260000)
- Yampa River at Deerlodge Park, Colorado (09260050)
- White River below Meeker, Colorado (09304800)
- White River near Watson, Utah (09306500)

NATURALIZED FLOW

Naturalized flows reflect conditions that would occur in the absence of human activities. Baseline flows reflect current conditions as influenced by existing infrastructure and river operations. While observations regarding naturalized flows may be informative, baseline flows reflect actual conditions and the diverse operations of a river's many users.

Figure 4.10.30 Flow Tool Nodes Selected for the Yampa/White Basin



Results and observations regarding Flow Tool analyses using flow data developed in the water supply and gap analyses for baseline conditions and the planning scenarios are described in Table 4.10.16 below.

Table 4.10.16 Summary of Flow Tool Results in the Yampa-White-Green Basin

Category	Observation
Projected Flows	On the Yampa and White Rivers, peak flow magnitudes under baseline conditions are only slightly reduced (10 percent) from naturalized conditions. A similar status holds for *Business as Usual* and *Weak Economy*. Under *Hot Growth*, total peak flows decline approximately 10 percent.
	At all locations, the timing of peak flow is projected to move earlier in the year under all climate change impacted scenarios (*Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth*). Under these scenarios, June flow may decrease approximately 30 percent at higher elevations (e.g., Elk River at Clark) and continue to decrease more at lower elevations (e.g., Yampa River at Deerlodge Park). Under these same scenarios, April flows may increase at a similar rate. May flows may increase or decrease depending on location and scenario.
	Under baseline conditions, mid- and late-summer flows are minimally depleted at higher elevations under naturalized conditions, are reduced further through mid-elevations (e.g., Steamboat Springs), and continue to decline through low-elevations (e.g., White River below Meeker and Yampa River at Deerlodge Park). Under all climate change scenarios, in most locations, mid- and late-summer flows are projected to have a wide departure from naturalized conditions.
Ecological Risk	Despite declines in peak flow magnitude, flow-related risk to riparian/wetland plants remains low to moderate across the basin. However, flow-related risk to warmwater fish is projected to increase, with the most risk occurring under *Hot Growth*. The change in timing for peak flows may result in mismatches between peak flow timing and species' needs.
	Projected reductions in mid- and late-summer flows may result in increased risks for trout at high and mid-elevations and for warmwater fish at low elevations. Increased risk would be caused by reduction in habitat under reduced flows.
	For trout, increased stream temperatures under low-flow conditions also increases risks, as has been the case in some recent years in Steamboat Springs. Additionally, the projected reductions in flows in mid- and late-summer may result in flows that are below the recommendations for endangered fish. For comparison, flows in August and September of 2018 were among the lowest flows on record and resulted in the first ever call on the Yampa River.
	September flows are projected to be similarly low in nearly one-quarter of all years under *Cooperative Growth* and nearly one-third of all years under *Adaptive Innovation* and *Hot Growth*. These low flows lead to a loss of habitat for endangered fish and favor reproduction and survival of non-native fish that prey upon endangered fish.
ISFs and RICDs	ISFs and RICDs are at risk of being met less often in mid- to late-summer under all future scenarios that include climate change (*Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth*). An example of an ISF at risk is the 65 cfs ISF on the Elk River. This ISF is met in July in every year under the baseline scenario; however, under *Cooperative Growth*, average July flow is projected to drop below 65 cfs in approximately one-third of years and is unmet in approximately half of the modeled years under *Adaptive Innovation* and *Hot Growth*. In August, the Elk River ISF is projected to be unmet in nearly every year under all climate change scenarios.
	The total amount of boating flows during runoff may not change significantly if peak flow magnitude does not decline substantially, but the timing of boating opportunities will shift to earlier in the year under all climate change scenarios. An example of a RICD at risk is for the whitewater park in Steamboat Springs. The August RICD decreed flow of 95 cfs is often not met under baseline conditions. Under *Adaptive Innovation* and *Hot Growth*, the August RICD decree is almost never met.
E&R Attributes	Under baseline conditions and *Business as Usual*, and *Weak Economy*, current flow risk related to E&R attributes arises primarily because of depletions that increase moving downstream.
	Under climate change scenarios, both the projected shift in the timing of peak flow and reductions in total runoff may contribute to reductions in mid- and late-summer flows.

SECTION 5
INSIGHTS, TOOLS, AND RECOMMENDATIONS

In addition to the core analysis of this report, the Technical Update incorporates a set of topic-specific evaluations (insights), supporting tools, and recommendations. These efforts aim to provide insights, assistance and direction to basin roundtables as they update their BIPs and consider solutions for addressing future gaps. Technical memoranda on each of the insights and existing tools are included in Volume 2 (see Appendix A for a full list). An overview of each of these topics is provided in the following subsections and as summarized below:

Insights: Section 5.1 provides a summary of high-level and conceptual analyses on the following focused topics related to implications of supply/demand gaps and key points to consider when developing potential solutions to solving future gaps. Basin roundtables may choose to expand on these analyses if necessary or desirable when updating their BIPs. The analyses focused on the following water-related areas:

- Public values regarding water issues in Colorado
- Overview and case study descriptions of Alternative Transfer Methods (ATM)
- Overview of water reuse mechanism
- Storage opportunities in Colorado
- Economic impacts of failing to solve future projected supply/demand gaps

Tools: Section 5.2 highlights several tools for basin roundtables to use when updating their BIPs. During the Technical Update, the consistency of data across all the existing BIPs was reviewed. The results of this review pointed to a strong need to improve the completeness and uniformity of information on all water supply projects/strategies and related costs. The tools developed in the Technical Update build on prior efforts in the following areas:

- Costing Tool
- E&R Flow Tool
- E&R database
- Projects database

Recommendations: Section 5.3 outlines several recommendations that primarily focus on how to use, enhance, and integrate findings from the Technical Update into the BIP updates. Recommendations stem from multiple stakeholder interactions and divide into five major update areas:

- BIP
- Project
- Technical
- Outreach
- Strategic

5.1 INSIGHTS

5.1.1 Public Perception Insights

In 2012 and 2013, a survey entitled, *Public Opinions, Attitudes and Awareness Regarding Water in Colorado*, was conducted on behalf of the CWCB. In addition, other survey research was documented relevant to understanding social values in the context of the Technical Update planning scenarios and water supply challenges that Colorado will face. Findings from the survey are documented in the technical memorandum, *Observations Regarding Public Perceptions on Water* (included in Volume 2, Section 12) and summarized below.

- Coloradans have varied levels of knowledge regarding water use in the state. Only one in three residents recognizes that agriculture is the largest water user in Colorado. In 2012 and 2013, a large majority of the state's residents were paying more attention to water issues and their own water use than they had in the past. In part, this was likely due to 2012's dry summer conditions. Repeated surveys in other locations found that water awareness rises during droughts and diminishes after the drought recedes.
- Among eight potential water-related concerns, Coloradans identified protecting home water quality, having enough water for Colorado's farms and ranches, and having enough water for Colorado's cities and towns as the most important issues. These were the top three issues in each region of the state, although the ranking order of the issues varied by region.
- Coloradans most frequently described conservation as their preferred approach to addressing Colorado's water issues, followed by prioritizing environmental needs and building new water supply projects. Conservation was the most frequently recommended strategy in every region, and support for prioritizing environmental needs was consistent across Colorado's regions. Support for developing new water supply projects was more varied.
- Coloradans perceive home water service to be affordable compared to other home services, and they are willing to pay more to address Colorado's water issues. On average, Coloradans are willing to pay between $5 and $10 more per month to address water-related concerns. At $5 per month per household, this willingness to pay would correspond to statewide annual financial support of about $125 million.

5.1.2 ATM Insights

Overview

The Technical Update shows that under multiple planning scenarios a growing population, healthy economy, and climate change will lead to increasing municipal and industrial water demands and subsequently intensify pressure to permanently transfer agricultural water rights. In particular, the South Platte and Arkansas basins face significant reductions in irrigated agricultural land due to increasing demand. Other drivers of permanent reductions in irrigated acreage include urbanization, inadequate augmentation water supplies, declining aquifers, and compact compliance.

Across the state, water stakeholders want to minimize permanent reductions in irrigated agricultural land and support a variety of alternative options, such as water banking and interruptible water supply agreements. Colorado's Water Plan sets a goal of achieving 50,000 acre-feet of water transfers through voluntary ATMs by 2030. The Water Plan also sets a goal that ATMs compete with, if not out-perform, traditional transactions in the water market. Through the long-standing ATM Grant Program and other initiatives, the CWCB continues to facilitate the development and implementation of ATM projects across the state

The technical memorandum, *Review of Successful Alternative Transfer Method Programs and Future Implementation* (included in Volume 2, Section 11) reviews select ATM projects that have been successfully implemented and highlights key characteristics of each ATM that provide insight into how future ATMs might also be successfully structured. Additionally, the study provides perspectives on agricultural to municipal transfers, and includes recommendations for monitoring metrics to track the effectiveness of future ATM programs.

ATM projects provide several general benefits when compared to permanent, buy-and-dry water transfers. For municipalities, ATMs may provide a reliable source of dry-year water supplies and can be more cost effective than permanent transfers and other traditional new supply sources. By maintaining some farm operations as part of the ATM program, rural economies that depend on agricultural activities can be sustained, and agricultural users can have access to new income streams for purchasing new equipment and investing in infrastructure improvements or other operational needs. ATMs can also be useful in preserving ecosystem services associated with working agricultural lands, such as open space and wildlife habitat. Additionally, ATMs can be applied to address multiple water supply challenges, including municipal and industrial needs, compact compliance, groundwater management, and non-consumptive needs.

Challenges to ATM implementation include balancing the municipal and industrial user's desire for certainty and permanence of long-term supply with the supplier's desire to maintain profitable agriculture, and potentially high infrastructure costs needed to implement a viable water transfer (potentially high infrastructure costs are a barrier to implementing a permanent transfer and are not necessarily unique to ATMs). Furthermore, high transaction and administration costs common to nearly all transfers can discourage some parties from pursuing an ATM arrangement. Several efforts have been made to address these challenges over recent years, including the continued financing of ATM projects through the CWCB's ATM Grant Program and development of more flexible, administrative ATM project approvals through the HB13-1248 Fallowing-Leasing Pilot Program and Agricultural Water Protection Water Right.

ATM Case Study Examples **(can this just be Case Studies throughout? case study and examples seems redundant)**

ATMs in Colorado are predominantly used to transfer water from agriculture to municipal, industrial, or environmental uses on a temporary basis, but several long-term ATM projects have been developed based on the needs of the parties involved. Case study examples of recently implemented ATMs in Colorado were developed to better understand methods used to overcome challenges and past barriers to implementing ATMs, unique issues between the parties involved, overall benefits, and key lessons learned that can apply to future ATM implementation. The case studies selected represent different ATMs, and are shown below:

Agricultural to Municipal and Industrial

- Little Thompson Farm
- Catlin Canal

Agricultural to Environmental

- McKinley Ditch

Compact Compliance

- Grand Valley Water Users Association Conserved Consumptive Use Pilot Program

Hypothetical Agricultural to Municipal Transfer Considerations

A hypothetical example ATM program was considered to provide context into how a coordinated, large-scale rotational fallowing program could be developed to meet a significant portion of the M&I gap. The example describes a large-scale fallowing program and concluded that a significant portion of irrigated acreage would need to be enrolled in the program to yield significant amounts of supply. Additionally, several infrastructure components may be required to implement a large-scale ATM program, including augmentation and operational storage, pipelines and pump stations, and water treatment systems. This infrastructure may be needed even if traditional agricultural transfers were implemented from the same geographical areas.

ATM Implementation and Effectiveness Monitoring

Following recommendations in the Water Plan concerning ATM data compilation, future ATM monitoring metrics were identified to help give insight to the effectiveness and operation of a single ATM, or a large-scale ATM program across a larger geographic area to gauge regional or basinwide trends. Obtaining this data for a wide variety of implemented ATMs (both geographically and for different ATMs) will provide more information to decision makers to evaluate the effectiveness of proposed ATMs, identify trends, and evaluate pricing. ATMs provide an opportunity to meet increasing water demands of a growing population while lessening the impacts to Colorado agricultural communities. Next steps to be considered include:

- Developing better guidance as to what types of projects and processes further Water Plan goals related to maintaining or enhancing agricultural viability while meeting potential new demands and addressing other water resource management issues
- Assessing institutional support of ATMs and evaluating progress made on addressing the primary barriers to ATM development and implementation
- Developing additional pilot projects for the varying ATM programs and engaging in thoughtful monitoring of their effectiveness
- Working with basin roundtables to consider how ATMs can play a role in addressing basin needs and priorities
- Pursuing further the collection of recommended monitoring data for ATMs as they are developed and sharing this information through existing platforms such as CDSS or new platforms such as an ATM data clearinghouse.

5.1.3 Water Reuse Insights

The Colorado Water Plan notes that various forms of water reuse will be an important component of closing future supply-demand gaps for municipalities; it also encourages water providers to build on the successes of the many reuse projects already implemented in Colorado. To advance these concepts, high-level comparisons of various water reuse mechanisms were compared and contrasted in a fact-sheet style format that summarized hypothetical mass balances of a municipal water system implementing reuse. Benefits, tradeoffs, unintended consequences, treatment requirements, and regulatory considerations pertaining to a particular reuse mechanism were also evaluated. This information was designed to provide guidance on how to define potential municipal reuse projects in future BIP efforts. Evaluated reuse mechanisms included:

- Reuse via. Exchange
- Non-potable reuse
- Indirect potable reuse
- Direct potable reuse
- Graywater reuse

The results of the comparisons are presented in a technical memorandum *Opportunities and Perspectives on Water Reuse* (see Volume 2, Section 13).

Key Findings

In this analysis, particular attention was paid to quantifying and qualifying the impact of a local reuse project on the greater basin and watershed system. The mass balance exercises noted previously identified the following key takeaways to consider when a municipality is evaluating implementation of a particular reuse mechanism:

- *Reuse of Existing Reusable Return Flows:* If a municipality can reuse existing legally reusable return flows, the amount of new supplies needed to meet future demands can be reduced. Indirect, direct, or reuse via exchange methods have the best opportunity to reduce the need for new supplies due to the ability to reuse water year-round. When a municipality begins to reuse return flows that historically have not been reused, a flow reduction to downstream users can result. Coordination between the water provider and downstream water users could help those users plan for this reduction in downstream water availability.
- *Reuse of New Supplies:* If a municipality cannot reuse existing return flows, reusing future, new, legally reusable supplies will reduce the amount of new supplies needed. Reuse of new supplies using indirect, direct, or reuse by exchange methods can be used year-round, which maximizes the benefit of reuse to the municipality and minimizes the amount of new supplies needed.

5.1.4 Storage Opportunity Insights

The CWP states that Colorado must develop additional storage to manage and share conserved water and manage the challenges of a changing climate. It sets a measurable objective of attaining 400,000 acre-feet of innovative water storage by 2050. The technical memorandum, *Opportunities for Increasing Storage* (see Volume 2, Section 10), investigates concepts related to increasing water storage to assist in meeting current and future water supply challenges throughout Colorado.

Conditional Storage Water Rights

To evaluate future storage opportunities in Colorado, the State's current water right database was queried for potential reservoir sites with conditional storage rights greater than 5,000 acre-feet. As shown in Figure 5.5.1, there are more than 6.5 million acre-feet (MAF) of conditional storage rights at reservoir sites with greater than 5,000 AF on file with the State of Colorado.

The 6.5 MAF of conditional storage rights (if constructed) would nearly double the existing surface water storage in Colorado and is more than 15 times the CWP's measurable objective of 400,000 AF of additional storage by 2050. It is not likely that the 6.5 MAF of new surface water storage will occur by 2050; however, if only a portion of the conditional storage sites were ultimately determined to be technically and environmentally feasible, those new surface water storage facilities could become a critical component to a balanced approach to meeting projected water resources gaps throughout Colorado.

Other Storage Opportunities

In addition to considering conditional storage rights, other opportunities for new storage and increasing operational storage in existing reservoirs were evaluated as a means to help solve Colorado's projected water supply and demand gaps. Table 5.5.1 summarizes the key considerations for each type of potential storage discussed in Volume 2, Section 10 titled *Opportunities for Increasing Storage*.

Figure 5.1.1 Sum of Conditional Storage Right Volumes in Various River Basins

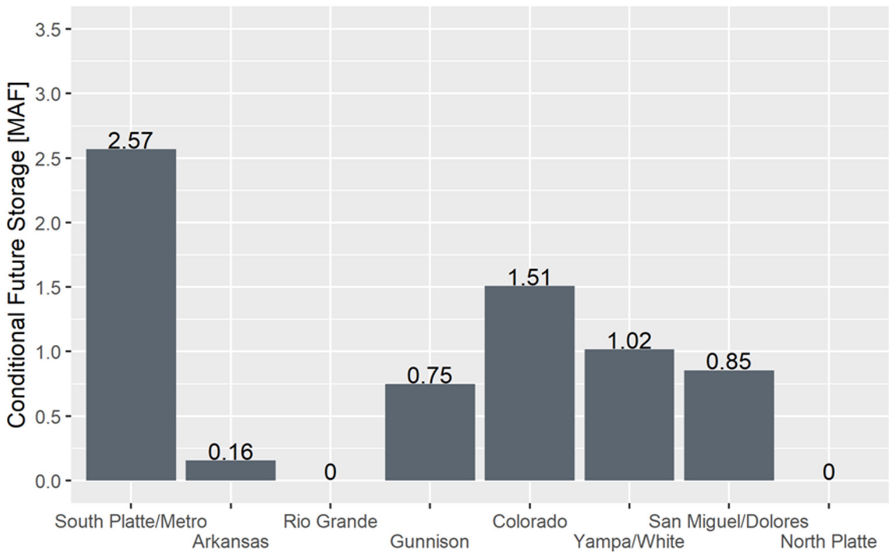
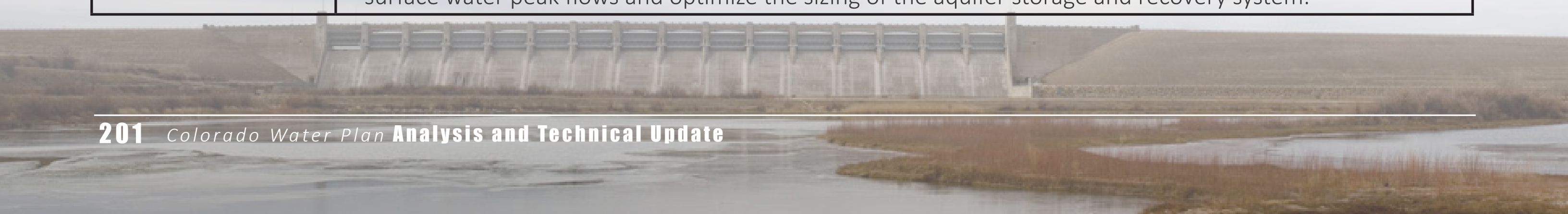


Table 5.1.1 Overview of Water Storage Opportunities

Reallocate Some Flood Storage to Active Storage	• Volume reallocation from flood control to reservoir operations (referred to as the storage delta concept) could be a part of achieving additional storage in existing reservoirs. • Further meteorological and hydrologic analysis could be performed on key reservoirs that have dedicated flood storage to identify the most likely opportunities for implementing the storage delta concept in the future.
Remove Sediment	• Further analysis should be completed on key reservoirs (i.e., reservoirs that have been in operation for a long period or are downstream of wildfire areas) to clarify the degree to which sediment removal could achieve additional operational storage volume.
Rehabilitate Fill Restricted Dams	• Further analysis should be completed on key reservoirs with fill restrictions to determine the degree to which dam rehabilitation and removal of fill restrictions could achieve additional operational storage volume. • Collaborative partnerships between municipal and agricultural water users should be explored as a way to share in the cost of reservoir rehabilitation in some cases.
Enlarge Dams	• In select cases where water is physically and legally available and the reservoir fits into existing system operations, raising the height of a dam could be a feasible option for achieving additional storage in an existing reservoir. • In a dam enlargement situation, significant permitting efforts will be required.
Create New Dam Sites	• Many of the largest of the 6.5 MAF of filed conditional storage water rights greater than 5,000 AF in each basin are decreed for municipal, industrial, and irrigation uses. • When considering future storage options, a larger number of smaller reservoirs do not accomplish the same operational objectives as a mix of larger reservoirs due to significant increases in evaporation losses and the loss of the benefits of economies of scale.
Aquifer Storage and Recovery	• Unconfined/Shallow aquifer storage and recovery projects may be best for near-term or seasonal surface water availability retiming due to potential connections to surface water systems that may limit the duration water can feasibly be stored in the unconfined system. • Confined/Deep aquifer storage and recovery projects may be most applicable for longer-term water storage and can be used in conjunction with a surface water storage system to better enable capture of surface water peak flows and optimize the sizing of the aquifer storage and recovery system.



5.1.5 Economic Impacts Insights

The technical memorandum *Potential Economic Impacts of Not Meeting Projected Gaps* (see Volume 2, Section 9) provides order-of-magnitude estimates of the economic consequences of failing to meet future supply gaps within Colorado and each of its basins. The study was based on data developed for the medium scenario[14] for 2050 M&I gaps from the previous SWSI effort (SWSI 2010), which anticipated a statewide gap for these uses of approximately 390,000 AF per year by 2050[15], and the projected 2050 shortage in water supplies for irrigated agriculture from the previous SWSI study, which was estimated at more than 1.7 MAF per year[16].

The economic analysis conducted for this study was based on a relatively simplified approach consistent with the goal of identifying the general magnitude of the economic consequences of failing to meet future gaps. The analysis focused on the economic implications of projected future gaps for agricultural and M&I uses. There are also significant economic implications for the state and each of its river basins in failing to meet non-consumptive needs for environmental and recreational purposes; however, quantifying the economic implications of shortfalls with respect to non-consumptive needs was beyond the scope of this study.

Three types of economic costs were included:

- Agricultural costs that are already being incurred
- Original costs of a portion of projected future M&I gaps
- Opportunity costs of foregone future economic development

The projected economic impacts of failing to meet the gaps identified in the specific 2010 SWSI demand conditions analyzed in this study provide a number of general insights regarding the importance of Colorado's water planning efforts.

The lack of sufficient supply to meet the full consumptive use requirements for irrigated crops in Colorado already results in an estimated annual loss in potential production value of more than $3 billion and about 28,000 fewer jobs directly and indirectly supported by irrigated agriculture[17]. In many basins, economic impacts on livestock production due to reduced crop and forage output are larger than the economic impacts on the crop producers. Projected gaps in 2050 irrigation water supplies indicate that these reductions in potential agricultural economic activity will continue into the future.

Economic effects of projected M&I gaps depend on the severity of the projected gap in each basin. In areas with smaller M&I gaps relative to projected 2050 demands (less than 10 or 15 percent of projected demand), the primary effects would likely be a substantial reduction in consumer welfare due to greatly reduced water availability for outdoor use and severe effects on the municipal "green industry," involving sectors such as landscape services, nurseries, and car washes. In areas with more severe M&I gaps (greater than 10 or 15 percent of projected future M&I demand), much larger economic impacts are projected due to the opportunity cost of foregone future residential, commercial, and industrial development.

Overall, the potential economic impacts and opportunity costs of the projected gaps in agricultural and M&I water supplies are substantial in every basin in Colorado. From a statewide perspective, failing to meet the gaps identified in the 2010 SWSI demand condition example analyzed in this case study could lead to between 355,000 and 587,000 fewer jobs in Colorado in 2050; $53 to $90 billion fewer dollars in annual economic output; a reduction in gross state product of between $30 and $51 billion per year; $20 to $33 billion in reduced labor income; and $3 to $6 billion fewer dollars in state and local tax revenues. To put these numbers in perspective, the projected economic impacts are equivalent to approximately 9 to 16 percent of current statewide economic output, gross state product, statewide employment, and statewide labor income.

The economic values associated with agricultural water use are substantial but are generally considerably lower than the economic values associated with M&I use. This reality, combined with the flexibility to move water among different uses and locations under Colorado law, implies that there will be continuing economic pressure to shift water from Colorado's farms to its cities and industrial users. Given the importance that the state's residents place on maintaining agriculture in Colorado, as noted in *Observations Regarding Public Perceptions on Water* (Volume 2, Section 12), these economic pressures highlight the need for strategies to mitigate potential future impacts resulting from water transfers that would negatively affect Colorado's agricultural economy. This fact underscores the importance of developing basin-specific water management and supply strategies, and collaborative BIP updates.

5.2 TOOLBOX FOR BASIN ROUNDTABLES

Several tools were developed during the Technical Update that will be useful for basin roundtables during the BIP update process. The tools will be further refined and upgraded in the future as they are used, additional data are gathered, and on-line portals capable of hosting these tools are developed.

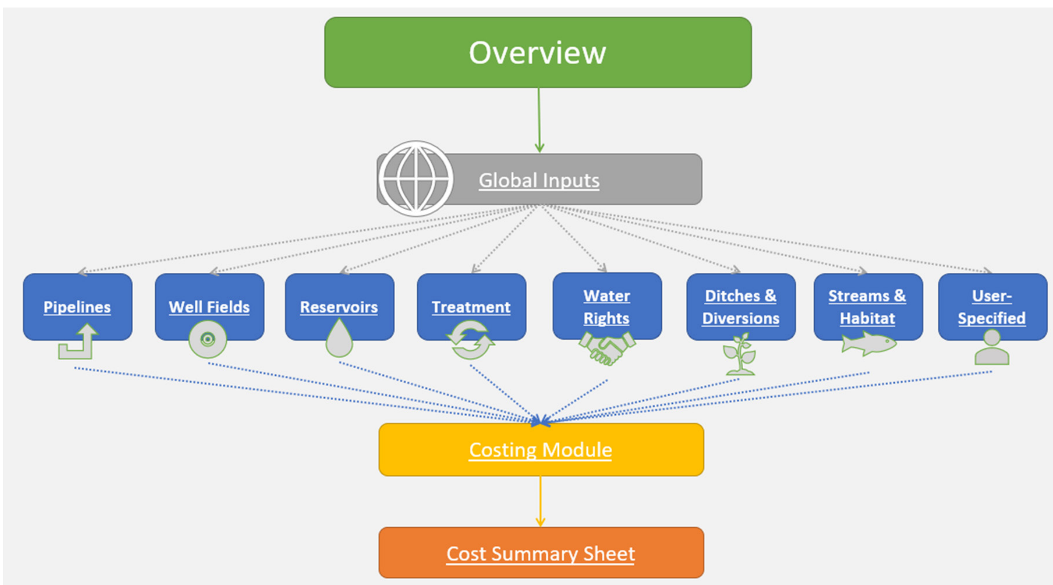
5.2.1 Project Costing Tool

The *Colorado Water Project Cost Estimating Tool* (Cost Estimating Tool) was developed for the Technical Update to provide a common framework for the basin roundtables to develop planning-level project cost estimates. Only 16 percent of the projects and methods listed in previous BIPs included cost estimates. The Cost Estimating Tool provides a baseline cost estimate for use in the planning process and serves as a mechanism to collect useful information for additional planning and tool refinement in future iterations. Its targeted use is for project concepts for which cost estimates have not yet been developed.

Cost Estimating Tool limitations and additional tool functionality recommendations are included in the technical memorandum titled *Colorado Water Project Cost Estimating Tool*, included in Volume 2, Section 5 of the Technical Update.

The Cost Estimating Tool is organized by Project Modules, with each module representing a different type of water supply project. Data from each Project Module is synthesized in the Costing Module and Cost Summary Sheets to develop the overall cost estimate (see Figure 5.2.1).

Figure 5.2.1 Cost Estimating Tool Schematic



Projects Module

The module overview page includes a navigation view of the tool and allows the user to modify global inputs such as project yield, peaking factors, cost indices, and life-cycle and annual costs. Links to each Project Module are also available from the overview page. The Project Modules represent either an entire water project or a component of a large-scale, complex project. The types of projects proposed in BIPs have been pre-loaded into the tool, and users able to customize the parameters associated with their project(s) to reflect a specific design and physical characteristics (see Table 5.2.1). Output from the Project Modules becomes input to the Costing Module.

Table 5.2.1 Project Cost Tool Module Types, Components and Inputs

Project Module	Types	Components	General User Inputs
Pipelines	raw, treated	pipelines, pump stations, storage	project yield and peaking factor, pipeline profile components, pipe size and length, pump type
Well Fields	public supply, aquifer storage and recovery, injection, irrigation wells	wells, booster pumps, pipe network	water table characteristics, project yield and peaking factor, transmission pipeline profile components, number of wells and average production, well depth and capacity, transmission pipe size and length, booster pump capacity
Reservoirs	new reservoir, reservoir expansion, reservoir rehabilitation	reservoir, reservoir rehabilitation, hydropower production	project type, new storage volume, project description, cost of rehabilitation, height of falling water, discharge through hydropower station
Treatment	typical treatment technologies such as direct filtration, conventional, reverse osmosis, etc.	various treatment technologies	average day demand and peaking factor, treatment type
Water Rights	instream flow requirements, recreational in-channel diversion, water supply	cost	total capital cost of water right purchase
Ditches and Diversion	new ditch, ditch rehabilitation	diversion structure, headgate structure, ditch	type of diversion structure, type of headgate structure, maximum diversion discharge/ditch capacity, type of ditch, ditch length
Streams and Habitat	stream restoration, conservation, habitat restoration/species protection, acid mine drainage water treatment	land acquisition, channel improvements, channel structures, channel realignment	stream width range, length of restoration, level of restoration
User-Specified Project	project types not represented by other modules	user-specified	project description, total capital costs, total operations and maintenance costs

Costing Module

The Costing Module brings together information supplied or calculated from the Project Modules to develop planning-level cost estimates. The costs are broken down into construction, project development, and annual costs. Costs are developed based on output from the Project Modules and by applying unit costs or cost curves where available. Unit costs or cost curves are adjustable to account for current market conditions using readily available indices. Other costs are based on industry standard or researched percent values of a direct cost. Values can be adjusted by the user as needed.

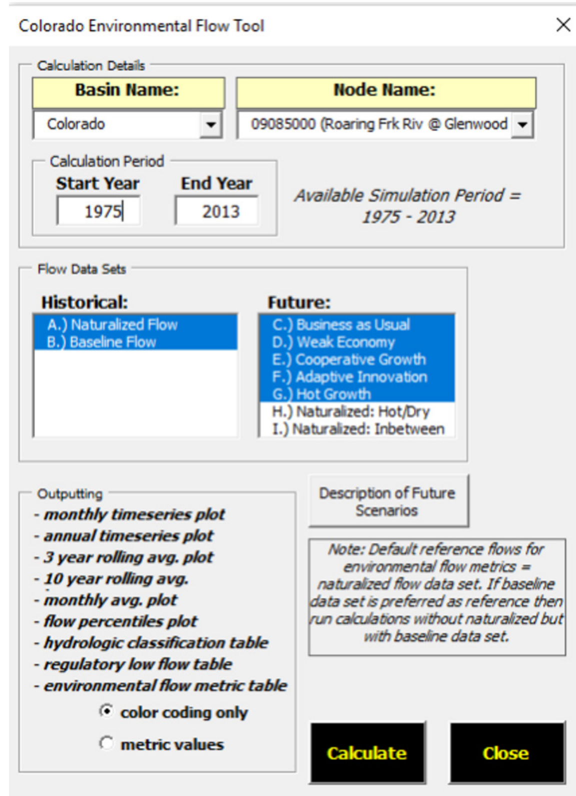
The Costing Module provides a final cost summary sheet that includes a summary outline of project costs by type, present-worth calculations, and a normalized cost that can be used for project comparison.

5.2.2 E&R Flow Tool

The Technical Update included the development of a Flow Tool designed to assess flow conditions in each basin. The Flow Tool was designed to serve as a resource to help basin roundtables refine, categorize, and prioritize their portfolio of E&R projects and methods through an improved understanding of flow needs and potential flow impairments, both existing and projected. The Flow Tool uses hydrologic data from CDSS, additional modeled hydrologic data for various planning scenarios, and established flow-ecology relationships to assess risks to flows and E&R attribute categories at pre-selected gages across the state.

The Flow Tool was constructed in Microsoft Excel by combining components of the Historical Streamflow Analysis Tool and the Watershed Flow Evaluation Tool. The platform provides a familiar and portable working space for the tool user, and offers standard spreadsheet pre- and post-processing capabilities. User inputs specific to the application of the tool are provided via a user-friendly input form (Figure 5.2.2).

Table 5.2.2 Example Input Window from Flow Tool



The flow tool provides the following outputs:

- Monthly and annual time series plots
- Three and ten year rolling average time series plots
- Plot of monthly means
- Monthly flow percentile plots
- A tabular summary of annual hydrologic classifications
- A tabular summary of statistical low flow
- A tabular summary of the calculated environmental flow metrics

The environmental flows table is generated using the flow-ecology relationships described in Section 2. Numeric output is presented as percent departure from reference flows. Reference flows can be specified as either the naturalized flow dataset (default) or the baseline flow dataset. The table is also color coded based on risk category (from low risk to very high risk). Risk categories are pre-defined by subject matter experts according to percent departure threshold values (compared to reference condition). Risk category thresholds differ for each metric. Flow Tool outputs for all 54 nodes across each of the nine basins are available for review and consideration by basin roundtables. Flow statistics under future planning scenarios can be compared to the timing and magnitude of historical peak and low flows. Risk categories identified through analysis of the environmental flow metrics are also available for review and can inform planning discussion in each basin.

The Flow Tool is easy to use and designed for a range of potential end users; however, adding new stream nodes to the tool is not currently an option available to the user and would require additional programming by the tool developers. While the Flow Tool is intended to provide data for use in planning E&R projects and methods, it is not prescriptive.

The Flow Tool does not:

- Designate any gap values
- Provide the basis for any regulatory actions
- Identify areas where ecological change may be associated with factors other than streamflow
- Provide results as detailed or as accurate as a site-specific analysis

The Flow Tool is intended to be a high-level planning tool that:

- Uses the foundations of the HSAT and Watershed Flow Evaluation Tool to scale to a statewide platform
- Post-processes CDSS projections to provide summaries of changes in monthly flow regime at pre-selected locations under different planning horizons
- Identifies potential risks to E&R attribute categories through flow-ecology calculation projections
- Serves as a complementary tool to CDSS to refine, categorize, and prioritize projects
- Provides guidance during Stream Management Plan development and BIP development

5.2.3 E&R Database

The Nonconsumptive Needs Assessment Database (NCNAdb) was developed in 2010 to help manage nonconsumptive data received by basin roundtables and other stakeholders. The database included information related to nonconsumptive attributes, projects, and protections. A significant focus of the Technical Update has been enhancing the NCNAdb (now referred to as the E&Rdb). The E&Rdb includes an enhanced technical foundation, a more engaging and meaningful user interface, and better integration into the Colorado water planning process.

The E&Rdb is a Microsoft Access database formatted in Microsoft Access 2010 file format. The database contains several tables, queries, and modules. The database uses industry standards such as indexes, keys, referential integrity, normalization, and naming standards for tables and fields.

The core data tables in the E&Rdb are described in Table 5.2.2. A more in-depth data dictionary is provided in the E&Rdb TM included in Volume 2 and is available within the database (tblDataDictionary).

Table 5.2.2 Core Data Tables in the E&Rdb

Table	Description
tblBasin	Contains basin information
tblContact	Contact information such as name, address, phone
tblContactProject	Intermediate table relates contacts to projects
tblDatabaseLog	Used to document modifications to database
tblDataDictionary	Contains all tables/fields and respective attributes within the database
tblProject	Projects
tblProjectProtection	Protections assigned to projects and their attributes
tblSegment	Stream segments
tblSegmentAttributeClass	Attribute classifications for attributes along a given stream segment
tblSegmentProject	List of projects that are related to stream segments, and the length of the segment
tblSegmentIDXRef	Contains cross-reference identification between COMID and GNISID
tblSegmentReach	List of Reaches by COMID

The database contains several tools to help browse, search, and extract data; a project data entry form contains the projects and related information. Predefined reports can be used to view and export data. Querying the database requires experience using Microsoft Access, a solid understanding of the question that is translated to a query, and familiarity with the database design to retrieve the information appropriately. The database includes a Microsoft Excel template that can be used to add or update projects and attributes associated with projects.

5.2.4 Project Database

SWSI 2010 and the BIPs led to the initial development and subsequent revision of project datasets for each basin roundtable. These datasets reflect potential projects and processes identified by stakeholders in each basin that may be developed to meet future water supply needs. Project data across basins are inconsistent in content and format due to the complexity of studies, variation by basin, and number of entities involved. Through the Technical Update, project data were reviewed and formatted to increase the usefulness of data products that can be created and to enhance the consistency of analyses using the data.

Project Dataset Content Standards

After a review of each basin roundtable's project dataset, the principal recommendation for developing a standard project dataset for the Technical Update effort was for the datasets to exist in a Microsoft Excel file (e.g., flat file) format and implement standard dataset fields.

Project Dataset Products

Ultimately, two primary data products were developed through this effort: a consistent standard table reflecting the statewide project dataset and mapping products displaying the project datasets. The original project datasets were inconsistent across each basin, and many of the basins did not provide information that could be represented using standard fields. Original project datasets were converted to the standard project format by interpreting the meaning of project data fields in individual basin's datasets and by using engineering judgement. As reflected in Table 5.2.3, several basins did not have data for all standard fields. In these cases, fields were left blank in the standard project dataset.

Table 5.2.3 Standard Project Data Fields and Presence of Fields in Final Basin Project Datasets

Data Field/Column	Arkansas	Colorado	Gunnison	North Platte	Rio Grande	South Platte / Metro	Southwest	Yampa-White-Green
Project_ID	X	X	X	X	X	X	X	X
Project_Name	X	X	X	X	X	X	X	X
Project_Description	X		X	X			X	X
Project_Keywords								
Status	X	X	X				X	
Lead_Proponent	X	X	X		X	X	X	X
Lead_Contact	X		X	X		X	X	
Municipal_Ind_Need	X	X	X	X	X	X	X	X
Agricultural_Need	X	X	X	X	X		X	X
Envr_Rec_Need	X	X	X	X	X		X	X
Admin_Need					X			
Latitude	X	X	X	X	X	X	X	X
Longitude	X	X	X	X	X	X	X	X
County	X	X	X	X	X	X	X	X
Lat_Long_Flag								
Water_District	X	X	X	X	X	X	X	X
Estimated_Yield	X	X	X			X		
Yield_Units	X	X	X			X		
Estimated_Capacity	X					X		
Capacity_Units	X					X		
Estimated_Cost	X	X	X		X	X		

Uses of Projects Dataset

The availability of required data fields will support several future uses of project datasets:

- **Filtered Lists.** It will be possible to create customized datasets, maps, spreadsheet files, and other formats for use in analysis and visualizations.
- **Maps.** The addition of general location coordinate data for each project allows for all projects to be easily located on maps. A user interested in a particular basin or region can then quickly determine the projects in that area and find more information.

5.3 BIP UPDATES

Recommendations from the Technical Update have been distilled into five "next step" categories: 1) BIP Updates, 2) Project Updates, 3) Technical Updates, 4) Strategic Updates, and 5) Outreach Updates. These recommendations, detailed below, will be used to guide upcoming discussion with Colorado's nine basin roundtables, including future phases of work to update BIPs and the Water Plan.

Each action item is accompanied by a brief background description that provides insight into the history of stakeholder processes and conversations that led to the recommended action. This includes, but is not limited to, input from roundtables; public education, participation and outreach workgroups (known as PEPO); the Interbasin Compact Committee; and the 2018-2019 Implementation Working Group.

The following list of recommendations is intended to provide basin roundtables flexibility in the update process, tailoring approaches to best suit roundtable goals. These recommendations provide a framework for some level of standardization across the BIP updates. This iterative process is meant to support statewide water supply planning, cross-basin dialogue, project funding, enhanced future supply analyses, revised goals, and updated project lists. Integrating Technical Update findings with the BIPs, project lists, and the Colorado Water Plan update ensures state water planning will continue to be informed by the best available data.

5.3.1 BIP Updates

A. Evaluate the scope of BIP updates to integrate Technical Update findings

Basin roundtables will work with the CWCB and their membership to identify how to best update their BIPs. In the first BIP process, the CWCB created a guidance document that each roundtable tailored to suit its own needs. Each roundtable then hired separate contractors to assist with its first plan development. To lighten the level of effort required to update these plans, the CWCB, roundtables, and the IWG reviewed the benefit of hiring a central contractor (selected by the CWCB and roundtable chairs) to support each roundtable and coordinate a path forward. Local expert contractors (selected by each roundtable) will play an important role in supporting the roundtables and the general contractor. A first order of business will be coordinating on the full scope of the BIP update, including an evaluation of core needs (e.g., reviewing project lists) and any additional analysis that may be beneficial to each roundtable.

B. Integrate relevant studies and local plans into BIP updates

Basin roundtables will evaluate which plans and studies should inform and be referenced in their BIPs. As noted by the IWG, several local, regional, and statewide studies are available since the initial BIPs (2015) that may provide important context to basin planning. Examples include stream management plans, conservation plans, forest health studies, climate studies, city/master plans, and resilience plans.

C. Identify opportunities for enhanced data inputs that improve modeling output

Basin roundtables will identify if additional data inputs can support enhanced analysis. In all modeling studies, future projections are only as good as the data that inform the model. In the Technical Update, basin-specific data were limited in certain areas and could likely be refined. For example, municipal irrigated acreage data were not something to which the state had access, which limited the ability to model outdoor municipal water use analysis in more detail; however, municipal providers may have this information, and sharing it could be used to refine the model. Other opportunities exist across municipal, environmental, and agricultural reporting where the Technical Update could likely be enhanced in future iterations with the basin roundtable's help to refine model input data.

5.3.2 Project Updates

A. Enhance planned project data

Basin roundtables will enhance and maintain project data with the help of the contracting team as part of the BIP update. The Technical Update review of basin project lists (previously known as identified projects and processes, or IPPs) recommends 20 data fields to be associated with every project (e.g., project name, location, yield, proponent and cost). The Implementation Working Group reviewed the attribute list and added fields such as water rights and permitting status. While much of the data are not captured in existing project lists, the CWCB is working to develop a project database to assist with consistent data collection and input. This not only helps better support water supply planning needs, but also supports roundtable funding and the refinement of funding needs identified in the Water Plan.

B. Improve project costs in Water Plan

Basin roundtables will update project costs to help confirm Water Plan funding needs. The Water Plan identifies how project cost estimates will be improved upon in the BIP update process. Currently, less than 50 percent of the projects in any BIP have associated costs. To assist in this next step, the Technical Update scope included developing a costing tool to help evaluate project costs. As Water Plan funding is an increasing focus, it is critical to have more accurate cost information to better support how funds would be spent.

C. Assess how to best use project tiers

Basin roundtables will work collectively to help inform simplified and standardized project tiers. To be strategic with limited resources, some level of prioritization is necessary. Three of the eight BIPs already utilize some form of project ranking or tier system. At a minimum, missing data can serve as a de facto tiering system in which projects with clearly listed project proponents, costs, and other data are ranked over those without these data points; however, this needs to be reviewed more carefully as it may not be feasible to have all the data listed based on where a project is in the planning cycle.

To assist with this effort, the IWG reviewed a draft "Project Tier Matrix" that will need to be evaluated further during the BIP updates. The IWG determined that both proof-of-concept and shovel-ready (immediately implementable) projects are equally important to fund. The IWG also saw value in a placeholder category for Projects that may be more conceptual in their current phase but might be fleshed out in the future. This is especially true if the project lists are used establish future funding needs. Similarly, the IWG noted that a tier system should not generate competition in funding between basin roundtables.

5.3.3 Technical Updates

A. Review modeling assumptions + consider refinement

Basin roundtables will review beneficial localized and statewide modeling changes as needed. Every model is based on a set of assumptions. The TAG process reviewed, evaluated, and agreed on baseline model assumptions. However, a number of decision points on additional/refined assumptions arose in later stages of modeling. If roundtables decide additional modeling is desired for their BIP update, roundtables will work with the central contractor to ensure their modeling questions are in-line with baseline model assumptions (to support an "apples-to-apples" analysis). Modeling assumptions cannot be changed in ways that could potentially be used to address sensitive legal issues (local or statewide), conflict with policy, or create divisions across the basins.

B. Consider modeling projects

Basin roundtables will evaluate modeling needs and if/how they choose to model projects. Roundtables may choose to model their own unique variables as appropriate (such as projects). Unlike SWSI 2010, the Technical Update did not include any specific projects (e.g. water savings from planned projects) in the analysis, largely due to insufficient project data. The opportunity remains for roundtables to model their own unique projects to explore offsets to the Technical Update supply gaps. Any modeling would carefully consider potential implications of modeling discrete projects that could conflict with ongoing planning or permitting efforts (or any caveats outlined by the Attorney General's Office).

C. Review sub-basin modeling needs

Basin roundtables will review need and trade-offs of summarizing more granular subbasin data. Each of the original BIPs divided their basins into tributary regions differently, resulting in regional data and planning at different scales; however, it was unclear if each roundtable found their BIP sub-basin breakouts to be helpful, if they would have done them differently, or if they would potentially need them at all. Additionally, modeling at granular scales is intensive, costly, and complex. The CWCB chose to report modeling findings at the basin level only. If higher resolution data are desirable, regional delineations would require roundtable input.

5.3.4 Strategic Updates

A. Continue to focus on adaptive management strategies through scenario planning

Basin roundtables will evaluate how they can be nimble amidst changing conditions. Adaptive management has been a key component of roundtable and IBCC discussions for many years. This discussion directly informed the adoption of using a scenario planning approach to account for key drivers and uncertainties within the planning horizon (2050). How basin projects and plans can be tested against these variant futures (the five scenarios) or could be shifted to respond to future changes is something that needs to be considered. Projects and basin roundtable planning should be reviewed for impact and responsiveness. This is at the heart of the No-and-Low Regrets Action Plan that comprise not only core strategies in the Water Plan but also received 100 percent consensus by the IBCC and CWCB board. These core strategies aim to establish a set of plans having the highest benefit with the least unintended consequences, regardless of the future condition.

B. Develop signposts with CWCB support

Basin roundtables will work with the CWCB to identify and establish signposts as appropriate. Using signposts, or check-in points, is fundamental to scenario planning. There may be triggers or key indicators that help determine if specific actions are needed and/or there should be a set frequency for review to help determine growth trajectories. A signpost may also be seen as the frequency by which the state and/or basin roundtables look for and review key indicators. Roundtables and the CWCB need to collaborate on the best approach for establishing clear signposts that help provide the necessary review and analysis of current conditions.

C. Evaluate climate extremes for greater integration

Basin roundtables should identify how to best integrate climate change into planning. Climate change factors are incorporated into three of the five scenarios. Beyond temperature, other issues with climate extremes and greater variability are a major concern for acute and chronic impacts. For example, earlier runoff can affect agricultural operations in early and late season. Additionally, the scale of climate extremes, like major floods, may not be reflected in all the current modeling (e.g., the floods of 2013). Issues such as flood, forest fires, invasive species, and drought need to be considered in future planning. Evaluating and planning for climate impacts and extreme weather events with adaptive and resilient management strategies should be a focus that helps with planning for any potential future.

5.3.5 Outreach Updates

A. Enhance water plan goals, messaging and stakeholder engagement

Basin roundtables will work to engage new audiences in water planning and outreach. The Water Plan set education and outreach goals through 2020, which are all on track to be met. Roundtables will review and enhance their Education Action Plans while considering the Statewide Education Action Plan, which is still under development by Water Education Colorado, to further improve coordination and continue the effort to reach beyond the traditional roundtable audience. Each roundtables Education Action Plan will be coordinated with the BIP updates in support of the greater Water Plan goals. The CWCB will need to work across these groups to identify what new outreach goals will need to be established in future plans.

B. Rebrand around the Water Plan for consistency

Basin roundtables will support rebranding that integrates BIPs around the Water Plan. The Technical Update, Basin Implementation Plans, and Water Plan update are all intertwined. Each effort builds on the last and, as such, the collective process informs the comprehensive Water Plan update. Basin roundtables will need to help evaluate creative ways to communicate this comprehensive message using new and innovative strategies. This may include improved data visualization, surveys, statewide events, water-related contests, campaigns, or other means of engaging with and focusing on the Water Plan.

SECTION 6
CITATIONS

[1] Colorado Water Conservation Board, IBCC Annual Report (CWCB, 2012), 78 .

[2] Figure 4.9 in Colorado's Water Plan shows the three composite scenarios selected representing "Hot and Dry", "Between 20th century observed and Hot and Dry" (or "In-Between"), and the current hydrology (or "Baseline Hydrology").

[3] Temperature and precipitation were not attributes that were used in estimates of future hydrologies but are extracted from the datasets to help contextualize what the changes in IWR and runoff relate to. See Technical Update Volume 2 technical memo, "Temperature Offsets and Precipitation Change Factors Implicit in the CRWAS-II Planning Scenarios." A temperature offset (°C) quantifies the predicted temperature change from baseline conditions (1970–1999) to future conditions (2050), summarized as (future = historical + offset). A precipitation change factor (unitless) is the ratio of predicted future (2050) to baseline (1970–1999) precipitation totals, summarized as (future = historical x factor)

[4] The planning scenarios developed for Colorado's Water Plan and this Technical Update were built upon the foundational work of the multiphase Colorado River Water Availability Study, Phase II (CRWAS-II). Detailed methodology and analysis results can be found in CRWAS-II Task 7: Climate Change Approach and Results.

[5] House Bill 2010-1051 requires that the CWCB implement a process for the reporting of water use and conservation data by covered entities. A "covered entity" is defined as each municipality, agency, utility, including any privately owned utility, or other publicly owned entity with a legal obligation to supply, distribute, or otherwise provide water at retail to domestic, commercial, industrial, or public facility customers, and that has a total demand for such customers of two thousand acre-feet or more, per Section 37-60-126(1)(b) of the Colorado Revised Statutes (C.R.S.). 1051 reporting data provided by CWCB for the Technical Update in February 2018.

[6] The adoption rate was applied to all demand categories except for non-revenue water.

[7] Source: https://www.onthesnow.com/colorado/skireport.html

[8] SWSI 2010 did not conduct any surface water modeling but Section 6 of that report provided a cursory review of water availability from existing studies.

[9] Colorado Springs Utilities has water supply to meet additional future demands, and the additional supply was accounted for in gap calculations. Pueblo Board of Water Works did not have an estimate additional future demand that could be met with existing supplies, and gaps were not adjusted.

[10] Source: Contribution of Agricultural to Colorado's Economy (January 2012, Colorado State University Extension)

[11] Source: Rio Grande Basin Implementation Plan (April 2015)

[12] RGDSS represents groups of wells with similar hydraulic characteristics as a "response area", and their combined impact to streams is represented as a "response function". Each Subdistrict represents the geographic area reflected in the RGDSS "response area".

[13] The San Juan Chama Project delivers water from San Juan tributaries to the Rio Grande basin in New Mexico. The baseline and planning scenario models include the current demand and operations, but the project deliveries are not considered a transbasin export for the Technical Update as the project does not operate under a Colorado water right; cannot call out Colorado water users; and the supply is not delivered to a Colorado entity.

[14] Other scenarios examined in the SWSI 2010 analysis projected the 2050 gap in M&I supplies to potentially be as low as 190,000 AFY or as high as 630,000 AFY.

[15] See Table ES-6 from SWSI 2010 Executive Summary.

[16] See Table ES-4 from SWSI 2010 Executive Summary

[17] Based on the estimated existing gap between available water supplies for irrigated agriculture and the full irrigation requirement for current irrigated acres shown in Table ES-3 from SWSI 2010 Executive Summary.

SECTION 4
STATEWIDE & BASIN RESULTS

Statewide and basin-specific results of Technical Update analyses are described in Section 4. Statewide results are described first followed by basin-specific results. Results are described for:

- Agricultural diversion demands
- M&I diversion demands
- Agricultural and M&I gaps
- Environment and recreation conditions
- Available water supply

4.1 KEY ASSUMPTIONS AND LIMITATIONS

The analyses used to estimate demands and gaps incorporated some key assumptions and limitations that are important to consider when reviewing and using the results of the Technical Update:

- As stated in Section 3, future water supply projects (or IPPs) were not included in the Technical Update (see section 3.2.1).
- While the models used for this analysis consider a wide range of detailed information on river diversions, water provider operations, etc., the analyses were conducted and reported at a regional scale for understanding basinwide and statewide demands, supplies, and gaps. Attempting to extrapolate model results for specific water providers is not useful given the regional scale of model input data, the regional focus of the modeling, and the relatively high level of uncertainty associated with individual water provider operations under various scenarios.

Agricultural considerations:

» Livestock water demands were not included in the analysis because they are difficult to quantify, are relatively small compared to irrigation demands and are not a component of the CDSS tools used for the agricultural diversion demand analysis and gap calculations.

» The analysis did not consider different types of crops that may be grown in the future under the different scenarios; however, it accounted for future changes in crop types in a general sense in the *Adaptive Innovation* scenario and assumed that future crops would have 10 percent lower IWR.

M&I considerations:

» Projected water demands for the planning scenarios do not contemplate how municipal water providers or industrial water users would respond to acute drought conditions (e.g., implementation of watering restrictions, etc.).

Operations with respect to transbasin imports/exports:

» Imports from transbasin diversion projects were set at historical levels and reflect historical operations. To accurately reflect how the change in water availability on the Western Slope would have impacted transbasin diversions, it would have been necessary to work with the major transbasin diverters to understand how their operations may change on both the Western and Eastern Slope in response to West Slope shortages and include those operations in the assessment. The level of investigation and modeling necessary to properly assess changed operations was beyond the scope of this current effort. Agricultural and M&I gaps do not directly reflect reductions in supply that would occur if transbasin imports are reduced.

» Data presented in Section 4.2.4 show how much of the historical transbasin imported supply is projected to be potentionally reduced by 2050 in some of the planning scenarios.

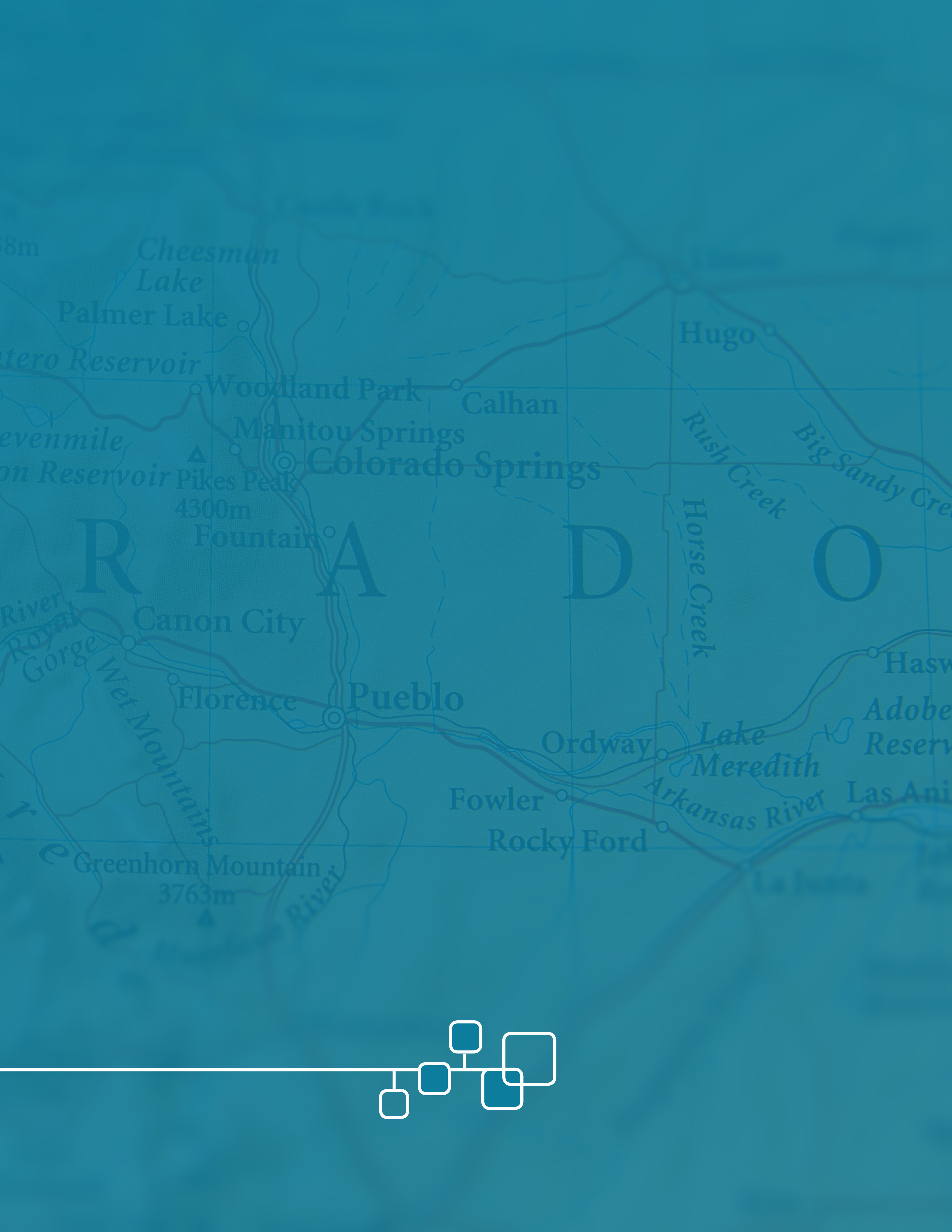
Statewide modeling results are shown in the following section followed by the results for each of the eight major river basins

CO
COLORADO STATEWIDE

A	C	G	RG	NP	SP METRO	SW	YWG
ARKANSAS BASIN	COLORADO BASIN	GUNNISON BASIN	RIO GRANDE BASIN	NORTH PLATTE BASIN	SOUTH PLATTE /METRO BASIN	SOUTHWEST BASIN	YAMPA-WHITE-GREEN BASIN

The results and findings of the Technical Update pertaining to statewide agricultural and M&I demands and gaps as well as findings related to environmental and recreational attributes and future conditions are summarized in the following section, which is followed by findings in each of the state's eight major river basins.

STATEWIDE


Cheesman Lake
Palmer Lake
Woodland Park
Calhan
Hugo
Manitou Springs
Colorado Springs
Pikes Peak
4300m
Fountain
Rush Creek
Big Sandy Cre
Horse Creek
R A D O
Canon City
Royal Gorge
Wet Mountains
Florence
Pueblo
Ordway
Lake Meredith
Fowler
Rocky Ford
Arkansas River
Greenhorn Mountain
3763m
River
Adobe
Las Ani

4.2 STATEWIDE RESULTS

4.2.1 Summary of Technical Update Results

Key results and findings of the Technical Update pertaining to statewide agricultural and M&I demands and gaps, as well as findings related to environmental and recreational attributes and future conditions, are summarized below.

Agriculture

- On a statewide basis, current average annual agricultural diversion demands are approximately 13,000,000 AFY.
- Demand for groundwater is approximately 19 percent of the overall demand. Groundwater demands occur primarily in the Arkansas, Republican, Rio Grande, and South Platte basins.
- Future agricultural diversion demands will be affected by changes in irrigated acreage due to urbanization, aquifer sustainability, and agricultural to urban transfers of water.
  - » Urbanization is projected to reduce irrigated lands statewide by 5 percent. Most of the reduction will occur in the South Platte Basin, with more than 12 percent of the basin's irrigated acreage projected to be urbanized.
  - » 6 to 7 percent of irrigated acres supplied by groundwater is projected to be lost due to aquifer sustainability issues. The impacts of this will be focused in the Arkansas, Republican, and Rio Grande basins.
  - » Stakeholders in the Arkansas and South Platte basins estimated that between 33,000 and 76,000 irrigated acres may be lost due to water rights purchases that have already taken place or are very likely to take place in the future. Specific estimates in the South Platte are likely understated because stakeholders did not have a projection of acreage that is likely to be lost in the reach of the South Platte between Denver and Greeley and in the tributaries in this region. The estimated loss of agricultural lands due to permanent water transfers conducted for the Technical Update is different than the amount estimated in SWSI 2010. The SWSI 2010 estimates included water transfers contemplated in portfolios of projects to fill future M&I gaps statewide, whereas the estimates in the Technical Update were focused in the South Platte and Arkansas basins and were conducted for the purposes of reducing agricultural diversion demands based on pending transfers that are very likely to occur in the foreseeable future. Basin roundtables may expand on this in their BIP updates and consider how alternative water transfers or future permanent transfers should be considered as future water supply projects and strategies to mitigate gaps.
- On average, approximately 80 percent of the overall agricultural diversion demand is currently met on a statewide basis, though this varies in each basin.
- Agricultural diversion demands statewide are projected to decrease in three of the five scenarios. In *Business as Usual* and *Weak Economy*, loss of irrigated land is projected to reduce diversion demands by around 9 percent. In *Adaptive Innovation*, demand reductions due to losses of irrigated lands will be offset in part by increases in crop consumptive use demand due to climate change. Adoption of emerging technologies that increase efficiency and decrease consumptive use, however, are projected to reduce overall diversion demand by 20 percent relative to current demand. In *Hot Growth*, irrigated lands are projected to be lost, but climate change is projected to more than offset the demand reductions associated with loss of irrigated lands and result in an overall increase in diversion demand of 5 percent compared to current conditions.
- In basins with significant potential acreage reductions like the South Platte and Republican, diversion demands in all planning scenarios are projected to be less than current.

M&I Demands

- M&I demands currently comprise approximately 10 percent of overall statewide water demands.
- Current statewide population (as of 2015) is 5 percent less than the level projected in SWSI 2010.
- Current population is 5,448,100, and by 2050 is projected by the State Demography Office to increase by more than 3 million people to 8,461,300—a 55 percent increase. Low population projections estimate the population to increase by 41 percent (to 7,683,200 people) while high projections estimate the increase at 71 percent (to 9,312,400 people).
- The statewide baseline per capita systemwide demand has decreased from 172 gpcd in SWSI 2010 to approximately 164 gpcd, which is a nearly 5 percent reduction in demands between 2008 and 2015.
- Statewide per capita demands are projected to decrease compared to current conditions in each scenario except *Hot Growth*. *Adaptive Innovation* assumes the highest levels of conservation and has the lowest projected per capita demand at 143 gpcd, which is 13 percent lower than current per capita demand in spite of assumed hot and dry future climate conditions.
- While per capita usage is expected to decrease compared to current conditions in all but *Hot Growth*, overall statewide M&I water demand is projected to increase from current conditions to 35 percent in *Weak Economy* up to 77 percent in *Hot Growth*.

- Increase in overall M&I demand is very similar in *Adaptive Innovation* compared to *Business as Usual* despite the assumptions in *Adaptive Innovation* of high population growth and hot and dry future climate conditions. In addition, *Hot Growth* and *Adaptive Innovation* have similar assumptions related to population and climate, but *Adaptive Innovation* assumes much more aggressive conservation that result in M&I demands that are 15 percent lower than *Hot Growth*. These results demonstrate the potential benefit of aggressive conservation in managing future M&I demands.
- Self-supplied industrial demands are approximately 13 percent of overall M&I demands statewide, but are a greater proportion in certain basins.

Projected Gaps

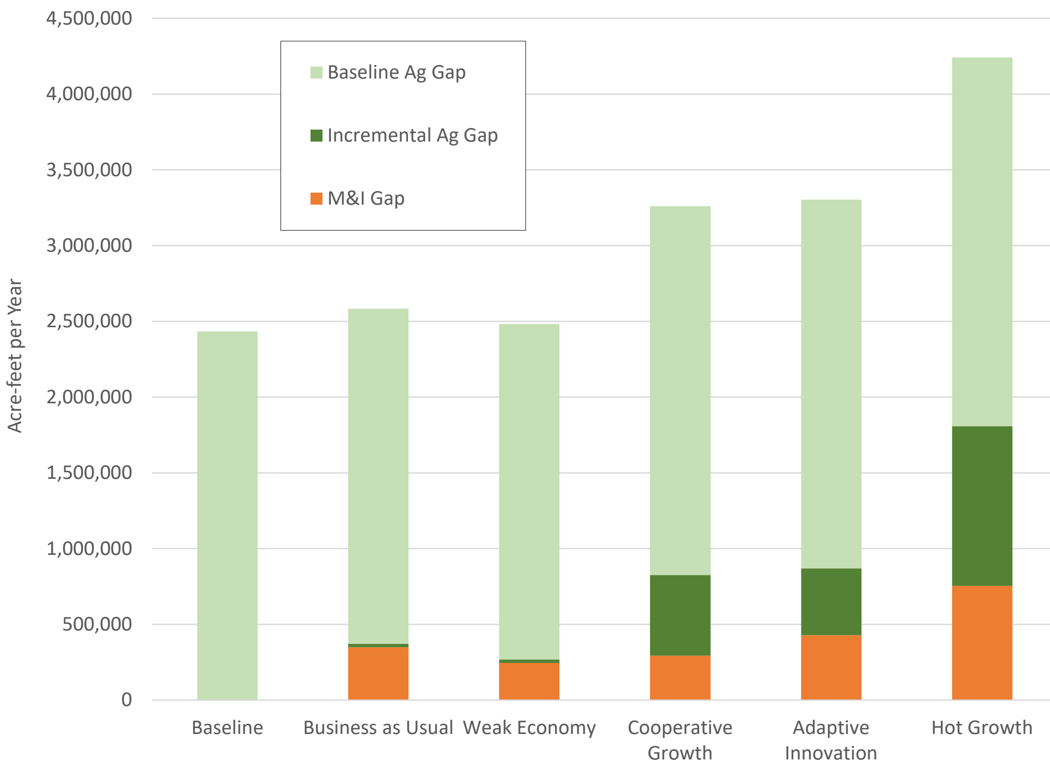
- **Agriculture**
  - » Agriculture currently experiences gaps, and gaps may increase in the future if climate conditions are hotter (which increases irrigation water demand) and supplies diminish (due to drier hydrology). Future gaps may increase by 440,000 AFY (in *Adaptive Innovation*) to 1,053,000 AFY (in *Hot Growth*) or 18 to 43 percent beyond what agriculture experiences, despite the loss of irrigated acreage.
  - » Agricultural gaps under *Adaptive Innovation* are significantly less than *Hot Growth* despite similar assumptions related to future climate conditions, which demonstrates the potential benefits of higher system efficiencies and emerging technologies that could reduce consumptive use. While conservation and efficiency improvements can be a tool for addressing future agricultural gaps, particularly in return-flow-driven systems, it is important to consider projects on a case-by-case basis.
- **M&I**
  - » Municipal and self-supplied industrial users do not currently experience a gap, but increasing population and potentially hotter and drier future climate conditions will create a need for additional supply despite efforts to conserve water. Statewide M&I gaps are projected to be from 250,000 AF (in *Weak Economy*) to 750,000 AF (in *Hot Growth*) in dry years. These gap estimates do not account for yields from water supply projects and strategies that water providers are pursuing.
  - » Municipal conservation efforts, however, create significant future benefits in lowering the gap, as demonstrated by comparing *Adaptive Innovation* and *Hot Growth* (which have similar assumptions on population and climate). Projected future gaps under *Adaptive Innovation* are 325,000 AF less than projected gaps under *Hot Growth*.
  - » Scenarios that include climate change project reduced available supplies for transbasin diversion projects. Reductions in transbasin imports will contribute to projected gaps, potentially to a greater degree than suggested in the analyses, because water providers reuse the return flows from transbasin imports.

Environment and Recreation

- Climate change and its impact on streamflow will be a primary driver of risk to E&R attributes.
- Projected future streamflow hydrographs in most locations across the state show earlier peaks and potentially drier conditions in the late summer months under scenarios with climate change.
- Under climate change scenarios, runoff and peak flows may occur earlier, resulting in possible mis-matches between peak flow timing and species' needs.
- Climate change may lead to more frequent flooding events, especially in disturbed areas, including fire scars. Stream and watershed health may be impacted by these events and thresholds may be crossed, resulting in impaired ecosystem structure and function. While these are important considerations, they were beyond the scope of this analysis.
- Drier conditions in late summer months could increase risk to coldwater and warmwater fish due to higher water temperatures and reduced habitat. The degree of increased risk is related to the level of streamflow decline.
- In many mountainous regions without significant influence of infrastructure, peak flow and low flows are projected to be sufficient to sustain low to moderate risk for riparian plants and fish, but risks are projected to increase in scenarios with climate change.
- In mountainous regions with infrastructure, risks to E&R attributes may vary. Streams that are already depleted may see increased risks in scenarios with climate change; however, some streams may be sustained by reservoir releases, which will help moderate risks in scenarios with climate change.
- Instream flow water rights and recreational in-channel diversion water rights may be met less often in climate-impacted scenarios.

Results describing current and potential future statewide M&I and agricultural gaps are summarized in Figure 4.2.1 and Table 4.2.1. Statewide gaps may vary substantially depending on future climate conditions and population increases, which underscores the need to take an adaptive approach to developing water management strategies, and projects and methods, to fill potential future gaps.

Figure 4.2.1 Summary of Statewide Gap Estimates by Planning Scenario



Results of calculations and analyses that support estimates of the statewide gap are presented in the subsections below.

INCREMENTAL GAP

The incremental agricultural gap quantifies the degree to which the gap could increase beyond what agriculture has historically experienced under water shortage conditions.

Table 4.2.1 Summary of Statewide Gap Results

Basin	Gap	Baseline	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Arkansas	Ag- Average annual gap (AFY)	617,300	586,400	585,200	701,700	734,800	819,500
	Ag- Average annual incremental gap (AFY)	0	0	0	84,400	117,500	202,200
	M&I- Max annual gap (AF)	0	68,500	53,100	58,500	62,900	108,700
Colorado	Ag- Average annual gap (AFY)	45,300	44,000	44,000	76,200	61,500	103,800
	Ag- Average annual incremental gap (AFY)	0	0	0	30,900	16,200	58,500
	M&I- Max annual gap (AF)	0*	4,200	3,300	5,300	6,600	15,800
Gunnison	Ag- Average annual gap (AFY)	87,300	77,200	77,300	157,600	112,600	222,000
	Ag- Average annual incremental gap (AFY)	0	0	0	70,300	25,300	134,700
	M&I- Max annual gap (AF)	0*	2,300	700	3,500	4,300	11,500
North Platte	Ag- Average annual gap (AFY)	85,700	108,000	107,900	177,900	168,100	231,100
	Ag- Average annual incremental gap (AFY)	0	22,200	22,200	92,100	82,400	145,400
	M&I- Max annual gap (AF)	0	0	0	0	0	0
Rio Grande	Ag- Average annual gap (AFY)	683,900	655,800	661,500	737,400	741,900	826,400
	Ag- Average annual incremental gap (AFY)	0	0	0	53,500	58,000	142,500
	M&I- Max annual gap (AF)	0	3,400	0	2,400	4,000	8,100
Southwest	Ag- Average annual gap (AFY)	126,600	120,300	119,800	276,700	219,000	355,100
	Ag- Average annual incremental gap (AFY)	0	0	0	150,100	92,400	228,400
	M&I- Max annual gap (AF)	0*	7,500	1,800	7,700	13,800	24,800
South Platte /Metro *(and Republican)*	Ag- Average annual gap (AFY)	773,500	606,300	604,000	610,900	577,600	665,400
	Ag- Average annual incremental gap (AFY)	0	0	0	0	0	0
	M&I- Max annual gap (AF)	0*	257,000	184,500	213,300	333,700	543,500
Yampa-White-Green	Ag- Average annual gap (AFY)	14,500	14,800	14,800	66,200	62,300	155,800
	Ag- Average annual incremental gap (AFY)	0	400	300	51,700	47,800	141,400
	M&I- Max annual gap (AF)	0*	5,600	1,600	2,600	3,800	41,700
Statewide Total	**Ag- Average annual gap (AFY)**	**2,434,200**	**2,212,800**	**2,214,500**	**2,804,500**	**2,677,800**	**3,379,100**
	Ag- Average annual incremental gap (AFY)	**0**	**22,600**	**22,500**	**533,000**	**439,600**	**1,053,000**
	M&I- Max annual gap (AF)	**0**	**348,500**	**245,100**	**293,300**	**429,200**	**754,200**

* *CDSS water allocation models in these basins calculate small baseline M&I gaps, but they are either due to calibration issues or they are reflective of infrequent, dry-year shortages that are typically managed with temporary demand reductions such as watering restrictions.*

4.2.2 Statewide Agricultural Diversion Demands

Current Diversion Demands

Currently, 3.28 million acres of agricultural land are irrigated statewide. Irrigated agriculture supports a wide network of agribusiness in Colorado from producers of agricultural goods to those that process and deliver those goods to consumers. Agricultural production in Colorado is a large part of the state's economy, with agribusiness contributing $41 billion annually and employing nearly 173,000 people.[10] Working agricultural operations also remain the economic backbone of many of Colorado's rural communities and provide important ecosystem services such as open space and wildlife habitat.

Figure 4.2.2 Proportion of Statewide Irrigated Acreage in Each Basin

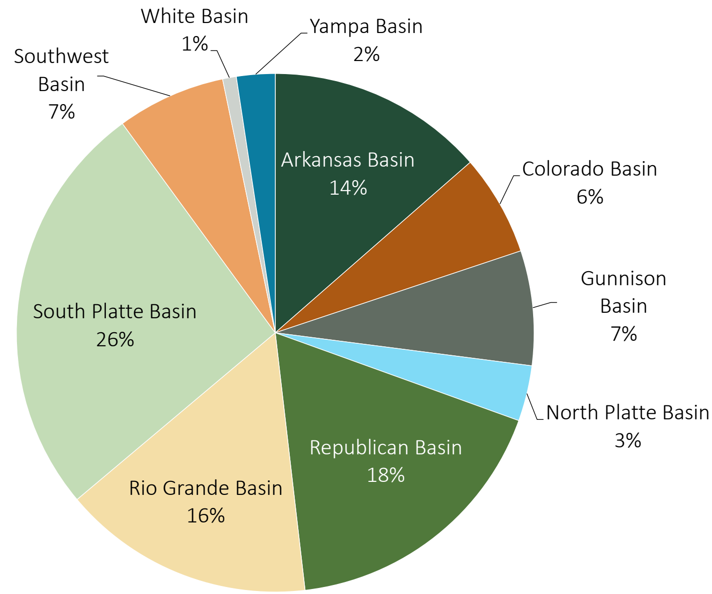
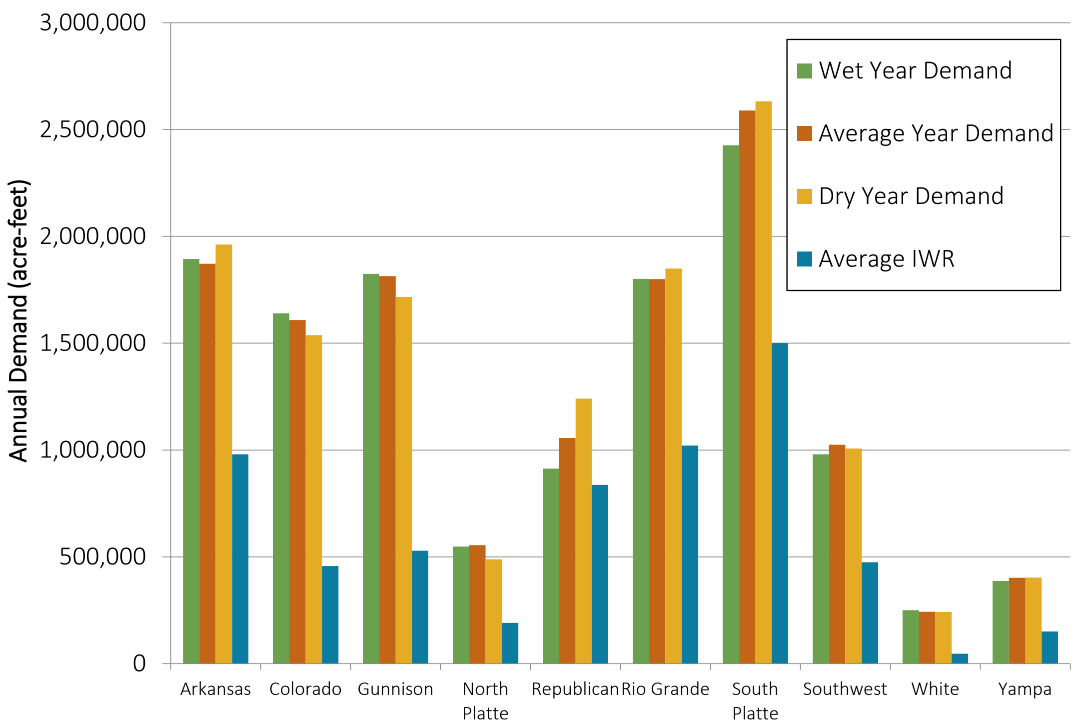


Figure 4.2.2 shows the proportion of statewide irrigated acreage in each basin. Over a quarter of the irrigated acreage in Colorado is located in the South Platte Basin. The Arkansas, Rio Grande, and Republican Basins also have significant acreage, each with approximately 15 percent of the statewide total. Grass pasture is the predominant crop grown in the state, particularly in the West Slope basins; however, irrigators also grow alfalfa, wheat, cereals/grains, fruits, and vegetables. Much of the irrigated acreage supports ranching operations, either through grass hay production for livestock operations or grazing of irrigated pastures. Refer to the basin-specific results summaries for more information on crops grown in each basin.

Tables 4.2.2 and 4.2.3 and Figure 4.2.3 show the agricultural diversion demand for surface and groundwater supplies summarized by basin for wet, dry, and average hydrological year types compared to average IWR. Results are displayed over a range of hydrological year types to illustrate both how demands and system efficiencies change under different climatic/hydrological conditions and when different types of supplies are used.

Figure 4.2.3 Current Agricultural Diversion Demand by Basin



As discussed in Section 2, the agricultural diversion demand is calculated by dividing the IWR by system efficiency. In dry years for example, IWR is generally higher due to increased temperatures, lower precipitation, and decreased available surface water supplies for irrigation. In these types of years, many irrigators implement additional operational measures to be more efficient with the limited surface water irrigation supplies, resulting in a lower overall dry-year diversion demand. For irrigators with groundwater supplies, the groundwater demand generally increases in response to higher IWR in dry years. System efficiencies range across basins and year types due to availability of irrigation supplies; irrigation practices (i.e., sprinkler or flood applications); and on-farm conditions such as ditch/lateral alignments, soil types, and field topography. Refer to the basin-specific results for more information on conditions that impact the system efficiency and the agricultural diversion demand.

DIVERSION DEMAND

The diversion demand represents the amount of water that would need to be diverted or pumped to meet the full crop IWR and does not reflect historical irrigation supplies. Irrigators often operate under water-short conditions and do not have enough supply to fully irrigate their crop.

Table 4.2.2 Current Irrigated Acreage, Average Annual IWR, and Diversion Demand

Basin	Acreage	Average IWR (AF)	Unit IWR (feet)	Total Diversion Demand (AF)		
				Wet Year	Average Year	Dry Year
Arkansas	445,000	980,000	2.20	1,894,000	1,872,000	1,962,000
Colorado	206,700	456,500	2.21	1,640,000	1,608,000	1,538,000
Gunnison	234,400	528,200	2.25	1,824,000	1,814,000	1,716,000
North Platte	113,600	191,100	1.68	548,000	555,000	489,000
Rio Grande	515,300	1,021,000	1.98	1,801,000	1,800,000	1,849,000
South Platte/Metro (and Republican)	1,433,100	2,337,000	1.63	3,340,000	3,645,000	3,873,000
Southwest	222,500	474,900	2.13	980,000	1,025,000	1,007,000
Yampa-White-Green	107,000	197,000	1.84	637,000	645,000	645,000
Total	**3,280,000**	**6,190,000**	**1.89**	**12,664,000**	**12,964,000**	**13,079,000**

Table 4.2.3 Current Agricultural Diversion Demand for Surface and Groundwater Supplies

Basin	Surface Water Demand (AF)			Groundwater Demand (AF)		
	Wet Year	Average Year	Dry Year	Wet Year	Average Year	Dry Year
Arkansas	1,567,000	1,497,000	1,501,000	327,000	375,000	461,000
Colorado	1,640,000	1,608,000	1,538,000	-	-	-
Gunnison	1,824,000	1,814,000	1,716,000	-	-	-
North Platte	548,000	555,000	489,000	-	-	-
Rio Grande	1,237,000	1,172,000	1,195,000	564,000	628,000	654,000
South Platte/Metro (and Republican)	2,078,000	2,186,000	2,108,000	1,262,000	1,459,000	1,765,000
Southwest	980,000	1,025,000	1,007,000	-	-	-
Yampa-White-Green	637,000	645,000	645,000	-	-	-
Total	**10,511,000**	**10,502,000**	**10,199,000**	**2,153,000**	**2,462,000**	**2,880,000**

As reflected in the Tables 4.2.2 and 4.2.3 (on previous page), the current statewide total agricultural diversion demand is approximately 13 million acre-feet, with more than 80 percent of that demand attributable to surface water supplies.

Future Diversion Demands

The following graphics and tables summarize the acreage, IWR, and the agricultural diversion demand attributable to surface and groundwater supplies in each basin calculated for the five planning scenarios based on the adjustment factors and approach discussed in Section 2. Future agricultural diversion demands were adjusted to reflect:

- Urbanization
- Planned Agricultural Projects
- Groundwater Acreage Sustainability
- Climate
- Emerging Technologies

The two factors anticipated to have substantial statewide impact are urbanization and climate. Table 4.2.4 reflects basin-specific and statewide historical urbanization, projected urbanized acreage and current levels of irrigated acreage for context. Between the late 1980s and early 1990s to present, more than 58,000 irrigated acres were urbanized (based on historical irrigated acreage assessments and current municipal boundaries). By 2050, approximately 152,500 additional irrigated acres are projected to be taken out of production due to urbanization (based on irrigated lands within or intersecting current municipal boundaries). This is approximately 5 percent of the total irrigated land statewide. The largest amount of urbanization is expected in the South Platte Basin, with more than 12 percent of the irrigated acreage in basin projected to be urbanized.

Table 4.2.4 Projected Loss of Irrigated Acreage Due to Urbanization

Basin	Historically Urbanized Irrigated Acreage	Projected Urbanized Irrigated Acreage	Current Irrigated Acreage
Arkansas	N/A*	7,240	445,000
Colorado	6,060	13,590	206,700
Gunnison	2,380	14,600	234,400
North Platte	2	40	113,600
Rio Grande	N/A*	4,010	515,300
South Platte/Metro (and Republican)	49,400	107,310	1,433,100
Southwest	100	3,800	222,500
Yampa-White-Green	135	1,860	107,000
Total	**58,060**	**152,450**	**3,277,600**

* *Neither a 1987 nor a 1993 basin-wide acreage assessment has been developed.*

Future agricultural diversion demands will be affected by climate conditions. Section 2 described two climate projections with warmer and drier futures (“Hot and Dry” and “In Between” projections) that are incorporated into three of the five planning scenarios. Figure 4.2.4 shows annual factors used to adjust IWR and reflect future conditions in “Hot and Dry” and “In Between”. The factors in Figure 4.2.4 were averaged across the West Slope and East Slope basins. “Hot and Dry” and “In Between” generally predict warmer summer conditions in basins at higher elevations. Consequently, the West Slope factors are generally higher than those developed for the East Slope basins. Additionally, projections tend to show warmer conditions during years that were historically cooler and/or had higher precipitation, resulting in higher IWR adjustment factors. The opposite occurs during drought periods, when some warming may occur, but during periods that are expected to already be hot and dry. As a result, IWR adjustment factors during drought years tend to be lower (for example, 2002 or 2012).

Statewide Results

Future statewide agricultural diversion demand estimates range from 10 million AFY in *Adaptive Innovation* to 13.5 million AFY in *Hot Growth*. For basins with limited acreage adjustments, such as the Colorado, Gunnison, and Southwest basins, the agricultural diversion demands in *Business as Usual* and *Weak Economy* are projected to be similar to current demand. In these basins, climate change projections and efficiency adjustments had a significant impact on results, showing more variable demands in *Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth*. For basins with significant irrigated acreage reductions, such as the South Platte and Republican basins, demands in all planning scenarios are projected to be lower than current demand. The largest variation in most basins occurred in the *Adaptive Innovation.* scenario due to the 10 percent reduction in IWR and 10 percent increase to system efficiency. In some basins, such as the Southwest basin, the combined impact of the *Adaptive Innovation* scenario adjustments resulted in lower projected agricultural diversion demands than current.

Figure 4.2.4 Average IWR Change Factors

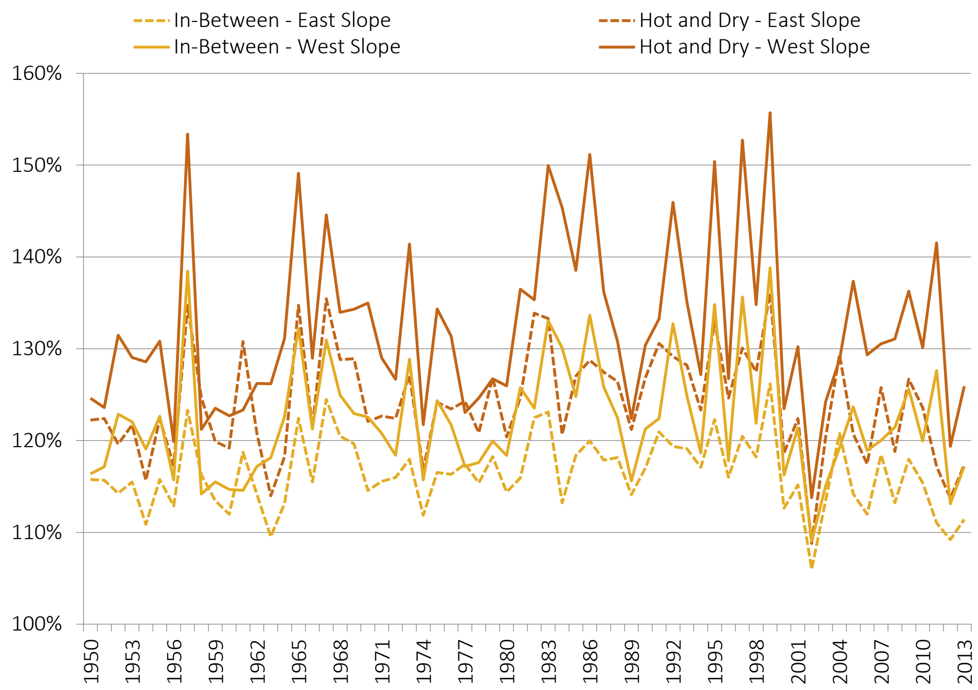
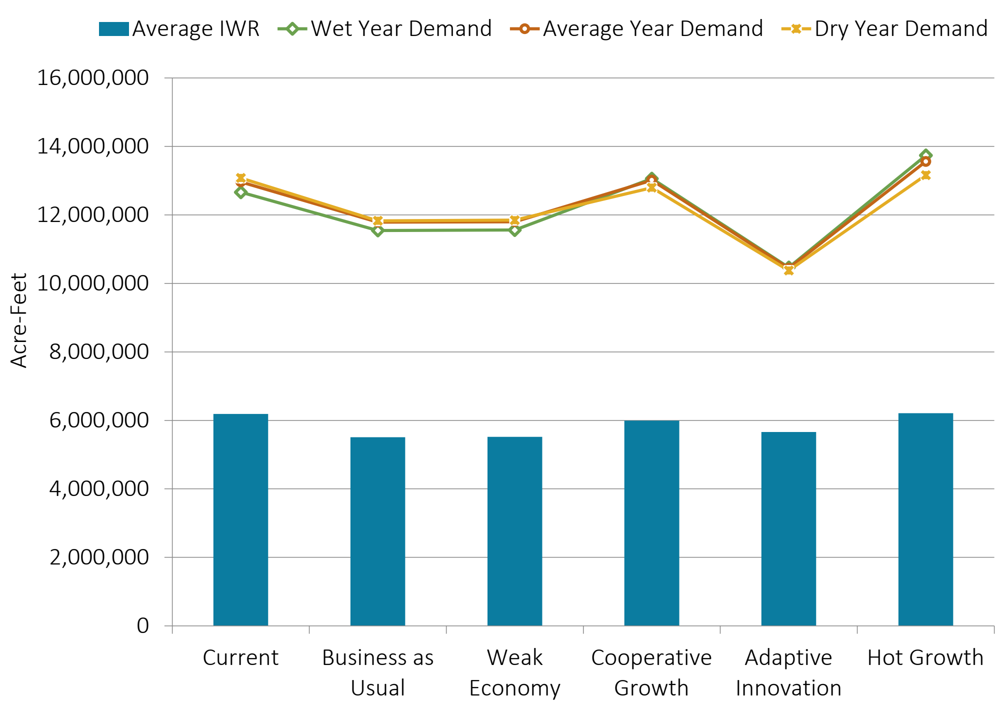


Figure 4.2.5 Statewide Agricultural Diversion Demand Estimates for Scenarios



RETURN FLOWS

Irrigation return flows (irrigation water not consumed by crops) return to streams and are part of the supply that downstream irrigators divert. In effect, diverted irrigation water can be used and reused several times in a basin. The agricultural diversion demand is the amount of water that would need to be diverted or pumped to meet the full crop irrigation demand, it but does not consider the re-diversion of return flows. As a result, it is not appropriate to assume the total diversion demand reflects the amount of native streamflow that would need to be diverted to fully irrigate crops.

Table 4.2.5 Statewide Summary of Projected Agricultural Diversion Demands

Planning Scenario	Acreage	Average IWR (AF)	Total Diversion Demand (AF)		
			Wet Year	Average Year	Dry Year
Current	3,280,000	6,190,000	12,664,000	12,964,000	13,079,000
Business as Usual	2,890,000	5,510,000	11,544,000	11,786,000	11,829,000
Weak Economy	2,890,000	5,520,000	11,559,000	11,802,000	11,846,000
Cooperative Growth	2,840,000	5,990,000	13,059,000	13,012,000	12,796,000
Adaptive Innovation	2,820,000	5,660,000	10,465,000	10,442,000	10,377,000
Hot Growth	2,780,000	6,210,000	13,736,000	13,561,000	13,163,000

Table 4.2.6 Statewide Summary of Projected Surface Water and Groundwater Diversion Demands

Basin	Surface Water Demand (AF)			Groundwater Demand (AF)		
	Wet Year	Average Year	Dry Year	Wet Year	Average Year	Dry Year
Current	10,511,000	10,502,000	10,199,000	2,153,000	2,462,000	2,880,000
Business as Usual	9,755,000	9,714,000	9,393,000	1,789,000	2,072,000	2,436,000
Weak Economy	9,775,000	9,735,000	9,415,000	1,784,000	2,067,000	2,431,000
Cooperative Growth	11,226,000	10,899,000	10,369,000	1,833,000	2,113,000	2,427,000
Adaptive Innovation	8,771,000	8,492,000	8,164,000	1,694,000	1,950,000	2,213,000
Hot Growth	11,848,000	11,399,000	10,723,000	1,888,000	2,162,000	2,440,000

4.2.3 Statewide M&I Diversion Demands

The updated M&I diversion demands include baseline demands (estimated for the year 2015) and projected future demands for the year 2050 for the five planning scenarios. Results of population projections, water usage rates, total municipal demands and total SSI demands are described below.

Population Projections

Approximately 88 percent of the state's population lives along the Front Range in either the Arkansas or South Platte Basins (which includes the "Metro" sub-basin). The statewide baseline population, which is based on 2015, is less than the amount that SWSI 2010 projected for the year 2015. While most basins have increased in population, the Gunnison, North Platte, Rio Grande, and Yampa-White basins have decreased. A basin-level summary is provided in Table 4.2.7.

As described in Section 2, population projections for the five planning scenarios were derived from 2017 SDO population projections and statistically-derived high and low growth projections for each basin. Population projections based on these methodologies are shown in Table 4.2.7.

DROUGHT RESPONSE

M&I demand projections do not represent drought conditions when more aggressive conservation may occur or associated responses to drought when measures such as watering restrictions may be imposed.

POPULATION GROWTH PROJECTIONS

Business as Usual:	Medium
Weak Economy:	Low
Cooperative Growth:	Medium, Adjusted
Adaptive Innovation:	High, Adjusted
Hot Growth:	High

Table 4.2.7 Current and Projected Future Population (in number of people unless otherwise indicated)

Basin	SWSI 2010 Projection for 2015*	SWSI Update Baseline (2015)		Planning Scenarios				
		Population	% of state total	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Arkansas	1,067,000	1,008,400	19%	1,509,500	1,462,800	1,544,400	1,626,000	1,568,000
Colorado	366,000	307,600	6%	515,500	456,300	549,200	572,900	577,800
Gunnison	125,000	103,100	2%	162,600	123,100	158,600	196,000	204,900
North Platte	1,600	1,400	0%	1,300	1,100	1,200	1,400	1,500
Rio Grande	54,000	46,000	1%	55,100	42,300	52,100	63,000	67,300
South Platte/Metro ** (and Republi-can)	3,964,000	3,829,800	70%	5,954,300	5,433,200	5,884,400	6,492,400	6,507,700
Southwest	123,000	108,000	2%	195,800	125,800	201,000	264,200	282,100
Yampa-White-Green	53,000	43,700	1%	67,300	38,600	70,500	96,600	103,200
Statewide	**5,754,600**	**5,448,100**	**100%**	**8,461,300**	**7,683,200**	**8,461,300**	**9,312,400**	**9,312,400**

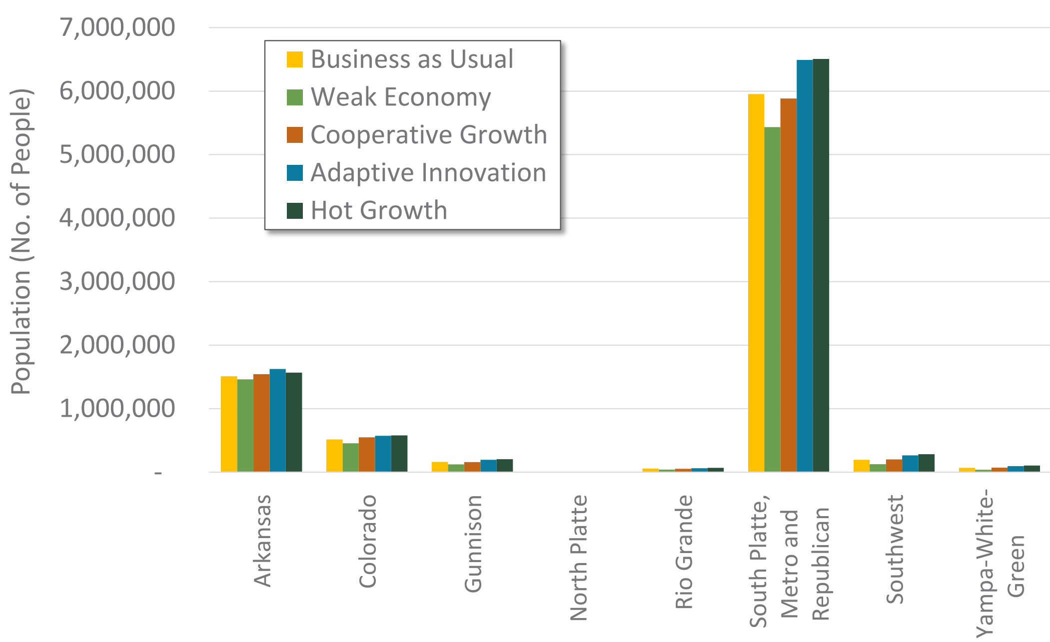
* *SWSI 2010 Appendix H, Exhibit 36 (CWCB, 2010a)*

** *Metro region was reported separately in SWSI 2010*

Note: Due to rounding, the statewide total may not precisely match the sum of basin results shown in the table above

Figure 4.2.6 shows population projections for 2050, summarized by river basin. Between the years 2015 and 2050, the population is projected to grow from approximately 5.5 million to between 7.7 million to 9.3 million in the low and high scenarios, respectively, which is an increase of about 41 to 71 percent.

Figure 4.2.6 2050 Projected Population by Scenario by Basin



Municipal Demands

Municipal demands were calculated for each county and then summarized by river basin. Water demands for counties located in multiple basins were distributed between basins by using the portion of the county population located within each basin to prorate the water demands.

The statewide baseline water demands were largely based on water provider-reported data, with approximately 70 percent of the baseline population demands represented by 1051 data as shown in Figure 4.2.7. The figure also shows the sources of other demand data.

The statewide baseline per capita systemwide demand has decreased from 172 gpcd in SWSI 2010 to approximately 164 gpcd, which is nearly a 5 percent reduction in demands between 2008 and 2015. The reduction is associated with improved data availability, conservation efforts, and ongoing behavioral changes. There are more significant differences from SWSI 2010 at a basin level and these are described in Volume 2 titled *Current and Projected Planning Scenario Municipal and Self-Supplied Industrial Water Demands*.

Figure 4.2.7 Statewide Baseline Municipal Demand Data Sources

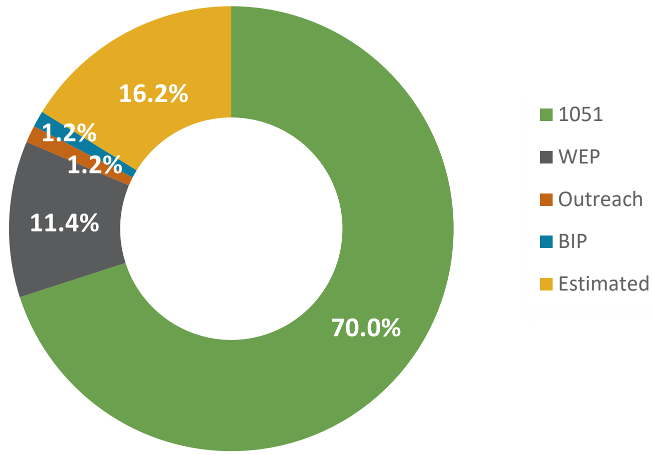


Table 4.2.8 shows baseline and projected per capita demands for basins throughout the state for the five planning scenarios. *Adaptive Innovation* has the lowest per capita demands, and *Hot Growth* has the highest per capita demands, both statewide and within each basin. Note that the statewide per capita demand projections do not match the Water Plan scenario ranking and they were not intended to do so. For example, *Adaptive Innovation* results in the lowest per capita demand, but coupling this with the highest population projection results in the second highest overall demand volume across the scenarios, as further described below.

Table 4.2.8 Per Capita Demand Projections by Planning Scenario for Each Basin (gpcd)

Basin	SWSI 2010 Projection for 2015 *	2015 Baseline	Planning Scenarios				
			Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Arkansas	185	194	179	179	170	164	192
Colorado	182	179	153	156	145	136	165
Gunnison	174	158	146	149	140	133	160
Metro	155	141	138	135	130	126	148
North Platte	310	264	245	254	242	232	270
Rio Grande	314	207	194	198	188	177	209
Republican	see note**	245	236	236	221	214	251
South Platte	188	181	176	174	164	158	190
Southwest	183	198	181	186	173	166	199
White	see note***	252	240	254	240	231	269
Yampa	230	224	172	197	161	150	180
Statewide	**172**	**164**	**157**	**155**	**148**	**143**	**169**

** SWSI 2010 per capita values from SWSI 2010 Appendix L, Tables 8, 14, 15, and 16 (CWCB, 2011b)*
*** The Republican Basin demands were included in the South Platte Basin demand reporting for SWSI 2010*
**** The White Basin demands were included with the Yampa Basin demand reporting for SWSI 2010.*

Statewide baseline municipal water demands are comprised of the water use classes shown in Figure 4.2.8. Residential indoor is the largest category of municipal demand statewide followed by residential outdoor and non-residential indoor.

For each planning scenario, residential indoor demands represent the largest category of water demand, starting at nearly 52 gpcd for the 2015 Baseline. The projected residential indoor demands vary greatly across planning scenarios, from 46 gpcd in *Weak Economy* to 36.5 gpcd in *Adaptive Innovation*. Other demand categories show less variability across the scenarios, as shown in Figure 4.2.9.

Adjustments related to climate change that increase demand tended to offset reductions in outdoor use that decreased demand, especially in *Cooperative Growth* and *Adaptive Innovation*. In spite of climate change impacts, however, *Adaptive Innovation* projects the lowest total per capita demand.

CONSERVATION POTENTIAL

The indoor and outdoor demand driver adjustments, coupled with the adoption rate methodology, generally result in higher per-capita demand projections than the active conservation savings projected in SWSI 2010. Unlike SWSI 2010, the Technical Update demand projections are not intended to capture the full range of future active conservation potential. Additional future conservation may still be achieved under each planning scenario through identified projects and processes.

CONSERVATION & GROWTH

The planning scenarios often paired high water-savings drivers with high population growth or low demand reductions with low growth, resulting in a narrowing of the range in demand projections.

Figure 4.2.8 Statewide Baseline Municipal Demand Category Distribution

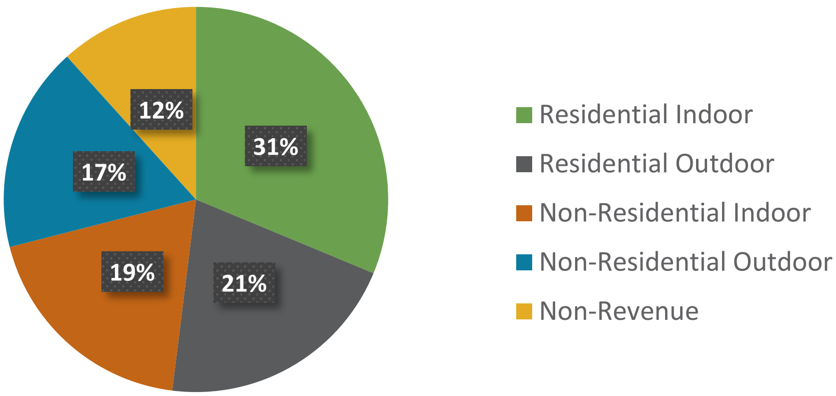


Figure 4.2.9 Statewide per Capita Demand for Five Planning Scenarios by Demand Category

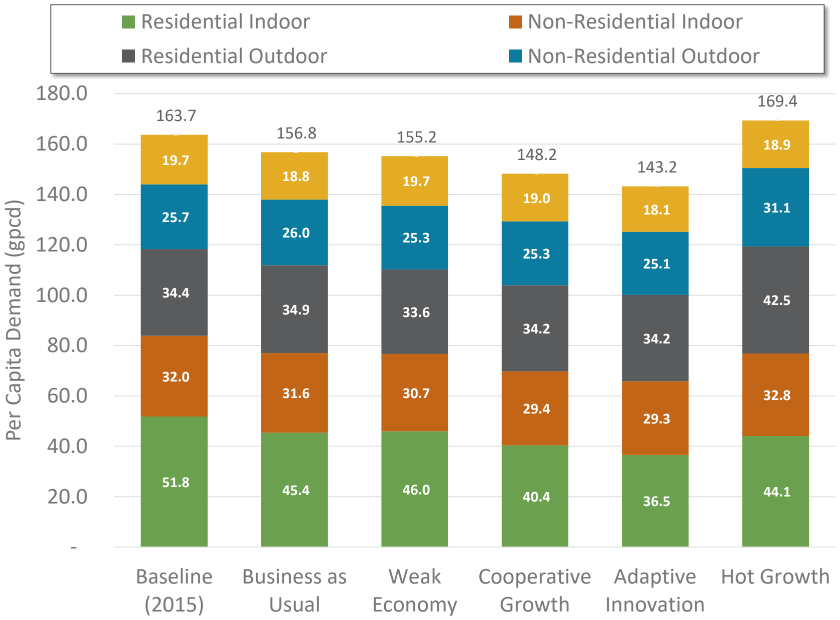


Table 4.2.9 presents baseline and projected demands for basins throughout the state, showing the combined effect of population and per capita demands. The municipal demands are projected to grow from approximately 1.0 million AFY in 2015 to between 1.34 and 1.77 million AFY in 2050.

Table 4.2.9 Statewide Municipal Baseline and Project Demands by Basin (AFY)

Basin	Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Arkansas	219,200	303,400	293,800	294,500	298,100	337,200
Colorado	61,800	88,600	79,900	89,000	87,500	106,600
Gunnison	18,300	26,700	20,500	24,900	29,100	36,800
North Platte	400	400	300	300	400	400
Rio Grande	10,600	11,900	9,400	11,000	12,500	15,700
South Platte/Metro (and Republican)	653,300	1,001,600	896,600	932,800	999,900	1,185,200
Southwest	24,000	39,800	26,200	38,900	49,200	62,900
Yampa-White-Green	11,200	13,500	8,800	13,300	17,200	21,900
Statewide	**998,700**	**1,485,800**	**1,335,500**	**1,404,700**	**1,493,900**	**1,766,700**

Note: Due to rounding, the statewide total may not precisely match the sum of basin results shown in the table above

Figure 4.2.10 Statewide Baseline and Projected Population and Municipal Demands

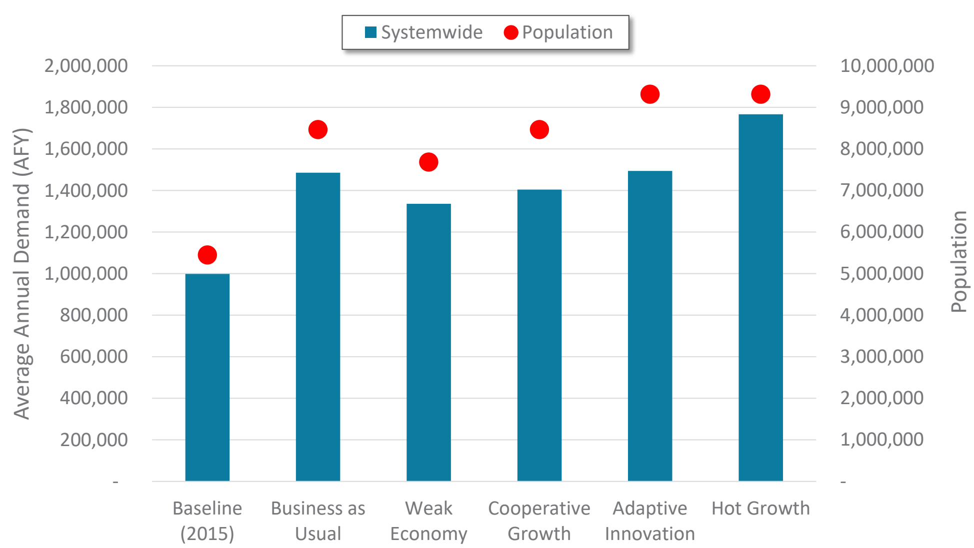


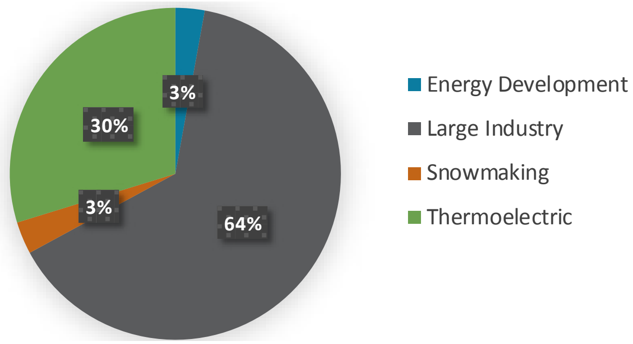
Figure 4.2.10 compares municipal water demands with population projections for each of the planning scenarios. *Business as Usual* and *Cooperative Growth* both use the medium population projection on a statewide basis, with different distributions between counties. Similarly, *Adaptive Innovation* and *Hot Growth* both use the high population projection on a statewide basis, with different distributions between counties. The influence of the population is so significant that the demand projections for all scenarios are relatively similar aside from *Hot Growth*, which has high population coupled with climate change. *Adaptive Innovation* stands out among the others in that it has the greatest reductions in per capita demand but is paired with both the highest population and "Hot and Dry" climate projection. Even with the high population projection and high outdoor demands due to hot and dry future climate conditions, the water-saving measures included in *Adaptive Innovation* are projected to reduce demands to just above *Business as Usual*, demonstrating the benefits of increased conservation.

Self-Supplied Industrial Diversion Demands

As with municipal diversion demands, the updated SSI demands include both baseline demands (estimated as 2015 demands) and demands in the year 2050 for the five planning scenarios. The demand projections do not reflect drought conditions or associated responses. SSI demands were calculated at the county level and then summarized by river basin. No county-level SSI demands had to be distributed between multiple basins.

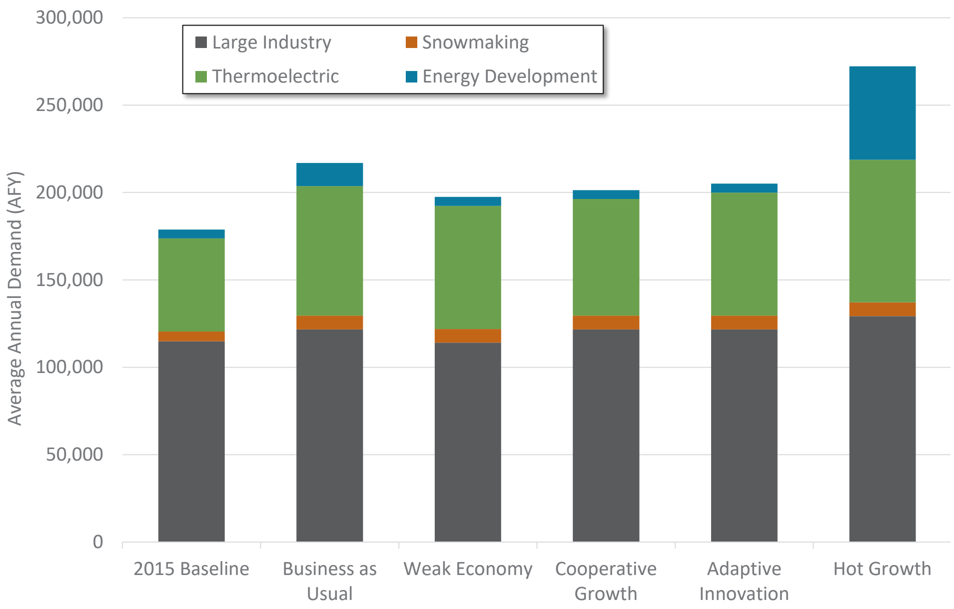
Statewide baseline SSI water demands are comprised of four major industrial uses, as shown on Figure 4.2.11.

Figure 4.2.11 Statewide Baseline SSI Sub-Sector Distribution



The projected demands for all planning scenarios were calculated based on the methodology described in Section 2. The results of the calculations are illustrated in Figure 4.2.12 and shown in Table 4.2.10. With the exception of *Hot Growth*, the updated projections for all planning scenarios were below SWSI 2010 estimates, primarily due to changes in assumptions for thermoelectric demands related to regulations that require an increase in power generation from renewable sources (the assumption was based on input from M&I TAG participants). Thermoelectric demand accounts for a large component of total SSI demand, and the methodology changes had a relatively large effect on the results. Large industry, snowmaking, and energy development projections are generally comparable to the ranges projected in SWSI 2010. There is little variation in the projections aside from *Hot Growth*.

Figure 4.2.12 Statewide Baseline and Projected SSI Demands



Total M&I

Table 4.2.10 and Figure 4.2.13 show statewide municipal and industrial baseline 2015 and projected 2050 water demands for the five planning scenarios. Total statewide M&I demands projected for 2050 range from approximately 1.5 million AFY (*Weak Economy*) to 2.0 million AFY (*Hot Growth*).

For all basins except for the Yampa, municipal demands exceed the self-supplied industrial demands for every planning scenario. Statewide, self-supplied industrial demands are around 15 percent to 18 percent of the municipal demands.

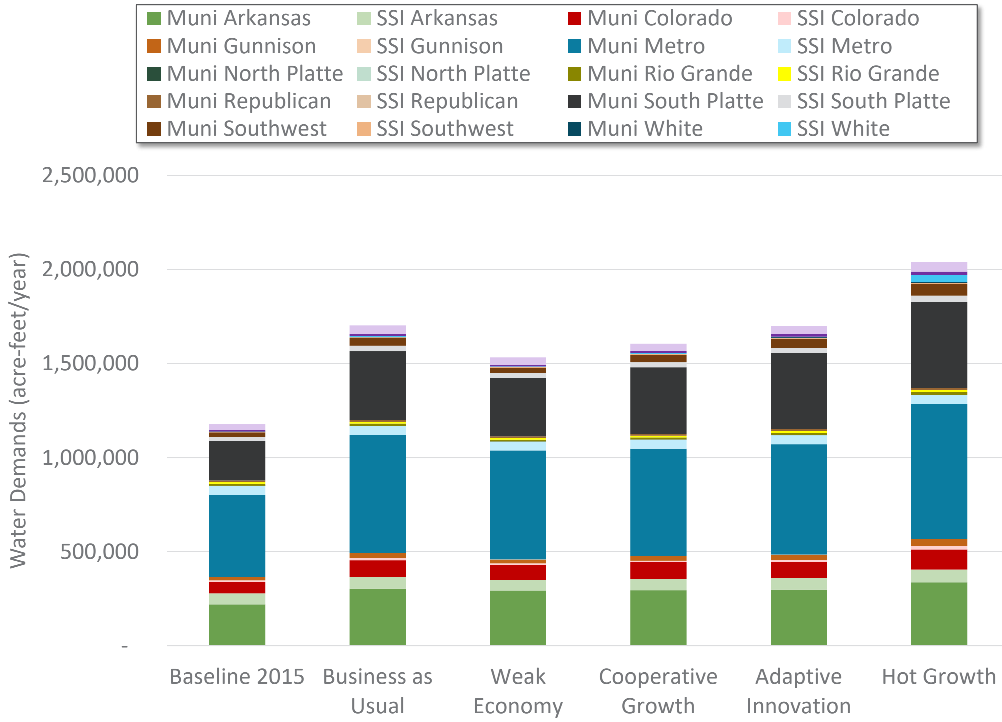
As discussed previously, the Water Plan rankings were the guiding objective in preparing average annual statewide volumetric demands. Statewide municipal projections followed the Water Plan rankings; however, industrial and combined M&I demands deviated to a limited degree, with *Business as Usual* demands exceeding *Adaptive Innovation* demands. These results show that *Business as Usual* and *Adaptive Innovation* futures may be similar, which indicates innovative conservation program measures have the potential to significantly offset the higher population and much warmer climate in *Adaptive Innovation* scenario.

Table 4.2.10 Summary of M&I Demands for Each Basin and Statewide (AFY)

Basin	Demand Type	Baseline 2015	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Arkansas	Municipal	219,200	303,400	293,800	294,500	298,100	337,200
	SSI	58,700	61,700	56,200	60,500	61,100	67,900
	Total	277,900	365,100	350,000	355,000	359,200	405,100
Colorado	Municipal	61,800	88,600	79,900	89,000	87,500	106,600
	SSI	7,800	12,300	7,600	7,800	7,800	18,500
	Total	69,600	100,900	87,500	96,800	95,300	125,000
Gunnison	Municipal	18,300	26,700	20,500	24,900	29,100	36,800
	SSI	300	700	700	700	700	700
	Total	18,500	27,300	21,200	25,500	29,800	37,400
North Platte	Municipal	400	400	300	300	400	400
	SSI	-	-	-	-	-	-
	Total	400	400	300	300	400	400
Rio Grande	Municipal	10,600	11,900	9,400	11,000	12,500	15,700
	SSI	7,900	9,900	9,000	9,900	9,900	10,800
	Total	18,500	21,800	18,300	20,900	22,400	26,500
South Platte /Metro (and Republi-can)	Municipal	653,300	1,001,600	896,600	932,800	999,900	1,185,200
	SSI	72,200	78,200	76,300	75,700	76,900	81,500
	Total	725,500	1,079,800	972,900	1,008,500	1,076,900	1,266,700
Southwest	Municipal	24,000	39,800	26,200	38,900	49,200	62,900
	SSI	2,300	4,300	4,100	3,900	4,100	4,700
	Total	26,300	44,100	30,400	42,800	53,300	67,600
Yampa-White-Green	Municipal	11,200	13,500	8,800	13,300	17,200	21,900
	SSI	29,600	49,800	43,700	43,000	44,600	88,300
	Total	40,800	63,300	52,400	56,300	61,800	110,200
Statewide	**Municipal**	**998,700**	**1,485,800**	**1,335,500**	**1,404,700**	**1,493,900**	**1,766,700**
	SSI	**178,800**	**216,900**	**197,500**	**201,400**	**205,100**	**272,200**
	Total	**1,177,500**	**1,702,700**	**1,533,000**	**1,606,100**	**1,699,000**	**2,039,000**

Note: Due to rounding, the statewide total may not precisely match the sum of basin results shown in the table above

Figure 4.2.13 Baseline and Projected M&I Demands by Basin



4.2.4 East Slope Transbasin Imports

Water from the West Slope of Colorado is a significant source of supply to East Slope municipal and agricultural water users in the South Platte and Arkansas basins. In the future, historical levels of West Slope supply may not be available, and a portion of the demand could go unmet depending on future climate conditions. Table 4.2.11 below provides combined demands for West Slope supplies for both the South Platte and Arkansas basins and combined unmet demands in these basins for the planning scenarios. The amount of unmet demand for West Slope supplies would increase the gap in these basins, likely in an amount that is more than the unmet demand, because municipalities reuse their return flows from water imported from the West Slope.

The focus of this section and Table 4.2.11 is on East Slope transbasin imports, but transbasin imports occur in other basins aside from the South Platte and Arkansas; however, the amount of water associated with these other basin transfers are significantly less. While data describing other transbasin imports and potential changes in the planning scenarios is not presented in the Technical Update report, the modeling data will be available to basin roundtables that choose to evaluate potential future changes to transbasin imports.

Table 4.2.11 Transbasin Demands in the South Platte and Arkansas Basins

	Scenario					
	Baseline	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average Annual Import Demand (ac-ft)	515,000	515,000	515,000	515,000	515,000	515,000
Average Annual Unmet Demand (ac-ft)	0*	0*	0*	26,000	50,000	55,000
Import in Max East Slope Gap Year (ac-ft)	495,000	495,000	495,000	560,000	467,000	467,000
Unmet Demand in Max East Slope Gap Yr (ac-ft)	0*	0*	0*	57,000	122,000	158,000
Percent Unmet Demand in Max East Slope Gap Year	0%	0%	0%	10%	26%	34%

**CDSS water allocation models calculate unmet demands in the baseline and Business as Usual and Weak Economy scenarios. Because historical values were used for import demand, the unmet demands in these scenarios indicate a calibration issue in the source basin.*

4.2.5 Water Availability

The projected availability of future water supplies varies across the state and is influenced by basin-specific hydrology and water uses, geographic location within basins, and compact constraints. As a result, it is difficult to generalize future water availability on a statewide basis and can be complicated to describe within basins. The following general observations can be made:

- No water is currently available or will be available in the future to meet additional needs in the Republican, Arkansas, and Rio Grande basins.
- Water availability is projected to decrease in *Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth* due to the impacts of warmer and drier climate conditions. Peak flows are projected to occur earlier in the runoff season, and streamflows may be diminished later in the summer.
- In locations where available flows occur only periodically under current conditions (mainly during wet years), it may be available less frequently and in lower volumes. If the climate becomes warmer and drier, droughts and periods of low to no flow availability in these basins may be longer in duration.
- In basins where water is generally available every year, volumes of annual available flow may decrease overall and timing may change (peak flows may occur earlier in the runoff season).

4.2.6 Yield of Future Projects

As described in Section 3, the Technical Update analyses did not include future water supply projects and strategies that will help mitigate M&I and agricultural gaps; however, water providers are contemplating a wide variety of projects and strategies to meet their future needs. SWSI 2010 provided information on future projects and strategies that were then being pursued by water providers to meet future demands. The types of projects and strategies included agricultural water transfers (traditional and alternative), reuse, growth into existing supplies, regional in-basin projects, new transbasin projects, firming in-basin water rights, and firming transbasin rights. Ranges of potential yields for these projects and strategies by type and by basin were presented assuming 100 percent and also lower rates of success in achieving the contemplated yield of the projects. Table 4.2.12 shows the amount of yield in each basin for various rates of success that were included in the gap calculations in SWSI 2010.

The data in Table 4.2.12 were not updated in the Technical Update, and yields of future projects in SWSI 2010 were not developed considering future potential impacts of the planning scenarios. Nevertheless, the data in the table show that water providers are currently pursuing significant water supply projects and strategies that will help fill future gaps. Basin roundtables will be encouraged to update and improve the quality of their data describing future projects and strategies during upcoming BIP updates (see Section 5 for more details).

Table 4.2.12 Yields of Identified Projects and Processes from SWSI 2010

	SWSI 2010 Estimated Yield of Identified Projects and Processes (AFY)		
	100% IPP Success Rate (low)	Alternative IPP Success Rate (medium)	Status Quo IPP Success Rate (high)
Arkansas	88,000	85,000	76,000
Colorado	42,000	49,000	63,000
Gunnison	14,000	14,000	16,000
Metro	140,000	97,000	100,000
North Platte	100	200	300
Rio Grande	5,900	6,400	7,700
South Platte	120,000	78,000	58,000
Southwest	14,000	13,000	15,000
Yampa-White-Green	10,000	11,000	13,000
Statewide	**430,000**	**350,000**	**350,000**

This table reflects data from Table 5-12 in the SWSI 2010 report.

4.2.7 Environment and Recreation Conditions

Future conditions and risks for E&R attributes vary across the state depending on location and planning scenario. Future E&R conditions will be influenced by basin-specific hydrology, water uses, and geographic location within basins. As a result, it is difficult to precisely characterize future E&R conditions and risks on a statewide basis (regional specific observations are included in basin summaries). The following general observations can be made:

- Climate change and its impact on streamflow will be a primary driver of risk to E&R attributes.
- Projected future streamflow hydrographs in most locations across the state show earlier peaks and potentially drier conditions in the late summer months under scenarios with climate change.
- Under climate change scenarios, runoff and peak flows may occur earlier, resulting in possible mismatches between peak flow timing and species' needs.
- Drier conditions in late summer months could increase risk to coldwater and warmwater fish due to higher water temperatures and reduced habitat. The degree of increased risk is related to the level of streamflow decline.
- In many mountainous regions without significant influence of infrastructure, peak flow, and low flows are projected to be sufficient to sustain low to moderate risk for riparian plants and fish, but risks are projected to increase in scenarios with climate change.
- In mountainous regions with infrastructure, risks to E&R attributes may vary. Streams that are already depleted may see increased risks in scenarios with climate change. However, some streams may be sustained by reservoir releases, which will help moderate risks in scenarios with climate change.
- Instream flow water rights and recreational in-channel diversion water rights may be met less often in climate-impacted scenarios.

Modeling results for each of the eight major river basins are listed alphabetically in the following sections.

ANALYSIS & TECHNICAL UPDATE TO THE

COLORADO WATER PLAN

VOLUME II

SUPPORTING DOCUMENTS

[Disclaimer]

The Analysis and Technical Update to the Colorado Water Plan (Technical Update) provides technical data and information regarding Colorado's water resources. The technical data and information generated are intended to help inform decision making and planning regarding water resources at a statewide or basinwide planning level. The information made available is not intended to replace projections or analyses prepared by local entities for specific project or planning purposes.

The Colorado Water Conservation Board intends for the Technical Update to help promote and facilitate a better understanding of water supply and demand considerations within the State; however, the datasets provided are from a snapshot in time and cannot reflect actual or exact conditions in any given basin or the State at any given time. While this Technical Update strives to reflect the Colorado Water Conservation Board's best estimates of future water supply and demands under various scenarios, the reliability of these estimates is affected by the availability and reliability of data and the current capabilities of data evaluation. Moreover, the Technical Update cannot incorporate the varied and complex legal and policy considerations that may be relevant and applicable to any particular basin or project; therefore, nothing in the Technical Update or the associated Flow Tool or Costing Tool is intended for use in any administrative, judicial or other proceeding to evince or otherwise reflect the State of Colorado's or the CWCB's legal interpretations of state or federal law.

Furthermore, nothing in the Technical Update, Flow Tool, Costing Tool, or any subsequent reports generated from these datasets is intended to, nor should be construed so as to, interpret, diminish, or modify the rights, authorities, or obligations of the State of Colorado or the CWCB under state law, federal law, administrative rule, regulation, guideline or other administrative provision.

Prior to the 2015 Colorado Water Plan (Water Plan), past statewide water supply analyses included data analysis, project information and policy components. After the Water Plan's release, these elements were divided among the Water Plan (policy), Basin Implementation Plans (local projects) and statewide water supply initiatives (technical data analysis). To better recognize these delineations and make the connection to the Water Plan clear, the statewide water supply initiative (often referenced as SWSI) is now being referred to as the Analysis and Technical Update to the Water Plan (or Technical Update). The new name more accurately reflects the technical nature of the evaluations described in the report and better establishes how that data will be used to inform Water Plan updates. While the Technical Update is a statewide water supply initiative and continues that legacy, the SWSI acronym will be relegated to referencing earlier efforts that proceeded the Water Plan (e.g., SWSI 2010).

[Technical Memorandum Table of Contents]

Analysis and Technical Update to the Colorado Water Plan

Technical Memorandum

Prepared for:

Colorado Water Conservation Board

Subject:

Current and Projected Planning Scenario Municipal and Industrial Water Demands

Date:July 15, 2019

Prepared by: ELEMENT Water Consulting, Inc.
Reviewed by: WaterDM and Jacobs

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This document provides an overview of Municipal and Industrial (M&I) water demand projections that have been prepared for the analysis and technical update (Technical Update) to the Colorado Water Plan (CWP), formerly known as the Statewide Water Supply Initiative or SWSI.

Section 1: Description of Methodology

The Technical Update uses a scenario planning process, including five plausible future scenarios for the year 2050 that are described in the CWP and summarized in Figure 1-1 and Appendix A[1].

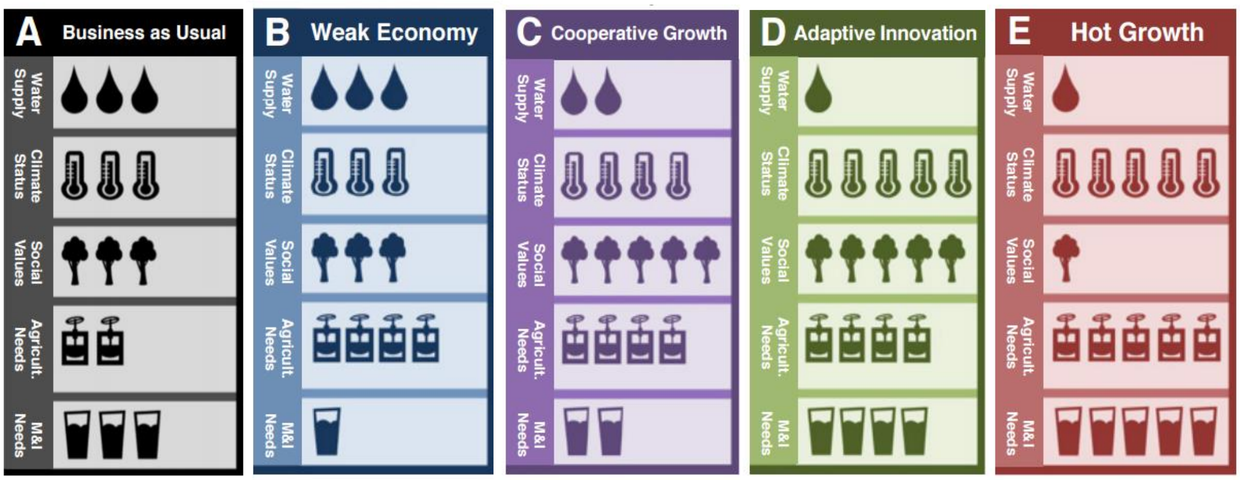

Figure 1-1: Planning Scenario Descriptions from the Colorado Water Plan.

Section 6.1 of the CWP provides the relative demand ranking, from low at a value of 1 to high at a value of 5, for the statewide M&I demand projections, as shown in Figure 1-1 and summarized in Table 1-3 and Table 1-10 below. These rankings were previously defined in the CWP and provide direction for how the combinations of demand drivers should affect the statewide future volumetric demands under each scenario, e.g. the Weak Economy scenario has the lowest volumetric demands and the Hot Growth scenario has the highest volumetric demands.

The methodologies used in SWSI 2010 were expanded upon to prepare 2050 demand projections for the five CWP planning scenarios. The following criteria were used in considering potential methodology enhancements:

- Sound, integrated, and widely accepted methods.
- Transparent, understandable, and reproducible.
- Based on data available statewide.
- Capable of producing demands representative of the five planning scenarios.

[1] Section 6.1 of the CWP provides a narrative framework for the five planning scenarios that were developed by the Interbasin Compact Committee (IBCC). (CWCB, 2015b).

This section provides an overview of the methodologies used in SWSI 2010 and the enhancements developed for the Technical Update, which were initially outlined in the Draft Municipal and Industrial Demand Methodologies Technical Memorandum prepared by ELEMENT Water Consulting for the Colorado Water Conservation Board, and the last draft was dated November 14, 2017 ("Methodologies TM"). The Methodologies TM was developed with input and review by a Technical Advisory Group ("TAG") comprised of individuals from municipal and industrial water providers throughout the state who were identified by the Colorado Water Conservation Board (CWCB) to provide representative input and information. The TAG recognized and supported that some adjustments to the methodologies may be necessary as they were applied to the updated population and water use data. Through the process of preparing the Technical Update demand projections, relatively few modifications were made to the approach outlined in the Methodologies TM, and these are reflected in the methodology overview provided below which thereby supersedes the Methodologies TM.

As with prior SWSI demand projections, the methods utilized in this Update are for the purpose of general statewide and basinwide planning and are not intended to replace demand projections prepared by local entities or for project-specific purposes. The M&I demand projections provide a snapshot of demands for the year 2050 for each scenario and do not contemplate how demands change at any point between now and then. This is primarily because the planning scenarios include a climate driver and the climate projections are only available for the year 2050. Some of the calculations and assumptions were made to maximize the use of available data and to apply a consistent methodology throughout the state, and different decisions may be made when looking at a subset of available information for a particular region or location within the state. The recommended methodologies are designed to be adaptable and used again in future Technical Updates or Basin Implementation Plan updates, as additional data become available, and potentially under new scenarios.

Note that throughout this report, the number of significant figures in tables and figures are generally used for continuity in reporting and do not mean to imply a level of accuracy. Occurrences of reporting percentages not adding to 100% or totals not equating to the sum of individually reported items are due to rounding that occurs when displaying model results in reporting tables and figures.

1.1 MUNICIPAL DEMANDS

1.1.1 SWSI 2010 METHODOLOGY

SWSI 2010 defined Municipal and Industrial (M&I) demands as the water uses typical of municipal systems including residential, commercial, light industrial, non-agricultural related irrigation, non-revenue water, and firefighting. Demands for self-supplied households not connected to a public water supply were also included in the municipal demand category. The M&I demand category from SWSI 2010 is equivalent to the municipal portion of the demands in the Technical Update. SWSI 2010 separately defined self-supplied industrial demands, as further described in Section 1.2.1 below, which are equivalent to the industrial demands in the Technical Update.

"Baseline future" M&I water demands were prepared as follows, using a driver multiplied by rate-of-use, where population was the primary driver:

- Population was projected with the process and models utilized by the Colorado State Demography Office (SDO), which include assumptions about economic conditions including availability of future employment opportunities. Population projections were provided at a county level and were only available from the SDO through the year 2035 but were extended from 2035 to 2050 by adjusting the SDO models. Low, medium, and high population scenarios were developed to represent the uncertainty in projecting conditions in 2050.

- The then-current (circa 2008) rate of water use was represented by systemwide gallons per capita per day (gpcd) values, which were calculated at a water-provider level and then aggregated on a service area population-weighted basis to county and basin levels. Service area population and total water delivery[2] data were compiled from a variety of sources including water conservation plans, master plan reports, other independent reports, the 2007 Colorado Drought and Water Supply Update, and water provider interviews. A large portion of the data were reported for the year 2008, however some of the data represented demands prior to 2003 that had been compiled under prior SWSI planning. For data reported between the years of 2003 and 2010, the most recent year available was used. Where data were only available prior to 2003, water use information was averaged to account for the 2002 drought. While service area populations include only permanent residents, the systemwide gpcd values included water used by commercial, light industrial, tourism and other transient influences. For this and other reasons, gpcd values from one location were and are not directly comparable to values from another location with different characteristics. This remains the case for the Technical Update.

- Baseline future low, medium, and high demands were calculated for the year 2050, using the 2050 population projection and the baseline (circa 2008) rate of water use. Passive water conservation savings were subtracted to account for impacts from new construction and retrofitting housing stock and businesses with high-efficiency toilets, clothes washers, and dishwashers. A range of potential passive savings were estimated for each county and the upper end of the range was incorporated into the M&I demands to produce low, medium, and high demand projections for the year 2050 with passive conservation savings3. A summary of the SWSI 2010 baseline future demand values, in acre-feet per year (AFY), are provided in Table 1-1 (CWCB, 2010a).

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[2] Based on review of the data, it appears that these data represent ‘distributed water’ as defined under 1051 reporting or ‘water supplied’ as defined in the AWWA Water Loss Control audit methodology, which is based on water production records and includes water loss.

[3] Future demand values that incorporated effects of passive conservation were also sometimes referred to as “baseline demands minus passive conservation.”

Table 1-1: SWSI 2010 M&I Baseline Future Water Demands with Passive Conservation and No Active Conservation[4].

Table 1-1A.

Basin	No. Utilities in Database	No. Updated Since SWSI Phase I	SWSI Phase I gpcd	SWSI 2010 gpcd
Arkansas	65	40	214	185
Colorado	55	46	244	182
Gunnison	21	18	226	174
Metro	100	35	191	155
North Platte	1	1	267	310
Rio Grande	9	4	332	314
South Platte	60	53	220	188
Southwest	16	9	246	183
Yampa-White	10	8	230	230
Statewide	337	214	210	172

Table 1B.

Basin	SWSI 2010 Baseline Demand in 2008 (AFY)	SWSI 2010 Baseline Future Water Demands (AFY)				SWSI 2010 Future Water Demands with Passive Conservation (AFY)			
		2035	2050 Low	2050 Medium	2050 High	2035	2050 Low	2050 Medium	2050 High
Arkansas	196,000	299,000	327,000	349,000	380,000	273,000	298,000	320,000	352,000
Colorado	63,000	115,000	135,000	150,000	174,000	106,000	125,000	140,000	164,000
Gunnison	20,000	36,000	40,000	43,000	46,000	33,000	36,000	39,000	43,000
Metro	437,000	627,000	695,000	717,000	785,000	557,000	620,000	642,000	709,000
North Platte	500	600	700	800	900	600	700	700	800
Rio Grande	18,000	24,000	26,000	27,000	30,000	22,000	24,000	26,000	28,000
South Platte	206,000	338,000	377,000	397,000	430,000	311,000	347,000	367,000	401,000
Southwest	22,000	38,000	42,000	47,000	52,000	35,000	39,000	43,000	49,000
Yampa-White	12,000	21,000	25,000	31,000	41,000	20,000	23,000	30,000	40,000
Statewide	974,500	1,498,600	1,667,700	1,761,800	1,938,900	1,357,600	1,512,700	1,607,700	1,786,800

Three "water conservation strategies" – low, medium, and high – were developed with varying assumptions about effects of social values, urban land use patterns, regulations, and technology on the future rate of use, as follows:

- Data from over 40 municipal water conservation plans that had been approved by the CWCB as of July 2010 were used to estimate how water was distributed to each of the following water use sectors: Residential (Single Family and Multi-Family) Indoor, Non-Residential Indoor, Single Family Residential Outdoor, Multi-Family Residential Outdoor, Non-Residential Outdoor, and Utility Water Loss. The "baseline future" demands (with passive conservation) for the 2050 *medium* population were disaggregated into these categories at the basin scale.

[4] The Statewide M&I and SSI Gaps in 2050 reported in Table ES-6 of the SWSI 2010 Report appear to represent the demands in 2050 as if the then-current gpcd (circa 2008) continued, adjusted for passive conservation, with future population projections and do not include active conservation.

- Potential demand reductions were estimated for implementation of specific "active" conservation measures and programs, largely founded upon those identified in the Best Practices Guide for Municipal Water Conservation in Colorado (Colorado WaterWise and Aquacraft, 2010). Water demand reduction targets were based on an extensive review of the literature documenting impacts of conservation measures and programs, and engineering judgement was used to estimate implementation levels necessary to achieve the targets.

- Average annual demand projections were prepared for each basin using the 2050 *medium* population under future conditions that did not consider the potential impacts of climate change. The results are provided in Table 1-2 (CWCB, 2011a).

Table 1-2: SWSI 2010 M&I Statewide Savings Projections for Conservation Strategies with Medium Population[5].

Phase	Level	2030 Forecast Savings (AFY)	2050 Forecast Savings (AFY)
SWSI Phase 1	Level 1 (Passive)	101,900	NA
	Level 2 (active only)	68,633	
	Level 3 (active only)	170,952	
	Level 4 (active only)	341,485	
	Level 5 (active only)	597,283	
SWSI 2010	Passive	131,000	154,000
	Low (active only)	78,000	160,200
	Medium (active only)	133,000	331,200
	High (active only)	197,100	461,300

The active water savings projections were described as conditional in that they assumed the identified strategies would be implemented and did not account for water providers' management decisions, such as storing a portion of the savings for drought planning or using a portion to improve stream flows for environmental or recreational benefits. Some of the other topics that were not addressed in the savings methodology, but recommended for future consideration, included:

- The demand projections were prepared at a basin scale and did not address differences between individual water providers, such as one provider within the basin having an adequate water supply while another has an identified future need.

- Changes in density and impacts from new construction were not explicitly modeled.

- A representative average statewide split between indoor and outdoor demands of 46% and 54%, respectively, was estimated and applied to all demands. Impacts on return flows from the different conservation strategies were not analyzed.

The CWP utilized results from SWSI 2010 to describe total potential water savings by 2050, ranging from 160,000 to 461,000 AF. This range appears to have been based on demand projections using the medium population projection with low, active-only conservation savings and high, active-only savings, respectively. An additional 150,000 AF of passive savings was projected in addition to the active conservation

[5] SWSI 2010 Report Table ES-7.

savings under the medium population projection. Additionally, the CWCB adopted a 400,000 AF "aspirational savings goal" identified by the Interbasin Compact Committee (IBCC), which was between the SWSI 2010 medium and high levels of active conservation savings potential projected with a medium population growth.

1.1.2 TECHNICAL UPDATE METHODOLOGY ENHANCEMENTS

Similar to SWSI 2010, the Technical Update uses a driver multiplied by per-capita rate of use in preparing a range of possibilities that reflect the uncertainties in future municipal demands. This is a commonly applied methodology that accounts for driving changes in water demand (Billings and Jones, 2008; Donker et al., 2014) and is being used in other statewide planning, as demonstrated in California, Texas, and Georgia.

Unlike SWSI 2010, the Update provides projected 2050 demands for five future scenarios that each include a different level of conservation and demand management that is characteristic of the scenario as defined in the CWP. The potential impact from drivers of climate, urban land use, technology, regulations, and social values are incorporated into the municipal demand projections through an adjustment to the current gpcd rate of use. This is different from SWSI 2010 where there was a "baseline future" demand projection using then-current gpcd values with future population, upon which various levels of "active" conservation strategies were evaluated but only for the medium population projection. The differences in methodology between SWSI 2010 and the Technical Update make it challenging to directly compare the future demand projections. A comparison of the projected population is provided throughout this report, however the relationship between the projected municipal demands is generally limited to the statewide projections presented in Section 2 below.

Key words from the CWP narrative descriptions that influenced the municipal demand projections are provided in Table 1-3. These rankings provide direction for how the combinations of M&I drivers should affect the future volumetric demands under each scenario, and it should be noted that the CWP rankings were interpreted to apply to the average annual statewide volumetric demands rather than per capita demands. For example, the Adaptive Innovation scenario drivers have some of the lowest future per capita demand values paired with a high population, ranking it the second highest projected statewide volumetric municipal demand in accordance with the CWP rankings. These rankings heavily influenced, and in some cases constrained, the combinations of drivers and population utilized in each scenario.

Table 1-3: CWP Relative Demand Ranking and Narrative for Municipal Planning Scenarios.

A. Business as Usual	B. Weak Economy	C. Cooperative Growth	D. Adaptive Innovation	E. Hot Growth
Demand Rank 3	Demand Rank 1	Demand Rank 2	Demand Rank 4	Demand Rank 5
• Recent trends continue • Regular economic cycles • Slow increase in denser developments • Social values and regs remain the same • Water conservation efforts slowly increase • Climate is similar	• Economy struggles • Maintenance of infrastructure becomes difficult to fund • Little change in social values, levels of water conservation, urban land use patterns, and environmental regulations • Climate is similar	• Environmental stewardship • Integrated and efficiency planning/development • More development in urban centers and mountains • Embrace water and energy conservation • New water-saving technologies • Env. regs are more protective • Moderate warming of climate	• Much warmer climate causes major environmental problems • Social attitudes shift towards shared responsibility • Technological innovation and strong research investments • Warmer climate increases irrigation demand, but technology mitigates increases • Higher water efficiency helps maintain streamflows • Regulations are well defined and permitting is predictable and expedited • More compact urban development	• Vibrant economy fuels population growth • Regulations are relaxed • Hot and dry conditions • Families prefer low-density housing

The approach and results for the baseline and projected future demands are further described in the sections below.

1.1.2.1 POPULATION

County-level population data for the Technical Update were prepared by BBC Research & Consulting (BBC, 2017 and 2018). Baseline population data for the year 2015 are based on data from the SDO. A unique 2050 population projection was prepared for each growth scenario based on the November 2017 growth projections from the Colorado State Demography Office, as shown in Table 1-4. The CWP scenario narrative describes a low, medium, and high projection for each scenario. The medium population projection used for the Business as Usual scenario is the SDO projection. BBC prepared a low and high projection for the Weak Economy and Hot Growth scenarios, respectively, and “adjusted” medium and high projections for the Cooperative Growth and Adaptive Innovation scenarios, respectively. The adjusted scenarios reflect the movement to mountain resort and urban areas that is described in the CWP, partially addressing the urban land use and growth pattern driver influences. This resulted in a unique population growth for each county under each scenario. Within a given scenario, population may be increasing in some counties while it is decreasing in others.

Table 1-4: 2050 Population Projection for the Five Planning Scenarios.

A. Business as Usual	B. Weak Economy	C. Cooperative Growth	D. Adaptive Innovation	E. Hot Growth
Medium	Low	Medium, Adjusted	High, Adjusted	High

1.1.2.2 BASELINE WATER DEMANDS

Key Definitions:

Baseline Demands – Reported and estimated demands representing average conditions for the Technical Update baseline year of 2015. Municipal demands are represented by the per capita rate of use (gpcd) and on a volumetric basis, which is calculated from population and gpcd data.

Demand – Portion of *Distributed Water* attributable to uses typical of municipal systems including residential, commercial, light industrial, non-agricultural related irrigation, firefighting, and non-revenue water. Demands for self-supplied households not connected to a public water supply are also included in the municipal demand category.

Distributed Water – Volume of water entering the distribution system. Calculated as total water production from all sources minus water exported to another water provider.

Metered Water Use – Water that reaches the end use, including billed/unbilled and authorized/unauthorized uses.

Non-Revenue Water – The calculated difference between *Distributed Water* and authorized *Metered Water Use*, which is also the sum of real and apparent loss. Represents system water loss, or water produced but not billed. Includes transmission and distribution system losses in water systems as well as apparent losses from unauthorized uses and water that is unaccounted for due to metering inaccuracies and data handling errors.

Systemwide Demand – Equivalent to *Distributed Water* as defined by 1051 or *Water Supplied* as defined in the

Baseline municipal water demands were prepared by county, on a per-capita and volumetric basis. One of the key objectives for the Technical Update was to maximize the use of new data that were not available for SWSI 2010. The baseline (circa 2015) demands were prepared for each county using the following four data sources:

- Data Reported to the CWCB by Water Providers Pursuant to House Bill 2010-1051 ("1051")[6]
    - Annual water provider-reported water use data for 2013 through 2016 reported by 53 water providers.
    - A high-level review and data validation were conducted for this analysis.
- Municipal Water Efficiency Plans ("WEP")
    - A total of 68 out of 85 WEPs were used to supplement the 1051 report data (data provided in the other 17 WEPs were already represented in the 1051 reports).

[6] House Bill 2010-1051 requires that the CWCB implement a process for the reporting of water use and conservation data by covered entities. A "covered entity" is defined as each municipality, agency, utility, including any privately owned utility, or other publicly owned entity with a legal obligation to supply, distribute, or otherwise provide water at retail to domestic, commercial, industrial, or public facility customers, and that has a total demand for such customers of two thousand acre-feet or more, per Section 37-60-126(1)(b) of the Colorado Revised Statutes (C.R.S.). 1051 reporting data provided by CWCB for the Technical Update in February 2018.

  - All WEPs utilized were on file with the CWCB as of February 2018.
- Targeted Water Provider Outreach ("Targeted Outreach")[7]
  - Conducted for select counties that had no 1051, WEP, or Basin Implementation Plan data.
  - Outreach was facilitated by CWCB.
- Basin Implementation Plans ("BIP")
  - Each BIP prepared in 2015 was reviewed for the availability of new water use data; however, only the Colorado and Rio Grande Basins had sufficient information to be relied upon for the Technical Update methodology.
  - The majority of data in the Rio Grande BIP was reported at a county level, rather than for individual water providers. All data in the Colorado BIP was available at the provider level.
  - Available data only included systemwide demands, rather than for individual customer categories, creating some limitations for utilization in baseline water demand calculations.

The availability of data for statewide planning is dramatically improving through the 1051 reporting process, which provides water use data at the customer category level and includes all distributed water supplies (i.e. potable treated, non-potable raw, and non-potable reuse[8]). WEPs also provide this type of data but are typically updated on a seven-year cycle, to meet the statutory obligation, whereas 1051 is an annual reporting process. There were 53 water providers with at least one year of 1051 data[9] and WEP data were available for an additional 68 water providers who were not represented by 1051 reporting, yielding detailed water use information for at least 121 providers and approximately 84% of the statewide population (see Figure 2-4).[10] These data were combined and used to represent demands in the year 2015. The WEP data were based on varying time periods; however, almost all data was from 2008 through 2016.

The data were reviewed and aside from parts of the state with incomplete data representation, the most significant data issues were identified by preparing a mass balance analysis at the water provider level. Engineering judgement was used where data issues resulted in negative or unreasonably high non-revenue values and to address other challenges such as data not being reported for individual demand categories. In comparing the updated volumetric and per capita demands to values from SWSI 2010, some differences were attributed to the inclusion of raw and reuse water supplies in the Technical Update, which may not have been included in some of the SWSI 2010 data reporting. All reported types of water supply (potable, non-potable raw, and non-potable reuse) were included in the Technical Update demand calculations to the extent that data were available. It was assumed that only potable supplies were used

[7] Facilitated and tabulated by CWCB.

[8] Statewide, the 1051 reported dataset was comprised of approximately 92% potable treated, 6% non-potable raw, and 2% non-potable reuse supplies.

[9] Based on 1051 reporting through 2016.

[10] BIPs also provide some water use data for additional providers.

for residential customers. Non-potable raw water supplies were largely classified as non-residential outdoor use with the exception of three providers where there was relatively extensive wintertime use. Non-potable reuse water supplies were classified entirely as non-residential outdoor use. Compared to potable water supplies, less information is available regarding how raw water and reuse supplies are coupled with demands. However, it was determined that the demands associated with raw water and reuse should be included in the Technical Update demand analysis, to reflect the potential impacts in the hydrologic modeling. It is recommended that additional information about these types of supplies and associated demands be collected to support future modeling efforts.

Baseline systemwide demands were calculated for each county. Reported water use data from the 1051, WEPs, outreach, and BIPs data sources were used to calculate an average per-capita demand, in gpcd, for the portion of the county population represented by the data sources. Demands were estimated for the remaining population within each county that was not represented by one of the data sources. If over 40% the county population was represented by any combination of the data sources, then the county average systemwide gpcd calculated from the available data was used to estimate the average gpcd for the entire county. For counties with less than 40% of the population represented by the data sources, the per-capita demands from neighboring counties were used to estimated demands for the population that was not represented by the data sources. Neighboring counties used to fill the missing data were selected based on a combination of geographic proximity and a comparison of the relative baseline demands from SWSI 2010.

Certain drivers, such as the climate driver, are expected to primarily affect outdoor demands whereas other drivers, such as technology, could affect both indoor and outdoor demands. Similar to SWSI 2010, systemwide municipal demands were disaggregated into the following water demand categories, prior to applying the per-capita drivers:

- Residential (Single Family & Multi-Family) Indoor[11]
- Non-Residential Indoor
- Residential (Single Family & Multi-Family) Outdoor[12]
- Non-Residential Outdoor
- Non-Revenue Water[13]

For water providers with adequate information, indoor and outdoor demands were estimated from total residential and total non-residential water use data, using a representative winter or other month(s) to estimate indoor, i.e. non-seasonal use, and assuming that the indoor use remains relatively constant throughout the year. The 1051 data provide an indication of which months(s) are typically representative of indoor use for a particular water provider. If not specifically identified by water providers, then the in-

[11] Sufficient information was not available to further disaggregate the residential indoor category into single and multi-family categories

[12] Sufficient information was not available to further disaggregate the outdoor residential category into single and multi-family categories.

[13] This category was referred to in SWSI 2010 as “water loss”.

door use was estimated from the average use for the months of December through February. This technique has potential for error because there may be some outdoor use included in the winter or other identified indoor-representative month(s) and indoor use may not remain constant throughout the year. However, this is a commonly used method for estimating indoor and outdoor uses from total water use data in locations that have limited outdoor use during winter months.

A demand category distribution, as a percentage of the systemwide use, was calculated for each county and as a basin-wide average. Similar to the gpcd calculations described above, the reported distributions were used for the portion of the county populations represented by the data sources. Distributions for the remaining population within each county that was not represented by one of the data sources were based on the basin average. The statewide average demand category distribution was applied to the Rio Grande and North Platte basins because there were insufficient data available to calculate unique distributions for these basins.

1.1.2.3 PER-CAPITA WATER DEMAND PROJECTIONS

Key Definitions:

Adoption Rate – Portion of existing (2015) population that will have water use consistent with the future gpcd value for a given scenario by the year 2050 (i.e. retrofit population). Water use for all new population is based on the future gpcd value for a given scenario. Adoption rate is applied to all demand drivers except non-revenue adjustments.

Projected Demands – Calculated future demands representing average conditions for Technical Update projection year 2050.

Projected future per capita rates of water demand in gpcd were calculated for each county by adjusting the baseline gpcd values by future demand drivers representing urban land use, technology, regulations, and social values. The following descriptions provide an overview of possible future effects and uncertainties associated with these drivers.

- Changes in urban land use primarily impact outdoor municipal water demand, due to impacts on the amount and type of irrigated landscape (Clarion, 2015), although low density can also be associated with higher leakage (EPA, 2006) and some high-density developments use water-intensive cooling towers (Clarion, 2015). For service areas with significant projected population increases that are already substantially built out, the additional population may cause an increase in the current density due to infill, e.g. from single-family detached residential housing products to a denser attached or multi-family type of housing. Alternatively, service areas may be expanded, adding acreage to the service area, in which case the density of the current and future population may not change significantly. With increased density, the amount of outdoor landscaped area per person generally decreases and, in some circumstances, the landscape characteristics also change from a higher water use category, such as lawn grass, to include more low water use plants and shrubs. The relationship between density and landscaping demands is further complicated because irrigation methods and management of irrigation systems have a significant effect on water use, in addition to the amount and type of landscape vegetation. A theoretical analysis completed by CWCB (2010b) indicated that a 20% increase in residential density, on average, could decrease total (indoor and outdoor) residential water demand by approximately 10%. Other studies have reported even greater water savings from increased density (Clarion, 2015); however, it is unclear whether savings can be exclusively attributed to increased density.

For certain planning scenarios, the Technical Update Agricultural Demand Methodology included a reduction in future agricultural demands, due to the removal of irrigated agricultural acres from municipal urbanization. Data from the population projections were utilized to inform the locations and extent to which future agricultural irrigated acres were reduced.

- **Technology** affects the level and extent to which water use can be managed without requiring significant behavioral changes. Substantial reductions in indoor water uses have occurred over the past two decades, primarily from improved indoor fixture and appliance technology. End use studies and metered water use data provide useful data-based methodologies for benchmarking water-efficient residential uses. While there has historically been a substantial behavioral component related to landscape irrigation, the equipment and technology is changing and becoming more user-friendly, which has the potential to reduce the behavioral influence in the future. Improved efficiencies in non-residential uses and landscape irrigation equipment have also started to be implemented relatively recently.

- Water rates, provider policies, and state/federal **regulations** (e.g., WaterSense, EnergyStar, Colorado Senate Bill 14-103) have the potential to affect all water demand categories. Often there is a relationship between technology and regulations, e.g. Colorado adopted WaterSense plumbing fixture legislation once efficient technology was reliable and affordable. Regulations also affect the prioritization of investment in water efficient technology, conservation programs, managing water loss control through replacement of aging infrastructure, etc. Recent regulations have primarily impacted indoor uses, but a shift toward focusing on outdoor uses and water loss control is beginning to occur. There is also some level of inelasticity related to indoor demands, and a limit in the extent to which rates will impact water demand. Affordability may increasingly become a social issue into the future as rates increase.

- **Social values** affect the level of support for higher municipal water efficiency efforts and preference for human water uses versus other concerns.

The potential future impact of these drivers on each of the five water demand categories was evaluated. The driver values were developed with input from the M&I TAG. The residential indoor demand category was adjusted to a fixed gpcd value, while a percentage adjustment to baseline values was applied to the other demand categories with positive values creating an increase and negative values a decrease in gpcd. The adjustment values are shown in Table 1-5 below. The adjusted future indoor and outdoor gpcd rates were used to represent all new population (associated with new construction) and a portion of the existing population reflected by the adoption rates[14] shown in Table 1-6 (associated with retrofits), with the remainder of the existing population continuing at the baseline gpcd rate. This methodology assumes that by 2050, all "new" population between the current and 2050 populations, and a portion of the current population, will use water at the future per-capita demand rate. Thereby, the future gpcd rates that were used in the demand modeling included the combined effects of active and passive conservation.

[14] The adoption rate was applied to all demand categories except for non-revenue water.

Table 1-5: Municipal Per Capita (gpcd) Rate Adjustments for 2050 Projections.

Demand Category	A. Business as Usual	B. Weak Economy	C. Cooperative Growth	D. Adaptive Innovation	E. Hot Growth
Residential Indoor	42.4	42.4	36.4	33.3	42.4
Non-Residential Indoor	0%	-5%	-10%	-10%	+5%
Outdoor	0%	-5%	-15%	-20%	+5%
Non-Revenue Water	0%	+5%	0%	-5%	0%

Table 1-6: Municipal Adoption Rates Applied to Indoor and Outdoor Demand Categories for 2050 Projections.

Scenario:	A. Business as Usual	B. Weak Economy	C. Cooperative Growth	D. Adaptive Innovation	E. Hot Growth
Adoption Rate	50%	40%	60%	70%	60%

The following information provides additional detail regarding the basis for these adjustments:

- Future Residential Indoor gpcd: Residential indoor demands have significantly decreased throughout much of the state in recent years, largely due to advancements in technology. In preparing the South Platte BIP, the Metro Basin concluded that 34 gpcd is a realistic goal for its future indoor demand and the South Platte Basin envisioned reducing its indoor demand to 40 gpcd. Similar targets were not specified in other BIPs. Therefore, it is recommended that the same future gpcd values be used for all basins, based on the best available literature at this time, and the individual basins can modify the values as part of future BIP updates. Based on data from end use studies of existing homes (including homes located in Colorado and throughout the nation) and water efficiency benchmarks summarized below, future gpcd values are expected to range between around 30 and 45 gpcd as follows (DeOreo et al., 2016):
    - 58.6 gpcd – 2016 average indoor daily water use from 737 existing study homes across 9 study sites.
    - 42.4 gpcd – 'current efficiency benchmark' based on 247 retrofit homes equipped with high efficiency fixtures and appliances which generally meet or exceed the WaterSense specifications; included both existing homes that were retrofit and new homes built with high efficiency devices.
    - 40.9 gpcd – efficiency benchmark achievable in coming years with high-efficiency fixtures and appliances widely installed.
    - 36.4 gpcd - benchmark for ultra-efficient average indoor water use in the future, as even more efficient devices are adopted.
    - 33.3 gpcd – achievable if household leakage can be reduced.

The M&I TAG recommended that 33.3 gpcd be used for either the Cooperative Growth or Adaptive Innovation scenario, assuming that advanced metering infrastructure, regulations, and rates could support this future demand rate.

- Non-Residential Indoor: Non-residential indoor demands have not decreased as significantly in recent years as the residential demands. Whereas residential demands are generally associated with new/retrofitted homes that are likely to utilize new technology, only a portion of the non-residential demands are similarly influenced by new growth. Depending upon the nature of the non-residential use (e.g. type of business), some demands are not able to decrease as significantly while still providing the same product. Due to the breadth of the non-residential category, it is impractical to further disaggregate the category such that a future gpcd value can be selected. Although SWSI 2010 estimated future non-residential indoor demands by using comparable adjustment factors to the percent reduction represented in the residential indoor sector, resulting in a future reduction of up to 25%, the M&I TAG recommended against this method for the reasons described above. The percentages shown in Table 1-5 are based, in part, on the M&I TAG recommendation to show smaller changes relative to the residential indoor category. This factor is applied as a percentage change to the disaggregated non-residential indoor portion of the gpcd values calculated from the current available data.

- Outdoor: Advancement in landscape irrigation technology and associated regulations have the potential to significantly reduce future outdoor demands. Water savings over 50% have been reported from some outdoor efficiency programs (Mayer et al., 2015), and savings of between 20% and 30% are often reported from the types of programs currently being implemented and anticipated on a broader scale over the planning period. Some of these reported values may be influenced, at least in part, by increases in density. However, some of the estimates are based on retrofits and technology, which are not dependent upon changes in density. Future urbanization and land use changes will also impact outdoor uses and are generally expected to result in a reduction in gpcd. For the Technical Update, the statewide average total outdoor adjustment associated with the land use, technology, regulations, and social values was limited to a maximum of around 20%. Note that there is a relational effect between the outdoor adjustment and the climate adjustment. The adjustments shown in Table 1-5 are made prior to considering climate effects, which are described in Section 1.1.2.4 below.

- Non-Revenue Water: Transmission and distribution losses from potable water produced in the United States has been reported to average between 14% and 18% of all potable water produced (Water Research Foundation, 2017). As of 2009, reported utility water losses[15] in Colorado ranged from between 2% and 12% (Aquacraft, 2009). An 8% statewide average water loss was used for the SWSI 2010 baseline demands and the representative future gpcd rates prepared for the Conservation Strategies were assumed to achieve real losses of 6% to 7%, as a percentage of the water deliveries. The relevant data available through 1051 reporting is non-revenue water, which is the difference between Distributed Water and authorized Metered Water Use, as those terms are defined above, which is also the sum of real and apparent losses. Based on review of the 1051 data, there is a wide range of reported values in this category. The percentage adjustment values are intended to demonstrate that a lower factor would be used for the Adaptive Innovation scenario, and a higher factor would be used for Weak Economy scenario.

[15] The reported values were described as non-uniform across water providers but typically based on system input or production volume minus billed water data.

Some important considerations about this methodology include:

- The projected demands represent potential demands under conditions described in the CWP for each scenario, however they do not necessarily represent the full potential for demand management under each scenario, e.g. more aggressive active conservation programs.
- Erroneous or suspect reported non-revenue water loss values were adjusted to provide a reasonable range of planning values for several water providers. An emphasis should continue to be placed on improving this data and an understanding of the associated real and apparent losses.
- Aside from the climate driver described below, per capita drivers were not modified by basin or county. Drivers were applied using the same values and methodology for each county and are intended to prepare a scenario planning approach that can be further customized at the basin level.
- Planning scenarios do not include acute drought management planning (e.g. imposing restrictions), so comparing to other areas of the country (e.g. Southern California) is not appropriate if their current demands reflect not only aggressive active conservation, but also imposed restrictions.
- Demand projections were prepared using the same adoption rate for indoor and outdoor demands and for residential and non-residential demands. The adoption rate should be further investigated at a local level because it is highly influenced by new construction and active water conservation programs. The adoption rate also encompasses effects such as the persistence of demand reductions associated with indoor and outdoor uses, which should be considered. For example, unless repeated over time, demand reductions associated with certain outdoor demand management programs such as an irrigation audit may result in less permanent savings than changing indoor plumbing fixtures to lower water use models.
- The per capita gpcd metric is being used as a projection tool for this statewide planning project, even in areas with a significant influence from non-permanent residents such as mountain resort communities, and is not applicable as a comparison tool between communities. It is not appropriate to compare a gpcd value from areas that have a significant influence from tourism and non-permanent residents to areas that have a primarily year-round residential type of population. Specific characteristics about each community need to be understood when interpreting per-capita demand data.
- Urban land use changes have the potential to significantly affect future municipal, primarily outdoor, and agricultural demands. The range of impacts may not be fully reflected in the Technical Update municipal and agricultural demand projections, primarily due to a lack of information available for use in statewide planning projections. Future demand projections may be improved by collecting service area delineations (e.g. irrigated acreage) and density information regarding developed and irrigated landscaped areas under current conditions and anticipated for the future planning year, i.e. 2050.
- The climate factor adjustments described in Section 1.1.2.4 below represent the average annual change in 2050 for the climate represented in each scenario. Regardless of the climate status, there will be annual and monthly variability in outdoor demands. Figure 1-2 shows an illustrative

example of the historical annual variability in modeled irrigation water demands under a full water supply for bluegrass at representative climate stations throughout the state and presented as a relative change to the average demand over the historical period. A review of historical water provider-reported data shows that while some municipal systems experience this type of annual variability in outdoor water use, others do not, which may be an indication of water use management or that there is an issue with using the full irrigation water requirement of bluegrass as proxy for outdoor water demands. It was determined that applying this level of variability to all outdoor demands is unreasonable without having additional information regarding the irrigated landscaped areas represented in the reported data. Furthermore, the historical patterns may not be representative of likely future patterns under all five scenarios. Therefore, this type of annual variability is not included in the hydrological modeling for the Technical Update but should be considered and incorporated in future Technical Updates as additional information regarding irrigated landscaped areas and types of landscaping are known.

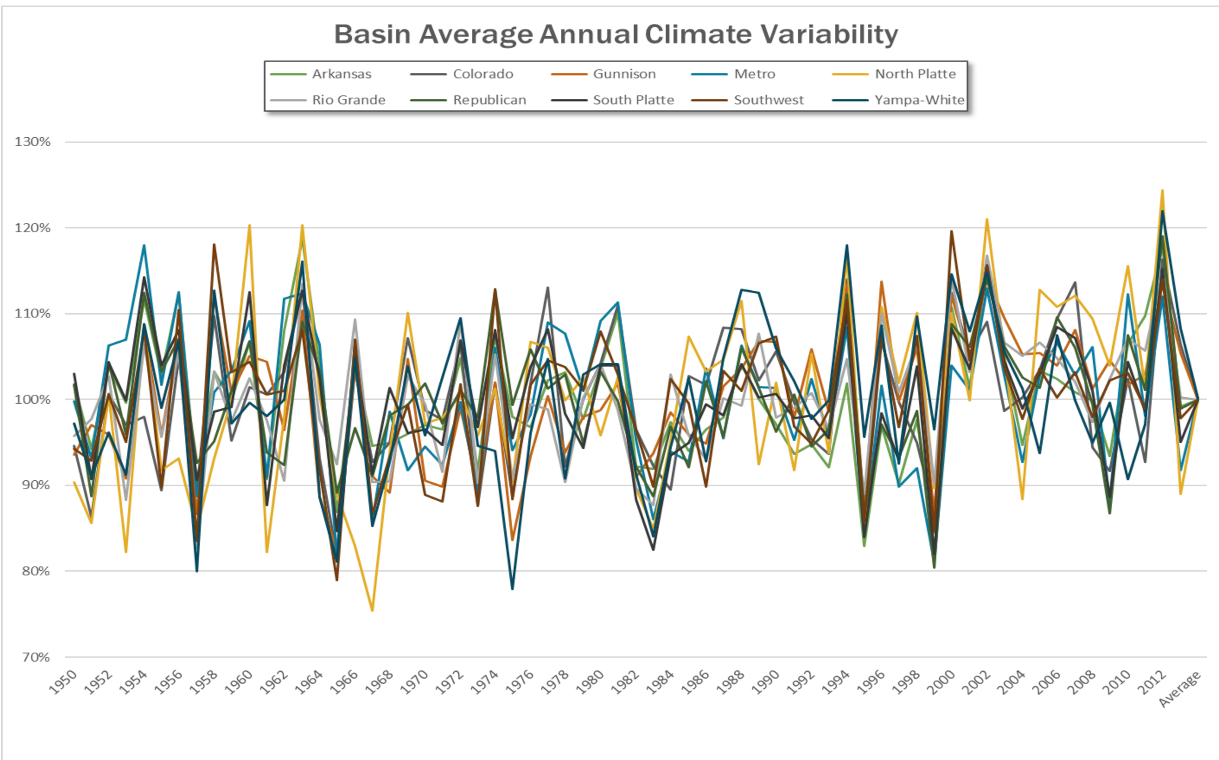
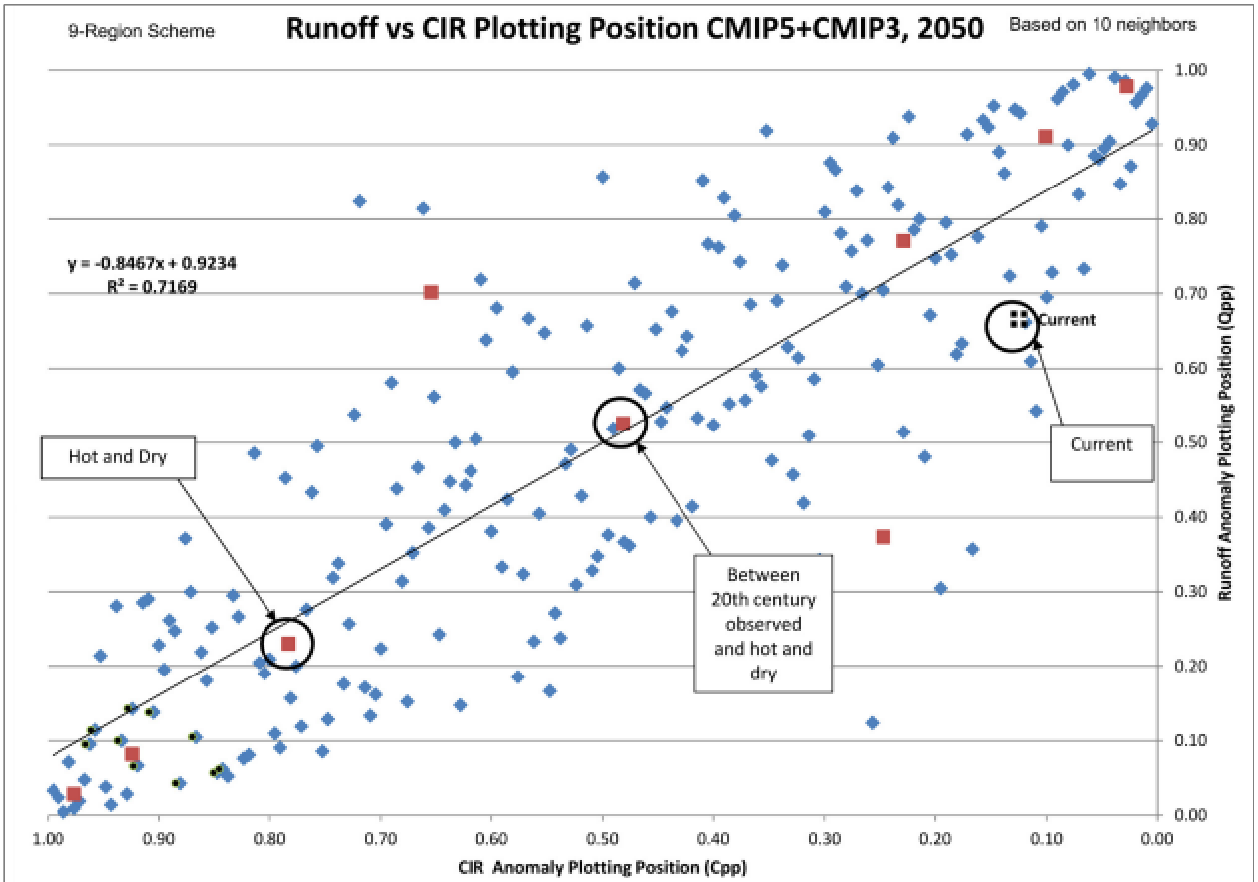


Figure 1-2: Basin Average Annual Variability in Bluegrass ET.

1.1.2.4 CLIMATE DRIVER

The Colorado Climate Plan, published by the State of Colorado, describes the most recent global climate projections (CMIP5) and recommends the integration of these results with the previous global climate projections (CMIP3) to provide a representative range of potential future climate and hydrological conditions. Using this information, three of the CWP scenarios have a climate different from what was observed during the 20th century (referred to as "Current"). Section 4 of the CWP describes uncertainties in future water supplies and the two future potential climate projections selected by the IBCC to represent "Hot and Dry" conditions and "between 20th century observed and hot and dry" conditions (referred to as

“In-Between”), in addition to Current climate conditions. Figure 1-3 below, which is Figure 4-9 on page 4-11 of the CWP, illustrates the runoff versus crop irrigation requirement relationship for these scenarios.



"Hot and dry" is defined as the 75th percentile of climate projections for crop irrigation requirements (water use), and the 25th percentile for natural flows. In other words, only 25 percent of projections have lower natural flows and 25 percent of projections have higher crop irrigation requirements. "Between 20th century-observed and hot and dry" is defined as the 50th percentile for both natural flows and crop irrigation requirements. This scenario represents the middle of the range in terms of severity. Historical or current conditions, which represents no change in runoff or in crop irrigation requirements, fall at roughly the 9th and 67th percentiles; this means that 91 percent of runs show increases in crop irrigation requirements and about two-thirds show reductions in runoff.

Figure 1-3: Runoff versus Crop Irrigation Requirement (from the CWP), Illustrating Climate Scenarios.

The CWP assigned a climate projection to each of the five scenarios, as shown in Table 1-7.

Table 1-7. Climate Status for Each Planning Scenario.

Scenario:	A. Business as Usual	B. Weak Economy	C. Cooperative Growth	D. Adaptive Innovation	E. Hot Growth
Climate:	Current	Current	In-Between	Hot and Dry	Hot and Dry

Changes in climate primarily influence outdoor aspects of municipal demands, due to impacts on landscape vegetation irrigation water needs (WWA, 2014). These impacts are typically associated with warmer temperatures that increase evapotranspiration (“ET”) rates and lengths of growing seasons, which increase the landscape irrigation water demand and consumptive use. For the Technical Update, it was assumed that indoor demands and non-revenue water are not affected by climate changes.

Climate effects on outdoor demands can be quantified through an ET-based analysis. Where sufficient data are available, the irrigation water requirement ("IWR") under varying climates could be used to evaluate the range of effects on future municipal outdoor demands. This type of analysis would require data or assumptions about the mix of landscaping materials, e.g. low versus high water-demand plants and grasses and irrigated areas. Irrigation application efficiency data would also need to be available or assumed. Some water providers have begun reporting landscaped areas through the 1051 reporting, but sufficient information to apply this type of methodology on a statewide basis are not yet available. It is recommended that efforts continue to be made to collect this data. This will be challenging as permeable areas, landscaping materials, and application efficiencies change over time, however it is the type of information that will better inform future municipal outdoor demand projections. In the absence of the irrigated landscape area and other related data, IWR based on ET rates serves as a proxy for water use. The Technical Update utilizes the relative difference between ET rates under current conditions and the future climate status under a given scenario to develop a percentage adjustment to the outdoor portion of the future per capita demand values for the residential and non-residential outdoor demand categories.

ET change factors were developed under the Colorado River Water Availability Study Phase II (BOR, 2012), by processing projected climate data and downscaling the information for use at the water district level. This effort resulted in a time series of 64 years of annual change factors for each water district, reflecting the relative change in IWR under each climate projection. The factors were prepared for use with irrigated agriculture crops rather than municipal landscaping but are the best available information at this time. To estimate the impacts of changing climate on future outdoor demands for the Technical Update analysis, the water district factors were translated to county factors. In areas where multiple water districts cover a single county (mostly occurring in the west-slope basins), the current geographic population distribution was used to weight the water district factors based on the relative population distribution. These factors were applied to outdoor demands at a county level to represent the average annual change in outdoor demand in the year 2050 due to the climate status (Table 1-8).

Some important considerations about this methodology include:

- The analysis assumes that an adequate water supply is available in that the methodology adjusts the outdoor demand by the relative change in the demand that would occur with a full landscaping water supply to meet the IWR, which does not account for deficit irrigation under current or future conditions.

- The adjustments assume that amount and type of vegetative cover and the irrigation methods and management remain the same in the future as today. Other driver adjustments should be considered in the future modeling, to reflect potential changes in land use, including landscaping characteristics that may be influenced by climate changes (e.g. a shift toward vegetation that needs less water).

- The methodology assumes that the percentage reduction in outdoor use found from existing programs, i.e. 20% to 30%, remains possible and representative of the potential percentage reductions under future climate scenarios. However, the percentages are a net effect between the current and future conditions. Some communities are already struggling to support healthy landscapes in response to utility rate charge increases. It is anticipated that it will require active management and a concerted effort to maintain healthy landscapes under future climate scenarios or that landscapes will have to change.

Table 1-8: County Climate Adjustment Factors by Planning Scenario.

Scenario:	A. Business as Usual	B. Weak Economy	C. Cooperative Growth	D. Adaptive Innovation	E. Hot Growth
Climate:	Current	Current	In Between	Hot and Dry	Hot and Dry
Adams	1	1	1.09	1.15	1.15
Alamosa	1	1	1.15	1.18	1.18
Arapahoe	1	1	1.09	1.15	1.15
Archuleta	1	1	1.16	1.23	1.23
Baca	1	1	1.12	1.17	1.17
Bent	1	1	1.12	1.17	1.17
Boulder	1	1	1.08	1.14	1.14
Broomfield	1	1	1.09	1.15	1.15
Chaffee	1	1	1.12	1.17	1.17
Cheyenne	1	1	1.07	1.13	1.13
Clear Creek	1	1	1.08	1.14	1.14
Conejos	1	1	1.15	1.18	1.18
Costilla	1	1	1.15	1.18	1.18
Crowley	1	1	1.12	1.17	1.17
Custer	1	1	1.12	1.17	1.17
Delta	1	1	1.16	1.22	1.22
Denver	1	1	1.09	1.15	1.15
Dolores	1	1	1.16	1.23	1.23
Douglas	1	1	1.09	1.15	1.15
Eagle	1	1	1.13	1.21	1.21
El Paso	1	1	1.12	1.17	1.17
Elbert	1	1	1.10	1.15	1.15
Fremont	1	1	1.12	1.17	1.17
Garfield	1	1	1.13	1.21	1.21
Gilpin	1	1	1.08	1.14	1.14
Grand	1	1	1.13	1.21	1.21
Gunnison	1	1	1.16	1.22	1.22
Hinsdale	1	1	1.16	1.22	1.22
Huerfano	1	1	1.12	1.17	1.17
Jackson	1	1	1.16	1.26	1.26
Jefferson	1	1	1.09	1.15	1.15
Kiowa	1	1	1.12	1.17	1.17
Kit Carson	1	1	1.04	1.11	1.11
Lake	1	1	1.12	1.17	1.17
La Plata	1	1	1.16	1.23	1.23
Larimer	1	1	1.08	1.14	1.14
Las Animas	1	1	1.12	1.17	1.17
Lincoln	1	1	1.10	1.16	1.16
Logan	1	1	1.08	1.14	1.14
Mesa	1	1	1.13	1.21	1.21
Mineral	1	1	1.15	1.18	1.18
Moffat	1	1	1.20	1.35	1.35
Monte-zuma	1	1	1.16	1.23	1.23
Montrose	1	1	1.16	1.22	1.22
Morgan	1	1	1.08	1.14	1.14
Otero	1	1	1.12	1.17	1.17

Scenario:	A. Business as Usual	B. Weak Economy	C. Cooperative Growth	D. Adaptive Innovation	E. Hot Growth
Climate:	Current	Current	In Between	Hot and Dry	Hot and Dry
Ouray	1	1	1.16	1.22	1.22
Park	1	1	1.08	1.14	1.14
Phillips	1	1	1.04	1.11	1.11
Pitkin	1	1	1.13	1.21	1.21
Prowers	1	1	1.12	1.17	1.17
Pueblo	1	1	1.12	1.17	1.17
Rio Blanco	1	1	1.22	1.37	1.37
Rio Grande	1	1	1.15	1.18	1.18
Routt	1	1	1.20	1.35	1.35
Saguache	1	1	1.15	1.18	1.18
San Juan	1	1	1.16	1.23	1.23
San Miguel	1	1	1.16	1.23	1.23
Sedgwick	1	1	1.06	1.13	1.13
Summit	1	1	1.13	1.21	1.21
Teller	1	1	1.10	1.15	1.15
Washing-ton	1	1	1.05	1.11	1.11
Weld	1	1	1.08	1.14	1.14
Yuma	1	1	1.04	1.11	1.11

1.2 INDUSTRIAL DEMANDS

1.2.1 SWSI 2010 METHODOLOGY

SWSI 2010 defined self-supplied industrial (SSI) demands as large industrial water users that have their own water supplies or lease raw water from others. Domestic water demands that result from increases in population associated with SSI activities ("indirect demands") were represented in the municipal demands. The future demand projections were prepared on an average annual basis and potential impacts of climate change were not considered in any of the demand analyses. The SSI demand category from SWSI 2010 is equivalent to the industrial portion of the demands in the Technical Update.

SWSI 2010 included demands for the following four SSI sub-sectors:

- **Large industry** demand data were primarily collected during the prior SWSI Phase 1 study (CWCB, 2004). In SWSI 2010, three large industries in the South Platte Basin that receive their water supply from municipalities were added to the SSI category and removed from the municipal calculations, to avoid double counting in the M&I demands. SSI demands for Routt and Moffat Counties were increased through 2035 based on mining and golf course projections in the Yampa Valley Water Demand Study (BBC, 1998); demands were then held constant through 2050. SSI demands for all other counties were held constant between 2008 and 2050.

- **Snowmaking** demand projections were based on estimates of 2008 snowmaking acres for each resort, the amount of water used for snowmaking in 2008, and expected future snowmaking water demand based on regional studies. Demands for resorts without water use data were estimated using a "water use factor" (WUF) per acre of snowmaking for each basin. Water use was held constant for resorts with no known or reported future expansions.

- **Thermoelectric power generation** demand data for coal-fired and natural gas power facilities through 2035 were largely based on information provided by power producers for the SWSI Phase 1 study (CWCB, 2004). SWSI Phase 1 demands for the Colorado and Yampa-White basins were modified and extended through 2050 using specific study information. Data for all other counties relied on SWSI Phase 1 projections for 2035 and were extended through 2050 using 5%, 25%, and 50% increases for low, medium, and high demand scenarios, respectively.

- **Energy development** demand projections were primarily based on the Phase I and II Energy Development Water Needs Assessment Reports released by the Colorado and Yampa-White Roundtables (URS, 2008; AMEC, 2011). The local reports estimated direct demands needed to support extraction and production of natural gas, coal, uranium, and oil shale through 2050. Information in the local reports were interpreted to develop low, medium, and high scenarios for the energy industry in northwest Colorado. The Rio Grande Basin was also projected to include the development of a solar energy industry over a period of 40 to 50 years (i.e. thru 2050/2060).

Low, medium, and high demand projections were developed for the energy and thermoelectric power generation sub-sectors whereas a single 2050 demand value was prepared for the large industry and snowmaking subsectors as shown in Table 1-9. The potential for future conservation savings was not evaluated.

Table 1-9. SWSI 2010 Self-Supplied Industry Demands by Basin (AFY).[16]

Basin	Sub-Sector	2008	2035	2050 Low	2050 Med	2050 High
Arkansas	Energy Development	-	-	-	-	-
	Large Industry	49,400	49,400	49,400	49,400	49,400
	Snowmaking	-	-	-	-	-
	Thermoelectric	9,000	14,700	15,400	18,400	22,100
	Basin Total	58,400	64,100	64,800	67,800	71,500
Colorado	Energy Development	2,300	500	200	4,700	10,700
	Large Industry	-	-	-	-	-
	Snowmaking	3,180	4,740	4,740	4,740	4,740
	Thermoelectric	-	-	-	-	-
	Basin Total	5,480	5,240	4,940	9,440	15,440
Gunnison	Energy Development	-	-	-	-	-
	Large Industry	-	-	-	-	-
	Snowmaking	260	650	650	650	650
	Thermoelectric	-	-	-	-	-
	Basin Total	260	650	650	650	650
Metro	Energy Development	-	-	-	-	-
	Large Industry	52,400	52,400	52,400	52,400	52,400
	Snowmaking	-	-	-	-	-
	Thermoelectric	12,000	12,000	12,600	15,000	17,900
	Basin Total	64,400	64,400	65,000	67,400	70,300
Rio Grande	Energy Development	-	600	1,200	1,500	2,000
	Large Industry	-	-	-	-	-
	Snowmaking	-	-	-	-	-
	Thermoelectric	-	-	-	-	-
	Basin Total	-	600	1,200	1,500	2,000
South Platte	Energy Development	-	-	-	-	-
	Large Industry	6,600	6,600	6,600	6,600	6,600
	Snowmaking	320	320	320	320	320
	Thermoelectric	21,400	35,400	37,200	44,400	53,100
	Basin Total	28,320	42,320	44,120	51,320	60,020
Southwest	Energy Development	-	-	-	-	-
	Large Industry	-	-	-	-	-
	Snowmaking	410	410	410	410	410
	Thermoelectric	1,900	3,900	4,100	4,900	5,900
	Basin Total	2,310	4,310	4,510	5,310	6,310
Yampa-White	Energy Development	2,000	6,000	3,900	7,500	41,800
	Large Industry	6,100	9,500	9,500	9,500	9,500
	Snowmaking	290	570	570	570	570
	Thermoelectric	20,200	38,300	36,700	40,500	44,000
	Basin Total	28,590	54,370	50,670	58,070	95,870
Statewide Total		187,760	235,990	235,890	261,490	322,090

[16] Copied from Table 4-13 of CWCB, 2010a.

1.2.2 TECHNICAL UPDATE METHODOLOGY ENHANCEMENTS

The CWP provides some narrative guidance regarding effects on industrial demands under the five planning scenarios, as described in Table 1-10, although less specific than for the municipal demands.

Table 1-10: CWP Guidance on Industrial Demands for the Five Planning Scenarios.

A. Business as Usual	B. Weak Economy	C. Cooperative Growth	D. Adaptive Innovation	E. Hot Growth
• Recent trends continue • Regular economic cycles • Social values and regulations remain the same • Oil-shale development continues to be researched	• Economy struggles • Greenhouse gas emissions do not grow as much	• Embrace water and energy conservation • Widespread water efficiency and increased environmental protection	• Renewable and clean energy become dominant	• Rapid business and population growth • Fossil fuel is the dominant energy source • Large production of oil shale, coal, natural gas, and oil

New and updated information related to current and projected future industrial demands is limited. SWSI 2010 values were updated where possible and appropriate as follows, based on published references and data collected through outreach with the M&I TAG. To the extent possible with the available information, 1051 data that were relied upon in preparing municipal demands were reviewed and adjusted to exclude water uses associated with industrial demands, to avoid double counting. The drivers in Table 1-11 were developed with input from the M&I TAG and as further summarized below.

- Large Industry: Baseline large industry demands for facilities represented in SWSI 2010 were updated using either: i) BIP data; ii) recent data from existing hydrologic models; or iii) interpolating between 2008 and 2035 values in SWSI 2010. A mining facility was also added in Grand County (Colorado Basin) because it is an explicitly-modeled location in an existing hydrologic model. Business as Usual demands were developed using BIP data and information provided by M&I TAG participants to the extent possible, while all remaining values were based on projections from SWSI 2010. All large industry demands were varied by scenario according to the factors in Table 1-11 except for those occurring in Jefferson County as further described under the South Platte Basin.

- Snowmaking: Baseline demands were updated based on current snowmaking acres for each resort[17] and WUFs from SWSI 2010. Baseline snowmaking demands are estimated to have increased by approximately 15% as compared to the 2008 values used in SWSI 2010, which is in line with the linear increase from 2008 to 2050 reported in SWSI 2010. Therefore, SWSI 2010 projections appear to provide a reasonable estimate of Business as Usual demands. SWSI 2010 projections represent the best-available information for Business as Usual demands in 2050. As with

[17] Source: https://www.onthesnow.com/colorado/skireport.html

SWSI 2010, snowmaking demands were not varied by scenario, in part, due to uncertainty regarding the effects of climate change.

- **Thermoelectric Power Generation:** Baseline and Business as Usual thermoelectric demands for 10 of the 13 facilities were updated using data provided by M&I TAG participants. Baseline and Business as Usual demands for one facility were based on information from the Yampa-Green-White BIP. SWSI 2010 values were used to define Baseline and Business as Usual demands for the remaining two facilities where no updated information was available. Thermoelectric demands for all facilities were varied by scenario according to the factors in Table 1-11.

- **Energy Development:** Baseline energy development demands were updated using either BIP data or interpolating between 2008 and 2035 values in SWSI 2010. 2050 demand projections in the Rio Grande Basin were based on information from the BIP and did not vary by scenario. 2050 demands in all other basins were based on low, medium, and high projections from SWSI 2010 as summarized in Table 1-11.

Table 1-11: Industrial Adjustments for 2050 Projections.

Industrial Category	A. Business as Usual [a]	B. Weak Economy	C. Cooperative Growth	D. Adaptive Innovation	E. Hot Growth
Large Industry [b]	-	-10%	0%	0%	10%
Snowmaking	-	0%	0%	0%	0%
Thermoelectric	-	-5%	10%	-5%	10%
Energy Development [c]	SWSI 2010 - Medium	SWSI 2010 - Medium	SWSI 2010 - Low	SWSI 2010 - Low	SWSI 2010 - High

a) The Business as Usual scenario is based on updated baseline demands. The percentage values shown for other scenarios are an adjustment to the baseline demands from the Business as Usual scenario.

b)Jefferson County large industry demands were not varied by scenario.

c) Rio Grande energy development demands were not varied by scenario.

In addition to the industrial demands described above, the hydrologic modeling for the Technical Update includes demands associated with hydroelectric power generation. Hydroelectric demands are non-consumptive and were not adjusted from the values that were included in the existing models, for the baseline or planning scenarios in the hydrologic modeling, because no new information was available for this demand category. As previously noted, limited new information about industrial demands was available for the Technical Update. It is recommended that targeted outreach for each sub-sector, including hydroelectric power, be completed as part of the BIP updates and/or well in advance of the next Technical update. For example, oil and gas demands are known to exist in the South Platte and North Platte Basins; however, no data were available to be relied upon at the time the analysis was completed.

1.3 PREPARING DEMANDS FOR HYDROLOGIC MODELING

As part of the Technical Update, the M&I demands are incorporated into a hydrologic modeling analysis that combines water demand and water supply projections on a spatial basis throughout the state of Colorado, using monthly basin-scale models. The M&I baseline and projected future demands were developed at a county scale however, the hydrologic models use water district boundaries.[18] The models include representative monthly municipal and industrial demand distributions and explicitly model most larger water users at a representative model demand location or "node." Demands not represented at explicit locations (generally smaller municipalities, unincorporated municipal areas including use from wells, and county-wide industrial uses) were aggregated at the water district scale. Explicitly modeled[19] demands are evaluated at their respective model node locations, with the remaining county demands translated to aggregated water district demands in the hydrologic modeling.

The M&I demands were prepared by ELEMENT for each county using the methodologies described above. The hydrologic modeling consultant, Wilson Water Group, provided a list of the explicitly-modeled M&I water demands and ELEMENT used the following methodology to separate the explicitly-modeled demands from the remainder of the county demands:

- Municipal – The per capita rate of water use and population for each county were calculated using the methodologies described above. For each explicitly modeled water provider with data reported under one of the available sources used in this analysis (1051, WEP, Outreach, or BIP), the reported population for that provider was applied to the county-representative gpcd to calculate the total demands for that provider. These calculated demands were used rather than actual provider-reported demands for the explicitly modeled demands based on input from the TAG and in order to provide a consistent statewide methodology. For explicitly modeled providers with no information available from the data sources used in this analysis, the modeled demands within the current WWG models were used. Where explicit providers' service areas cover multiple counties, ELEMENT created a population-weighted gpcd using the representative gpcd for each county served and the associated population within that county. County aggregate demands were calculated by subtracting the explicitly modeled demands within that county from the total county demand.

- Industrial – All snowmaking, thermoelectric, and hydropower demands, and the majority of large industry demands, are associated with specific industrial users (e.g. at a ski resort or power generating facility); however, some large industry and all energy development demands were calculated at the county-scale. To the extent a specific industrial user was represented in the hydrologic models, its baseline and projected demands were used to for the explicitly modeled demands. The remaining county-level demands were translated to aggregated water district demands in the hydrologic modeling.

ELEMENT reviewed the municipal and industrial monthly demand curves in the existing hydrologic models and found them to be generally representative for statewide modeling purposes.

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[18] Water districts are administrative boundaries used by the Colorado State Engineer's Office, typically aligned with hydrologic boundaries. This is not a reference to a special district water provider.

[19] Specific water provider demands modeled as independent model nodes in the hydrologic modeling.

Section 2: Statewide M&I Results

The updated M&I demands presented below include baseline demands, estimated for the year 2015, and projected future demands for the year 2050 for multiple planning scenarios. It is important to note that these demand projections do not represent drought conditions or associated responses.

2.1 MUNICIPAL

Municipal demands were calculated for each county and then summarized by basin. Water demands for counties that are located in multiple basins were distributed between basins by using the portion of the county population located within each basin to prorate the water demands.

2.1.1 POPULATION

Similar to the SWSI 2010 baseline, approximately 88% of the state lives in one of three basins – the Arkansas, Metro, and South Platte. The Technical Update statewide baseline population, which is based on 2015 population data, is approximately 8% higher than the SWSI 2010 baseline, which used 2008 population as a baseline. However, the increase is less than the amount that SWSI 2010 had projected for the year 2015. While most basins have increased in population between 2008 and 2018, the Gunnison, North Platte, Rio Grande, and Yampa-White have decreased. A basin-level summary is provided in Table 2-1 and Figure 2-1, with more detailed data provided in Section 3 below.

Table 2-1: Current Baseline Population for SWSI 2010 and Technical Update.

(number of people unless otherwise indicated)

Basin	SWSI 2010 Baseline (2008)[a]	SWSI 2010 Projection for 2015[b]	Technical Update Baseline (2015)	
			People	% of Statewide Total
Arkansas	948,000	1,067,000	1,008,434	18.51%
Colorado	307,000	366,000	307,570	5.65%
Gunnison	105,000	125,000	103,121	1.89%
Metro	2,513,000	2,846,000	2,768,126	50.81%
North Platte	1,500	1,600	1,353	0.02%
Rio Grande	50,000	54,000	45,975	0.84%
Republican	see note c	see note c	31,616	0.58%
South Platte	977,000	1,118,000	1,030,138	18.91%
Southwest	105,000	123,000	107,999	1.98%
White	see note d	see note d	6,529	0.12%
Yampa	45,000	53,000	37,194	0.68%
Statewide	5,051,500	5,754,600	5,448,055	100.00%

a) SWSI 2010 Report Table 4-1 (CWCB, 2011a).

b) SWSI 2010 Appendix H, Exhibit 36 (CWCB, 2010a).

c) Republican included in the South Platte total for SWSI 2010 reporting.

d) Yampa and White combined for SWSI 2010 reporting and included here under the Yampa.

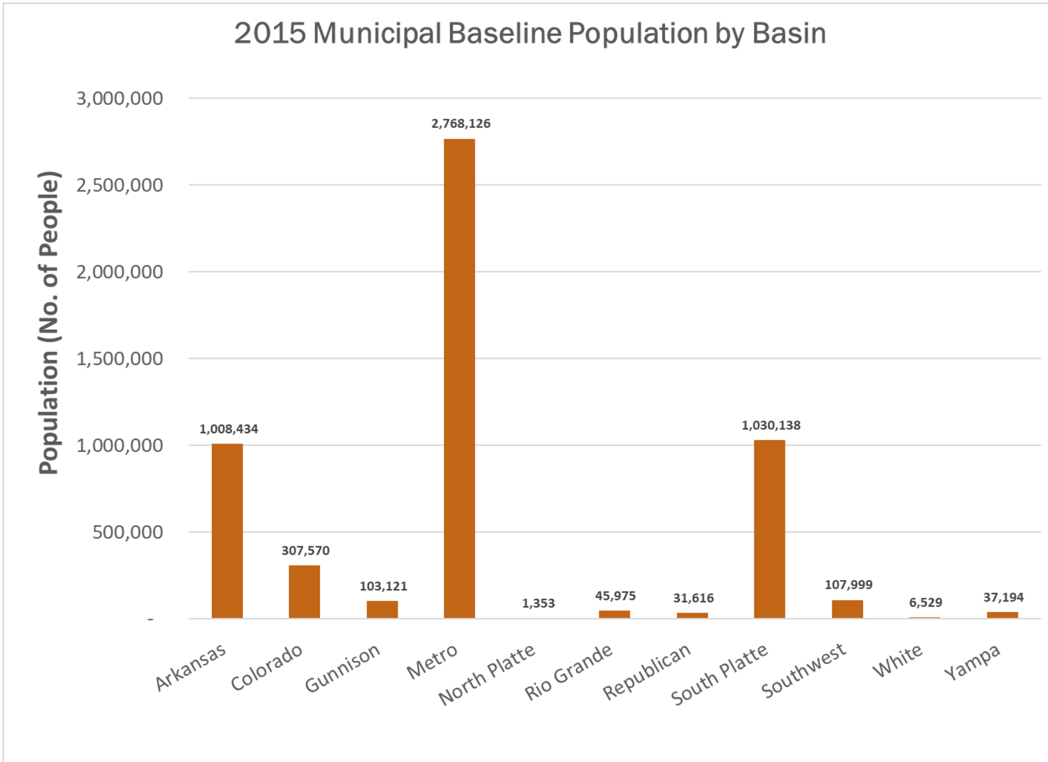

Figure 2-1: SWSI 2015 Municipal Baseline for each Basin.

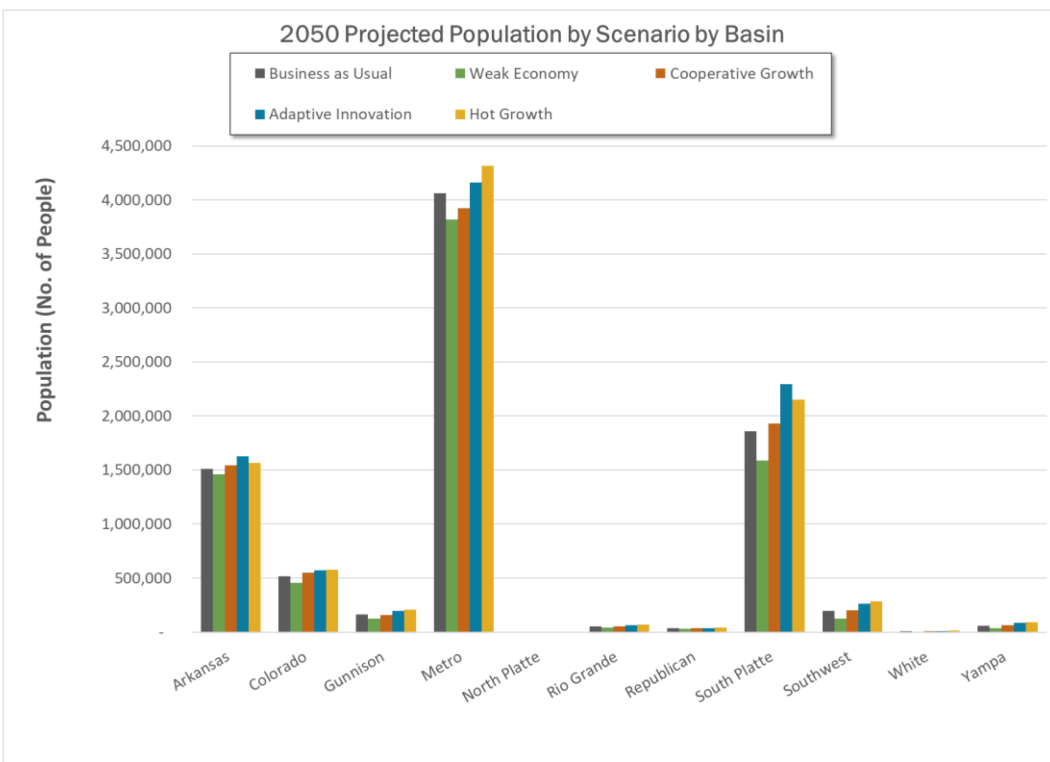

Figure 2-2: Projected Population Summarized by Basin for each Planning Scenario.

Figure 2-2 and Appendix B show the Technical Update population projections for 2050, summarized by basin. Between the years 2015 and 2050, the State of Colorado is projected to grow from approximately 5.5 million to between 7.7 million to 9.3 million in the low and high scenarios, respectively. Using the specific numbers, this is an increase in population of about 41% to 71%.

Figure 2-3 provides a comparison of the population baseline and projections between SWSI 2010 and the Technical Update. Although the Technical Update baseline population is higher than the SWSI 2010 baseline, it is lower than the SWSI 2010 projection for the Technical Update baseline year of 2015. All of the Technical Update planning scenario projections for 2050 anticipate lower population than the SWSI 2010 high population projection. The Technical Update medium growth projection that is used for the Business as Usual and Cooperative Growth scenarios is similar to, within about 2%, the SWSI 2010 Low population projection. The Technical Update high growth projection that is used for the Adaptive Innovation and Hot Growth scenarios is similar to, within about 2%, the SWSI 2010 Medium population projection.

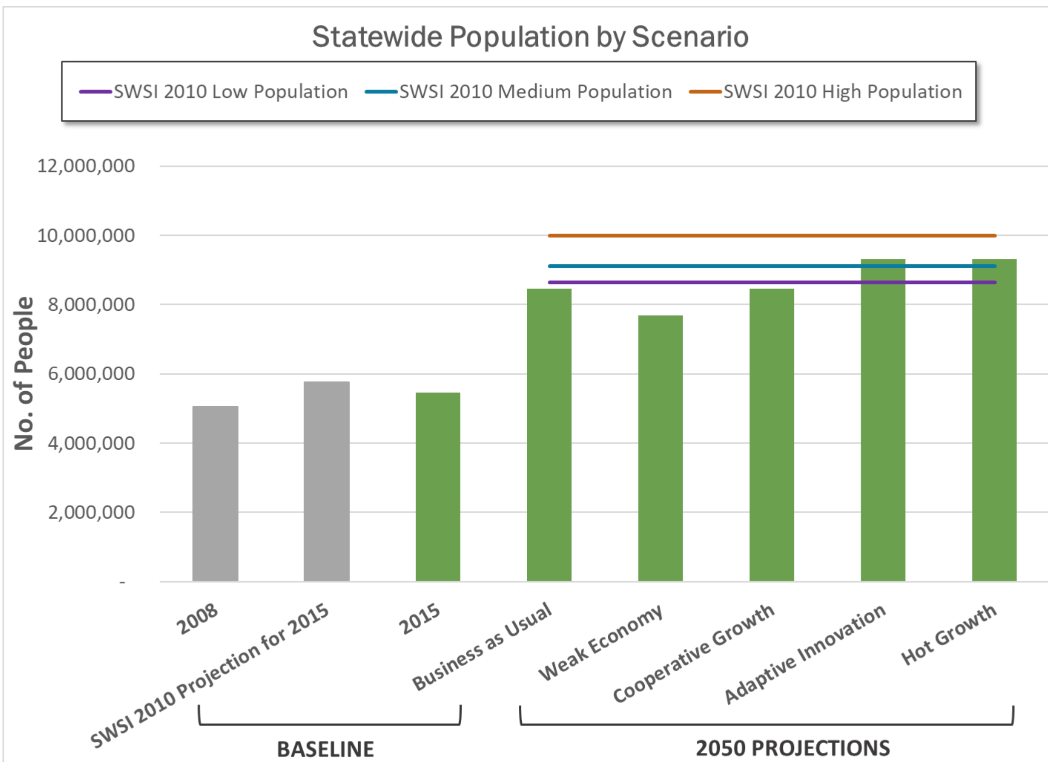

Figure 2-3: Statewide Baseline and Projected Population.

2.1.2 MUNICIPAL DEMANDS

The statewide baseline water demands were largely based on water provider-reported data, with approximately 70% of the baseline population demands represented by 1051 data, 11% from WEPs, 1% from water provider outreach, and 1% from BIP data. This resulted in demands for about 16% of the statewide population having to be estimated, as shown in Figure 2-4.

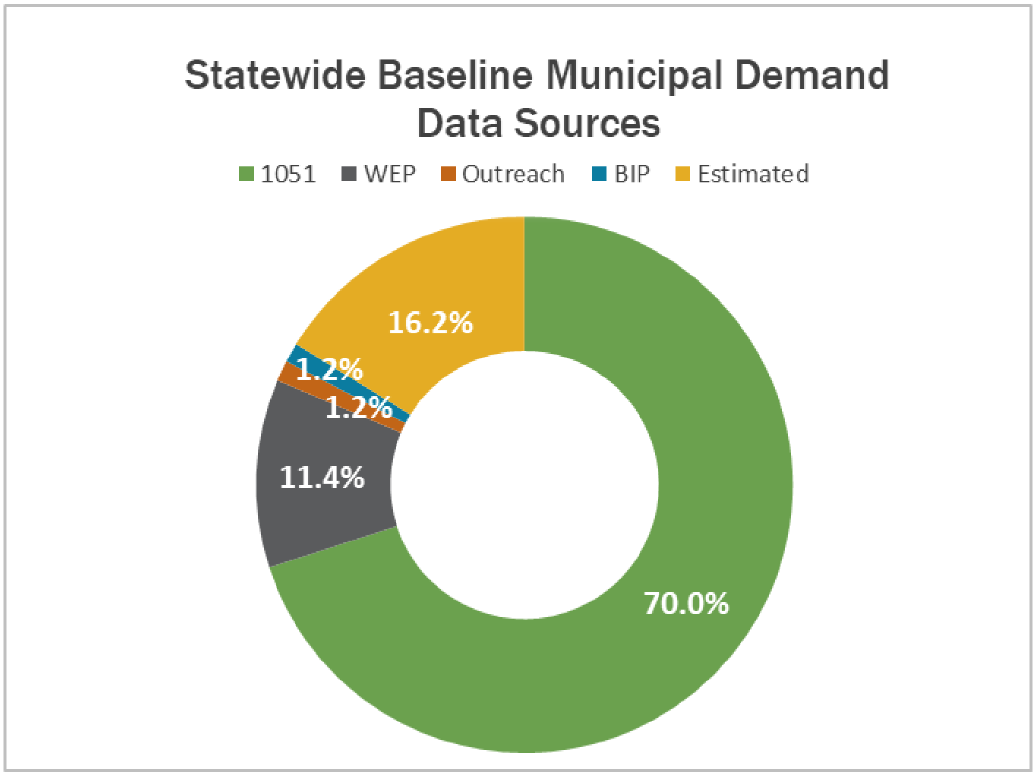

Figure 2-4: Statewide Baseline Municipal Demand Data Sources.

The statewide baseline per capita systemwide demand has decreased from 172 in SWSI 2010 to approximately 164 gpcd, which is nearly a 5% reduction in demands between 2008 and 2015. The reduction is associated with improved data availability, conservation efforts, and ongoing behavioral changes. There are more significant differences from SWSI 2010 at a basin level (Figure 2-5). The differences are largely attributable to updated data, with a significant portion of the state represented by 1051 reporting and updated WEPs.

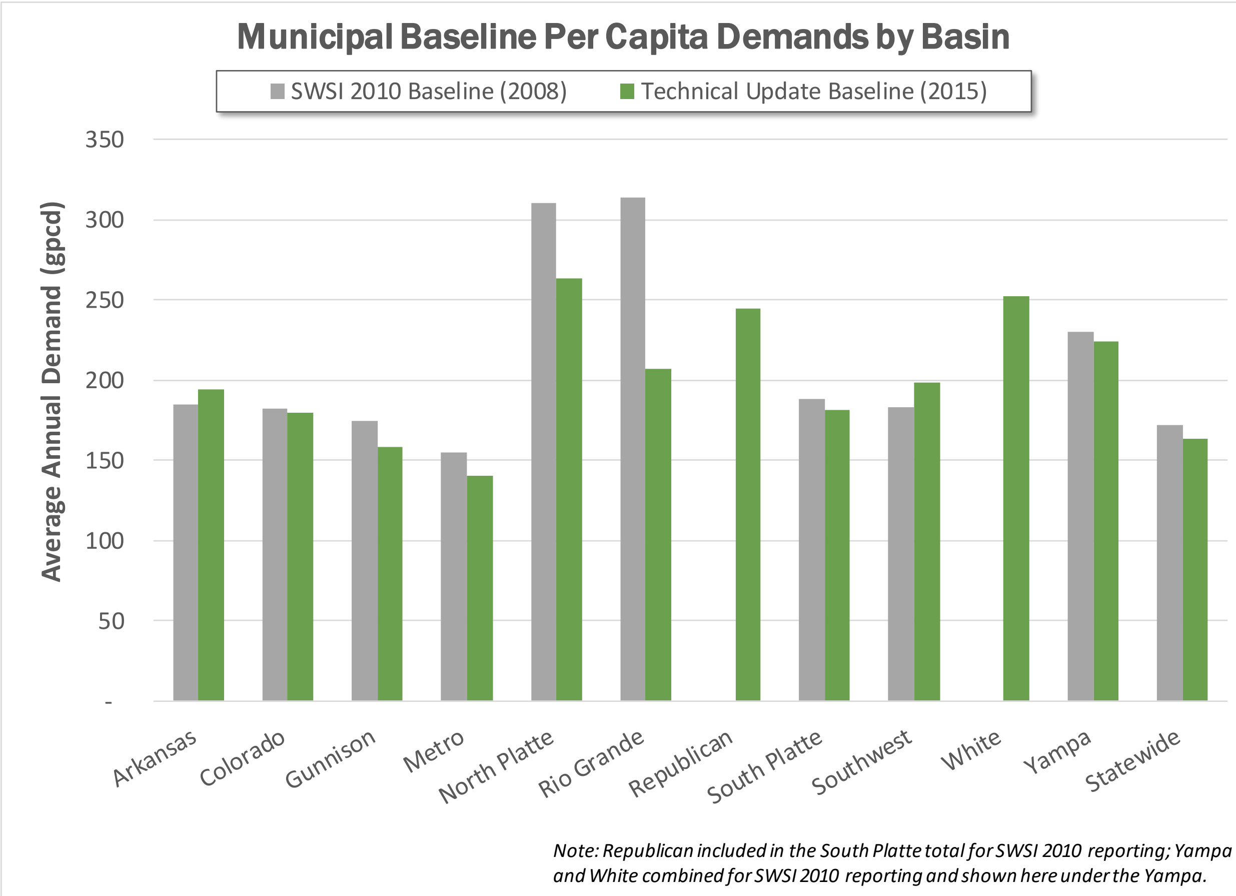

Figure 2-5. Municipal Baseline Per Capita Water Demands.

Table 2-2 below represents baseline and projected per capita demands for basins throughout the state. The Adaptive Innovation planning scenario has the lowest per capita demands and Hot Growth has the highest per capita demands, both statewide and within each basin. On an average statewide basis, all of the Technical Update planning scenario projections of per capita demands are higher than the SWSI 2010 low savings forecasts. Differences in the per-capita driver approaches, the adoption rate methodology, and the influence of climate change all contribute to the Technical Update projections being consistently higher than the SWSI 2010 values. Note that the statewide per capita demand projections do not match the CWP M&I volumetric demand scenario ranking, and they were not intended to do so. For example, the Adaptive Innovation planning scenario results in the lowest per capita demand but coupling this with the highest population projection results in the second highest overall demand volume across the scenar-ios, as further described below.

Table 2-2: Per Capita Demand Projections by Planning Scenario for Each Basin.

Basin	SWSI 2010 [a]				Technical Update					
	Base-line (2008)	Low Savings [b]	Medium Savings [b]	High Savings [b]	Baseline (2015)	Busi-ness as Usual	Weak Econ-omy	Cooper-ative Growth	Adaptive Innova-tion	Hot Growth
Arkansas	185	149	132	119	194	179	179	170	164	192
Colorado	182	148	131	117	179	153	156	145	136	165
Gunnison	174	138	124	113	158	146	149	140	133	160
Metro	155	135	118	106	141	138	135	130	126	148
North Platte	310	253	225	207	264	245	254	242	232	270
Rio Grande	314	254	228	209	207	194	198	188	177	209
Republican	see note "c"				245	236	236	221	214	251
South Platte	188	146	129	116	181	176	174	164	158	190
Southwest	183	124	110	98	198	181	186	173	166	199
White	see note "d"				252	240	254	240	231	269
Yampa	230	179	158	114	224	172	197	161	150	180
Statewide	172	142	126	113	164	157	155	148	143	169

a) SWSI 2010 per capita values from SWSI 2010 Appendix L, Tables 8, 14, 15, and 16 (CWCB, 2011b).

b) 2050 projected demands with passive and active conservation savings included.

c) The Republican Basin demands were included in the South Platte Basin demand reporting for SWSI 2010.

d) The White Basin demands were included with the Yampa Basin demand reporting for SWSI 2010.

Statewide baseline municipal water demands are comprised of approximately 51% indoor, 37% outdoor, and 12% non-revenue water uses, as shown in Figure 2-6. On a statewide average basis, residential indoor demands represent the greatest demand category at 32%, however this varies by basin and by county. Non-revenue water represents the smallest demand category statewide at 12% but varies between basins from approximately 5% to 18%. The 1051 and WEP data are the primary sources of water demand category distribution data.

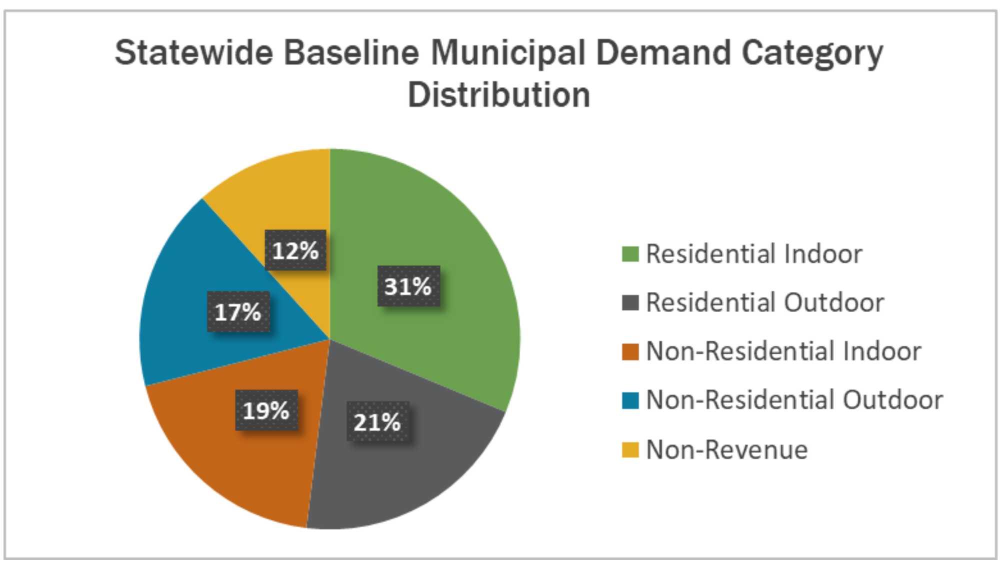

Figure 2-6: Statewide Baseline Municipal Demand Category Distribution.

For each planning scenario, residential indoor demands represent the largest category of water demand, starting at nearly 52 gpcd for the 2015 Baseline on a statewide level. The projected residential indoor demands vary greatly across planning scenarios, from 46 gpcd in the Weak Economy to 36.5 gpcd in the Adaptive Innovation scenario. Other demand categories show less variability across the scenarios, as represented in Figure 2-7. This is influenced by the following projection drivers/methodology:

- The residential indoor demands account for both the gpcd values shown in Table 1-5 and the adoption rate. In other words, the projected rates contemplate that some existing residences will not have adopted water saving technologies by 2050, and therefore the projected rate is slightly higher than the values shown in Table 1-5.

- The Technical Update indoor and outdoor demand driver adjustments, coupled with the adoption rate methodology, generally result in higher per-capita demand projections than the active conservation savings projected in SWSI 2010. **The Technical Update demand projections are not intended to capture the full range of future active conservation potential, as was the intent of SWSI 2010.** Additional future conservation may still be achieved under each planning scenario through identified projects and processes. To that end, basins may still continue to develop water conservation efforts as part of existing and future projects that could further reduce demands.

- The residential indoor driver was the only category that was assigned an absolute gpcd value. Drivers for all other categories were represented as a percent increase/reduction from the baseline.

- The outdoor driver reductions in the Cooperative Growth and Adaptive Innovation scenarios were offset by climate change adjustments.

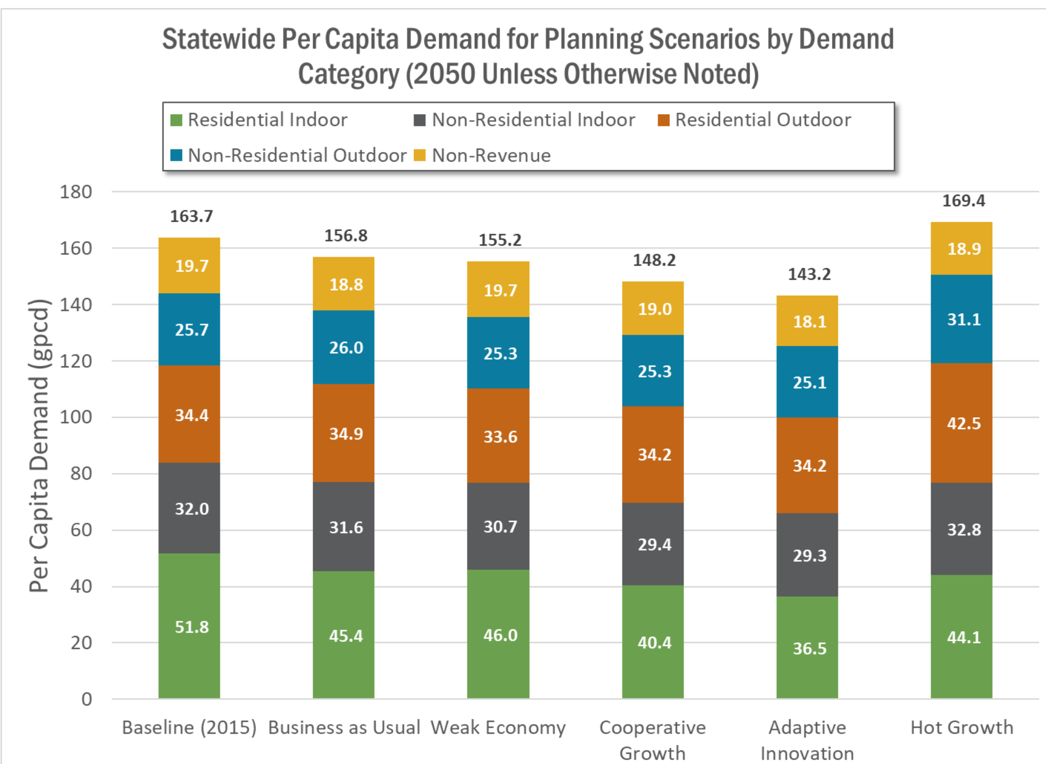

Figure 2-7: Statewide per Capita Demand for Planning Scenarios by Demand Category.

Figure 2-8 depicts the influence of the climate driver on per capita water demands, with outdoor demands increasing by 5 to 10 gpcd with the climate change factors applied. Without the climate change factors, the per capita demand projections range from 135 to 159 gpcd, which exceed the SWSI 2010 projection of 126 gpcd for medium active conservation[20]. On a county scale, the climate change factors increased the outdoor demands by 4% to 22% for the In-Between and 11% to 37% for Hot and Dry adjustments. Although it was impacted by the Hot and Dry climate change factors, Adaptive Innovation still resulted in the lowest per capita demands.

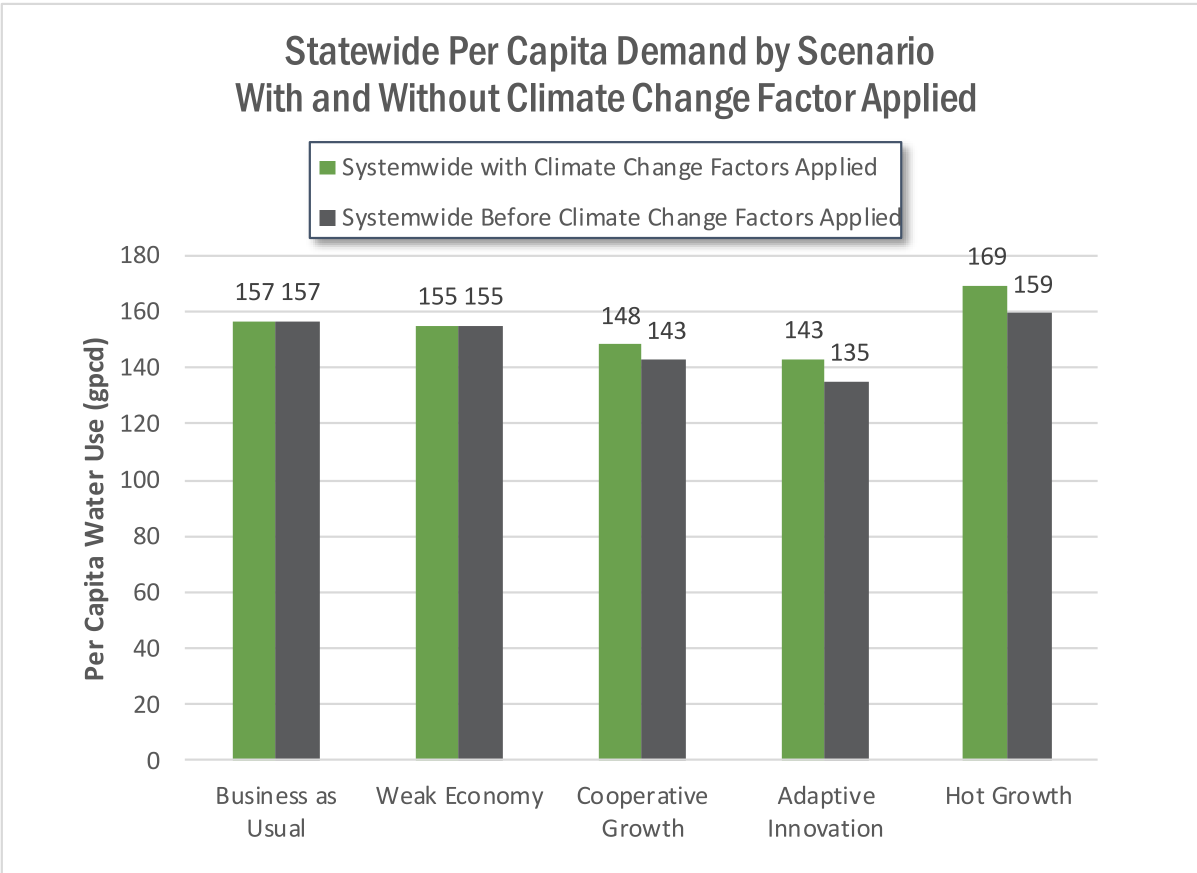

Figure 2-8: Effect of Climate Change Driver on the Statewide Average Per Capita Demand.

The projection scenarios, as described by the CWP, often paired high water demand savings drivers with high population growth or low demand reductions with low growth, resulting in a narrowing of the range in demand projections. There are no scenarios that represent high demand reductions with low growth or low demand reductions with high growth. Table 2-3 presents baseline and projected demands for basins throughout the state, showing the combined effect of population and per capita demands. The volumetric municipal demand projections match the CWP ranking listed in Table 1-3 on a statewide basis and are projected to grow from approximately 1.0 million AFY in 2015 to between 1.34 and 1.77 million AFY in

[20] SWSI 2010 projected per capita demands include savings from passive conservation.

2050. While total statewide demand projections for the five planning scenarios meet the CWP ranking, individual basin results do not.

As shown in Figure 2-9, the Business as Usual and Cooperative Growth scenarios both use the medium population projection on a statewide basis, with different distributions between counties. Similarly, the Adaptive Innovation and Hot Growth scenarios both use the high population projection on a statewide basis, with different distributions between counties. As previously noted, the CWP rankings limited the extent to which the per capita drivers could be adjusted to reflect future demand reductions. The influence of the population is so significant that the demand projections for all scenarios aside from the Hot Growth, which has the high population coupled with climate change, are relatively similar. For example, the Adaptive Innovation scenario has the greatest reductions in per capita demand but is paired with both the highest population and the Hot and Dry climate. Applying much additional reduction in the Adaptive Innovation per capita demand values would result in the Business as Usual scenario projections exceeding the Adaptive Innovation scenario. Similarly, much additional reduction in the Cooperative Growth per capita demands would result in the Weak Economy scenario projections exceeding the Cooperative Growth scenario. To some extent, the scenario rankings precluded evaluating the potential for future demand management activities, such as lower water demand landscapes, to further offset the effects of climate change. These types of activities should be further considered for local or basin-level planning.

Table 2-3. Statewide Municipal Baseline and Projected Volumetric Demands by Basin (AFY).

Basin	Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Arkansas	219,208	303,352	293,842	294,540	298,095	337,222
Colorado	61,790	88,589	79,886	88,984	87,534	106,578
Gunnison	18,262	26,674	20,509	24,887	29,142	36,789
Metro	435,745	626,501	578,969	570,151	586,176	715,885
North Platte	400	351	301	328	355	441
Rio Grande	10,639	11,947	9,370	11,000	12,496	15,732
Republican	8,666	9,361	8,019	8,323	9,208	11,524
South Platte	208,842	365,716	309,615	354,319	404,554	457,803
Southwest	24,009	39,810	26,214	38,864	49,164	62,851
White	1,845	1,980	1,203	1,875	2,737	3,405
Yampa	9,324	11,552	7,580	11,418	14,471	18,511
Statewide	998,730	1,485,833	1,335,508	1,404,688	1,493,931	1,766,740

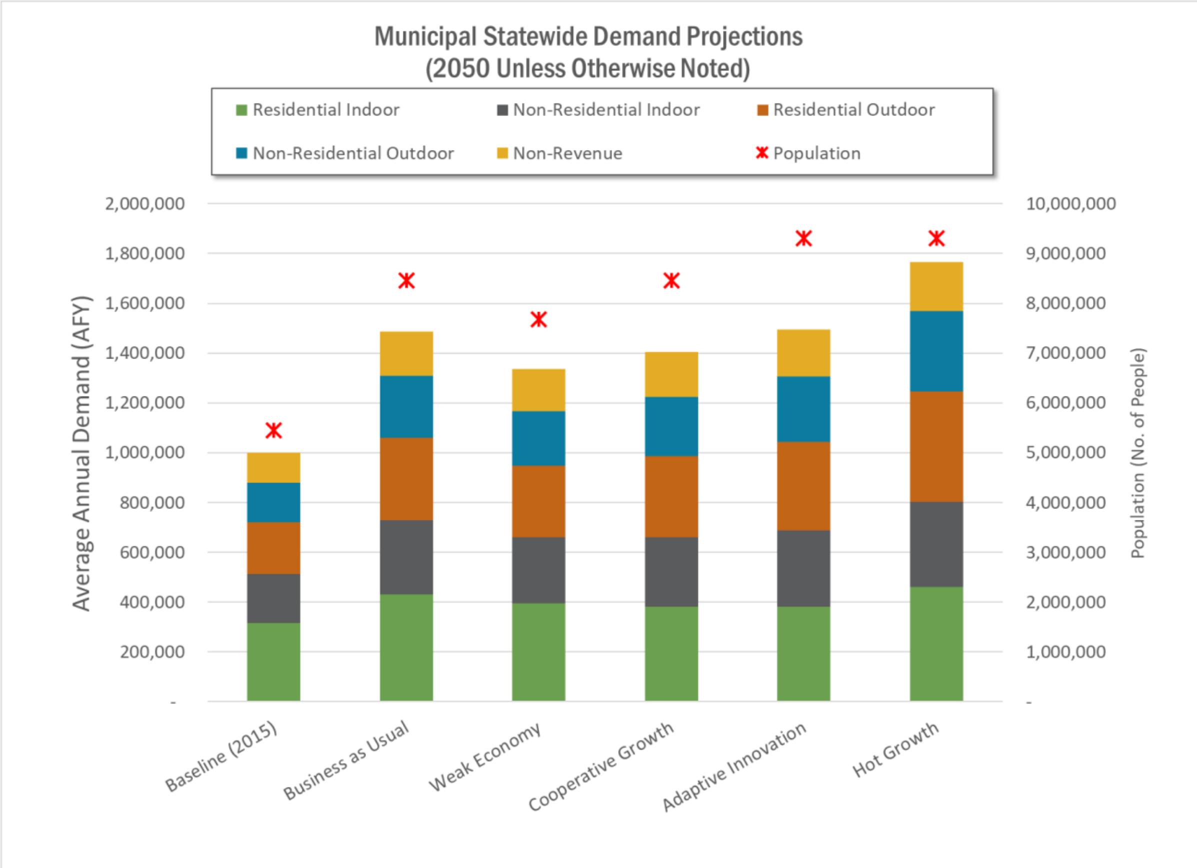

Figure 2-9. Statewide Baseline and Projected Population and Municipal Demands.

Figure 2-10 provides a comparison of the Technical Update results with the SWSI 2010 projected demands for 2050. As previously described, it is challenging to directly compare the municipal demand projections due to differences in the methodologies. The SWSI 2010 projections selected for Figure 2-10 are intended to show a range of the spread in the SWSI 2010 projections relative to the Technical Update projections. For SWSI 2010, the passive savings methodology that was included with low, medium, and high population projections was different from the Technical Update methodology that uses an adoption rate. Therefore, the SWSI 2010 low, medium, and high projections that incorporated passive savings are provided for comparison, along with the SWSI 2010 high projection that had no passive or active conservation savings as the highest demand projection from SWSI 2010. The low, medium, and high level of active conservation savings potential that was evaluated in SWSI 2010 was only prepared for the medium population projection. The SWSI 2010 medium active savings potential, which includes the passive savings, with the SWSI 2010 medium population projection is provided in Figure 2-10 as an example of the level of active savings that was considered. The Technical Update demand projections for all planning scenarios fall within the spread of the SWSI 2010 high population demands with passive conservation savings and the SWSI 2010 medium population growth with passive and high active conservation savings. This result was anticipated with the Technical Update methodology, considering that the updated projections represent potential demands under conditions described for each scenario and do not necessarily represent the full potential for demand management under each scenario.

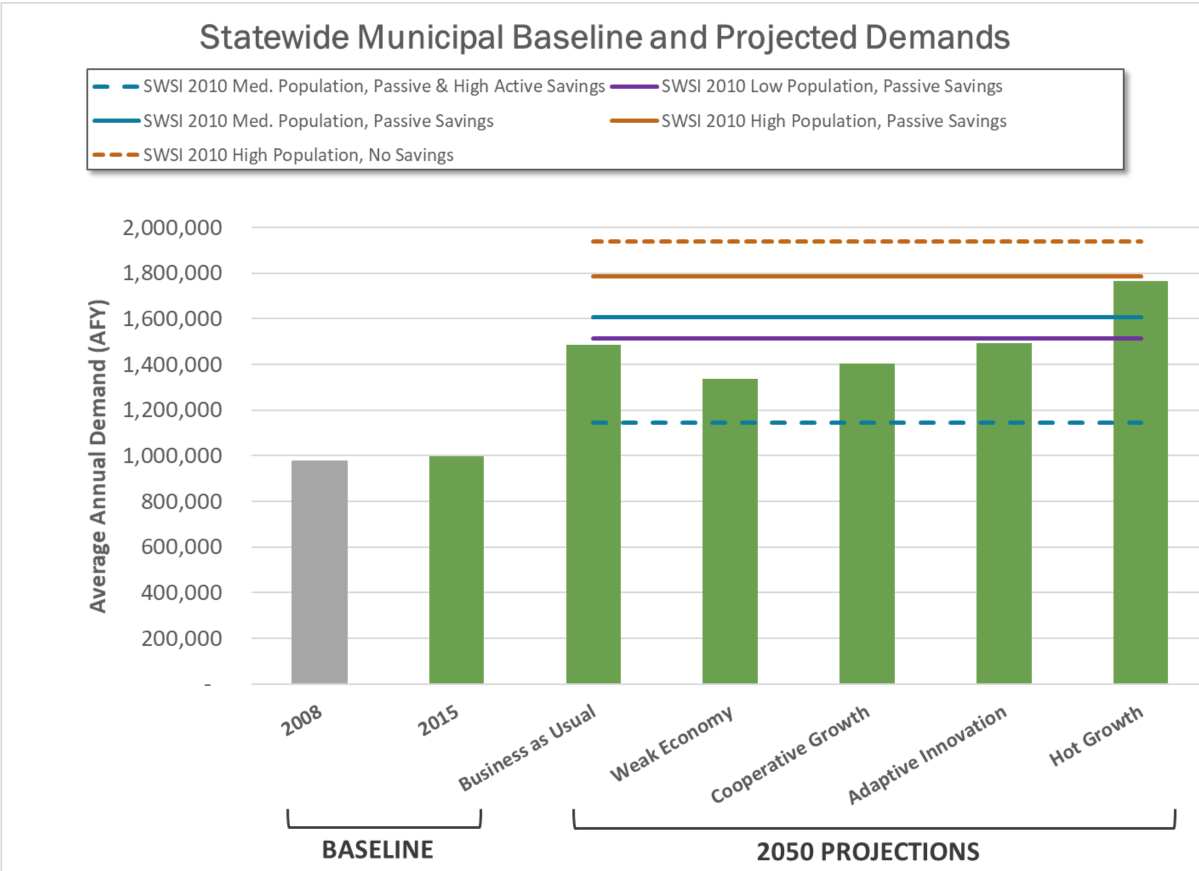

Figure 2-10: Statewide Municipal Baseline and Projected Volumetric Demands.

2.2 INDUSTRIAL

As with municipal, the updated industrial demands presented herein include both baseline demands (estimated as 2015 demands) and future demands for multiple planning scenarios (estimated as 2050 demands). These demand projections do not include drought conditions or associated responses. Industrial demands were calculated at the county level and then summarized by basin. No county-level industrial demands had to be distributed between multiple basins.

Statewide baseline industrial water demands are comprised of approximately 64% large industry, 3% snowmaking, 30% thermoelectric, and 3% energy development, as shown in Figure 2-11.

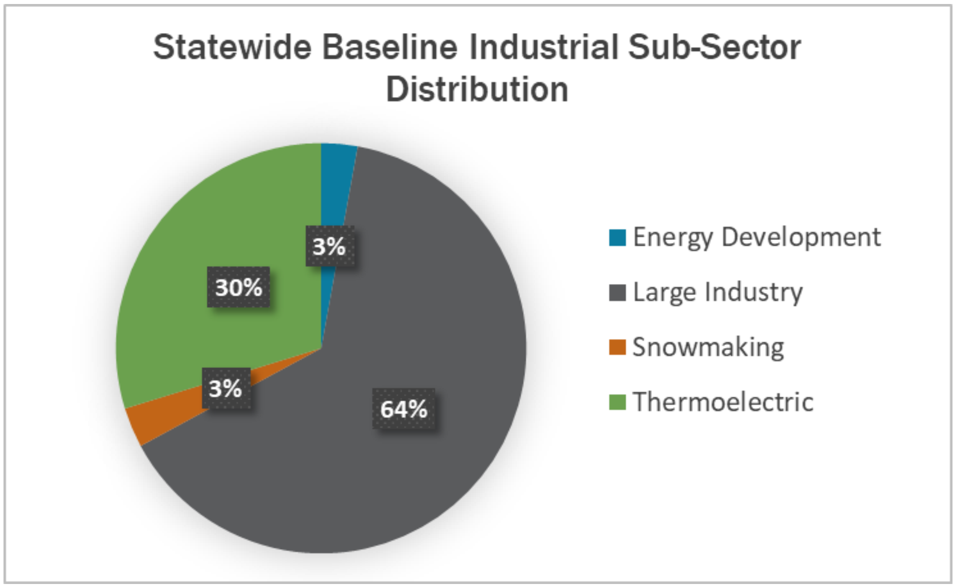

Figure 2-11: Statewide Baseline Industrial Sub-Sector Distribution.

The projected demands for all planning scenarios were compared with the SWSI 2010 projected demands for 2050. With the exception of the Hot Growth scenario, the updated demand projections for all planning scenarios were below the SWSI 2010 range, as shown on Figure 2-12. This is primarily related to changes in assumptions for thermoelectric demands. The thermoelectric baseline has decreased relative to SWSI 2010 largely due to regulations that require an increase in power generation from renewable sources, per M&I TAG participants. SWSI 2010 also assumed thermoelectric demands would increase by 5%, 25%, and 50% under Low/Medium/High scenarios, respectively; however, the TAG indicated that slightly varying demands by scenario up to +/- 10% would be more appropriate. Thermoelectric accounts for a large component of total industrial demand (Figure 2-11), therefore, the methodology changes had a relatively large effect on the results. Large industry, snowmaking, and energy development projections are generally comparable to the ranges projected in SWSI 2010.

The industrial demand projections do not match the CWP ranking listed in Table 1-3 on a statewide basis. The Business as Usual and Adaptive Innovation rankings were flipped as compared to the municipal projections. However, as with the municipal demand projections, there is little variation in the projections aside from the Hot Growth scenario.

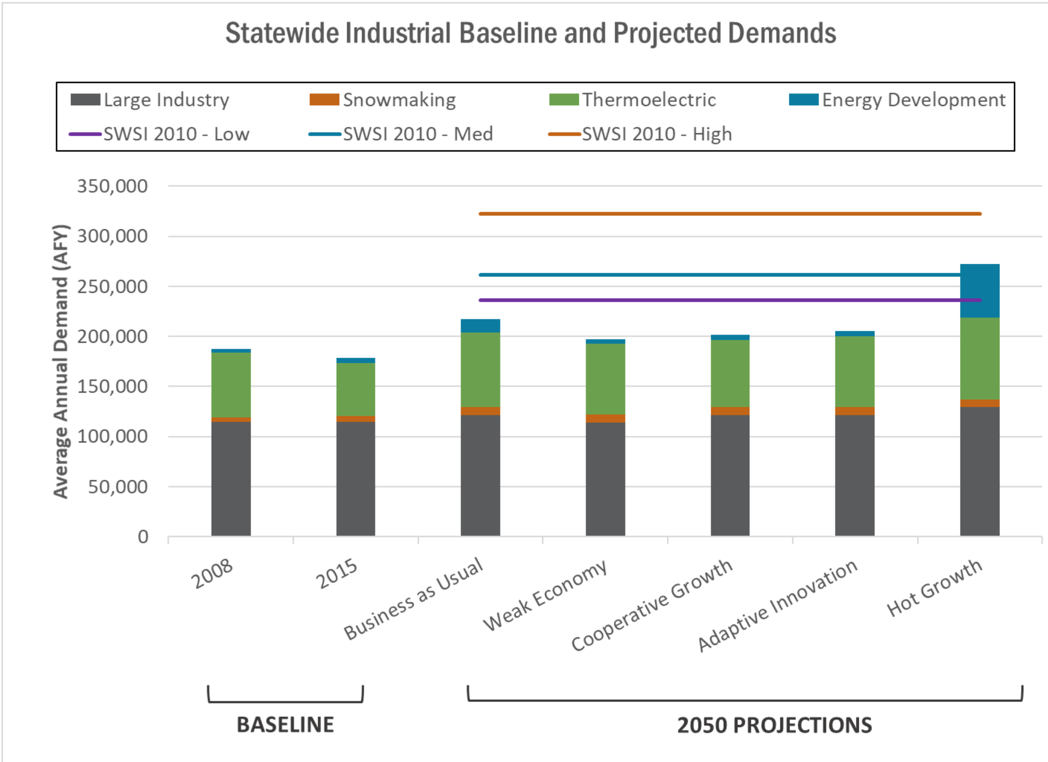

Figure 2-12: Industrial Statewide Baseline and Projected Demands.

2.3 TOTAL M&I DEMANDS

Total statewide M&I demands projected for 2050 range from approximately 1.5 million AFY (Weak Economy) to 2.0 million AFY (Hot Growth). The Hot Growth projected demands are just under the SWSI 2010 projected high demands of 2.1 million AFY, which included high growth with passive savings municipal demands combined with high industrial demand projections. The Weak Economy projected demands fall significantly under the SWSI 2010 projected low demands of 1.7 million AFY, which included low growth with passive savings municipal demands combined with low industrial demand projections[21].

Figure 2-13 Table 2-3 represent statewide municipal and industrial baseline 2015 and projected 2050 water demands for the planning scenarios. For all basins except for the Yampa, municipal demands exceed the industrial demands for every planning scenario. Statewide, industrial demands are around 15% to 18% of the municipal demands.

As discussed in Section 1.1.2, the CWP rankings were the guiding objective in the preparation of average annual statewide volumetric demands. Statewide municipal projections followed the CWP rankings; however, industrial and combined M&I demands deviated to a limited degree, with the Business as Usual demands exceeding the Adaptive Innovation demands. Preliminary municipal demands were prepared with an outdoor per capita reduction of 10%, which resulted in combined M&I demands for the Adaptive Inno-

[21] Table 4-9 Summary of M&I and SSI Demands for Each Basin and Statewide, SWSI 2010 (CWCB, 2011a).

vation scenario being ranked higher than Business as Usual and meeting the CWP ranking guideline. However, based on review of the initial results and peer review by members of the TAG, the outdoor savings factor was adjusted to -20% to better reflect the narrative guidance in the CWP and potential range of achievable future savings. The resulting statewide M&I demands for the Business as Usual and Adaptive Innovation scenarios vary by approximately 3,700 AFY (0.2%); therefore, were determined to be sufficiently representative of the CWP rankings.

These results show that the Business as Usual and Adaptive Innovation scenario futures may be similar, which indicates innovative demand management measures have the potential to significantly offset the higher population and much warmer climate in the Adaptive Innovation scenario. The potential effects of demand management are also demonstrated by comparing the Adaptive Innovation and Hot and Dry scenarios. Both use a high population, although distributed differently across counties, with Hot and Dry climate, yet the Adaptive Innovation scenario has approximately 300,000 AFY less demand.

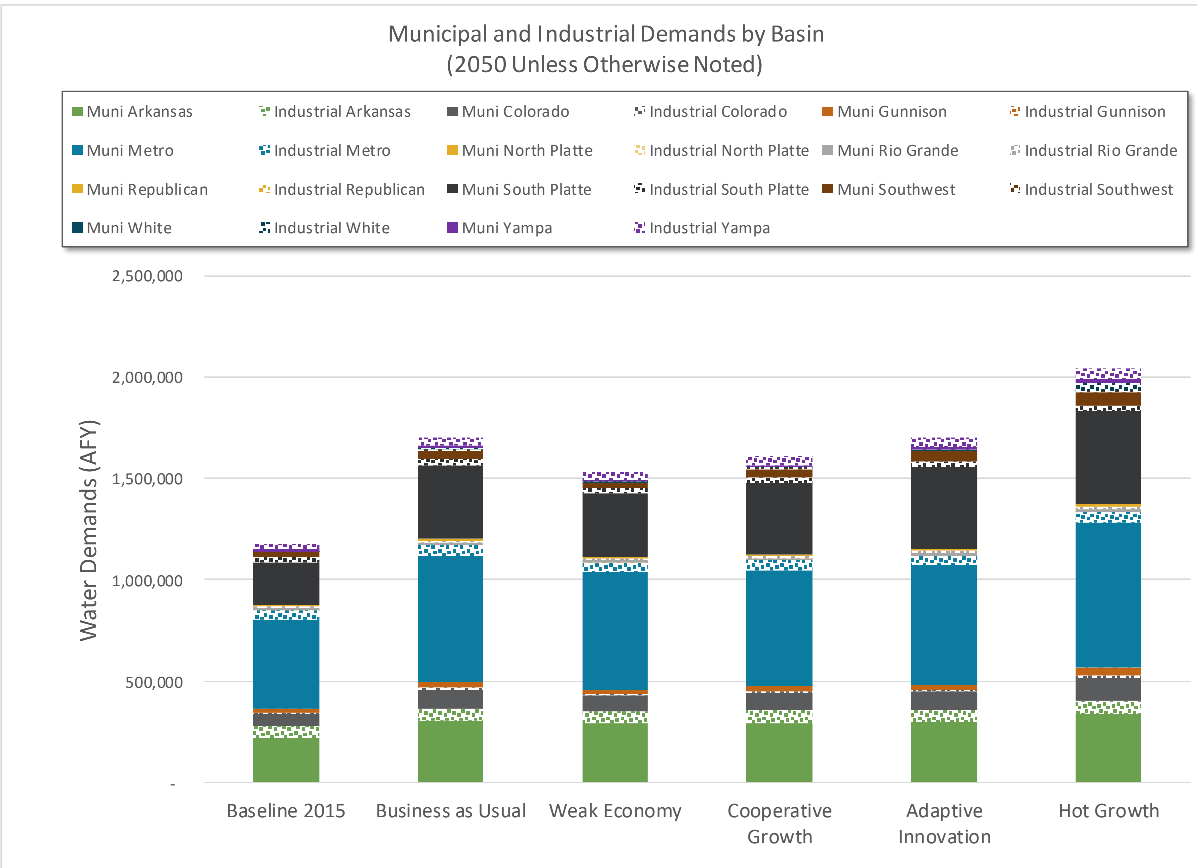

Figure 2-13. Municipal and Industrial Baseline and Projected M&I Demands by Basin.

Table 2-4: Summary of M&I Demands for Each Basin and Statewide (AFY)

Basin	Demand Type	Baseline 2015	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Arkansas	Municipal	219,208	303,352	293,842	294,540	298,095	337,222
	Industrial	58,720	61,720	56,160	60,490	61,100	67,890
	Total	277,928	365,072	350,002	355,030	359,195	405,112
Colorado	Municipal	61,790	88,589	79,886	88,984	87,534	106,578
	Industrial	7,840	12,290	7,620	7,790	7,790	18,460
	Total	69,630	100,879	87,506	96,774	95,324	125,038
Gunnison	Municipal	18,262	26,674	20,509	24,887	29,142	36,789
	Industrial	270	650	650	650	650	650
	Total	18,532	27,324	21,159	25,537	29,792	37,439
Metro	Municipal	435,745	626,501	578,969	570,151	586,176	715,885
	Industrial	48,670	48,670	48,520	48,370	48,520	48,980
	Total	484,415	675,171	627,489	618,521	634,696	764,865
North Platte	Municipal	400	351	301	328	355	441
	Industrial	-	-	-	-	-	-
	Total	400	351	301	328	355	441
Rio Grande	Municipal	10,639	11,947	9,370	11,000	12,496	15,732
	Industrial	7,860	9,860	8,960	9,860	9,860	10,760
	Total	18,499	21,807	18,330	20,860	22,356	26,492
Republi-can	Municipal	8,666	9,361	8,019	8,323	9,208	11,524
	Industrial	-	-	-	-	-	-
	Total	8,666	9,361	8,019	8,323	9,208	11,524
South Platte	Municipal	208,842	365,716	309,615	354,319	404,554	457,803
	Industrial	23,530	29,550	27,760	27,290	28,420	32,470
	Total	232,372	395,266	337,375	381,609	432,974	490,273
Southwest	Municipal	24,009	39,810	26,214	38,864	49,164	62,851
	Industrial	2,280	4,330	4,140	3,940	4,140	4,720
	Total	26,289	44,140	30,354	42,804	53,304	67,571
White	Municipal	1,845	1,980	1,203	1,875	2,737	3,405
	Industrial	1,600	5,800	3,000	3,000	3,000	37,900
	Total	1,845	7,780	4,203	4,875	5,737	41,305
Yampa	Municipal	9,324	11,552	7,580	11,418	14,471	18,511
	Industrial	28,040	44,010	40,650	39,990	41,600	50,380
	Total	38,964	55,562	48,230	51,408	56,071	68,891
Statewide	Municipal	998,730	1,485,833	1,335,508	1,404,688	1,493,931	1,766,740
	Industrial	178,810	216,880	197,460	201,380	205,080	272,210
	Total	1,177,540	1,702,713	1,532,968	1,606,068	1,699,011	2,038,950

Section 3: Basin M&I Results

The Technical Update M&I results in the following sections are summarized by river or planning (Southwest and Metro) basin. Figure 3-1 depicts the counties located within each basin. Note that some counties are located in multiple basins.

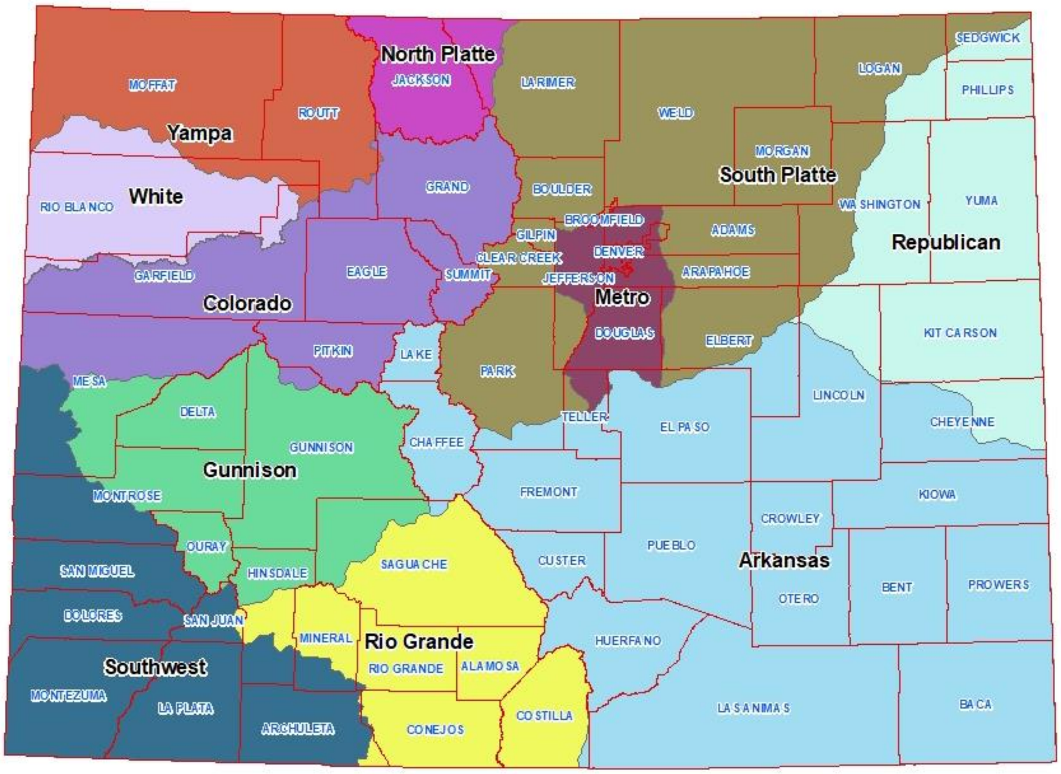

Figure 3-1: Colorado County and Basin Boundaries

3.1 ARKANSAS BASIN

3.1.1 MUNICIPAL

3.1.1.1 POPULATION

The Arkansas Basin currently includes about 19% of the statewide population. Between the years 2015 and 2050, it is projected to grow from approximately 1.0 million to between 1.46 million and 1.63 million people in the low and high growth scenarios, respectively. Using the specific numbers, this is an increase in population of 45% to 61%.

Table 3-1 shows how population growth is projected to vary across counties under each planning scenario. While the basin as a whole is projected to increase in population under all scenarios, 7 of the 18 counties are projected to decrease under all scenarios. The two most populous counties, El Paso County followed by Pueblo County, are projected to account for most of the growth and remain the largest population centers in the basin. Elbert County, which currently has about 1% of the basin population, is projected to have the highest growth rate for an individual county, ranging from about 154% to 179% increase in the low and high growth scenarios, respectively. Even with this large percentage increase, Elbert County is still projected to account for only about 1% of the future total basin population. Note that Cheyenne, Elbert, Lincoln, and Teller Counties are split between multiple basins, with the county demands prorated between basins based on the population located within each basin. This approach is consistent with prior SWSI analyses.

Table 3-1: Arkansas Basin 2015 Baseline and 2050 Projected Populations by County.

County	Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Baca	3,594	2,949	2,858	2,790	2,868	3,063
Bent	5,847	6,607	6,403	6,252	6,426	6,863
Chaffee	18,603	27,145	26,306	25,686	26,403	28,197
Cheyenne*	686	615	596	582	599	639
Crowley	5,569	7,754	7,514	7,337	7,542	8,055
Custer	4,457	5,934	5,751	5,615	5,772	6,164
El Paso	676,178	1,076,486	1,043,223	1,116,517	1,177,637	1,118,209
Elbert*	7,634	20,526	19,891	19,422	19,964	21,321
Fremont	46,659	56,406	54,663	53,373	54,864	58,592
Huerfano	6,456	5,983	5,798	5,661	5,819	6,215
Kiowa	1,396	1,193	1,156	1,129	1,160	1,239
Lake	7,502	9,868	9,563	9,337	9,598	10,250
Las Animas	14,061	13,249	12,840	12,537	12,887	13,763
Lincoln*	4,485	6,857	6,645	6,488	6,669	7,123
Otero	18,265	15,302	14,829	14,479	14,884	15,895
Prowers	11,905	11,441	11,087	10,826	11,128	11,884
Pueblo	163,196	224,184	217,257	230,283	245,249	232,873
Teller*	11,941	16,964	16,440	16,052	16,501	17,622
Basin Total	1,008,434	1,509,463	1,462,821	1,544,367	1,625,970	1,567,968

*Counties with population located in multiple basins. This table represents the portion of the county located in the Arkansas Basin.

The Arkansas Basin baseline for the Technical Update, which is based on 2015 population, is approximately 6% higher than the SWSI 2010 baseline, which used 2008 population. The SWSI 2010 medium growth population projection for 2050 exceeded the Technical Update population projections for all planning scenarios by between about 4% and 15%. High growth in the Technical Update Adaptive Innovation is the only population projected to exceed the SWSI 2010 low growth projection. A comparison of the baseline and projected populations for the Technical Update and SWSI 2010 are shown in Figure 3-2.

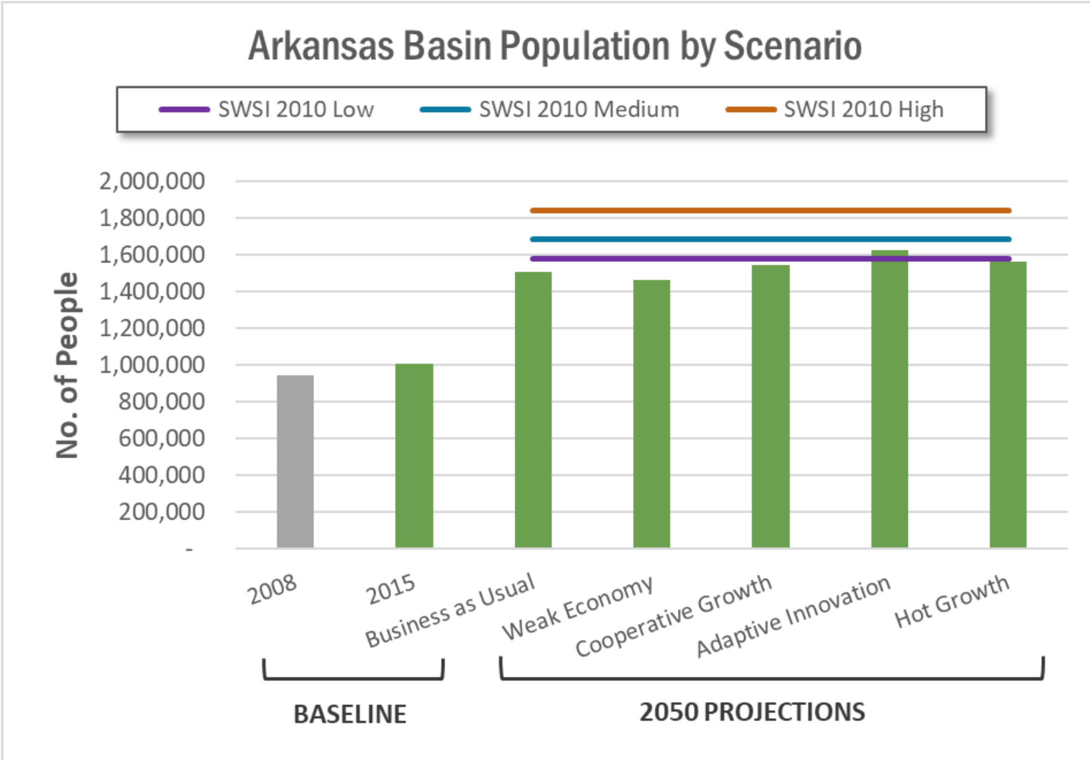

Figure 3-2: Arkansas Basin Baseline and Projected Population.

3.1.1.2 WATER DEMANDS

The Arkansas Basin baseline water demands were largely based on water provider-reported data, with approximately 67% of the baseline population demands represented by 1051 data, 8% from WEPs, and 4% from water provider outreach, requiring demands for about 21% of the basin's baseline population to be estimated, as shown in Figure 3-3.

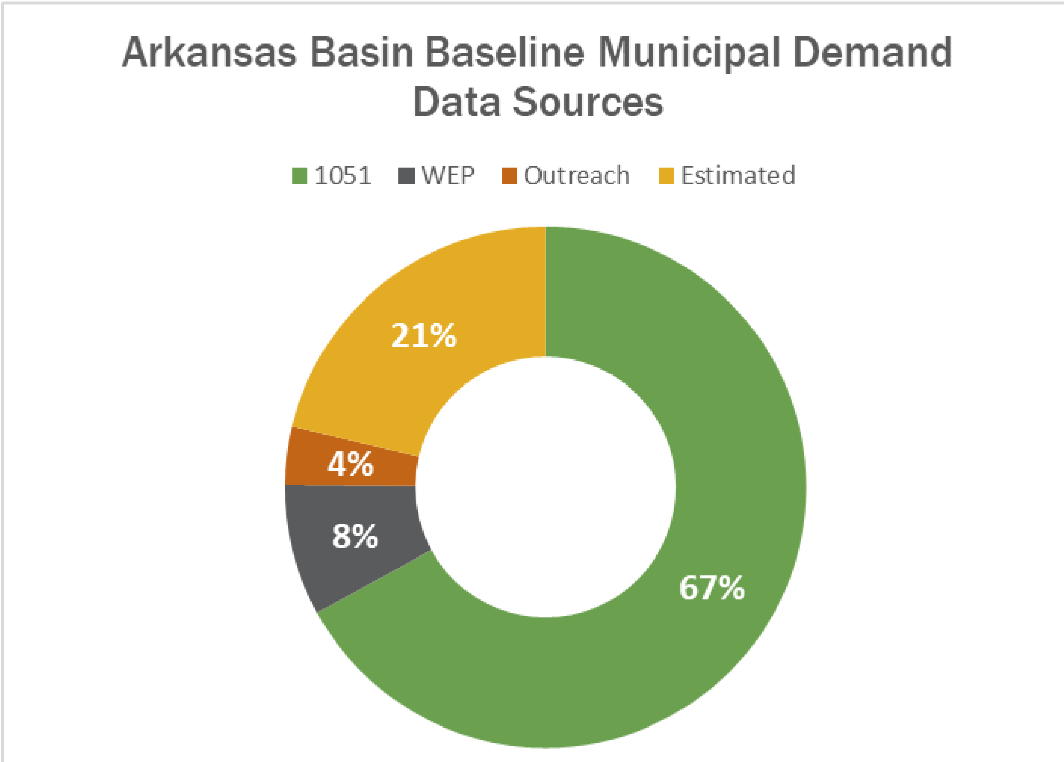

Figure 3-3: Arkansas Basin Baseline Municipal Water Demand Data Sources.

The Arkansas Basin average baseline per capita systemwide demand has increased from 185 gpcd in SWSI 2010 to approximately 194 gpcd. There are more significant differences from SWSI 2010 at a county level. The differences are largely attributable to updated data, with a significant portion of the basin represented by 1051 reporting and updated WEPs. Some counties include a significant amount of raw and reuse water supplies reported for the Technical Update, which may not have been quantified and included in the SWSI 2010 water use data. Table 3-2 represents baseline and projected per capita demands for counties within the basin.

Table 3-2: Arkansas Basin Municipal Baseline and Projected Per Capita Demands by County (gpcd).

County	SWSI 2010 Baseline [a]	Technical Update Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Baca	329	296	279	286	272	259	294
Bent	113	198	189	190	183	175	202
Chaffee	297	167	163	162	156	150	175
Cheyenne*	183	222	216	218	207	199	229
Crowley	141	208	196	197	188	180	210
Custer	226	167	163	163	156	150	175
El Paso	172	147	138	137	129	124	148
Elbert*	111	137	138	135	128	124	149
Fremont	219	152	151	151	146	140	162
Huerfano	155	204	197	199	191	183	209
Kiowa	325	436	401	414	391	370	421
Lake	183	174	169	169	162	156	181
Las Animas	221	227	216	219	210	201	230
Lincoln*	254	238	222	222	211	203	238
Otero	185	216	208	211	203	194	220
Prowers	232	236	225	228	219	210	240
Pueblo	206	397	383	387	370	356	407
Teller*	173	163	159	159	152	146	171
Basin Total	185	194	179	179	170	164	192

a) SWSI 2010 per capita values from SWSI 2010 Appendix H, Table 3-1 (CWCB, 2010a).

**Counties with population located in multiple basins. Per capita demand is calculated at a county level.*

The Arkansas Basin baseline municipal water demands are comprised of approximately 51% indoor, 31% outdoor, and 18% non-revenue water uses, as shown in Figure 3-4. With nearly 80% of the population represented through 1051, WEPs, and water provider outreach, the basin average demand category distribution was well informed. Still, only 6 of the 18 counties had sufficient demand category data available to apply a county-specific distribution. The basin average demand category distribution was used for the remaining counties. On a basin scale, the residential outdoor demand as a percentage of the systemwide demands is one of the lowest reported throughout the state, at approximately 17%. Conversely, the baseline non-revenue water demand is one of the highest statewide, at approximately 18% of the systemwide demands.

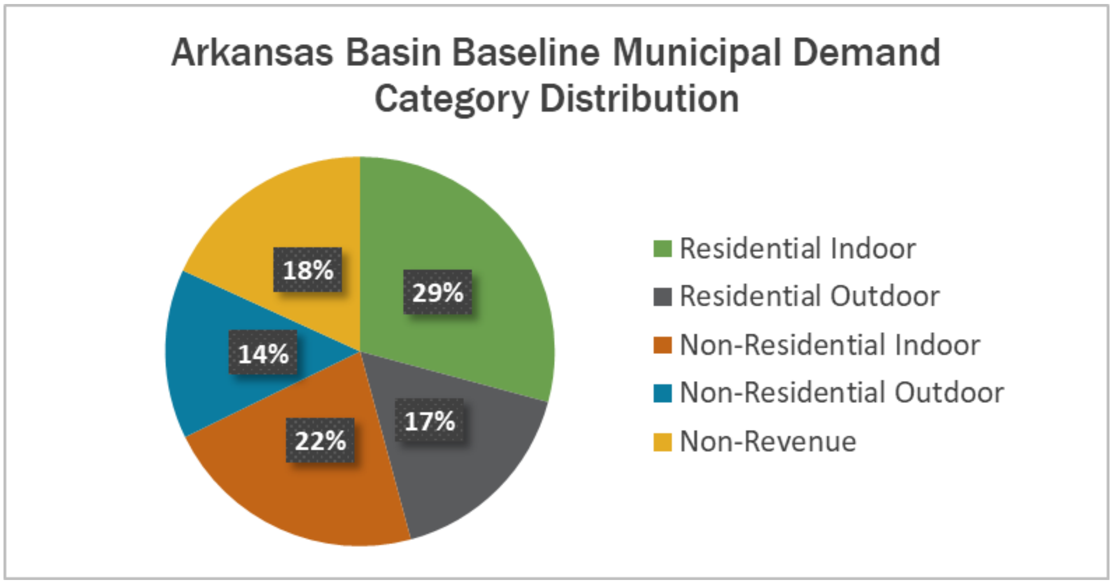

Figure 3-4: Arkansas Basin Baseline Municipal Demand Category Distribution.

Figure 3-5 provides a summary of per capita baseline and projected water demands for the Arkansas Basin. Systemwide, all of the projected per capita demands decrease relative to the baseline. The Hot Growth scenario is nearly as high as the baseline, with lower residential indoor but higher residential and non-residential outdoor demands that are significantly influenced by the climate driver. Consistently across all scenarios, residential indoor demand is the greatest individual demand category while non-residential outdoor is the lowest. Aside from the Hot Growth scenario, there is minimal variation in outdoor demands between scenarios. This is due to the scenario pairing of water demand reductions and climate drivers, particularly for the Adaptive Innovation scenario which has high outdoor reductions coupled with the “Hot and Dry” climate. Outdoor demands increased significantly for the Hot Growth scenario, largely due to the influence of the “Hot and Dry” climate.

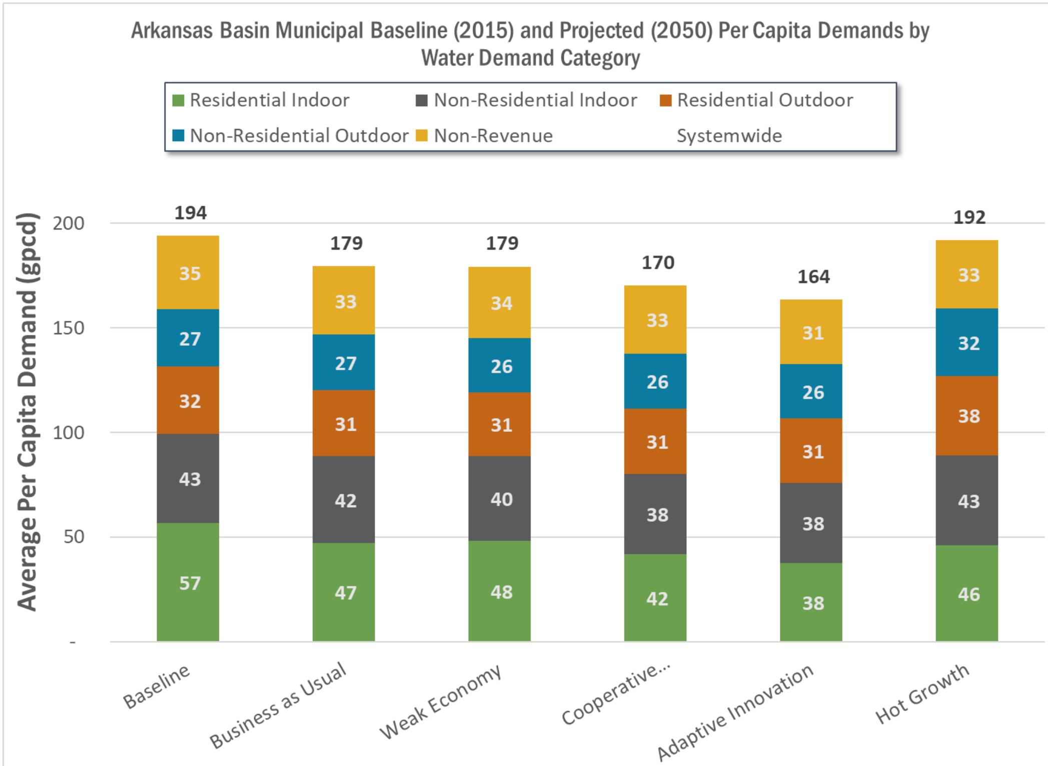

Figure 3-5: Arkansas Basin Municipal Baseline and Projected Per Capita Demands by Water Demand Category.

Figure 3-6 demonstrates the influence of the climate driver on per capita water demands, with outdoor demands increasing by 6 to 10 gpcd with the climate change factors applied. Without the climate change factors, the per capita demand projections range from 156 to 182 gpcd, which exceed the SWSI 2010 projection of 132 gpcd for medium population with active conservation[22]. This is partly due to the Technical Update baseline per capita demand exceeding the SWSI 2010 baseline.

[22] SWSI 2010 projected per capita demands include savings from passive conservation.

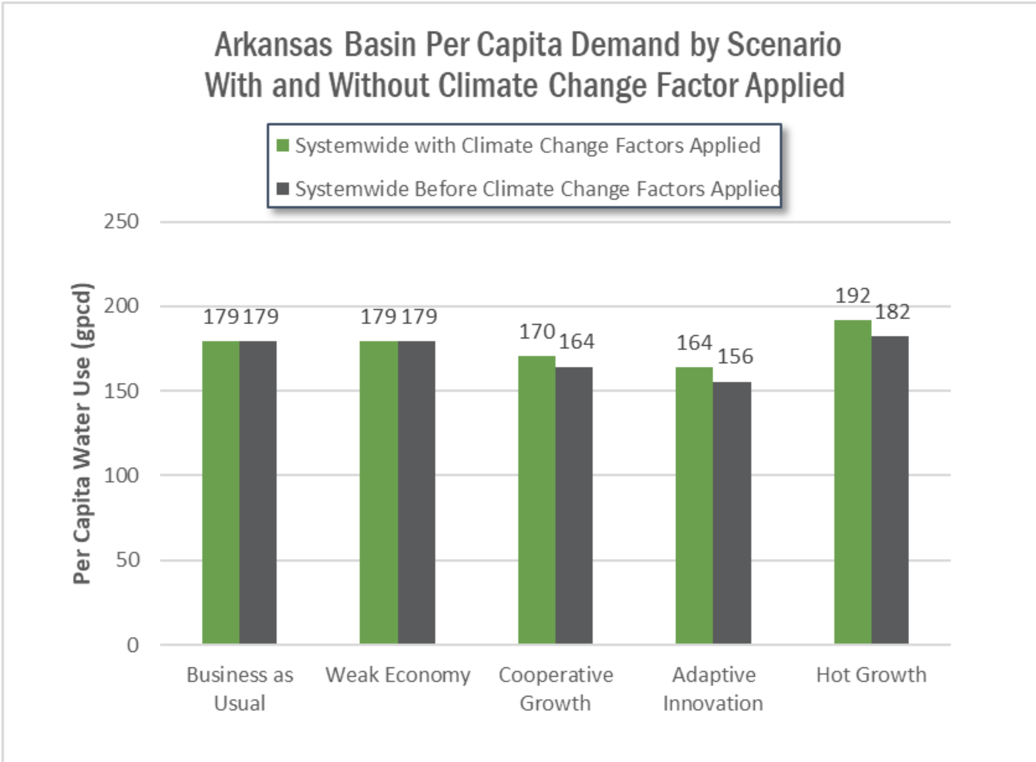

Figure 3-6: Effect of Climate Change Driver on the Arkansas Basin Average Per Capita Demand.

The Arkansas Basin municipal baseline and projected volumetric demands are provided in Table 3-3, showing the combined effect of population and per capita demands. Municipal demands are projected to grow from approximately 219,000 AFY in 2015 to between 294,000 and 337,000 AFY in 2050. El Paso County accounts for around half of the baseline demand followed by Pueblo County at about one-third of the basin demand.

Table 3-3: Arkansas Basin Municipal Baseline and Projected Volumetric Demands by County (AFY).

County	Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Baca	1,192	921	916	852	831	1,008
Bent	1,295	1,400	1,365	1,280	1,262	1,556
Chaffee	3,473	4,945	4,778	4,476	4,425	5,525
Cheyenne*	171	149	135	135	143	176
Crowley	1,296	1,703	1,654	1,546	1,525	1,899
Custer	832	1,082	1,047	983	971	1,208
El Paso	111,144	166,041	159,910	161,662	163,337	185,392
Elbert*	1,176	3,172	2,945	2,790	2,815	3,627
Fremont	7,962	9,553	9,236	8,705	8,614	10,662
Huerfano	1,478	1,317	1,291	1,214	1,194	1,456
Kiowa	682	536	536	494	481	584
Lake	1,461	1,865	1,807	1,695	1,674	2,081
Las Animas	3,578	3,206	3,151	2,951	2,898	3,539
Lincoln*	1,197	1,704	1,614	1,533	1,548	1,942
Otero	4,421	3,562	3,509	3,297	3,237	3,924
Prowers	3,151	2,888	2,833	2,660	2,616	3,198
Pueblo	72,522	96,277	94,074	95,539	97,912	106,171
Teller*	2,177	3,029	2,758	2,730	2,849	3,573
Basin Total	219,208	303,352	293,842	294,540	298,095	337,222

Counties with population located in multiple basins. This table represents systemwide demands for the portion of the county located in the Arkansas Basin.

The baseline and projected demands shown in Table 3-4 and Figure 3-7 also illustrate how the population varies between the scenarios. All of the projection scenarios result in an increase relative to the baseline. Except for Hot Growth, the systemwide demand projections are similar, demonstrating how the pairing of drivers and population can offset each other and even out the results.

Table 3-4: Arkansas Basin Municipal Baseline and Projected Volumetric Demands by Demand Category (AFY).

Scenario	Residential Indoor	Non-Residential Indoor	Residential Outdoor	Non-Residential Outdoor	Non-Revenue	System-wide
Baseline (2015)	63,980	48,134	36,404	30,847	39,843	219,208
Business as Usual	79,733	70,173	53,107	45,040	55,298	303,352
Weak Economy	79,065	65,995	49,933	42,343	56,224	293,560
Cooperative Growth	72,114	66,542	53,898	45,641	56,344	294,540
Adaptive Innovation	68,613	69,676	56,004	47,382	56,658	298,333
Hot Growth	80,964	75,634	66,791	56,648	57,484	337,522

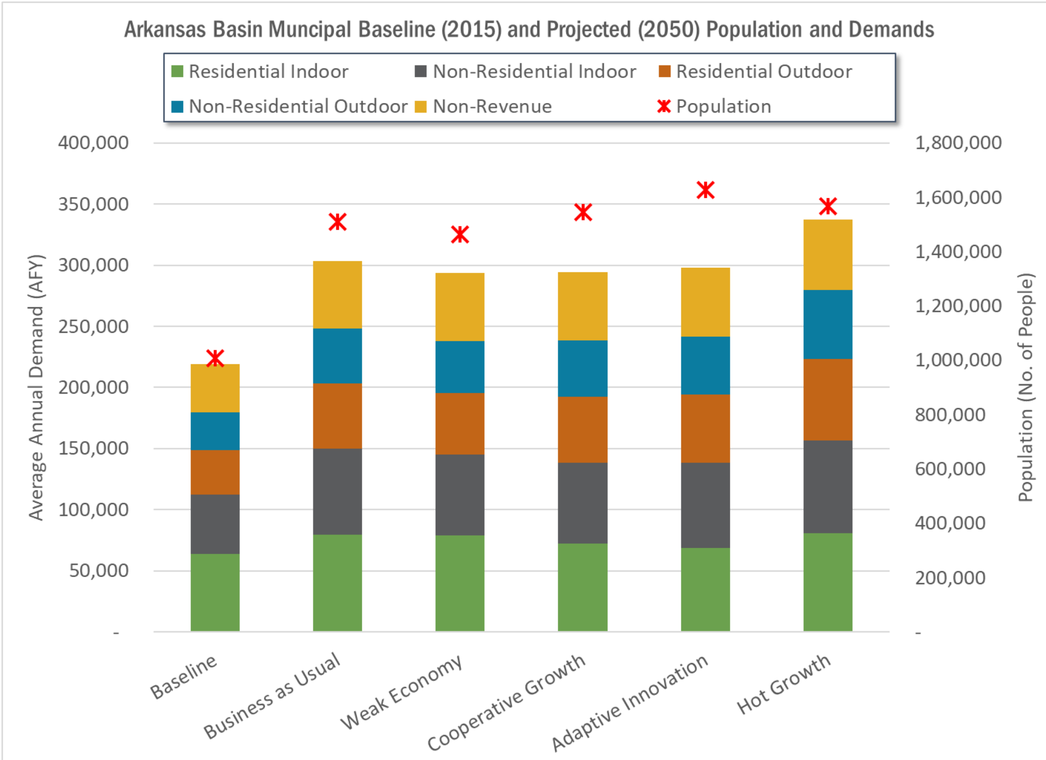

Figure 3-7: Arkansas Basin Baseline and Projected Population and Municipal Demands.

3.1.2 INDUSTRIAL

The Arkansas Basin currently includes about 33% of the statewide industrial demand. Industrial demands in this basin are associated with the Large Industry and Thermoelectric sub-sectors, with no demands projected for Snowmaking or Energy Development sub-sectors. Basin-scale industrial demands are shown on Figure 3-8 and county-scale industrial demands are summarized in Table 3-5.

Large Industry demands are related to steel manufacturing in Pueblo County and were based on the data provided in the BIP. The baseline demand has decreased from 49,400 AFY in SWSI 2010 to 46,400 AFY. Projected 2050 Large Industry demands range from 44,460 AFY to 54,340 AFY.

Thermoelectric demands are related to one facility located in Pueblo County and were based on information from Xcel Energy. The baseline demand has increased from 9,000 AFY in SWSI 2010 to 12,320 AFY. Projected 2050 Thermoelectric demands range from 11,090 AFY to 13,550 AFY.

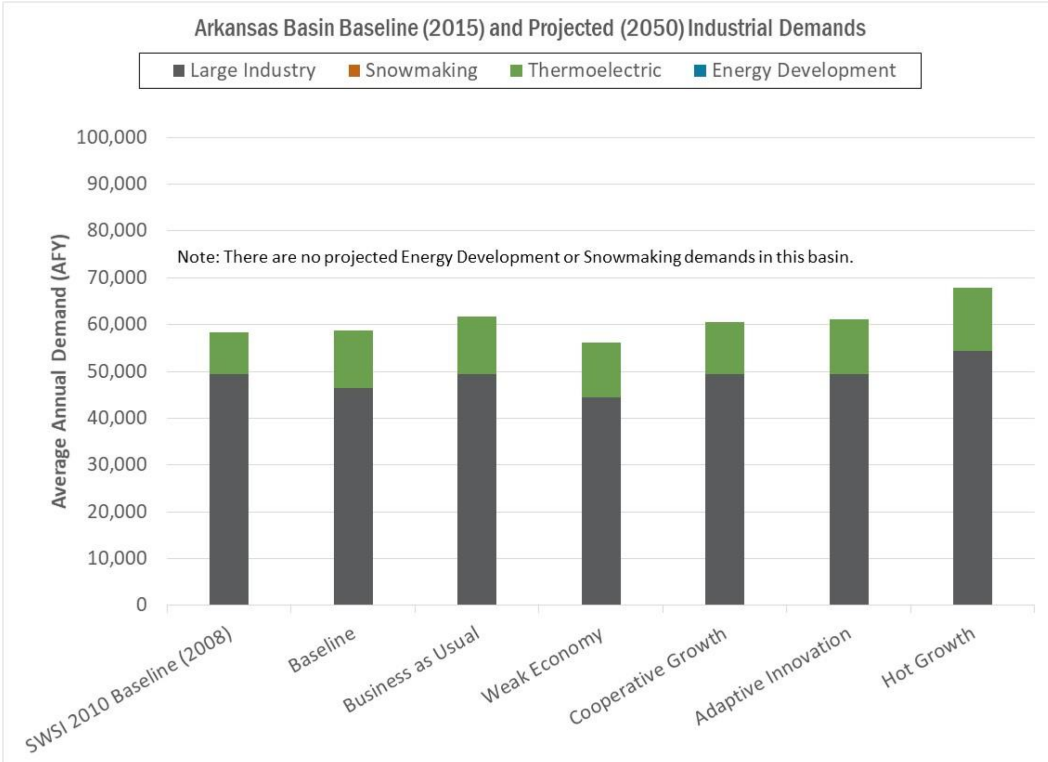

Figure 3-8: Arkansas Basin Industrial Baseline and Projected Demands.

Table 3-5: Arkansas Basin Industrial Baseline and Projected Demands by County (AFY).

County	Sub-Sector	Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Pueblo	Large Industry	46,400	49,400	44,460	49,400	49,400	54,340
	Snowmaking	-	-	-	-	-	-
	Thermoelectric	12,320	12,320	11,700	11,090	11,700	13,550
	Energy Development	-	-	-	-	-	-
Basin Total		58,720	61,720	56,160	60,490	61,100	67,890

3.1.3 TOTAL

Arkansas Basin combined M&I demand projections for 2050 range from approximately 350,000 AFY in the Weak Economy scenario to 405,000 AFY in the Hot Growth scenario, as shown in Figure 3-9. Industrial demands account for 16% to 17% of the projected M&I demands. On a basin scale, the total M&I demand projections do not follow the statewide sequence of the scenario rankings described in the CWP, with the Adaptive Innovation scenario falling out of sequence.

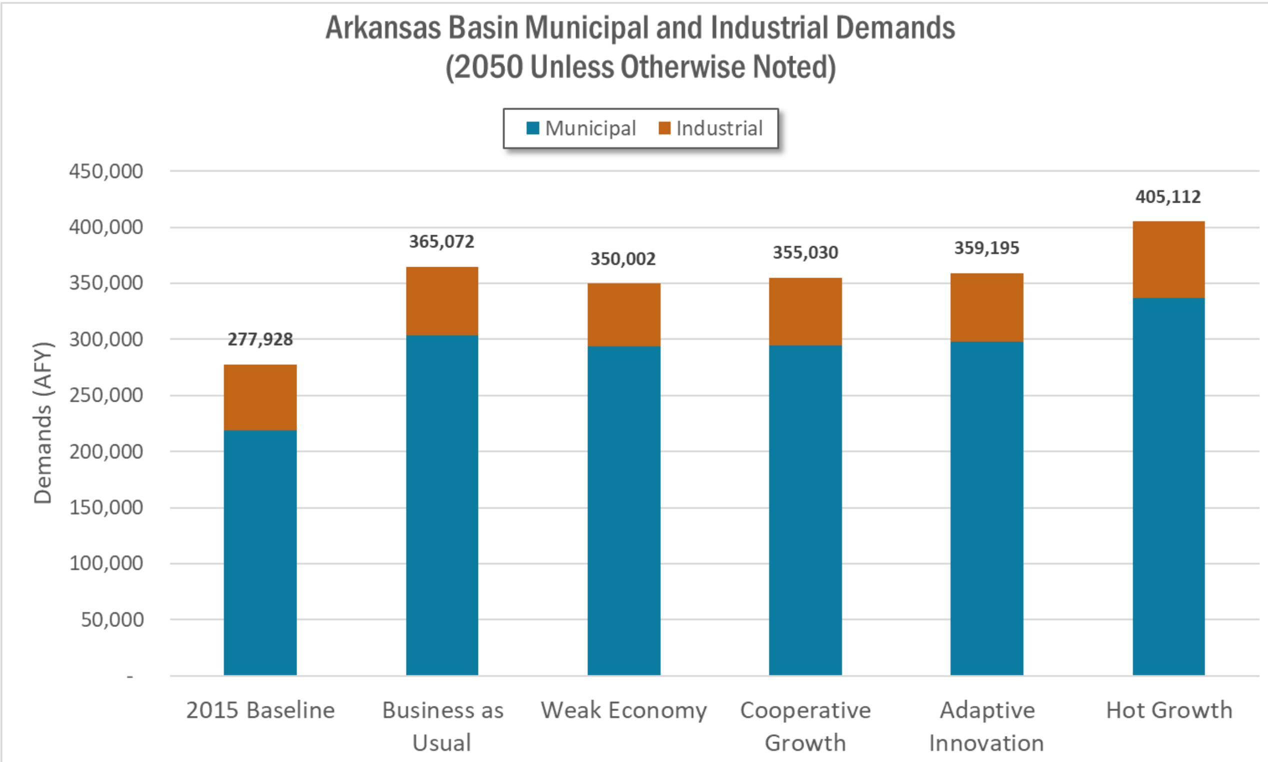

Figure 3-9: Arkansas Basin Baseline and Projected M&I Demands.

3.2 COLORADO BASIN

3.2.1 MUNICIPAL

3.2.1.1 POPULATION

The Colorado Basin currently includes about 6% of the statewide population. Between the years 2015 and 2050, it is projected to grow from approximately 310,000 to between 460,000 and 580,000 people in the low and high growth scenarios, respectively. Using the specific numbers, this is an increase in population of 48% to 88%.

Table 3-6 shows how population growth is projected to vary across counties under each planning scenario. All counties are projected to increase in population under all scenarios. Mesa County is the most populous and is projected to account for a substantial portion of the basin growth, followed by Garfield and Eagle Counties. Grand County is projected to have the highest growth rate for an individual county, ranging from about 66% to 110% increase in the low and high growth scenarios, respectively. Pitkin County has the lowest growth projection, estimated at 46% in the high growth scenario. Note that Mesa County is split between multiple basins, with the county demands pro-rated between basins based on the population located within each basin. This approach is consistent with prior SWSI analyses.

Table 3-6: Colorado Basin 2015 Baseline and 2050 Projected Populations by County.

County	Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Eagle	53,320	94,459	83,620	102,687	99,147	105,885
Garfield	57,779	105,711	93,581	115,297	110,957	118,498
Grand	14,602	27,406	24,261	29,967	28,766	30,721
Mesa*	134,096	212,859	188,433	220,735	255,228	238,608
Pitkin	17,845	23,209	20,546	24,282	24,361	26,017
Summit	29,928	51,828	45,881	56,208	54,400	58,097
Basin Total	307,570	515,472	456,321	549,176	572,860	577,827

**Counties with population located in multiple basins. This table represents the portion of the county located in the Colorado Basin.*

The Colorado Basin baseline for the Technical Update, which is based on 2015 population, is approximately the same as the SWSI 2010 baseline, which used 2008 population. All SWSI 2010 projections for 2050 exceeded the Technical Update population projections for all planning scenarios by at least 14%. Comparison of the baseline and projected populations for the Technical Update and SWSI 2010 are shown in Figure 3-10.

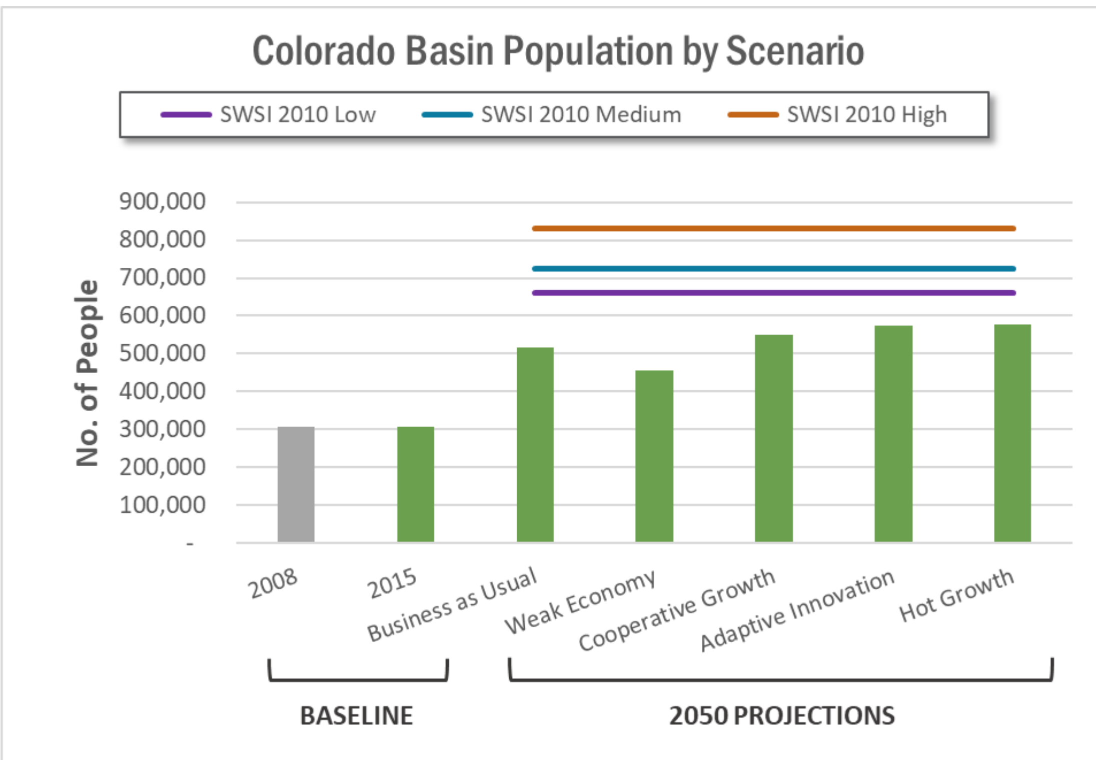

Figure 3-10: Colorado Basin Baseline and Projected Population.

3.2.1.2 WATER DEMANDS

The Colorado Basin baseline water demands were largely based on water provider-reported data, with approximately 43% of the baseline population demands represented by WEPs, 25% from 1051 data, and

9% from BIPs, requiring demands for about 23% of the basin's baseline population demands to be estimated, as shown in Figure 3-11.

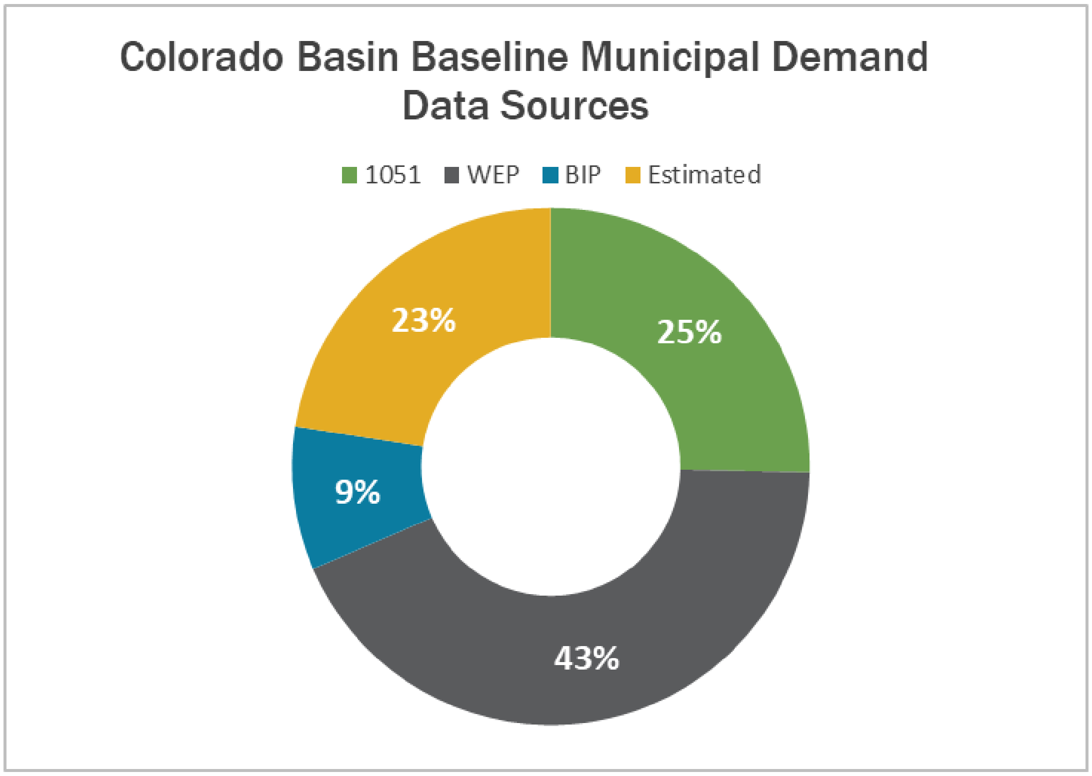

Figure 3-11: Colorado Basin Baseline Municipal Water Demand Data Sources.

The Colorado Basin average baseline per capita systemwide demand has decreased slightly from 182 gpcd in SWSI 2010 to approximately 179 gpcd. While the basin average per capita demand changed very little, there are more significant differences from SWSI 2010 at a county level. Demands associated with tourism and non-permanent population are significant for some areas of the basin, which must be considered when using per capita water demand data. Table 3-7 represents baseline and projected per capita demands for counties within the basin.

Table 3-7: Colorado Basin Municipal Baseline and Projected Per Capita Demands by County (gpcd).

County	SWSI 2010 Baseline [a]	Technical Update Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Eagle	209	175	150	153	140	135	158
Garfield	198	218	182	186	171	164	194
Grand	250	300	228	237	213	204	241
Mesa*	127	115	112	111	106	102	124
Pitkin	284	392	337	348	322	311	364
Summit	246	215	152	160	138	130	154
Basin Total	182	179	153	156	145	136	165

a) SWSI 2010 per capita values from SWSI 2010 Appendix H, Table 3-1 (CWCB, 2010a).

**Counties with population located in multiple basins. Per capita demand is calculated at a county level.*

The Colorado Basin baseline municipal water demands are comprised of approximately 57% indoor, 29% outdoor, and 14% non-revenue water uses, as shown in Figure 3-12. The basin average demand category distribution was used for Grand County, due to insufficient demand category data, and all other counties had sufficient demand category data available to apply a county-specific distribution. On a basin scale, the residential indoor demand as a percentage of the systemwide demands is the highest reported throughout the state, at approximately 44% of the systemwide demands. Conversely, the baseline outdoor demands are the lowest percentages statewide.

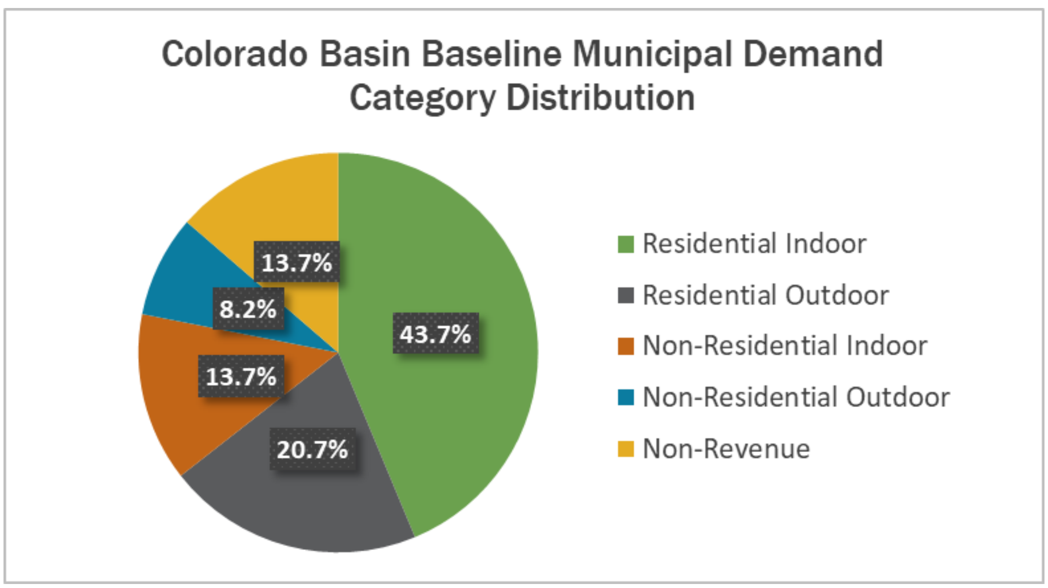

Figure 3-12: Colorado Basin Baseline Municipal Demand Category Distribution.

Figure 3-13 provides a summary of per capita baseline and projected water demands for the Colorado Basin. Systemwide, all of the projected per capita demands decrease relative to the baseline. Consistently across all scenarios, residential indoor demand is the greatest individual demand category while non-residential outdoor is the lowest. Aside from the Hot Growth scenario, there is minimal variation in outdoor demands between scenarios. This is due to the scenario pairing of water demand reductions and climate drivers, particularly for the Adaptive Innovation scenario which has high outdoor reductions coupled with the “Hot and Dry” climate. Outdoor demands increased significantly for the Hot Growth scenario, due to an increase in outdoor demands coupled with the “Hot and Dry” climate.

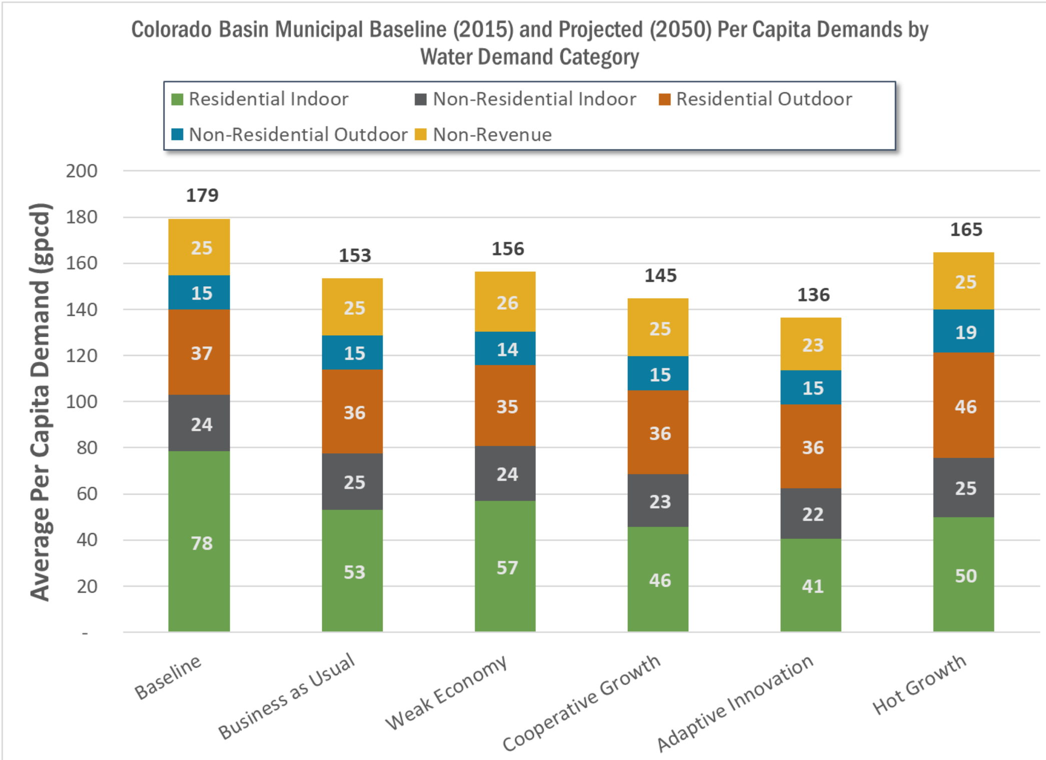

Figure 3-13: Colorado Basin Municipal Baseline and Projected Per Capita Demands by Water Demand Category.

Figure 3-14 demonstrates the influence of the climate driver on per capita water demands, with outdoor demands increasing by 6 to 12 gpcd with the climate change factors applied. Without the climate change factors, the per capita demand projections range from 127 to 156 gpcd, as compared to the SWSI 2010 projection of 131 gpcd for medium population with active conservation[23].

[23] SWSI 2010 projected per capita demands include savings from passive conservation.

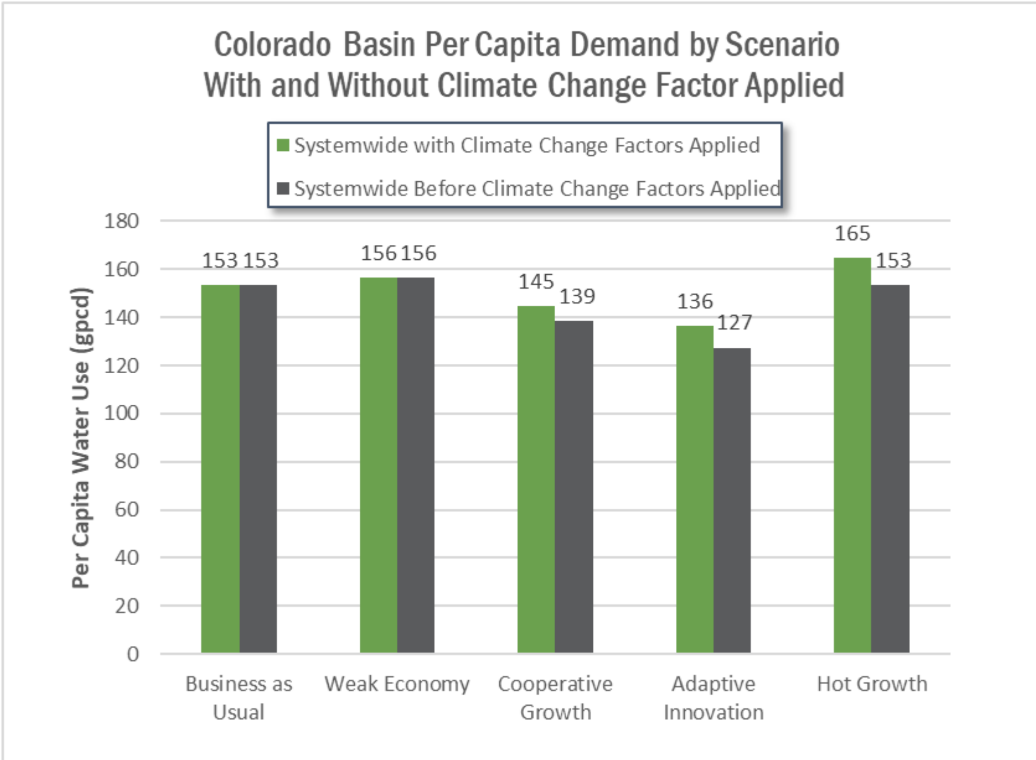

Figure 3-14: Effect of Climate Change Driver on the Colorado Basin Average Per Capita Demand.

The Colorado Basin municipal baseline and projected volumetric demands are provided in Table 3-8, showing the combined effect of population and per capita demands. Municipal demands are projected to grow from approximately 62,000 AFY in 2015 to between 80,000 and 107,000 AFY in 2050. Mesa County accounts for about 28% of the baseline demand followed by Garfield County at about 23% of the basin demand.

Table 3-8: Colorado Basin Municipal Baseline and Projected Volumetric Demands by County (AFY).

County	Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Eagle	10,449	15,846	14,327	16,147	14,953	18,799
Garfield	14,141	21,530	19,476	22,036	20,417	25,779
Grand	4,915	7,006	6,430	7,144	6,572	8,280
Mesa*	17,242	26,641	23,436	26,230	29,207	33,070
Pitkin	7,829	8,761	8,006	8,761	8,474	10,606
Summit	7,215	8,806	8,212	8,665	7,912	10,044
Basin Total	61,790	88,589	79,886	88,984	87,534	106,578

**Counties with population located in multiple basins. This table represents systemwide demands for the portion of the county located in the Colorado Basin.*

The baseline and projected demand distributions are shown in Table 3-9 and Figure 3-15 also shows how the population varies between the scenarios. All of the projection scenarios result in an increase relative to the baseline. Except for Hot Growth, the systemwide demand projections for all of the Colorado Basin scenarios are similar, demonstrating how the pairing of drivers and population can offset each other and even out the results.

Table 3-9: Colorado Basin Municipal Baseline and Projected Volumetric Demands by Demand Category (AFY).

Scenario	Residential Indoor	Non-Residential Indoor	Residential Outdoor	Non-Residential Outdoor	Non-Revenue	System wide
Baseline (2015)	27,021	8,439	12,796	5,090	8,445	61,790
Business as Usual	30,688	14,151	20,907	8,553	14,290	88,589
Weak Economy	29,134	12,155	17,968	7,347	13,283	79,886
Cooperative Growth	28,184	13,992	22,290	9,137	15,382	88,984
Adaptive Innovation	26,025	14,064	23,358	9,543	14,545	87,534
Hot Growth	32,405	16,487	29,567	12,099	16,018	106,578

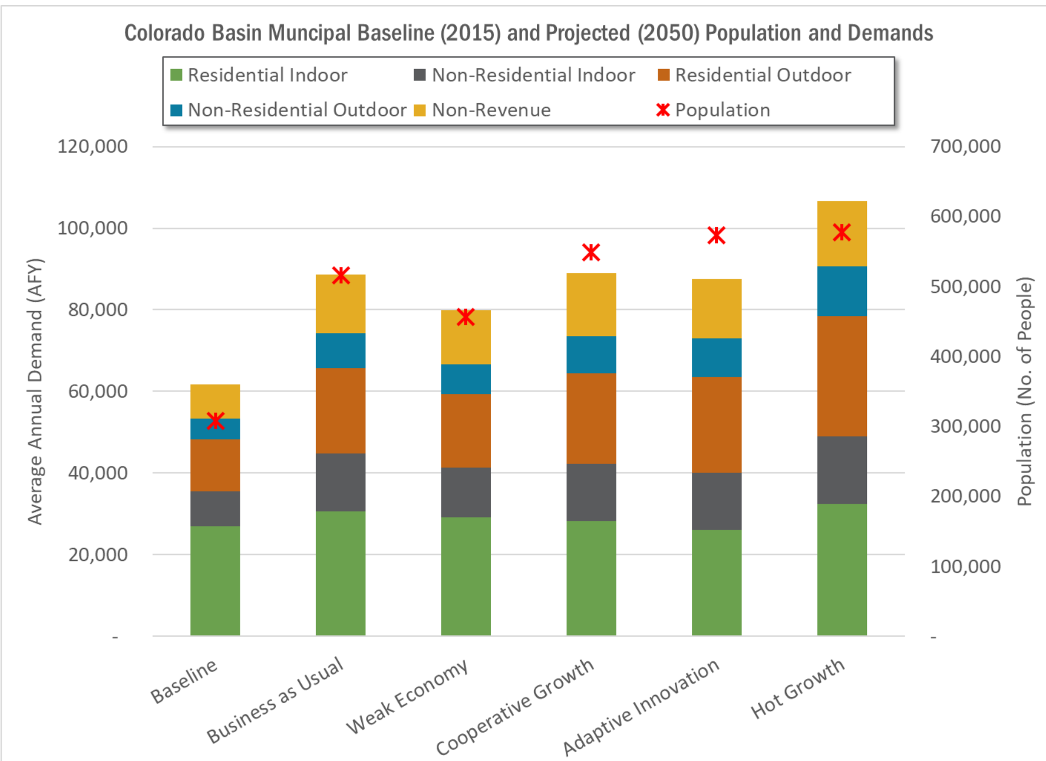

Figure 3-15: Colorado Basin Baseline and Projected Population and Municipal Demands.

3.2.2 INDUSTRIAL

The Colorado Basin currently includes about 4% of the statewide industrial demand. Industrial demands in this basin are associated with the Large Industry, Snowmaking, and Energy Development sub-sectors, with no demands projected for the Thermoelectric sub-sector. Basin-scale industrial demands are shown on Figure 3-16 and county-scale industrial demands are summarized in Table 3-10.

Large Industry demands are related to a mining facility in Grand County. This facility was not represented in SWSI 2010 and was added to the Technical Update because it is an explicitly-modeled location in an existing hydrologic model. The baseline demand of 1,700 AFY was based on data from the hydrologic model. Projected Large Industry demands range from 1,530 AFY to 1,870 AFY.

The baseline Snowmaking demand is 4,340 AFY as compared to 3,180 AFY in SWSI 2010. Snowmaking occurs in the following counties: Eagle, Garfield, Grand, Mesa, Pitkin, and Summit. Projected demands increase to 5,890 under all scenarios.

Energy Development demands are located in Garfield and Mesa counties. The baseline Energy Development demand in the Colorado Basin is 1,800 AFY as compared to 2,300 AFY in SWSI 2010. SWSI 2010 indicated that demands related to natural gas generation were shifted from Garfield County to Rio Blanco County (White Basin), which caused 2050 demands in the Colorado Basin to be less than in 2008. SWSI 2010 also showed no Energy Development demands in Mesa County in 2035 or under the "low" projection for 2050. Projected demands range from 200 AFY to 10,700 AFY.

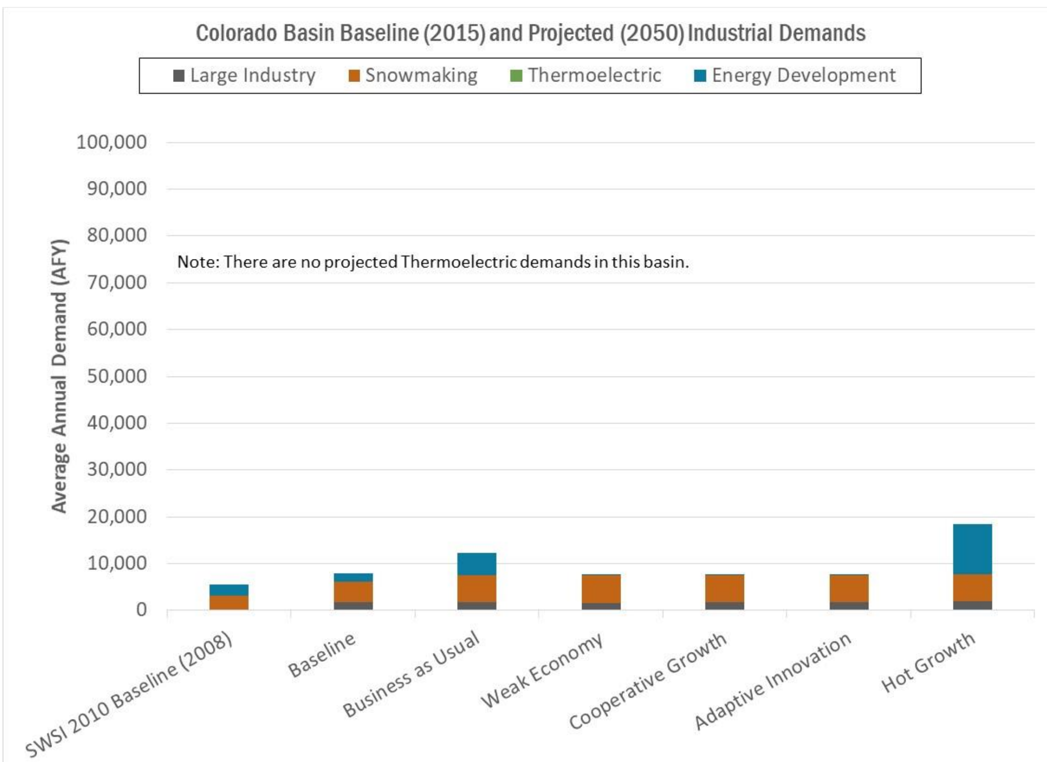

Figure 3-16: Colorado Basin Baseline and Projected Industrial Demands.

Table 3-10: Colorado Basin Industrial Baseline and Projected Demands by County (AFY).

County	Sub-Sector	Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Eagle	Large Industry	-	-	-	-	-	-
	Snowmaking	1,310	1,310	1,310	1,310	1,310	1,310
	Thermoelectric	-	-	-	-	-	-
	Energy Development	-	-	-	-	-	-
Garfield	Large Industry	-	-	-	-	-	-
	Snowmaking	20	20	20	20	20	20
	Thermoelectric	-	-	-	-	-	-
	Energy Development	1,600	3,300	200	200	200	6,900
Grand	Large Industry	1,700	1,700	1,530	1,700	1,700	1,870
	Snowmaking	360	630	630	630	630	630
	Thermoelectric	-	-	-	-	-	-
	Energy Development	-	-	-	-	-	-
Mesa	Large Industry	-	-	-	-	-	-
	Snowmaking	40	50	50	50	50	50
	Thermoelectric	-	-	-	-	-	-
	Energy Development	200	1,400	0	0	0	3,800
Pitkin	Large Industry	-	-	-	-	-	-
	Snowmaking	1,000	1,000	1,000	1,000	1,000	1,000
	Thermoelectric	-	-	-	-	-	-
	Energy Development	-	-	-	-	-	-
Summit	Large Industry	-	-	-	-	-	-
	Snowmaking	1,610	2,880	2,880	2,880	2,880	2,880
	Thermoelectric	-	-	-	-	-	-
	Energy Development	-	-	-	-	-	-
Basin Total		7,840	12,290	7,620	7,790	7,790	18,460

3.2.3 TOTAL

Colorado Basin combined M&I demand projections for 2050 range from approximately 88,000 AFY in the Weak Economy scenario to 125,000 AFY in the Hot Growth scenario, as shown in Figure 3-17. Industrial demands account for between 8% and 15% of the M&I demands. On a basin scale, the demand projections do not follow the statewide sequence of the volumetric demand scenario rankings described in the CWP, with the Adaptive Innovation scenario falling out of sequence.

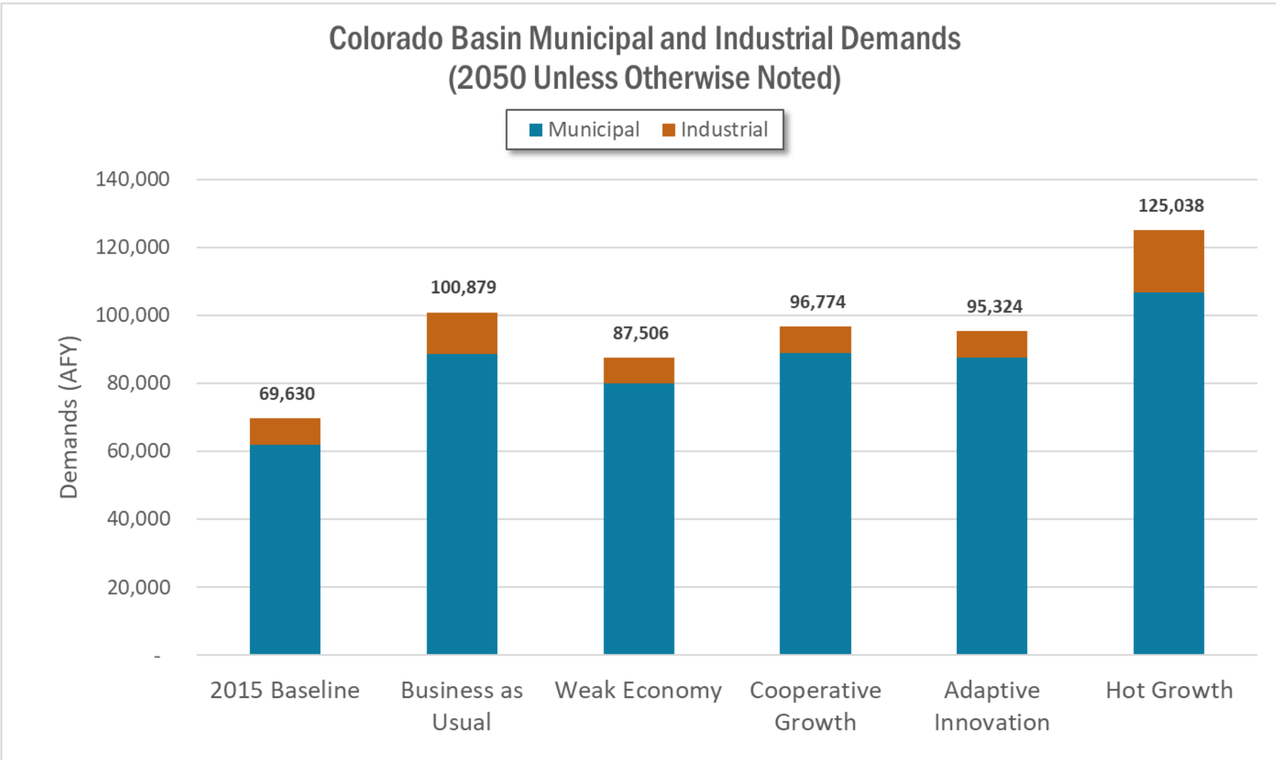

Figure 3-17: Colorado Basin Baseline and Projected M&I Demands.

3.3 GUNNISON BASIN

3.3.1 MUNICIPAL

3.3.1.1 POPULATION

The Gunnison Basin currently includes about 2% of the statewide population. Between the years 2015 and 2050, it is projected to grow from approximately 100,000 to between 120,000 and 200,000 people in the low and high growth scenarios, respectively. Using the specific numbers, this is an increase in population of 19% to 99%.

Table 3-11 shows how population growth is projected to vary across counties under each planning scenario. With the exception of Ouray County, all counties are projected to increase in population for all scenarios. Ouray County is projected to decrease by approximately 9% in the low growth scenario and increase by up to 51% in the high growth scenario. Montrose County is the most populous and is projected to account for a substantial portion of the basin growth. Hinsdale County is projected to have the highest growth rate for an individual county, ranging from about 55% to 160% increase in the low and high growth scenarios, respectively. While it is projected to have the largest percent increase, Hinsdale County is still projected to account for only about 1% of the future total basin population. Note that Mesa and Montrose Counties are split between multiple basins, with the county demands pro-rated between basins based on the population located within each basin. This approach is consistent with prior SWSI analyses.

Table 3-11: Gunnison Basin Baseline and Projected Populations by County.

County	Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Delta	29,973	42,126	31,878	39,861	49,704	53,082
Gunnison	16,097	22,728	17,199	24,054	26,817	28,639
Hinsdale	767	1,573	1,190	1,488	1,856	1,982
Mesa*	14,927	23,695	17,931	24,572	32,067	29,858
Montrose*	36,710	66,942	50,658	63,343	78,985	84,353
Ouray	4,647	5,568	4,214	5,269	6,570	7,016
Basin Total	103,121	162,632	123,070	158,587	195,998	204,931

**Counties with population located in multiple basins. This table represents the portion of the county located in the Gunnison Basin.*

The Gunnison Basin baseline for the Technical Update, which is based on 2015 population, is approximately 2% lower than the SWSI 2010 baseline, which used 2008 population. All SWSI 2010 projections for 2050 exceeded the Technical Update population projections for all planning scenarios. Comparison of the baseline and projected populations for the Technical Update and SWSI 2010 are shown in Figure 3-18.

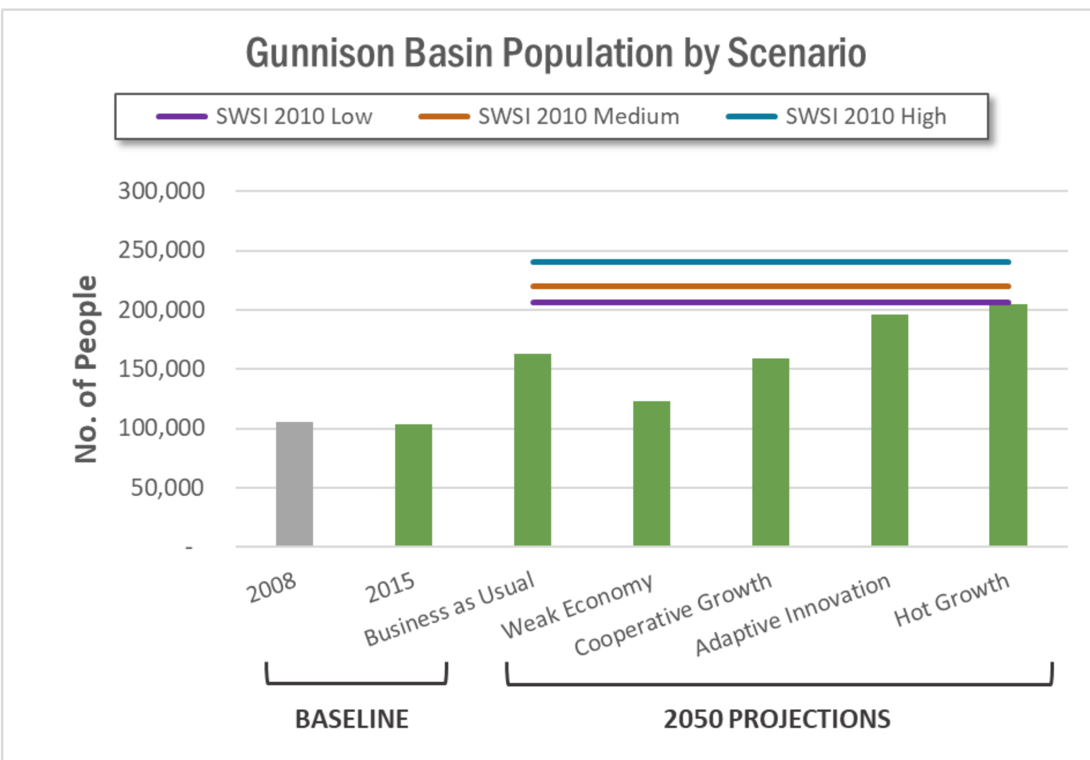

Figure 3-18: Gunnison Basin Baseline and Projected Population.

3.3.1.2 WATER DEMANDS

The Gunnison Basin baseline water demands were based on a mix of data sources, with approximately 36% of the baseline population demands represented by 1051 data, 11% from WEPs, and 3% from water provider outreach, requiring demands for about 50% of the basin's baseline population demands to be estimated, as shown in Figure 3-19.

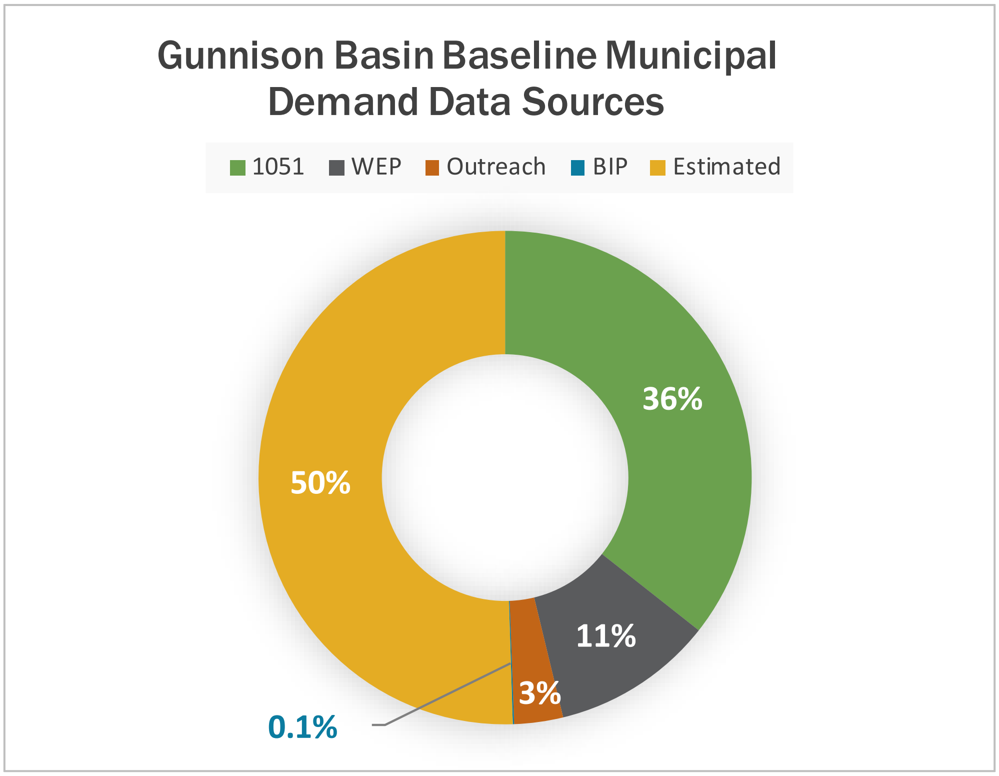

Figure 3-19: Gunnison Basin Baseline Municipal Water Demand Data Sources.

The Gunnison Basin average baseline per capita systemwide demand has decreased from 174 gpcd in SWSI 2010 to approximately 158 gpcd. County-level baseline per capita demands are either comparable or have also decreased from SWSI 2010. Table 3-12 represents baseline and projected per capita demands for counties within the basin.

Table 3-12: Gunnison Basin Municipal Baseline and Projected Per Capita Demands by County (gpcd).

County	SWSI 2010 Baseline [a]	Technical Update Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Delta	165	132	122	124	117	110	131
Gunnison	197	176	161	164	154	147	176
Hinsdale	375	169	153	154	146	139	169
Mesa*	127	115	112	111	106	102	124
Montrose*	187	192	171	174	164	156	188
Ouray	157	135	127	130	123	116	138
Basin Total	174	158	146	149	140	133	160

a) SWSI 2010 per capita values from SWSI 2010 Appendix H, Table 3-1 (CWCB, 2010a).

**Counties with population located in multiple basins. Per capita demand is calculated at a county level.*

The Gunnison Basin baseline municipal water demands are comprised of approximately 57% indoor, 35% outdoor, and 9% non-revenue water, as shown in Figure 3-20. Three of the six counties had sufficient demand category distribution data available to apply a county-specific distribution. The basin average demand category distribution was used for the remaining counties. On a basin scale, the residential indoor demand as a percentage of the systemwide demands are relatively high, at approximately 40% of the systemwide demands.

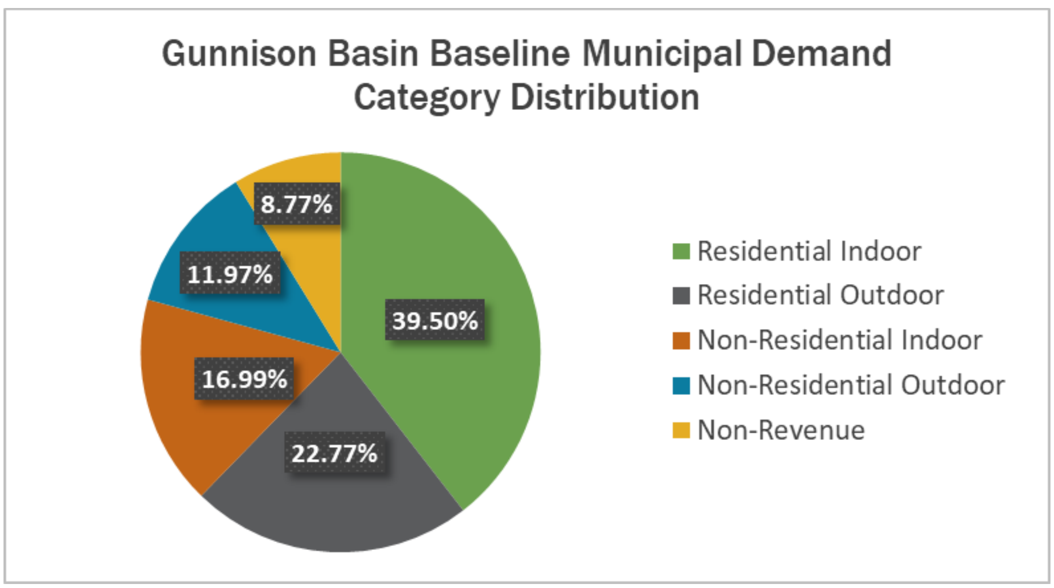

Figure 3-20: Gunnison Basin Baseline Municipal Demand Category Distribution.

Figure 3-21 provides a summary of per capita baseline and projected water demands for the Gunnison Basin. Systemwide, the projected per capita demands decrease relative to the baseline except for the Hot Growth Scenario. The residential indoor demand is the greatest demand category in the baseline and each projection except for Hot Growth where the residential outdoor demand is slightly higher. Outdoor demands increased significantly for the Hot Growth scenario, due to an increase in outdoor demands coupled with the “Hot and Dry” climate.

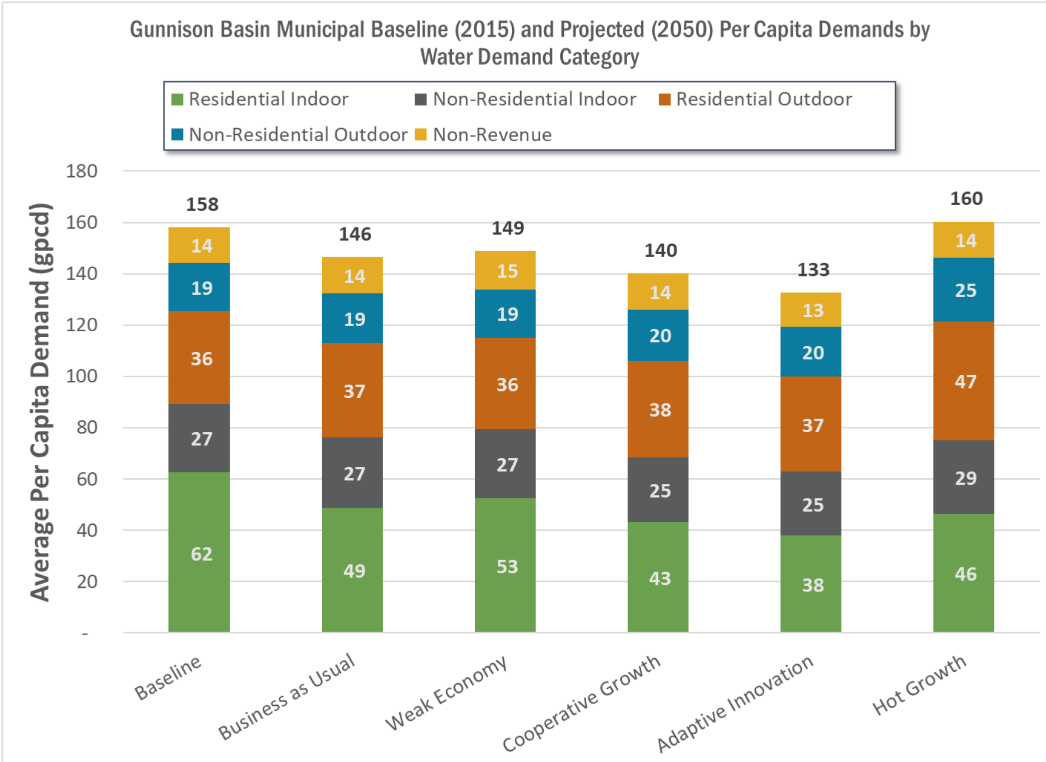

Figure 3-21: Gunnison Basin Municipal Baseline and Projected Per Capita Demands by Water Demand Category.

Figure 3-22 demonstrates the influence of the climate driver on per capita water demands, with outdoor demands increasing by 8 to 13 gpcd with the climate change factors applied. Without the climate change factors, the per capita demand projections range from 123 to 149 gpcd, as compared to the SWSI 2010 projection of 124 gpcd for medium population with active conservation[24].

[24] SWSI 2010 projected per capita demands include savings from passive conservation.

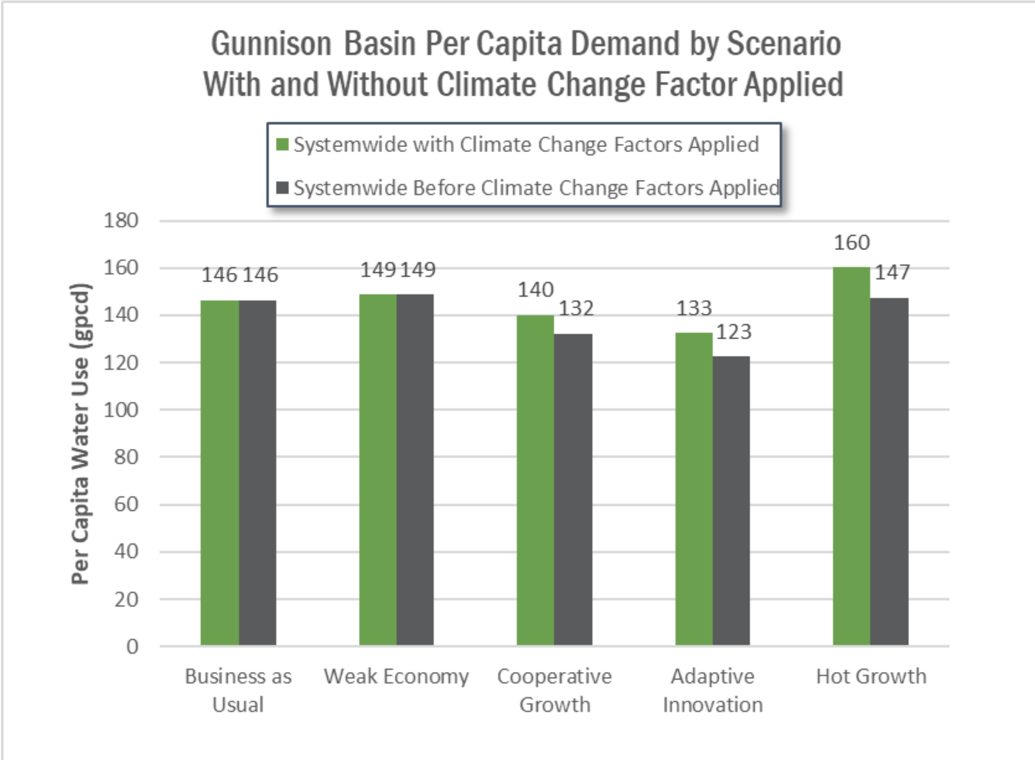

Figure 3-22: Effect of Climate Change Driver on the Gunnison Basin Average Per Capita Demand.

The Gunnison Basin municipal baseline and projected volumetric demands are provided in Table 3-13, showing the combined effect of population and per capita demands. Municipal demands are projected to grow from approximately 18,000 AFY in 2015 to between 21,000 and 37,000 AFY in 2050. Montrose County accounts for almost one-half of the baseline demand followed by Delta County at about one-fifth of the basin demand.

Table 3-13: Gunnison Basin Municipal Baseline and Projected Volumetric Demands by County (AFY).

County	Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Delta	4,440	5,751	4,446	5,213	6,125	7,804
Gunnison	3,171	4,088	3,163	4,145	4,413	5,635
Hinsdale	145	269	205	244	290	375
Mesa*	1,919	2,966	2,230	2,920	3,670	4,138
Montrose*	7,881	12,807	9,851	11,638	13,789	17,749
Ouray	705	793	614	728	856	1,088
Basin Total	18,262	26,674	20,509	24,887	29,142	36,789

**Counties with population located in multiple basins. This table represents the systemwide demands for the portion of the county located in the Gunnison Basin.*

The baseline and projected demand distributions are shown in Table 3-14 and Figure 3-23 also shows how the population varies between the scenarios. All of the projection scenarios result in an increase relative to the baseline.

Table 3-14: Gunnison Basin Municipal Baseline and Projected Volumetric Demands by Demand Category (AFY).

Scenario	Residential Indoor	Non-Residential Indoor	Residential Outdoor	Non-Residential Outdoor	Non-Revenue	System wide
Baseline (2015)	7,214	3,103	4,158	2,185	1,602	18,262
Business as Usual	8,882	4,999	6,681	3,537	2,575	26,674
Weak Economy	7,241	3,687	4,926	2,608	2,046	20,509
Cooperative Growth	7,670	4,493	6,686	3,539	2,500	24,887
Adaptive Innovation	8,322	5,459	8,143	4,293	2,924	29,142
Hot Growth	10,656	6,552	10,680	5,656	3,245	36,789

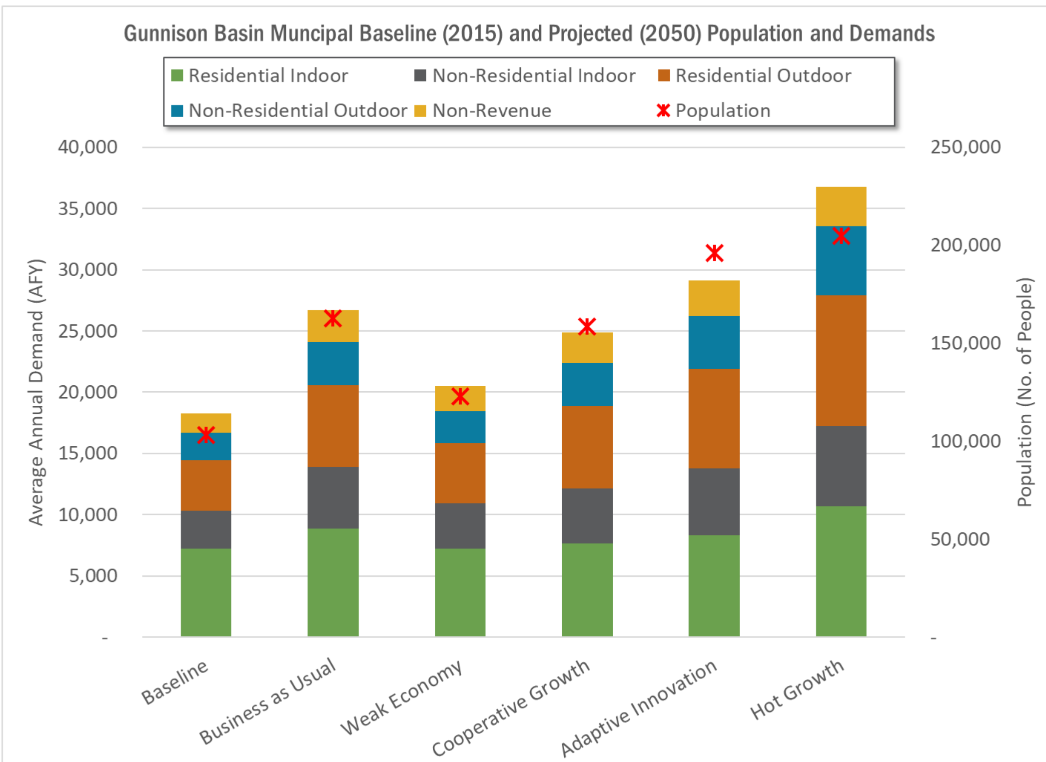

Figure 3-23: Gunnison Basin Baseline and Projected Population and Municipal Demands.

3.3.2 INDUSTRIAL

The Gunnison Basin currently includes less than one percent of the statewide industrial demand. Industrial demands in this basin are associated exclusively with the Snowmaking sub-sector. There are no demands projected for the Large Industry, Thermoelectric, and Energy Development sub-sectors. Basin-scale industrial demands are shown on Figure 3-24 and county-scale industrial demands are summarized in Table 3-15.

The baseline Snowmaking demand is 270 AFY as compared to 260 AFY in SWSI 2010. All snowmaking occurs in Gunnison County. Projected demands increase to 650 AFY under all scenarios.

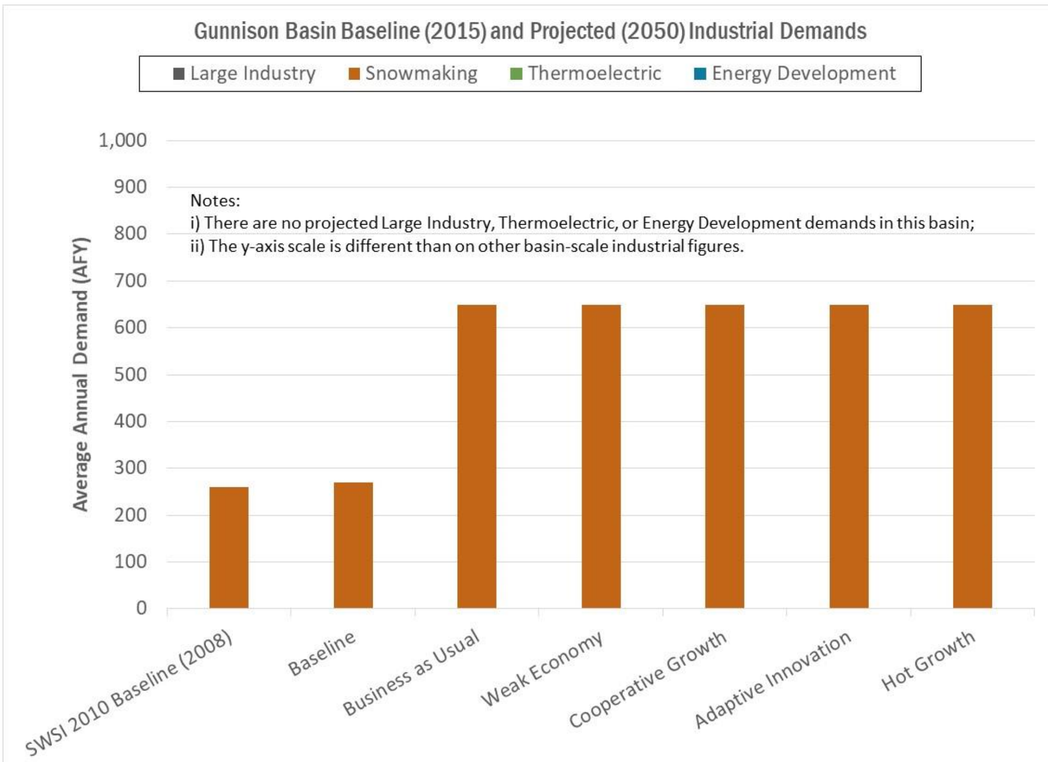

Figure 3-24: Gunnison Basin Industrial Baseline and Projected Demands.

Table 3-15: Gunnison Basin Industrial Baseline and Projected Demands by County (AFY).

County	Sub-Sector	Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Gunnison	Large Industry	-	-	-	-	-	-
	Snowmaking	270	650	650	650	650	650
	Thermoelectric	-	-	-	-	-	-
	Energy Development	-	-	-	-	-	-
Basin Total		270	650	650	650	650	650

3.3.3 TOTAL

Gunnison Basin combined M&I demand projections for 2050 range from approximately 21,000 AFY in the Weak Economy scenario to 37,000 AFY in the Hot Growth scenario, as shown in Figure 3-25. Industrial demands account for up to about 3% of the M&I demands. On a basin scale, the demand projections follow the statewide sequence of the volumetric demand scenario rankings described in the CWP.

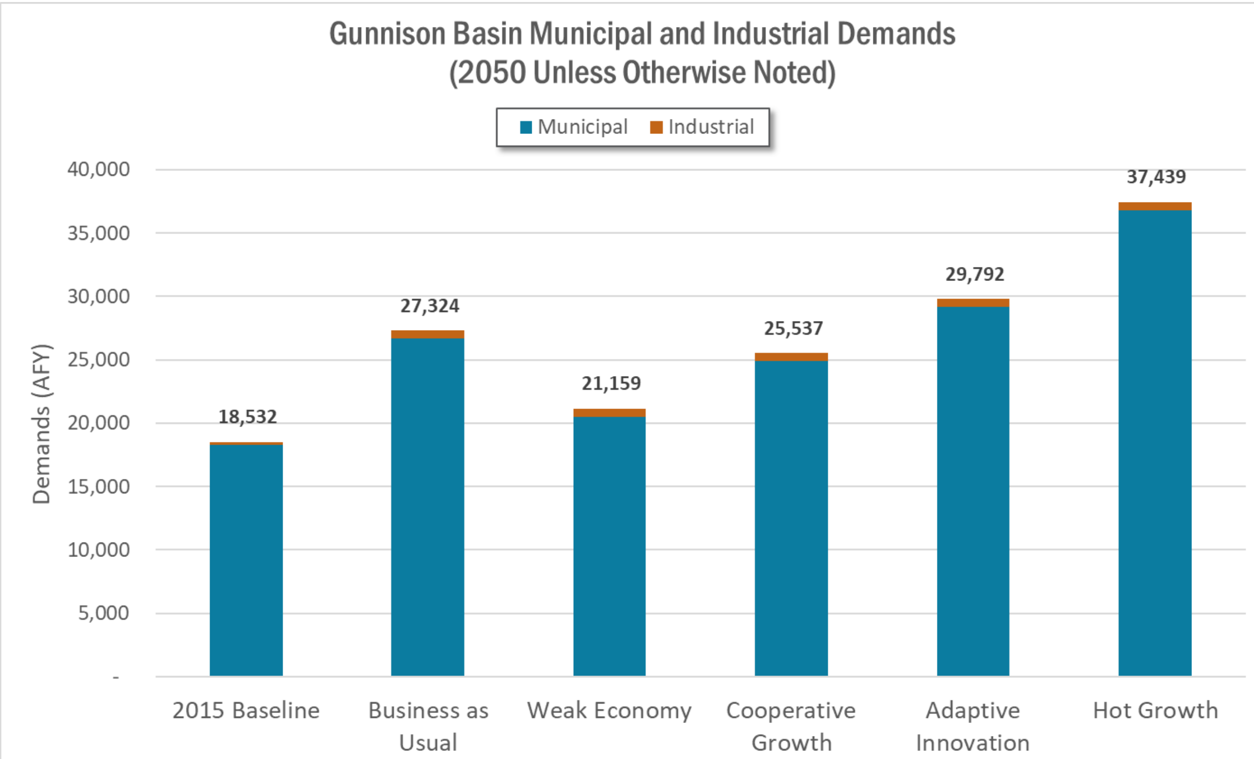

Figure 3-25: Gunnison Basin Baseline and Projected M&I Demands.

3.4 NORTH PLATTE BASIN

3.4.1 MUNICIPAL

3.4.1.1 POPULATION

The North Platte Basin currently includes about 0.02% of the statewide population. Between the years 2015 and 2050, it is projected to change from approximately 1,400 to between 1,100 and 1,500 people in the low and high growth scenarios, respectively. Using the specific numbers, this ranges from a 22% decrease in population to an increase of 8%. On a basin scale, the North Platte Basin represents the lowest baseline population and the lowest basin-wide growth amongst all basins in the state. Table 3-16 shows how population growth is projected to vary for Jackson County, which is the only county in the North Platte Basin, under each planning scenario.

Table 3-16: North Platte Basin Baseline and Projected Populations by County.

County	2015 Population	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Jackson	1,353	1,279	1,055	1,210	1,364	1,457
Basin Total	1,353	1,279	1,055	1,210	1,364	1,457

The North Platte Basin baseline for the Technical Update, which is based on 2015 population, has decreased by approximately 10% from the SWSI 2010 baseline, which used 2008 population. All SWSI 2010 population projections for 2050 exceeded all Technical Update population projections for all planning scenarios by at least 37%. Comparison of the baseline and projected populations for the Technical Update and SWSI 2010 are shown in Figure 3-26.

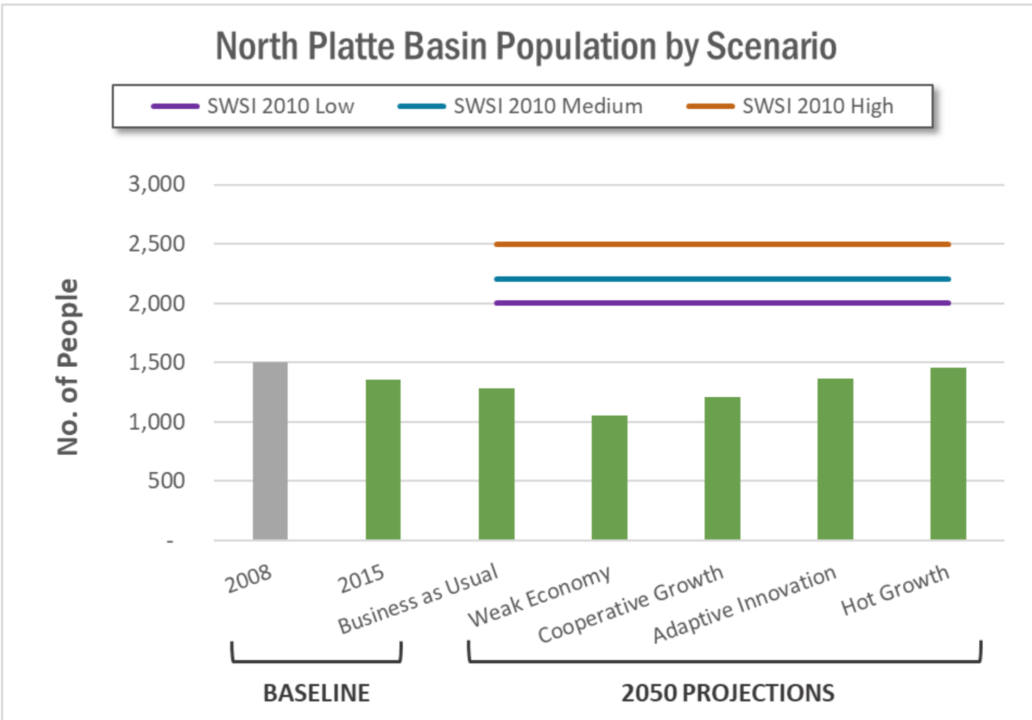

Figure 3-26: North Platte Basin Baseline and Projected Population.

3.4.1.2 WATER DEMANDS

The North Platte Basin baseline demands relied entirely on estimated data from neighboring counties. No municipal data were available for utilities within Jackson County, which is the only county in the North Platte Basin. The North Platte Basin average baseline per capita systemwide demand has decreased from 310 gpcd in SWSI 2010 to approximately 264 gpcd. Table 3-17 represents baseline and projected per capita demands for counties within the basin.

Table 3-17: North Platte Basin Baseline and Projected Per Capita Demands by County (gpcd).

County	SWSI 2010 Baseline [a]	Technical Update Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Jackson	310	264	245	254	242	232	270
Basin Total	310	264	245	254	242	232	270

a) SWSI 2010 per capita values from SWSI 2010 Appendix H, Table 3-1 (CWCB, 2010a).

Because there was no water provider-reported data available for Jackson County, the statewide weighted average demand category distribution was used for the North Platte Basin, as shown in Figure 3-27.

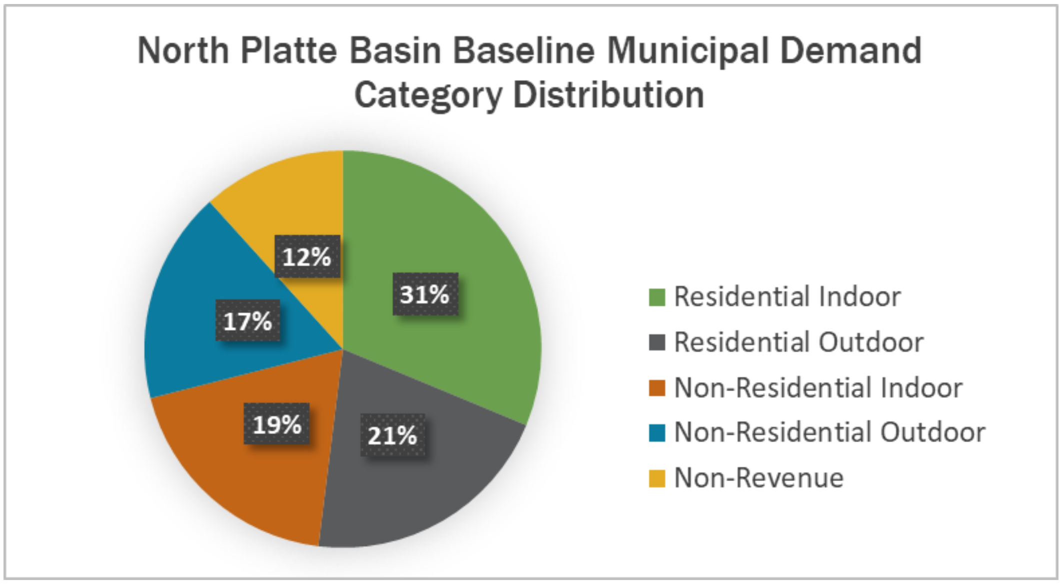

Figure 3-27: North Platte Basin Baseline Municipal Demand Category Distribution.

Figure 3-28 provides a summary of per capita baseline and projected water demands for the North Platte Basin. Systemwide, the projected per capita demands decrease relative to the baseline except for the Hot Growth scenario. The residential indoor demand is the greatest demand category in the baseline, but the residential outdoor demand exceeds the residential indoor demand in the Cooperative Growth, Adaptive Innovation, and Hot Growth scenarios. Outdoor demands increased significantly for the Hot Growth scenario, due to an increase in outdoor demands coupled with the "Hot and Dry" climate.

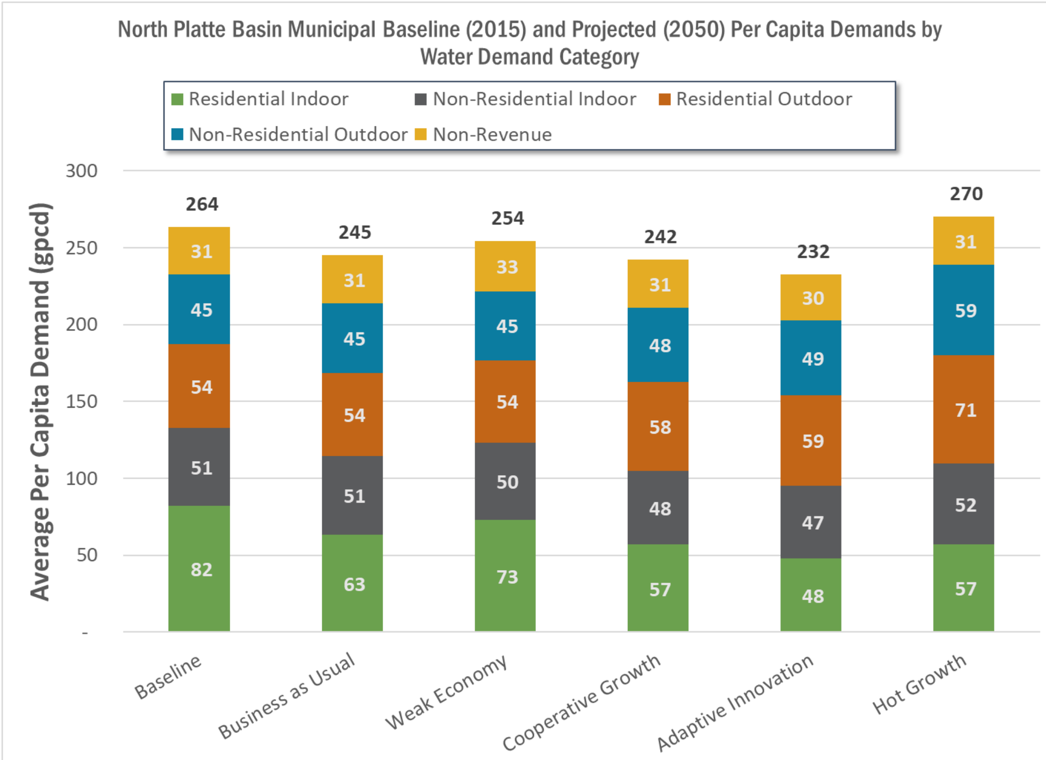

Figure 3-28: North Platte Basin Municipal Baseline and Projected Per Capita Demands by Water Demand Category.

Figure 3-29 demonstrates the influence of the climate driver on per capita water demands, with outdoor demands increasing by 15 to 27 gpcd with the climate change factors applied. Without the climate change factors, the per capita demand projections range from 210 to 254 gpcd, as compared to the SWSI 2010 projection of 225 gpcd for medium population with active conservation[25].

[25] SWSI 2010 projected per capita demands include savings from passive conservation.

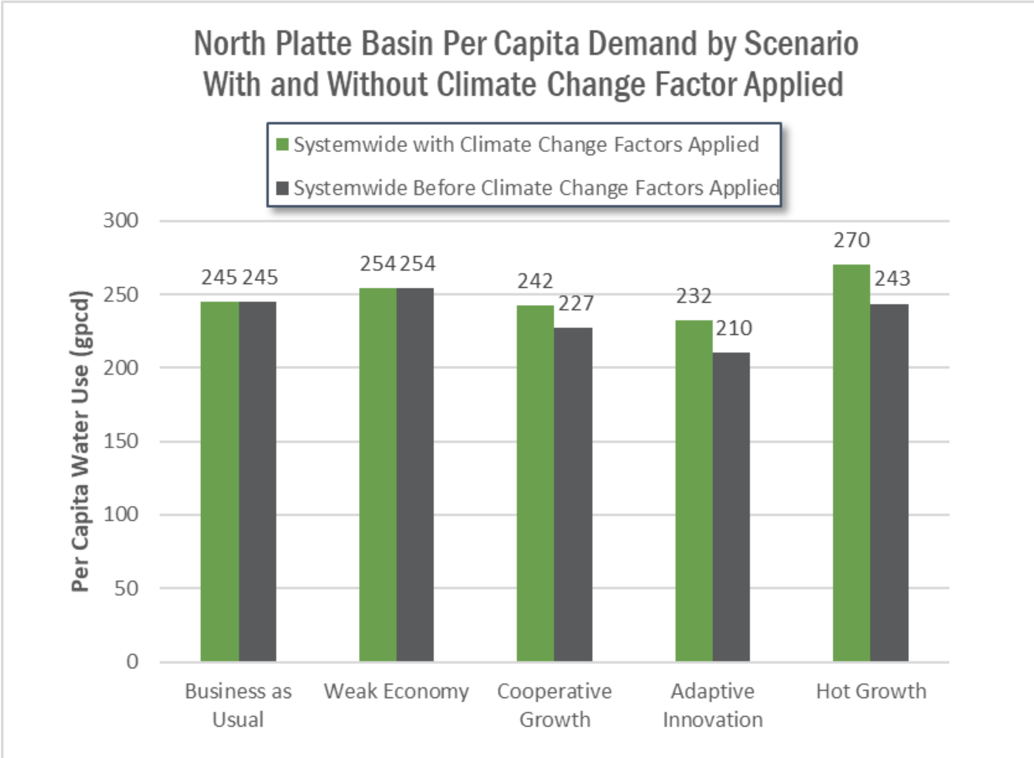

Figure 3-29: Effect of Climate Change Driver on the North Platte Basin Average Per Capita Demand.

The North Platte Basin municipal baseline and projected volumetric demands are provided in Table 3-18, showing the combined effect of population and per capita demands. Municipal demands are projected to change from approximately 400 AFY in 2015 to between 300 and 440 AFY in 2050.

Table 3-18: North Platte Basin Municipal Baseline and Projected Volumetric Demands by County (AFY).

County	Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Jackson	400	351	301	328	355	441
Basin Total	400	351	301	328	355	441

The baseline and projected demand distributions are shown in Table 3-19 and Figure 3-30 also shows how the population varies between the scenarios. Hot Growth is the only planning scenario in which the projected demands increase from the baseline; all other planning scenarios show an overall decrease in demands by 2050.

Table 3-19: North Platte Basin Municipal Baseline and Projected Demand by Demand Category (AFY).

Scenario	Residential Indoor	Non-Residential Indoor	Residential Outdoor	Non-Residential Outdoor	Non-Revenue	System wide
Baseline (2015)	124	77	82	69	47	400
Business as Usual	91	73	78	65	45	351
Weak Economy	86	59	63	53	39	301
Cooperative Growth	77	65	79	66	42	328
Adaptive Innovation	73	72	90	75	45	355
Hot Growth	93	86	115	96	51	441

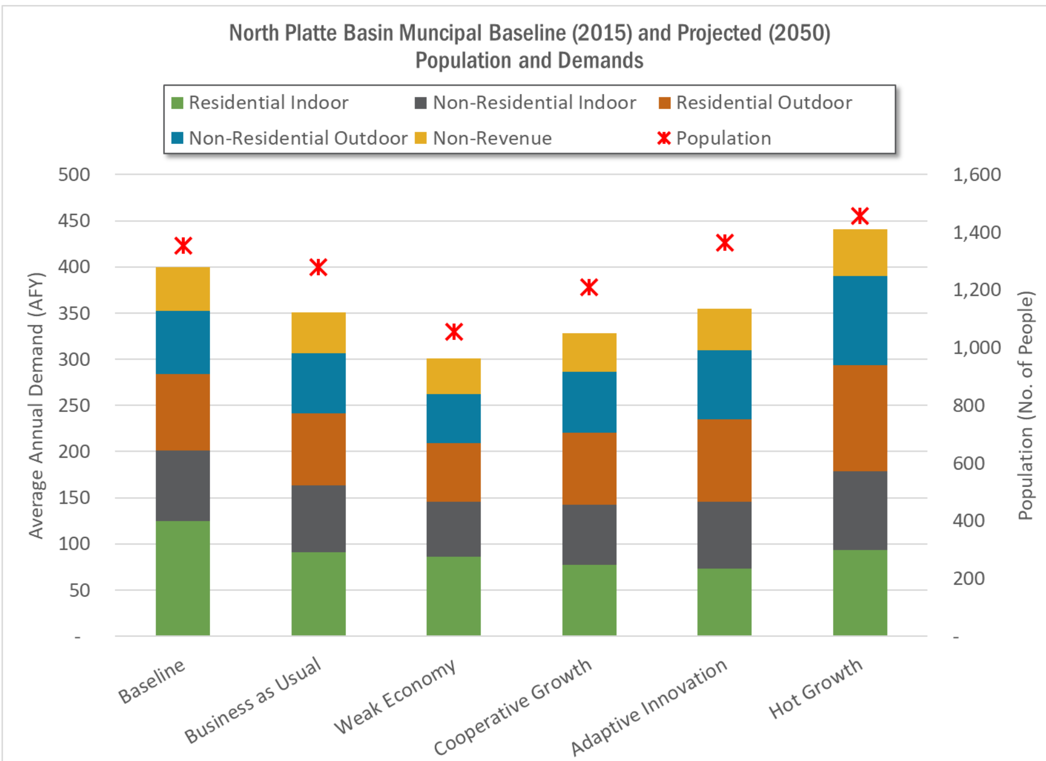

Figure 3-30: North Platte Basin Baseline and Projected Population and Municipal Demands.

3.4.2 INDUSTRIAL

There are no baseline or projected industrial demands in the North Platte Basin.

3.4.3 TOTAL

North Platte Basin combined M&I demand projections for 2050 range from approximately 300 AFY under Weak Economy to 440 AFY in the Hot Growth scenario, as shown in Figure 3-31. There are no current or projected industrial demands. On a basin scale, the demand projections follow the statewide sequence of the scenario rankings described in the CWP.

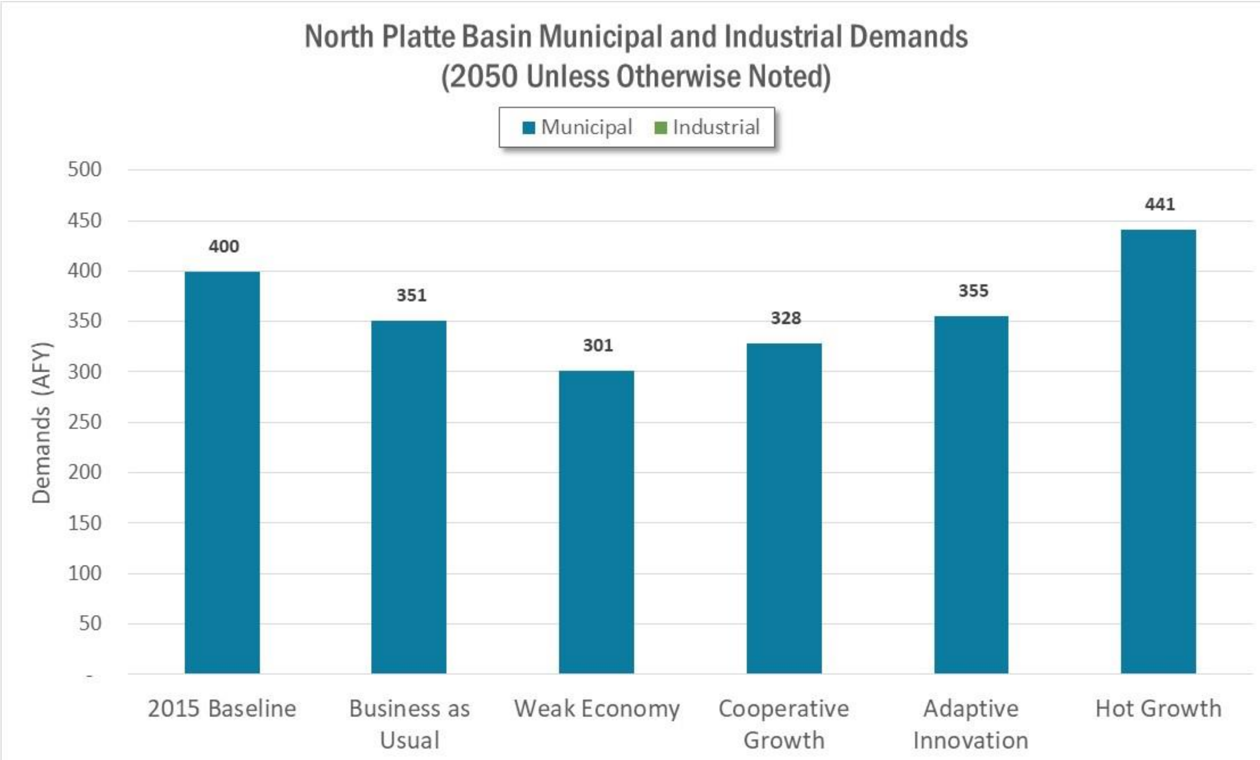

Figure 3-31: North Platte Basin Baseline and Projected M&I Demands.

3.5 RIO GRANDE BASIN

3.5.1 MUNICIPAL

3.5.1.1 POPULATION

The Rio Grande Basin currently includes less than 1% of the statewide population. Between the years 2015 and 2050, it is projected to change from approximately 46,000 people to between 42,000 and 67,000 people in the low and high growth scenarios, respectively. Using the specific numbers, this ranges from an 8% decrease in population to an increase of 46%.

Table 3-20 shows how population growth is projected to vary across counties under each planning scenario. Four of the six counties are projected to decrease in population for the low growth scenario. All counties are expected to grow by about 24% to 75% in the high growth scenario. The most populous county, Alamosa County, is projected to increase under all scenarios and account for most of the growth.

Table 3-20: Rio Grande Basin Baseline and Projected Populations by County

County	2015 Population	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Alamosa	15,968	22,934	17,593	21,701	26,209	27,990
Conejos	8,074	8,997	6,902	8,513	10,282	10,980
Costilla	3,572	3,934	3,018	3,722	4,496	4,801
Mineral	729	959	736	907	1,096	1,170
Rio Grande	11,413	11,612	8,907	10,988	13,270	14,172
Saguache	6,219	6,668	5,115	6,309	7,620	8,138
Basin Total	45,975	55,104	42,270	52,141	62,972	67,252

The Rio Grande Basin baseline for the Technical Update, which is based on 2015 population, is approximately 8% lower than the SWSI 2010 baseline, which used 2008 population. All SWSI 2010 projections for 2050 exceeded the Technical Update population projections for all planning scenarios by at least 10%. Comparison of the baseline and projected populations for the Technical Update and SWSI 2010 are shown in Figure 3-32.

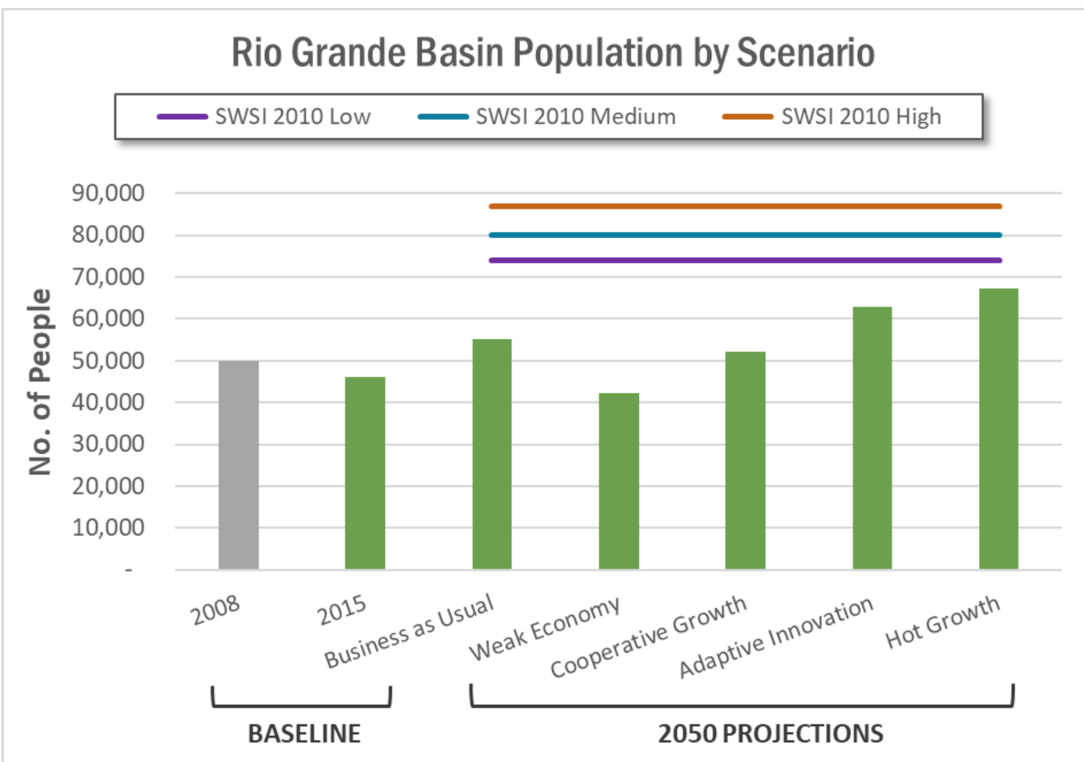

Figure 3-32: Rio Grande Basin Baseline and Projected Population.

3.5.1.2 WATER DEMANDS

The Rio Grande Basin baseline water demands were primarily based on BIP data, with approximately 79% of the baseline population demands represented by those reports. This is the highest representation of BIP data for any basin in the state. Data from WEPs represent demands for another 9% of the population, requiring about 12% of the basin's baseline population demands to be estimated, as shown in Figure 3-33.

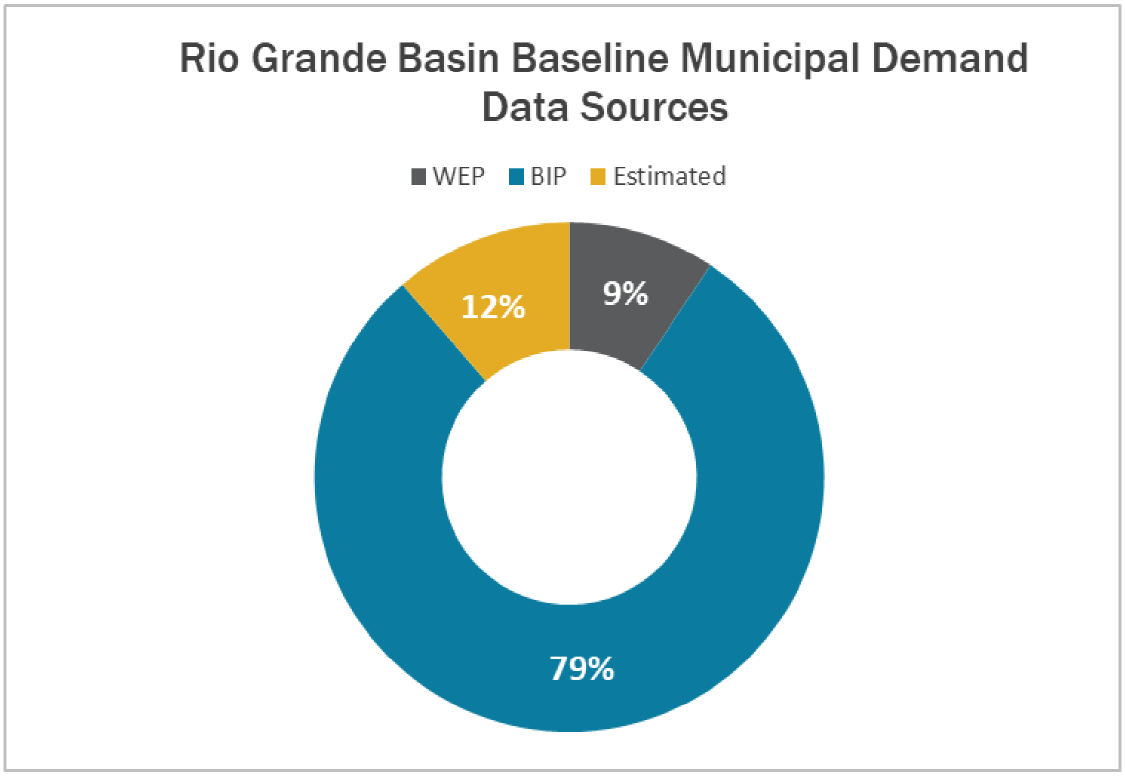

Figure 3-33: Rio Grande Basin Baseline Municipal Demand Data Sources.

The Rio Grande Basin average baseline per capita systemwide demand has decreased significantly from 314 gpcd in SWSI 2010 to approximately 207 gpcd. Baseline demands have also decreased for every county.

Table 3-21 represents baseline and projected per capita demands for counties within the basin.

Table 3-21: Rio Grande Basin Municipal Baseline and Projected Per Capita Demands by County (gpcd).

County	SWSI 2010 Baseline [a]	Technical Update Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Alamosa	258	201	188	190	181	171	204
Conejos	521	279	255	265	249	232	273
Costilla	193	157	153	155	150	142	166
Mineral	296	154	151	151	146	139	164
Rio Grande	306	203	193	198	189	177	207
Saguache	274	168	162	165	159	150	176
Basin Total	314	207	194	198	188	177	209

a) SWSI 2010 per capita values from SWSI 2010 Appendix H, Table 3-1 (CWCB, 2010a).

The Rio Grande Basin had very high water demand data representation, primarily from the BIP. However, the BIP data did not include breakdowns of water use by demand category. Because there was insufficient demand category data available to apply county-specific distributions, the statewide weighted average demand category distribution was used for the Rio Grande Basin, as shown in Figure 3-34.

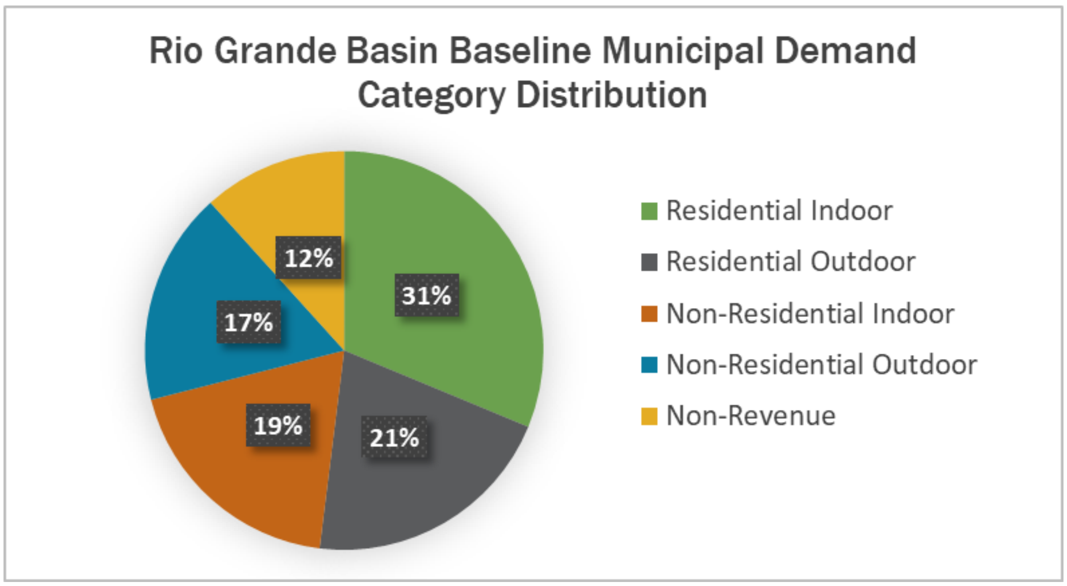

Figure 3-34: Rio Grande Basin Baseline Municipal Demand Category Distribution.

Figure 3-35 provides a summary of per capita baseline and projected water demands for the Rio Grande Basin. Systemwide, the projected per capita demands decrease relative to the baseline except for the Hot Growth scenario. The residential indoor demand is the greatest demand category in all scenarios except Adaptive Innovation and Hot Growth where the residential outdoor demand is higher. Aside from the Hot Growth scenario, there is minimal variation in outdoor demands between scenarios. This is due to the scenario pairing of water demand reductions and climate drivers, particularly for the Adaptive Innovation scenario which has high outdoor reductions coupled with the “Hot and Dry” climate. Outdoor demands increased significantly for the Hot Growth scenario, due to an increase in outdoor demands coupled with the "Hot and Dry" climate.

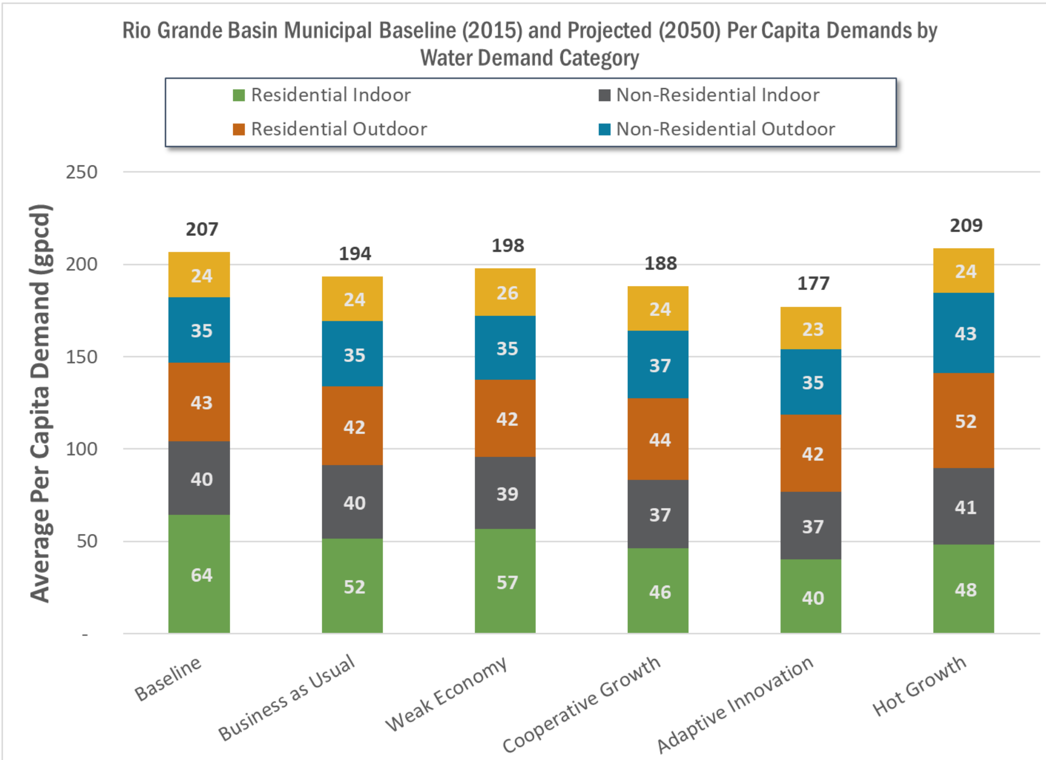

Figure 3-35: Rio Grande Basin Municipal Baseline and Projected Per Capita Demands by Water Demand Category.

Figure 3-36 demonstrates the influence of the climate driver on per capita water demands, with outdoor demands increasing by 10 to 14 gpcd with the climate change factors applied. Without the climate change factors, the per capita demand projections range from 166 to 198 gpcd, which are all lower than the SWSI 2010 projection of 228 gpcd for medium population with active conservation[26]. This is partly due to the Technical Update baseline being lower than the SWSI 2010 baseline.

[26] SWSI 2010 projected per capita demands include savings from passive conservation.

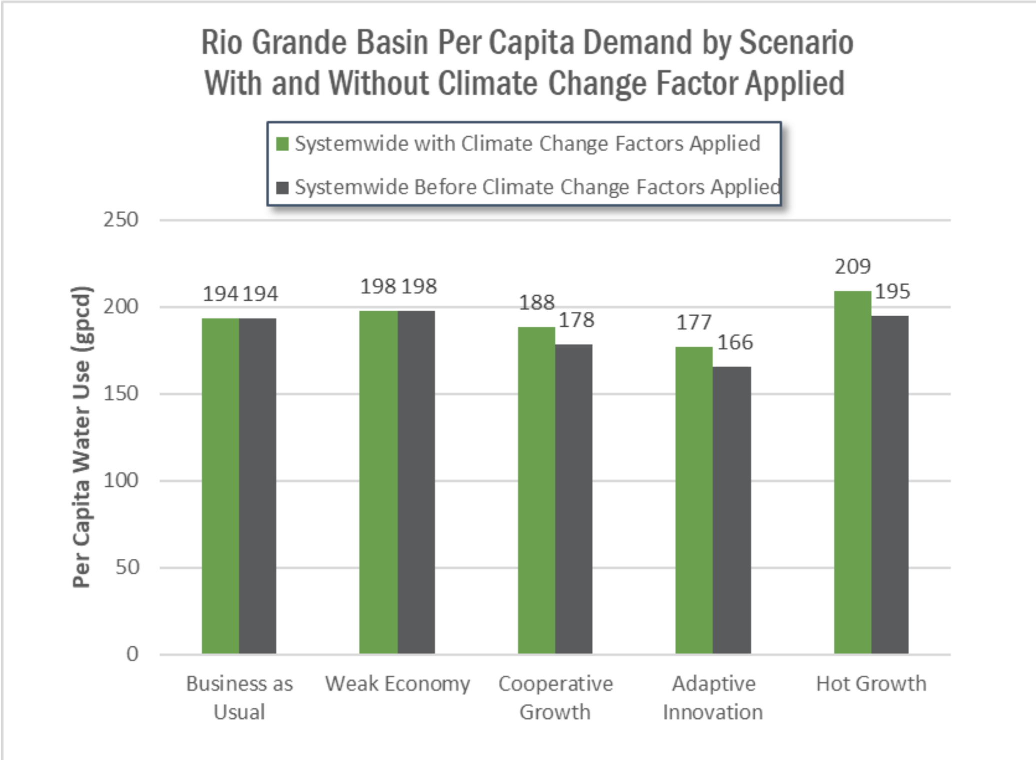

Figure 3-36: Effect of Climate Change Driver on the Rio Grande Basin Average Per Capita Demand.

The Rio Grande Basin municipal baseline and projected volumetric demands are provided in Table 3-22, showing the combined effect of population and per capita demands. Municipal demands are projected to grow from approximately 11,000 AFY in 2015 to between 9,000 and 16,000 AFY in 2050. Alamosa County accounts for around one-third of the baseline demand followed by Conejos and Rio Grande Counties, each at about one-quarter of the basin demand.

Table 3-22: Rio Grande Basin Municipal Baseline and Projected Volumetric Demands by County (AFY).

County	Baseline	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Alamosa	3,592	4,822	3,749	4,411	5,030	6,382
Conejos	2,525	2,567	2,050	2,371	2,672	3,353
Costilla	627	676	523	624	713	894
Mineral	126	162	125	148	170	215
Rio Grande	2,601	2,507	1,980	2,324	2,633	3,288
Saguache	1,168	1,213	943	1,122	1,279	1,601
Basin Total	10,639	11,947	9,370	11,000	12,496	15,732

The baseline and projected demand distributions are shown in Table 3-23 and Figure 3-37 also shows how the population varies between the scenarios. The projected demands increase from the baseline under all scenarios except for Weak Economy.

Table 3-23: Rio Grande Basin Municipal Baseline and Projected Volumetric Demands by Demand Category (AFY).

Scenario	Residential Indoor	Non-Residential Indoor	Residential Outdoor	Non-Residential Outdoor	Non-Revenue	System wide
Baseline (2015)	3,312	2,052	2,191	1,828	1,256	10,639
Business as Usual	3,181	2,455	2,621	2,187	1,503	11,947
Weak Economy	2,685	1,851	1,976	1,648	1,210	9,370
Cooperative Growth	2,701	2,173	2,564	2,140	1,422	11,000
Adaptive Innovation	2,828	2,587	2,971	2,479	1,631	12,496
Hot Growth	3,646	3,105	3,897	3,251	1,834	15,732

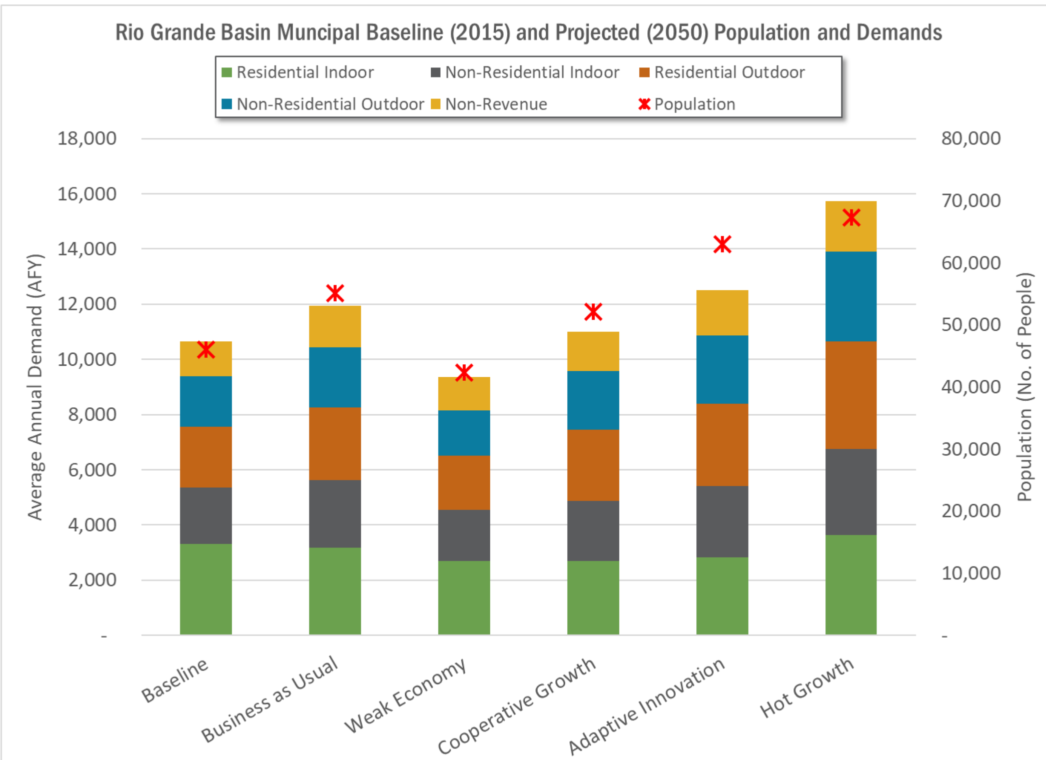

Figure 3-37: Rio Grande Basin Baseline and Projected Population and Municipal Demands.

3.5.2 INDUSTRIAL

The Rio Grande Basin currently includes about 4% of the statewide industrial demand. Modeled industrial demands in this basin are associated with the Large Industry and Energy Development sub-sectors. While there are approximately 5 acres of snowmaking in the Rio Grande Basin, the estimated demand of less than 5 AFY was not represented in the projections because it is relatively insignificant as compared to other industrial demands in the basin. with no demands projected for the Snowmaking and Thermoelectric sub-sectors. Basin-scale industrial demands are shown on Figure 3-38 and county-scale industrial demands are summarized in Table 3-24.

There were no Large Industry demands in the Rio Grande Basin in SWSI 2010. Large Industry demands were added based on information in the BIP, which described the following categories water uses: i) fisheries and aquaculture; ii) agricultural product processing; and iii) other, including manufacturing. The baseline Large Industry demand is 7,660 AFY and projected demands range from 7,960 AFY to 9,760 AFY.

Energy Development demands were also updated based on information in the BIP. The total baseline Energy Development demand is 200 AFY and is associated with solar power generation. Solar power generation demands are projected to increase to 800 AFY and oil and gas development demands are projected to be 200 AFY, totaling 1,000 AFY. Demand projections were not varied by scenario as directed by BIP representatives.

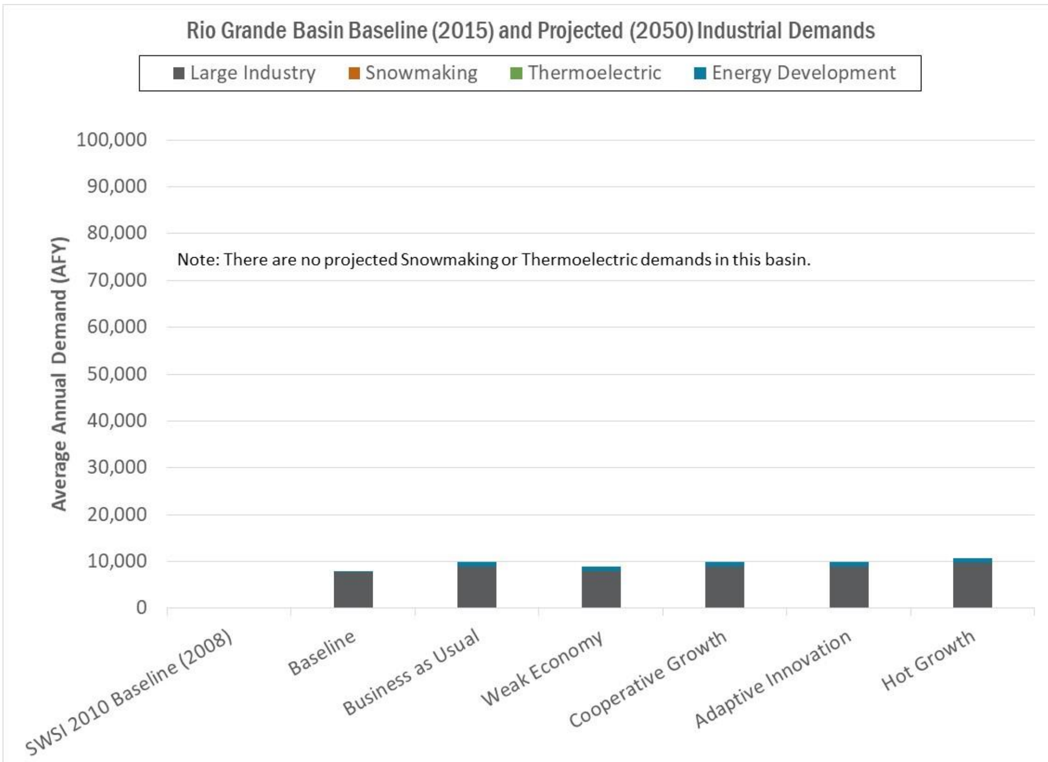

Figure 3-38: Rio Grande Basin Industrial Baseline and Projected Demands.

Table 3-24: Rio Grande Basin Industrial Baseline and Projected Demands by County (AFY).

County	Sub-Sector	Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Alamosa	Large Industry	2,830	3,190	2,870	3,190	3,190	3,510
	Snowmaking	-	-	-	-	-	-
	Thermoelectric	-	-	-	-	-	-
	Energy Development	160	640	640	640	640	640
Conejos	Large Industry	100	160	140	160	160	180
	Snowmaking	-	-	-	-	-	-
	Thermoelectric	-	-	-	-	-	-
	Energy Development	20	80	80	80	80	80
Costilla	Large Industry	160	280	250	280	280	310
	Snowmaking	-	-	-	-	-	-
	Thermoelectric	-	-	-	-	-	-
	Energy Development	-	-	-	-	-	-
Rio Grande	Large Industry	2,340	2,670	2,400	2,670	2,670	2,940
	Snowmaking	-	-	-	-	-	-
	Thermoelectric	-	-	-	-	-	-
	Energy Development	20	280	280	280	280	280
Saguache	Large Industry	2,230	2,560	2,300	2,560	2,560	2,820
	Snowmaking	-	-	-	-	-	-
	Thermoelectric	-	-	-	-	-	-
	Energy Development	-	-	-	-	-	-
Basin Total		7,860	9,860	8,960	9,860	9,860	10,760

3.5.3 TOTAL

Rio Grande Basin combined M&I demand projections for 2050 range from approximately 18,000 AFY in the Weak Economy scenario to 26,000 AFY in the Hot Growth scenario, as shown in Figure 3-39. Industrial demands account for about 40% to 50% of the M&I demands. On a basin scale, the demand projections follow the statewide volumetric demand sequence of the scenario rankings described in the CWP.

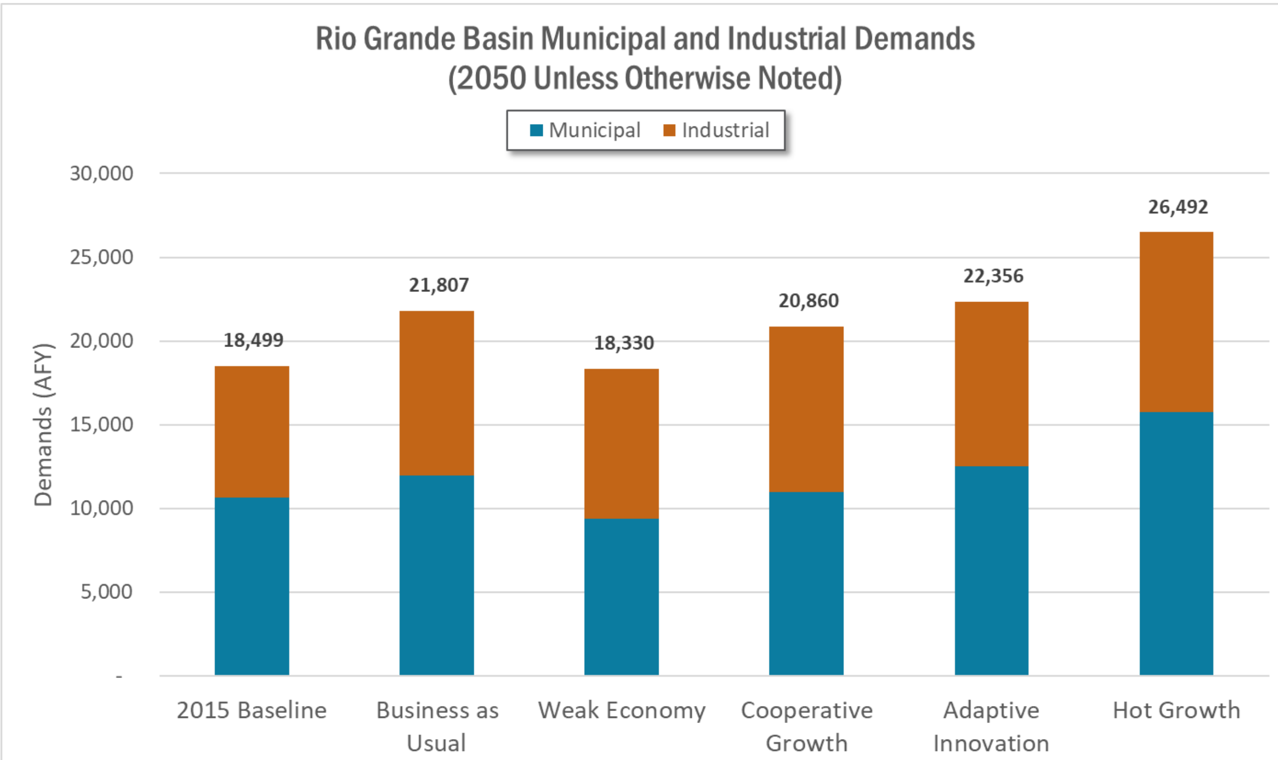

Figure 3-39: Rio Grande Basin Baseline and Projected M&I Demands.

3.6 SOUTH PLATTE BASIN

3.6.1 MUNICIPAL

For purposes of the Technical Update M&I demand reporting, the South Platte Basin includes three sub-basins (as shown in Figure 3-1): the Metro Region as defined by the basin roundtables, the Republican Basin, and the South Platte Without Metro or Republican Sub-Basin.[27] SWSI 2010 included the Republican Basin M&I demands in the reporting of the South Platte Basin demands, but separately reported demands for the Metro Region. The three sub-basins are each summarized in the following sections, along with the combined South Platte Basin.

[27] The hydrologic modelling for the Technical Update includes one model for the Republican Basin and a separate model for the South Platte Basin that includes the Metro Region.

3.6.1.1 POPULATION

Combined South Platte Basin

The South Platte Basin (including the three sub-basins described below) is currently the most populous basin and includes about 70% of the statewide population. Between the years 2015 and 2050, the South Platte Basin is projected to grow from approximately 3.8 million people to between 5.4 million and 6.5 million people in the low and high growth scenarios, respectively. Using the specific numbers, this is an increase in population of 42% to 70%. Table 3-25 shows how population growth is projected to vary across counties under each planning scenario and is summarized by sub-basin.

Metro Region Sub-Basin

The Metro Region currently includes about 51% of the statewide population. Between the years 2015 and 2050, it is projected to grow from approximately 2.8 million to between 3.8 million and 4.3 million people in the low and high growth scenarios, respectively. Using the specific numbers, this is an increase in population of 38% to 56%.

All counties are projected to increase in population under all scenarios, ranging from about 16% to 186% increases. Denver County is currently the most populous county at about 680,000 people and is projected to remain the largest under all scenarios, ranging from about 896,000 to 1.07 million people by 2050. However, under some scenarios, Arapahoe and Adams Counties increase by more people. Elbert County, which currently has about 1% of the sub-basin population, is projected to have the highest growth rate for an individual county, with increases of about 153% to 185% in the low and high growth scenarios, respectively. Even with this large percentage increase, Elbert County is still projected to account for only about 1% of the future total sub-basin population.

Republican Sub-Basin

The Republican Sub-Basin currently includes less than 1% of the statewide population. Between the years 2015 and 2050, it is projected to change from approximately 32,000 to between 30,000 and 41,000 people in the low and high growth scenarios, respectively. Using the specific numbers, this ranges from a decrease in population of 4% to an increase of 30%.

All counties are projected to increase in population for the high growth scenario, but only Lincoln and Logan Counties are projected to increase in the low growth scenario. The two most populous counties, Yuma County followed by Kit Carson County, are projected to account for most of the growth and remain the largest population centers in the basin. Lincoln County, which currently has about 3% of the sub-basin population, is projected to have the highest growth rate for an individual county, with increases of about 31% to 77% in the low and high growth scenarios, respectively. Even with this large percentage increase, Lincoln County is still projected to account for only about 5% of the future total sub-basin population.

South Platte Without Metro Region or Republican Sub-Basin

The portion of the South Platte Basin that is not included in the Metro Region or the Republican Sub-Basins currently includes about 19% of the statewide population. Between the years 2015 and 2050, it is projected to grow from approximately 1.0 million to between 1.6 million and 2.3 million people in the low and high growth scenarios, respectively. Using the specific numbers, this is an increase in population of 54% to 123%.

All counties are projected to increase in population for the high growth scenario, but three of the eleven counties are projected to decrease in the low growth scenario. Larimer County is currently the most populous county, followed by Boulder and Weld Counties. Weld County has the largest projected growth rate and becomes t`he most populous county in the sub-basin under low and high scenarios, followed by Larimer and Boulder Counties.

Table 3-25: South Platte Basin and Sub-Basin Baseline and Projected Populations by County

County	2015 Population	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
METRO REGION SUB-BASIN						
Adams	489,923	890,148	836,501	842,289	886,001	946,216
Arapahoe	629,066	899,738	845,513	851,363	895,546	956,410
Broomfield	64,656	95,566	89,806	90,428	95,121	101,585
Denver	680,658	952,955	895,523	980,185	1,067,123	1,012,979
Douglas	322,198	482,824	453,725	456,865	480,575	513,236
Jefferson	564,619	694,943	653,061	657,579	691,705	738,716
Elbert*	17,006	45,725	42,970	43,267	45,512	48,606
Sub-Basin Total	2,768,126	4,061,899	3,817,099	3,921,976	4,161,584	4,317,749
REPUBLICAN SUB-BASIN						
Cheyenne*	1,144	1,026	876	970	1,111	1,187
Kit Carson	8,219	9,595	8,194	9,079	10,397	11,104
Lincoln*	1,064	1,627	1,390	1,540	1,763	1,883
Logan*	2,032	2,711	2,315	2,565	2,938	3,137
Phillips	4,307	4,372	3,734	4,137	4,737	5,059
Sedgwick*	1,008	984	840	931	1,066	1,139
Washington*	3,790	3,763	3,214	3,561	4,078	4,355
Yuma	10,052	11,398	9,734	10,785	12,351	13,190
Sub-Basin Total	31,616	35,476	30,297	33,569	38,441	41,054
SOUTH PLATTE WITHOUT METRO OR REPUBLICAN SUB-BASIN						
Boulder	318,570	447,843	382,458	460,770	558,020	518,258
Clear Creek	9,392	12,448	10,631	11,779	13,488	14,405
Gilpin	5,824	6,626	5,659	6,270	7,180	7,668
Larimer	332,830	543,588	464,224	564,664	677,320	629,057
Logan*	20,090	26,805	22,891	25,364	29,045	31,019
Morgan	28,230	42,734	36,495	40,436	46,306	49,453
Park	16,716	23,797	20,323	22,518	25,786	27,539
Sedgwick*	1,381	1,348	1,151	1,275	1,461	1,560
Teller*	11,490	16,323	13,939	15,445	17,687	18,889
Washington*	1,044	1,037	885	981	1,123	1,200
Weld	284,571	734,343	627,129	779,320	915,004	849,804
Sub-Basin Total	1,030,138	1,856,891	1,585,784	1,928,822	2,292,420	2,148,852
TOTAL SOUTH PLATTE BASIN						
Basin Total	3,829,880	5,954,267	5,433,180	5,884,366	6,492,445	6,507,655

**Counties with population located in multiple basins. This table represents the portion of the county located in each sub-basin.*

The Metro Region baseline for the Technical Update, which is based on 2015 population, is approximately 10% higher than the SWSI 2010 baseline, which used 2008 population. The SWSI 2010 medium growth population projection for 2050 exceeded the low and medium projections in the Technical Update for the Business as Usual, Weak Economy, and Cooperative Growth scenarios by up to about 9% and the SWSI 2010 high growth projection also exceeded the Technical Update high growth projections for the Adaptive Innovation and Hot Growth scenarios by up to about 9%. Comparison of the baseline and projected populations for the Technical Update and SWSI 2010 are shown in Figure 3-40.

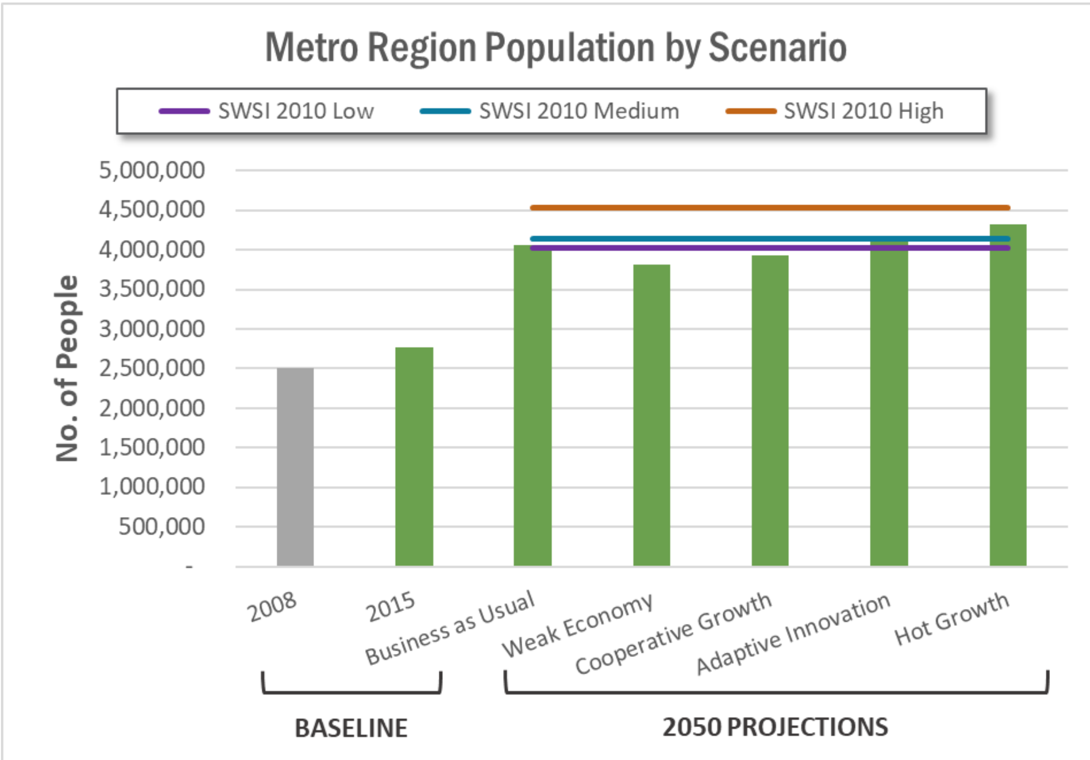

Figure 3-40: Metro Region Baseline and Projected Population.

The South Platte Basin including the Republican Sub-Basin but without the Metro Region Sub-Basin baseline for the Technical Update, which is based on 2015 population, is approximately 9% higher than the SWSI 2010 baseline, which used 2008 population. The SWSI 2010 low growth projection for 2050 exceeded the Technical Update projection for the Weak Economy scenario by about 12%. The SWSI 2010 medium growth population projection exceeded the Technical Update projection for Business as Usual but was slightly lower than the Cooperative Growth projection. The SWSI 2010 high growth population projection exceeded Technical Update projections by at least 12%. Comparison of the baseline and projected populations for the Technical Update and SWSI 2010 are shown in Figure 3-41.

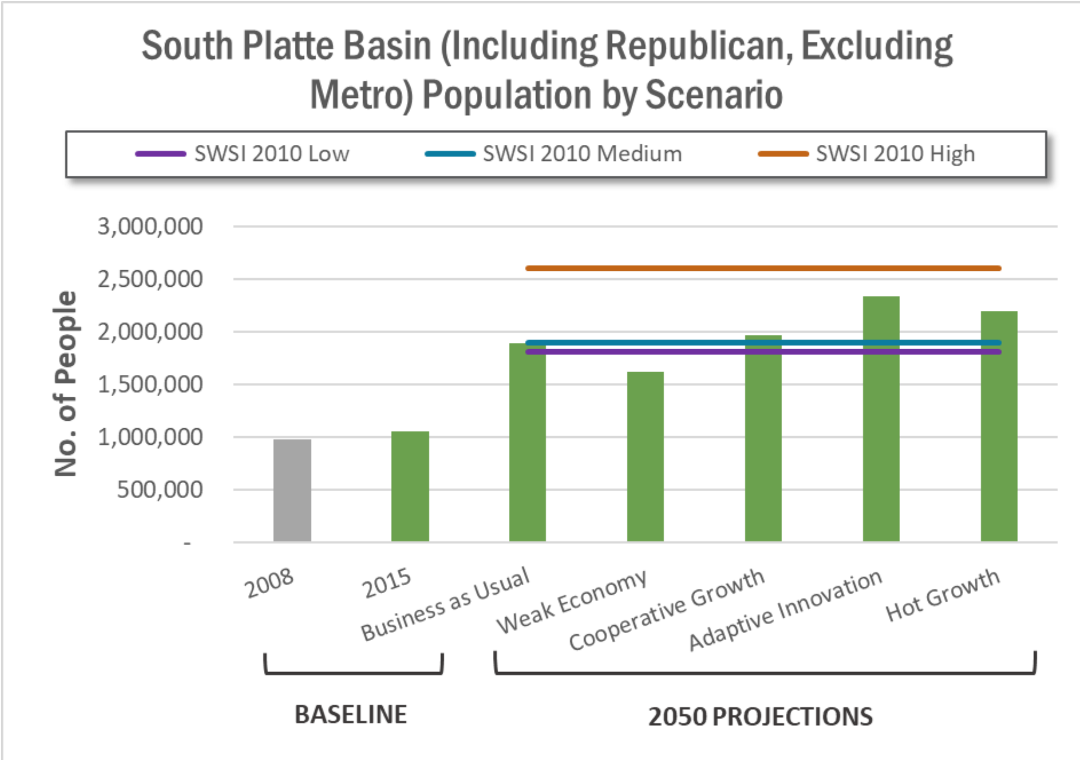

Figure 3-41: South Platte Basin Including Republican, Excluding Metro Region, Baseline and Projected Population.

3.6.1.2 WATER DEMANDS

The Metro Region baseline water demands were largely based on water provider-reported data, with approximately 86% of the baseline population demands represented by 1051 data, and 4% form WEPs, requiring 10% of the basin's baseline population demands to be estimated, as shown in Figure 3-42. This is the highest representation of 1051 data for any basin in the state.

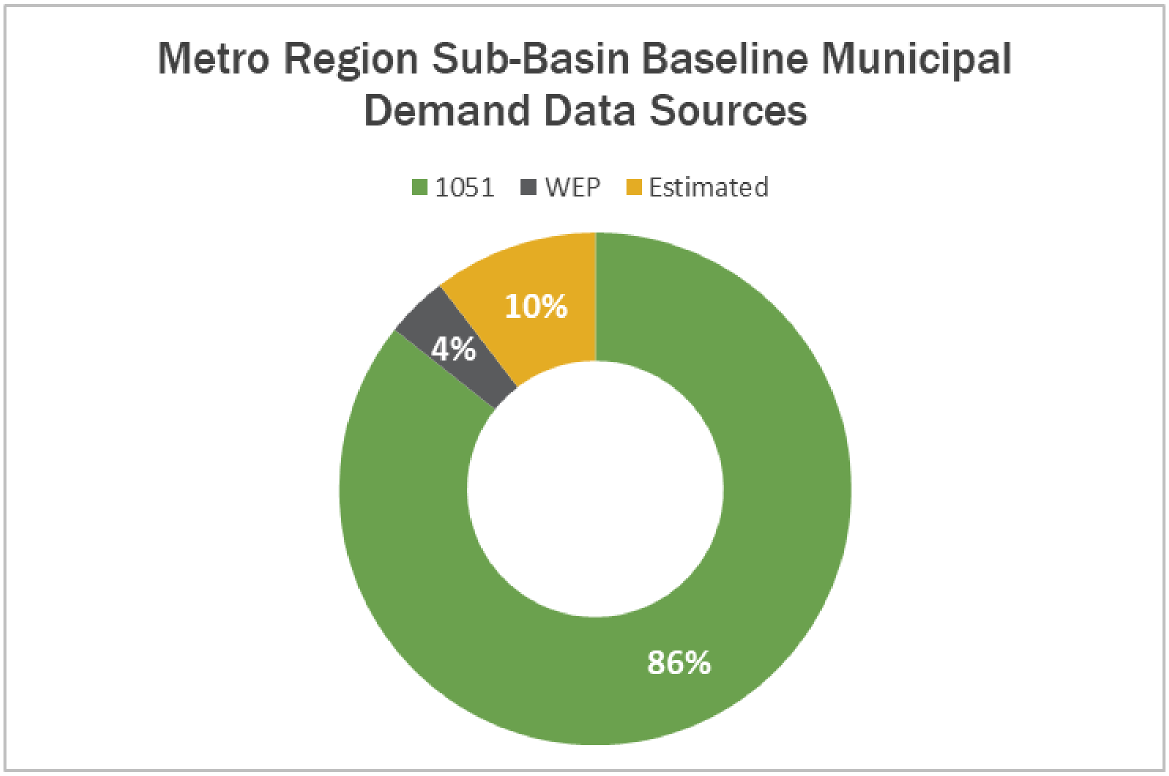

Figure 3-42: Metro Region Sub-Basin Baseline Municipal Water Demand Data Sources.

The Republican Sub-Basin baseline water demands were largely estimated. Approximately 13% of the baseline population demands were represented by water provider outreach and 4% from WEPs, requiring demands for about 83% of the basin's baseline population demands to be estimated, as shown in Figure 3-43. This is the second highest percentage of estimated demands for a basin in the state.

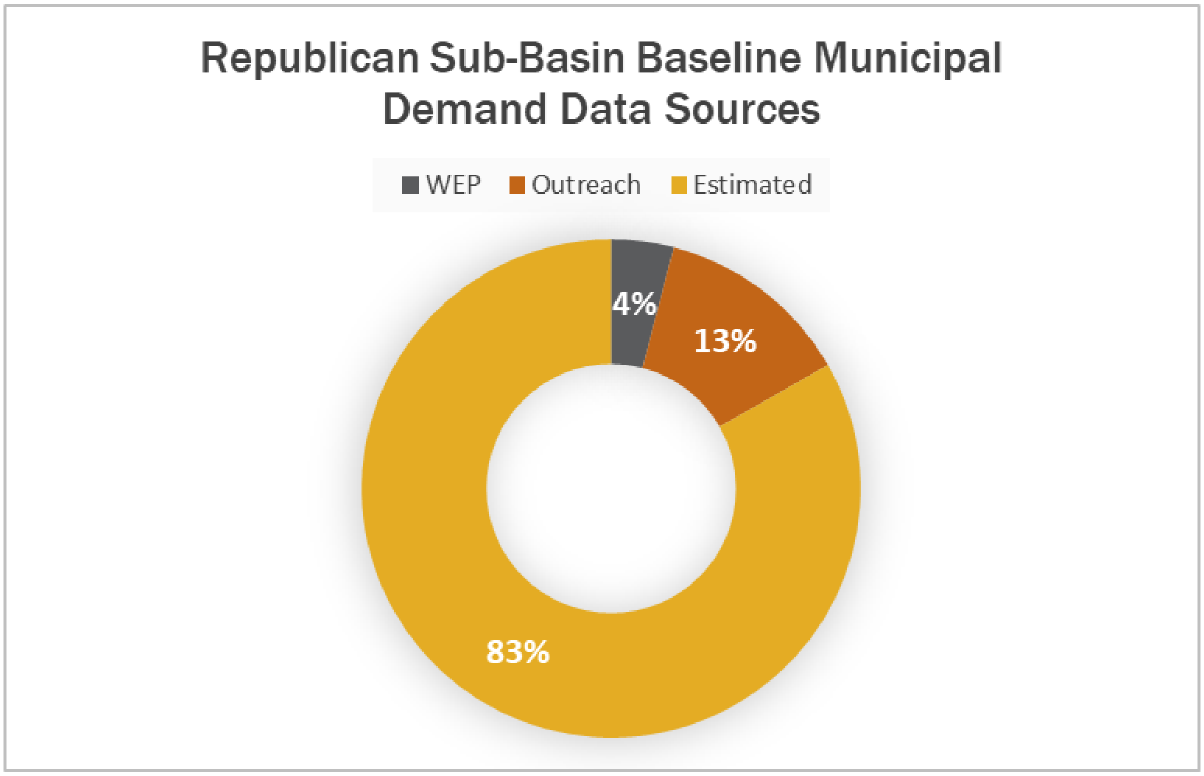

Figure 3-43: Republican Basin Baseline Municipal Water Demand Data Sources.

The baseline demands for the South Platte Without Metro or Republican Sub-Basin were also largely based on water provider-reported data, with approximately 60% of the baseline population demands represented by 1051 data, 27% from WEPs, and 0.1% from water provider outreach, requiring 13% of the basin's population demands to be estimated, as shown in Figure 3-44.

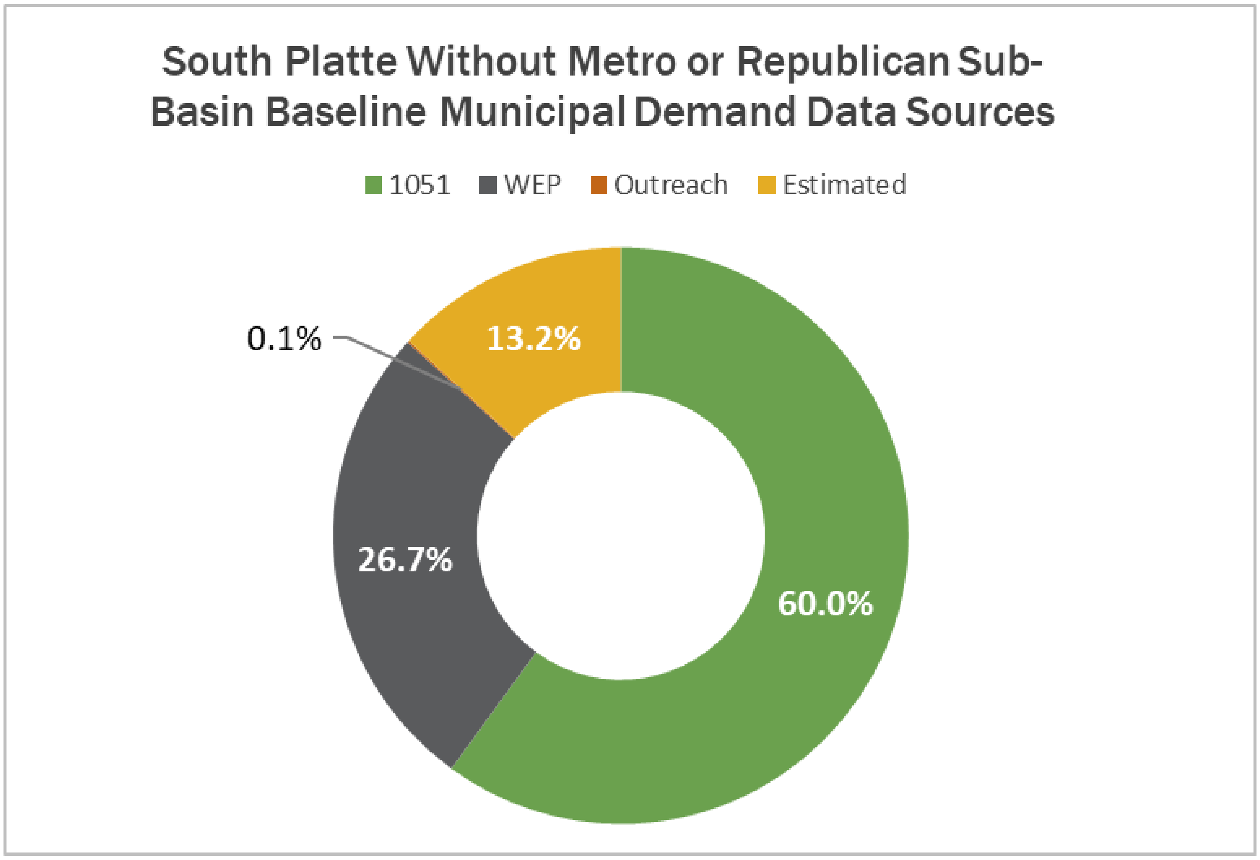

Figure 3-44: South Platte Without Metro or Republican Sub-Basin Baseline Municipal Demand Data Sources.

The combined South Platte Basin, including the Metro Region and the Republican Basin, average baseline per capita systemwide demand is approximately 152 gpcd. The Metro Region baseline has decreased from 155 gpcd in SWSI 2010 to approximately 141 gpcd and demands for most of the counties within this basin have also decreased. The average for the portion of the South Platte Without Metro or Republican Sub-Basin cannot be directly compared to SWSI 2010 because of differences in reporting. While baseline demands for counties outside of the Metro Region are generally higher, many decreased as compared to SWSI 2010. Some of the higher per capita values in the more rural areas are non-residential demands associated with businesses such as dairies, which are included in the municipal rather than industrial demand category. Table 3-26 represents baseline and projected per capita demands for counties within the basin.

Table 3-26: South Platte Basin Municipal Baseline and Projected Per Capita Demands by County (gpcd).

County	SWSI 2010 Baseline [a]	Technical Update Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
METRO REGION SUB-BASIN							
Adams	142	135	129	128	121	118	141
Arapahoe	164	127	123	122	116	112	133
Broomfield	177	175	167	165	157	152	181
Denver	163	141	144	138	135	132	152
Douglas	146	130	126	125	118	114	137
Elbert*	111	137	138	135	128	124	149
Jefferson	152	163	162	162	155	150	174
Sub-Basin Total	155	141	138	135	130	126	148
REPUBLICAN SUB-BASIN							
Cheyenne*	183	222	216	218	207	199	229
Kit Carson	334	210	206	204	192	187	220
Lincoln*	254	238	222	222	211	203	238
Logan*	319	341	306	312	290	276	325
Phillips	390	252	244	245	229	221	258
Sedgwick*	322	284	272	277	260	249	288
Washington*	320	215	210	211	198	192	223
Yuma	281	261	250	250	234	226	266
Sub-Basin Total	NA	245	236	236	221	214	251
SOUTH PLATTE BASIN WITHOUT METRO OR REPUBLICAN SUB-BASIN							
Boulder	176	143	140	139	131	126	151
Clear Creek	224	265	243	247	230	220	259
Gilpin	75	216	204	207	195	186	218
Larimer	178	191	179	180	168	161	190
Logan*	319	341	306	312	290	276	325
Morgan	241	387	355	356	335	322	381
Park	110	147	145	145	137	132	156
Sedgwick*	322	284	272	277	260	249	288
Teller*	173	163	159	159	152	146	171
Washington*	320	215	210	211	198	192	223
Weld	186	179	180	175	167	162	198
Sub-Basin Total	NA	181	176	174	164	158	190
TOTAL SOUTH PLATTE BASIN							
Basin Total	NA	152	150	147	142	137	163

a) SWSI 2010 per capita values from SWSI 2010 Appendix H, Table 3-1 (CWCB, 2010a).

**Counties with population located in multiple basins. Per capita demand is calculated at a county level.*

The demand category distributions were individually evaluated for each sub-basin and the sub-basin average was used for counties within the respective sub-basin that had insufficient data to prepare a county-specific distribution. A summary of each sub-basin is provided below.

The Metro Region sub-basin baseline municipal water demands are comprised of approximately 53% indoor, 39% outdoor, and 8% non-revenue water uses, as shown in Figure 3-45. On a basin scale, the non-revenue water demand as a percentage of the systemwide demands is one of the lowest throughout the state. With a significant portion of the state population located in the Metro sub-basin, this relatively low non-revenue water demand percentage has a significant impact on the statewide average non-revenue water percentage.

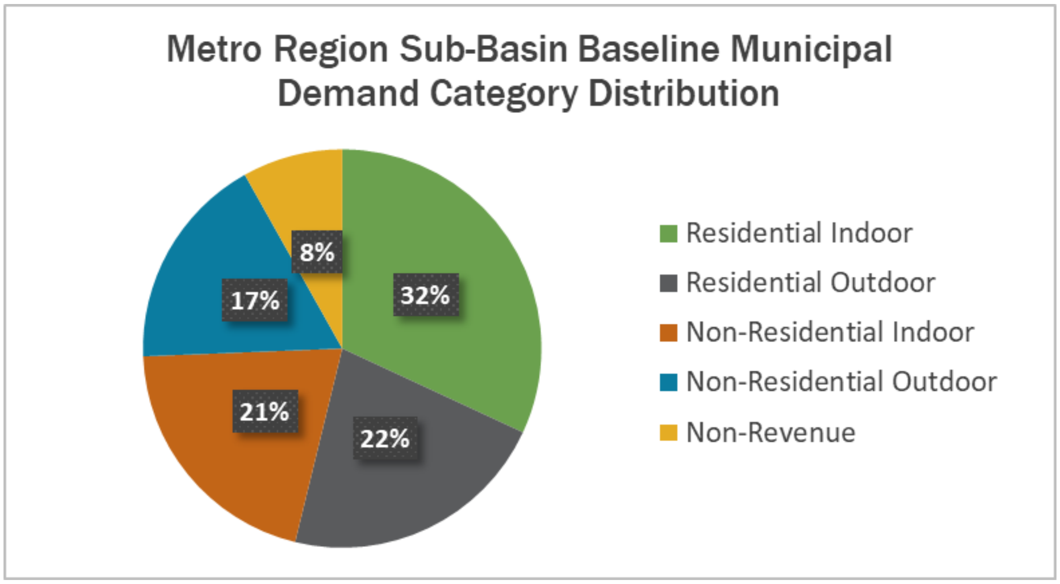

Figure 3-45: Metro Region Sub-Basin Baseline Municipal Demand Category Distribution.

The Republican sub-basin baseline municipal water demands are comprised of approximately 54% indoor, 40% outdoor, and 6% non-revenue water uses, as shown in Figure 3-46. The Republican sub-basin demands were mostly based on estimated demand data and the demand category distribution was based on outreach from one water provider. Two of the eighteen counties had sufficient demand category data available to apply a county-specific distribution. The basin average demand category distribution was used for the remaining counties. On a basin and sub-basin scale, the non-revenue water demand as a percentage of the systemwide demands is the lowest throughout the state.

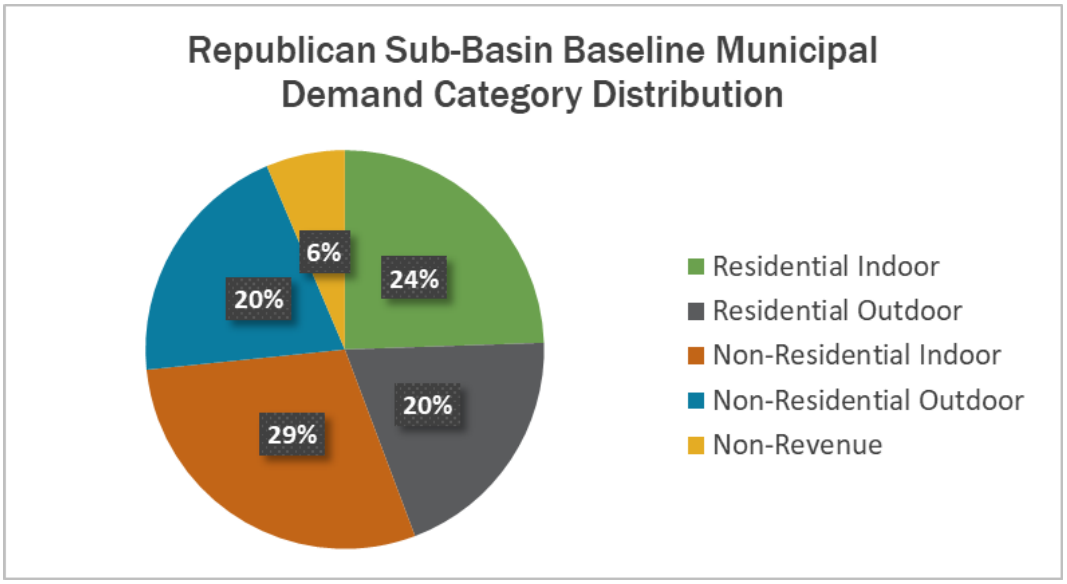

Figure 3-46: Republican Sub-Basin Baseline Municipal Demand Category Distribution.

The baseline municipal water demands for the South Platte Without Metro or Republican Sub-Basin are comprised of approximately 45% indoor use, 41% outdoor, and 14% non-revenue water, as shown in Figure 3-47. The South Platte Without Metro or Republican Sub-Basin had sufficient demand category data represented in seven of the eleven counties located in the basin. The basin average demand category distribution was used for the remaining counties. With the second largest population of all basins and sub-basins in the state, and a lower indoor demand percentage and higher non-revenue demand percentage than the Metro Region Sub-Basin, the influence of the South Platte Without Metro or Republican Sub-Basin on the statewide average partially offsets the Metro Region influence in these categories.

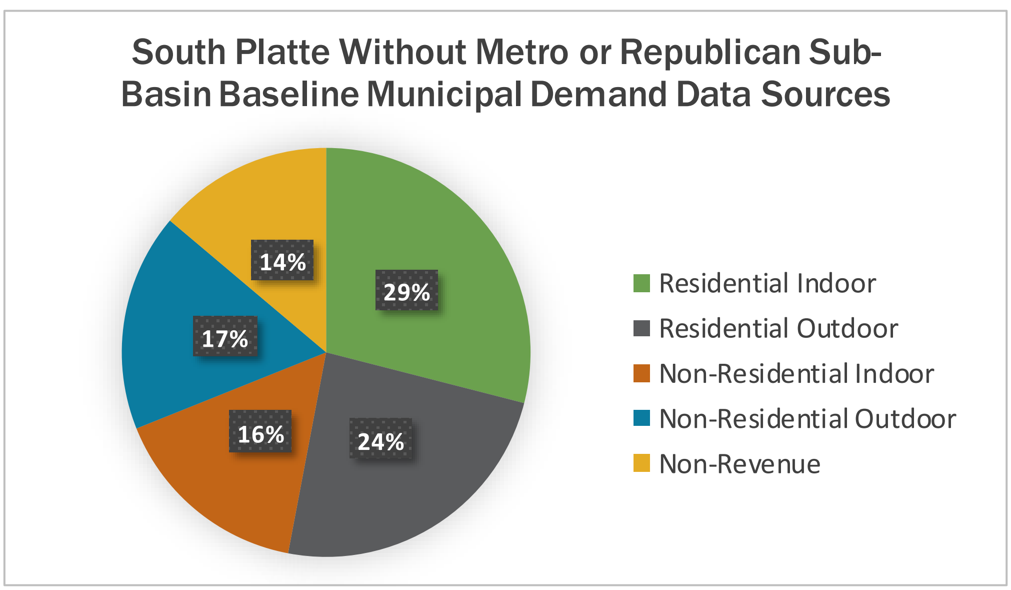

Figure 3-47: South Platte Without Metro or Republican Sub-Basin Baseline Municipal Demand Category Distribution.

Figure 3-48 provides a summary of per capita baseline and projected water demands for the Metro Region. Systemwide, the projected per capita demands decrease relative to the baseline except for the Hot Growth scenario. Consistently across all scenarios, residential indoor demand is the greatest individual demand category while non-revenue water is the lowest. Outdoor demands increased significantly for the Hot Growth scenario, due to an increase in outdoor demands coupled with the “Hot and Dry” climate.

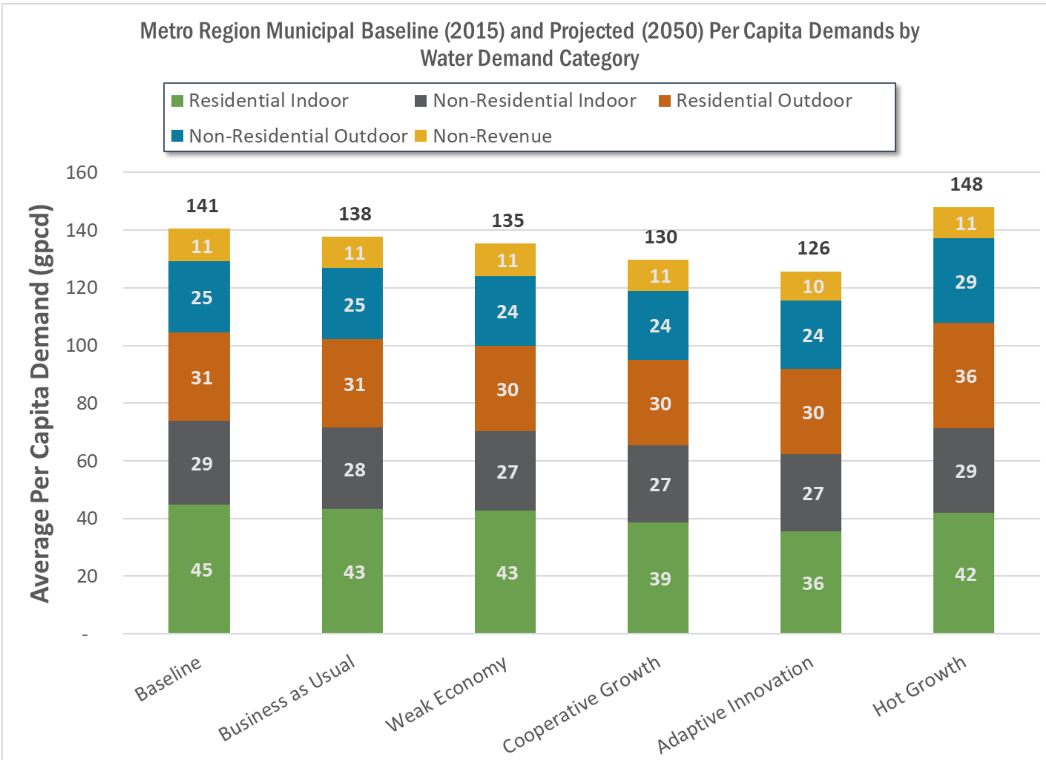

Figure 3-48: Metro Region Municipal Baseline and Projected Per Capita Demands by Water Demand Category.

Figure 3-49 provides a summary of per capita baseline and projected water demands for the Republican Sub-Basin. Systemwide, the projected per capita demands decrease relative to the baseline except for the Hot Growth scenario. Consistently across all scenarios, non-residential indoor demand is the greatest individual demand category while non-revenue water is the lowest. Outdoor demands increased significantly for the Hot Growth scenario, due to an increase in outdoor demands coupled with the “Hot and Dry” climate.

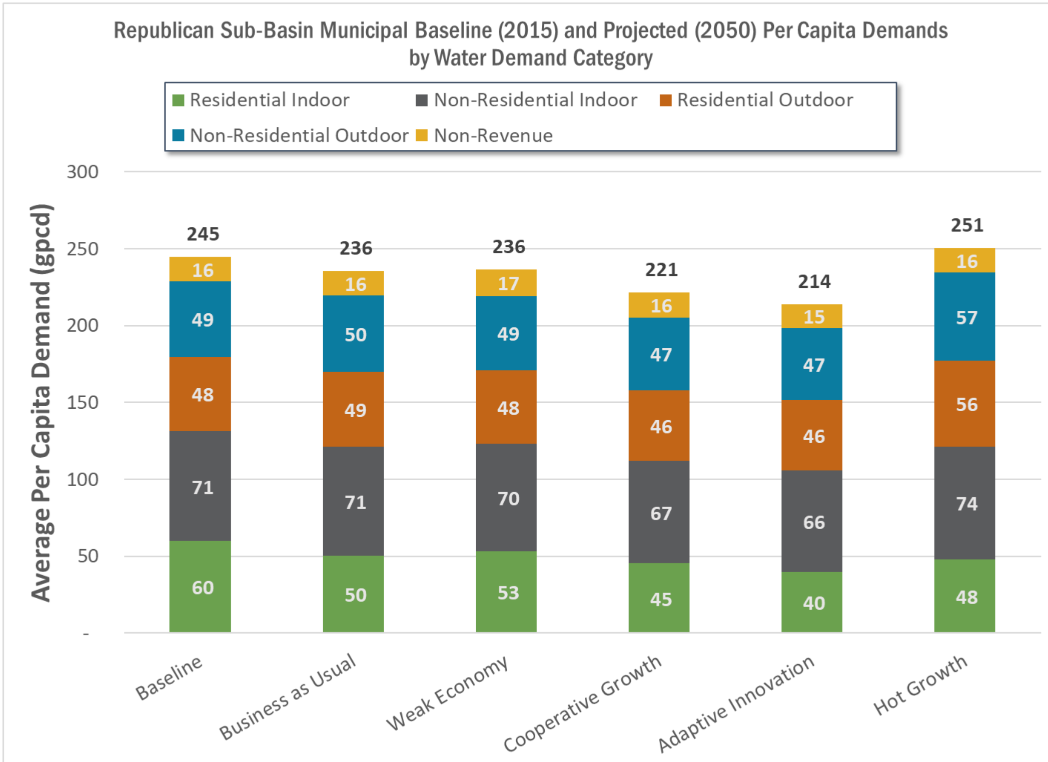

Figure 3-49: Republican Sub-Basin Municipal. Baseline and Projected Per Capita Demands by Water Demand Category.

Figure 3-50 provides a summary of per capita baseline and projected water demands for the South Platte Without Metro or Republican Sub-Basin. Systemwide, the projected per capita demands decrease relative to the baseline except for the Hot Growth scenario. The residential indoor demand is the greatest demand category in the baseline, but the residential outdoor demand exceeds the residential indoor demand in the Cooperative Growth, Adaptive Innovation, and Hot Growth scenarios. Outdoor demands increased significantly for the Hot Growth scenario, due to an increase in outdoor demands coupled with the “Hot and Dry” climate.

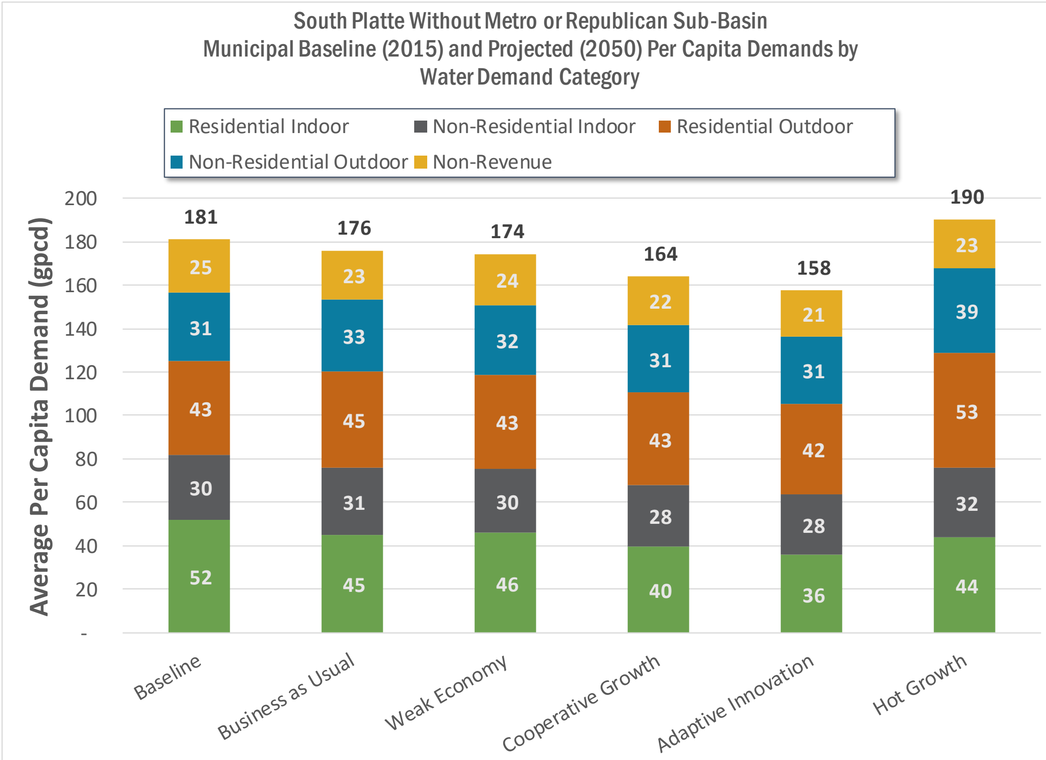

Figure 3-50: South Platte Without Metro or Republican Sub-Basin Municipal Baseline and Projected Per Capita Demands by Water Demand Category.

Figure 3-51 demonstrates the influence of the climate driver on per capita water demands in the Metro Region, with outdoor demands increasing by 5 to 8 gpcd with the climate change factors applied. Without the climate change factors, the per capita demand projections range from 119 to 140 gpcd, which exceed the SWSI 2010 projection of 118 gpcd for medium population with active conservation[28].

[28] SWSI 2010 projected per capita demands include savings from passive conservation.

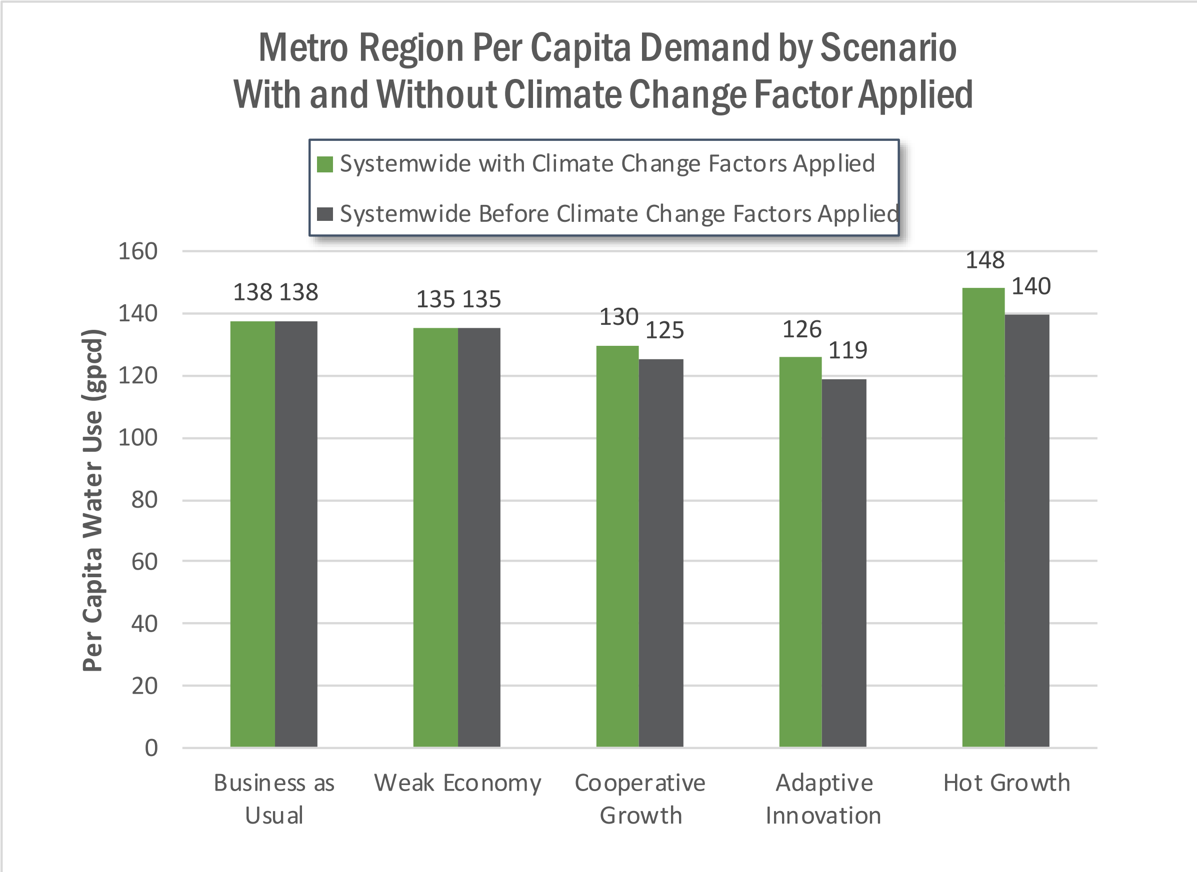

Figure 3-51: Effect of Climate Change Driver on the Metro Region Average Per Capita Demand.

Figure 3-52 demonstrates the influence of the climate driver on per capita water demands in the Republican Sub-Basin, with outdoor demands increasing by 4 to 12 gpcd with the climate change factors applied. Without the climate change factors, the per capita demand projections range from 204 to 239 gpcd. SWSI 2010 did not explicitly evaluate the Republican Sub-Basin. For the South Platte Basin, including the Republican Sub-Basin but excluding the Metro Region, SWSI 2010 projected a per capita demand of 129 gpcd for medium population with active conservation[29].

[29] SWSI 2010 projected per capita demands include savings from passive conservation.

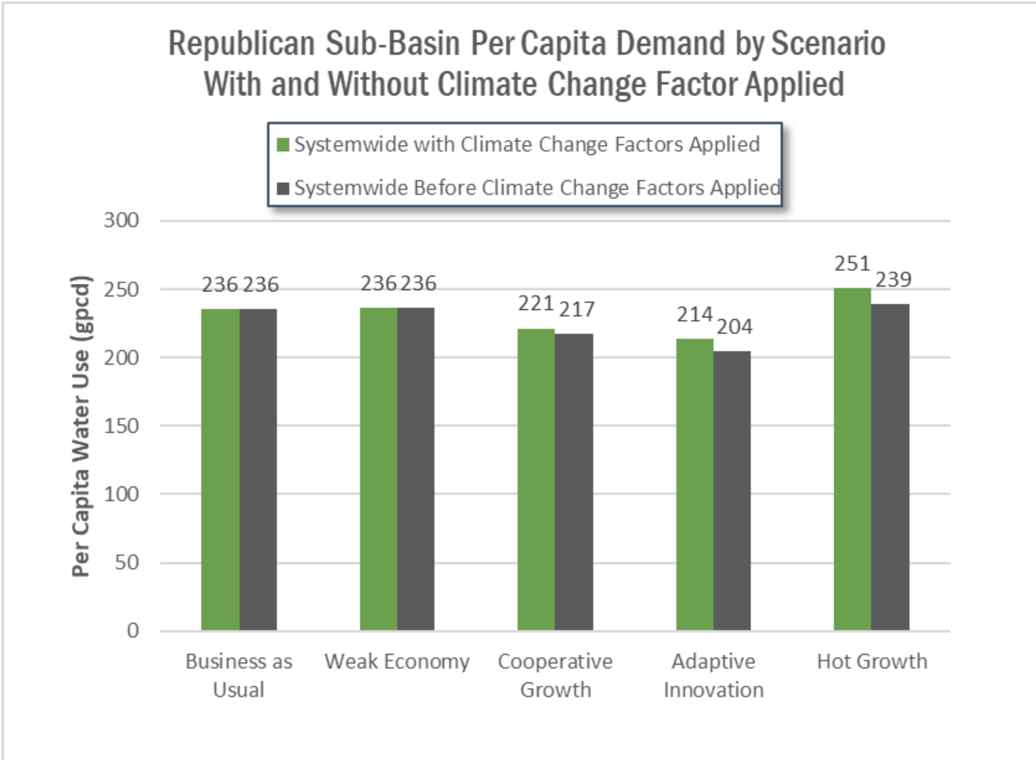

Figure 3-52: Effect of Climate Change Driver on the Republican Sub-Basin Average Per Capita Demand.

Figure 3-53 demonstrates the influence of the climate driver on per capita water demands in the South Platte Without Metro or Republican Sub-Basin, with outdoor demands increasing by 6 to 11 gpcd with the climate change factors applied. Without the climate change factors, the per capita demand projections range from 149 to 179 gpcd. As previously described, SWSI 2010 did not explicitly evaluate the South Platte Without Metro or Republican Sub-Basin. For the South Platte Basin, including the Republican Sub-Basin but excluding the Metro Region, the SWSI 2010 projected per capita demand was 129 gpcd for medium population with active conservation[30].

[30] SWSI 2010 projected per capita demands include savings from passive conservation.

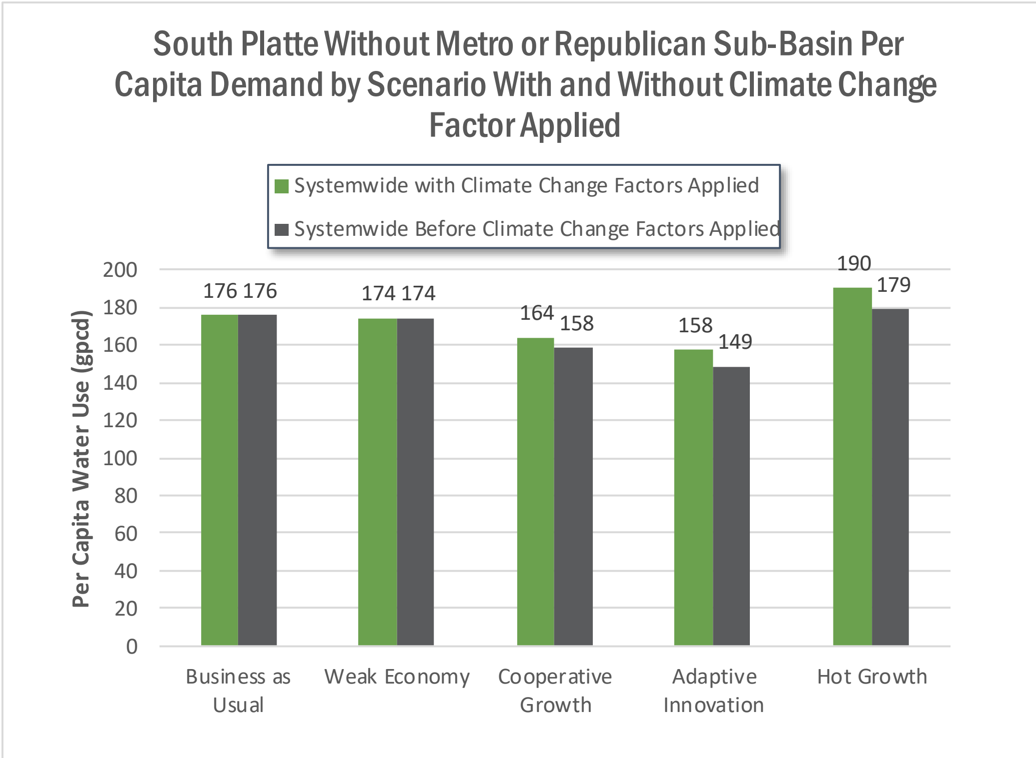

Figure 3-53: Effect of Climate Change Driver on the South Platte Without Metro or Republican Sub-Basin Average Per Capita Demand.

The total South Platte Basin municipal baseline and projected volumetric demands are provided in Table 3-27 and Table 3-28, showing the combined effect of population and per capita demands. Municipal demands are projected to grow from approximately 653,000 AFY in 2015 to between 900,000 and 1,200,000 AFY in 2050. The projected demands increase under all of the planning scenarios. The Metro Region accounts for about 67% of the baseline demand but slightly decreases as a percentage of the total basin demand under all of the planning scenarios.

Table 3-27: South Platte Basin Baseline and Projected Demands by County (AFY)

County	Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
METRO REGION SUB-BASIN						
Adams	73,865	128,982	119,888	114,098	116,998	149,049
Arapahoe	89,320	124,348	115,718	110,521	111,948	142,660
Broomfield	12,701	17,851	16,632	15,902	16,153	20,560
Denver	107,129	153,810	138,561	148,680	157,418	172,789
Douglas	47,090	68,206	63,425	60,612	61,411	78,861
Jefferson	103,021	126,239	118,247	114,122	115,932	143,829
Elbert*	2,619	7,066	6,498	6,214	6,317	8,137
Sub-Basin Total	435,745	626,501	578,969	570,151	586,176	715,885
REPUBLICAN SUB-BASIN						
Cheyenne*	285	248	214	225	248	304
Kit Carson	1,932	2,211	1,876	1,954	2,174	2,731
Lincoln*	284	404	345	364	401	502
Logan*	775	928	809	833	908	1,142
Phillips	1,218	1,193	1,024	1,061	1,175	1,464
Sedgwick*	321	299	261	272	297	367
Washington*	914	884	758	791	875	1,088
Yuma	2,936	3,192	2,731	2,823	3,130	3,925
Sub-Basin Total	8,666	9,361	8,019	8,323	9,208	11,524
SOUTH PLATTE BASIN WITHOUT METRO OR REPUBLICAN BASINS						
Boulder	51,028	70,079	59,666	67,765	78,616	87,389
Clear Creek	2,784	3,382	2,936	3,040	3,320	4,172
Gilpin	1,407	1,518	1,315	1,371	1,499	1,870
Larimer	71,037	108,813	93,801	106,439	121,795	133,966
Logan*	7,666	9,178	8,002	8,232	8,981	11,293
Morgan	12,246	16,987	14,567	15,158	16,720	21,099
Park	2,743	3,874	3,294	3,467	3,818	4,819
Sedgwick*	440	410	358	372	407	503
Teller*	2,095	2,915	2,483	2,627	2,892	3,627
Washington*	252	244	209	218	241	300
Weld	57,145	148,317	122,984	145,630	166,264	188,765
Sub-Basin Total	208,842	365,716	309,615	354,319	404,554	457,803
TOTAL SOUTH PLATTE BASIN						
Basin Total	653,253	1,001,578	896,603	932,792	999,938	1,185,213

**Counties with population located in multiple basins. This represents the systemwide demands associated with the Arkansas Basin only.*

Table 3-28: Total South Platte Basin Municipal Baseline and Projected Volumetric Demands by County (AFY).

Scenario	Residential Indoor	Non-Residential Indoor	Residential Outdoor	Non-Residential Outdoor	Non-Revenue	System wide
Baseline (2015)	201,179	126,911	146,739	114,162	64,261	653,253
Business as Usual	292,434	195,475	234,077	182,843	96,750	1,001,578
Weak Economy	265,948	172,871	205,653	160,940	91,192	896,603
Cooperative Growth	257,934	180,055	224,300	174,513	95,990	932,792
Adaptive Innovation	259,675	198,900	247,167	191,604	102,592	999,938
Hot Growth	311,080	222,253	305,972	238,591	107,317	1,185,213

Figure 3-54 shows how the projected demand and population vary between the scenarios for the Metro Region. All of the projection scenarios result in an increase relative to the baseline. Projected demand for Weak Economy, Cooperative Growth, and Adaptive Innovation are all within 3% of each other, even though each scenario has a different population projection – low, medium, and high, respectively.

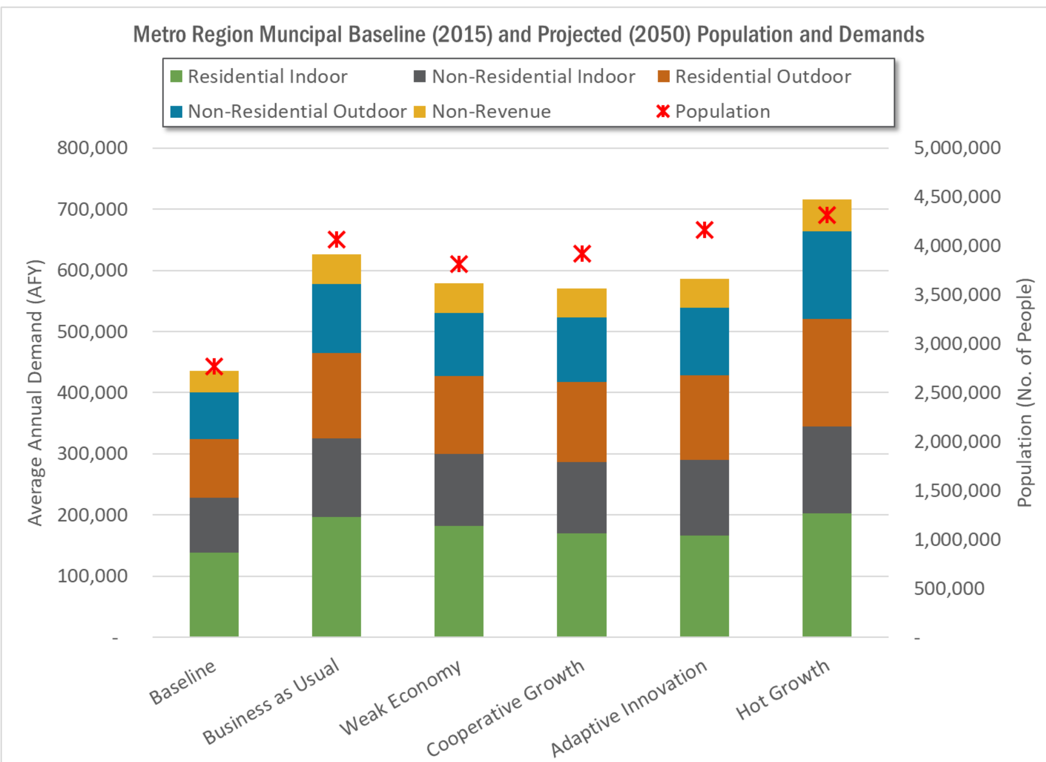

Figure 3-54: Metro Region Baseline and Projected Population and Municipal Demands.

Figure 3-55 shows how projected demand and population vary between the scenarios for the Republican Sub-Basin. Demands are projected to decrease relative to the baseline in the Weak Economy and Cooperative Growth scenarios.

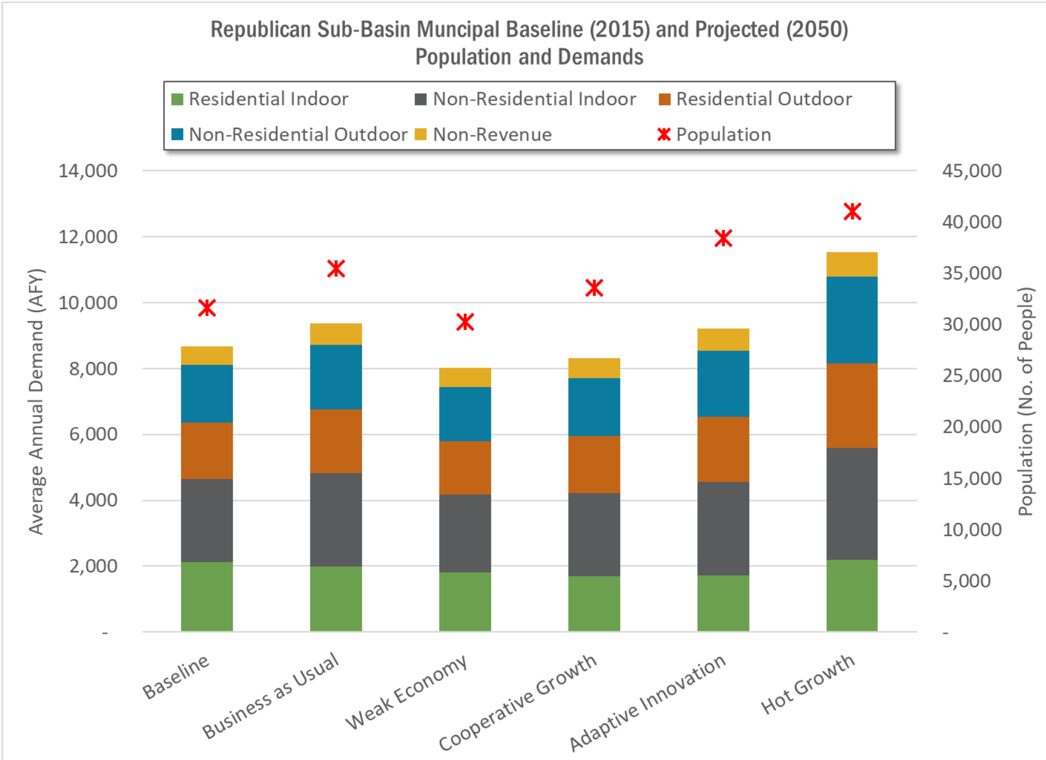

Figure 3-55: Republican Basin Baseline and Projected Population and Municipal Demands.

Figure 3-56 shows how the projected demand and population vary between the scenarios for the South Platte Without Metro or Republican Sub-Basin. All of the projection scenarios result in an increase relative to the baseline. Projected demands tend to follow population trends. This is not the case, however, for the Adaptive Innovation scenario in which the population exceeds the Hot Growth scenario population but the systemwide demand projection is lower. This shows the influence of projected per capita demands for this basin.

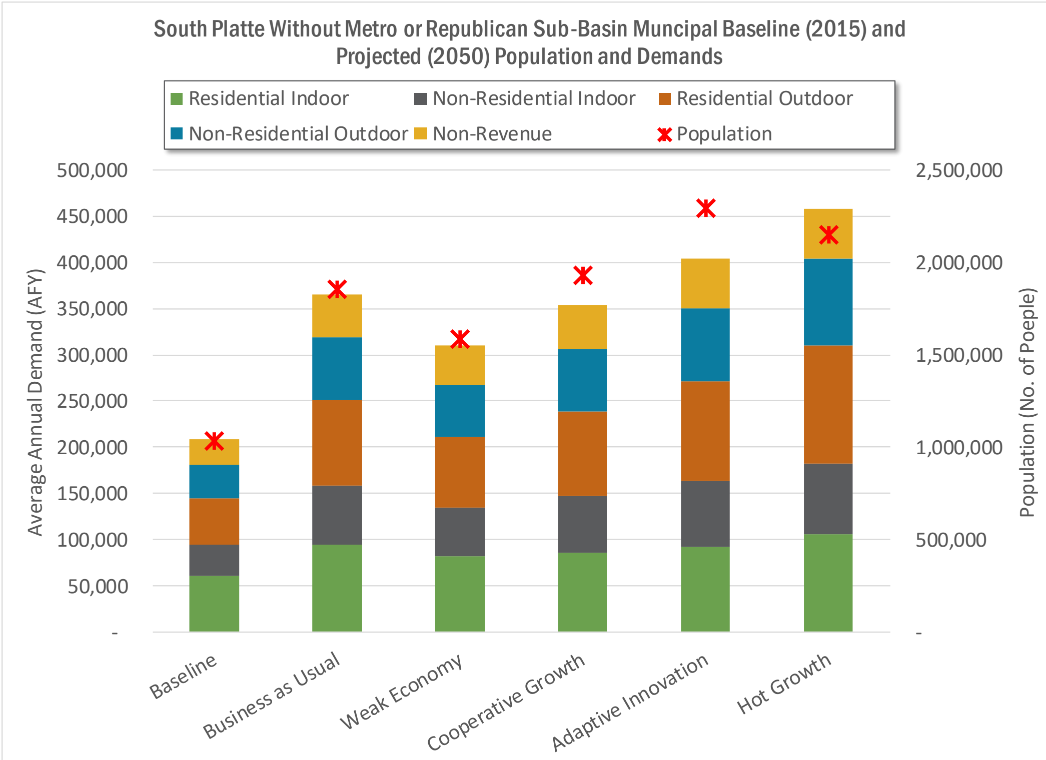

Figure 3-56: South Platte Without Metro or Republican Sub-Basin Baseline and Projected Population and Municipal Demands.

Figure 3-57 shows how projected demand and population vary between the scenarios for the entire South Platte Basin, including the three sub-basins. All of the projection scenarios result in an increase relative to the baseline. Projected demands in the Business as Usual and Adaptive Innovation scenarios are similar, although population projected for the Adaptive Innovation scenario is about 10% higher.

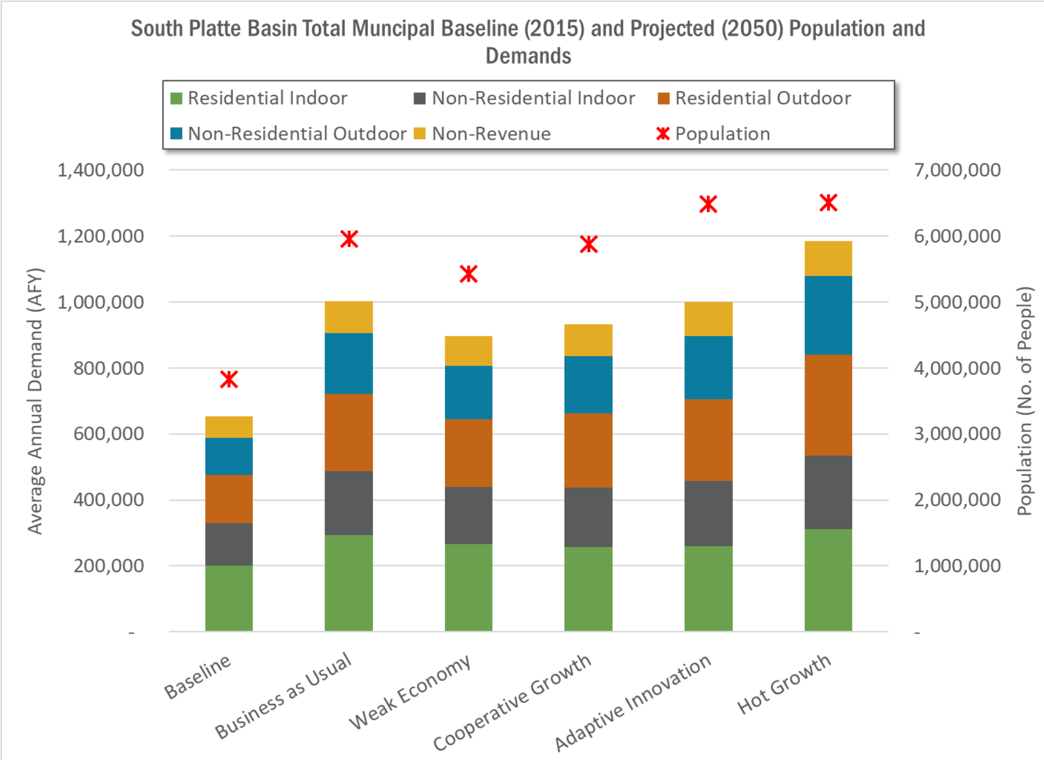

Figure 3-57: Total South Platte Basin Baseline and Projected Population and Municipal Demands.

3.6.2 INDUSTRIAL

The South Platte Basin currently includes about 40% of the statewide industrial demand. Approximately 67% of the baseline industrial demands are in the Metro Region and 33% are in the South Platte Without Metro or Republican Sub-Basin. There are no industrial demands in the Republican Basin. Industrial demands in the South Platte Basin are associated with the Large Industry, Snowmaking, and Thermoelectric sub-sectors. No demands were projected for the Energy Development sub-sector because data were not publicly available for the Technical Update. While water demands for energy development are generally small compared to other demands represented in the Technical Update, demands for this category could be represented in the future if additional data become available. Basin-scale industrial demands are shown on Figure 3-58 and county-scale industrial demands are summarized in Table 3-29 through Table 3-31.

Large Industry demands in this basin are located in three counties. Baseline demands in Jefferson County were based on data from an existing hydrologic model, and projected demands were not varied by scenario at the direction of the water user. Large Industry demands in Morgan and Weld counties were based on data from SWSI 2010. The baseline demand has decreased from 59,000 AFY in SWSI 2010 to 52,230 AFY in the Technical Update analysis, due to a decrease in Jefferson County. Projected 2050 Large Industry demands range from 51,570 AFY to 52,890 AFY.

The baseline Snowmaking demand is 300 AFY as compared to 320 AFY in SWSI 2010. The reduction in demand is due to a decrease in snowmaking acres in Clear Creek County. Projected demands are 320 AFY and were not varied by scenario.

Thermoelectric demands are related to eight facilities in seven counties. Baseline demands for seven of the facilities were updated based on information from Xcel and the eighth facility was based on data from SWSI 2010. This basin had a ninth facility in Denver County that was previously represented in SWSI 2010, but it has since been decommissioned. The total baseline demand has decreased from 33,400 AFY in SWSI 2010 to 19,670 AFY in the Technical Update analysis. Projected 2050 Thermoelectric demands range from 23,110 AFY to 28,240 AFY.

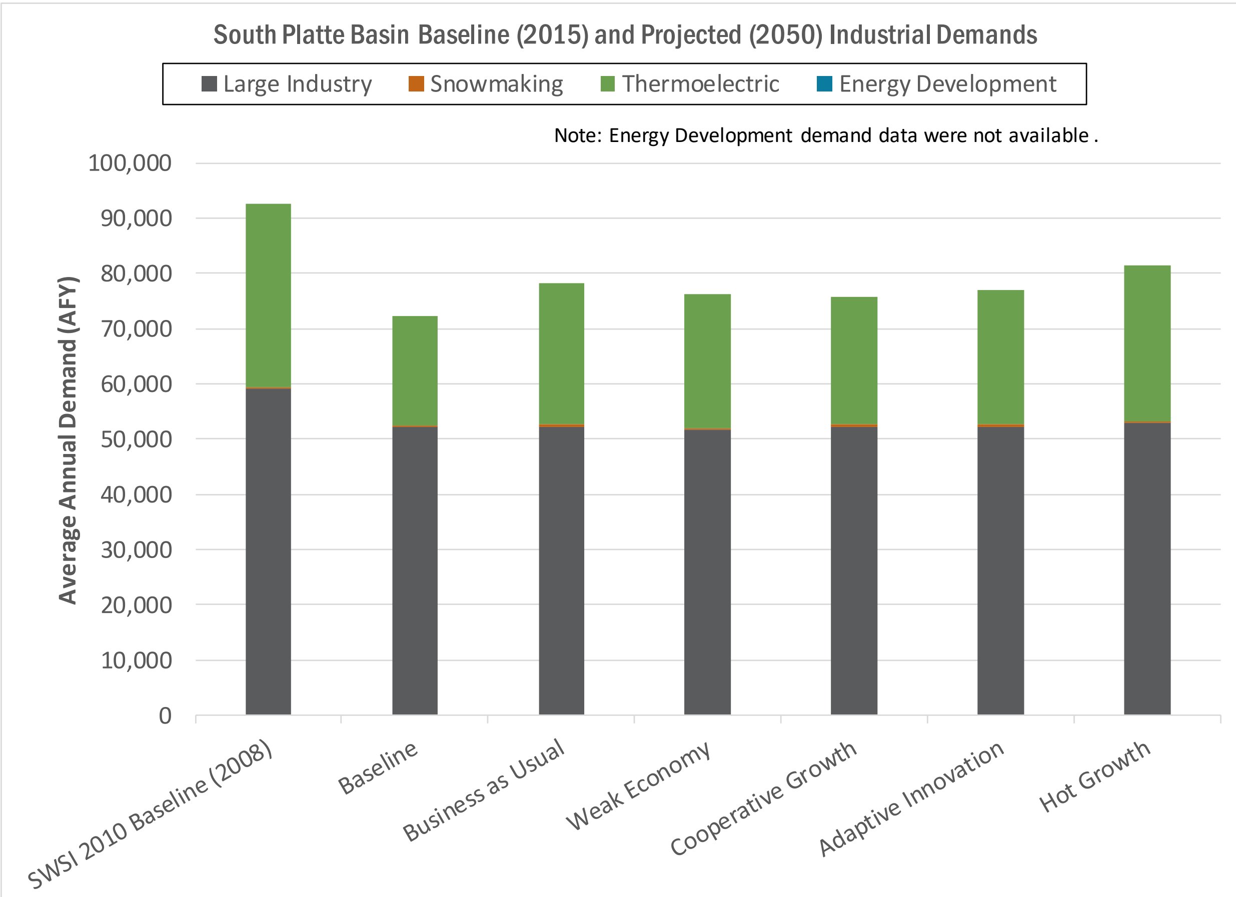

Figure 3-58: Total South Platte Basin Industrial Baseline and Projected Demands.

Table 3-29: Metro Region Industrial Baseline and Projected Demands by County (AFY).

County	Sub-Sector	Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Adams	Large Industry	-	-	-	-	-	-
	Snowmaking	-	-	-	-	-	-
	Thermoelectric	2,990	2,990	2,840	2,690	2,840	3,290
	Energy Development	-	-	-	-	-	-
Arapahoe	Large Industry	-	-	-	-	-	-
	Snowmaking	-	-	-	-	-	-
	Thermoelectric	50	50	50	50	50	60
	Energy Development	-	-	-	-	-	-
Denver	Large Industry	-	-	-	-	-	-
	Snowmaking	-	-	-	-	-	-
	Thermoelectric	0	0	0	0	0	0
	Energy Development	-	-	-	-	-	-
Jefferson	Large Industry	45,630	45,630	45,630	45,630	45,630	45,630
	Snowmaking	-	-	-	-	-	-
	Thermoelectric	-	-	-	-	-	-
	Energy Development	-	-	-	-	-	-
Sub-Basin Total		48,670	48,670	48,520	48,370	48,520	48,980

Table 3-30: South Platte Without Metro or Republican Sub-Basin Industrial Baseline and Projected Demands by County (AFY).

County	Sub-Sector	Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Boulder	Large Industry	-	-	-	-	-	-
	Snowmaking	230	230	230	230	230	230
	Thermoelectric	1,890	1,890	1,800	1,700	1,800	2,080
	Energy Development	-	-	-	-	-	-
Clear Creek	Large Industry	-	-	-	-	-	-
	Snowmaking	70	90	90	90	90	90
	Thermoelectric	-	-	-	-	-	-
	Energy Development	-	-	-	-	-	-
Larimer	Large Industry	-	-	-	-	-	-
	Snowmaking	-	-	-	-	-	-
	Thermoelectric	5,200	11,200	10,640	10,080	10,640	12,320
	Energy Development	-	-	-	-	-	-
Morgan	Large Industry	2,100	2,100	1,890	2,100	2,100	2,310
	Snowmaking	-	-	-	-	-	-
	Thermoelectric	4,830	4,830	4,590	4,350	4,590	5,310
	Energy Development	-	-	-	-	-	-
Weld	Large Industry	4,500	4,500	4,050	4,500	4,500	4,950
	Snowmaking	-	-	-	-	-	-
	Thermoelectric	4,710	4,710	4,470	4,240	4,470	5,180
	Energy Development	-	-	-	-	-	-
Sub-Basin Total		23,530	29,550	27,760	27,290	28,420	32,470

Table 3-31: Total South Platte Basin Industrial Baseline and Projected Demands (AFY).

Basin	Sub-Sector	Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Metro Sub-Region	Large Industry	45,630	45,630	45,630	45,630	45,630	45,630
	Snowmaking	0	0	0	0	0	0
	Thermoelectric	3,040	3,040	2,890	2,740	2,890	3,350
	Energy Development	0	0	0	0	0	0
South Platte Without Metro or Re-publican Sub-Basin	Large Industry	6,600	6,600	5,940	6,600	6,600	7,260
	Snowmaking	300	320	320	320	320	320
	Thermoelectric	16,630	22,630	21,500	20,370	21,500	24,890
	Energy Development	0	0	0	0	0	0
Basin Total		72,200	78,220	76,280	75,660	76,940	81,450

3.6.3 TOTAL

South Platte Basin combined M&I demand projections for 2050 range from approximately 970,000 AFY in the Weak Economy scenario to 1.27 million AFY in the Hot Growth scenario, as shown in Figure 3-59. Industrial demands account for 6% - 10% of the total M&I demands. On a basin scale, the demand projections do not follow the statewide sequence of the volumetric demand scenario rankings described in the CWP, with the Adaptive Innovation scenario falling out of sequence.

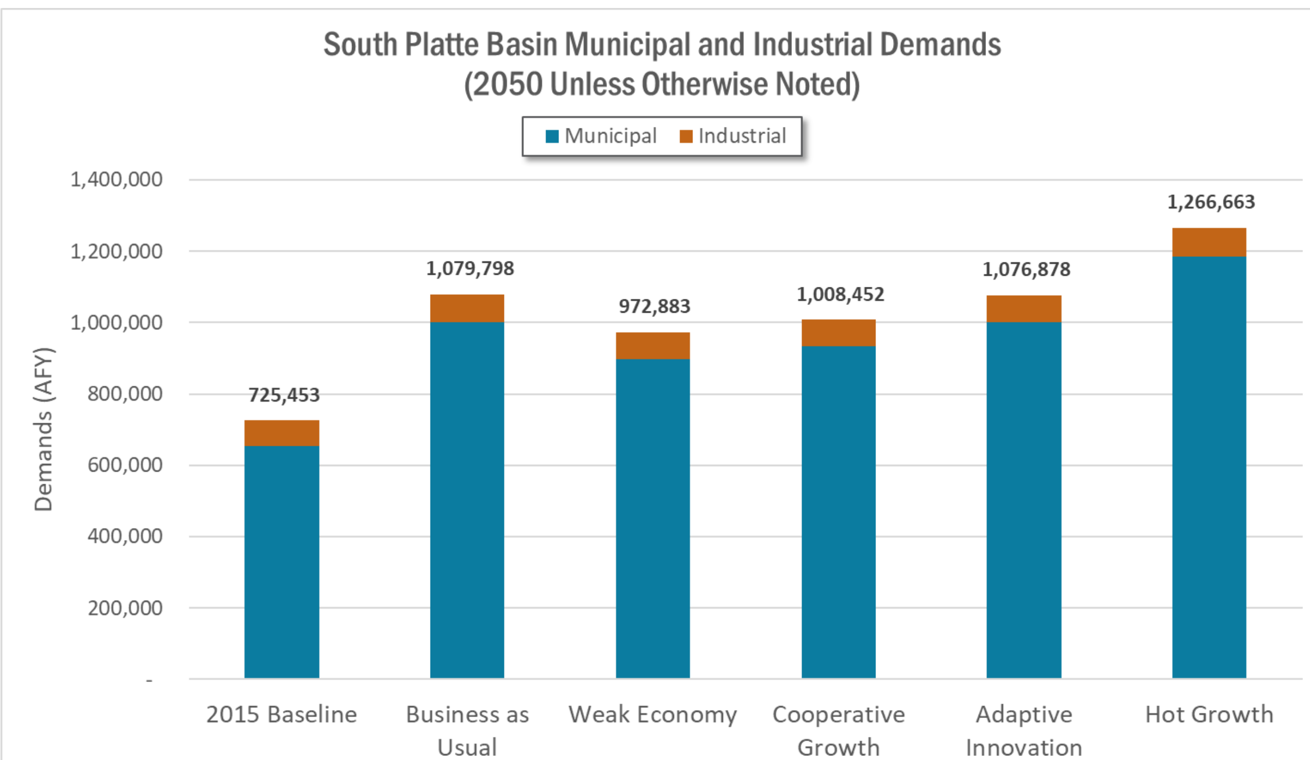

Figure 3-59: Total South Platte Basin Baseline and Projected M&I Demands.

3.7 SOUTHWEST REGION

3.7.1 MUNICIPAL

3.7.1.1 POPULATION

The Southwest Region currently includes about 2% of the statewide population. Between the years 2015 and 2050, it is projected to grow from approximately 110,000 to between 130,000 and 280,000 people in the low and high growth scenarios, respectively. Using the specific numbers, this is an increase in population of 16% to 161%,. On a percentage basis, the Southwest Region has the largest projected increase of all basins throughout the state. Yet, even with the 161% population increase under the high growth scenarios, the Southwest Region would include only about 3% of the future statewide population.

Table 3-32 shows how population growth is projected to vary across counties under each planning scenario. All counties are projected to increase in population for the high growth scenario, ranging from about 59% to 218%. Dolores and San Juan Counties are projected to decrease in population for the low growth scenario, with all other counties projected to increase. The most populous county, La Plata County, is projected to increase under all scenarios and account for most of the growth. San Miguel County is projected to have the highest growth rate for an individual county, ranging from about 42% to 218%. Note that Montrose County is split between multiple basins, with the county demands pro-rated between basins based on the population located within each basin. This approach is consistent with prior SWSI analyses.

Table 3-32: Southwest Region Baseline and Projected Populations by County

County	2015 Population	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Archuleta	12,417	26,571	17,070	25,142	35,845	38,281
Dolores	1,972	2,597	1,668	2,457	3,503	3,742
La Plata	54,857	94,002	60,391	101,831	126,811	135,430
Montezuma	26,129	47,158	30,296	44,623	63,617	67,941
Montrose*	4,085	7,449	4,785	7,048	10,048	10,731
San Juan	696	767	493	726	1,035	1,105
San Miguel	7,843	17,293	11,110	19,183	23,329	24,914
Basin Total	107,999	195,837	125,814	201,010	264,189	282,144

**Counties with population located in multiple basins. This table represents the portion of the county located in the Southwest Region.*

The Southwest Region baseline for the Technical Update, which is based on 2015 population, is approximately 3% higher than the SWSI 2010 baseline, which used 2008 population. The SWSI 2010 medium growth population projection for 2050 exceeded the Technical Update population projections for the Business as Usual, Weak Economy, and Cooperative Growth scenarios by at least 11%. However, the Technical Update projections for the Adaptive Innovation and Hot Growth scenarios exceed the SWSI 2010 high growth projection. Comparison of the baseline and projected populations for the Technical Update and SWSI 2010 are shown in Figure 3-60.

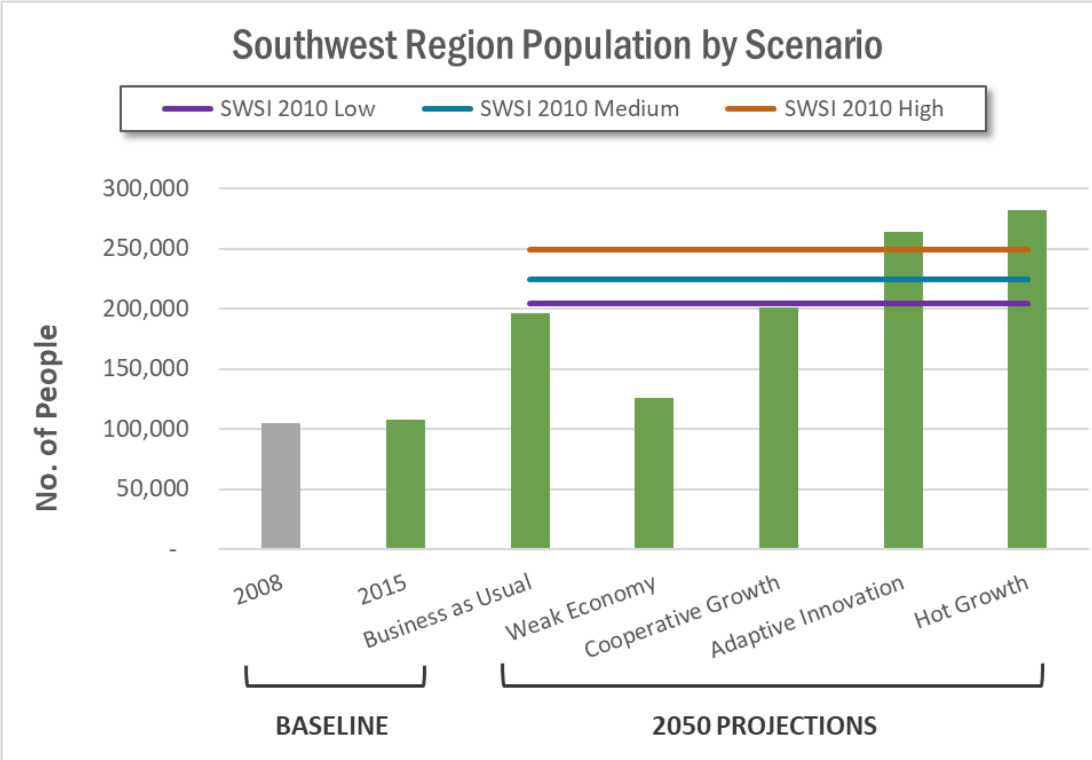

Figure 3-60: Southwest Region Baseline and Projected Population.

3.7.1.2 WATER DEMANDS

The Southwest Region baseline water demands were based on a mix of data sources, with approximately 27% of the baseline population demands represented by 1051 data, 18% from water provider outreach, and 3% from WEPs, requiring demands for about 52% of the basin's baseline population demands to be estimated, as shown in Figure 3-61.

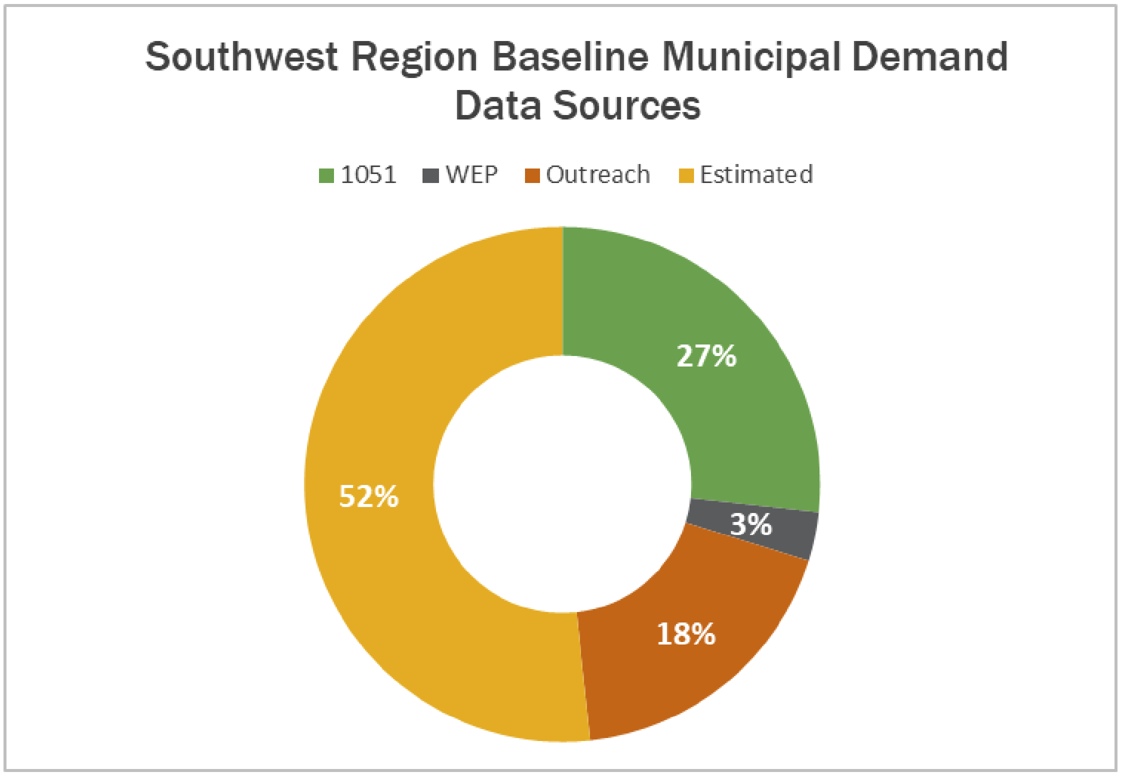

Figure 3-61: Southwest Region Baseline Municipal Water Demand Data Sources.

The Southwest Region average baseline per capita systemwide demand has increased from 183 gpcd in SWSI 2010 to approximately 198 gpcd. Table 3-33 represents baseline and projected per capita demands for counties within the Southwest Region. While demands for over half of the basin population were estimated, more water provider-reported data were available for the Technical Update as compared to SWSI 2010.

Table 3-33: Southwest Region Municipal Baseline and Projected Per Capita Demands by County (gpcd).

County	SWSI 2010 Baseline [a]	Technical Update Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Archuleta	182	220	197	201	189	180	216
Dolores	242	108	112	108	108	104	119
La Plata	169	184	171	175	163	157	187
Montezuma	172	244	217	225	209	198	237
Montrose*	187	192	171	174	164	156	188
San Juan	182	199	173	193	166	151	175
San Miguel	289	137	135	134	128	123	149
Basin Total	183	198	181	186	173	166	199

a) SWSI 2010 per capita values from SWSI 2010 Appendix H, Table 3-1 (CWCB, 2010a).

**Counties with population located in multiple basins. While this represents the per capita demand associated with the Southwest Region only, per capita use does not change within a given county by basin.*

The Southwest Region baseline municipal water demands are comprised of approximately 51% indoor, 34% outdoor, and 15% non-revenue water uses, as shown in Figure 3-62. Only one of seven counties had sufficient demand category data available to apply a county-specific distribution. The basin average demand category distribution was used for the remaining counties. On a basin scale, the non-residential outdoor demand as a percentage of the systemwide demand is one of the lowest reported throughout the state, at approximately 9%. Conversely, the baseline non-revenue water demand is one of the highest statewide, at approximately 15% of the systemwide demands.

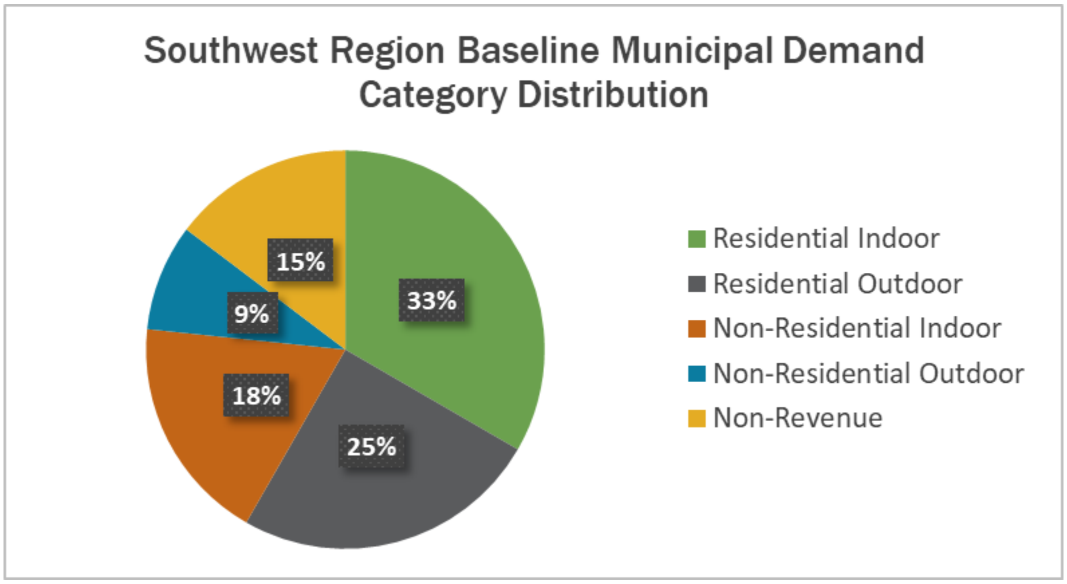

Figure 3-62: Southwest Region Baseline Municipal Demand Category Distribution.

Figure 3-63 provides a summary of per capita baseline and projected water demands for the Southwest Region. Systemwide, the projected per capita demands decrease relative to the baseline except for the Hot Growth scenario which has a similar systemwide per capita demand as the baseline, but the demand category distributions are different. The residential indoor demand is the greatest demand category in the baseline, but the residential outdoor demand exceeds the residential indoor demand in the all of the projections except for the Weak Economy scenario. Outdoor demands increased significantly for the Hot Growth scenario, due to an increase in outdoor demands coupled with the “Hot and Dry” climate.

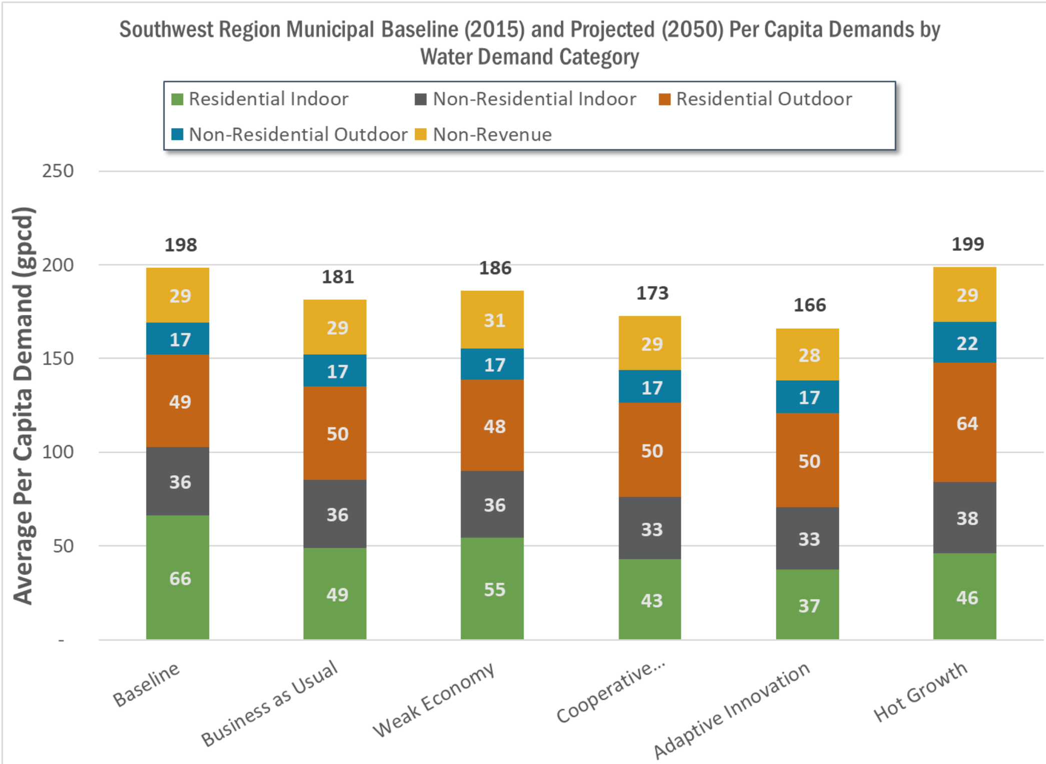

Figure 3-63: Southwest Region Municipal Baseline and Projected Per Capita Demands by Water Demand Category.

Figure 3-64 demonstrates the influence of the climate driver on per capita water demands, with outdoor demands increasing by 9 to 16 gpcd with the climate change factors applied. Without the climate change factors, the per capita demand projections range from 153 to 186 gpcd, which exceed the SWSI 2010 projection of 110 gpcd for medium population with active conservation[31]. This is partly due to the Technical Update baseline exceeding the SWSI 2010 baseline. The Southwest Region per capita demand reported in SWSI 2010 was the lowest throughout the entire state.

[31] SWSI 2010 projected per capita demands include savings from passive conservation.

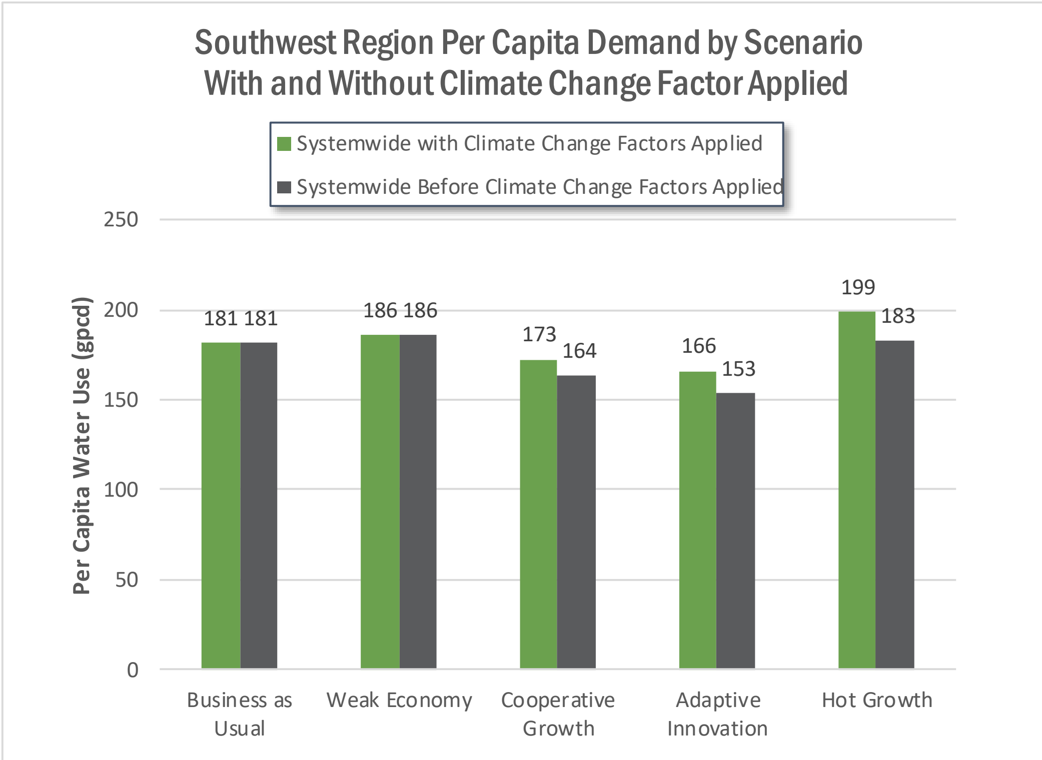

Figure 3-64: Effect of Climate Change Driver on the Southwest Region Average Per Capita Demand.

The Southwest Region municipal baseline and projected volumetric demands are provided in Table 3-34, showing the combined effect of population and per capita demands. Municipal demands are projected to grow from approximately 24,000 AFY in 2015 to between 26,000 and 63,000 AFY in 2050. La Plata County accounts for nearly half of the baseline demand followed by Montezuma County at just under one-third of the basin demand.

Table 3-34: Southwest Region Basin Municipal Baseline and Projected Volumetric Demands by County (AFY).

County	Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Archuleta	3,060	5,853	3,848	5,314	7,226	9,270
Dolores	239	326	202	297	410	499
La Plata	11,322	18,011	11,837	18,645	22,269	28,441
Montezuma	7,152	11,436	7,620	10,430	14,109	18,021
Montrose*	877	1,425	931	1,295	1,754	2,258
San Juan	155	149	107	135	175	217
San Miguel	1,204	2,609	1,671	2,747	3,221	4,146
Basin Total	24,009	39,810	26,214	38,864	49,164	62,851

**Counties with population located in multiple basins. This table represents systemwide demands for the portion of the county located in the Southwest Region.*

The baseline and projected demand distributions are shown in Table 3-35 and Figure 3-65 and are reflective of population variations among the scenarios. All of the projection scenarios result in an increase relative to the baseline.

Table 3-35: Southwest Region Municipal Baseline and Projected Volumetric Demands by Demand Category (AFY).

Scenario	Residential Indoor	Non-Residential Indoor	Residential Outdoor	Non-Residential Outdoor	Non-Revenue	Systemwide
Baseline (2015)	8,006	4,409	5,986	2,079	3,528	24,009
Business as Usual	10,740	8,006	10,879	3,784	6,401	39,810
Weak Economy	7,689	5,018	6,819	2,371	4,318	26,214
Cooperative Growth	9,636	7,506	11,285	3,920	6,516	38,864
Adaptive Innovation	11,054	9,854	14,878	5,174	8,203	49,164
Hot Growth	14,536	12,023	20,085	6,985	9,221	62,851

Figure 3-65: Southwest Region Baseline and Projected Population and Municipal Demands.

3.7.2 INDUSTRIAL

The Southwest Region currently includes about 1% of the statewide industrial demand. Industrial demands in this basin are associated with the Snowmaking and Thermoelectric sub-sectors, with no demands projected for Large Industry or Energy Development sub-sectors. Southwest region total industrial demands are shown on Figure 3-66 and county-scale industrial demands are summarized in Table 3-36.

The baseline Snowmaking demand is 430 AFY as compared to 410 AFY in SWSI 2010. Projected demands remain at 430 AFY because there is no planned expansion of snowmaking acreage. Projected demands were not varied by scenario.

Thermoelectric demands are related to one facility located in Montrose County and were based on information in SWSI 2010. The baseline demand remains 1,850 AFY as represented in SWSI 2010. Projected Thermoelectric demands range from 3,510 AFY to 4,290 AFY.

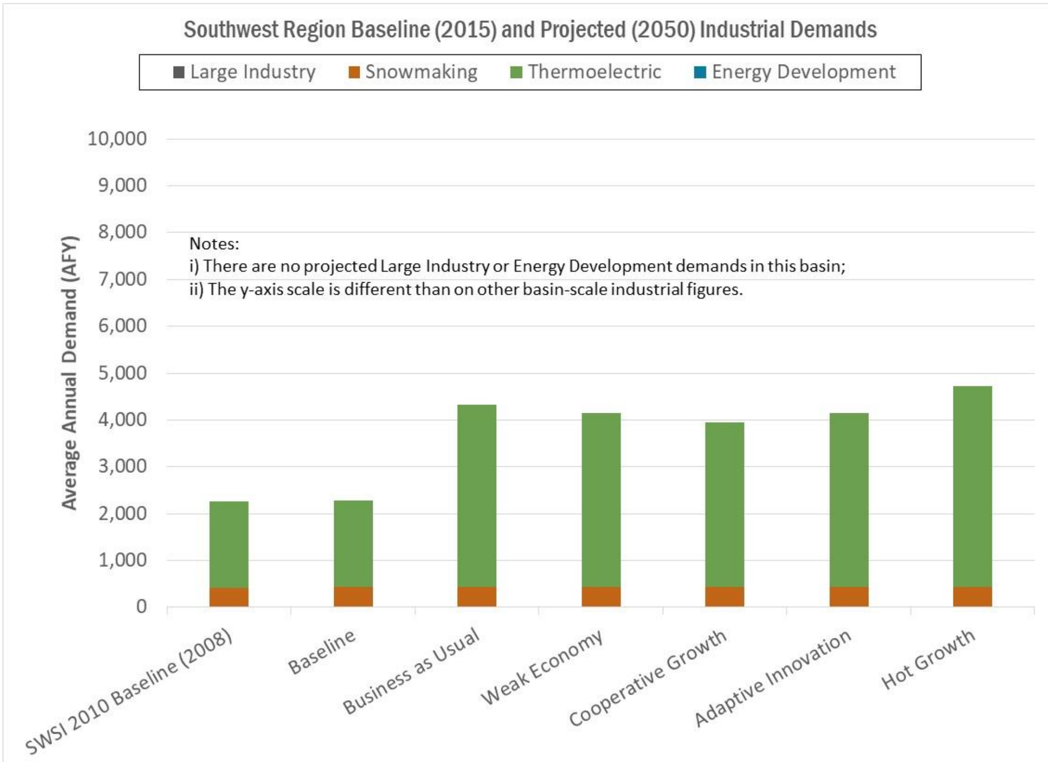

Figure 3-66: Southwest Region Industrial Baseline and Projected Demands.

Table 3-36: Southwest Region Industrial Baseline and Projected Demands by County (AFY).

County	Sub-Sector	Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
La Plata	Large Industry	-	-	-	-	-	-
	Snowmaking	230	230	230	230	230	230
	Thermoelectric	-	-	-	-	-	-
	Energy Development	-	-	-	-	-	-
Montrose	Large Industry	-	-	-	-	-	-
	Snowmaking	-	-	-	-	-	-
	Thermoelectric	1,850	3,900	3,710	3,510	3,710	4,290
	Energy Development	-	-	-	-	-	-
San Miguel	Large Industry	-	-	-	-	-	-
	Snowmaking	200	200	200	200	200	200
	Thermoelectric	-	-	-	-	-	-
	Energy Development	-	-	-	-	-	-
Basin Total		2,280	4,330	4,140	3,940	4,140	4,720

3.7.3 TOTAL

Southwest Region combined M&I demand projections for 2050 range from approximately 30,000 AFY in the Weak Economy scenario to 68,000 AFY in the Hot Growth scenario, as shown in Figure 3-67. Industrial demands account for around 7% - 14% of the M&I demands in the Southwest Region. On a basin scale, the demand projections follow the statewide sequence of the volumetric demand scenario rankings described in the CWP.

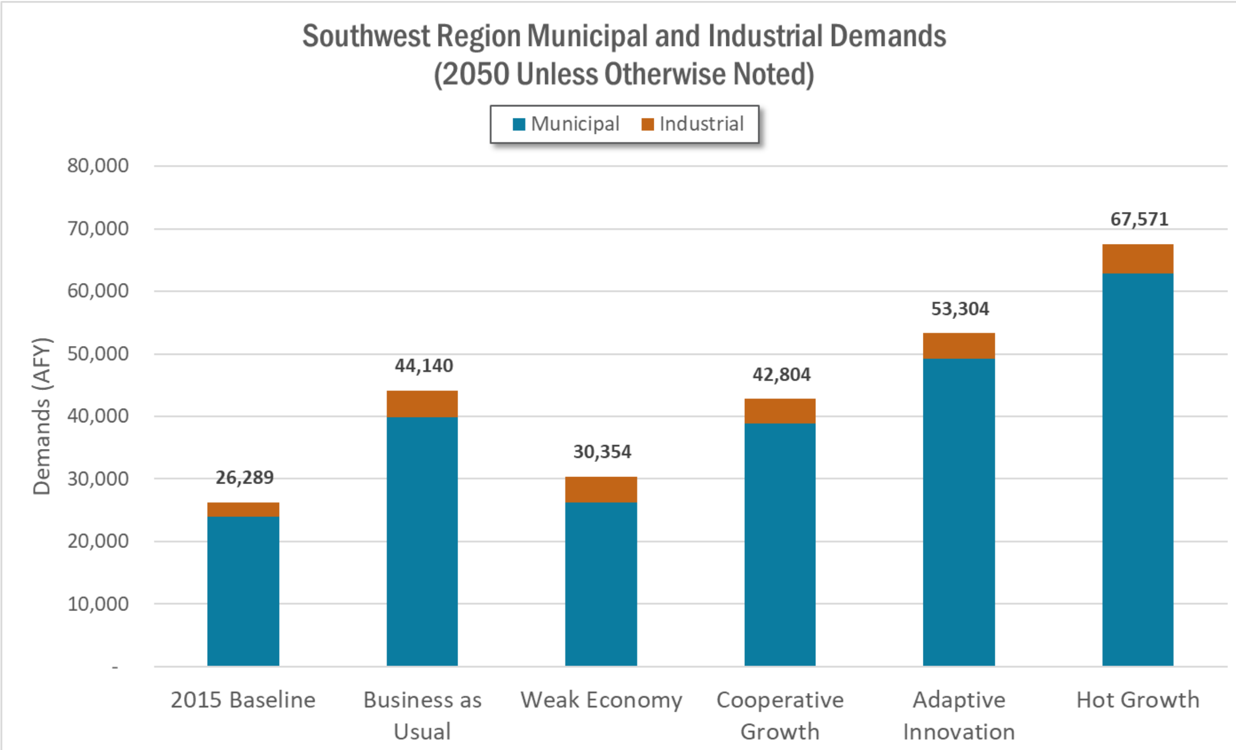

Figure 3-67: Southwest Region Baseline and Projected M&I Demands.

3.8 YAMPA-WHITE BASIN

3.8.1 MUNICIPAL

The Yampa-White Basin information summarized below includes municipal demands from the Yampa, Green, and White River sub-basins. For consistency and integration with the hydrologic modelling, the population and municipal demand data were separated into the Yampa and White Basins, with the population and demands from the Green included within the Yampa sub-basin.

3.8.1.1 POPULATION

Combined Yampa-White Basin

The combined Yampa-White Basin currently includes less than 1% of the statewide population. Between the years 2015 and 2050, it is projected to change from approximately 44,000 to between 39,000 and 103,000 people in the low and high growth scenarios, respectively. Using the specific numbers, this ranges from a decrease in population of 12% to an increase of 136%. Table 3-37 shows how population growth is projected to vary across counties under each planning scenario and is summarized by sub-basin.

White Sub-Basin

Between the years 2015 and 2050, the White Basin is projected to change from approximately 6,500 to between 4,200 and 11,300 people in the low and high growth scenarios, respectively. Using the specific numbers, this ranges from a decrease in population of 35% to an increase of 73%. Rio Blanco County is the only county in the White Basin.

Yampa Sub-Basin

Between the years 2015 and 2050, the Yampa Basin is projected to change from approximately 37,000 to between 34,000 and 92,000 people in the low and high growth scenarios, respectively. Using the specific numbers, this ranges from a decrease in population of 8% to an increase of 147%.

Routt County is currently the most populous county in the sub-basin at about 24,000 people and is projected to remain the largest in all scenarios, ranging from about 26,000 to 71,000 people by 2050. Moffat County population is projected to decrease by approximately 38% in the low growth scenario and to increase by 65% in the high growth scenario.

Table 3-37: Yampa-White Basin and Sub-Basin Baseline and Projected Populations by County

County	2015 Population	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
WHITE BASIN						
Rio Blanco	6,529	7,376	4,237	6,979	10,599	11,319
Sub-Basin Total	6,529	7,376	4,237	6,979	10,599	11,319
YAMPA BASIN						
Moffat	12,884	13,868	7,966	13,122	19,927	21,281
Routt	24,310	45,998	26,420	50,336	66,095	70,587
Sub-Basin Total	37,194	59,866	34,386	63,458	86,022	91,869
TOTAL YAMPA-WHITE BASIN						
Basin Total	43,723	67,242	38,623	70,437	96,621	103,188

The combined Yampa-White Basin baseline for the Technical Update, which is based on 2015 population, is about 3% lower than the SWSI 2010 baseline, which used 2008 population. The SWSI 2010 medium growth population projection for 2050 exceeded the Technical Update population projections for all planning scenarios by between about 13% and 203%. Comparison of the baseline and projected populations for the Technical Update and SWSI 2010 are shown in Figure 3-68.

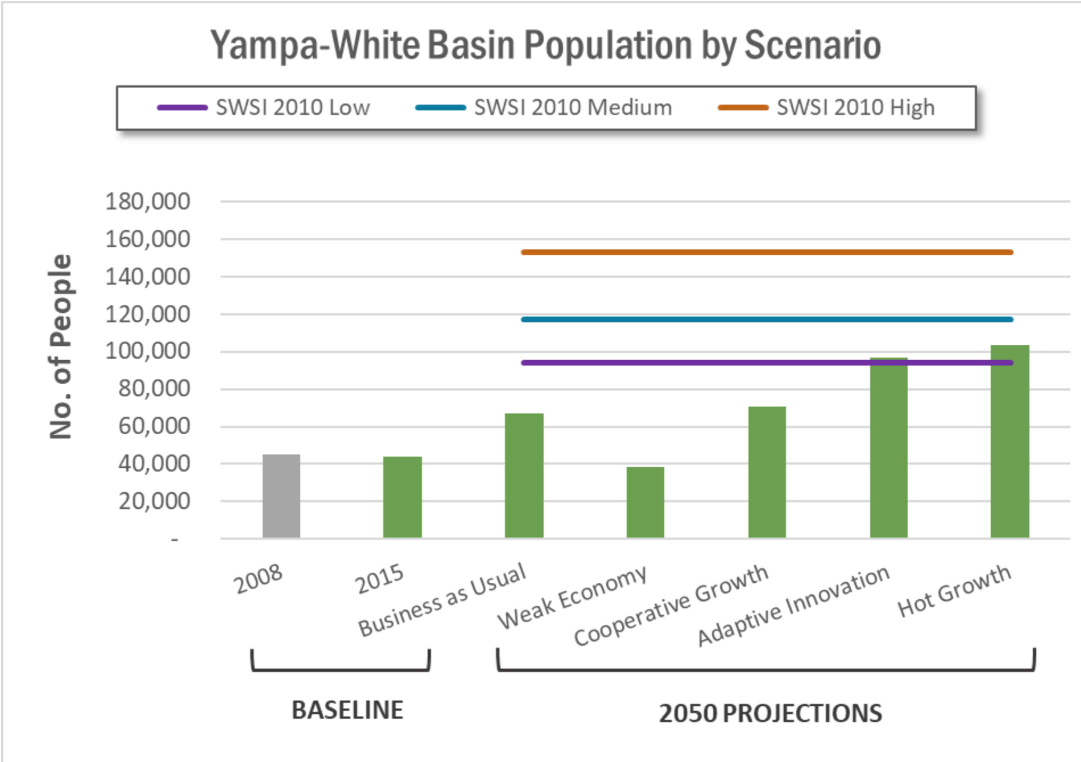

Figure 3-68: Yampa-White Basin Baseline and Projected Population.

3.8.1.2 WATER DEMANDS

The Yampa-White baseline water demands were largely estimated. Approximately 12% of the baseline population demand were represented by 1051 data and 8% from water provider outreach, requiring demands for about 80% of the basin's baseline population demands to be estimated, as shown in Figure 3-69. The data filling analyses were completed at the county level, resulting in different gpcd rate of use values for the Yampa and White sub-basins. In the Yampa sub-basin, some data were available from 1051 reporting, water efficiency plans, and targeted outreach, but much of the data still needed to be filled by using results from the other available sources. In the White sub-basin, some data were available from targeted outreach but most of the data were filled based on the outreach information. It is recommended that the Basin Roundtable work to acquire better data during the BIP update process.

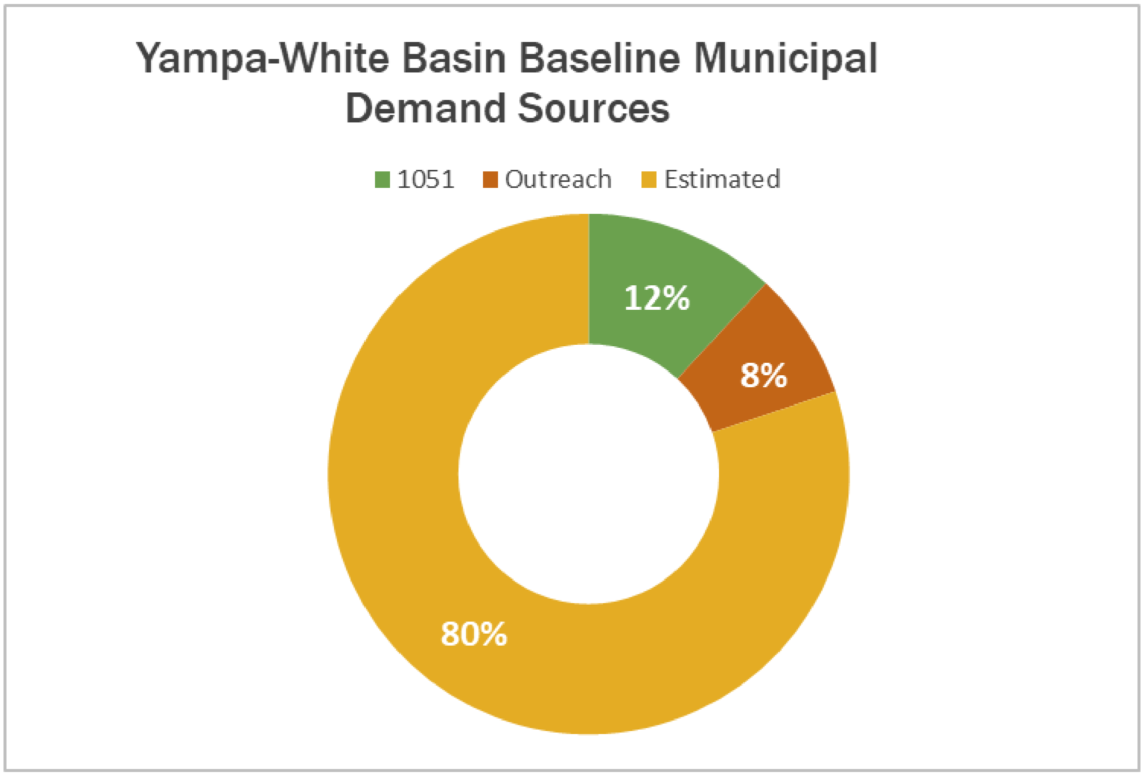

Figure 3-69: Yampa-White Basin Baseline Municipal Water Demand Data Sources.

The Yampa-White Basin average baseline per capita systemwide demand has decreased slightly from 230 gpcd in SWSI 2010 to approximately 228 gpcd. While the basin average per capita demand changed very little, there are more significant differences from SWSI 2010 at a county level. Table 3-38 below represents baseline and projected per capita demands for counties within the basin.

Table 3-38: Yampa-White Total Basin Municipal Baseline and Projected Per Capita Demands by County (gpcd).

County	SWSI 2010 Baseline [a]	Update Baseline	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
WHITE BASIN							
Rio Blanco	262	252	240	254	240	231	269
YAMPA BASIN							
Moffat	194	216	179	214	171	153	181
Routt	243	228	170	192	158	149	180
TOTAL YAMPA-WHITE BASIN							
Basin Total	230	228	180	203	168	159	190

a) SWSI 2010 per capita values from SWSI 2010 Appendix H, Table 3-1 (CWCB, 2010a).

The demand category distributions were individually evaluated for each sub-basin and the sub-basin average was used for counties within the respective sub-basin that had insufficient data to prepare a county-specific distribution. A summary of each sub-basin is provided below.

The White Sub-Basin baseline municipal water demands are comprised of approximately 42% indoor, 30% outdoor, and 27% non-revenue water uses, as shown in Figure 3-70. Rio Blanco County had sufficient demand category data available to apply a county-specific distribution.

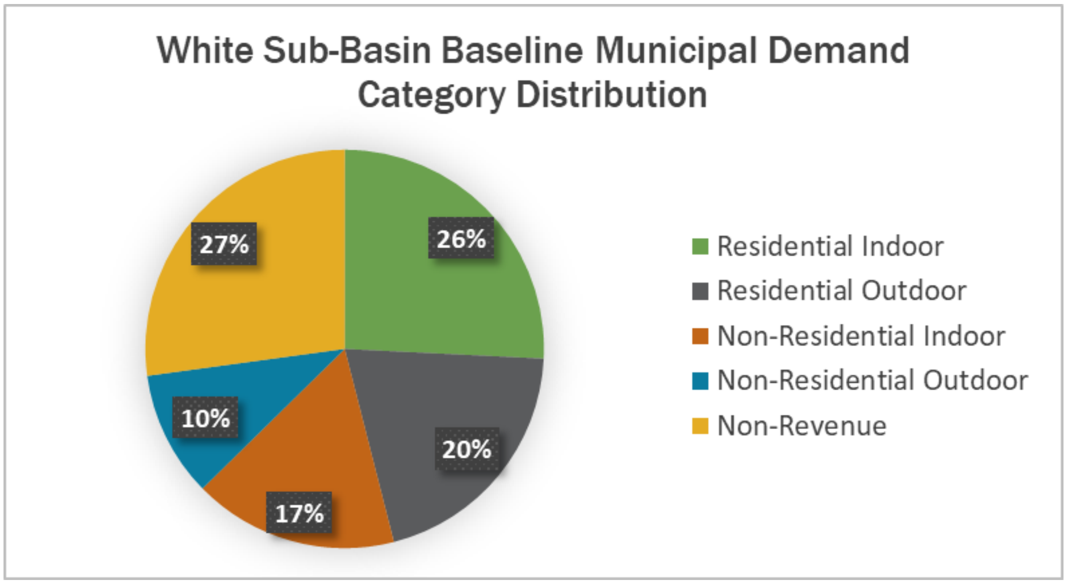

Figure 3-70: White Sub-Basin Baseline Municipal Demand Category Distribution.

The Yampa Sub-Basin baseline municipal water demands are comprised of approximately 75% indoor, 18% outdoor, and 6% non-revenue water uses, as shown in Figure 3-71. Routt County had sufficient demand category data available to apply a county-specific distribution. Moffat County was based on the basin distribution. On a basin scale, the residential indoor demand as a percentage of the systemwide demands is the highest reported throughout the state, at over 50%. Conversely, the baseline residential outdoor water demand is the lowest statewide, at approximately 18% of the systemwide demands.

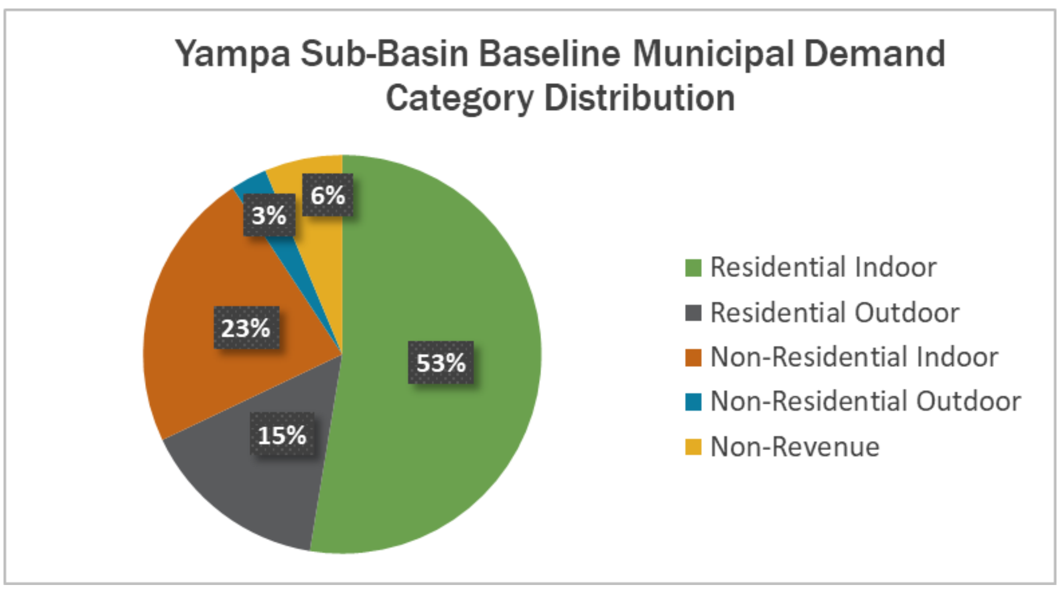

Figure 3-71: Yampa Sub-Basin Baseline Municipal Demand Category Distribution.

Figure 3-72 provides a summary of per capita baseline and projected water demands for the White Sub-Basin. Systemwide, the projected per capita demands decrease relative to the baseline except in the Weak Economy and Hot Growth scenarios. Consistently across all scenarios, the non-revenue water is the greatest demand category.

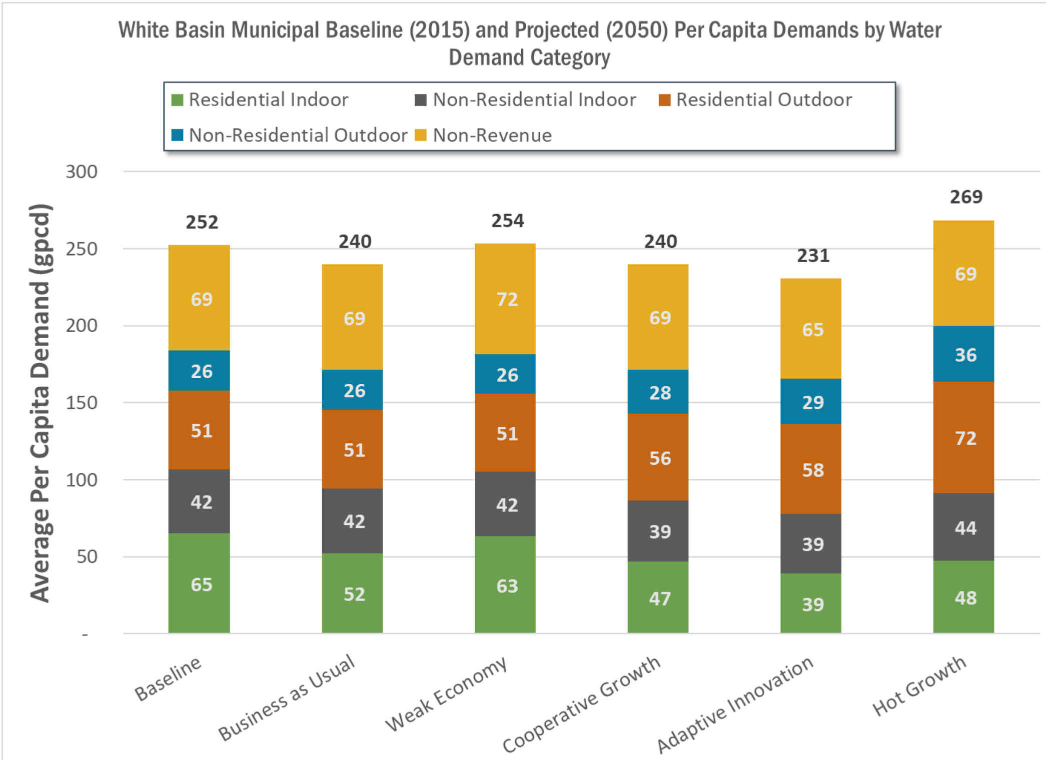

Figure 3-72: White Sub-Basin Municipal Baseline and Projected Per Capita Demands by Water Demand Category.

Figure 3-73 provides a summary of per capita baseline and projected water demands for the Yampa Sub-Basin. Systemwide, the projected per capita demands decrease relative to the baseline under all scenar-ios.

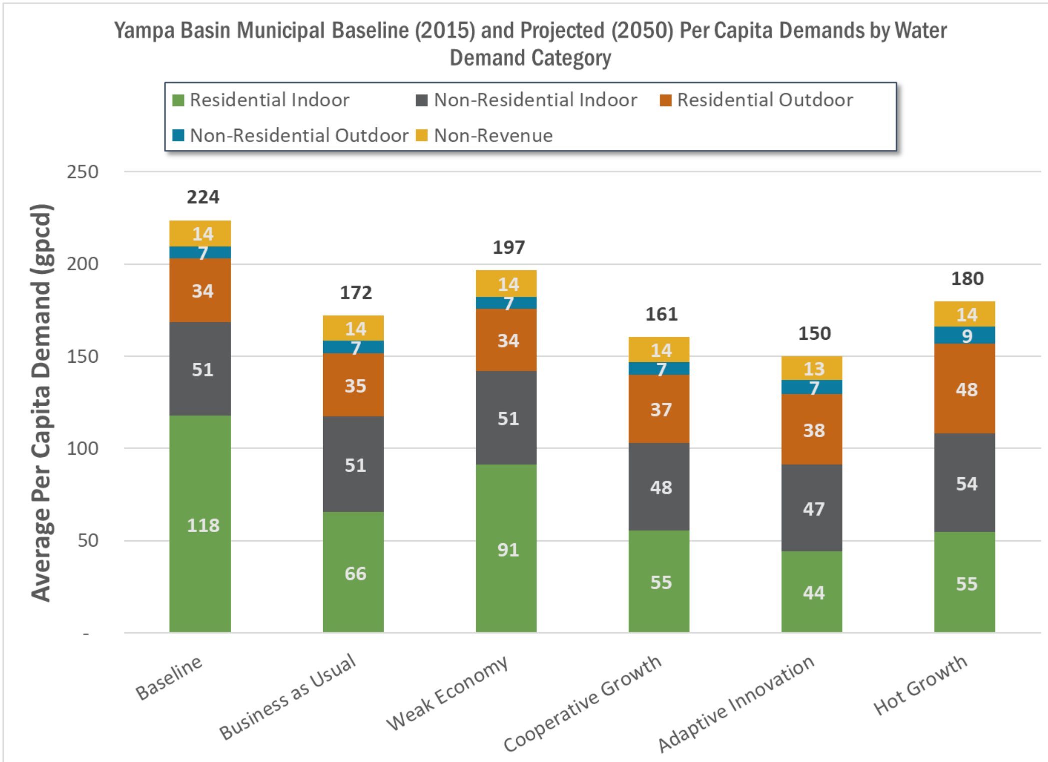

Figure 3-73: Yampa Municipal Baseline and Projected Per Capita Demands by Water Demand Category.

Figure 3-74 demonstrates the influence of the climate driver on the White Sub-Basin per capita water demands, with outdoor demands increasing by 15 to 30 gpcd with the climate change factors applied. Without the climate change factors, the per capita demand projections range from 207 to 254 gpcd. Figure 3-75 demonstrates the influence of the climate driver on the Yampa Sub-Basin per capita water demands, with outdoor demands increasing by 8 to 15 gpcd with the climate change factors applied. Without the climate change factors, the per capita demand projections range from 138 to 197 gpcd. The Yampa and White Sub-Basins were not evaluated separately for the SWSI 2010 evaluation. For the combined Yampa-White Basin, SWSI 2010 projected a per capita demand of 158 gpcd for medium population with active conservation[32].

[32] SWSI 2010 projected per capita demands include savings from passive conservation.

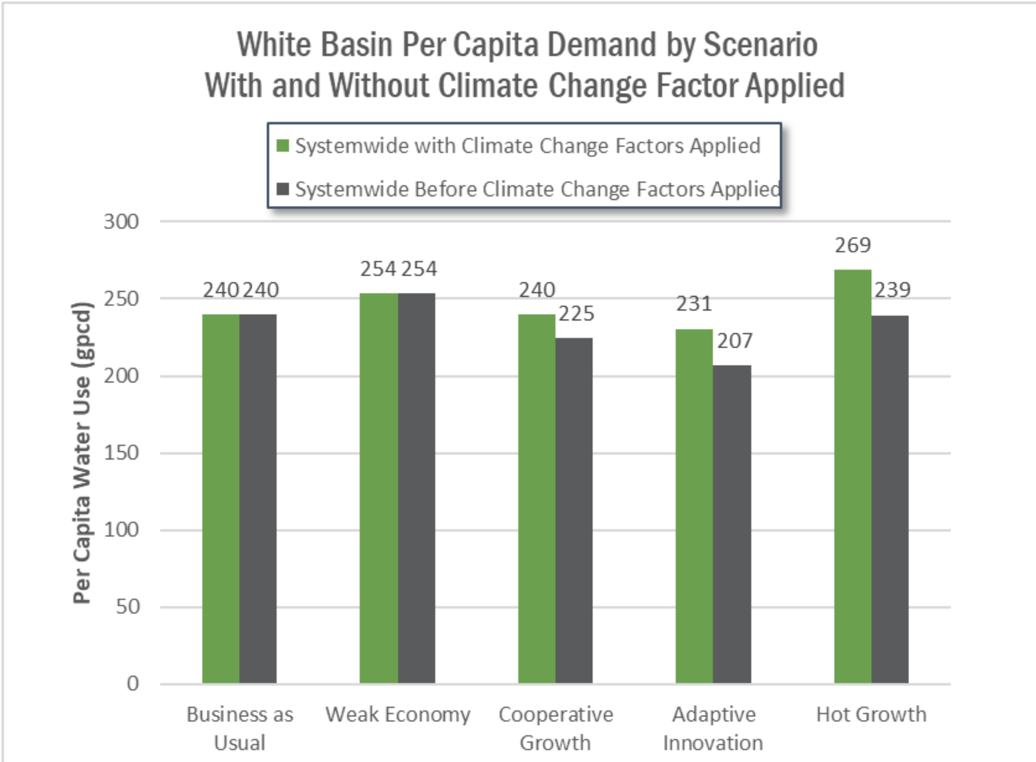

Figure 3-74: Effect of Climate Change Driver on the White Sub-Basin Average Per Capita Demand.

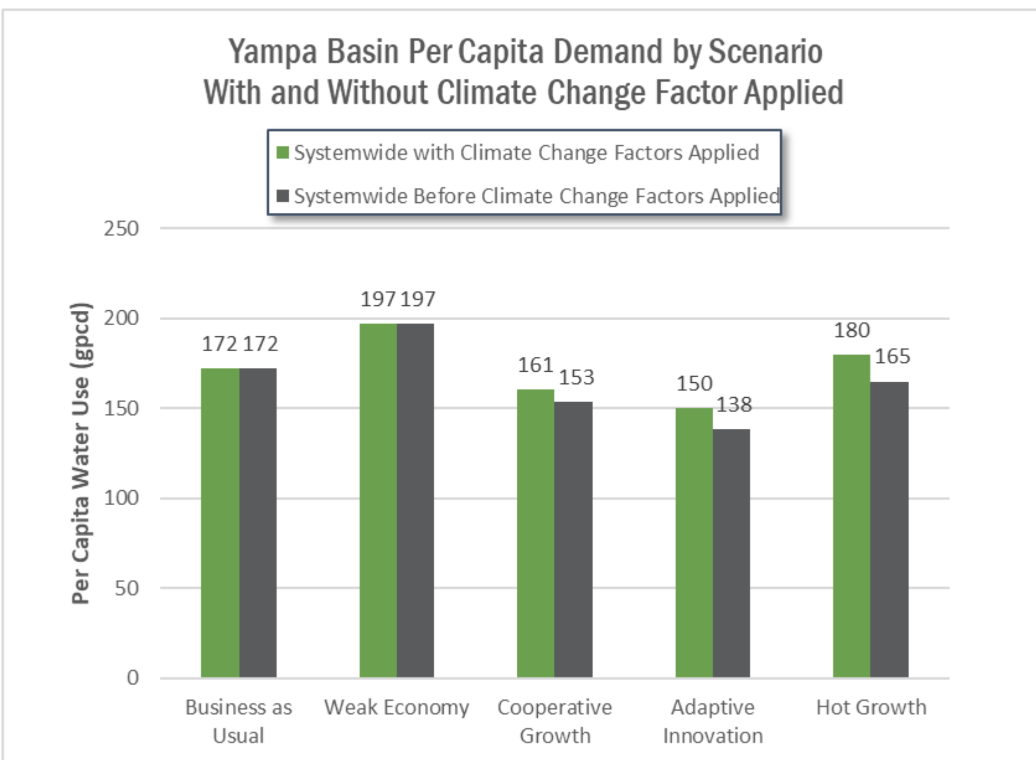

Figure 3-75: Effect of Climate Change Driver on the Yampa Sub-Basin Average Per Capita Demand.

The Yampa-White Basin municipal baseline and projected volumetric demands are provided in Table 3-39, showing the combined effect of population and per capita demands. Municipal demands are projected to grow from approximately 11,000 AFY in 2015 to between 9,000 and 22,000 AFY in 2050. Routt County accounts for over half of the basin demands.

Table 3-39: Yampa-White Basin Municipal Baseline and Projected Volumetric Demands by County (AFY).

County	Base-line (2015)	Business as Usual	Weak Econ-omy	Coopera-tive Growth	Adaptive Innova-tion	Hot Growth
WHITE SUB-BASIN						
Rio Blanco	1,845	1,980	1,203	1,875	2,737	3,405
Sub-Basin Total	1,845	1,980	1,203	1,875	2,737	3,405
YAMPA SUB-BASIN						
Moffat	3,113	2,773	1,913	2,507	3,412	4,306
Routt	6,211	8,779	5,667	8,911	11,060	14,204
Sub-Basin Total	9,324	11,552	7,580	11,418	14,471	18,511
TOTAL YAMPA-WHITE BASINS						
Basin Total	11,169	13,532	8,783	13,293	17,208	21,916

The baseline and projected demand distributions are shown in Table 3-40. Projected demands in the Business as Usual and Cooperative Growth scenarios are nearly identical, and all of the projection scenarios except for the Weak Economy scenario result in an increase relative to the baseline.

Table 3-40: Yampa-White Basin Municipal Baseline and Projected Volumetric Demands by Demand Category (AFY).

Scenario	Residential Indoor	Non-Residential Indoor	Residential Outdoor	Non-Residential Outdoor	Non-Revenue	System wide
Baseline (2015)	5,380	2,431	1,804	465	1,089	11,169
Business as Usual	4,845	3,800	2,736	663	1,488	13,532
Weak Economy	3,817	2,146	1,547	376	897	8,783
Cooperative Growth	4,311	3,694	3,051	730	1,507	13,293
Adaptive Innovation	4,729	4,987	4,393	1,069	2,031	17,208
Hot Growth	6,222	6,074	5,904	1,432	2,283	21,916

Figure 3-76 through Figure 3-78 shows how population differs between the scenarios for the White Sub-Basin, the Yampa Sub-Basin, and the entire Yampa-White Basin, respectively. For each, demands and population are projected to decrease by 2050 from current baseline conditions in the Weak Economy scenario.

Demands generally follow the population patterns, which shows the influence that population has within this basin. Projected demands and populations in the Business as Usual and Cooperative Growth scenarios are similar, with a slightly more noticeable distinction with the White Sub-Basin.

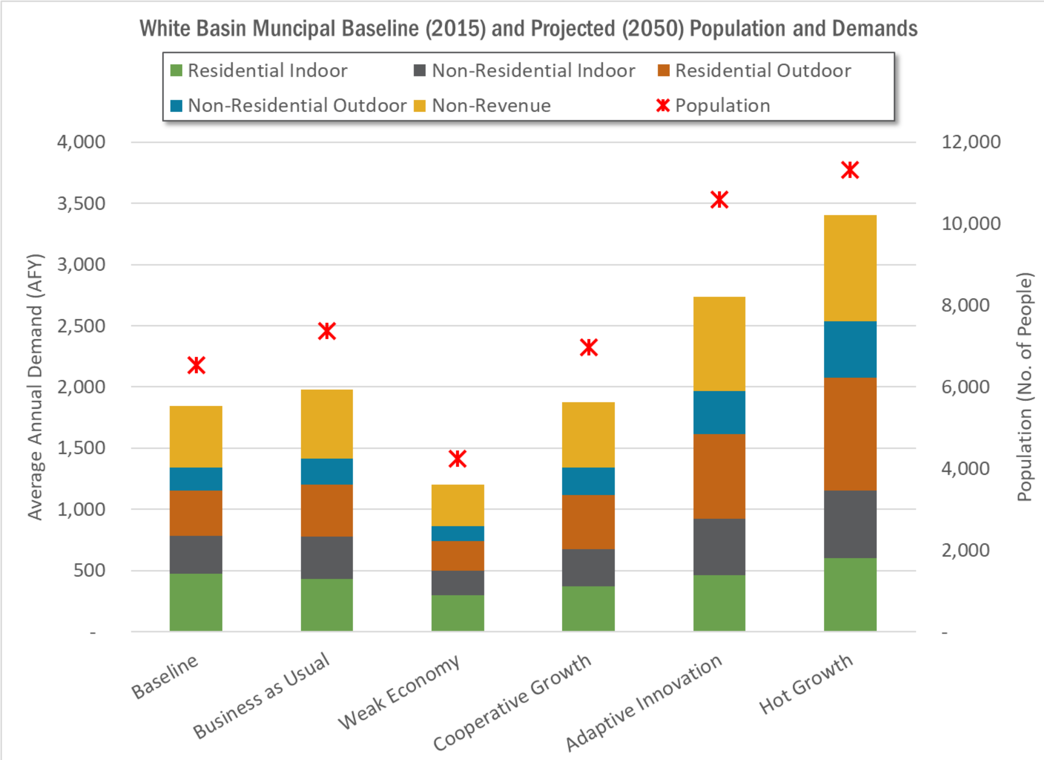

Figure 3-76: White Sub-Basin Baseline and Projected Population and Municipal Demands.

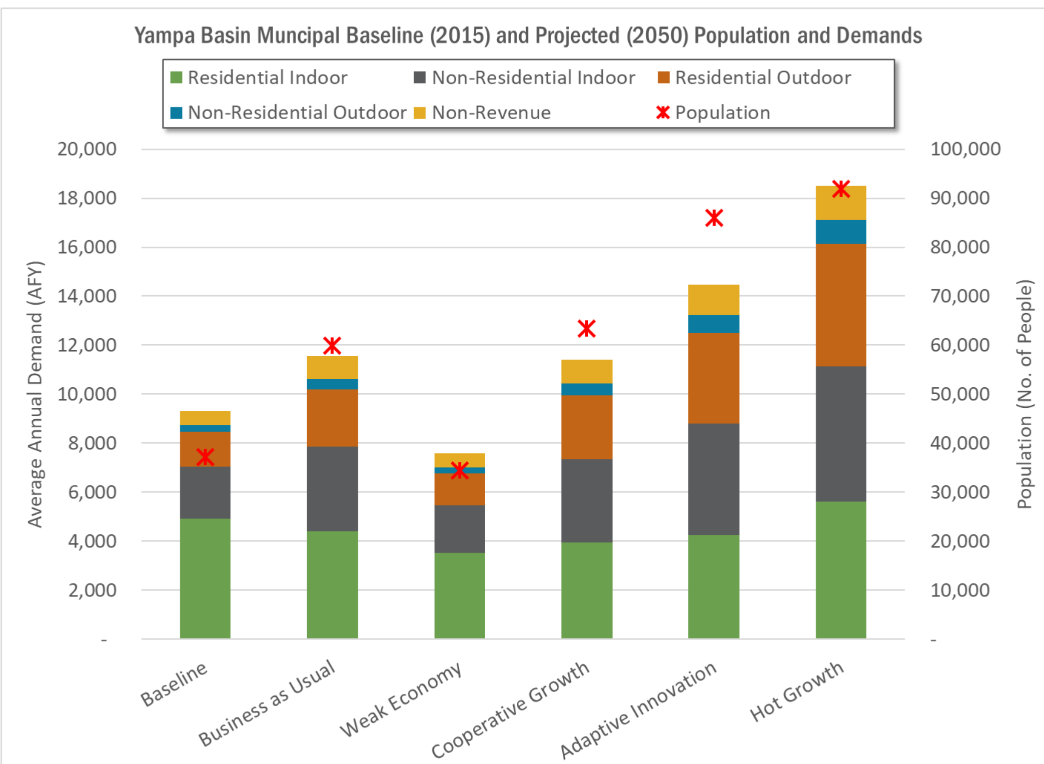

Figure 3-77: Yampa Sub-Basin Baseline and Projected Population and Municipal Demands.

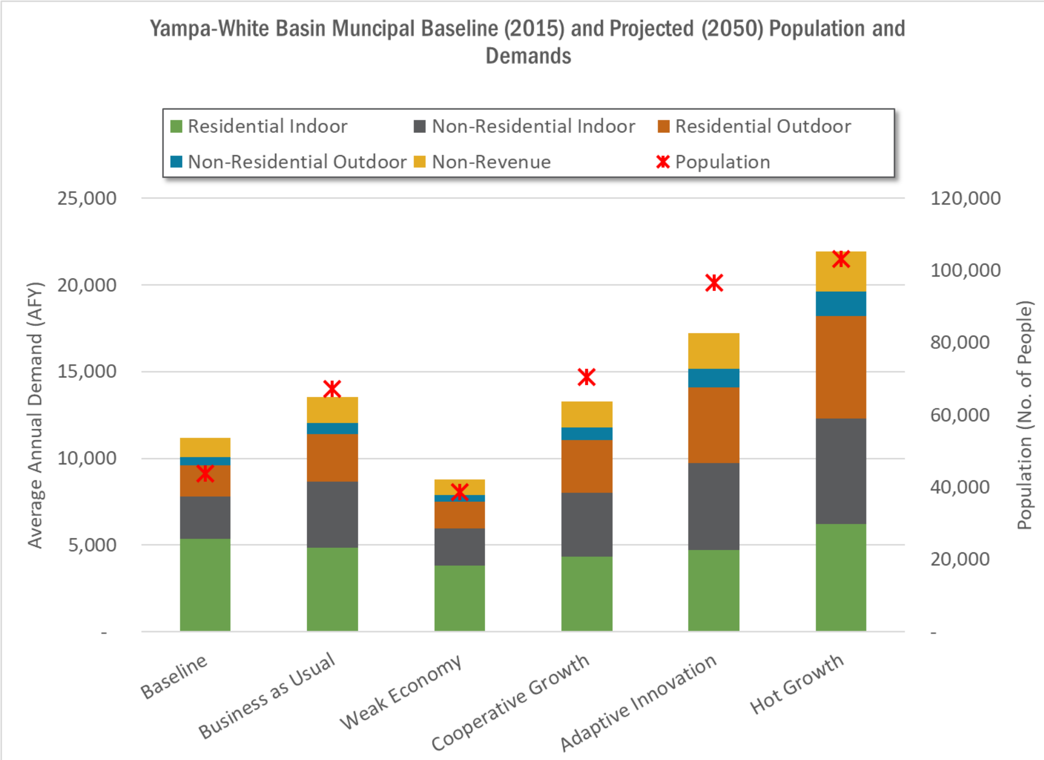

Figure 3-78: Yampa-White Basin Baseline and Projected Population and Municipal Demands.

3.8.2 INDUSTRIAL

The Yampa-White Basin currently includes about 17% of the statewide industrial demand. Approximately 93% of the baseline industrial demands are in the Yampa Sub-Basin and 7% are in the White Sub-Basin. Industrial demands in the Yampa-White Basin are associated with all four sub-sectors. Basin-scale industrial demands are shown on Figure 3-79 and county-scale industrial demands are summarized in Table 3-41.

Large Industry demands in this basin are located in Moffat and Routt counties. All baseline demands were based on data from SWSI 2010 and are related to mining in Moffat County and mining and golf courses in Routt County. The baseline demand has increased from 6,100 AFY in SWSI 2010 to 6,900 AFY in the Technical Update analysis. Projected Large Industry demands range from 8,550 AFY to 10,450 AFY.

The baseline Snowmaking demand is 290 AFY, which is the same as in SWSI 2010 because there has been no increase in snowmaking acreage. Projected demands are 570 AFY and were not varied by scenario.

Thermoelectric demands are related to two facilities. Baseline demands for the facility on Routt County were updated based on information from Xcel. Baseline demands for the facility in Moffat County were updated based on the BIP. The total baseline demand has decreased from 20,200 AFY in SWSI 2010 to 19,350 AFY. Projected Thermoelectric demands range from 29,020 AFY to 35,460 AFY.

Energy Development demands are located in Moffat, Rio Blanco, and Routt counties. The baseline Energy Development demand in the Yampa-White Basin is 3,100 AFY as compared to 2,000 AFY in SWSI 2010. Projected demands range from 3,900 AFY to 41,800 AFY.

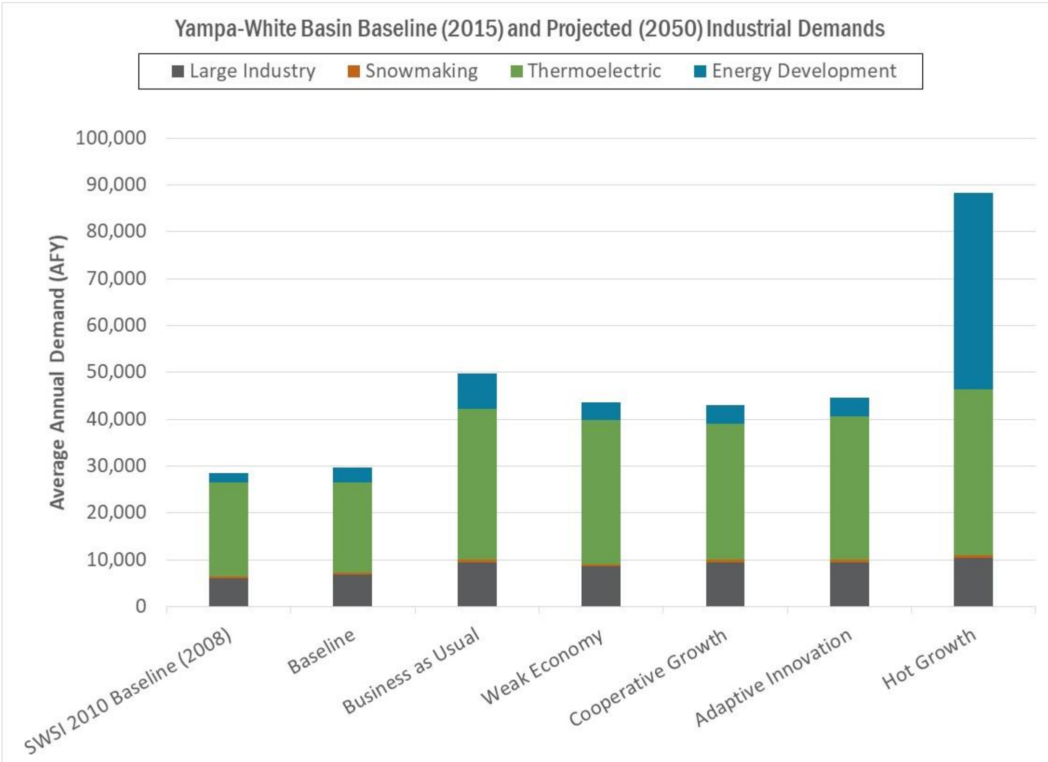

Figure 3-79: Total Yampa-White Basin Industrial Baseline and Projected Demands.

Table 3-41: Yampa-White Industrial Baseline and Projected Demands by County (AFY).

County	Sub-Sector	Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
YAMPA SUB-BASIN							
Moffat	Large Industry	2,900	3,900	3,510	3,900	3,900	4,290
	Snowmaking	-	-	-	-	-	-
	Thermoelectric	14,010	26,900	25,560	24,210	25,560	29,590
	Energy Development	1,000	1,200	400	400	400	2,300
Routt	Large Industry	4,000	5,600	5,040	5,600	5,600	6,160
	Snowmaking	290	570	570	570	570	570
	Thermoelectric	5,340	5,340	5,070	4,810	5,070	5,870
	Energy Development	500	500	500	500	500	1,600
Sub-Basin Total		28,040	44,010	40,650	39,990	41,600	50,380
WHITE SUB-BASIN							
Rio Blanco	Large Industry	-	-	-	-	-	-
	Snowmaking	-	-	-	-	-	-
	Thermoelectric	-	-	-	-	-	-
	Energy Development	1,600	5,800	3,000	3,000	3,000	37,900
Sub-Basin Total		1,600	5,800	3,000	3,000	3,000	37,900
TOTAL YAMPA-WHITE BASINS							
Basin Total		29,640	49,810	43,650	42,990	44,600	88,280

3.8.3 TOTAL

Yampa-White Basin combined M&I demand projections for 2050 range from approximately 52,000 AFY in the Weak Economy scenario to 110,000 AFY in the Hot Growth scenario, as shown in Figure 3-80. Under every planning scenario, industrial demands exceed the municipal demands. This is influenced by industrial use in the Yampa Sub-Basin and is the only basin in the state in which industrial demands exceed municipal. Industrial demands make up approximately 70% to 80% of the total M&I demands in the Yampa-White Basin, depending on planning scenario. On a basin scale, the demand projections do not follow the statewide sequence of the volumetric demand scenario rankings described in the CWP, with the Adaptive Innovation scenario falling out of sequence.

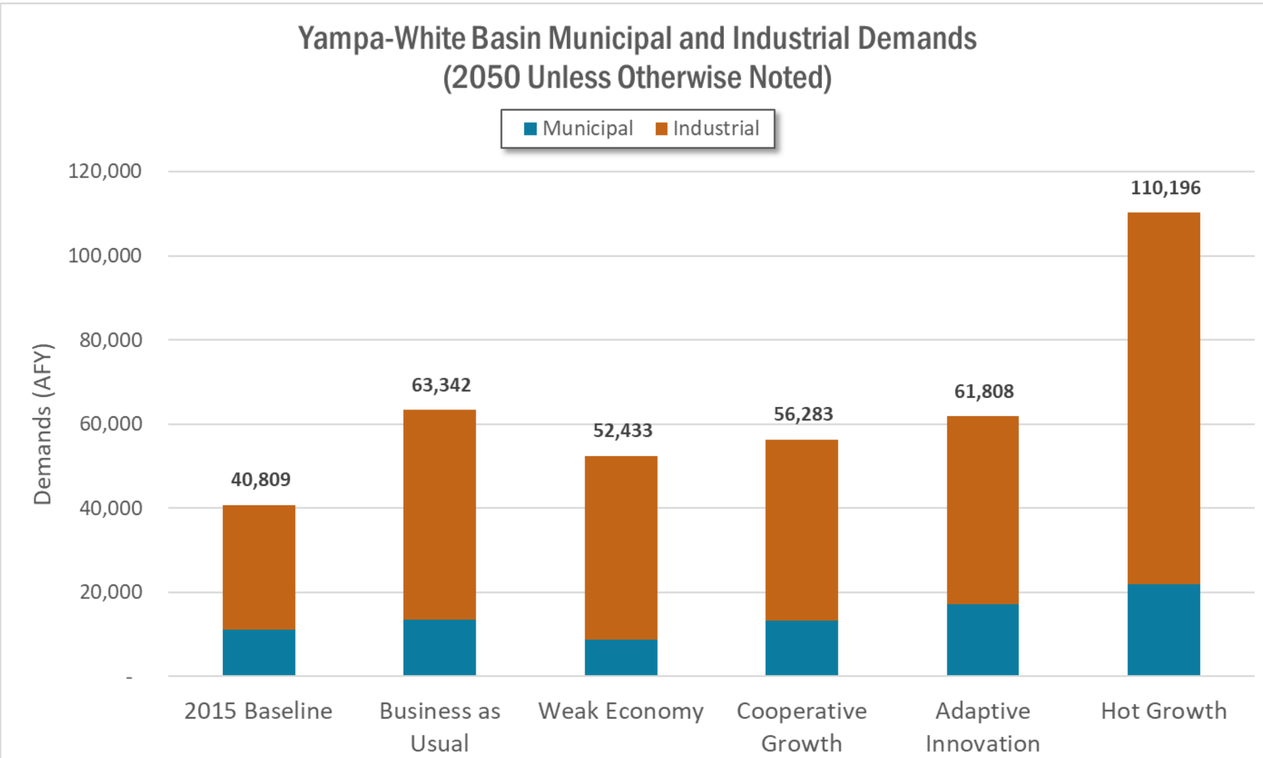

Figure 3-80: Yampa-White Basin Baseline and Projected M&I Demands.

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Appendix A: CWP PLANNING SCENARIO DESCRIPTIONS

Scenario:	Narrative Description
A: Business as Usual	Recent trends continue into the future. Few unanticipated events occur. The economy goes through regular economic cycles but grows over time. By 2050, Colorado's population is close to 9 million people. Single family homes dominate, but there is a slow increase of denser developments in large urban areas. Social values and regulations remain the same, but streamflows and water supplies show increased stress. Regulations are not well coordinated and create increasing uncertainty for local planners and water managers. Willingness to pay for social and environmental mitigation of new water development slowly increases. Municipal water conservation efforts slowly increase. Oil-shale development continues to be researched as an option. Large portions of agricultural land around cities are developed by 2050. Transfer of water from agriculture to urban uses continues. Efforts to mitigate the effects of the transfers slowly increase. Agricultural economics continue to be viable, but agricultural water use continues to decline. The climate is similar to the observed conditions of the 20th century.
B: Weak Economy	The world's economy struggles, and the state's economy is slow to improve. Population growth is lower than currently projected, slowing the conversion of agricultural land to housing. The maintenance of infrastructure, including water facilities, becomes difficult to fund. Many sectors of the state's economy, including most water users and water dependent businesses, begin to struggle financially. There is little change in social values, levels of water conservation, urban land use patterns, and environmental regulations. Regulations are not well coordinated and create increasing uncertainty for local planners and water managers. Willingness to pay for social and environmental mitigation decreases due to economic concerns. Greenhouse gas emissions do not grow as much as currently projected and the climate is similar to the observed conditions of the 20th century.
C: Cooperative Growth	Environmental stewardship becomes the norm. Broad alliances form to provide for more integrated and efficient planning and development. Population growth is consistent with current forecasts. Mass transportation planning concentrates more development in urban centers and in mountain resort communities, thereby slowing the loss of agricultural land and reducing the strain on natural resources compared to traditional development. Coloradans embrace water and energy conservation. New water-saving technologies emerge. Eco-tourism thrives. Water-development controls are more restrictive and require both high water-use efficiency and environmental and recreation benefits. Environmental regulations are more protective, and include efforts to re-operate water supply projects to reduce effects. Demand for more water-efficient foods reduces water use. There is a moderate warming of the climate, which results in increased water use in all sectors, in turn affecting streamflows and supplies. This dynamic reinforces the social value of widespread water efficiency and increased environmental protection.
D: Adaptive Innovation	A much warmer climate causes major environmental problems globally and locally. Social attitudes shift to a shared responsibility to address problems. Technological innovation becomes the dominant solution. Strong investments in research lead to breakthrough efficiencies in the use of natural resources, including water. Renewable and clean energy become dominant. Colorado is a research hub and has a strong economy. The relatively cooler

Scenario:	Narrative Description
	weather in Colorado (due to its higher elevation) and the high-tech job market cause population to grow faster than currently projected. The warmer climate increases demand for irrigation water in agriculture and municipal uses, but innovative technology mitigates the increased demand. The warmer climate reduces global food production increasing the market for local agriculture and food imports to Colorado. More food is bought locally, increasing local food prices and reducing the loss of agricultural land to urban development. Higher water efficiency helps maintain streamflows, even as water supplies decline. The regulations are well defined and permitting outcomes are predictable and expedited. The environment declines and shifts to becoming habitat for warmer-weather species. Droughts and floods become more extreme. More compact urban development occurs through innovations in mass transit.
E: Hot Growth	A vibrant economy fuels population growth and development throughout the state. Regulations are relaxed in favor of flexibility to promote and pursue business development. A much warmer global climate brings more people to Colorado with its relatively cooler climate. Families prefer low-density housing and many seek rural properties, ranchettes, and mountain living. Agricultural and other open lands are rapidly developed. A hotter climate decreases global food production. Worldwide demand for agricultural products rises, greatly increasing food prices. Hot and dry conditions lead to a decline in streamflows and water supplies. The environment degrades and shifts to becoming habitat for species adapted to warmer waters and climate. Droughts and floods become more extreme. Communities struggle unilaterally to provide services needed to accommodate the rapid business and population growth. Fossil fuel is the dominant energy source, and there is large production of oil shale, coal, natural gas, and oil in the state.

Source: CWCB, Colorado's Water Plan, Section 6.1, "Scenario Planning and Developing an Adaptive Water Strategy" and Section 4, "Water Supply". 2010.

Appendix B: BASELINE (2015) POPULATION AND 2050 POPULATION PROJECTIONS

Basin Forecasts	Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Arkansas	1,008,434	1,509,463	1,462,821	1,544,367	1,625,970	1,567,968
Colorado	307,570	515,472	456,321	549,176	572,860	577,827
Gunnison	103,121	162,632	123,070	158,587	195,998	204,931
Metro	2,768,126	4,061,899	3,817,099	3,921,976	4,161,584	4,317,749
North Platte	1,353	1,279	1,055	1,210	1,364	1,457
Rio Grande	45,975	55,104	42,270	52,141	62,972	67,252
South Platte	1,061,754	1,892,367	1,616,081	1,962,391	2,330,861	2,189,906
Southwest	107,999	195,837	125,814	201,010	264,189	282,144
Yampa	43,723	67,242	38,623	70,437	96,621	103,188
Basin Totals	**5,448,055**	**8,461,296**	**7,683,154**	**8,461,296**	**9,312,421**	**9,312,421**

Forecasts by County		Baseline (2015)	Business as (2015)	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Arkansas							
Baca		3,594	2,949	2,858	2,790	2,868	3,063
Bent		5,847	6,607	6,403	6,252	6,426	6,863
Chaffee		18,603	27,145	26,306	25,686	26,403	28,197
Cheyenne	*part*	686	615	596	582	599	639
Crowley		5,569	7,754	7,514	7,337	7,542	8,055
Custer		4,457	5,934	5,751	5,615	5,772	6,164
El Paso		676,178	1,076,486	1,043,223	1,116,517	1,177,637	1,118,209
Elbert	*part*	7,634	20,526	19,891	19,422	19,964	21,321
Fremont		46,659	56,406	54,663	53,373	54,864	58,592
Huerfano		6,456	5,983	5,798	5,661	5,819	6,215
Kiowa		1,396	1,193	1,156	1,129	1,160	1,239
Lake		7,502	9,868	9,563	9,337	9,598	10,250
Las Animas		14,061	13,249	12,840	12,537	12,887	13,763
Lincoln	*part*	4,485	6,857	6,645	6,488	6,669	7,123
Otero		18,265	15,302	14,829	14,479	14,884	15,895

Prowers		11,905	11,441	11,087	10,826	11,128	11,884
Pueblo		163,196	224,184	217,257	230,283	245,249	232,873
Teller	*part*	11,941	16,964	16,440	16,052	16,501	17,622
Colorado							
Eagle		53,320	94,459	83,620	102,687	99,147	105,885
Garfield		57,779	105,711	93,581	115,297	110,957	118,498
Grand		14,602	27,406	24,261	29,967	28,766	30,721
Mesa	*part*	134,096	212,859	188,433	220,735	255,228	238,608
Pitkin		17,845	23,209	20,546	24,282	24,361	26,017
Summit		29,928	51,828	45,881	56,208	54,400	58,097
Gunnison							
Delta		29,973	42,126	31,878	39,861	49,704	53,082
Gunnison		16,097	22,728	17,199	24,054	26,817	28,639
Hinsdale		767	1,573	1,190	1,488	1,856	1,982
Mesa	*part*	14,927	23,695	17,931	24,572	32,067	29,858
Montrose	*part*	36,710	66,942	50,658	63,343	78,985	84,353
Ouray		4,647	5,568	4,214	5,269	6,570	7,016
Metro							
Adams		489,923	890,148	836,501	842,289	886,001	946,216
Arapahoe		629,066	899,738	845,513	851,363	895,546	956,410
Broomfield		64,656	95,566	89,806	90,428	95,121	101,585
Denver		680,658	952,955	895,523	980,185	1,067,123	1,012,979
Douglas		322,198	482,824	453,725	456,865	480,575	513,236
Jefferson		564,619	694,943	653,061	657,579	691,705	738,716
Elbert	*part*	17,006	45,725	42,970	43,267	45,512	48,606
North Platte							
Jackson		1,353	1,279	1,055	1,210	1,364	1,457
Rio Grande							
Alamosa		15,968	22,934	17,593	21,701	26,209	27,990
Conejos		8,074	8,997	6,902	8,513	10,282	10,980
Costilla		3,572	3,934	3,018	3,722	4,496	4,801
Mineral		729	959	736	907	1,096	1,170
Rio Grande		11,413	11,612	8,907	10,988	13,270	14,172

Forecasts by County		Baseline (2015)	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Saguache		6,219	6,668	5,115	6,309	7,620	8,138
South Platte							
Boulder		318,570	447,843	382,458	460,770	558,020	518,258
Cheyenne	*part*	1,144	1,026	876	970	1,111	1,187
Clear Creek		9,392	12,448	10,631	11,779	13,488	14,405
Gilpin		5,824	6,626	5,659	6,270	7,180	7,668
Kit Carson		8,219	9,595	8,194	9,079	10,397	11,104
Larimer		332,830	543,588	464,224	564,664	677,320	629,057
Lincoln	*part*	1,064	1,627	1,390	1,540	1,763	1,883
Logan		22,122	29,516	25,207	27,929	31,983	34,157
Morgan		28,230	42,734	36,495	40,436	46,306	49,453
Park		16,716	23,797	20,323	22,518	25,786	27,539
Phillips		4,307	4,372	3,734	4,137	4,737	5,059
Sedgwick		2,389	2,332	1,992	2,207	2,527	2,699
Teller	*part*	11,490	16,323	13,939	15,445	17,687	18,889
Washington		4,834	4,800	4,099	4,542	5,201	5,555
Weld		284,571	734,343	627,129	779,320	915,004	849,804
Yuma		10,052	11,398	9,734	10,785	12,351	13,190
Southwest							
Archuleta		12,417	26,571	17,070	25,142	35,845	38,281
Dolores		1,972	2,597	1,668	2,457	3,503	3,742
La Plata		54,857	94,002	60,391	101,831	126,811	135,430
Montezuma		26,129	47,158	30,296	44,623	63,617	67,941
Montrose	*part*	4,085	7,449	4,785	7,048	10,048	10,731
San Juan		696	767	493	726	1,035	1,105
San Miguel		7,843	17,293	11,110	19,183	23,329	24,914
Yampa							
Moffat		12,884	13,868	7,966	13,122	19,927	21,281
Rio Blanco		6,529	7,376	4,237	6,979	10,599	11,319
Routt		24,310	45,998	26,420	50,336	66,095	70,587

Multi-basin Counties (complete totals by county)

Cheyenne	1,830	1,641	1,472	1,553	1,710	1,826
Elbert	24,640	66,251	62,861	62,689	65,477	69,927
Lincoln	5,549	8,484	8,035	8,028	8,432	9,006
Mesa	149,023	236,554	206,364	245,307	287,295	268,465
Montrose	40,795	74,391	55,443	70,391	89,034	95,084
Teller	23,431	33,287	30,380	31,497	34,187	36,511

Analysis and Technical Update to the Colorado Water Plan

Technical Memorandum

Prepared for:

Colorado Water Conservation Board

Subject:

Updated Population Projections for Water Plan Scenarios

Date: March 15, 2019

Prepared by: Doug Jeavons and Michael Verdone, BBC Research & Consulting
Reviewed by: CH2M

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Section 1: Overview

Population projections, by basin and for the state as a whole, are a primary driver in the municipal and industrial demand projections developed by Element Water. This memo describes the methodology used by BBC Research & Consulting (BBC) to develop updated population projections for each of the scenarios in the Water Plan.

Section 2: Background on Previous Methodologies

2.1 OVERVIEW OF METHODOLOGIES USED IN SWSI 2010

As documented in Appendix H, "State of Colorado 2050 Municipal & Industrial Water Use Projections", alternative population scenarios through 2050 were also developed for the previous SWSI effort. That work, primarily conducted in 2008-09, required both extending the county and state population projections available at the time from the State Demography Office (SDO) from 2035 to 2050 and developing alternative high and low scenarios.

Harvey Economics, in collaboration with the SDO, essentially sought to extend the existing SDO projections using a similar approach to the methods the SDO used to develop their forecasts (which at the time covered the period of 2005 through 2035). Those methods included developing economic (e.g. employment) forecasts for the state and each county to develop estimates of future labor demand. Future labor demand was then compared to projected future labor supply based on an extended cohort component demographic model similar to the SDO's demographic model. In areas where labor demand was projected to exceed available labor supply, additional net in-migration was assumed to occur in order to balance the labor markets. In situations where labor supply was projected to exceed labor demand, net out-migration was assumed to occur to balance the labor markets.

The need to extend the SDO's projections from 2035 to 2050 also served as the basis for developing the alternative high growth and low growth scenarios. In the previous SWSI effort, the population scenarios all assumed the same growth (the SDO forecast) through 2035. However, the high growth scenario incorporated more aggressive economic/employment growth assumptions for the extension from 2035 through 2050, while the low growth scenario incorporated lower economic/employment assumptions from 2035 through 2050 compared to either the high scenario or the medium scenario.

2.2 METHODOLOGY ENHANCEMENTS FOR TECHNICAL UPDATE

Two factors led to modifications to the approach to developing population projection scenarios for the Technical Update:

- The SDO population projections are now available through 2050 (which remains the endpoint for this SWSI update). It was no longer necessary to extend the SDO projections in order to create the middle, or base case, population projections.
- During the scenario planning workshop held in early March 2017, CWCB (and other members of the SWSI team) suggested it would be beneficial to find a simpler approach for developing the alternative scenarios that would be easier to explain and involve fewer assumptions.

After further discussions with other members of the study team and the SDO, BBC developed a simplified approach for constructing the alternative population scenarios for this Technical Update. While the previous approach was methodologically rigorous in producing an internally consistent set of employment and population forecasts, only the population numbers were actually used in deriving the future water demand forecasts. Moreover, development of alternative employment forecast scenarios for various sectors in all 64 counties in Colorado inevitably involved making numerous assumptions about conditions far in the future that were based almost entirely on judgment. By avoiding these types of judgment-based assumptions, the methodology adopted for the SWSI update also avoids "picking winners and losers" in developing population scenarios for smaller areas such as the basins and individual counties.

Section 3: Description of Revised Methodology

The updated population forecasts for the planning scenarios were based on the existing SDO population forecasts that now span the entire Technical Update study period and provide the base case or middle projection, and probabilistic analysis of the potential variance around those forecasts to develop high and low growth projections. The variance around the SDO projections was estimated from the historical population growth experience of the state, and each of its basins. As discussed later in Section 5, these three sets of initial projections, with some modifications to the distribution of growth within the state, were then used to develop population forecasts consistent with the five planning scenarios developed in the Colorado Water Plan.

3.1 SPECIFIC METHODOLOGY

Only three pieces of information were required to develop probabilistic estimates of the potential range surrounding the "median" population projections produced by the SDO. Those information requirements were:

- **The compound average annual growth rate implied by the SDO forecast.** For example, for the State of Colorado as a whole, the SDO's 2017 forecast anticipates a 2050 population of 8,461,296 residents. By comparing that projection to the 2010 population of 5,029,196, we can calculate the compound average annual growth rate over the 40-year period to be 1.309 percent per year.
- **The historical standard deviation in population growth rates by decade.** As shown in Table 1, from 1940 through 2010, the standard deviation in average annual population growth rates by decade for the State of Colorado was 0.634 percent.
- **The historical compound average annual growth rate for the area being projected.** Also shown in Table 1, from 1940 through 2010, the average annual compound growth rate for Colorado as a whole was 2.165 percent.

State of Colorado Population Growth 1940-2010 (Compound Average Growth Rate and Standard Deviation by Decade)		
Year	**Population**	**Avg. Rate**
1940	1,123,296	
1950	1,325,089	1.67%
1960	1,753,947	2.84%
1970	2,207,259	2.33%
1980	2,889,964	2.73%
1990	3,294,394	1.32%
2000	4,301,261	2.70%
2010	5,029,196	1.58%
1940-2010 Compound Growth Rate	2.165%	
Standard Deviation in Growth Rate by Decade		0.634%

Table 1. State of Colorado Population Growth, 1940-2010 (Compound Average Growth Rate and Standard Deviation in Average Growth Rate by Decade)

Source: U.S. Census Bureau, 2017. Growth rates and standard deviations calculated by BBC.

Fundamentally, this approach relies on a couple of key assumptions:

- The compound growth rate for 2015 through 2050 derived from SDO population projections represents the median average annual growth rate forecast for each area. Out of a hypothetical million potential alternative futures, the future described in the SDO forecast would fall in the middle.
- The variability of growth rates in future decades (and corresponding potential variance around the SDO-based median forecast) can be estimated based on historical variability in growth rates by decade since 1940. However, BBC has further assumed that the "coefficient of variation" for the growth rates in each basin will remain the same in the future as they have been in the past. This means that the size of the standard deviation in each basin's future growth rate will change in proportion to the ratio of their projected median growth rate in the future to their median growth rate in the past. For example, if the median future annual growth rate is projected to be ½ of the historical annual growth rate, the future standard deviation by decade is also assumed to be ½ of the historical standard deviation.

The second assumption described above is both logical and supported by the historical data.

BBC calculated the historical compound average annual growth rates for each of Colorado's 63 counties (excluding Broomfield) from 1940 through 2010, and the historical standard deviations in growth rates by decade for each county. There was a correlation of 0.50 between the absolute values of the compound average annual growth rates and the standard deviations across all of the counties.

We also sorted the counties into quintiles based on their compound average annual growth rates and reviewed the average standard deviation across each quintile. In the fastest growing quintile of counties, the historical compound average annual growth rate from 1940 to 2010 averaged 3.7 percent per year, while the standard deviations in growth rates by decade averaged 3.1 percent. In the slowest growing quintile of counties, the historical compound average annual growth rate from 1940 to 2010 averaged 0.1 percent per year, while the standard deviations in growth rates by decade averaged 1.3 percent.

3.1.1 STEPS TO IMPLEMENT THIS ANALYSIS

The following sequence of steps was used to implement the analysis.

1. Calculate median compound average annual growth rate for the state (as shown in Figure 1) and each basin based on the 2017 SDO projections through 2050.
2. Estimate the standard deviation in future growth rates by decade for the state and each basin based on the following calculation:

   Future standard deviation = historical standard deviation (1940 – 2010) x projected median compound growth rate in future (2010-2050) / historical compound growth rate (1940 – 2010)
3. Use Monte Carlo simulation techniques to simulate alternative future populations for each area based on baseline compound average annual growth rate (from SDO projections) and estimated standard deviation in growth rates by decade. Each “run” for each geographic area built to a 2050 population projection as follows:
   a. 2020 population = 2010 population (estimate from SDO) x (1 + X) ^10, where X is a randomly drawn average annual growth rate from a normal distribution with its mean based on the compound growth rate from the SDO projections, and its standard deviation estimated based on step 2.
   b. 2030 population = 2020 population estimate (from step 3a) x (1 + X) ^10, where X is another randomly drawn average annual growth rate from the distribution described in step 3a.
   c. Repeat step 3b until we reach 2050.
4. Based on thousands of “runs”, identify the estimated overall distribution of potential future population totals for the state and each basin in 2050.

To encompass a wide range of potential future population growth outcomes, BBC and CWCB selected the 10 percent exceedance probability for the “high growth” projections and the 90 percent exceedance probability for the “low growth” projections. Based on these thresholds, there is an estimated 1 in 10 chance that the actual future 2050 population could be higher than the “run” with the estimated 10 percent exceedance probability, and a 1 in 10 chance the actual future 2050 population could turn out to be lower than the “run” with the estimated 90 percent exceedance probability.

3.1.2 STATEWIDE POPULATION EXAMPLE

To more specifically illustrate the application of this methodology, Figure 1 shows the resulting estimated range of possible future population totals for the State of Colorado as a whole.

The SDO’s 2017 population projection for Colorado in 2050 was 8,461,296 residents. That projection is represented in Figure 1 by the red line labelled “median population,” and provides the middle or base case population scenario for SWSI.

Using the 10 percent exceedance probability for the high growth forecast, the 2050 population projection for that forecast is 9,312,421. Using the 90 percent exceedance probability to represent the low growth forecast for future population, that forecast has a projected statewide population in 2050 of 7,683,154 residents.

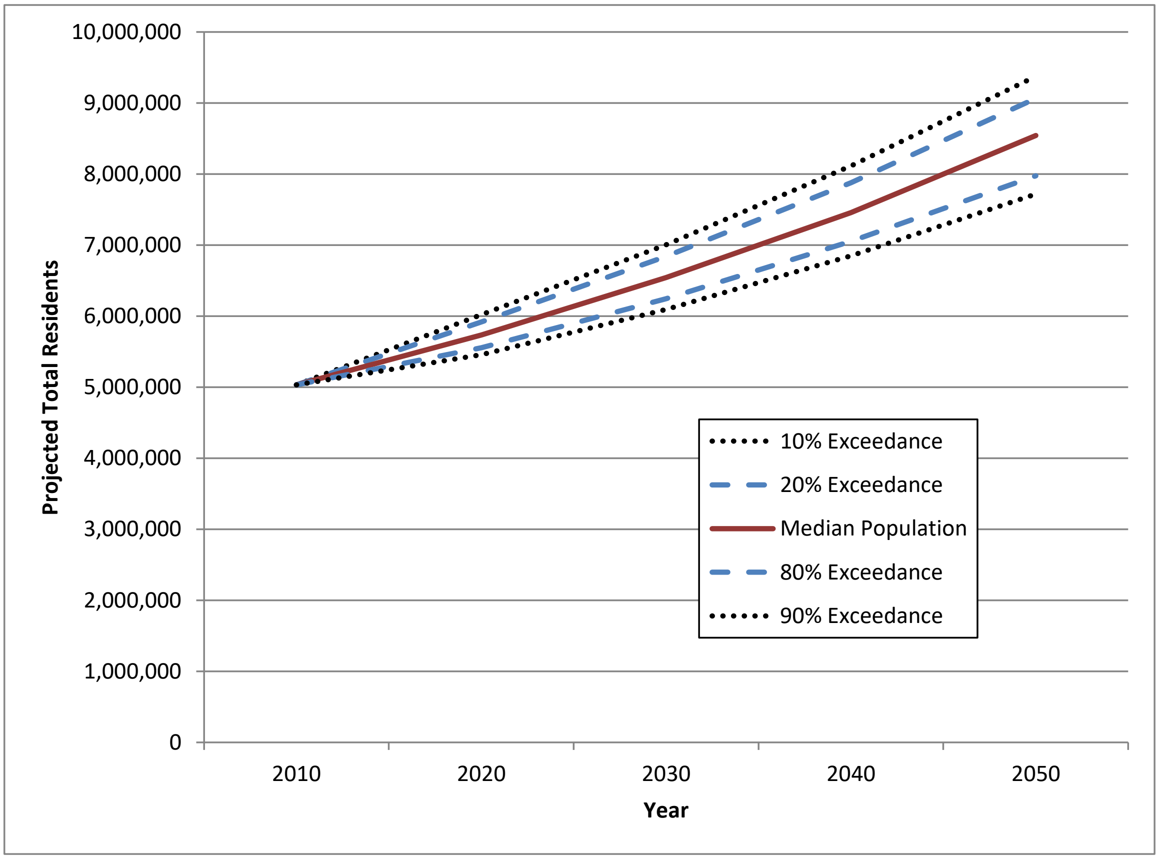


Figure 1. Range of Potential State of Colorado Population Growth, 2010-2050 (Selected Exceedance Intervals)

Note: For simplicity in calculation and illustration, this example uses the average compound growth rate from the SDO statewide projections over the entire period, and does not reflect the declining growth rates from decade to decade embodied in the SDO projections. Consequently, the median population line is lower than the actual SDO projections for all years before 2050.

3.1.3 APPLICATION TO BASINS AND COUNTIES

The same methodology was applied to generate high growth and low growth projections for each of the basins and counties, with a couple of refinements.

In general, the smaller geographic areas represented by the basins have larger coefficients of variation in their historical population growth rates than the state as a whole. This implies that their population projections, under the methodology described in this memo, also have larger variance (on a relative basis) than the state as a whole. Carried further, the larger variance in the basin population projections means that the sum of the basin populations for the high growth projections (the 10 percent exceedance probability) is greater than the overall statewide population projection for the same exceedance probability. Correspondingly, the sum of the low growth projections for the basins (the 90 percent exceedance probability) is lower than the 90 percent exceedance probability estimate for Colorado as a whole.

It could be argued that these discrepancies are logical. There is no reason to believe that a future high population growth scenario for Colorado as a whole necessarily means that every basin would simultaneously experience high growth, and vice-versa for the low scenario.

However, it would be problematic from a planning standpoint to deal with a set of high growth projections for the basins that collectively exceed the high growth projection for the State (or vice versa for the low growth projections). BBC dealt with this issue by constraining the high and low projections for the basins to sum to the statewide total. The constraint was imposed by proportionally reducing growth in each basin (under the high growth projections) as needed to make the sum of the basin projections match the statewide total – or proportionally increasing growth in each basin (under the low growth projections) so that the sum of the basin projections matched the statewide low projections.

Alternative population scenarios for the state's individual counties were also used in developing the Technical Update municipal demand forecasts. The potential issues regarding consistency between the statewide population projections and projections for smaller areas are even greater at the individual county level. Consequently, BBC did not develop probabilistic population forecasts for the individual counties. Instead, BBC apportioned the probabilistic basin growth projections to their component counties based on each county's share of the median, SDO projections for its basin.

Six of Colorado's 64 counties include lands located in more than one basin. Current and projected future populations for these counties were divided between the relevant basins using the same proportions utilized in the SWSI 2010 population projections.

Section 4: Illustration of Range of Population Growth Projections for Selected Basins

The following charts illustrate the SDO projections and the statistically-derived high growth projections and low growth projections for three basins. One of the basins (the Arkansas Basin) is an example of an area which has historically experienced comparatively low variability in terms of its growth trajectory. The second example is the Colorado River Basin, which has historically experienced medium variability in terms of its growth trajectory. The final example is the Gunnison Basin, which has historically experienced high variability in its growth trajectory. The high growth and low growth projections shown in these figures reflect the unconstrained statistical projections for each basin, prior to adjustments to make the sum of the basin projections match the overall state high growth and low growth projections.

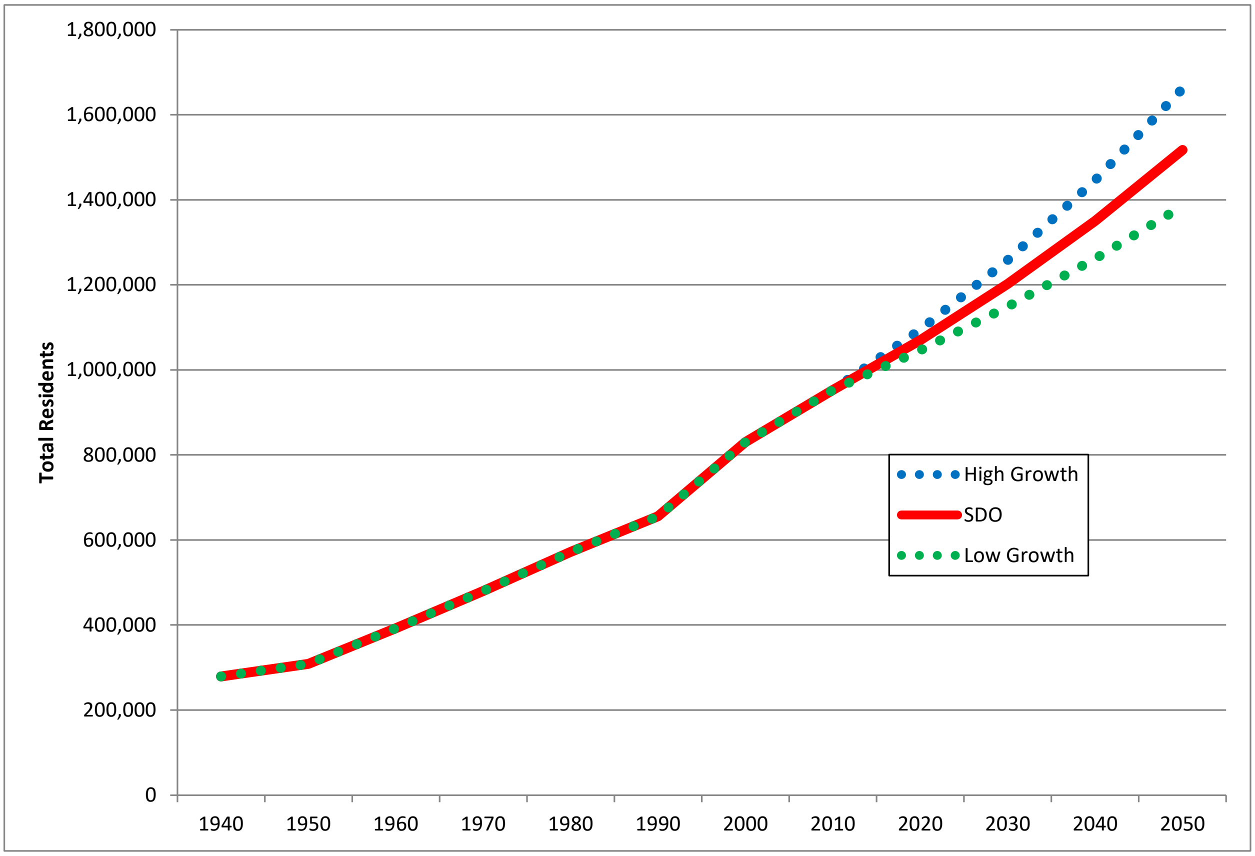


Figure 2. Arkansas Basin SDO and Statistically-derived Low and High Growth Projections
(Example of basin with low historical growth variability)

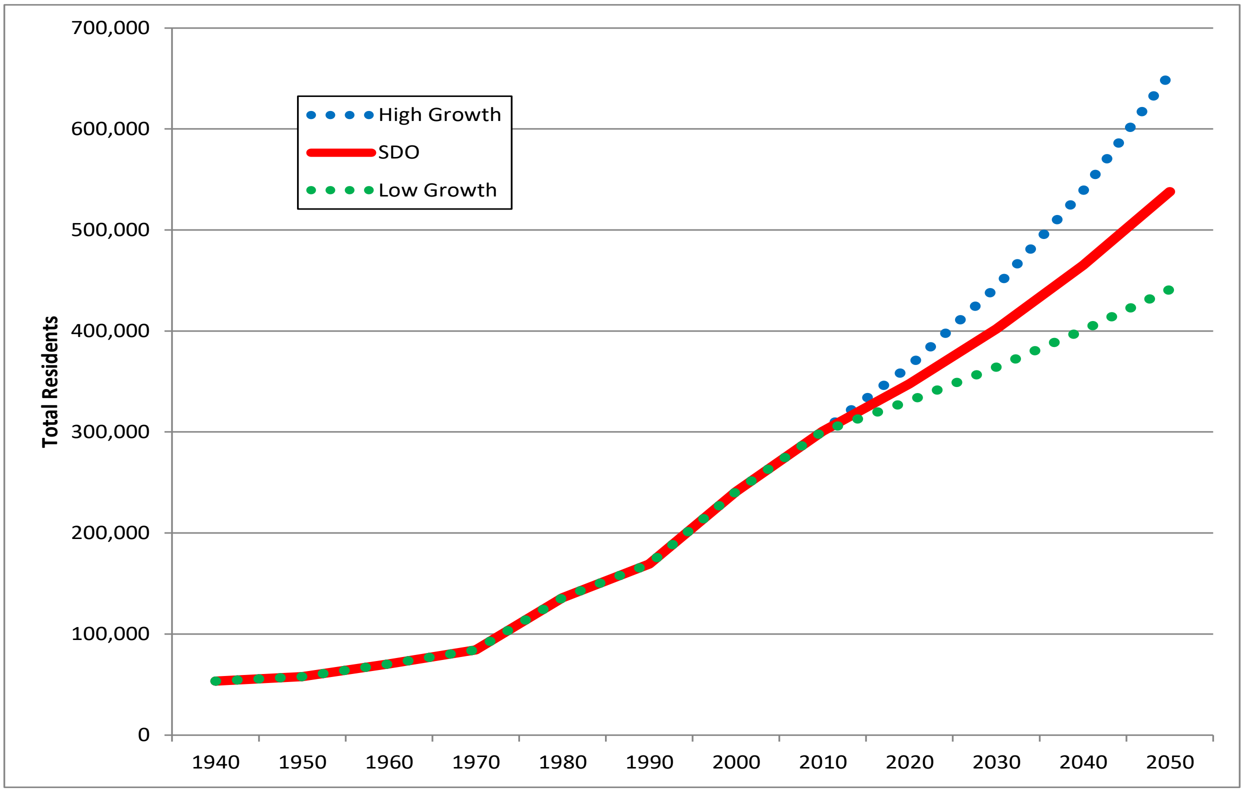


Figure 3. Colorado Basin SDO and Statistically-derived Low and High Growth Projections
(Example of basin with medium historical growth variability)

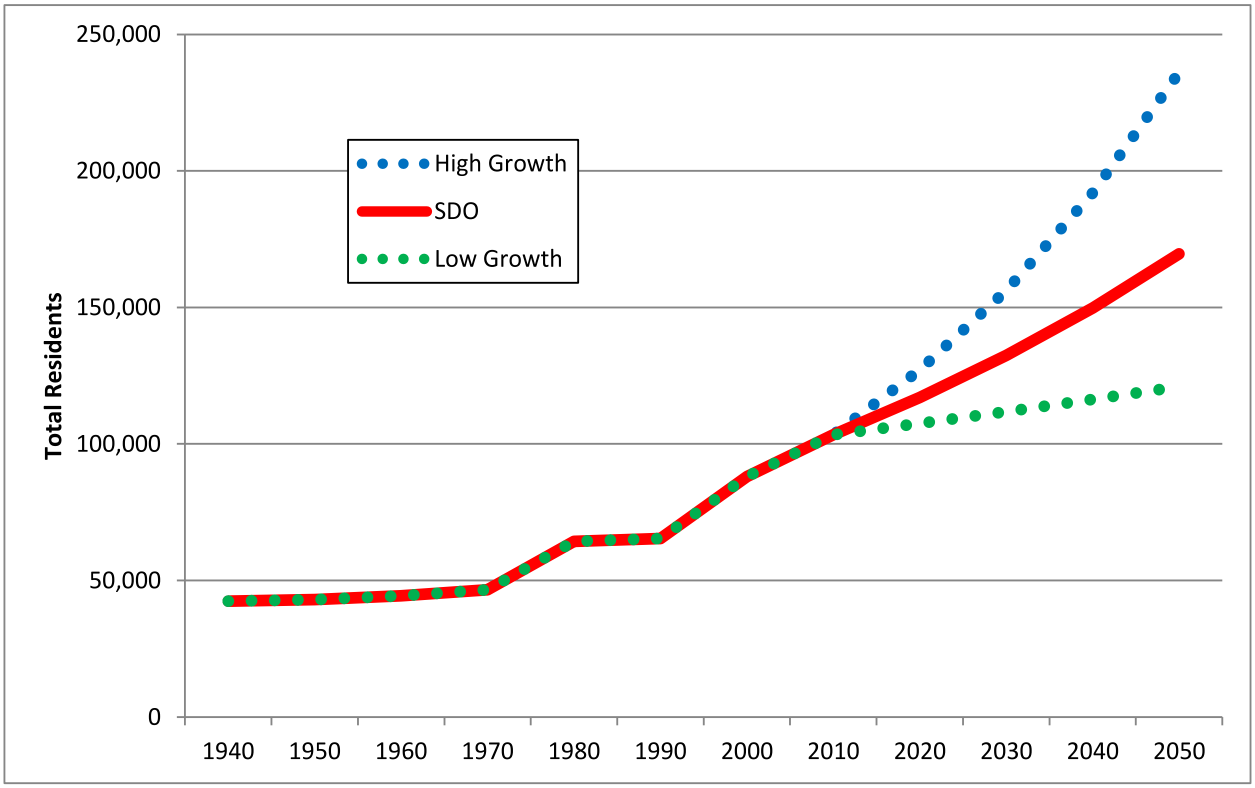


Figure 4. Gunnison Basin SDO and Statistically-derived Low and High Growth Projections
(Example of basin with high historical growth variability)

Section 5: Development of the Five Technical Update Population Scenarios

During the creation of the Colorado Water Plan, five alternative future scenarios were developed. These scenarios were entitled "business as usual," "weak economy," "cooperative growth," "adaptive innovation," and "hot growth."

As described in the Water Plan, each of the five scenarios includes distinctive assumptions regarding future demographic growth. The following are excerpts from the descriptions of each scenario specifically related to population growth, and descriptions of the manner in which BBC implemented the population projections for each scenario.

5.1 BUSINESS AS USUAL SCENARIO

- Excerpts from Colorado Water Plan description:

  "Recent trends continue into the future. Few unanticipated events occur. The economy goes through regular cycles, but grows over time. By 2050, Colorado's population is close to 9 million people. Single family homes dominate, but there is a slow increase of denser developments in large urban areas."

- Implementation:

  Used the current SDO state and county projections for 2050. BBC met with the SDO on 5/30/2017 and confirmed that this scenario was consistent with the assumptions embodied in their forecast. As noted in Section 2.1 of this memo, the SDO projections are based on a sophisticated combination of a cohort component demographic model and regional employment forecasts throughout the state. Further, the SDO projections are regularly reviewed with local governments and planners, and modified (as necessary) based on local input. The SDO projections are also the "official" population projections for the State of Colorado and are used for a variety of purposes, including the distribution of funds to local governments.

5.2 WEAK ECONOMY SCENARIO

- Excerpts from Colorado Water Plan description:

  "The world's economy struggles, and the state's economy is slow to improve. Population growth is lower than currently projected, slowing the conversion of agricultural land to housing… Many sectors of the state's economy, including most water users and water-dependent businesses, begin to struggle financially."

- Implementation:

  Used the statistically-derived low growth projections. These projections are consistent with an overall reduction of future growth in Colorado. Based on the methods used to develop the low growth projections, areas with the most consistent growth histories (through booms and busts) would see the smallest reductions in their projected growth relative to the SDO forecasts, while areas that have historically been the most vulnerable to economic busts would see larger reductions in their projected growth.

5.3 COOPERATIVE GROWTH SCENARIO

- Excerpts from Colorado Water Plan description:

  "Environmental stewardship becomes the norm. Broad alliances form to provide for more integrated and efficient planning and development. Population growth is consistent with current forecasts. Mass transportation planning concentrates more development in urban centers and mountain resort communities, thereby slowing the loss of agricultural land and reducing the strain on natural resources compared to traditional development."

- Implementation:

  Constrained overall growth to statewide SDO projections. Defined mountain resort communities and urban centers. Increased projected 2015-2050 BAU population growth in mountain resort communities by 20%, increased projected 2015-2050 BAU population growth in urban centers by 10%. Adjusted other areas (basins and counties) to maintain overall state totals from SDO projections.

- Definitions of mountain resort communities: Grand, Summit, Eagle, Garfield, Routt, Pitkin, Gunnison, San Miguel, and La Plata counties.
- Definitions of urban centers: Denver, El Paso, Pueblo, Boulder, Larimer, Weld, and Mesa counties.

5.4 ADAPTIVE INNOVATION SCENARIO

- Excerpts from Colorado Water Plan description:

  "A much warmer climate causes major environmental problems globally and locally... Colorado is a research hub and has a strong economy. The relatively cooler weather in Colorado (due to its higher elevation) and the high-tech job market cause population to grow faster than currently projected… The warmer climate reduces global food production, increasing the market for local agriculture and food

imports to Colorado. More food is grown locally, increasing local food prices and reducing the loss of agricultural land to urban development... More compact urban development occurs through innovations in mass transit."

- Implementation:

  Used statewide forecast from high growth projections. Used unconstrained high growth forecast for urban center counties (see definitions recommended for Cooperative Growth Scenario) and reduced forecast as needed in other areas to balance to state totals.[1]

5.5 HOT GROWTH SCENARIO

- Excerpts from Colorado Water Plan description:

  "A vibrant economy fuels population growth and development throughout the state... A much warmer global climate brings more people to Colorado with its relatively cooler climate. Families prefer low-density housing and many seek rural properties, ranchettes, and mountain living. Agricultural and other open lands are rapidly developed… Communities struggle unilaterally to provide services needed to accommodate the rapid business and population growth."

- Implementation:

  Used statistically-derived high growth projections, which project disproportionate population increases in the state's more rural areas (due to their greater historical variability in population growth and their higher growth rates during boom periods).

Section 6: Projected Population by Basin and County for the Planning Scenarios

As described in the preceding sections, population projections for the five planning scenarios were derived from the 2017 SDO population projections and statistically-derived high growth projections and low growth projections for each basin.

The revised methodologies in this Technical Update for developing projected M&SSI water needs, and for hydrologic analysis, required further disaggregation of the basin population projections. GIS analysis was used to identify the portion of the South Platte Basin population that is located within the Republic River sub-basin. The population of the Yampa Basin was subdivided between the Yampa sub-basin and the White sub-basin for these purposes.

The following table presents the 2015 population estimates for each basin and county, and the projected 2050 population for each area under the five planning scenarios.

[1] Unconstrained high growth projections refer to projections for these areas based on their basins' probabilistic high growth projections, prior to downward adjustments to force the sum of all of the basins' high growth projections match the statewide high growth projection.

Basin Forecasts	2015 Population	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Arkansas Basin	**1,008,434**	**1,509,463**	**1,462,821**	**1,544,367**	**1,625,970**	**1,567,968**
Colorado Basin	**307,570**	**515,472**	**456,321**	**549,176**	**572,860**	**577,827**
Gunnison Basin	**103,121**	**162,632**	**123,070**	**158,587**	**195,998**	**204,931**
Metro	**2,768,126**	**4,061,899**	**3,817,099**	**3,921,976**	**4,161,584**	**4,317,749**
North Platte Basin	**1,353**	**1,279**	**1,055**	**1,210**	**1,364**	**1,457**
Rio Grande Basin	**45,975**	**55,104**	**42,270**	**52,141**	**62,972**	**67,252**
South Platte Basin	**1,061,754**	**1,892,367**	**1,616,081**	**1,962,391**	**2,330,861**	**2,189,906**
Republican Basin	31,616	35,476	30,297	33,569	38,441	41,054
Remainder S. Platte	1,030,138	1,856,891	1,585,784	1,928,822	2,292,420	2,148,852
Southwest Basin	**107,999**	**195,837**	**125,814**	**201,010**	**264,189**	**282,144**
Yampa-White Basin	**43,723**	**67,242**	**38,623**	**70,437**	**96,621**	**103,188**
Yampa Basin	37,194	59,866	34,386	63,458	86,022	91,869
White Basin	6,529	7,376	4,237	6,979	10,599	11,319
Statewide Totals	**5,448,055**	**8,461,296**	**7,683,154**	**8,461,296**	**9,312,421**	**9,312,421**

Table 2. Population Projections by Basin for the Five Planning Scenarios

Forecasts by County		2015 Population	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Arkansas Basin							
Baca		3,594	2,949	2,858	2,790	2,868	3,063
Bent		5,847	6,607	6,403	6,252	6,426	6,863
Chaffee		18,603	27,145	26,306	25,686	26,403	28,197
Cheyenne	*part*	686	615	596	582	599	639
Crowley		5,569	7,754	7,514	7,337	7,542	8,055
Custer		4,457	5,934	5,751	5,615	5,772	6,164
El Paso		676,178	1,076,486	1,043,223	1,116,517	1,177,637	1,118,209
Elbert	*part*	7,634	20,526	19,891	19,422	19,964	21,321
Fremont		46,659	56,406	54,663	53,373	54,864	58,592
Huerfano		6,456	5,983	5,798	5,661	5,819	6,215
Kiowa		1,396	1,193	1,156	1,129	1,160	1,239
Lake		7,502	9,868	9,563	9,337	9,598	10,250
Las Animas		14,061	13,249	12,840	12,537	12,887	13,763
Lincoln	*part*	4,485	6,857	6,645	6,488	6,669	7,123
Otero		18,265	15,302	14,829	14,479	14,884	15,895
Prowers		11,905	11,441	11,087	10,826	11,128	11,884
Pueblo		163,196	224,184	217,257	230,283	245,249	232,873
Teller	*part*	11,941	16,964	16,440	16,052	16,501	17,622
Colorado Basin							
Eagle		53,320	94,459	83,620	102,687	99,147	105,885
Garfield		57,779	105,711	93,581	115,297	110,957	118,498
Grand		14,602	27,406	24,261	29,967	28,766	30,721
Mesa	*part*	134,096	212,859	188,433	220,735	255,228	238,608
Pitkin		17,845	23,209	20,546	24,282	24,361	26,017
Summit		29,928	51,828	45,881	56,208	54,400	58,097
Gunnison Basin							
Delta		29,973	42,126	31,878	39,861	49,704	53,082
Gunnison		16,097	22,728	17,199	24,054	26,817	28,639
Hinsdale		767	1,573	1,190	1,488	1,856	1,982
Mesa	*part*	14,927	23,695	17,931	24,572	32,067	29,858
Montrose	*part*	36,710	66,942	50,658	63,343	78,985	84,353
Ouray		4,647	5,568	4,214	5,269	6,570	7,016

Table 3. Population Projections by County for the Five Planning Scenarios

Forecasts by County		2015 Population	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Metro							
Adams		489,923	890,148	836,501	842,289	886,001	946,216
Arapahoe		629,066	899,738	845,513	851,363	895,546	956,410
Broomfield		64,656	95,566	89,806	90,428	95,121	101,585
Denver		680,658	952,955	895,523	980,185	1,067,123	1,012,979
Douglas		322,198	482,824	453,725	456,865	480,575	513,236
Jefferson		564,619	694,943	653,061	657,579	691,705	738,716
Elbert	*part*	17,006	45,725	42,970	43,267	45,512	48,606
North Platte							
Jackson		1,353	1,279	1,055	1,210	1,364	1,457
Rio Grande							
Alamosa		15,968	22,934	17,593	21,701	26,209	27,990
Conejos		8,074	8,997	6,902	8,513	10,282	10,980
Costilla		3,572	3,934	3,018	3,722	4,496	4,801
Mineral		729	959	736	907	1,096	1,170
Rio Grande		11,413	11,612	8,907	10,988	13,270	14,172
Saguache		6,219	6,668	5,115	6,309	7,620	8,138
South Platte							
Republican Basin							
Cheyenne	*part*	1,144	1,026	876	970	1,111	1,187
Kit Carson		8,219	9,595	8,194	9,079	10,397	11,104
Lincoln	*part*	1,064	1,627	1,390	1,540	1,763	1,883
Logan	*part*	2,032	2,711	2,315	2,565	2,938	3,137
Phillips		4,307	4,372	3,734	4,137	4,737	5,059
Sedgwick	*part*	1,008	984	840	931	1,066	1,139
Washington	*part*	3,790	3,763	3,214	3,561	4,078	4,355
Yuma		10,052	11,398	9,734	10,785	12,351	13,190
Remainder South Platte							
Boulder		318,570	447,843	382,458	460,770	558,020	518,258
Clear Creek		9,392	12,448	10,631	11,779	13,488	14,405
Gilpin		5,824	6,626	5,659	6,270	7,180	7,668
Larimer		332,830	543,588	464,224	564,664	677,320	629,057
Logan	*part*	20,090	26,805	22,891	25,364	29,045	31,019
Morgan		28,230	42,734	36,495	40,436	46,306	49,453
Park		16,716	23,797	20,323	22,518	25,786	27,539
Sedgwick	*part*	1,381	1,348	1,151	1,275	1,461	1,560
Teller	*part*	11,490	16,323	13,939	15,445	17,687	18,889
Washington	*part*	1,044	1,037	885	981	1,123	1,200
Weld		284,571	734,343	627,129	779,320	915,004	849,804
Southwest							
Archuleta		12,417	26,571	17,070	25,142	35,845	38,281
Dolores		1,972	2,597	1,668	2,457	3,503	3,742
La Plata		54,857	94,002	60,391	101,831	126,811	135,430
Montezuma		26,129	47,158	30,296	44,623	63,617	67,941
Montrose	*part*	4,085	7,449	4,785	7,048	10,048	10,731
San Juan		696	767	493	726	1,035	1,105
San Miguel		7,843	17,293	11,110	19,183	23,329	24,914
Yampa-White							
White Basin							
Rio Blanco		6,529	7,376	4,237	6,979	10,599	11,319
Yampa Basin							
Moffat		12,884	13,868	7,966	13,122	19,927	21,281
Routt		24,310	45,998	26,420	50,336	66,095	70,587

Table 3. Population Projections by County for the Five Planning Scenarios (continued)

Forecasts by County	2015 Population	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Multi-basin Counties (complete totals by county)						
Cheyenne County	1,830	1,641	1,472	1,553	1,710	1,826
Elbert County	24,640	66,251	62,861	62,689	65,477	69,927
Lincoln County	5,549	8,484	8,035	8,028	8,432	9,006
Logan County	22,122	29,516	25,207	27,929	31,983	34,157
Mesa County	149,023	236,554	206,364	245,307	287,295	268,465
Montrose County	40,795	74,391	55,443	70,391	89,034	95,084
Sedgwick County	2,389	2,332	1,992	2,207	2,527	2,699
Teller County	23,431	33,287	30,380	31,497	34,187	36,511
Washington County	4,834	4,800	4,099	4,542	5,201	5,555

Table 3. Population Projections by County for the Five SWSI Scenarios (continued)

References

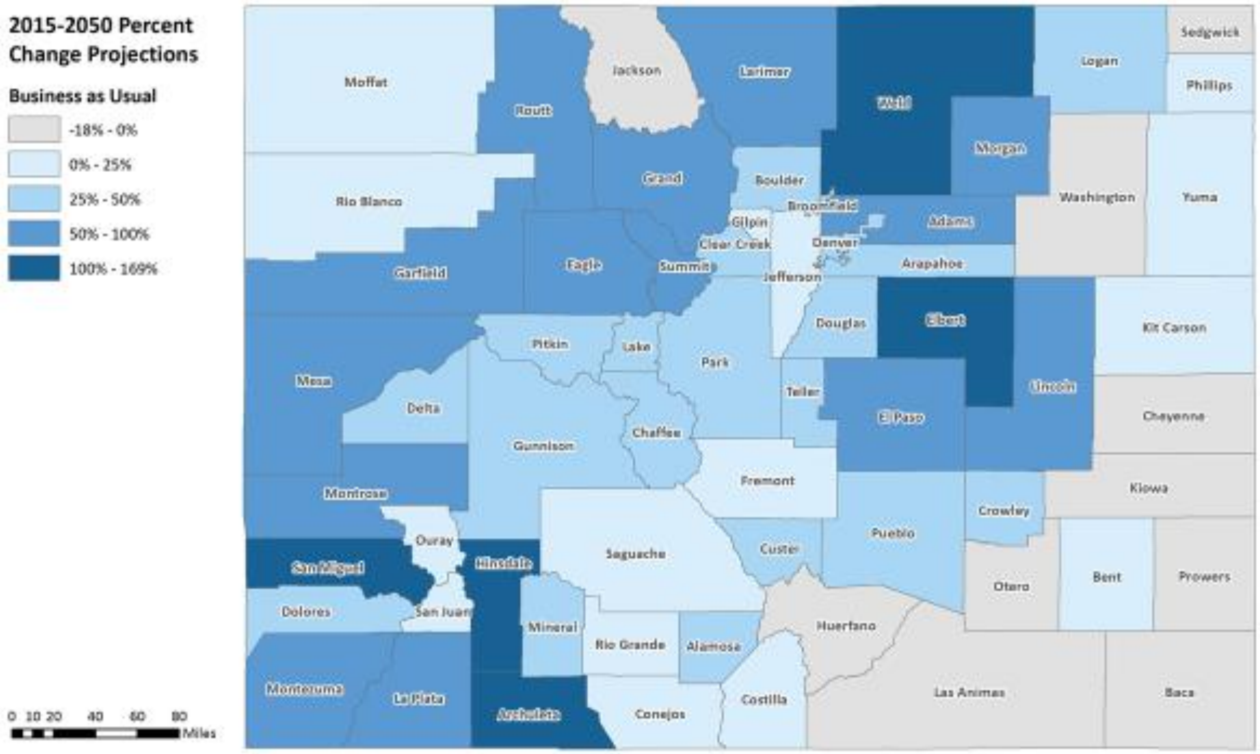
Harvey Economics, 2050 Population Projections for the State of Colorado Municipal and Industrial Water Use Projections, Colorado Water Conservation Board, 2010.

Colorado Division of Local Governments, State Demography Office. Preliminary Population Forecasts by Region and County, 2010 – 2050. 2016.

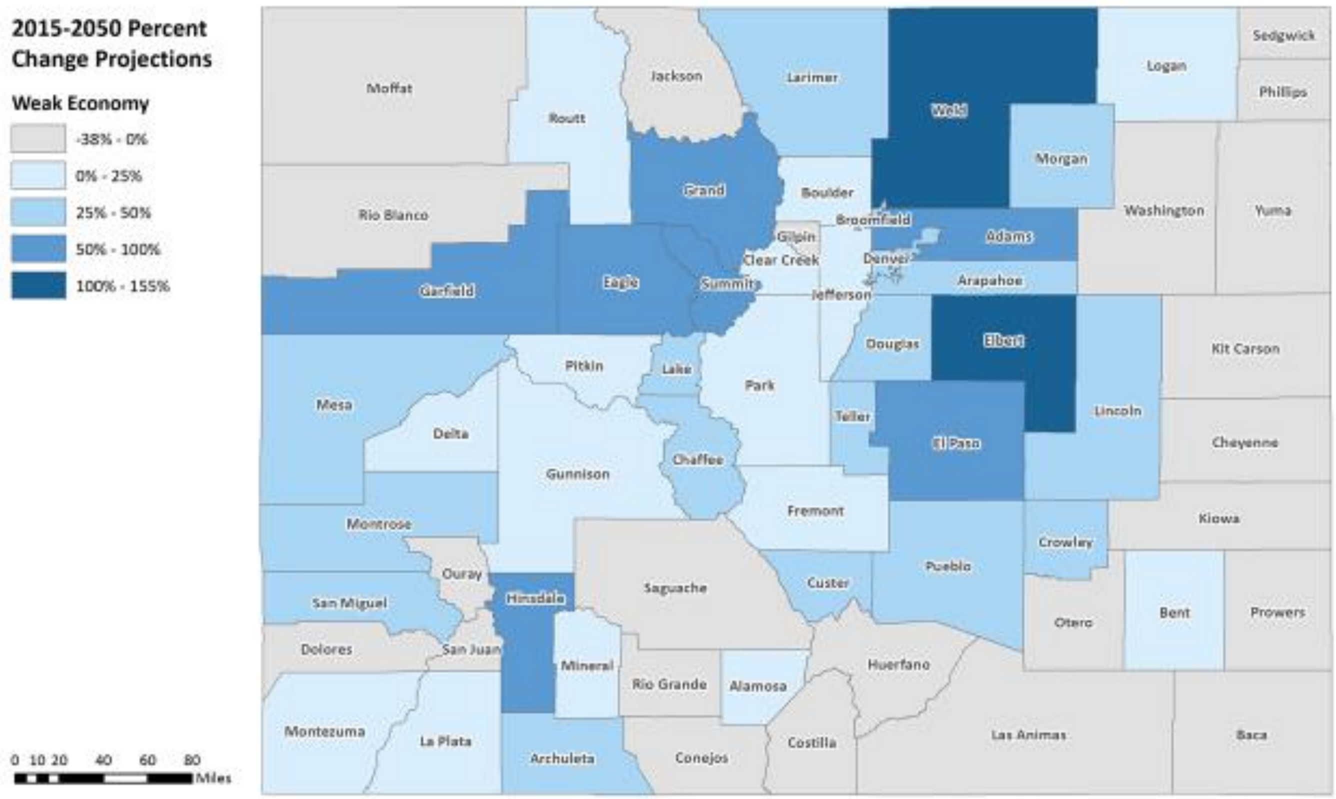
Colorado Water Conservation Board, Colorado's Water Plan, 2015. Chapter 6.

Appendix A: Maps of Population Projections for Three of the Five Planning Scenarios

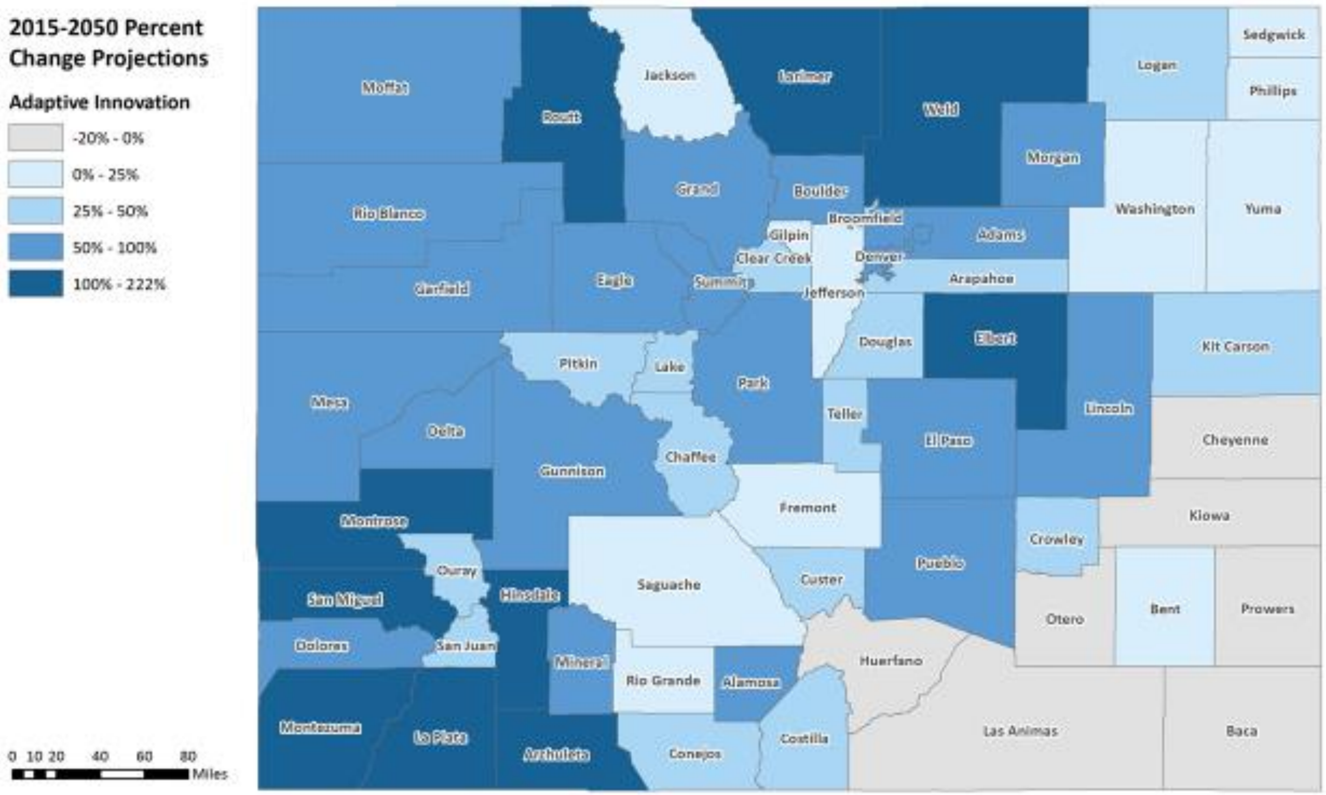
Growth by County in Business as Usual Projections



Growth by County in Weak Economy Projections

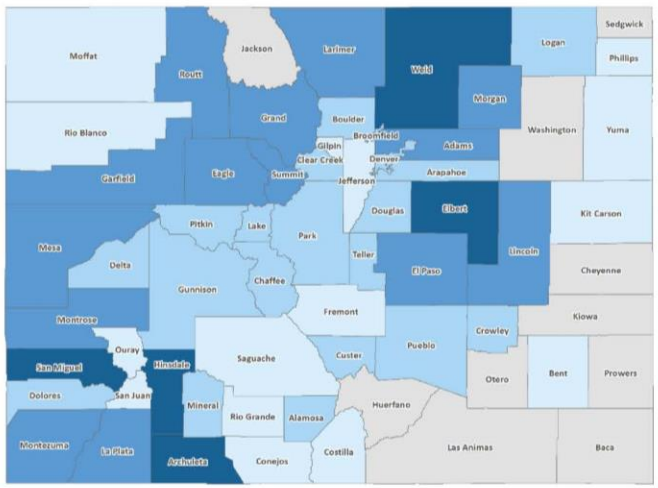


Growth by County in Adaptive Innovation Projections

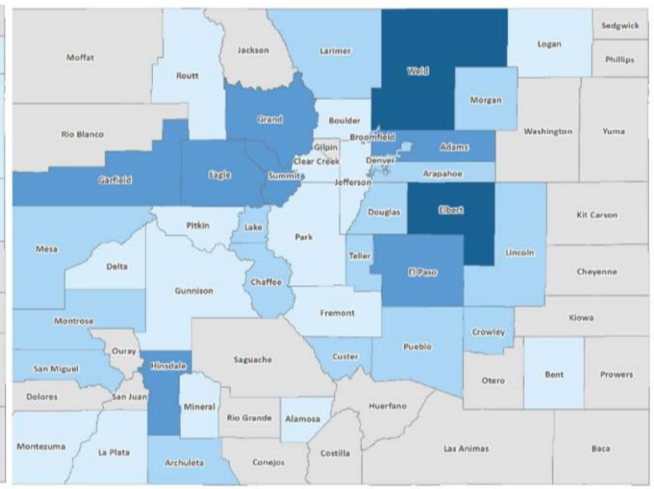


Growth by County Across Three of the Five Scenarios

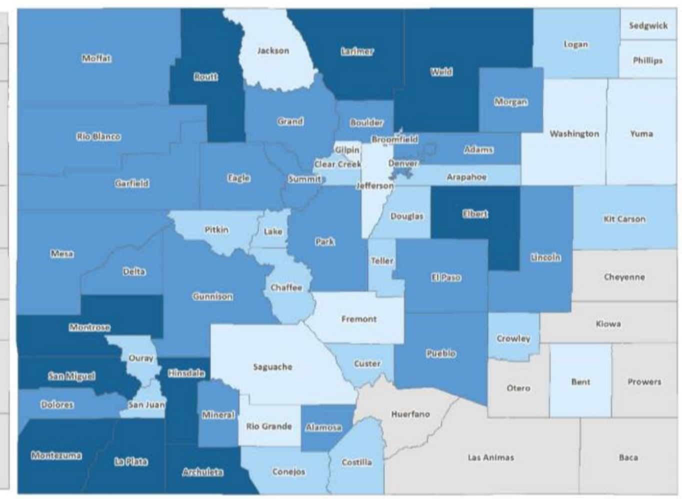
Business As Usual



Weak Economy



Adaptive Innovation



Below 0%
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25% - 50%
50% - 100%
Over 100%

Analysis and Technical Update to the Colorado Water Plan

Technical Memorandum

Prepared for:

Colorado Water Conservation Board

Project Title:

Current and 2050 Planning Scenario Agricultural Diversion Demand

Date: September 18, 2019

Prepared by: Wilson Water Group
Reviewed by: Jacobs, Brown & Caldwell

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Section 1: Introduction

This technical memorandum summarizes the analysis approach and results for the Technical Update Task 1: Agricultural Diversion Demand effort, including the current and 2050 agricultural diversion demand associated with each of the Technical Update Planning Scenarios. The current agricultural diversion demand used in the Technical Update is defined as the amount of water that needs to be diverted or pumped to meet the full crop irrigation water requirements associated with the current levels of irrigated acreage assuming historical climate conditions continued into the future. The current agricultural diversion demand serves as the foundational "baseline" for the Technical Update analysis, and can be used to estimate the change from current to future conditions. Irrigated acreage, climatic conditions, and efficiencies in the current agricultural diversion demand are then adjusted by various factors to estimate the agricultural diversion demand associated with the five plausible 2050 Planning Scenarios (hydrologic and other drivers associated with the scenarios are shown in Figure 1) that were previously developed presented in Colorado's Water Plan.

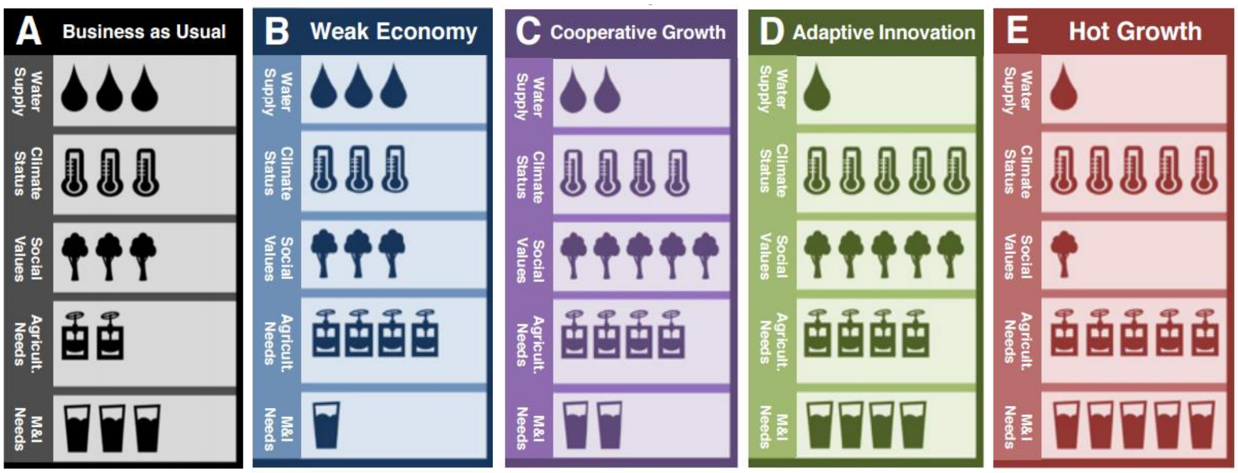

Figure 1: 2050 Planning Scenario Descriptions

This technical memorandum presents the approaches used to develop the current and 2050 agricultural diversion demand first, followed by basin-wide and statewide summaries of results. Basin-wide results were aggregated based on the river basin boundaries provided in Figure 2. Note that once developed, the agricultural diversion demands (along with other non-agricultural demands) will be incorporated into the Colorado Decision Support System (CDSS) water supply models, which will be used to determine how much water is available to meet the demands. Shortages to the agricultural diversion demands in the water supply modeling efforts will define the "agricultural gap". The *Technical Update Current and 2050 Planning Scenario Water Supply and Gap* documentation, available on the Colorado Water Plan website, can be referenced for more information on how the demands were implemented in the water supply models and how the "agricultural gap" was estimated.

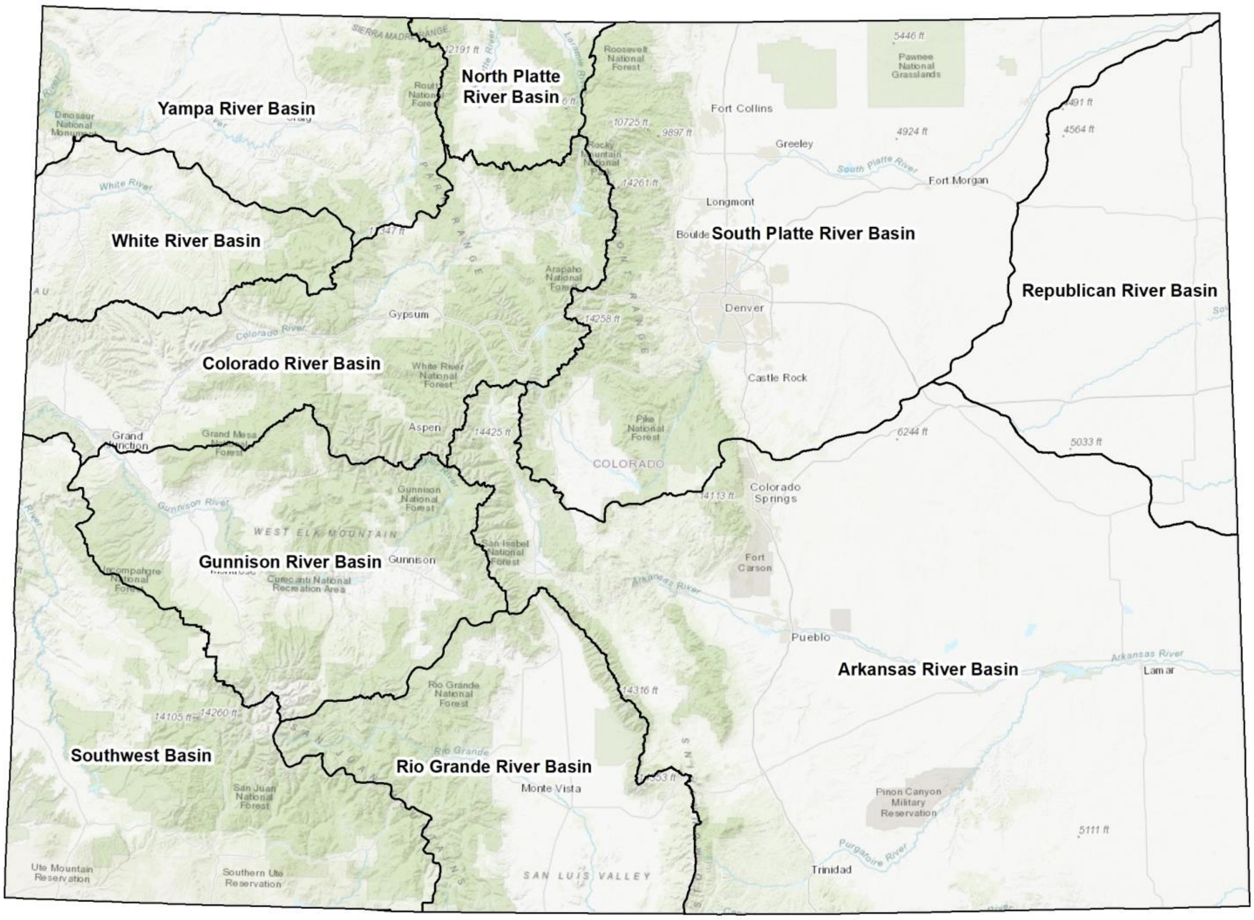

Figure 2: River Basin Boundaries

Section 2: Definitions/Terminology

This section summarizes the definitions and terminology used to discuss agricultural components in the Technical Update effort. As discussed in more detail below, there are differences in definitions and terminology between the SWSI 2010 and the Technical Update, particularly regarding the definition of "agricultural demand". The summaries below the definitions note legacy definitions from SWSI 2010 as applicable.

- Agricultural Diversion Demand: The amount of water that needs to be diverted or pumped to meet the full crop irrigation water requirement.
    - *SWSI 2010 defined agricultural demand as the amount of water currently consumed by the crops; not the amount of water that needs to be diverted to meet the current levels of agricultural production.*
- Irrigation Water Requirement (IWR): The amount of water that must be applied to the crop to meet the full crop consumptive use, also referred to as the crop demand. IWR provides an estimate of the maximum amount of applied water the crops could consume if it was physically and legally available.

- **Applied Water:** Water that is diverted from the river, pumped from ground water, or released from reservoirs for irrigation purposes; also referred to as irrigation supplies. Applied water does not include or reflect precipitation that is consumed by crops.
- **Water Supply Limited (WSL) Consumptive Use:** The amount of applied water consumed by the crop; also referred to as actual crop consumptive use. WSL is the minimum between the IWR and the amount of applied water that reaches the crops.
- **Irrigation System Efficiency:** The percent of diverted or pumped water consumed by the crops or stored in soil moisture; calculated by dividing the sum of WSL and water stored in soil moisture by the total applied water from all sources. System efficiency reflects the losses to applied water due to canal seepage and on-farm application losses.
- **Crop Shortages:** The difference between the amount of water the crops need to meet full crop consumptive use (IWR) and the amount of applied water the crops consumed (WSL).
- **Agricultural Gap:** The amount of additional water that would need to be diverted or pumped to meet the remaining crop shortages.
    - SWSI 2010 defined the agricultural gap as the crop shortages, although recognized that diversions and pumping would need to be much larger in order to meet the crop shortage.

Section 3: SWSI 2010 Methodologies

Agricultural "demands" in SWSI 2010 primarily reflected the consumptive use for the irrigation of crops[1]. Agricultural demands associated with irrigated crops were further defined as the Irrigation Water Requirement (IWR), Water Supply Limited Consumptive Use (WSL), and the difference between these two components was termed Shortages. As discussed throughout this documentation, the agricultural diversion demand developed for the Technical Update differ from the SWSI 2010 demands because the Technical Update estimates the amount of water that needs to be pumped or diverted at the headgate.

Note that the agricultural demands in SWSI 2010 reflected water consumptively used by the crops, not the greater demand of surface diversions and/or ground water pumping necessary to meet the crop consumptive use. It was recognized, however not quantified, that diversions and pumping are much larger in order to meet crop shortage.

3.1 SWSI 2010 IRRIGATED ACREAGE METHODOLOGY

The basis of the agricultural consumptive use was the quantification of currently irrigated acreage and an estimate of the irrigated acreage in 2050. Irrigated acreage mapping developed through the CDSS was used to determine current irrigated acreage in the West Slope Basins (Yampa, White, Colorado, Gunnison, and San Juan), the North and South Platte Basins, and the Rio Grande Basin. The CDSS mapping had not been completed in the remaining basins; therefore current irrigated acreage was determined using the following approaches:

[1] Additional smaller components of the agricultural demand included consumptive use associated with livestock production, stockpond evaporation, and losses incidental to delivering irrigation water. These non-irrigation demands were not included in the Technical Update effort; refer to the SWSI 2010 documentation for more information on how these demands were calculated.

- **Republican River Basin**: Groundwater irrigated acreage was obtained from the Republican River Compact Administration (RRCA) accounting spreadsheets for 2007.
- **Arkansas River Basin**: Irrigated acreage for the Lower Arkansas River basin was based on 2008 data obtained from the Irrigation Systems Analysis Model (ISAM), developed by Division 2 as a refinement of the Hydrological Institutional (HI) Model. Irrigated acreage in the Purgatoire River basin was obtained from 2008 mapping developed by Division 2 staff for the Purgatoire River Water Conservancy District (PRWCD). Irrigated acreage outside of these areas was developed by analyzing 2009 thermal imagery (Landsat 5 Thematic Mapper) with a vegetative index and removing non-agricultural and riparian areas.

2050 acreage estimates were developed by applying specific factors to the baseline Current acreage estimates. These factors included:

- Urbanization of existing irrigated lands
- Agricultural to municipal water transfers
- Water management decisions
- Demographic factors
- Biofuels production
- Climate change
- Farm programs
- Subdivision of agricultural lands and lifestyle farms
- Yield and productivity
- Open space and conservation easements
- Economics of agriculture

The first three factors were quantified based on future growth estimates, municipal water demand gaps that will be met by 2050, and interviews with water management agencies across the state. The urbanization of existing irrigated lands adjusted the current acreage by using 2050 population projections and estimation of future urban area size. The municipal water demand (M&I) gap was used in the analysis of irrigated acreage changes associated with agricultural to municipal water transfers. For each of the major river basins, the amount of the M&I gap was summarized on a low, medium, and high basis. For the purposes of estimating 2050 acreage, it was assumed that 70 percent of M&I gap would be met from agricultural to municipal transfers. Irrigated acreage needed for agricultural to municipal transfers to address M&I gaps was calculated by dividing the M&I gap by the historical consumptive use that may be transferred, increased by a 25 percent firm yield factor.

The remaining factors were qualitatively addressed based on information provided by the Colorado Water Conservation Board (CWCB) and the Colorado Department of Agriculture. CWCB interviewed entities within the South Platte, Rio Grande, and Republican River Basins to estimate what changes may occur in irrigated acres due to water management decisions affected by compact compliance or to maintain groundwater levels. For other factors (demographic factors, biofuels production, climate change, farm programs, subdivision of agricultural lands and lifestyle farms, yield and productivity, open space and conservation easements, economics of agriculture), CWCB identified trends that are expected to occur within each area over the next 40 years and then developed a qualitative assessment on whether each factor would cause a negative or positive impact on irrigated agriculture by 2050. Note that although climate change was listed as a factor, it was not quantitatively assessed or applied during the approach to developing 2050 acreage estimates.

Table 1 summarizes the irrigated acreage used for the Current scenario, the reduction in acreage associated with the factors discussed above, and the irrigated acreage used for the 2050 scenario in SWSI 2010.

Table 1: SWSI 2010 Current and 2050 Irrigated Acreage

Basin	Current Irrigated Acres	Decrease in Irrigated Acres Due to Urbanization		Decreases in Irrigated Acres Due to Other Reasons	Decreases in Irrigated Acres from Planned Agricultural to Municipal Transfers	Decreases in Irrigated Acres from Agricultural to Municipal Transfers to Address M&I Gap		Estimated 2050 Irrigated Acres	
		Low	High			Low	High	Low	High
Arkansas	428,000	2,000	3,000	–	7,000	26,000	63,000	355,000	393,000
Colorado	268,000	40,000	58,000	–	200	11,000	19,000	190,800	216,800
Gunnison	272,000	20,000	26,000	–	–	1,000	2,000	244,000	251,000
North Platte	117,000	–	–	–	–	–	–	117,000	117,000
Republican	550,000	300	600	109,000	–	–	–	440,400	440,700
Rio Grande	622,000	800	1,000	80,000	–	2,000	3,000	538,000	539,200
South Platte	831,000	47,000	58,000	14,000	19,000	100,000	176,000	564,000	651,000
Southwest	259,000	4,000	6,000	–	–	3,000	7,000	246,000	252,000
Yampa-White	119,000	1,000	2,000	–	–	3,000	64,000	53,000	115,000
Statewide Total	**3,466,000**	**115,100**	**154,600**	**203,000**	**26,200**	**146,000**	**334,000**	**2,748,200**	**2,975,700**

3.2 SWSI 2010 CONSUMPTIVE USE METHODOLOGY

The agricultural consumptive use associated with current irrigated acreage was reported in SWSI 2010 using both average IWR and WSL. As discussed in the Definitions section, WSL was considered to be the current "agricultural demand".

Where CDSS models were available, the results of the historical consumptive use analyses from the most recent 10-year period were averaged to develop the Current estimate of IWR and WSL. The analyses were performed in StateCU, the State's consumptive use model, using irrigated acreage and crop type information from the most recent CDSS acreage assessments and monthly climate data and water supply data available from HydroBase, the State's water resources database. The CDSS models used the Blaney-Criddle method described in the U.S. Soil Conservation Service Technical Report No. 21 (TR-21) for estimating potential consumptive use, and measured water supply data and historical irrigation practice efficiencies to determine WSL consumptive use. Additional details regarding the CDSS analyses are available in each basin's Historical Consumptive Use Report (cdss.state.co.us) and Appendix I of SWSI 2010.

Where CDSS models were not available, namely the Republican River Basin and the Arkansas River Basin, existing information used for accounting and administration in the basin was used to estimate IWR and WSL for the recent period.

- Republican River Basin: Values of "Annual Net IWR", as developed as part of the RRCA model, were averaged for the 1998 to 2007 period. The IWR values were calculated using the Hargreaves evapotranspiration equation calibrated to the Penman-Monteith equation as specified in the interstate settlement agreement in Kansas v. Nebraska and Colorado. Note that a portion of the IWR was assumed to be met by the accumulation of soil moisture over the winter. Current IWR for the basin was estimated by multiplying the RRCA irrigated acreage from 2007 by the Annual Net IWR. Current WSL was estimated as 75 percent of the Current IWR based on an assessment of ground water pumping from approximately 150 wells in the basin. Surface water diversions were being phased out in the basin; therefore no surface water supplies were considered during the development of WSL values.
- Arkansas River Basin: Current IWR and WSL for the Lower Arkansas River basin was obtained from ISAM and averaged over the 1997 to 2006 period. In the Purgatoire River basin, a StateCU scenario was developed specifically for the SWSI 2010 effort and results over the 1999 to 2008 period were averaged to estimate the Current IWR and WSL for the PRWCD area. The StateCU analysis was generally developed using CDSS modeling standards; refer to Appendix I of SWSI

2010 for specific modeling assumptions. Unit IWR for irrigated acreage outside of these areas was determined at representative climate stations over the recent period for the crops in the area, and multiplied by the Current acreage to determine the Current IWR. Current WSL was estimated by reviewing reported shortages, including information from ISAM, in several areas and applying that shortage percentage to the Current IWR. In general, shortage percentages ranged from 33 percent to 52 percent throughout the basin.

Table 2 summarizes the SWSI 2010 Current IWR, WSL, and resulting Shortages by basin. In general, the 2050 agricultural demand was developed by scaling the Current IWR and WSL values. The SWSI 2010 effort took this simplifying approach because:

- IWR is directly proportional to the change in irrigated acreage predicted for 2050
- The study intentionally avoided identifying specific water rights or ditches for change of use and therefore could not analyze the impact of these 2050 predicted changes to IWR or WSL on a structure basis
- The study did not analyze the change in water availability that may be caused by 2050 predicted changes and therefore could not determine changes in WSL due to water availability on a structure basis

Table 3 summarizes the 2050 IWR, WSL, and resulting Shortages by basin.

Table 2: SWSI 2010 Current Agricultural Consumptive Use

Basin	Irrigated Acres	Irrigation Water Requirement (AFY)	Water Supply-Limited Consumptive Use (AFY)	Shortage (AFY)
Arkansas	428,000	995,000	542,000	453,000
Colorado	268,000	584,000	485,000	100,000
Gunnison	272,000	633,000	505,000	128,000
North Platte	117,000	202,000	113,000	89,000
Republican	550,000	802,000	602,000	200,000
Rio Grande	622,000	1,283,000	855,000	428,000
South Platte	831,000	1,496,000	1,117,000	379,000
Southwest	259,000	580,000	382,000	198,000
Yampa-White	119,000	235,000	181,000	54,000
Statewide Total	**3,466,000**	**6,819,000**	**4,791,000**	**2,028,000**

Table 3: SWSI 2010 2050 Agricultural Consumptive Use by Basin

Basin	Irrigated Acres	Irrigation Water Requirement (AFY)	Water Supply-Limited Consumptive Use (AFY)	Shortage (AFY)
Arkansas	373,000	862,000	476,000	386,000
Colorado	204,000	443,000	366,000	77,000
Gunnison	219,000	573,000	457,000	116,000
North Platte	145,000	250,000	140,000	110,000
Republican	441,000	640,000	480,000	160,000
Rio Grande	537,000	1,108,000	739,000	369,000
South Platte	607,000	1,094,000	820,000	274,000
Southwest	249,000	558,000	367,000	191,000
Yampa-White	85,000	209,000	170,000	39,000
Statewide Total	**2,860,000**	**5,737,000**	**4,015,000**	**1,722,000**

3.3 METHODOLOGY ENHANCEMENTS FOR TECHNICAL UPDATE

The Technical Update will build on the approaches and information from SWSI 2010 to develop the agricultural diversion demand, however the application and use of the agricultural diversion demand in the Planning Scenarios in the Technical Update differs from the SWSI 2010 approach. SWSI 2010 reflected the "agricultural demand" in terms of IWR and WSL, not in terms of the irrigation diversions and pumping required to meet IWR. This led to ambiguous terminology in terms of "agricultural demand" and differed from the approach taken to determine the M&I demand, which was based on the amount of water needed to meet the per capita demand and not the M&I consumptive use. The Technical Update will define the "agricultural diversion demand" as the amount of diversions and pumping that would be required to meet the IWR demand.

The Technical Update will include the agricultural diversion demand as a component of the Planning Scenario models, which will look at existing water rights, operations, and supplies to estimate the agricultural gap. Incorporating the agricultural diversion demand into the Planning Scenario models also allows for future analysis of specific projects and methods to meet that demand. This differs from the SWSI 2010 approach whereby the analysis relied on historical diversions to estimate crop shortages.

In addition to the new approach to developing the agricultural diversion demand in the Technical Update, there have been several studies, models, reports, and datasets completed since SWSI 2010 that can be used to enhance the development of the agricultural diversion demand in the Technical Update.

- CDSS Irrigated Acreage Coverage Updates for more recent coverages in all basins, including revised assignment of water supply to irrigated acreage.
- Extended CDSS StateCU and StateMod models for the Western Slope basins, which include the 2010 irrigated acreage coverages and extend through 2013.
- South Platte StateCU and StateMod model for the 1950 to 2012 period, including current agricultural diversion demands and supplies.
- Republican River Compact Administration Resolution regarding the Compact Compliance Pipeline, including acreage and consumptive use reductions.

- Arkansas River Basin DSS development, including a StateMod model for acreage on the mainstem below Pueblo Reservoir and recent climate data developed to support daily consumptive use analyses throughout the basin.
- Rio Grande Subdistrict and DWR Rules and Regulations development, including current agricultural demands and supplies.

Section 4: Current Agricultural Diversion Demand Approach

The approach used to develop the current agricultural diversion demand for the Technical Update varied based on the available data and the type of supplies generally used to meet the demand in each basin. The Colorado Water Conservation Board (CWCB) has developed crop consumptive use datasets with the StateCU modeling platform for most basins in the state through the CDSS program, as reflected in Figure 3. Two consumptive use datasets have been developed for basins with full CDSS development:

1. **Historical Dataset**. This dataset calculates IWR and historical consumptive use associated with historical irrigated lands in each basin. It includes historical changes in irrigated acreage and crop types and contains historical diversions and pumping that reflect administrative and operational constraints on water supply as they occurred over time. It is an appropriate dataset to review the calibration of the model and for evaluating historical conditions in the basin over an extended period of time.
2. **Baseline Dataset**. This dataset calculates IWR associated with current irrigated acreage and historical climate variability, and estimates associated current agricultural diversion demand using average system efficiency. As it reflects current acreage, it is an appropriate dataset to use for “what if” planning scenarios.

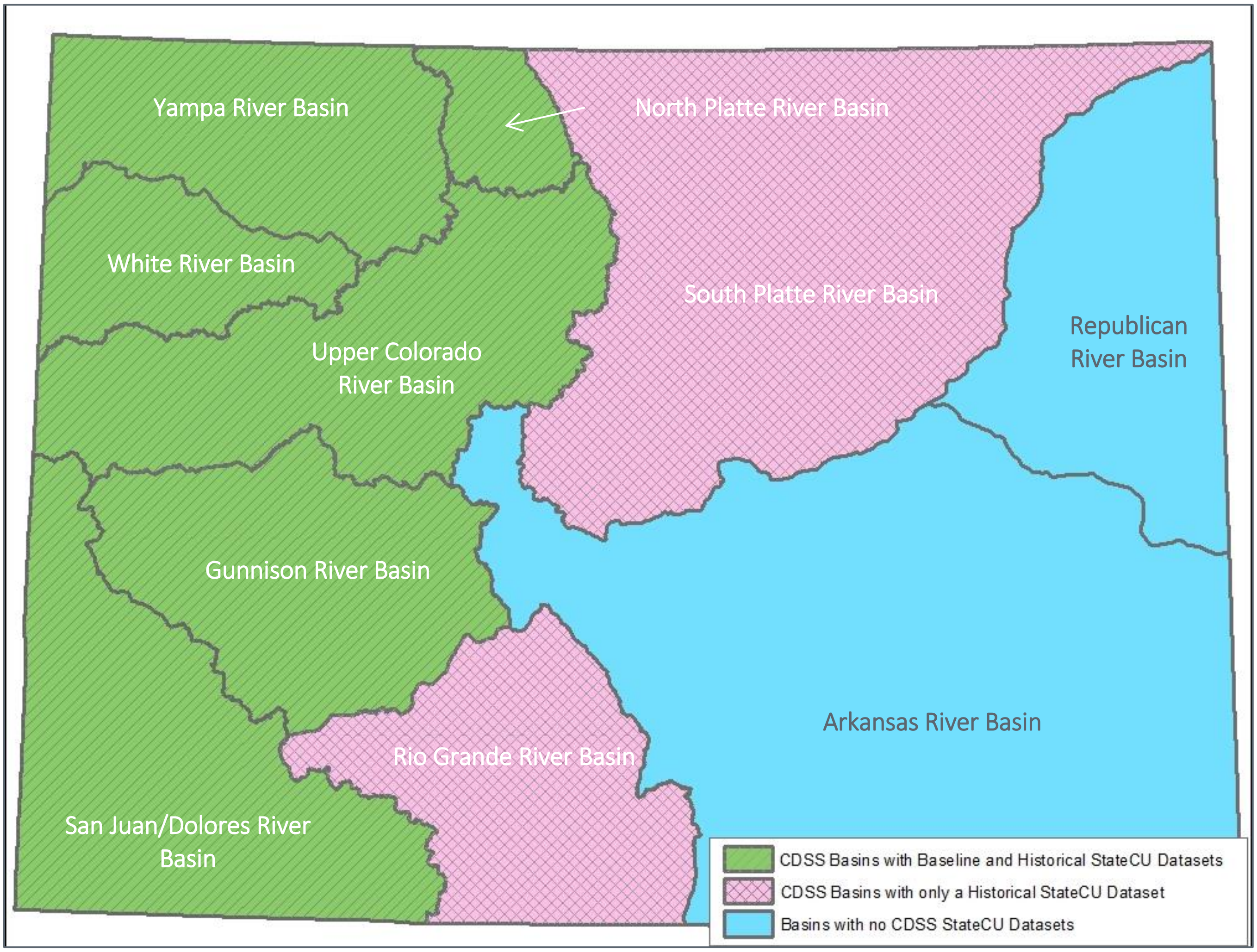

Figure 3: CDSS StateCU Model Availability

West Slope and North Platte Current Agricultural Diversion Demand Approach

The full CDSS program has been developed for the Western Slope basins (i.e. Yampa River, White River, Colorado River, Gunnison River, and Southwest Basins) and the North Platte River basin. The CDSS datasets for the Western Slope basins are available for the 1950 to 2013 period, and were recently revised to include irrigated acreage assessments through 2010. The Western Slope datasets are available on the CDSS website; minimal modifications were made to these datasets prior to their use in the Technical Update effort. These modifications include revisions to the total acreage and diversions in the Grand Valley Project area in the Colorado River Model and to Cimarron Canal area in the Gunnison River Basin model; removal of diversions for non-irrigation uses for aggregate structures in all datasets; and revisions to the Yampa River Basin to reflect recent modeling efforts undertaken by the Yampa/White/Green Basin Roundtable.

More significant revisions were required for the North Platte River datasets. The CDSS datasets for the North Platte River Basin only included irrigated acreage through 2001 and had not been updated since the previous SWSI effort; therefore the datasets in this basin were extended to include irrigated acreage through 2016 for this effort. During this effort, a total of six structures and irrigated acreage assessments from 2005 and 2010 through 2016 were added to the models. The North Platte River datasets are now available over the 1956 to 2016 period.

The Western Slope and North Platte River basins use minimal ground water supplies for irrigation. Therefore, the following approach was used to develop the irrigated acreage, IWR, system efficiencies, and current agricultural diversion demand attributable to surface water supplies:

1. Extract IWR, reflecting current acreage and crop types, from the most recent baseline StateCU datasets.
2. Develop a representative set of monthly system efficiency values[2] for wet, dry, and average year types[3] for each structure using information from the Historical StateCU datasets.
    a. Select a streamflow gage in each basin to serve as an "indicator" gage, and categorize each year type as wet, dry, or average based on annual natural flow.
    b. Divide the historical crop consumptive use by the total water diverted to determine monthly system efficiencies for each structure for every year in the dataset study period.
    c. Average the system efficiency information for each year type as determined by the indicator gage to develop a representative set of monthly system efficiencies for wet, dry, and average year types for each structure.
3. Divide the monthly Baseline IWR by either the wet, dry, or average monthly system efficiency values depending on the indicator gage year type to develop the current agricultural diversion demand.

South Platte and Rio Grande Current Agricultural Diversion Demand Approach

Only the Historical Dataset has been developed for the South Platte River and Rio Grande basins, therefore it was necessary to develop the Baseline Dataset prior to developing the current agricultural diversion demand.

- **South Platte River Basin**. The Historical Dataset in this basin was completed recently for the 1950 to 2012 period and includes irrigated acreage assessments through 2010. The Historical Dataset, however, excluded the Cache la Poudre basin (Water District 3) due to the ongoing permitting efforts for projects in the basin. Therefore, the Historical Dataset was first revised to include the agricultural demands and operations in Water District 3, then the Baseline dataset was developed using the 2010 irrigated acreage to calculate IWR.
- **Rio Grande Basin**. The most recent Historical Dataset in this basin was completed to support Phase 6 of the Rio Grande DSS Ground Water Modeling effort. The dataset, which includes irrigated acreage assessments through 2010 and extends over the 1950 to 2010 period, was used recently in the litigation to determine Rules and Regulations on ground water usage in the basin. The Baseline Dataset was developed using 2010 irrigated acreage from the Phase 6 dataset to calculate IWR.

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[2] System efficiencies generally developed based on the full model period; however a shorter period was used for structures that have experienced significant changes in irrigated acreage and/or diversions to be more representative of current conditions. Additionally, monthly system efficiencies were set to a minimum of 5 percent.

[3] Year types were calculated based on annual streamflow records for representative gages in each basin. Years with flow greater than the 25th percentile were categorized as wet; years with flow less than the 75th percentile were categorized as dry; and years with flow between the 25th and 75th percentile were categorized as average for the purposes of this effort.

An additional complication in these basins is the use of both surface and ground water as irrigation supplies. The total current agricultural diversion demand reflects the amount of water that needs to be diverted or pumped to meet a full crop demand, therefore it is necessary to partition the total demand into a surface water demand and a ground water demand.

Note that metered ground water pumping during the study period was generally not available in HydroBase for the South Platte and Rio Grande Basin Historical Datasets, therefore it was necessary to estimate ground water pumping. Pumping was generally estimated to meet the full crop IWR limited by known pumping restrictions such as well capacities or augmentation plan allocations. Actual ground water pumping is impacted by many factors including the irrigation practices, availability of surface water supplies, availability of recharge/augmentation supplies, aquifer levels, basin administration, crop types, and climate; and has changed significantly since the 2002 drought. These factors prove challenging when estimating the current and future agricultural diversion demand attributable to ground water supplies.

For the Baseline Dataset, it was necessary to make some general assumptions about how ground water supplies may be used to meet the agricultural diversion demand, particularly for ditches that irrigate with both surface and ground water supplies (i.e. co-mingled). Through discussions with ground water users and augmentation providers across the Eastern Slope basins, it was evident that ground water pumping levels on co-mingled lands would likely remain constant or decrease in the future due to declining aquifer levels and reduced augmentation supplies. As such, the pumping estimates from recent years (post-2002) reflect the maximum amount of co-mingled pumping that may be expected in the future.

This approach, summarized in more detail below, allows for pumping estimates to vary across hydrological conditions and limits pumping to current levels. Additionally, pumping estimates developed through this approach are a better indicator of the demand that may be met from co-mingled pumping in the future compared to other approaches such as attributing a static percentage to partition surface and ground water demand, or allowing surface water to meet full demand and estimate pumping from crop shortages which involves iterative modeling and could easily over or under estimate pumping depending on the seniority of the ditch or water availability. Refer to the Comments and Considerations section for additional discussion regarding estimates of well pumping information.

The following approach was used to determine the irrigated acreage, IWR, system efficiencies, and current agricultural diversion demand associated with surface and ground water supplies in the South Platte River and Rio Grande basins:

1. **Select a streamflow gage** in each basin to serve as an "indicator" gage, and categorize each year type as wet, dry, or average based on annual natural flow.
2. **Extract IWR**, reflecting current acreage and crop types, from the Baseline StateCU datasets.
3. **Divide the monthly Baseline IWR** for parcels only irrigated with ground water[4] (ground water only) by a static 80 percent system efficiency value (i.e. sprinkler application efficiency[5]) to develop the current ground water only agricultural pumping demand.
4. **Create a time series** of representative monthly pumping estimates for ditches that irrigate with both surface and ground water supplies (co-mingled) for wet, dry, and average year types using recent pumping estimates from the Historical StateCU datasets.
    a. Due to changes in administration and ground water pumping trends following the 2002 drought, select years to represent high, low, and average pumping values from post-2004

[4] Note structures that historically diverted surface water but now operate primarily with ground water supplies were treated as "ground water only" structures for the Technical Update effort.

[5] CDSS standard estimated efficiency for sprinkler systems; refer to South Platte DSS Technical Memoranda for more information on the development at use of system efficiency value.

co-mingled pumping estimates in the StateCU datasets. For example, 2009 was selected as the representative low pumping year for both basins.
    b. Create a time series of co-mingled pumping estimates by correlating low, high, and average pumping years to wet, dry, and average year types based on the indicator gage.
5. **Multiply the co-mingled pumping estimates** by a static 80 percent system efficiency (i.e. sprinkler application efficiency) to estimate the amount of IWR met by the co-mingled pumping.
6. **Subtract the IWR** met by co-mingled pumping from the Baseline IWR to determine the amount of IWR attributable to surface water supplies
7. **Develop a representative a set** of monthly system efficiency values for wet, dry, and average year types for each structure using information from the Historical StateCU datasets.
    a. Divide the historical crop consumptive use by the total water diverted and/or pumped to determine monthly system efficiencies for each structure for every year in the dataset study period.
    b. Average the system efficiency information for each year type from the indicator gage to develop a representative set of monthly system efficiencies for wet, dry, and average year types for each structure.
8. **Divide the IWR attributable to surface water supplies** by either the wet, dry, or average monthly system efficiency values depending on the indicator gage year type to develop the current agricultural diversion demand attributable to surface water supplies.

Arkansas Current Agricultural Diversion Demand Approach

A basin-wide consumptive use analysis has not yet been developed for the Arkansas River basin, although consumptive use analyses and other modeling efforts have been developed for portions of the basin. The primary source of agricultural consumptive use data available during the SWSI 2010 effort in the Arkansas River Basin was the Irrigation Systems Analysis Model (ISAM). ISAM is a refinement of the Hydrological Institutional (H-I) Model[6] to the individual farm level developed in support of the Arkansas Basin Agricultural Efficiency Rules. The ISAM and H-I models are limited to the irrigated acreage along the mainstem within the reach between Pueblo Reservoir and the Stateline (i.e. H-I Model area), therefore additional analyses are required to quantify the agricultural demand associated with acreage outside of this reach. There have been several efforts since SWSI 2010 to further the development of a basin-wide StateCU dataset in the Arkansas River Basin including:

- Development of a StateMod dataset reflecting historical diversions and irrigated acreage for the reach between Pueblo Reservoir and the Stateline.
- Development of a basin-wide daily and monthly climate dataset by DWR appropriate for use in an historical consumptive use analysis.
- Development of a basin-wide irrigated acreage coverage (2010 snapshot), assigned with water supply and crop types.

In addition, the State has embarked on the development of a complete Arkansas River DSS (ArkDSS), which includes a basin-wide StateCU and StateMod model in the basin. The ArkDSS project is running concurrently with this Technical Update effort. Information developed for the ArkDSS was used to the extent it was available.

[6] Colorado is required to use the HI Model for Compact accounting pursuant to settlement of the Kansas v. Colorado litigation; the model area includes irrigated lands served by canals that divert from the Arkansas River between Pueblo Reservoir and the Stateline

Using the basin-wide irrigated acreage coverage as the foundation, a Historical and Baseline StateCU dataset was developed for the Arkansas River Basin for the 1950 to 2017 period. Although Compact Accounting uses the Standardized ASCE Penman-Monteith equation to develop daily estimates of potential crop consumptive use, a monthly analysis using the Modified Blaney-Criddle equation was developed for this Technical Update effort. The monthly analysis under-estimates the potential crop consumptive use compared to the daily analysis, however the monthly approach provides estimates appropriate for this basin-wide planning level effort.

The following summarizes the general approach to developing the Historical Arkansas River StateCU dataset; refer to the StateCU documentation or other basin's historical consumptive use reports for more information on calculation methods or standard approaches.

- Historical irrigated acreage is available from the ISAM and H-I models for structures within the H-I Model area. Outside of the H-I Model area, the 2015 irrigated acreage coverage recently developed through the ArkDSS effort was used. Unfortunately, additional historical irrigated acreage coverages had not been developed at the time of the Technical Update and could not be incorporated into this analysis, however areas outside of the H-I Model area have not experienced as significant of changes in irrigated acreage.
- Climate station assignments are available from the ISAM and H-I models for structures within the H-I Model area. Climate stations were assigned to structures outside of the H-I Model area based on proximity to irrigated acreage, generally one climate station per Water District.
- Potential ET for all structures was determined using the SCS Modified Blaney-Criddle consumptive use methodology with TR-21 crop characteristics for acreage below 6,500 feet and the Original Blaney-Criddle consumptive use methodology with high-altitude crop coefficients developed for Denver Water for acreage above 6,500 feet. As recommended in the ASCE Manuals and Reports on Engineering Practice No. 70, Evapotranspiration and Irrigation Water Requirements (1990), an elevation adjustment of 10% adjustment upward for each 1,000 meters increase in elevation above sea level was applied to the Modified Blaney- Criddle method (i.e., for crops below 6,500 feet).
- The SCS effective rainfall method outlined in the SCS publication Irrigation Water Requirement Technical Release No. 21 (TR-21) was used for all structures to determine the amount of water available from precipitation.
- Conveyance loss is available from the ISAM and H-I models for structures within the H-I Model area, ranging from 34 to 6 percent. For structures outside of the H-I Model area, 10 percent conveyance loss was used. Maximum irrigation application efficiency for all structures was set to 65 and 85 percent for flood and sprinkler irrigated lands, respectively, based on the maximum efficiency in the H-I Model area.
- Historical diversions were obtained from HydroBase, with missing records filled using a wet, dry, and average pattern[7] at a nearby indicator gage. For lands irrigated with ground water, pumping was estimated to meet the full potential consumptive use. A majority of the pumping occurs within the H-I Model area, where records are available, however for areas outside of the H-I Model area, this approach likely over-estimates the amount of pumping. Additional analysis and

[7] Each month of the streamflow at the indicator gage was categorized as a wet/dry/average month through a process referred to as 'streamflow characterization'. Months with gage flows at or below the 25th percentile for that month are characterized as 'dry', while months at or above the 75th percentile are characterized as 'wet', and remaining months are characterized as 'average'. Using this characterization, missing data points were filled based on the wet, dry, or average pattern. For example, a data point missing for a wet March was filled with the average of other wet Marches in the partial time series, rather than all Marches.

potential supply limitations to this pumping are addressed in the *Technical Update Current and 2050 Planning Scenario Water Supply and Gap* documentation.

- Water supply-limited consumptive use was determined by including diversion records, conveyance efficiencies, application efficiencies, and soil moisture interactions. The model determined water supply-limited consumptive use by first applying surface water to meet irrigation water requirement for land under the ditch system. If excess surface water still remained, it was represented in the model as being stored in the soil moisture reservoir. Then if the irrigation water requirement was not satisfied, surface water stored in the soil moisture reservoir was used to meet remaining irrigation water requirement.
- System efficiency values for wet, dry, and average year types were estimated using the same approach outlined for other basins.

The Baseline StateCU dataset was then developed by revising the Historical StateCU dataset to reflect only the most current irrigated acreage over the entire study period. This dataset was simulated to estimate the IWR for the full study period, and the steps outlined for other basins was then used to estimate the current agricultural diversion demand. As with the South Platte and Arkansas River basins, ground water serves as a significant irrigation supply in the Arkansas basin. Therefore, the current agricultural diversion demand was partitioned into surface water and ground water demands in the Arkansas River basin using the same approach outlined for other basins with ground water.

Republican Current Agricultural Diversion Demand Approach

Agricultural diversion demand information in the Republican River basin is available from the most recent Compact accounting and model (RRCA), therefore a Historical or Baseline StateCU analysis was not developed for this basin. Irrigation in the Republican River basin is supplied primarily from ground water pumping. As such, the limited surface water diversions were not represented, and the current agricultural diversion demand was assumed to be attributable to ground water supplies. The following approach was used to develop the irrigated acreage, IWR, system efficiencies, and current agricultural diversion demand in the Republican River basin:

1. **Develop current irrigated acreage**, reflecting crop types and irrigation application type, using the CDSS 2016 irrigated acreage assessment. Parcels delineated in the CDSS 2016 assessment were compared to pumping records to determine which parcels were actively irrigated in 2016; parcels within the Compact boundary[8] with no active pumping records were excluded.
2. **Extract crop-specific monthly unit IWR** from the RRCA summary, available over the 2007 to 2016 period. Extend the period or record for unit IWR using previously published IWR values from the original SWSI effort back to 1998.
3. **Multiply the current acreage** by the unit IWR to develop the monthly Baseline IWR.
4. **Divide the monthly Baseline IWR** for acreage served by flood/furrow by a static 65 percent and divide the monthly Baseline IWR for acreage served by sprinklers by a static 80 percent to develop the current agricultural pumping demand attributable to ground water supplies.

[8] Note that the Republican River Compact boundary does not extend over the entire Republican River watershed (i.e. Water Districts 65 and 49) as reflected in Figure 10, therefore acreage totals from the RRCA were not representative of the total acreage in the watershed

Section 5: Current Results

There are currently 3.28 million acres of irrigated agricultural land in the State of Colorado. This acreage supports a wide network of agribusiness in Colorado from producers of agricultural goods to those that process and deliver those goods to the consumer. Agricultural production in the State of Colorado is a large part of the state's economy, with agribusiness contributing $41 billion annually and directly employing nearly 173,000 people[9].

As shown in Figure 4, over a quarter of the irrigated acreage in Colorado is located in the South Platte River Basin. The Arkansas River, Rio Grande, and Republican River Basins also have significant acreage. Grass pasture is the predominant crop grown in the state, particularly in the West Slope basins, however irrigators also grow alfalfa, wheat, cereals/grains, fruits, and vegetables. Much of the irrigated acreage supports ranching operations, either through grass hay production for livestock operations or grazing of irrigated pastures. The basin summaries below provide more information on crops grown in each basin.

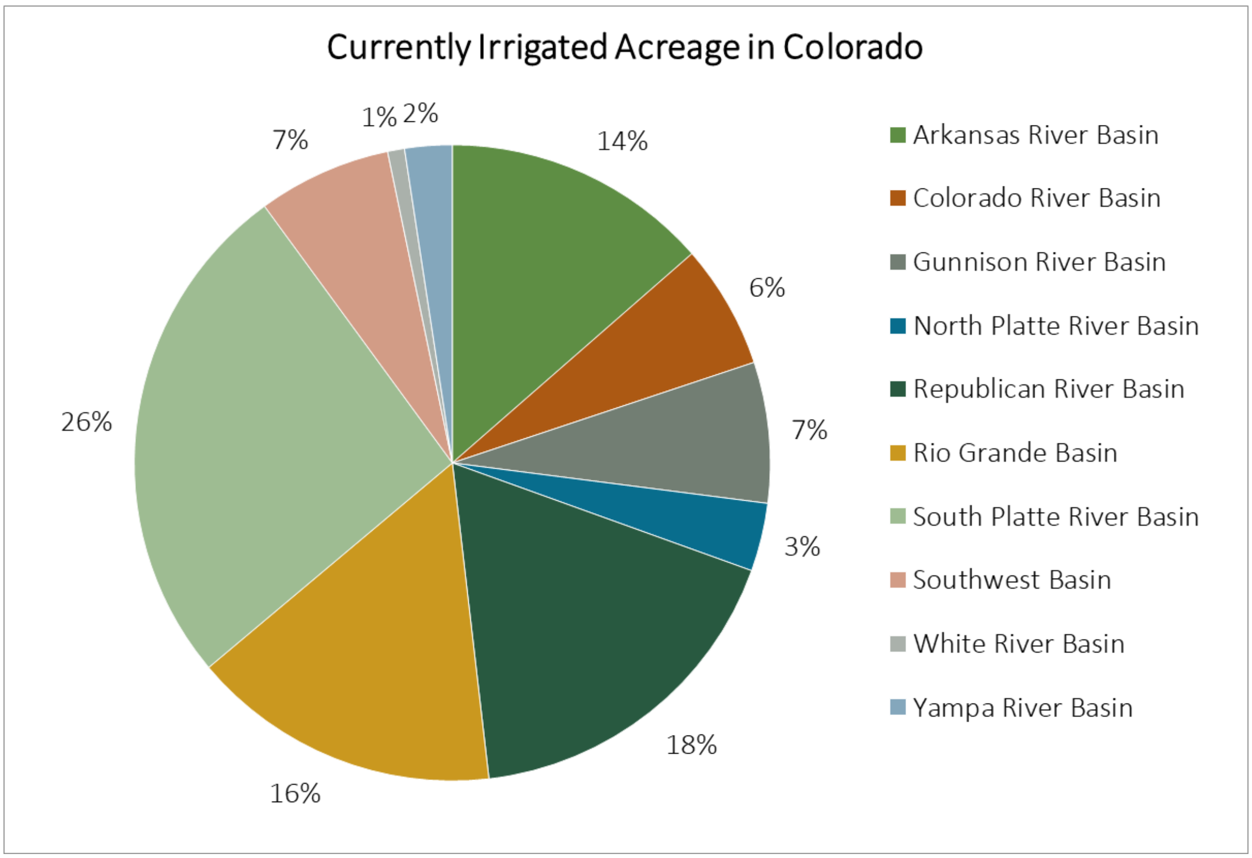


Figure 4: Currently Irrigated Acreage in Colorado

The following graphics and tables reflect the agricultural diversion demand for surface and ground water supplies summarized by basin for wet, dry, and average hydrological year types compared to average IWR. Results are provided over a range of hydrological year types to reflect how demands and system

[9] Source: Contribution of Agricultural to Colorado's Economy (January 2012, Colorado State University Extension)

efficiencies change under different climatic/hydrological conditions and to show how different types of supplies are used. As discussed in Section 4, the agricultural diversion demand is calculated by dividing the IWR by system efficiency. In dry years, for example, surface water irrigation supplies are reduced due to lower precipitation and streamflow and irrigators are more efficient with the surface water irrigation supplies that are available, resulting in a lower dry year diversion demand. For irrigators with supplemental ground water supplies, the ground water demand generally increases in response to decreased availability of surface water supplies. System efficiencies range across basins and year types for reasons other than supply including irrigation methods (i.e. sprinkler or flood applications), on-farm conditions such as ditch/lateral alignments, soil types, and field topography. The basin summaries below provide more information on conditions that impact the system efficiency and the agricultural diversion demand.

Table 4 shows the current irrigated acreage, average IWR and unit IWR by basin. Average IWR is driven by both climate conditions and crop type. For example, although climate conditions may be similar the row crops grown on the eastern plains of Colorado require less water than some of the perennial crops grown in the Grand Valley area of the Colorado River basin.

As reflected in Table 5 and Table 6, the statewide total agricultural diversion demand is currently approximately 13 million acre-feet; over 80 percent of that demand is from surface water supplies. The total diversion demand represents the amount of water that would need to be diverted or pumped to meet the full crop IWR, and does not reflect historical irrigation supplies. Irrigators often operate under water-short conditions resulting in an agricultural gap. Refer to the *Technical Update Current and 2050 Planning Scenario Water Supply and Gap* documentation for more information on how the demands were implemented in the water supply models and how the agricultural gap was estimated.

Table 4: Current Irrigated Acreage and Average Annual IWR

Basin	Acreage	Average IWR (acre-feet)	Unit IWR (feet)
Arkansas	445,000	980,000	2.20
Colorado	206,700	456,500	2.21
Gunnison	234,400	528,200	2.25
North Platte	113,600	191,100	1.68
Republican	578,800	837,000	1.45
Rio Grande	515,300	1,021,000	1.98
South Platte River	854,300	1,500,000	1.76
Southwest	222,500	474,900	2.13
White	28,100	46,400	1.65
Yampa	78,900	150,600	1.91
Total	**3,280,000**	**6,190,000**	**1.89**

Table 5: Current Agricultural Diversion Surface and Ground Water Demand

Basin	Acreage	Average IWR (acre-feet)	Surface Water Demand: Wet Year (acre-feet)	Surface Water Demand: Average Year (acre-feet)	Surface Water Demand: Dry Year (acre-feet)	Ground Water Demand: Wet Year (acre-feet)	Ground Water Demand: Average Year (acre-feet)	Ground Water Demand: Dry Year (acre-feet)
Arkansas	445,000	980,000	1,567,000	1,497,000	1,501,000	327,000	375,000	461,000
Colorado	206,700	456,500	1,640,000	1,608,000	1,538,000	-	-	-
Gunnison	234,400	528,200	1,824,000	1,814,000	1,716,000	-	-	-
North Platte	113,600	191,100	548,000	555,000	489,000	-	-	-
Republican	578,800	837,000	-	-	-	913,000	1,056,000	1,241,000
Rio Grande	515,300	1,021,000	1,237,000	1,172,000	1,195,000	564,000	628,000	654,000
South Platte	854,300	1,500,000	2,078,000	2,186,000	2,108,000	349,000	403,000	524,000
Southwest	222,500	474,900	980,000	1,025,000	1,007,000	-	-	-
White	28,100	46,400	250,000	243,000	242,000	-	-	-
Yampa	78,900	150,600	387,000	402,000	403,000	-	-	-
Total	3,280,000	6,190,000	10,511,000	10,502,000	10,199,000	2,153,000	2,462,000	2,880,000

Table 6: Total Current Agricultural Diversion Demand

Basin	Acreage	Average IWR (acre-feet)	Total Water Demand: Wet Year (acre-feet)	Total Water Demand: Average Year (acre-feet)	Total Water Demand: Dry Year (acre-feet)
Arkansas	445,000	980,000	1,894,000	1,872,000	1,962,000
Colorado	206,700	456,500	1,640,000	1,608,000	1,538,000
Gunnison	234,400	528,200	1,824,000	1,814,000	1,716,000
North Platte	113,600	191,100	548,000	555,000	489,000
Republican	578,800	837,000	913,000	1,056,000	1,241,000
Rio Grande	515,300	1,021,000	1,801,000	1,800,000	1,849,000
South Platte	854,300	1,500,000	2,427,000	2,589,000	2,632,000
Southwest	222,500	474,900	980,000	1,025,000	1,007,000
White	28,100	46,400	250,000	243,000	242,000
Yampa	78,900	150,600	387,000	402,000	403,000
Total	3,280,000	6,190,000	12,664,000	12,964,000	13,079,000

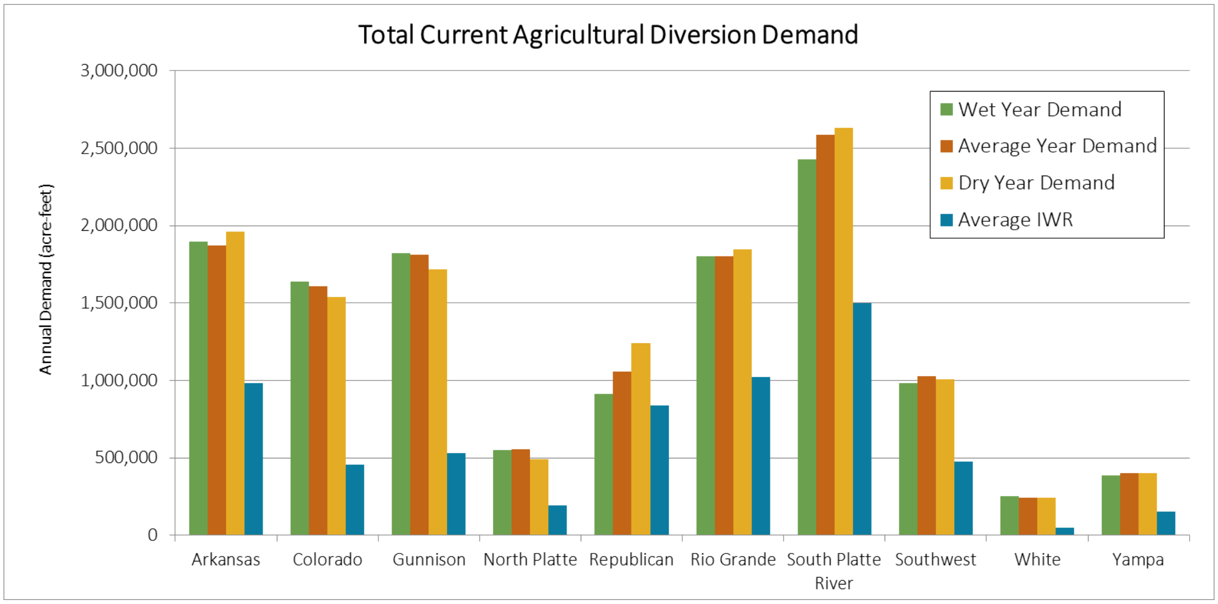


Figure 5: Total Current Agricultural Diversion Demand

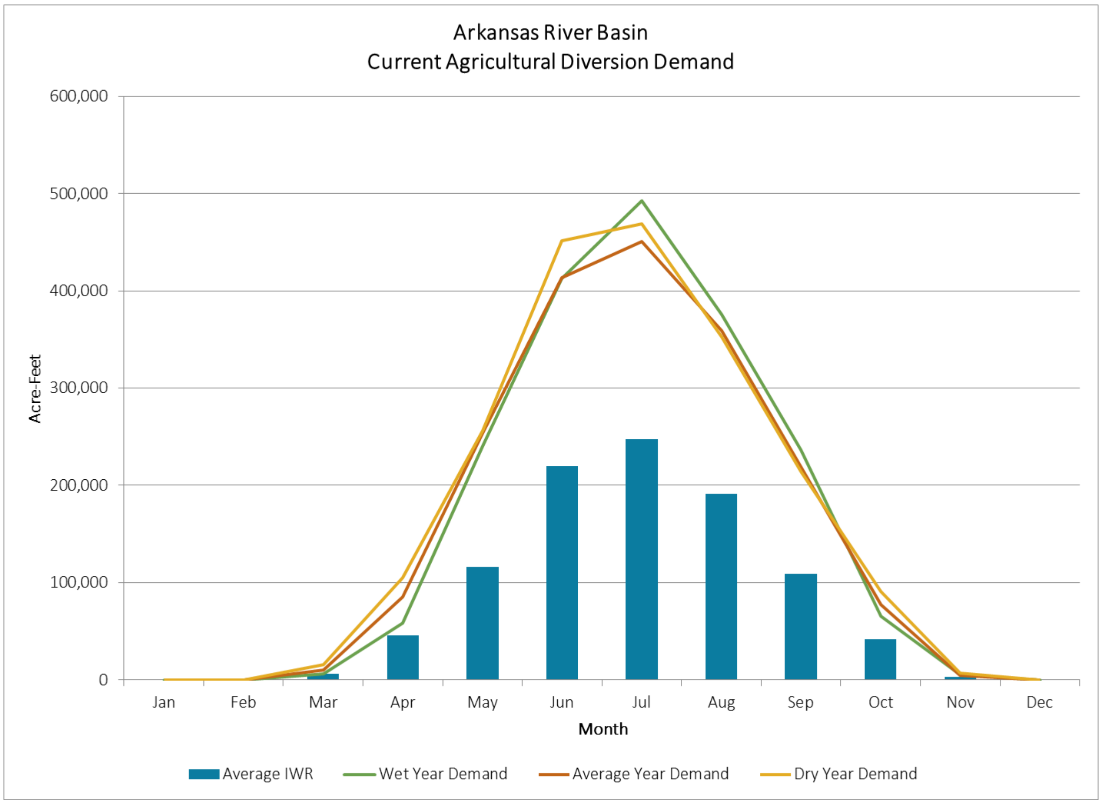


Figure 6: Arkansas River Basin Currently Agricultural Diversion Demand

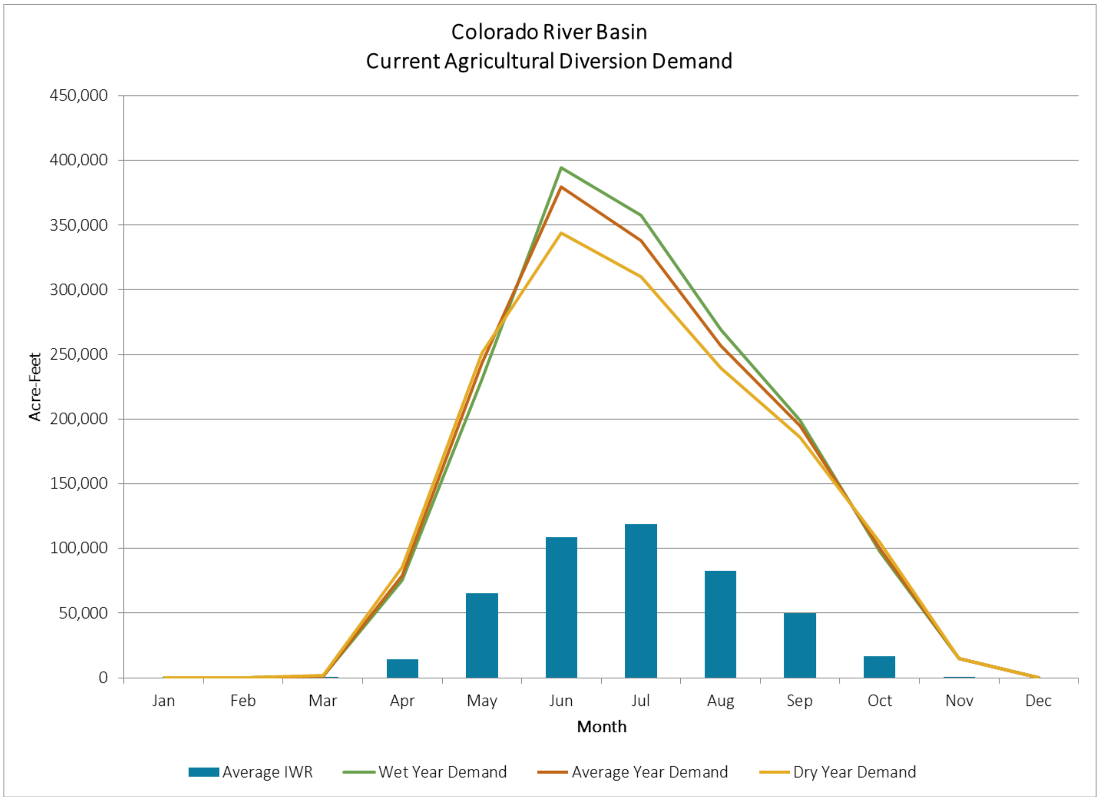


Figure 7: Colorado River Basin Current Agricultural Diversion Demand

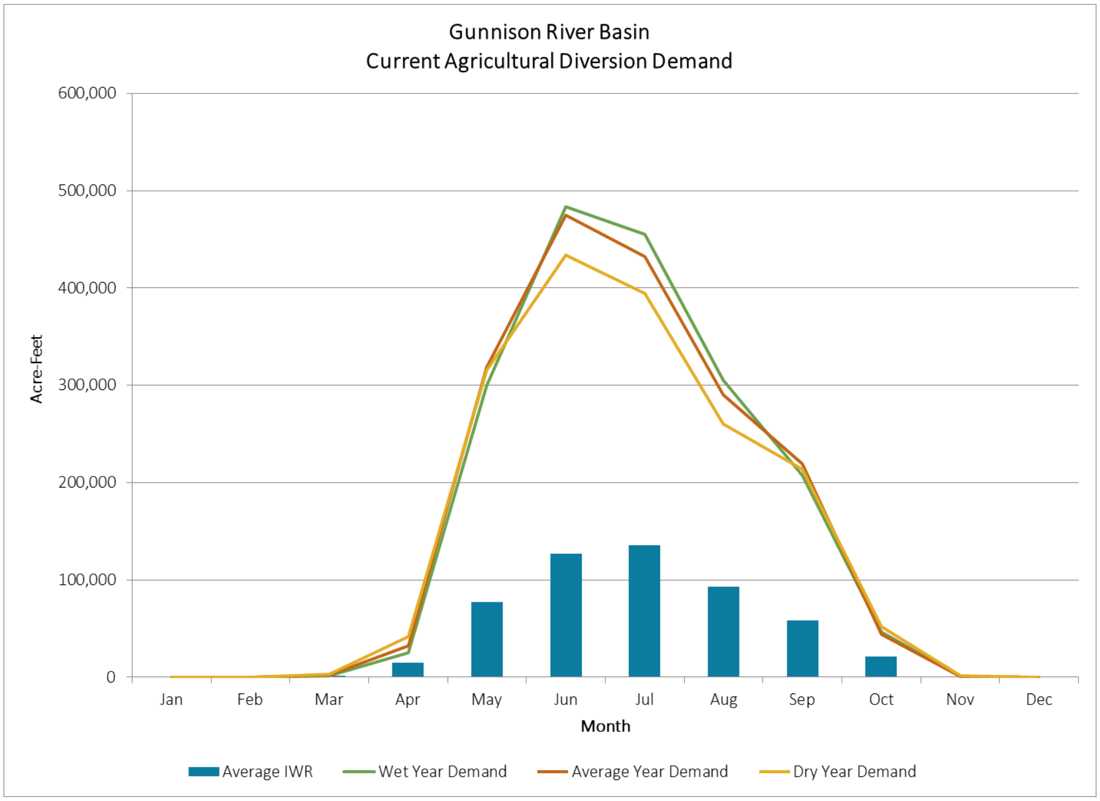


Figure 8: Gunnison River Basin Current Agricultural Diversion Demand

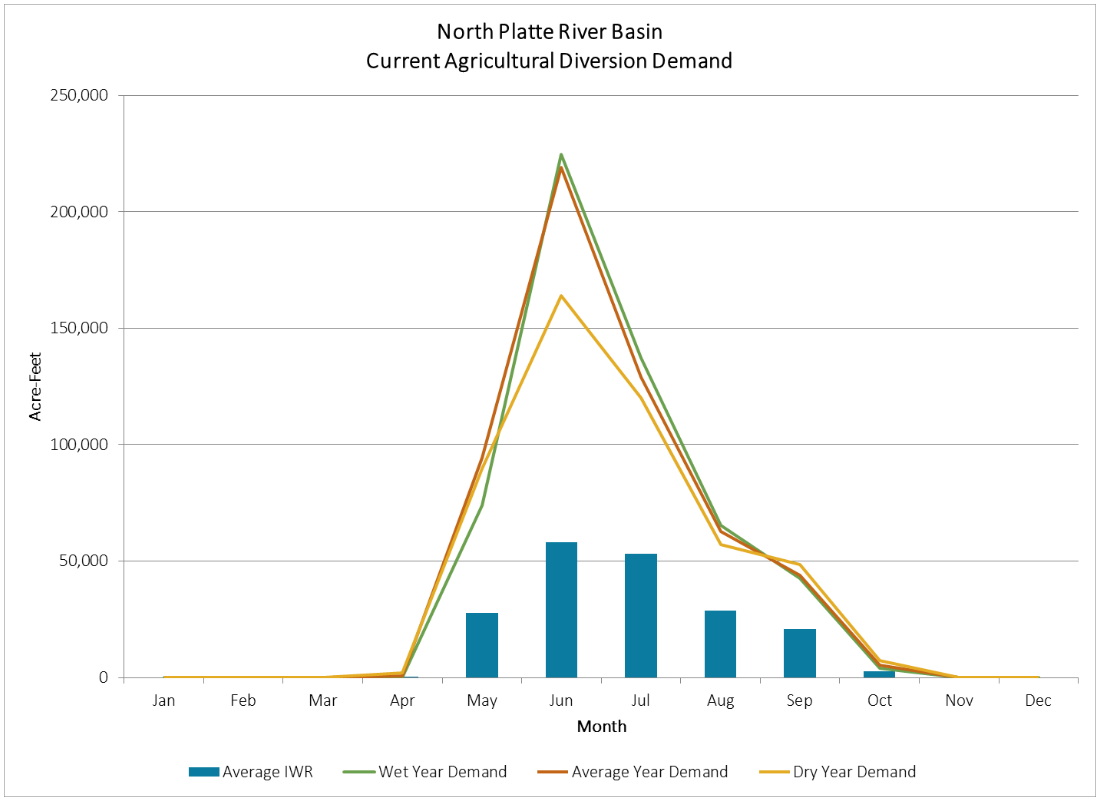


Figure 9: North Platte River Basin Current Agricultural Diversion Demand

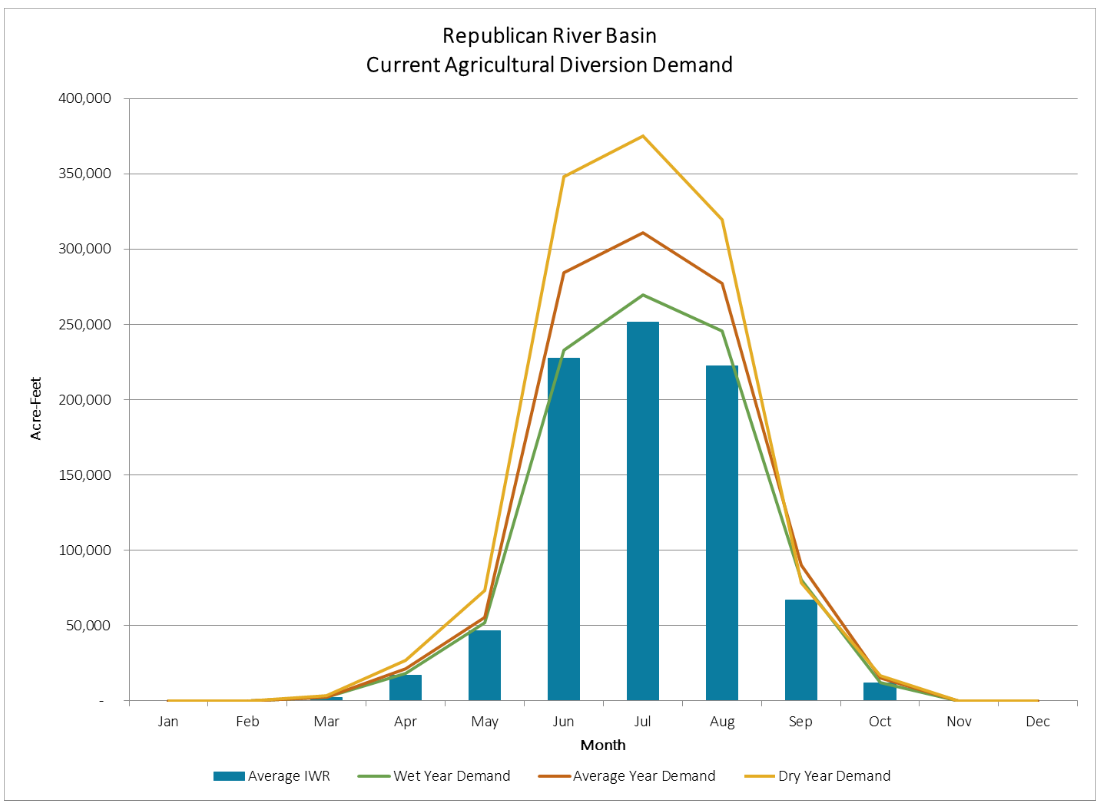


Figure 10: Republican River Basin Current Agricultural Diversion Demand

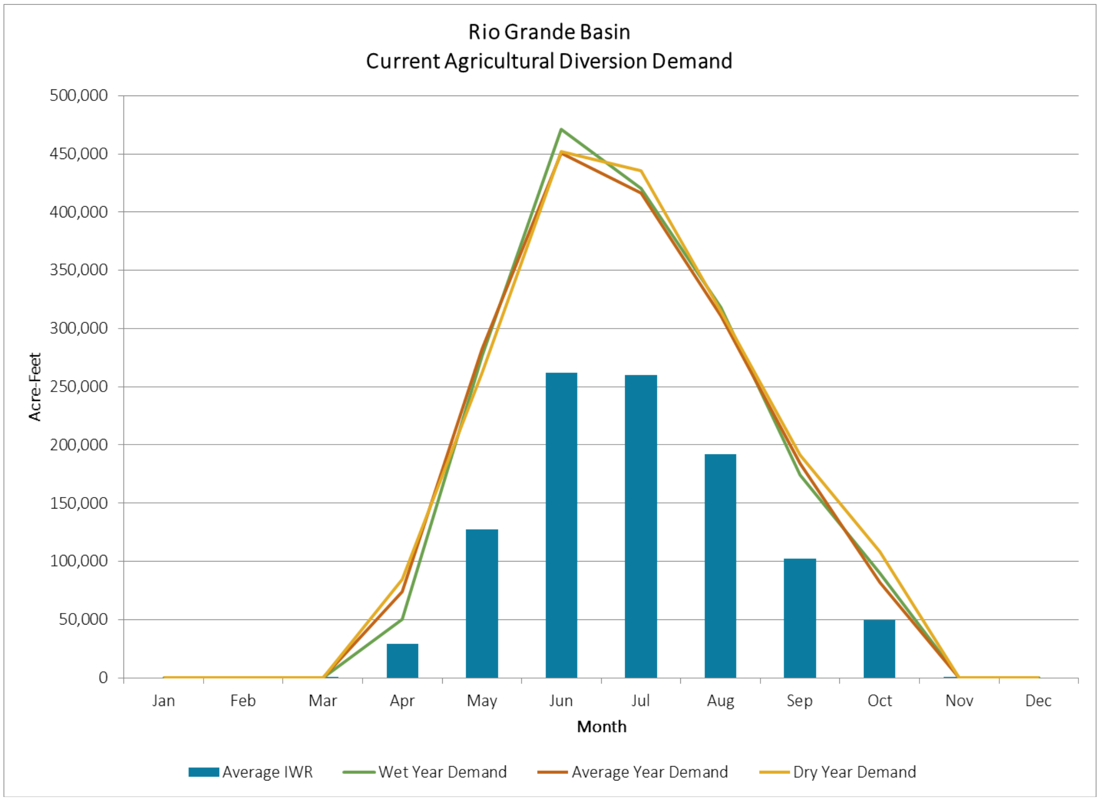


Figure 11: Rio Grande Basin Current Agricultural Diversion Demand

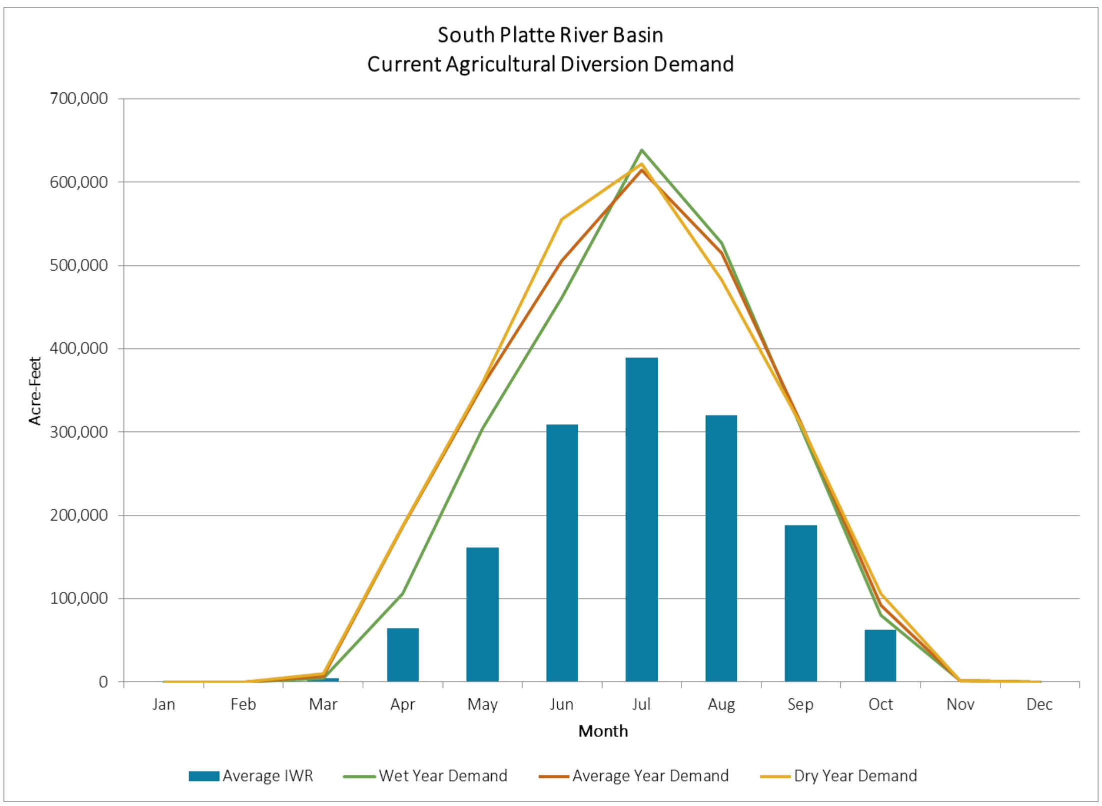


Figure 12: South Platte River Basin Current Agricultural Diversion Demand

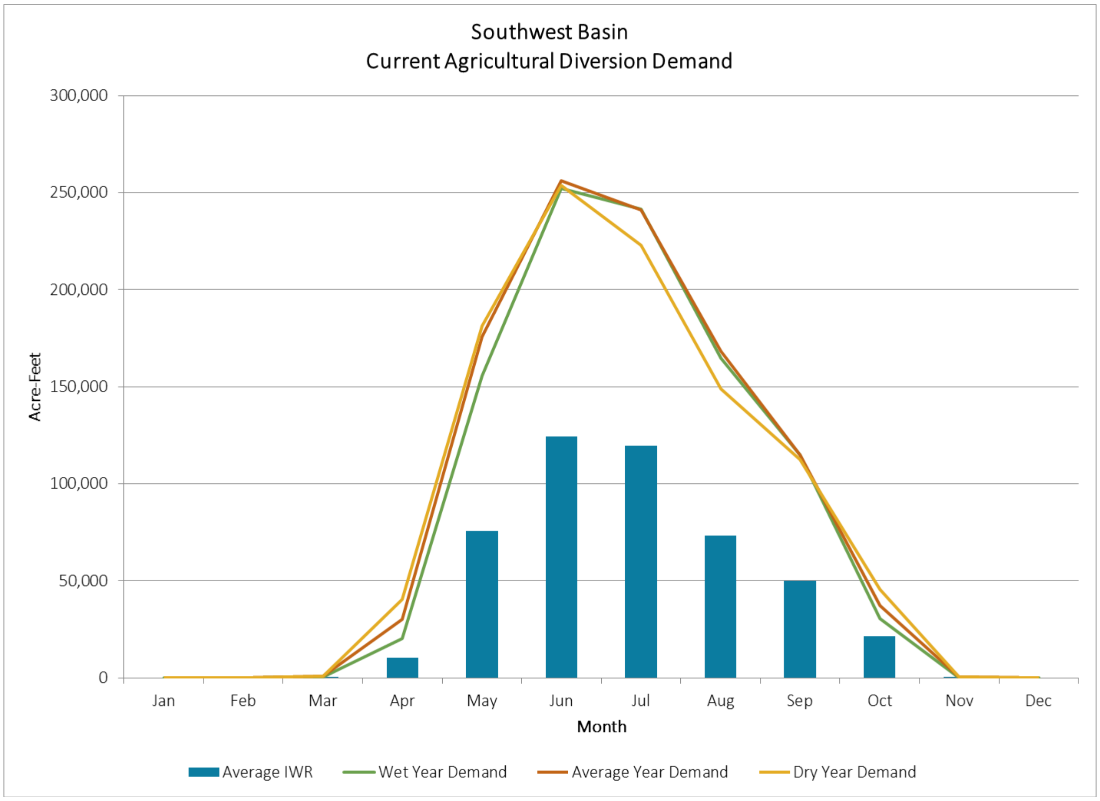


Figure 13: Southwest Basin Current Agricultural Diversion Demand

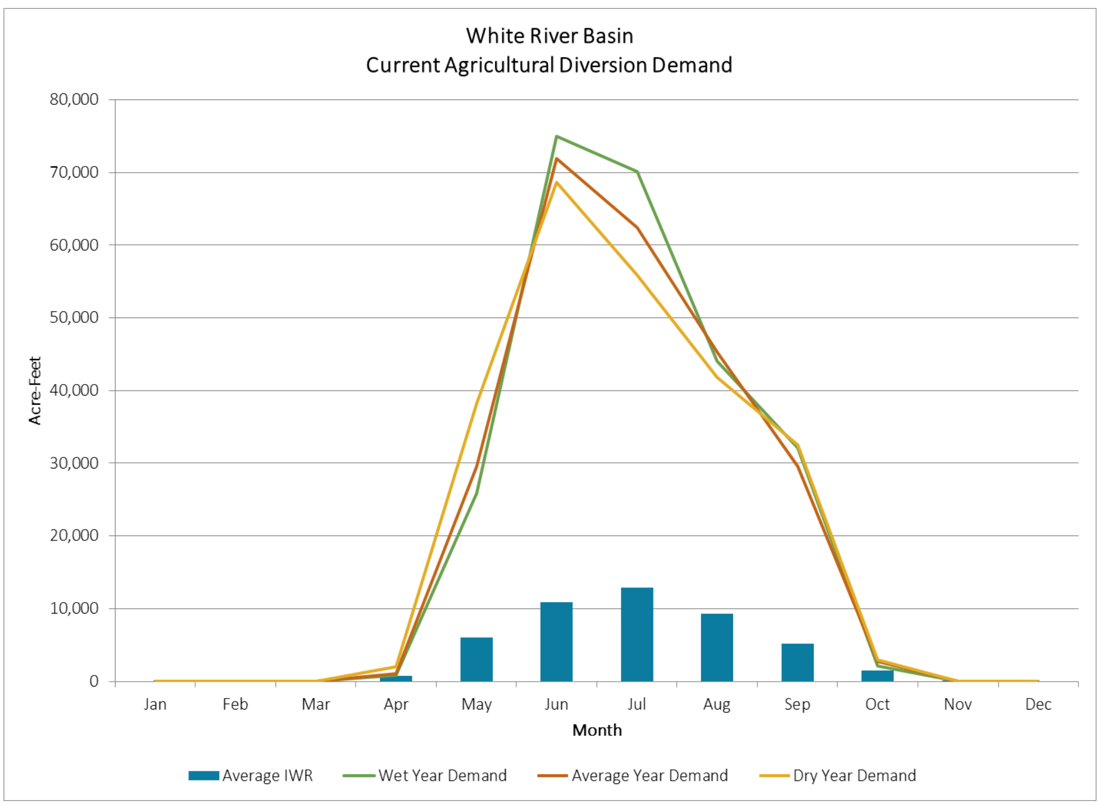


Figure 14: White River Basin Current Agricultural Diversion Demand

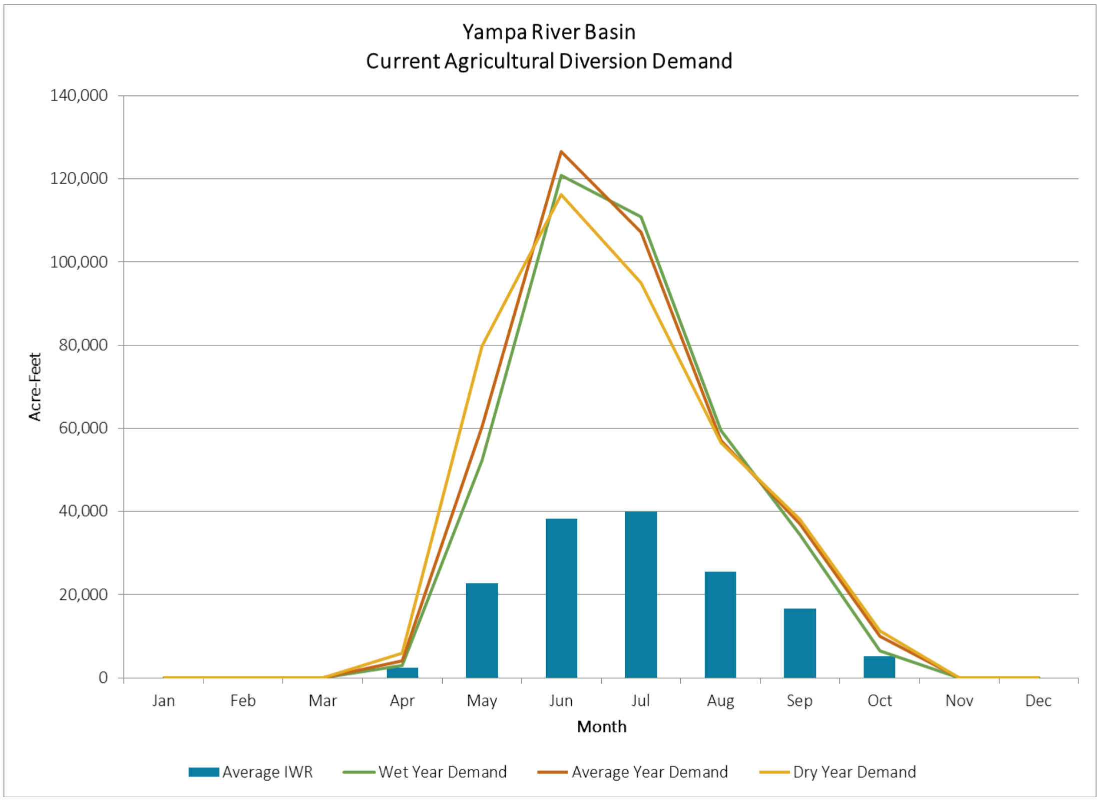


Figure 15: Yampa River Basin Current Agricultural Diversion Demand

Section 6: Planning Scenario Adjustments

Many different factors will impact the future of agriculture in the State of Colorado, including changing climatic conditions, increased demand for food, new irrigation and seed technologies, environmental regulations, and agricultural market fluctuations. Although these factors will all play a part in shaping the future of agriculture, the impact from many of these factors is difficult to quantify or predict. As such, the Technical Update focused on the following factors that can be consistently and quantitatively applied to adjust the agricultural diversion demand in each Planning Scenarios.

- Urbanization
- Planned Agricultural Projects
- Ground Water Acreage Sustainability
- Climate
- Emerging Technologies

Note that this section provides general descriptions of the Planning Scenario adjustment factors; refer to *Planning Scenario Agricultural Diversion Demand Approach* section for discussion on the general approach for applying each factor and the basin-wide summaries for specific information regarding how the factors were reflected in each basin.

6.1 URBANIZATION

As many municipalities are expected to grow in the 2050 Planning Scenarios, it is anticipated that some of the municipal growth will occur into currently irrigated agricultural lands. For this effort, this growth is referred to as "urbanization" and reflects the amount of irrigated acreage that will likely be converted for municipal uses under each Planning Scenario. Additional non-irrigated land may also be urbanized to accommodate projected population growth but non-irrigated lands were not considered or quantified for this factor since development on those lands would not impact the amount of projected irrigated acres.

The *Technical Update Agricultural Diversion Demand Methodology* outlined an approach to account for the impact of urbanization of irrigated acreage in the 2050 Planning Scenarios. The originally contemplated approach relied on estimates of population growth and urbanized acreage from a recent period (i.e. 1997 – 2015), and assumed that growth onto irrigated acreage would occur at the same rate. Applying this "urbanization rate" using the 2050 projected population, however, resulted in estimates of urbanized acreage greater than the available irrigated acreage in and around the municipal boundaries. This indicates that growth, at least with respect to urbanization of irrigated acreage, will look different in the future and a revised approach was developed.

The revised approach relies on current irrigated lands, current municipal boundaries, and basin-wide population projections to determine the amount of irrigated acreage that would likely be dried up and urbanized within each basin by 2050. First, a geo-spatial analysis was performed to identify currently irrigated lands within and directly adjacent to existing municipality boundaries. No assumptions or considerations were made to forecast how any individual municipality may expand or change boundaries in the future (direction or distance) or forecast changes in density of future growth. Second, population projections were reviewed to determine if the basin was projected to experience growth in each Planning Scenario. If so, then it was assumed the irrigated acreage from the spatial analysis would be urbanized and removed from production by 2050. If population was projected to decline in a basin by 2050 in a specific Planning Scenario, no changes to irrigated acreage were made. This approach results in a conservative estimate of urbanized acreage, however, it can be consistently applied statewide and does not require specific knowledge of future municipal growth or direction of expansion.

Table 7 reflects the amount of projected urbanized acreage by basin, historical urbanization, and also current levels of irrigated acreage for context. This approach estimates approximately 153,500 irrigated acres will be dried up and taken out of production due to urbanization by 2050, approximately 5 percent of the total irrigated acreage statewide. The largest impact is expected in the South Platte River basin, with dry up projected to exceed 12 percent of the irrigated acreage in basin.

Table 7: Projected Loss of Irrigated Acreage Due to Urbanization

Basin	Historically Urbanized Irrigated Acreage (1)	Projected Urbanized Irrigated Acreage (2)	Currently Irrigated Acreage
Arkansas	N/A (3)	7,240	445,000
Colorado	6,060	13,590	206,700
Gunnison	2,380	14,600	234,400
North Platte	2	40	113,600
Republican	0	1,410	578,800
Rio Grande	N/A (3)	4,010	515,300
South Platte/Metro	49,400	105,900	854,300
Southwest	100	3,800	222,500
White	-15 (4)	360	28,100
Yampa	135	1,500	78,900
Total	**58,060**	**152,450**	**3,277,600**

1) Irrigated acreage dried up between 1987/1993 and 2015 within current municipality boundaries. Based on CDSS irrigated acreage assessments and 2018 DOLA municipality boundaries.

2) 2015 irrigated acreage within or shares boundaries with 2018 municipality boundaries.

3) Neither a 1987 nor a 1993 basin-wide acreage assessment has been developed.

4) The White River basin showed a slight decline in irrigated acreage within municipal boundaries from 1993 to 2015.

Population estimates for some Planning Scenarios show a population decline in some basins; therefore, it is reasonable to assume no urbanization of irrigated acreage will occur in these basins under these Planning Scenarios. As a result, urbanization in basins with projected losses to population in 2050 Planning Scenarios will be set to zero. Table 8 shows a matrix of urbanized acres by basin and Planning Scenario.

Table 8: Urbanization of Irrigated Acreage by Planning Scenario

Basin	A: Business as Usual	B: Weak Economy	C: Cooperative Growth	D: Adaptive Innovation	E: Hot Growth
Arkansas	7,240	7,240	7,240	7,240	7,240
Colorado	13,590	13,590	13,590	13,590	13,590
Gunnison	14,600	14,600	14,600	14,600	14,600
North Platte	-	-	-	40	40
Republican	1,410	-	1,410	1,410	1,410
Rio Grande	4,010	-	4,010	4,010	4,010
South Platte/Metro	105,900	105,900	105,900	105,900	105,900
Southwest	3,800	3,800	3,800	3,800	3,800
White	360	-	360	360	360
Yampa	1,500	1,500	1,500	1,500	1,500
Total	**152,410**	**146,630**	**152,410**	**152,450**	**152,450**

In specific basins, additional irrigated acreage was removed to account for irrigation water rights that are currently being transferred for municipal uses, or rights that have been purchased and will be transferred for municipal uses in the future. Estimates of this acreage, termed *Municipal Transfers* in the basin summaries below, were provided by stakeholders in the basin. Note *Municipal Transfers* reflect acreage that is currently *planned* to be dried up and their water rights transferred for municipal purposes, not acreage that may be dried up in a future transfer as part of an Identified Project and Process (IPP) or in response to meeting a future 2050 Planning Scenario municipal gap.

The total acreage projected to be urbanized or part of a planned municipal transfer for the Technical Update is similar to the High Scenario estimates in SWSI 2010 (Table 1); however the distribution across the basins differs. Specifically, the Technical Update analysis reflected much lower urbanized acreage estimates in Colorado River basin and much higher estimates in the South Platte River basin, as compared to the SWSI 2010 effort. This difference may be a result of more current population projections and identifying potential urbanized parcels in the Technical Update approach, compared to a more regional or basin-wide approach taken in SWSI 2010.

6.2 PLANNED AGRICULTURAL PROJECTS

The Basin Implementation Plans (BIP) developed by each of the Basin Roundtables (BRT) outlined the current agricultural needs in each basin, as well as the basin's future agricultural goals and approaches to meeting those goals. All of the BIP indicated water shortages occur on existing agricultural demands, cited concern over the current trend of converting agricultural water supplies to municipal uses, and proposed solutions to address the agricultural gap. Two basins, the North Platte and Yampa River basin, also included a goal to increase agriculture in the basin by putting new lands under production. Planned agricultural projects in the North Platte River basin totaled 10,576 acres and projects in the Yampa River basin totaled 14,805 acres. Refer to the basin summaries below for more information on implementation of this factor in these basins.

SWSI 2010 efforts identified a total increase of 42,000 acres by 2050, with 14,000 acres in the Yampa River basin and 28,000 acres in the North Platte River basin. The Technical Update estimates correlate closely in the Yampa River basin as the estimates are generally based on the same source data. The Technical Update estimates for increased irrigated acreage in the North Platte Basin are approximately 10,500 acres and were based on planned agricultural projects identified by stakeholders in the basin. The SWSI 2010 effort relied on maximum irrigated acreage increases allowable under the Three States Agreement of the Platte River Recovery Implementation Plan and the North Platte Equitable Apportionment Decree (rev. 1953).

6.3 GROUND WATER ACREAGE SUSTAINABILITY

A large portion of the currently irrigated acreage in Colorado relies on ground water supplies, primarily in the South Platte, Republican River, Arkansas River, and Rio Grande basins. Sustaining these ground water supplies, both in terms of physical and legal availability, is necessary for maintaining irrigated acreage supplied by ground water into the future. If ground water levels or augmentation supplies cannot be sustained, irrigated acreage served by ground water in these basins will likely decrease in the future.

Meetings were held with several stakeholders in these basins to determine the primary considerations regarding the sustainability of ground water supplies in the future. The following provides a summary of these considerations and the general level of impact in each basin; refer to the basin summaries below for more information of implementation of this factor in these basins.

- **Republican -** Essentially all of the 578,800 acres in the Republican River Basin are served only by ground water supplies. Sustainability of this irrigated acreage is impacted by two primary issues;

achieving compliance with the 1942 Republican River Compact (and the 2002 Settlement) and declining levels in the High Plains Aquifer System. Discussions with Republican River Water Conservation District (RRWCD) Board Members yielded potential reductions to irrigated acreage across the counties within the basin; a total of 135,420 acres, or nearly 25 percent, is estimated to be taken out of production by 2050 in response these issues.

- South Platte - Sustainability of continued irrigation on acreage served by ground water in South Platte River Basin is vulnerable to the availability of augmentation supplies. Central Colorado Water Conservancy District, which operates two of the largest well augmentation plans in the South Platte River basin, provided information on current augmentation supplies and insight into the availability of projected augmentation supplies. In short, up to 20 percent of the irrigated acreage currently served solely by ground water may not have access to sufficient augmentation supplies to continue farming. Discussions with the Lower South Platte Water Conservancy District focused on the current and future trends in taking irrigated acreage out of production and converting those water rights over to municipal uses. While Colorado is making strides towards reducing the occurrence of permanent agricultural to municipal water transfers (e.g. buy and dry), the practice will likely continue in the future to some degree. In addition, even if permanent transfers are eliminated, reductions in irrigation demand will occur as a consequence of municipal uses pursuant to alternative transfer methods. Although augmentation shortages and water transfers are two distinctly different and unrelated drivers for reduction in irrigated lands, the impact of this issue is the same – the amount of irrigated acreage in the South Platte will decline in the future.

- Arkansas - Nearly 85,000 acres in the southeast corner of the Arkansas River Basin is solely irrigated with ground water pumped from the Southern High Plains aquifer system. DWR has measured aquifer levels in this area over the past two decades and has noted declines in all aquifers layers. Increasing IWR due to projected climate conditions will likely lead to increased pumping and more aggressive declines in aquifer levels than recently measured. This, in turn, will likely result in acreage reductions in this area in the future.

- Rio Grande - The Rio Grande Basin has already experienced a reduction to irrigated acreage as a result of declining aquifer levels, and administrators and stakeholders in the basin indicated additional reductions can be expected in the future. Pumping of the unconfined aquifer, which serves as the primary supply for irrigated acreage in the San Luis Valley, has depleted the aquifer by more than 1.1 million acre-feet since the early 1990s. The Rio Grande Water Conservation District (RGWCD) is tasked with managing the ground water depletions through the creation of Groundwater Management Subdistricts and recovering nearly 700,000 acre-feet of aquifer storage in the next 13 years. Although 20,000 acres have already been taken out of production, the stakeholder group indicated additional reductions will be needed to recharge the aquifer.

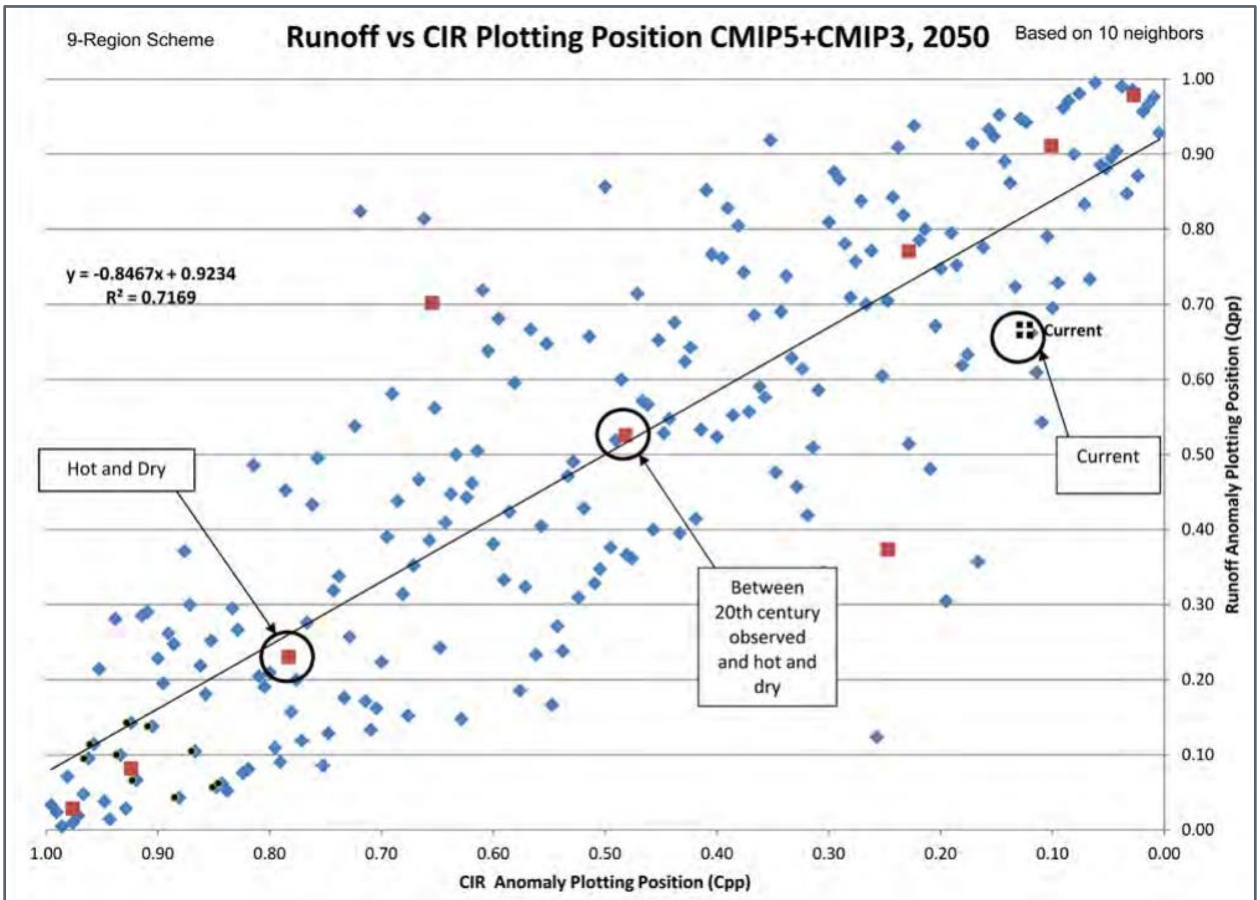
6.4 CLIMATE

CWCB has undertaken several studies and investigations on the potential impact of climate change and its effect on the future of water supply and use in Colorado. Most notably was the development of the Colorado Climate Plan (CCP), which focuses on observed climate trends, climate modeling, and climate and hydrology projections to assist with the planning and management of water resources in Colorado. The CCP discusses the most recent global climate projections (CMIP5) and recommends the integration of these results with the previous global climate projections (CMIP3) to provide a representative range of potential future climate and hydrological conditions.

Supported by the information from the CCP, Colorado's Water Plan identified two future potential climate projections for incorporation into the 2050 Planning Scenarios; a group of climate projections representative of "Between 20th Century Observed and Hot and Dry" conditions and another group of projections representative of "Hot and Dry" conditions, as reflected in Figure 16.

- "Hot and Dry" is defined as the 75th percentile of climate projections for crop irrigation requirements (water use), and the 25th percentile for natural flows. In other words, only 25 percent of projections have lower natural flows and 25 percent of projections have higher crop irrigation requirements.
- "Between 20th century-observed and hot and dry" (referred to as "In-Between") is defined as the 50th percentile for both natural flows and crop irrigation requirements. This scenario represents the middle of the range in terms of severity.

For comparison, historical or current conditions, which represent no change in runoff or in crop irrigation requirements, fall at roughly the 9th and 67th percentiles; meaning that 91 percent of individual projections show increases in crop irrigation requirements and 67 percent show reductions in runoff.



"Hot and dry" is defined as the 75th percentile of climate projections for crop irrigation requirements (water use), and the 25th percentile for natural flows. In other words, only 25 percent of projections have lower natural flows and 25 percent of projections have higher crop irrigation requirements. "Between 20th century-observed and hot and dry" is defined as the 50th percentile for both natural flows and crop irrigation requirements. This scenario represents the middle of the range in terms of severity. Historical or current conditions, which represents no change in runoff or in crop irrigation requirements, fall at roughly the 9th and 67th percentiles; this means that 91 percent of runs show increases in crop irrigation requirements and about two-thirds show reductions in runoff.

Figure 16: Colorado's Water Plan Selected Climate Projections

The effort associated with processing the projected climate data and downscaling the information for use at the Water District level was completed through the Colorado River Water Availability Study Phase II (CRWAS-II) project. This effort resulted in a time series of factors for each Water District reflecting the relative change in IWR under each climate projection. Refer to the *Technical Update Temperature Offsets and Precipitation Change Factors Implicit in the CRWAS-II Planning Scenarios* memorandum for more information on the development of the climate-adjusted factors. These factors were then limited to the 95th percentile of change factors in their river basin to eliminate large outliers that occurred due to the down-scaling process. The North Platte and Arkansas River Basin consumptive use analyses extend beyond 2013. Change factors for these additional years (e.g. 2014 – 2017) were developed by using a climate change factor from a year that most closely matched the monthly and annual IWR from the additional year.

Figure 17 reflects the annual IWR factors averaged over the West Slope and East Slope basins for the Hot and Dry and In-Between scenarios. The “pool” of climate scenarios used to develop the overall Hot and Dry and In-Between conditions over historical years in which climate projections were applied generally show a greater summer warming effect in basins at higher elevations, therefore the West Slope factors are generally greater than those developed for the East Slope basins. Additionally, the scenarios tend to show greater warming effects during years that were historically cooler and/or had higher precipitation, inversely resulting in lower factors during drought periods (i.e. periods that, historically, were already hot and dry).

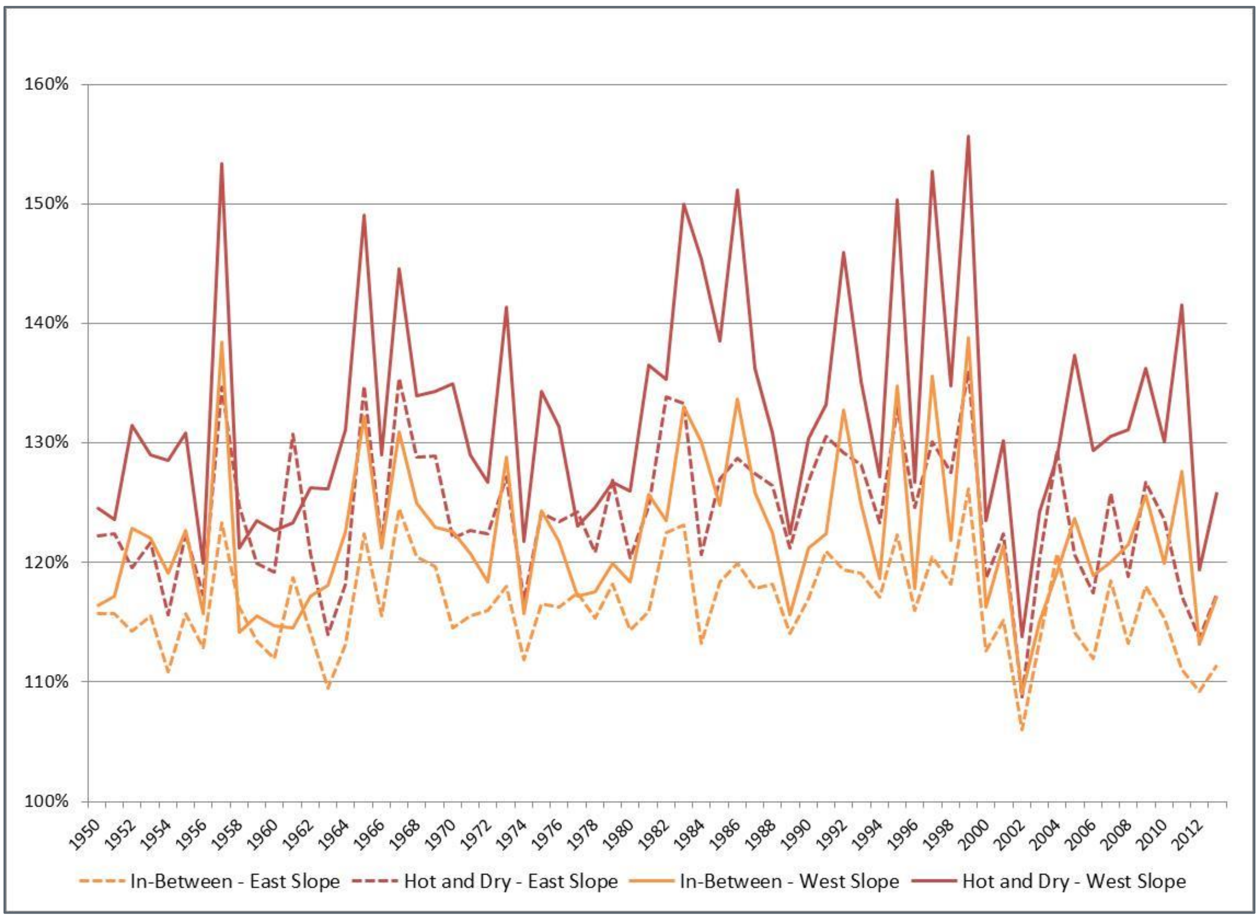


Figure 17: Average IWR Change Factors

It is important to note that factors must be applied to estimates of IWR, which also reflect monthly and annual variability due to changes in temperatures and precipitation. As an example, Figure 18 reflects the average annual unit IWR for irrigated acreage in the White River Basin; the In-Between and Hot and Dry IWR factors for the basin; and the resulting unit IWR after the application of the IWR factor. For this basin, the factors have the effect of significantly increasing the IWR during historically cooler periods and only slightly increasing the IWR during drought periods. Over the 1950 to 2013 period, the average annual unit IWR is projected to increase approximately 20 percent in the Cooperative Growth scenario compared to historical climate conditions and 35 percent compared to historical conditions in the Adaptive Innovation and Hot Growth scenarios.

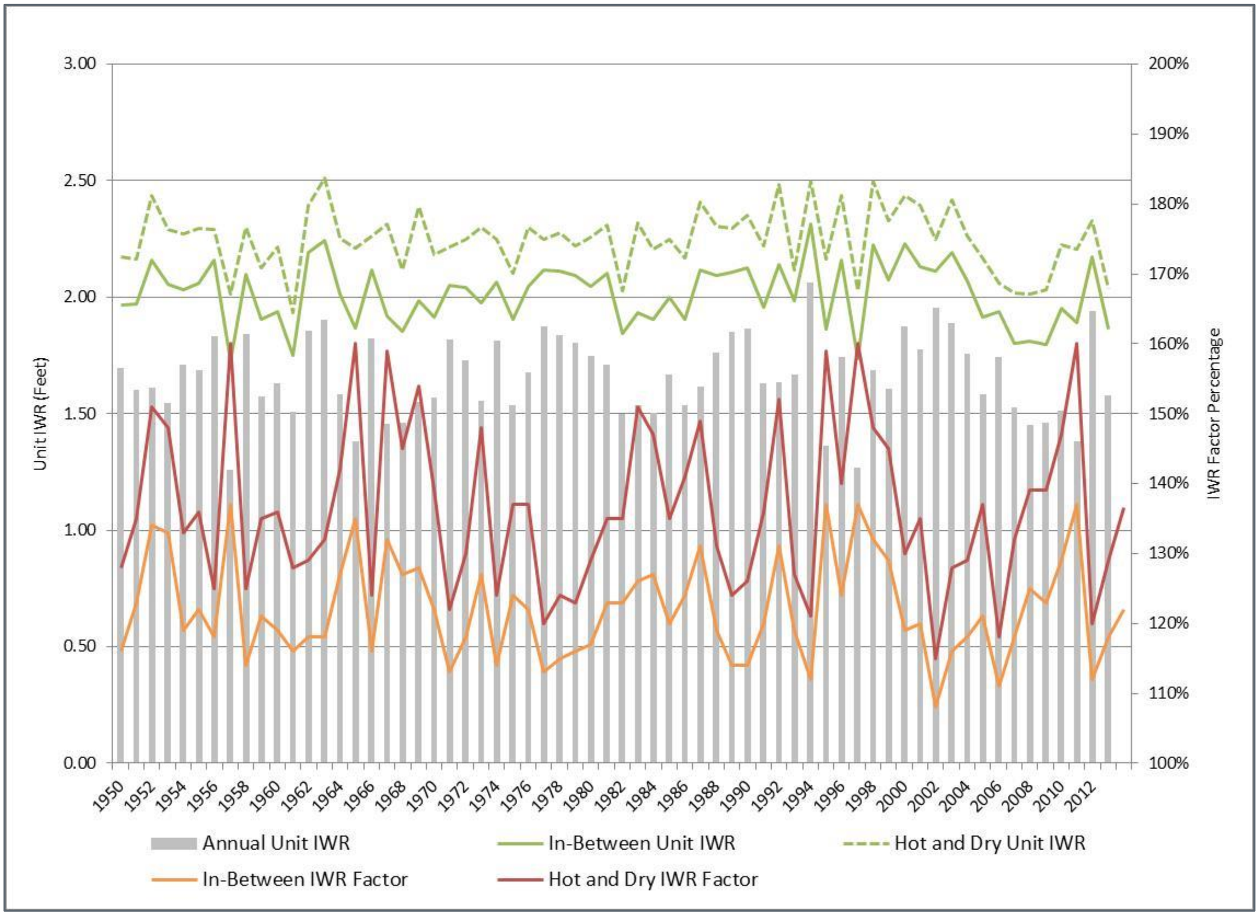


Figure 18: White River Basin Unit IWR and Planning Scenario Factors

Using the “Climate Status” driver under each Planning Scenario as a guide, Table 9 reflects the assignment of projected climate conditions for 2050 Planning Scenarios.

Table 9: Climate Factors by Planning Scenario

Planning Scenario	A: Business as Usual	B: Weak Economy	C: Cooperative Growth	D: Adaptive Innovation	E: Hot Growth
Climate Factor	Current	Current	In-Between	Hot and Dry	Hot and Dry

6.5 EMERGING TECHNOLOGIES

Emerging agricultural technologies will continue to play a significant role in water use by 2050. Instrumentation, automation, and telemetry have improved irrigation efficiency and scheduling in many areas of Colorado and will likely continue to improve into the future. Improvements to the efficient delivery and application of water, through new drip irrigation or sprinkler technologies (or additional adoption of these practices), may reduce water supply shortages and/or reduce the amount of water diverted or pumped. Innovations in seed technologies have resulted in more drought-tolerant hybrids and seed varieties that require less water to produce the same or greater crop yield. In order to capture the potential effect of these emerging technologies in the 2050 Planning Scenarios, two specific adjustments will be made under this Technical Update effort.

1. Sprinkler Development. The South Platte River basin has experienced significant conversion of flood irrigation practices to center-pivot sprinklers for the past several decades, effectively increasing the efficiency of the irrigated land. Based on the CDSS Irrigated Acreage Assessments, approximately 28 percent of the acreage in the South Platte River basin was irrigated using sprinklers in 1997; the percentage increased to 44 percent by 2010. The percentage is significantly higher when analyzing irrigated acreage served only by ground water; 43 percent in 1997 up to 59 percent by 2010. Discussions with stakeholders in the South Platte River Basin indicated a continued likelihood of this development to varying degrees in the Planning Scenarios. Ultimately, stakeholders agreed to assume 85 percent of total acreage served by ground water only will be under sprinklers by 2050 in the Business as Usual and Weak Economy Planning Scenarios, and 90 percent in the remaining Planning Scenarios. Stakeholders also contemplated sprinkler development in certain areas of the Arkansas River Basin in the future. Approximately 20 percent of the irrigated acreage between Pueblo Reservoir to the stateline is irrigated with sprinkler or drip systems. Stakeholders indicated that doubling the current amount of irrigated acreage supplied by more efficient systems would be feasible by 2050, even with Compact administration requiring mitigation of changes in return flows. Additional sprinkler development in the southeastern portion of the Arkansas River basin was also considered feasible; all of the irrigated acreage is to be supplied to sprinklers in the Cooperative Growth, Adaptive Innovation, and Hot Growth Planning Scenarios in this area. Sprinkler development has occurred in other basins but there are limitations preventing significant development in the future. Examples include limited amounts of irrigated land suitable for operating sprinklers, limitations to augmentation supplies required to offset irrigation improvements, or economic factors. As such, this adjustment is applicable only in the South Platte River and Arkansas River basins. Refer to Section 7.1 and Section 7.7 for additional information on how this adjustment will impact system efficiency and future agricultural diversion demand.

2. Adaptive Innovation. The Adaptive Innovation Planning Scenario narrative contemplates future technological innovations that mitigate the increased agricultural demand due to climate adjustments. In order to implement this narrative in the agricultural diversion demand methodology, the impact of these contemplated technological innovations is translated as reductions to IWR and improved system efficiencies in the methodology calculation. Because these contemplated innovations and technologies have yet to be developed; current trends or existing efficiency values were not evaluated to determine the adjustment factors. Rather, the irrigation water requirement will be reduced 10 percent Statewide to reflect increased use of drought-tolerant hybrids and changed agronomic management practices brought on by drier conditions. Additionally, system efficiency will be increased by 10 percent in select basins to

reflect improvements to conveyance/application efficiencies or irrigation/tillage practices in the future. The system efficiency adjustment will be applied in the Western Slope, North Platte River, and South Platte River basins. The adjustments will not be applied in the Arkansas River, Republican River, and Rio Grande basins due to limitations on the feasibility of significantly improving irrigation efficiencies in these basins or limitations of improving efficiencies due to Compact restrictions. Refer to each basin summary in Section 7 for additional information on how these adjustments to irrigation water requirement and efficiency are applied to the future agricultural diversion demand.

Section 7: Planning Scenario Adjustments – Basin Summaries

This section provides an overview of the current state of agriculture in each basin; opportunities and constraints that may affect agriculture in the basin by 2050; and how the Planning Scenario adjustments were implemented within each basin. The resulting Planning Scenario agricultural diversion demand by basin is provided in the next section.

7.1 ARKANSAS RIVER BASIN

Producers irrigate over 472,000 acres in the Arkansas River Basin, with nearly half of these acres located along the river between Pueblo Reservoir and the stateline (Figure 19). The fertile soils in the river valley support a wide variety of crops, including pasture grass, alfalfa, corn, grains, wheat, fruits, vegetables, and the renown Rocky Ford melons. Many of the large irrigation systems in this area rely on surface water diversions from the mainstem Arkansas River, supplemented with ground water and Fryingpan-Arkansas Project[10] deliveries. Pasture grass is the predominant crop grown outside of the Arkansas River Valley, with concentrated areas of irrigated acreage under the Trinidad Project on the Purgatoire River; along Fountain Creek downstream of Colorado Springs; and in the southeastern corner in the Southern High Plains ground water management area.

The basin also provides water to three of the fastest growing municipalities in the state, Colorado Springs, Aurora, and Pueblo, and competition for water is high. An over-appropriated basin coupled with the constraints of developing new water supplies under the Arkansas River Compact have historically led municipalities to purchase and transfer irrigation water rights to municipal uses to meet their growing needs. In the 1980s, large transfers of irrigation water rights in the Twin Lakes Reservoir and Irrigation Canal Company resulted in the dry up of 45,000 acres in Crowley County alone. More recently, however, the basin has been proactive at looking for solutions to share water supplies and has been one of the front-runners in developing alternative transfer methods, lease/fallow tools, and interruptible supply agreements in which irrigation rights can be temporarily leased to municipalities for a limited number of years (e.g. 3 years out of every 10 years).

[10] The Fryingpan-Arkansas Project is a transmountain diversion project that diverts an average of 69,000 acre-feet annually from the Colorado River Basin and delivers water for municipal, industrial, and supplemental irrigation purposes in the Arkansas River Basin.

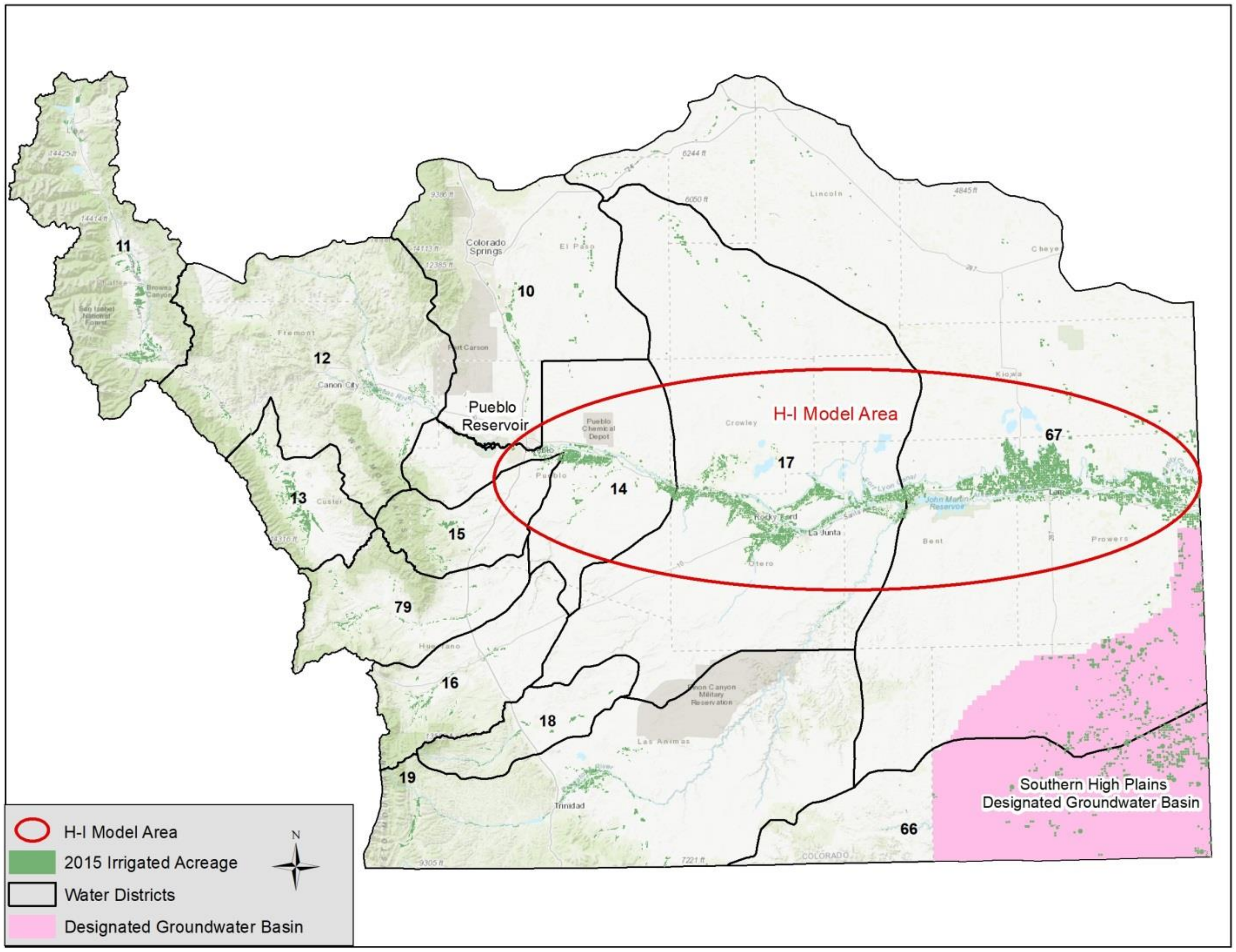


Figure 19: Arkansas River Basin Irrigated Acreage

Discussions with stakeholders in the basin regarding what agriculture in the basin may look like by 2050 focused on three major areas; additional dry up of acreage for municipal purposes, declining ground water aquifer levels in the Southern High Plains region, and irrigation practices. As discussed in more detail below, dry up of acreage and declining aquifer levels impacts the amount of projected 2050 irrigated acreage and irrigation practices effects projected 2050 efficiencies.

Population projections by 2050 in the basin reflect significant increases for Colorado Springs and Pueblo. The impact of that growth from urbanization, however, is tied to the proximity of existing municipality boundaries to agricultural operations. With limited acreage in close proximity, there is expected to be a smaller amount of irrigated acreage urbanized by their growth compared to urbanization that may occur around smaller agricultural towns such as Salida, Cañon City, and Lamar. Stakeholders in the basin noted that some of these smaller municipalities are inherently tied to the agricultural production and community that surrounds them, and if additional acreage is dried up, these municipalities will decline instead of grow as projected.

Currently portions of two irrigation ditches, Fort Lyon Canal and Bessemer Ditch, have been purchased by municipalities and their water rights are in the process of being transferred for municipal uses. It is anticipated that the portions of these ditches, totaling 12,600 irrigated acres, will be dried up by 2050. Although additional purchase of irrigation water rights is expected, the stakeholders in the basin are hopeful that leasing agreements or other solutions may limit the permanent dry up of irrigated acreage in the future.

From a ground water sustainability perspective in the basin, over 85,000 acres in the southeast corner of the basin are irrigated by ground water pumped from a series of deep aquifers, including the Ogallala, Dakota/Cheyenne, and Dockum aquifers. This area is largely disconnected from the mainstem of the Arkansas River and is managed as the Southern High Plains Designated Ground Water Basin (SHPDGWB). DWR has monitored and recorded well levels in these aquifers over time and annually reports their observations[11] . The 2018 report results are summarized in Table 10 and indicate a general downward trend over the past decade. The report notes that several monitoring wells showed rising water levels in 2018, however based on the annual well records, this is likely a temporary improvement.

Table 10: Southern High Plains Aquifer Levels (2018)

Aquifer	2018 Water Level Range (ft below ground)	Avg. Water Level Change 2017-2018 (ft)	Avg. Water Level Change 2013-2018 (ft)	Avg. Water Level Change 2008-2018 (ft)
Ogallala	94 to 305	0	-3.5	-21.2
Dakota/Cheyenne	58 to 321	0	-4.1	-13
Dockum	31 to 289	0.8	-4.2	-11.5

After review of the ground water reports, discussions with stakeholders, and conversations with landowners in the area, the acreage in this area was reduced between 10 and 33 percent across the 2050 Planning Scenarios. This range reflects the uncertainty associated with estimating the future water availability in the basin and the potential for increased pumping as projected climate change increases crop demands in the area.

The climate change conditions in the Arkansas River Basin project the largest increases to IWR in the southwest region of the basin, including the Purgatoire, Huerfano, Cucharas, and Apishapa River basins, averaging 32 percent for the In-Between climate conditions and 44 percent for the Hot and Dry conditions. Projected increases in the Upper Arkansas River Basin were slightly lower, averaging 24 percent for the In-Between conditions and 33 percent for the Hot and Dry conditions. The Lower Arkansas River Basin and Fountain Creek are projected to experience more moderate increases, averaging 5 percent and 9 percent for the In-Between and Hot and Dry conditions, respectively. As in other basins, IWR is reduced by 10 percent in the Adaptive Innovation planning scenario to account for technological innovations that may mitigate the increased agricultural demand due to climate adjustments.

The Arkansas River Basin has a unique constraint with respect to irrigation practices that improve the irrigation efficiencies. The 1948 Arkansas River Compact limits the use of irrigation return flows that were historically delivered to Kansas and therefore cannot be consumed by crops through the use of improved irrigation practices[12]. As such, any improvements to irrigation practices (e.g. methods that reduce seepage from canals, conversion from flood to sprinkler or drip irrigation systems) on acreage in the Lower Arkansas River Basin require analysis through the ISAM model to quantify the change in return flows. Any reductions to return flows must then be provided through alternative supplies, such as an augmentation plan. This limits the potential for wholesale sprinkler development in the basin (i.e. substantial conversion of flood irrigated fields over to sprinklers), however the stakeholders indicated it

[11] Source: Colorado Division of Water Resources, Groundwater Levels in the Southern High Plains Designated Groundwater Basin 2018

[12] Source: Summary of Irrigation Improvement Rules in the Arkansas River Basin by Tracy Kosloff, DWR

was feasible for the basin to experience more moderate sprinkler development in the future. Approximately 20 percent of the irrigated acreage in the H-I Model area is currently irrigated with sprinklers or drip systems. This percentage was doubled under all 2050 Planning Scenarios, resulting in 20 percent more acreage in the basin irrigated using sprinklers.

There is mixed potential for sprinkler development outside of the H-I Model area. Additional substantial sprinkler development is less likely in the Upper Arkansas River Valley and southwest tributary basins due to the topography/terrain of many fields and/or economic factors that are not conducive to the large capital investment needed for sprinkler equipment. Down in the southeast corner of the basin, however, nearly 90 percent of the irrigated acreage in the SHPDGWB area is currently under sprinkler irrigation and there is potential to fully develop the remaining 10 percent. Stakeholders indicated that in the Cooperative Growth, Adaptive Innovation, and Hot Growth Planning Scenarios, it is feasible that all of the acreage could be converted to sprinkler irrigation. Note that only adjustments to acreage irrigated by sprinklers were implemented as an Emerging Technology factor, no adjustments were made to the flood or sprinkler efficiency.

Table 11 provides a summary of the adjustments discussed above; refer to the Planning Scenario Results section below for agricultural diversion demand summaries.

Table 11: Arkansas River Planning Scenario Adjustments

Adjustment Factor	A: Business as Usual	B: Weak Economy	C: Cooperative Growth	D: Adaptive Innovation	E: Hot Growth
Change in Irrigated Land due to Urbanization & Municipal Transfers	19,840 Acre Reduction	19,840 Acre Reduction	19,840 Acre Reduction	19,840 Acre Reduction	19,840 Acre Reduction
GW Acreage Sustainability	10% Acre Reduction (SHPDGWB)	15% Acre Reduction (SHPDGWB)	20% Acre Reduction (SHPDGWB)	33% Acre Reduction (SHPDGWB)	33% Acre Reduction (SHPDGWB)
IWR Climate Factor	-	-	18%	26%	26%
Emerging Technologies	20% Increased Sprinkler Use (H-I Area)	20% Increased Sprinkler Use (H-I Area)	20% Increased Sprinkler Use (H-I Area) 100% use of Sprinklers (SHPDGWB)	20% Increased Sprinkler Use (H-I Area) 100% use of Sprinklers (SHPDGWB) 10% IWR Reduction	20% Increased Sprinkler Use (H-I Area) 100% use of Sprinklers (SHPDGWB)

7.2 COLORADO RIVER BASIN

There is great diversity in the irrigated agriculture industry across the Colorado River Basin. Large ranching operations dominate agriculture in the higher elevations of the basin, particularly around the Towns of Kremmling, Collbran, and Rifle. Farming regions focused on the cultivation of fruits, vegetables, and alfalfa are more prevalent in the lower basin due to a longer growing season and warmer summer temperatures. The largest of these farming operations, the Grand Valley Project (Figure 20), irrigates about a quarter of the 206,700 acres irrigated in the entire basin. Mixed between these agricultural operations are many growing municipal communities, including Grand Junction and resort towns such as Aspen and Vail. Future irrigated agriculture in the Colorado River Basin will be affected by urbanization of irrigated acreage, climate change, and technological improvements in the industry.

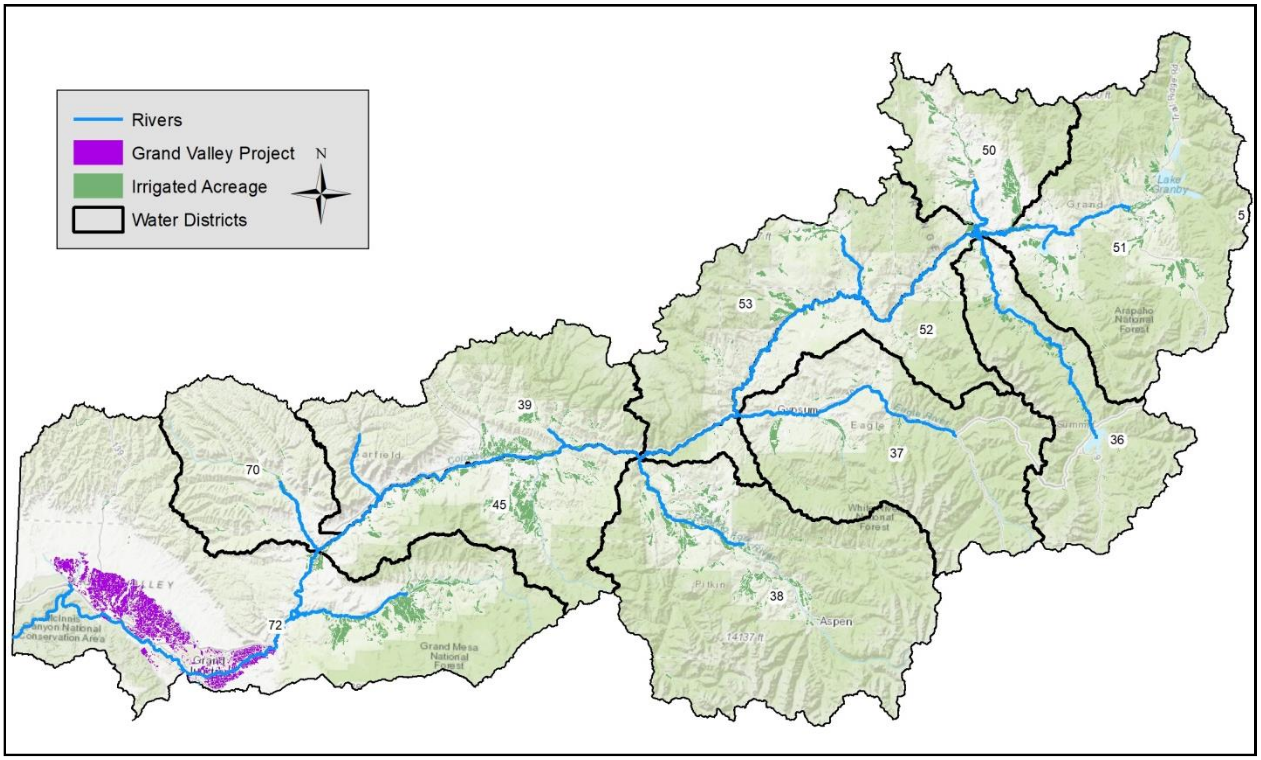


Figure 20: Colorado River Basin Irrigated Acreage

2050 population projections reflect significant increases for counties across the Colorado River Basin. The impact of urbanization, however, is tied to the proximity of existing municipalities to agricultural operations. As such, the impact of urbanization to resort communities such as the Towns of Winter Park, Breckenridge, Snowmass Village, Vail, and Avon is limited due to lack of adjacent irrigated acreage to urbanize. The impact of urbanization is expected to be much larger in agricultural-based communities such as Fruita, Grand Junction, Palisade, Eagle, and Rifle. In total, nearly 14,000 acres of irrigated land is expected to be urbanized, with one-third of that expected to occur in municipalities located in and around the Grand Valley Project.

In the Colorado River basin as a whole, IWR is projected to increase due to climate change by 20 percent and 31 percent on average for the In-Between and Hot and Dry climate conditions, respectively. Irrigated acreage upstream of the confluence of Plateau Creek with the Colorado River mainstem near Palisade is projected to experience an average increase of 21 percent for the In-Between climate conditions and 33 percent for the Hot and Dry conditions. The Lower Colorado River basin downstream of the Plateau Creek confluence, where approximately 40 percent of the irrigated acreage in the basin is located, could experience smaller projected increases in IWR of 3 percent for the In-Between conditions and 7 percent in the Hot and Dry conditions. As in other basins, IWR is reduced by 10 percent in the Adaptive Innovation planning scenario to account for technological innovations that may mitigate the increased IWR due to climate adjustments.

In addition to assuming reduced IWR, the average irrigation efficiency was assumed to increase by 10 percent in Adaptive Innovation scenario. Irrigation system efficiencies range across the Colorado River basin depending upon irrigation practices and irrigation infrastructure, averaging just under 30 percent for the basin as a whole. System efficiencies were improved by 10 percent for ditches that provide water solely for irrigation purposes in the Adaptive Innovation scenario; structures that carry water both for irrigation and for other purposes (e.g. power operations) were not adjusted.

Table 12 provides a summary of the adjustments discussed above; refer to the Planning Scenario Results section below for agricultural diversion demand summaries.

Table 12: Colorado River Planning Scenario Adjustments

Adjustment Factor	A: Business as Usual	B: Weak Economy	C: Cooperative Growth	D: Adaptive Innovation	E: Hot Growth
Change in Irrigated Land due to Urbanization	13,590 Acre Reduction	13,590 Acre Reduction	13,590 Acre Reduction	13,590 Acre Reduction	13,590 Acre Reduction
IWR Climate Factor	-	-	20%	31%	31%
Emerging Technologies	-	-	-	10% IWR Reduction 10% System Efficiency Increase	-

7.3 GUNNISON RIVER BASIN

Agriculture in the Upper Gunnison River Basin, above Blue Mesa Reservoir, is defined by large cattle and sheep ranches located along the tributaries and mainstem river. Ranchers generally rely on flood irrigation to fill the alluvium during the runoff season, as supplies are typically scarce later in the irrigation season. Gravelly soils lead to large diversions and lower efficiencies in the basin, a fact captured in the high duty of water (i.e. water decreed as reasonably necessary to grow and mature a valuable crop) in many of the irrigation decrees. Irrigation in the Lower Gunnison River basin was shaped by several Bureau of Reclamation Projects, which provide supplemental irrigation supplies for much of the irrigated acreage in the area. The most notable irrigation projects in the area include the Uncompahgre Project, Paonia Project, Smith Fork Project, Fruitland Mesa Project, Bostwick Park Project, and the Fruitgrowers Dam Project, as reflected in Figure 21. Due to lower elevations and warmer temperatures, irrigators in the Lower Gunnison River basin cultivate a variety of fruits, vegetables, corn grain, and root crops on over 185,000 acres of the total 234,400 acres irrigated in the basin.

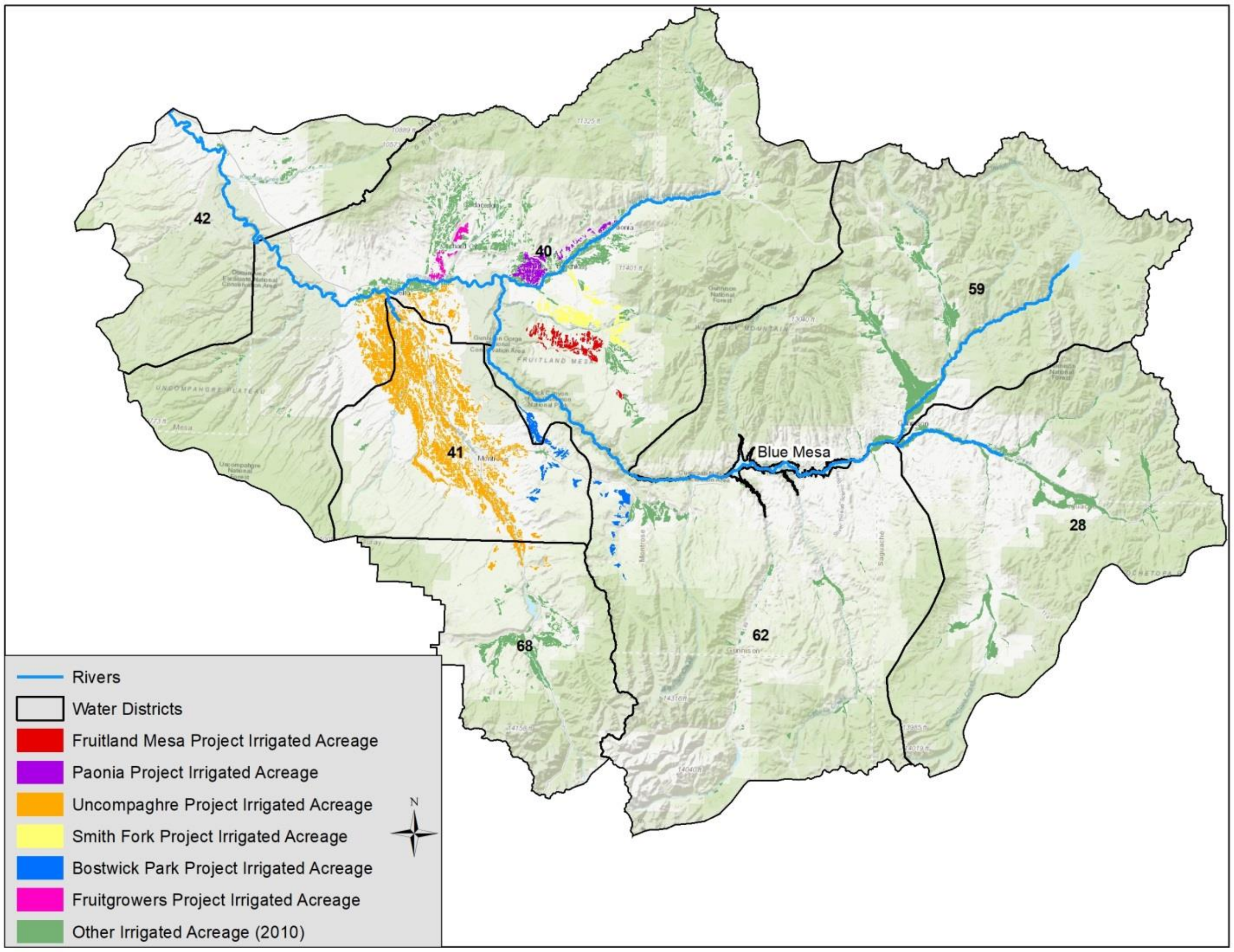


Figure 21: Gunnison River Basin Irrigated Acreage

Reflective of the importance of agriculture in the basin, many of the municipal communities in the area are surrounded by or in close proximity to irrigated acreage. Many counties in the basin are projected to have significant population increases by 2050. The resulting urbanization of irrigated acreage from this growth was estimated to be approximately 14,600 acres, primarily around Gunnison, Montrose, Delta, and the corridor between Cedaredge and Orchard City.

In the Gunnison River basin as a whole, IWR is projected to increase due to climate change by 22 percent and 33 percent on average for the In-Between and Hot and Dry climate conditions, respectively. A 32 percent and 43 percent average increase to IWR was projected for the In-Between and Hot and Dry conditions, respectively, for the Upper Gunnison River and the Upper Uncompaghre River (Water District 68). More moderate increases to IWR of 9 percent and 12 percent were estimated for irrigated lands at lower elevations. As in other basins, IWR is reduced by 10 percent in the Adaptive Innovation scenario to account for technological innovations that may mitigate the increased IWR due to climate adjustments.

In addition to assuming reduced IWR, the average irrigation efficiency was assumed to increase by 10 percent in the Adaptive Innovation scenario. Due to the prevalence of flood irrigation, system efficiency improvements have a moderate effect in the basin as a whole, increasing average system efficiency in the Adaptive Innovation scenario from 30 percent to 40 percent.

Table 13 provides a summary of the adjustments discussed above; refer to the Planning Scenario Results section below for agricultural diversion demand summaries.

Table 13: Gunnison River Planning Scenario Adjustments

Adjustment Factor	A: Business as Usual	B: Weak Economy	C: Cooperative Growth	D: Adaptive Innovation	E: Hot Growth
Change in Irrigated Land due to Urbanization	14,600 Acre Reduction	14,600 Acre Reduction	14,600 Acre Reduction	14,600 Acre Reduction	14,600 Acre Reduction
IWR Climate Factor	-	-	22%	30%	30%
Emerging Technologies	-	-	-	10% IWR Reduction 10% System Efficiency Increase	-

7.4 NORTH PLATTE RIVER BASIN

Ranchers in the North Platte River and Laramie River Basins irrigate over 113,000 acres of grass and hay to support numerous calf/cow operations throughout the basin. These high mountain meadows are generally flood irrigated, and with limited storage in the basin, irrigators rely on diversions of spring and summer runoff for supplies. With low future population projections for the basin, the future agricultural diversion demands in the basin will be most impacted by the ability to maintain and even increase irrigated acreage and potential impacts from climate change.

The North Platte BIP identified seven planned agricultural projects (Table 14, Figure 22) throughout the basin, including delineation of a total of 10,576 irrigable acres and descriptions as to what structures will likely serve the new acreage. Due to the prevalence of irrigated pasture grass related to ranching operations in the basin, it is reasonable to assume that the planned agricultural projects will also be operated for hay and cattle ranching. The North Platte BRT consistently emphasizes the importance of maintaining and increasing irrigated acreage in the basin allowable under the Nebraska v. Wyoming Equitable Apportionment Decree and foresees implementation of the planned agricultural projects in all 2050 Planning Scenarios.

Table 14: North Platte River Basin Planned Agricultural Projects

Project Name	Project Description
Hanson and Wattenberg Ditch Acreage	Irrigable acreage (1,612 acres) potentially served by rehabilitated Hanson and Wattenberg Ditch (4702030) or new North Platte diversion
Lost Creek Ditch Acreage	Irrigable acreage (1,646 acres) potentially served by existing or enlarged Darcy Reservoir or new Willow Creek pipeline (WDID 4700737)
Cumberland Ditch Acreage	Irrigable acreage (544 acres) potentially served by rehabilitation of existing Cumberland Ditch siphon under Canadian River (WDID 4700577)
Independence Ditch Acreage	Irrigable acreage (5,215 acres) potentially served by enlarged Independence Ditch and/or rehabilitated Big Creek Reservoir (WDID 4700683)
Cleveland Ditch Acreage	Irrigable acreage (1,097 acres) potentially served by rehabilitated Cleveland Ditch or new Spring Creek diversion (WDID 4700559)
Wolfer Ditch Acreage	Irrigable acreage (431 acres) potentially served by existing Wolfer Ditch (WDID 4700961) or existing or enlarged Butte Reservoir (WDID 4703598)
Bona Fide Ditch Acreage	Historically irrigated acreage (31 acres) served by rehabilitated Bona Fide Ditch (WDID 4700515)

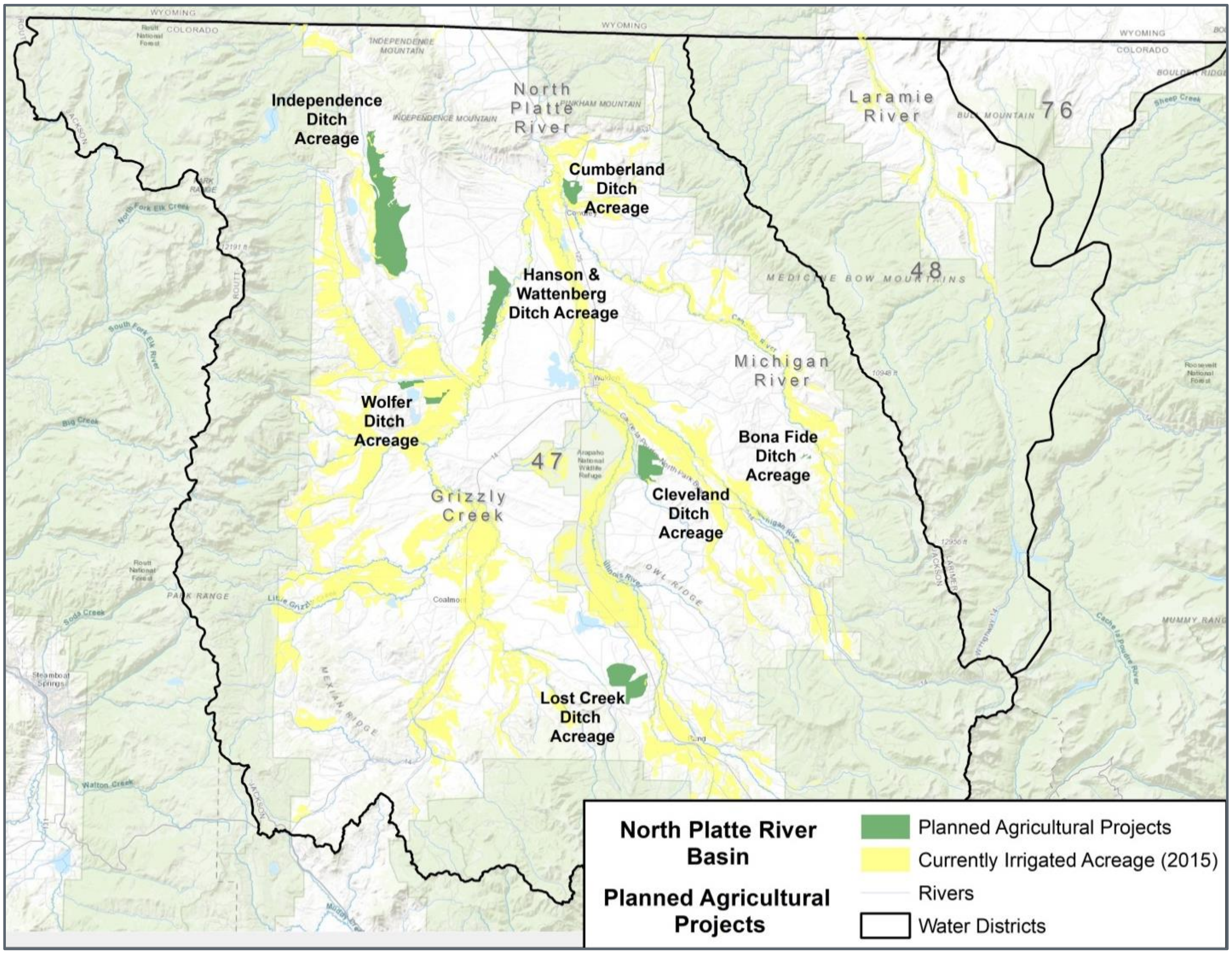


Figure 22: North Platte River Basin Planned Agricultural Projects

Based on modest projections of population increases for the basin in the Adaptive Innovation and Hot Growth scenarios, urbanization of approximately 40 acres of irrigated land was estimated to occur in and around the Town of Walden. The remainder of the Planning Scenarios reflected either no change or decreases to population in Jackson County, therefore urbanization is set to zero for these scenarios.

The climate change scenarios project modest increases to IWR in Jackson County relative to projections in adjacent basins, reflecting a 16 percent increase for the In-Between climate conditions and 26 percent for the Hot and Dry climate conditions. Higher increases to IWR are projected for the Laramie River basin, resulting in a 31 percent increase for the In-Between conditions and 49 percent for the Hot and Dry scenario. IWR is reduced by 10 percent in the Adaptive Innovation scenario to account for technological innovations that may mitigate the increased IWR due to climate adjustments.

In addition to assuming reduced IWR, the average irrigation efficiency was assumed to increase by 10 percent in the Adaptive Innovation scenario. As with other basins that primarily flood irrigate, system efficiency improvements have a moderate effect in the basin as a whole, increasing average system efficiency in the Adaptive Innovation scenario from 33 percent to 43 percent.

Table 15 provides a summary of the adjustments discussed above; refer to the Planning Scenario Results section below for agricultural diversion demand summaries.

Table 15: North Platte River Planning Scenario Adjustments

Adjustment Factor	A: Business as Usual	B: Weak Economy	C: Cooperative Growth	D: Adaptive Innovation	E: Hot Growth
Change in Irrigated Land due to Urbanization	-	-	-	40 Acre Reduction	40 Acre Reduction
Planned Agricultural Projects	10,576 Acre Increase	10,576 Acre Increase	10,576 Acre Increase	10,576 Acre Increase	10,576 Acre Increase
IWR Climate Factor	-	-	25%	39%	39%
Emerging Technologies	-	-	-	10% IWR Reduction 10% System Efficiency Increase	-

7.5 REPUBLICAN RIVER BASIN

The Republican River Basin has nearly 580,000 irrigated acres, making it one of the highest producing basins of irrigated crops in the State. The basin has very limited surface water supplies and as such, there are virtually no surface water diversions left in the basin. To irrigate crops, water users rely on ground water supplies from the High Plains Aquifer (also known as the Ogallala Aquifer). Approximately 10 percent of total pumping is subject to the Republican River Compact with the remaining 90 percent pumped from “storage” in the High Plains Aquifer. Ground water pumping is managed by the several Ground Water Management Districts in the basin, as reflected in Figure 23.

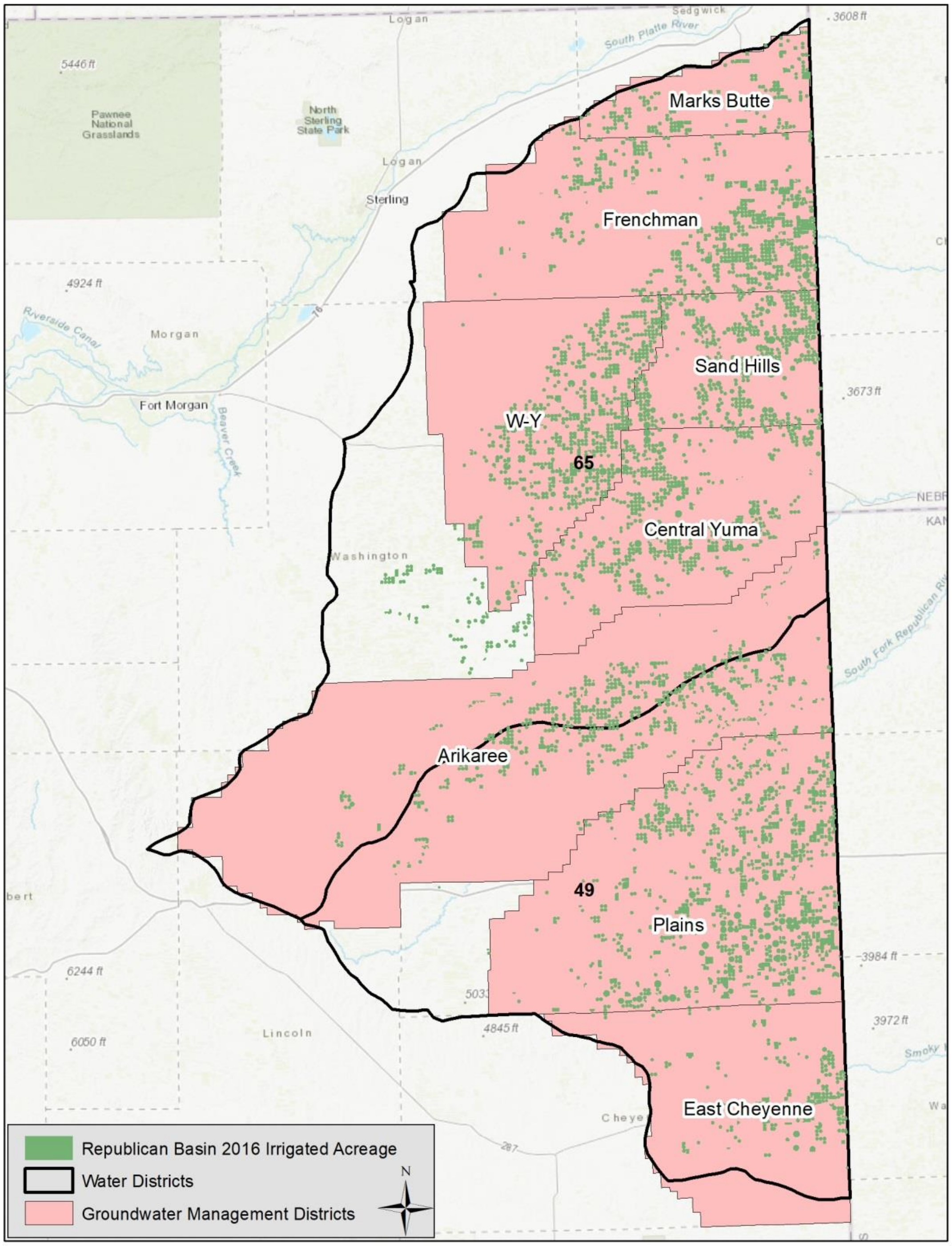


Figure 23: Republican River Basin Ground Water Management Districts

Large capacity (>50 gpm) irrigation and commercial wells developed in the basin after 1942 are subject to the Republican River Compact. Since 2002, when the Republican River Compact Final Settlement Stipulation was approved, water users in the basin have changed how water is managed to better assist the State of Colorado reach and maintain compact compliance. Efforts include establishment of the Republican River Water Conservation District (RRWCD) in 2004, voluntary retirement of more than

30,000 irrigated acres[13] , and construction of the Compact Compliance Pipeline to deliver pumping ground water from wells purchased by the RRWCD to downstream states. Bonny Reservoir was also drained in 2011 to reduce evaporative and seepage losses.

In addition to Compact compliance, the basin is also experiencing declining thickness of the High Plains Aquifer. Ground water modeling supporting the Republican River Compact Accounting reflects thinning aquifer levels, particularly in the southern and western areas of the basin, and if current pumping rates were to continue into the future the aquifer would be depleted such that irrigation in many of these areas could not continue. The future of agriculture in the basin will be dictated by the sustainability of High Plains Aquifer and Compact compliance.

Through discussions with RRWCD of these issues, stakeholders in the basin indicated that the current levels of irrigation will decline by 2050. Stakeholders noted that the recent resolution by the Republican River Compact Administration (August 24, 2016) called for the retirement of 25,000 irrigated acres in the South Fork Republican River basin by 2027 through Conservation Reserve Enhancement Program (CREP) or other voluntary acreage reduction programs. Additionally, the RRWCD has investigated purchasing and changing the use of additional ground water rights to increase deliveries through the Compact Compliance Pipeline. These reductions to acreage for compact compliance resulted in the removal of 35,000 acres for the Technical Update effort, however this removal may not be sufficient for long-term compliance and additional acreage may have to be retired.

Stakeholders also discussed inevitable reductions to irrigated acreage in the basin due to declining High Plains Aquifer (i.e. Ogallala Aquifer) levels. Guided by ground water modeling results performed for the RRWCD and considering reductions for Compact Compliance, stakeholders estimated the percent change of total acreage in each Ground Water Management District that could be expected by 2050. Stakeholders estimated reductions to acreage in all Ground Water Management Districts except the Sandhills District, as reflected in Table 16. A modest 5 percent increase was estimated for the Sandhills District as it may be one of the last areas with sufficient aquifer thickness to support irrigation pumping.

Table 16: Changes to Republican River Basin Irrigated Acreage by 2050 - Ground Water Sustainability

Ground Water Management District	Current (2016) Acreage	% Change	Estimated Dry-up	2050 Irrigated Acreage
Plains	134,640	-45%	-60,590	74,050
Frenchman	79,500	-15%	-11,925	67,575
Marks Butte	23,200	-15%	-3,480	19,720
Y-W	93,900	-20%	-18,780	75,120
Sand Hills	67,040	5%	3,350	70,390
Central Yuma	76,330	-10%	-7,630	68,700
Arikaree	78,760	-30%	-23,630	55,130
East Cheyenne	25,470	-50%	-12,735	12,735
Total	**578,840**	**-24%**	**-135,420**	**443,420**

In addition to these reductions, current population projections for the basin indicated that municipal growth may occur in all scenarios except for the Weak Economy scenario. The small agricultural communities in the basin are surrounded by irrigated acreage, and any population growth may result in

[13] Estimated reduction to irrigated acreage from 2004 to 2016; sourced from RRWCD

the urbanization of irrigated land. A total of 1,410 acres was projected to be urbanized in the basin for this effort. The economy in the basin, however, has historically been heavily reliant on agriculture and to the extent groundwater levels decline and land comes out of production, populations of local communities may also decline over time.

Modest increases to IWR are projected for the Republican River basin, relative to other areas of the State. For the northern portion of the basin (Water District 65), IWR is projected to increase by 4 percent for the In-Between climate conditions and 10 percent for the Hot and Dry conditions. The southern portion of the basin (Water District 49) is projected to experience a 5 percent and 13 percent increase to IWR in the In-Between and Hot and Dry climate conditions, respectively. IWR is reduced by 10 percent in the Adaptive Innovation scenario to account for technological innovations that may mitigate the increased IWR due to climate adjustments.

Over 95 percent of the acreage in the basin is currently irrigated by sprinklers. Very few flood operations remain in the basin, and stakeholders indicated that areas irrigated by flood practices are likely not suitable for conversion to sprinkler operations. As such, no adjustments for system efficiency improvements will be applied in the Planning Scenarios in the Republican River basin.

Table 17 provides a summary of the adjustments discussed above; refer to the Planning Scenario Results section below for agricultural diversion demand summaries.

Table 17: Republican River Planning Scenario Adjustments

Adjustment Factor	A: Business as Usual	B: Weak Economy	C: Cooperative Growth	D: Adaptive Innovation	E: Hot Growth
Change in Irrigated Land due to Urbanization	1,410 Acre Reduction	-	1,410 Acre Reduction	1,410 Acre Reduction	1,410 Acre Reduction
GW Acreage Sustainability	135,420 Acre Reduction	135,420 Acre Reduction	135,420 Acre Reduction	135,420 Acre Reduction	135,420 Acre Reduction
IWR Climate Factor	-	-	4%	11%	11%
Emerging Technologies	-	-	-	10% IWR Reduction	-

7.6 RIO GRANDE BASIN

Irrigated acreage in the Rio Grande basin, and particularly in the San Luis Valley, is inherently tied to the basin's unique surface and ground water supplies. Surface water supplies diverted from streams fed by snowmelt are highly variable from year to year, with annual runoff in high flow years yielding up to eight times[14] more than in drought years. Ground water supplies are available from stacked aquifers located in the Valley floor; the upper unconfined aquifer and the deeper confined aquifer. Ground water withdrawals (i.e. pumping and artesian supplies) provide for a more consistent irrigation supply. Although recharge to the unconfined aquifer occurs relatively quickly, decades of withdrawals greater than recharge have it severely depleted. The deeper confined aquifer supplies fewer wells than the unconfined aquifer due to its depth, however also experiences greater withdrawals compared to recharge. Daily administration of the Rio Grande Compact, which primarily restricts surface water diversions through

[14] Source: Rio Grande Basin Implementation Plan (April, 2015)

curtailment to meet Compact deliveries, further impacts water availability in the basin. These surface and ground supplies combined currently support the irrigation of approximately 515,000 acres in the basin, predominately in grass, alfalfa, small grains, and potatoes, however the future of agricultural in the basin is threatened by more frequent periods of drought and declining aquifer levels.

Spurred by the early 2000s drought, declining levels of the unconfined aquifer in the Closed Basin along with reduced confined aquifer pressure Valley-wide, and passage of Senate Bill 04-222 mandating the promulgation of ground water rules and regulations by the Division of Water Resources (DWR), the Rio Grande Water Conservation District (RGWCD) created the first Special Improvement District of the Rio RGWCD (Subdistrict No. 1) in 2012. Through management of ground water withdrawals and recharge, Subdistrict No. 1 operates on an annual basis to replace injurious stream depletions caused by the Subdistrict wells; recover aquifer levels; and maintain a sustainable irrigation supply from the aquifers for the long term. The impacts to streams covered by the Subdistricts are derived from a basin-wide ground water model, developed through the Rio Grande Decision Support System (RGDSS)[15].

The first Subdistrict formed, Subdistrict No. 1, began operations in 2012 and encompasses approximately 174,000 irrigated acres in the Closed Basin area. Additional Subdistricts located throughout the basin, as reflected on Figure 24 from the RGWCD, are currently in various stages of formation.

- Subdistrict No. 2 covering the Rio Grande Alluvium and Subdistrict No. 3 covering the Conejos area began operating in 2019.
- Subdistricts No. 4, No. 5 and No. 6 covering the San Luis Creek, Saguache, and Alamosa/La-Jara Creek areas, respectively, are under development.

Due to the large amount of acreage in the Subdistrict areas, management of these Subdistricts will likely shape how irrigated agriculture will look by 2050.

[15] RGDSS represents groups of wells with similar hydraulic characteristics as a “response area”, and their combined impact to streams is represented as a “response function”. Each Subdistrict represents the geographic area reflected in the RGDSS “response area”.

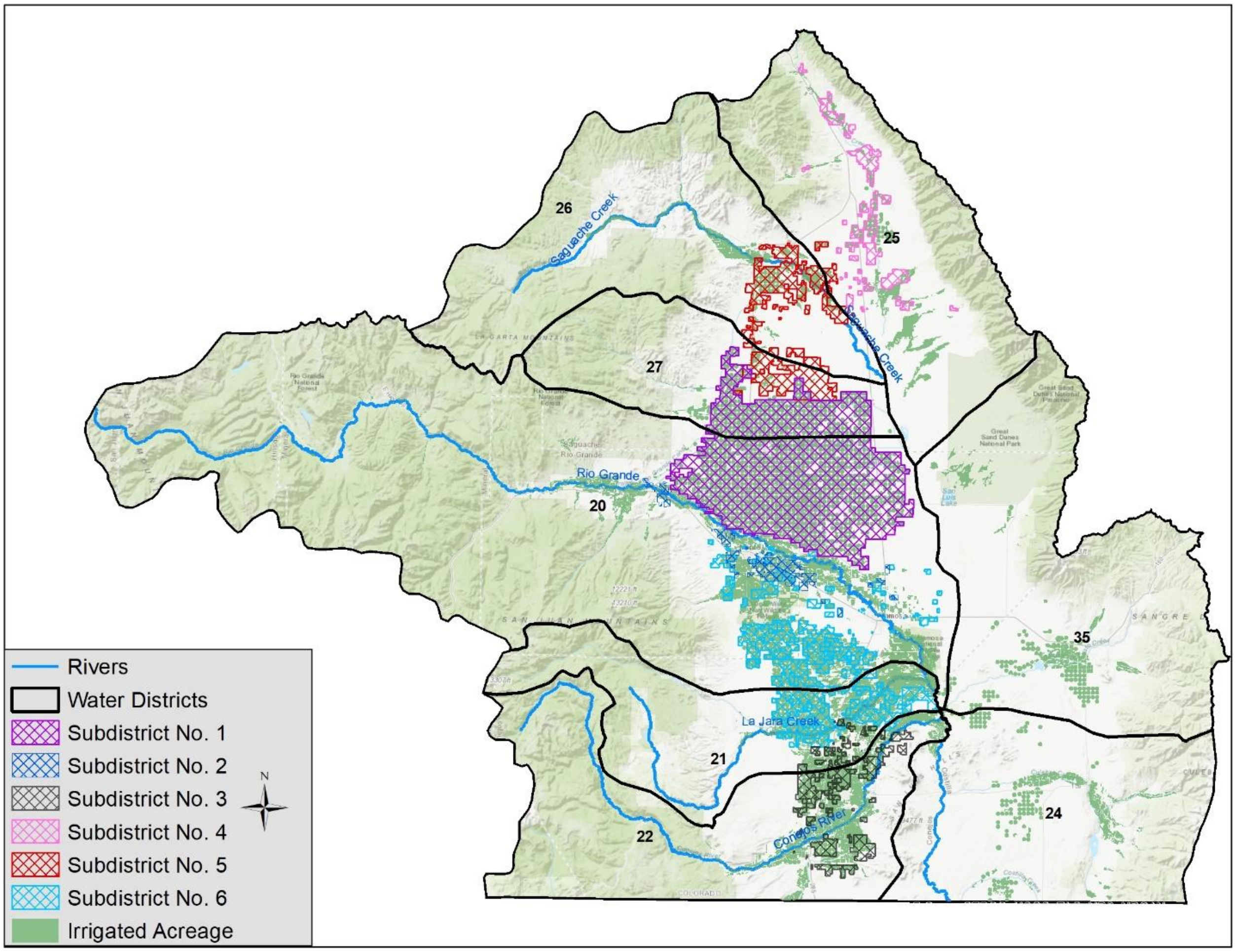


Figure 24: Rio Grande Basin Irrigated Acreage and Groundwater Management Subdistricts

Discussions with RGWCD, San Luis Valley Water Conservancy District (SLVWCD), Conejos Water Conservancy District (CWCD), stakeholders in the basin, and DWR staff for the Technical Update effort indicated that irrigated acreage will likely decline by 2050 in the basin. The group noted three primary reasons for this decline, discussed in more detail below:

1. Acreage already taken out of production in recent years
2. Reduction in pumping to mitigate declining unconfined aquifer levels
3. Reduction in pumping to mitigate declining confined aquifer levels

Analysis of the agricultural diversion demand for this Technical Update effort relied on data and modeling efforts completed by DWR in support of Rules and Regulations promulgation in the basin. The most recent irrigated acreage assessment available was developed for 2010 conditions. Between 2010 and 2018, approximately 20,000 irrigated acres were taken out of production in Subdistrict No. 1. Approximately 10,000 acres of the 20,000 acres have been enrolled in USDA's Conservation Reserve Enhancement Program (CREP) since 2012.

As reflected in Figure 25 below, a graphic available from RGWCD, storage in the unconfined aquifer in the West Central San Luis Valley has declined over 1.1 million acre-feet since the early-1990s. When the plan to create Subdistrict No. 1 was approved, the plan called for recovery of groundwater levels in the unconfined aquifer of the Closed Basin such that by the end of 2031 groundwater levels will have recovered to within 200,000 to 400,000 acre-feet below the January 1, 1976 storage levels . Based on the current unconfined aquifer storage, RGWCD and water users in Subdistrict No. 1 have thirteen years to overcome a minimum 700,000 acre-foot deficit in the unconfined aquifer. The stakeholder group estimated that it would need a reduction of 20,000 acres in the Subdistrict No. 1 area to refill the aquifer. This estimation is based on current hydrology; if drier conditions persist in the future more acreage may need to be removed.

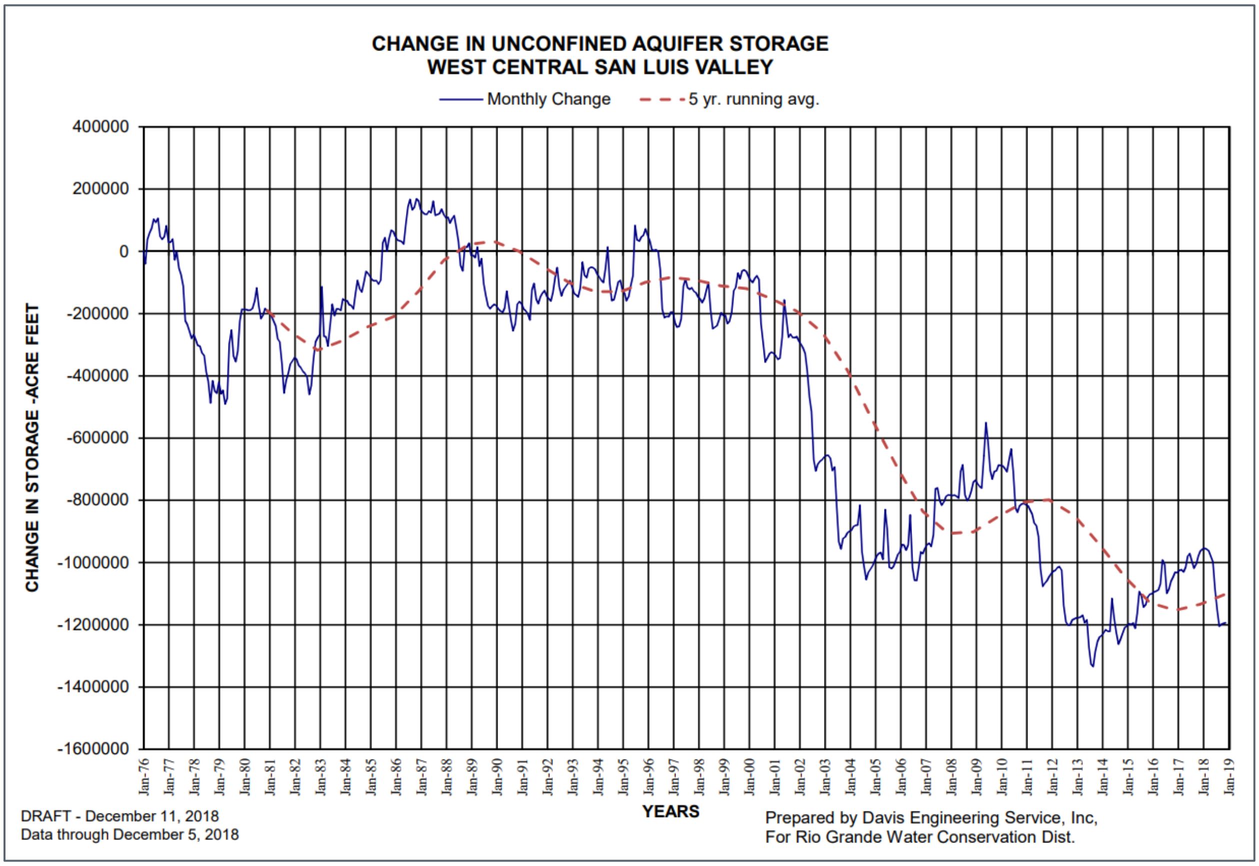


Figure 25: Change in San Luis Valley Unconfined Aquifer Storage

The stakeholder group also indicated that approximately 5,000 acres will need to come out of production to mitigate depletions in the confined aquifer. Metered ground water withdrawals from the confined aquifer in the Conejos, Alamosa/La-Jara, San Luis, and Saguache Creek areas over the most recent five years is compared to average withdrawals over the historical 1978 to 2000 period by DWR. Areas in which the five year average is greater than the historical average indicate an unsustainable level of withdrawals. The most recent reporting available from DWR[16] indicated that recent withdrawals were approximately 10,000 acre-feet greater than the historical average. This value led the stakeholders to estimate a 5,000 acre reduction across the basin to reach sustainability. As with the unconfined aquifer mitigation, this estimation is based on current hydrology; if drier conditions persist in the future more acreage may need to be removed. In total, 40,000 irrigated acres were removed from the Subdistrict No.1 area and 5,000

[16] Source: *Five Year Average Ground Water Withdrawals in Confined Aquifer Response Areas in Division 3: July 2018 Requirement of Division 3 Ground Water Rules Section 8.1.5* (DWR website)

irrigated acres were removed across the basin in all 2050 Planning Scenarios for the Ground Water Sustainability factor.

IWR in the Rio Grande Basin is projected to increase on average by 15 percent for the In-Between climate conditions and 18 percent on average for the Hot and Dry conditions. Water District 24 in the southeastern part of the basin is projected to have the largest increase in IWR in the basin with 17 percent and 20 percent under In-Between and Hot and Dry conditions, respectively. Faced with this information, the stakeholder group discussed what the ultimate effects on the basin may be if IWR increases to these levels, particularly in light of the Rio Grande Compact. The group ultimately decided that as the Compact will continue to limit surface water availability, any increase in IWR would likely lead to irrigated acreage being taken out of production because there would not be sufficient surface water supplies to meet these increased demands.

To account for this future potential outcome, it was assumed that the percent increase in IWR by Water District would result in the same percent decrease in irrigated acreage. With basin-wide unit IWR historically averaging 2 acre-feet per acre and crop consumptive use in the basin historically averaging 1.3 acre-feet per acre, this is potentially an underestimate of the total acreage that may come out of production under potential future climate conditions. Using this approach, however, does account for this impact and resulted in the removal of approximately 70,000 acres in the Cooperative Growth scenario and approximately 81,000 acres in the Adaptive Innovation and Hot Growth scenarios across the basin. Note that IWR is still reduced by 10 percent in the Adaptive Innovation scenario to account for technological innovations that may mitigate the increased IWR due to climate adjustments.

Modest population projections for the basin indicate that under all scenarios besides the Weak Economy scenario, the basin’s population will increase and municipal water demands will grow. Irrigated acreage surrounding small towns in the basin is vulnerable to urbanization. It was estimated that approximately 4,010 acres would come out of production due to urbanization of irrigated lands in the basin.

The stakeholder group did not envision any adjustment in irrigation efficiency in the basin; current levels of sprinkler development in the basin are expected to stay relatively steady. The stakeholder group indicated that any improvement to irrigation efficiencies in the future may be used as a solution to help meet the agricultural gap.

Table 18 provides a summary of the adjustments discussed above; refer to the Planning Scenario Results section below for agricultural diversion demand summaries.

Table 18: Rio Grande Basin Planning Scenario Adjustments

Adjustment Factor	A: Business as Usual	B: Weak Economy	C: Cooperative Growth	D: Adaptive Innovation	E: Hot Growth
Change in Irrigated Land due to Urbanization	4,010 Acre Reduction	-	4,010 Acre Reduction	4,010 Acre Reduction	4,010 Acre Reduction
GW Acreage Sustainability	45,000 Acre Reduction	45,000 Acre Reduction	45,000 Acre Reduction	45,000 Acre Reduction	45,000 Acre Reduction
IWR Climate Factor	-	-	15% 70,000 Acre Reduction (Basin-wide)	18% 81,000 Acre Reduction (Basin-wide)	18% 81,000 Acre Reduction (Basin -wide)
Emerging Technologies	-	-	-	10% IWR Reduction	-

7.7 SOUTH PLATTE RIVER BASIN

The South Platte River Basin is expected to experience the largest municipal growth in the state by 2050, straining already limited water supplies in the basin between municipal, industrial, agricultural, environmental and recreation users in the basin. By 2050, agriculture in the South Platte Basin will likely experience increased urbanization of irrigated lands; pressures of increased municipal needs to “buy and dry” irrigated acreage with senior water rights; limited augmentation supplies; and higher crop demands due to climate change.

There are approximately 854,300 acres of irrigated land currently in the South Platte River Basin. Urbanization of irrigated lands alone is projected to remove nearly 106,000 acres in and around existing municipalities in the basin by 2050. The majority, over 60 percent, of these 106,000 urbanized acres are projected to occur in the St. Vrain River, Big Thompson River, and Cache La Poudre River basins. This is partly driven by the projected population increases in Larimer and Weld Counties; however these basins also have some of the highest concentrations of irrigated acreage in close proximity to municipalities. Although large population increases are also anticipated in and around the Denver Metropolitan area, there is little to no irrigated acreage around the area that could potentially be urbanized. As such, urbanized acreage in Denver, Jefferson, Adams, and Arapahoe Counties totals less than 10,000 acres, or less than 10 percent of the total urbanized acreage in the basin.

For municipalities that are anticipated to grow onto existing irrigated acreage by 2050, it is reasonable to assume they will go through the process of “buy and dry”. This process involves acquiring and changing the irrigation water rights associated with the irrigated acreage in Water Court in order to use the changed water as a supply to meet future municipal demands, and drying up the irrigated parcel. Growth onto existing irrigated acreage by 2050 depends on many factors, including but not limited to the seniority of the water rights; type of supply (e.g. surface/ground water, storage); ability to treat the supply which is impacted by location or quality; and/or legal restrictions on the change of use. The process of “buy and dry”, however, is not limited to municipalities that urbanize irrigated acreage. Many municipalities throughout the basin have purchased irrigation water rights and ultimately dried up the acreage served by the rights; and ditches with the most senior water rights often experience the highest rates of “buy and dry”.

The prevalence and impact of this practice in the South Platte River basin was discussed with respect to the sustainability of irrigated agriculture in the basin with the Lower South Platte Water Conservancy District (LSPWCD) and Central Colorado Water Conservancy District (Central) staff. These entities have observed first-hand the amount of irrigated acreage that has gone through “buy and dry”, particularly under irrigation ditches that divert from the lower South Platte River in Water Districts 1 and 64 (Figure 26). LSPWCD indicated that although efforts are taking place to find flexible and innovative solutions to sharing water between agriculture and municipalities, irrigated acreage in the basin will likely continue to decrease due to “buy and dry” practices in the future. Based in part on recent trends in water rights purchases in the area, it was estimated that irrigated acreage served by surface water will decrease between 10 and 30 percent in Water Districts 1 and 64, depending on the Planning Scenario. A lower number of acres are anticipated in collaborative Planning Scenarios; and conversely a higher number of acres are anticipated in more aggressive Planning Scenarios, as reflected in Table 19. The values presented in the table below may underestimate the amount of acreage taken out of production by 2050 due to “buy and dry” as the practice is likely to occur in other areas in the South Platte River basin. Estimates of the amount of acreage however, were not readily available for this effort.

Table 19: Reduction to Irrigated Acreage Supplied by Surface Water (Water Districts 1 and 64)

Planning Scenario	A: Business as Usual	B: Weak Economy	C: Cooperative Growth	D: Adaptive Innovation	E: Hot Growth
Reduction to Surface Water Acreage	20%	20%	10%	10%	30%
	42,500 acres	42,500 acres	21,200 acres	21,200 acres	63,700 acres

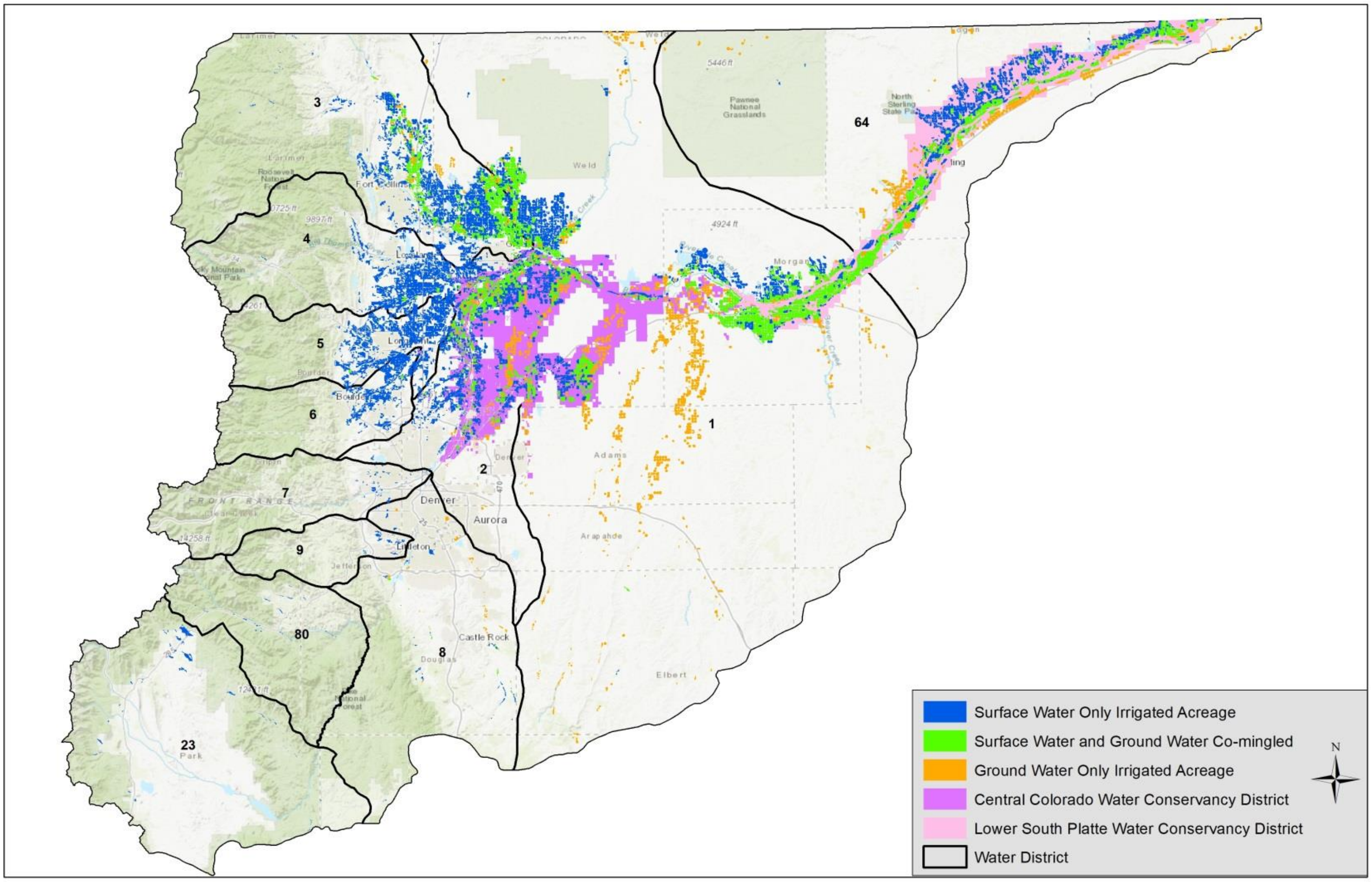


Figure 26: South Platte River Basin Irrigated Acreage

Another challenge to sustaining irrigated agriculture in the basin is the ability to maintain augmentation supplies in the future. Augmentation is the process of replacing well depletions in time and location as they impact the river flows and water supplies for senior water right holders. Irrigated acreage supplied only by junior ground water rights rely on augmentation supplies in order to pump when there is a senior call on the river and their resulting depletions are out-of-priority. The type of water used for augmentation supplies varies across the basin, however they primarily consist of water diverted under junior water rights for storage and recharge; water available from senior irrigation water rights changed for augmentation purposes; and leased reusable effluent from municipalities. As municipal entities seek opportunities to reuse more of their effluent, less effluent will be available to lease for augmentation uses. Additionally, when senior irrigation rights become available on the market, augmentation providers often compete against municipal entities to purchase these rights. These conditions put current augmentation supplies at risk and also make it difficult to obtain new augmentation supplies in the future. In response to these conditions, it was estimated that 20 percent of the irrigated acreage served only by ground water supplies within the Central service area are vulnerable and may come out of production due to a lack of augmentation supplies in 2050. This adjustment equated to approximately 4,800 acres of irrigated land removed from each of the Planning Scenarios.

Although water availability will be a limiting factor to sustaining current levels of irrigated acreage by 2050, innovative and emerging technologies will benefit the industry. As noted in the Emerging Technologies section above, 59 percent of the acreage in the South Platte River basin served only by ground water supplies was irrigated using sprinkler technologies in 2010. Stakeholders in the basin, including LSPWCD and Central, believe that sprinkler development will continue at a relatively fast pace as new technologies become available. By 2050, it is expected that between 85 to 90 percent of the acreage served only by ground water will be irrigated with sprinklers or a similar efficient form of irrigation application. This adjustment will impact system efficiency for irrigated lands located primarily in Designated Groundwater Basins and along the Lower South Platte River. In addition to the sprinkler adjustment, average system efficiency in the basin as a whole was increased by 10 percent, from 60 to 70 percent, in the Adaptive Innovation scenario. This adjustment is applicable to both flood and sprinkler irrigated lands across the basin.

In the South Platte River basin as a whole, IWR is projected to increase due to climate change by 15 percent and 24 percent on average for the In-Between and Hot and Dry climate conditions, respectively. The climate change scenarios projected relatively high increases to IWR for the headwaters of the South Platte River basin, averaging 49 percent and 73 percent for the In-Between and Hot and Dry conditions, respectively, for irrigated acreage upstream of Cheesman Lake. Projections, however, significantly decrease moving downstream in the basin. Projected increases to IWR in the Clear Creek, Cherry Creek, and Bear Creek basins are similar, averaging 13 percent for the In-Between conditions and 21 percent for the Hot and Dry conditions. Projections for basins downstream of the Boulder Creek confluence with the South Platte River reflect more moderate increases, averaging 7 percent and 12 percent, respectively, for the climate conditions. The lowest projected increases in IWR correspond to the basins with the greatest amount of irrigated acreage, muting the impact of the projected increases in the headwaters for the basin as a whole. Additionally, the Adaptive Innovation scenario contemplates that future technological innovations mitigate the increased agricultural demand due to climate adjustments anticipated by the Hot and Dry conditions. As such, the projected increases to IWR in this Planning Scenario are reduced by 10 percent.

Table 20 provides a summary of the adjustments discussed above; refer to the Planning Scenario Results section below for agricultural diversion demand summaries.

Table 20: South Platte River Planning Scenario Adjustments

Adjustment Factor	A: Business as Usual	B: Weak Economy	C: Cooperative Growth	D: Adaptive Innovation	E: Hot Growth
Change in Irrigated Land due to Urbanization & Municipal Transfers	105,900 Acre Reduction 20% SW Acre Reduction (WD 1 & 64)	105,900 Acre Reduction 20% SW Acre Reduction (WD 1 & 64)	105,900 Acre Reduction 10% SW Acre Reduction (WD 1 & 64)	105,900 Acre Reduction 10% SW Acre Reduction (WD 1 & 64)	105,900 Acre Reduction 30% SW Acre Reduction (WD 1 & 64)
GW Acreage Sustainability	20% GW-Only Acre Reduction (Central)	20% GW-Only Acre Reduction (Central)	20% GW-Only Acre Reduction (Central)	20% GW-Only Acre Reduction (Central)	20% GW-Only Acre Reduction (Central)

Adjustment Factor	A: Business as Usual	B: Weak Economy	C: Cooperative Growth	D: Adaptive Innovation	E: Hot Growth
IWR Climate Factor	-	-	15%	24%	24%
Emerging Technologies	85% GW Only Acreage in Sprinkler	85% GW Only Acreage in Sprinkler	90% GW Only Acreage in Sprinkler	90% GW Only Acreage in Sprinkler 10% IWR Reduction 10% System Efficiency Increase	90% GW Only Acreage in Sprinkler

7.8 SOUTHWEST BASIN

The Southwest Basin is made up of a series of nine sub-basins, each with their own unique hydrology and demands. The basin, as shown in Figure 27, is home to a diverse set of demands; several small towns founded primarily due to either mining or agricultural interests, two Native American reservations (Southern Ute Indian Tribe and Ute Mountain Ute Tribe), one major transmountain diversion (San Juan - Chama Project), and four major Reclamation Projects (Pine River Project, Dolores Project, Florida Project, and the Mancos Project) that both brought new irrigated acreage under production and provided supplemental supplies to existing lands. For areas outside of the Reclamation Projects, producers generally irrigate grass meadows for cattle operations aligned along the rivers and tributaries and rely on supplies available during the runoff season. Producers under the Reclamation Projects irrigate a wider variety of crops, such as alfalfa and row crops, due to lower elevations, warmer temperatures, and supplemental storage supplies during the later irrigation season.

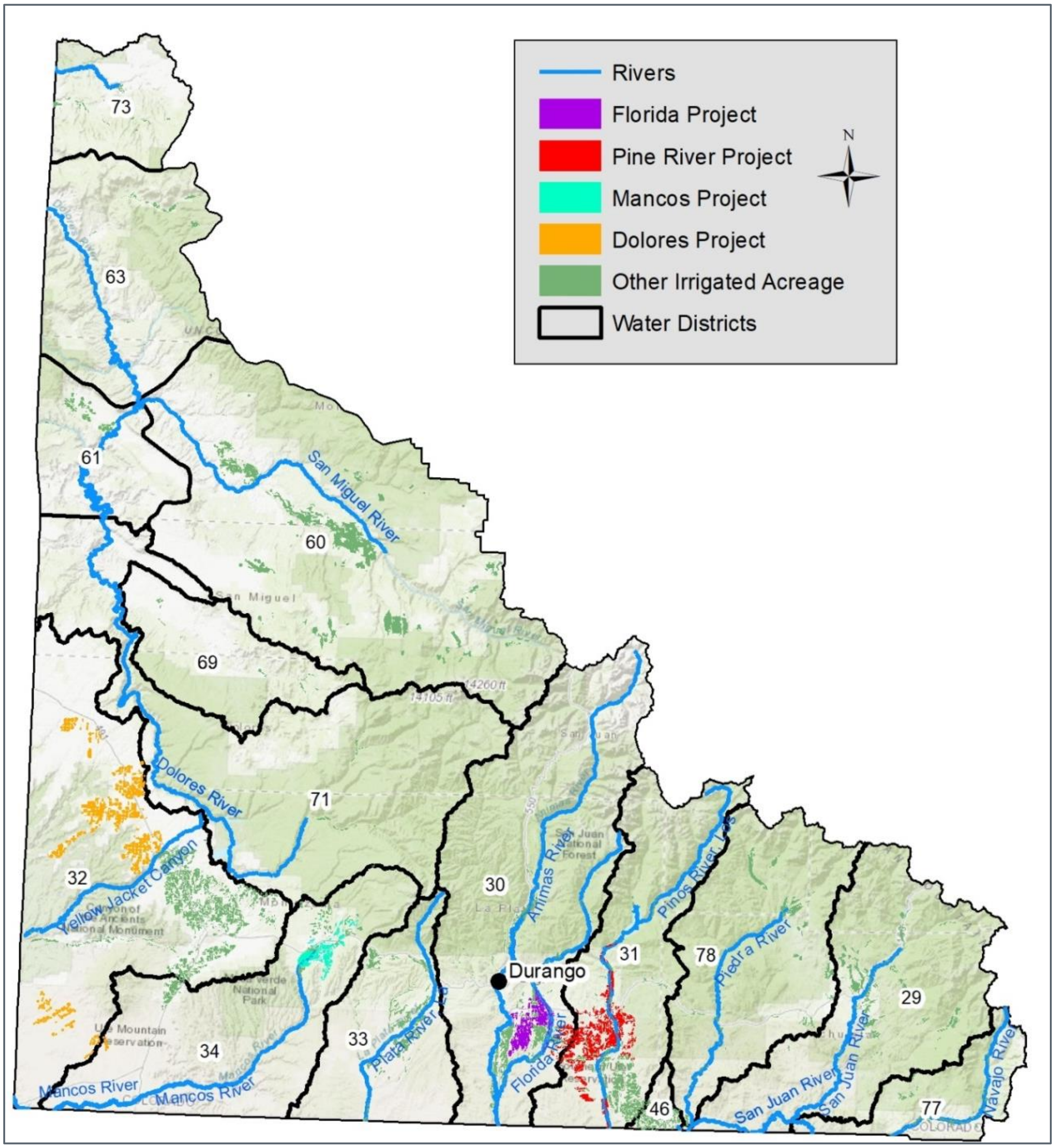


Figure 27: Southwest Basin Irrigated Acreage

Urbanization in the overall basin will likely have a limited impact on agriculture in the future, as 4,080 acres of irrigated land basin-wide were estimated to be urbanized by 2050. The larger towns of Durango, Cortez, and Pagosa Springs do not have significant areas of irrigated acreage located within or directly adjacent to the current municipal boundaries; therefore, urbanization of acreage in these areas is projected to be low in the future. Smaller towns in the basin, such as Norwood, Nucla, Bayfield, and Mancos are surrounded by irrigated agriculture, which may lead to some urbanization of irrigated lands by 2050.

In the Southwest basin as a whole, IWR is projected to increase due to climate change by 26 percent and 34 percent on average for the In-Between and Hot and Dry climate conditions, respectively. IWR is projected to increase by 42 percent and 53 percent on average for the In-Between and Hot and Dry conditions, respectively, on the ranches in the Upper San Juan, Navajo River, and Piedra River basins. More moderate increases of 22 percent and 29 percent on average for the In-Between and Hot and Dry conditions, respectively, are projected for the remainder of the basin. The sub-basin with the largest amount of irrigated acreage is the McElmo Creek basin (Water District 32) with nearly 20 percent of the total acreage in the basin. Increases of 11 percent and 15 percent to IWR on average are projected for the two climate change conditions for this sub-basin. As in other basins, IWR is reduced by 10 percent in the Adaptive Innovation scenario to account for technological innovations that may mitigate the increased IWR due to climate adjustments. In addition to assuming reduced IWR, the average irrigation efficiency was assumed to increase by 10 percent in the Adaptive Innovation scenario. System efficiency was increased from 47 to 57 percent in the Adaptive Innovation scenario basin-wide in this scenario.

Table 21 provides a summary of the adjustments discussed above; refer to the Planning Scenario Results section below for agricultural diversion demand summaries.

Table 21: Southwest River Planning Scenario Adjustments

Adjustment Factor	A: Business as Usual	B: Weak Economy	C: Cooperative Growth	D: Adaptive Innovation	E: Hot Growth
Change in Irrigated Land due to Urbanization	3,800 Acre Reduction	3,800 Acre Reduction	3,800 Acre Reduction	3,800 Acre Reduction	3,800 Acre Reduction
IWR Climate Factor	-	-	26%	34%	34%
Emerging Technologies	-	-	-	10% IWR Reduction 10% System Efficiency Increase	-

7.9 WHITE RIVER BASIN

The majority of irrigated acreage in the White River Basin, approximately 60 percent of the total 28,100 acres in the basin, is concentrated along the mainstem river near the Town of Meeker (Figure 28). The remaining acreage is found along tributaries and lower mainstem spread throughout the basin. Grass pasture is the predominant crop grown in the basin to support the cattle grazing and ranching operations in the basin, with smaller areas growing alfalfa. Cattle ranching is a major economic driver in the basin, however mining and oil and gas extraction are also important elements of the basin's economy.

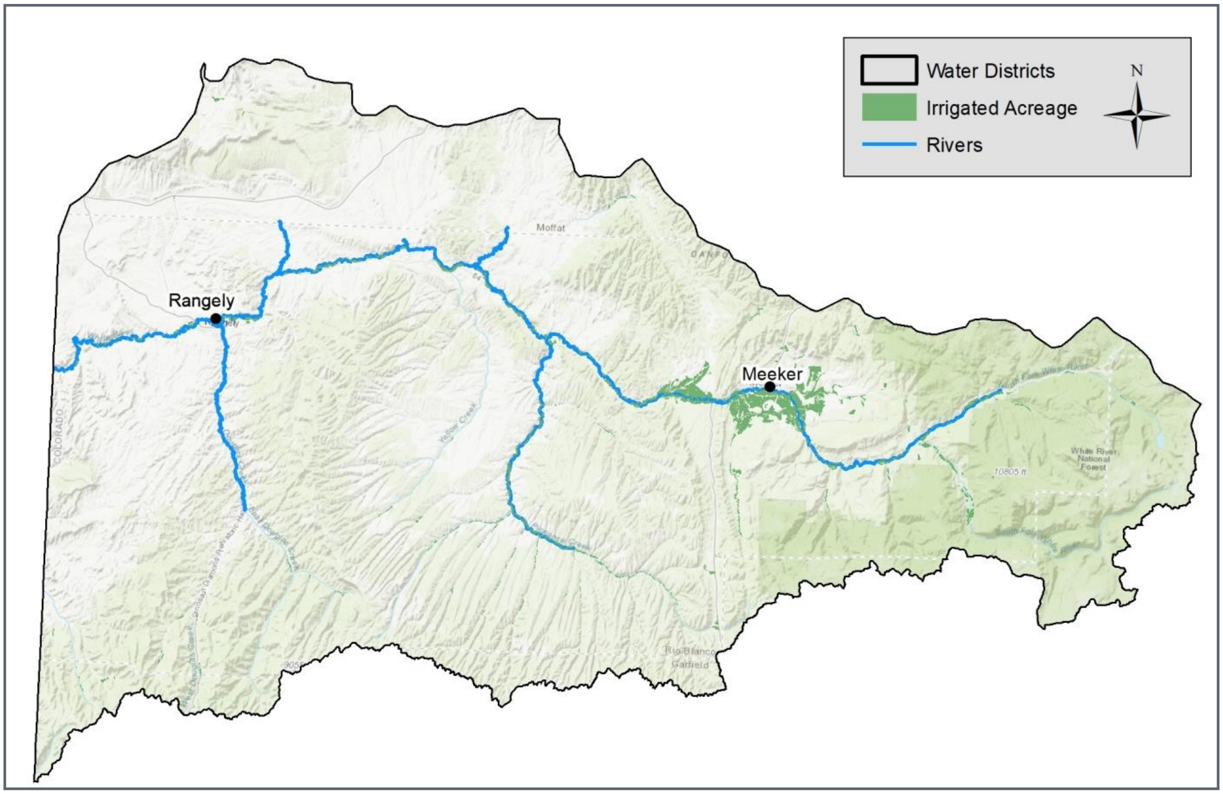


Figure 28: White River Basin Irrigated Acreage

Urbanization of irrigated lands is expected to be limited in the basin, with 360 acres total in and around the towns of Meeker and Rangely projected to be urbanized. Population projections in Rio Blanco County are expected to decline in the Weak Economy scenario, therefore urbanization in the White River Basin for this scenario was set to zero.

As reflected in the Planning Scenario Adjustment section above, IWR is projected to increase by approximately 22 percent and 37 percent on average under the In-Between and Hot and Dry conditions, respectively. IWR is reduced by 10 percent in the Adaptive Innovation scenario to account for technological innovations that may mitigate the increased IWR due to climate adjustments. Additionally, system efficiency will increase by 10 percent, from 35 to 45 percent in the Adaptive Innovation scenario to account for the impact of improved technologies that may more efficiently convey supplies to irrigated lands.

Table 22 provides a summary of the adjustments discussed above; refer to the Planning Scenario Results section below for agricultural diversion demand summaries.

Table 22: White River Planning Scenario Adjustments

Adjustment Factor	A: Business as Usual	B: Weak Economy	C: Cooperative Growth	D: Adaptive Innovation	E: Hot Growth
Change in Irrigated Land due to Urbanization	360 Acre Reduction	-	360 Acre Reduction	360 Acre Reduction	360 Acre Reduction
IWR Climate Factor	-	-	22%	37%	37%
Emerging Technologies	-	-	-	10% IWR Reduction 10% System Efficiency Increase	-

7.10 YAMPA RIVER BASIN

Irrigated acreage in the Yampa River Basin consists primarily of high mountain meadows and cattle ranches in the upper reaches of the basin along Elk Creek and the Yampa River. Water users also irrigate acreage along the Little Snake River as it meanders between Colorado and Wyoming. The Yampa River Basin is an agricultural-focused basin; producers in the basin desire to maintain and increase irrigated acreage along the Yampa River mainstem. The basin also has recreational industries with a top ski destination at Steamboat Springs and the canyons along the Yampa and Green Rivers in Dinosaur National Monument.

The Yampa/White/Green River Basin Roundtable completed an Agricultural Water Needs Study in 2010. Among other objectives, the study sought to better define the location of up to 40,000 acres of potentially irrigable land within the oxbows of the Yampa River mainstem originally identified by National Resource Conservation Service (NRCS) mapping. Though the NRCS mapping was lost in a fire, the Needs Study performed a spatial analysis and identified 14,805 acres of potentially irrigable land along the Yampa River Basin between the Fortification Creek and Little Snake Creek confluences, primarily in Water District 44 (Figure 29)[17].

[17] Sourced from the Agricultural Water Needs Study (2010), Yampa/White/Green River Basin Roundtable

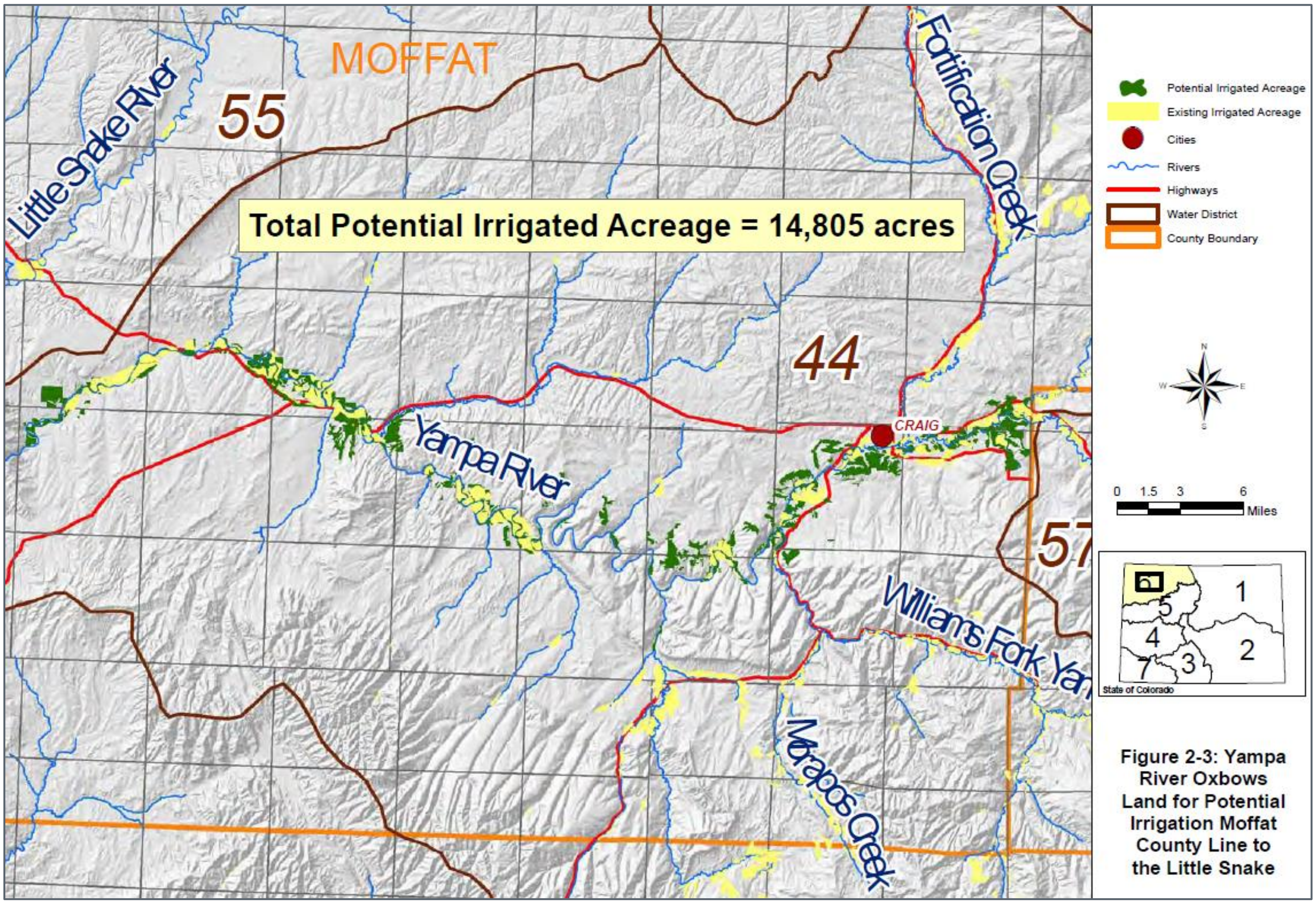


Figure 29: Yampa River Basin Planned Agricultural Projects

For the Technical Update effort, Yampa/White/Green BRT contemplated how the planned agricultural projects may be developed under the Planning Scenarios, recognizing that there may be variable growth depending on the future demand and economics for hay crops and cattle production. As such, the stakeholders in the basin provided a varying amount of acreage and crops types for the Planned Agricultural Projects in each Planning Scenario in the Yampa River basin as reflected in Table 23.

Population projections anticipate significant growth in the Yampa River Basin. The impact to irrigated areas, however, will be limited because the three largest municipal centers in the basin (Steamboat Springs, Hayden, and Craig) are not surrounded by irrigated agricultural areas. Approximately 2 percent of the irrigated acreage in the basin, or 1,500 acres, is estimated to be urbanized by 2050.

IWR in the basin is expected to increase a 19 percent on average under the In-Between climate conditions and 34 percent for the Hot and Dry conditions. These estimates are only slightly greater for the basins where there is planned irrigated acreage, projected as 21 percent and 36 percent under the two climate change conditions respectively. Estimates of IWR will be reduced by 10 percent in the Adaptive Innovation scenario, in which technological innovations mitigate the increased agricultural demand due to climate adjustments anticipated by the Hot and Dry conditions. Additionally, irrigation operations will experience a 10 percent increase to average system efficiency over the irrigation season, from 34 to 44 percent, in the Adaptive Innovation scenario.

Table 23 provides a summary of the adjustments discussed above; refer to the Planning Scenario Results section below for agricultural diversion demand summaries.

Table 23: Yampa River Planning Scenario Adjustments

Adjustment Factor	A: Business as Usual	B: Weak Economy	C: Cooperative Growth	D: Adaptive Innovation	E: Hot Growth
Change in Irrigated Land due to Urbanization	1,500 Acre Reduction	1,500 Acre Reduction	1,500 Acre Reduction	1,500 Acre Reduction	1,500 Acre Reduction
Planned Agricultural Projects	1,000 Acre Increase 100% Alfalfa	1,000 Acre Increase 100% Alfalfa	5,000 Acre Increase 50/50 Grass Pasture/Alfalfa	14,805 Acre Increase 50/50 Grass Pasture/Alfalfa	14,805 Acre Increase 50/50 Grass Pasture/Alfalfa
IWR Climate Factor	-	-	19%	34%	34%
Emerging Technologies	-	-	-	10% IWR Reduction 10% System Efficiency Increase	-

Section 8: Planning Scenario Agricultural Diversion Demand Approach

In general, the factors discussed in the previous sections impact the acreage, efficiency, or IWR components of the agricultural diversion demand analyses. The following general approach was used to integrate the factors into the agricultural demand process:

1. **Adjust current acreage by the Urbanization, Planned Agricultural Projects, and Ground Water Acreage Sustainability factors**. Using the current irrigated acreage as a starting point, irrigated acreage was increased or decreased in each basin using the acreage values associated with each factor. Some factors reflect an acreage adjustment to a regional area (e.g. Ground Water Acreage Sustainability factor in the South Platte River basin), whereas other factors were applied to acreage at a more specific location (e.g. Urbanized Acreage). In general, adjustments to acreage (e.g. Planned Agricultural Projects, Urbanized Acreage) were applied first, then adjustments based on percent of total acreage were applied. Note that total acreage was adjusted based on the factors; however, in general, crop types and irrigation methods were maintained. The only exception to this is the adjustment for sprinkler development in the South Platte River basin. For the South Platte, the Emerging Technologies factor was increased - effectively increasing the percent of acreage served by sprinklers under each irrigation system in the South Platte River basin.

2. **Calculate adjusted IWR**. Revise the consumptive use datasets developed for the current agricultural diversion demand effort with the adjusted acreage and simulate the models to calculate the adjusted IWR for each Planning Scenario in each basin. Note that the consumptive use datasets will reflect historical climate data; climate adjustments are applied to the IWR in Step 3.

3. **Adjust the IWR by the Climate factor**. Multiply the adjusted IWR from Step 2 by the CRWAS-II climate change data associated with the specific climate projection in each Planning Scenario. The CRWAS-II effort provided a time series of climate change factors for each Water District for both the "In-Between" and "Hot and Dry" projections. These Water District factors are multiplied by IWR to apply the effect of the climate projections on the crop water requirement. Note that in many basins, IWR is reduced by 10 percent in the Adaptive Innovation scenario to account for technological innovations that may mitigate the increased IWR due to climate adjustments. Additionally, note that the North Platte River, Republican River, and Arkansas River basin consumptive use datasets extend beyond the climate change factor dataset developed through the CRWAS-II effort. Climate change factors in recent years were filled from the available factors (i.e. 1950 – 2013) by correlating the IWR from recent years to historical years with similar IWR.

4. **Adjust the system efficiency by the Emerging Technologies factor**. Using the historical wet, dry, and average monthly system efficiencies as a starting point, increase the system efficiency of each ditch by 10 percent. For example, a monthly system efficiency of 40 percent would be increased to 50 percent. Note that is adjustment is only implemented in the Adaptive Innovation scenario; the remaining scenarios rely on the historical system efficiencies.

5. **Develop the 2050 Planning Scenario Agricultural Diversion Demand**. Divide the climate-adjusted IWR from Step 3 by system efficiency values to develop the agricultural diversion demand for each Planning Scenario. Note that wet, dry, and average year types used to assign the appropriate system efficiency in this step reflects climate-adjusted hydrology at the indicator gage, if specified for the Planning Scenario. As the climate-adjusted hydrology will be drier, this approach resulted in more dry-year efficiencies being used to develop the agricultural diversion demand. For basins that use both surface and ground water supplies, partition the total demand using the same method outlined in Section 4.

Section 9: Planning Scenario Results

The following graphics and tables summarize the acreage, IWR, and the agricultural diversion demand attributable to surface and ground water supplies in each basin calculated for the 2050 Planning Scenarios based on the adjustment factors and approach discussed above. From a statewide perspective, the agricultural diversion demand ranged from 10 million acre-feet in the Adaptive Innovation scenario to 13.5 million acre-feet in the Hot Growth scenario. For basins with limited acreage adjustments, such as the Colorado, Gunnison, and Southwest basins, the agricultural diversion demand in the Business as Usual and the Weak Economy scenarios was similar to the Current demand. In these basins, climate change projections and efficiency adjustments had a significant impact resulting in more variable demands in the Cooperative Growth, Adaptive Innovation, and Hot Growth scenarios.

For basins with significant acreage reductions, such as the South Platte River and Republican River basins, demands in all Planning Scenarios are lower than the Current demand. The largest variation in a majority of the basins occurred in the Adaptive Innovation scenario due to 10 percent reduction in IWR and 10 percent increase to system efficiency. In some basins, such as the Southwest basin, the combined impact of the Adaptive Innovation scenario adjustments resulted in an agricultural diversion demand that is lower than the Current demand.

As discussed above, agricultural diversion demands will be incorporated into the Planning Scenario models, which will be used to determine how much water is available to meet the demands. Shortages to the agricultural diversion demands in the Water Supply modeling efforts will define the agricultural gap. Refer to the *Technical Update Current and 2050 Planning Scenario Water Supply and Gap* documentation for more information on how the demands were implemented in the water supply models and how the agricultural gap was estimated.

Table 24: Arkansas River Basin Planning Scenario Results

Planning Scenario	Acreage	Average IWR (acre-feet)	Total Water Demand: Wet Year (acre-feet)	Total Water Demand: Average Year (acre-feet)	Total Water Demand: Dry Year (acre-feet)
Current	445,000	980,000	1,894,000	1,872,000	1,962,000
A	417,700	921,000	1,775,000	1,751,000	1,834,000
B	413,600	915,000	1,767,000	1,743,000	1,826,000
C	409,500	970,000	1,907,000	1,844,000	1,914,000
D	398,900	889,000	1,764,000	1,686,000	1,741,000
E	398,900	987,000	1,965,000	1,880,000	1,942,000

Planning Scenario	Surface Water Demand: Wet Year (acre-feet)	Surface Water Demand: Average Year (acre-feet)	Surface Water Demand: Dry Year (acre-feet)	Ground Water Demand: Wet Year (acre-feet)	Ground Water Demand: Average Year (acre-feet)	Ground Water Demand: Dry Year (acre-feet)
Current	1,567,000	1,497,000	1,501,000	327,000	375,000	461,000
A	1,466,000	1,394,000	1,392,000	309,000	357,000	442,000
B	1,466,000	1,394,000	1,392,000	301,000	349,000	434,000
C	1,585,000	1,473,000	1,483,000	322,000	371,000	431,000
D	1,477,000	1,340,000	1,353,000	287,000	346,000	388,000
E	1,653,000	1,509,000	1,528,000	312,000	371,000	414,000

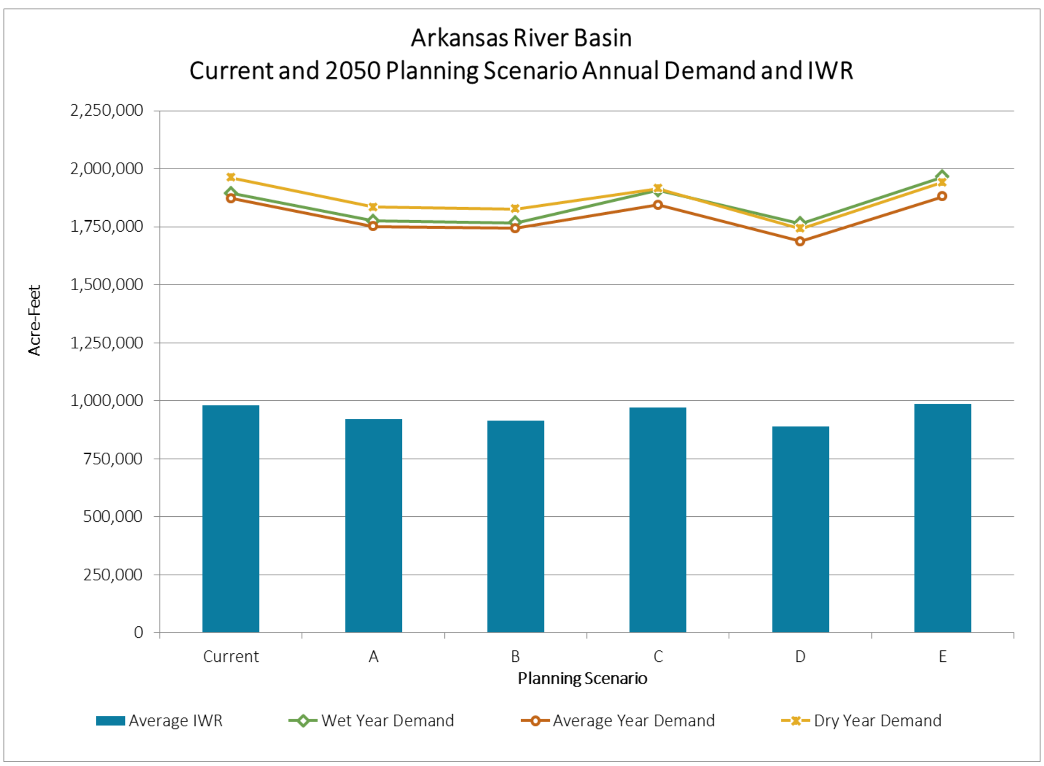


Figure 30: Arkansas River Basin Planning Scenario Results

Table 25: Colorado River Basin Planning Scenario Results

Planning Scenario	Acreage	Average IWR (acre-feet)	Surface Water Demand: Wet Year (acre-feet)	Surface Water Demand: Average Year (acre-feet)	Surface Water Demand: Dry Year (acre-feet)
Current	206,700	456,500	1,640,000	1,608,000	1,538,000
A	193,100	426,000	1,515,000	1,485,000	1,420,000
B	193,100	426,000	1,515,000	1,485,000	1,420,000
C	193,100	480,000	1,729,000	1,666,000	1,571,000
D	193,100	463,000	1,336,000	1,306,000	1,253,000
E	193,100	514,000	1,866,000	1,786,000	1,657,000

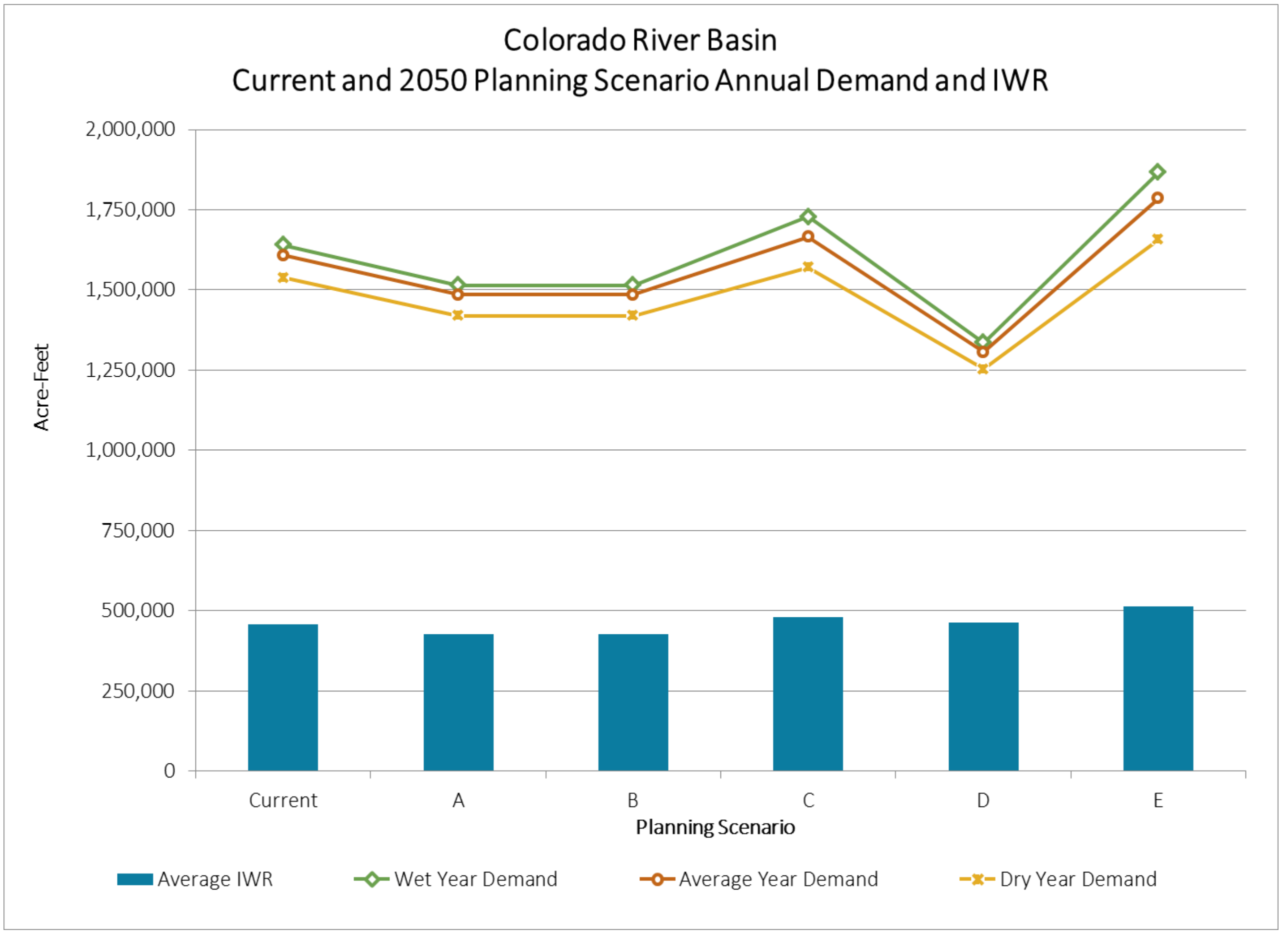


Figure 31: Colorado River Basin Planning Scenario Results

Table 26: Gunnison River Basin Planning Scenario Results

Planning Scenario	Acreage	Average IWR (acre-feet)	Surface Water Demand: Wet Year (acre-feet)	Surface Water Demand: Average Year (acre-feet)	Surface Water Demand: Dry Year (acre-feet)
Current	234,400	528,200	1,824,000	1,814,000	1,716,000
A	219,800	494,000	1,699,000	1,688,000	1,596,000
B	219,800	494,000	1,699,000	1,688,000	1,596,000
C	219,800	573,000	2,050,000	1,973,000	1,845,000
D	219,800	541,000	1,361,000	1,315,000	1,253,000
E	219,800	601,000	2,194,000	2,074,000	1,914,000

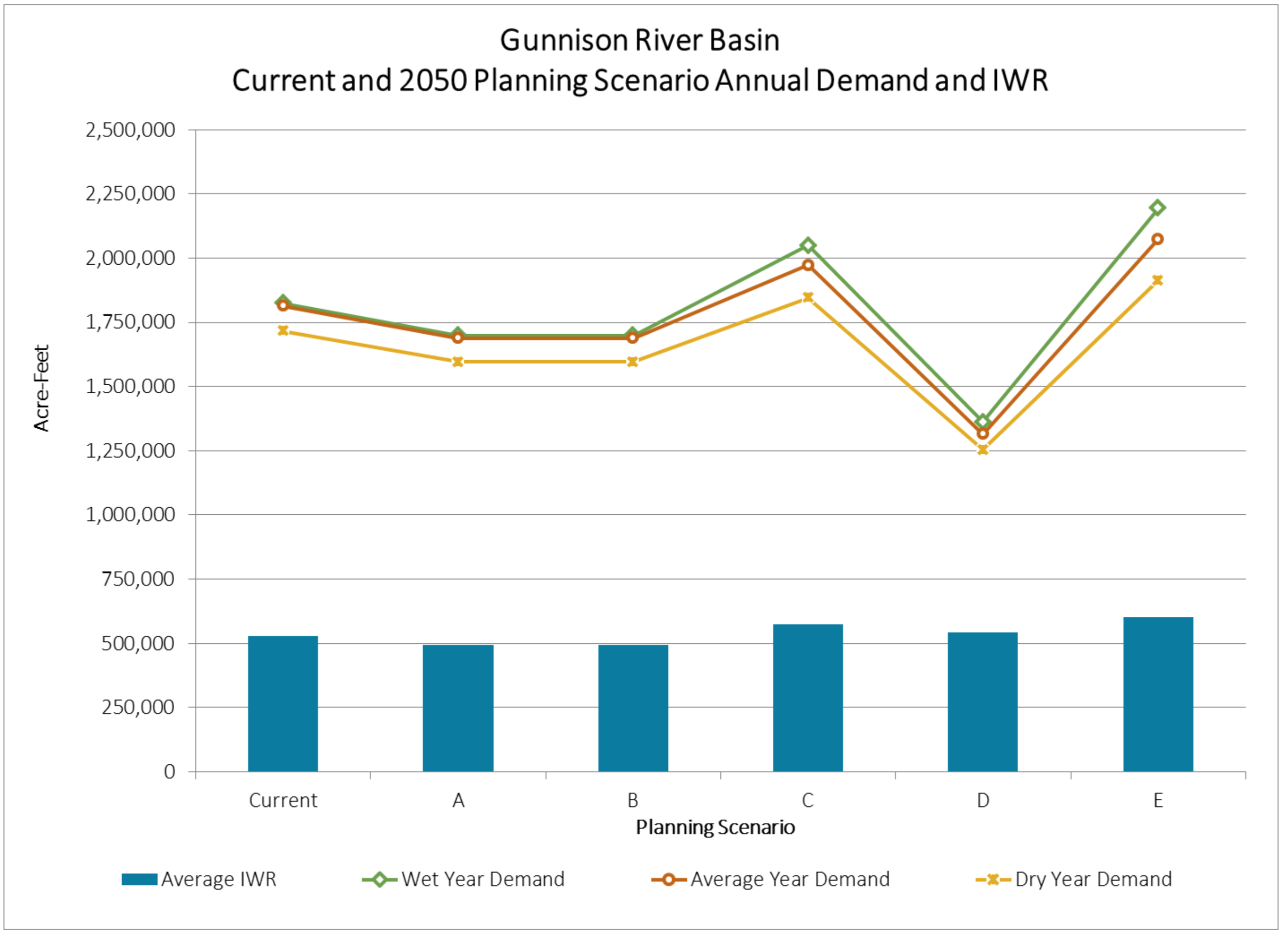


Figure 32: Gunnison River Basin Planning Scenario Results

Table 27: North Platte River Basin Planning Scenario Results

Planning Scenario	Acreage	Average IWR (acre-feet)	Surface Water Demand Wet Year (acre-feet)	Surface Water Demand Average Year (acre-feet)	Surface Water Demand Dry Year (acre-feet)
Current	113,600	191,100	548,000	555,000	489,000
A	124,200	208,000	623,000	640,000	546,000
B	124,200	208,000	623,000	640,000	546,000
C	124,200	243,000	736,000	754,000	619,000
D	124,200	236,000	530,000	531,000	476,000
E	124,200	263,000	801,000	806,000	665,000

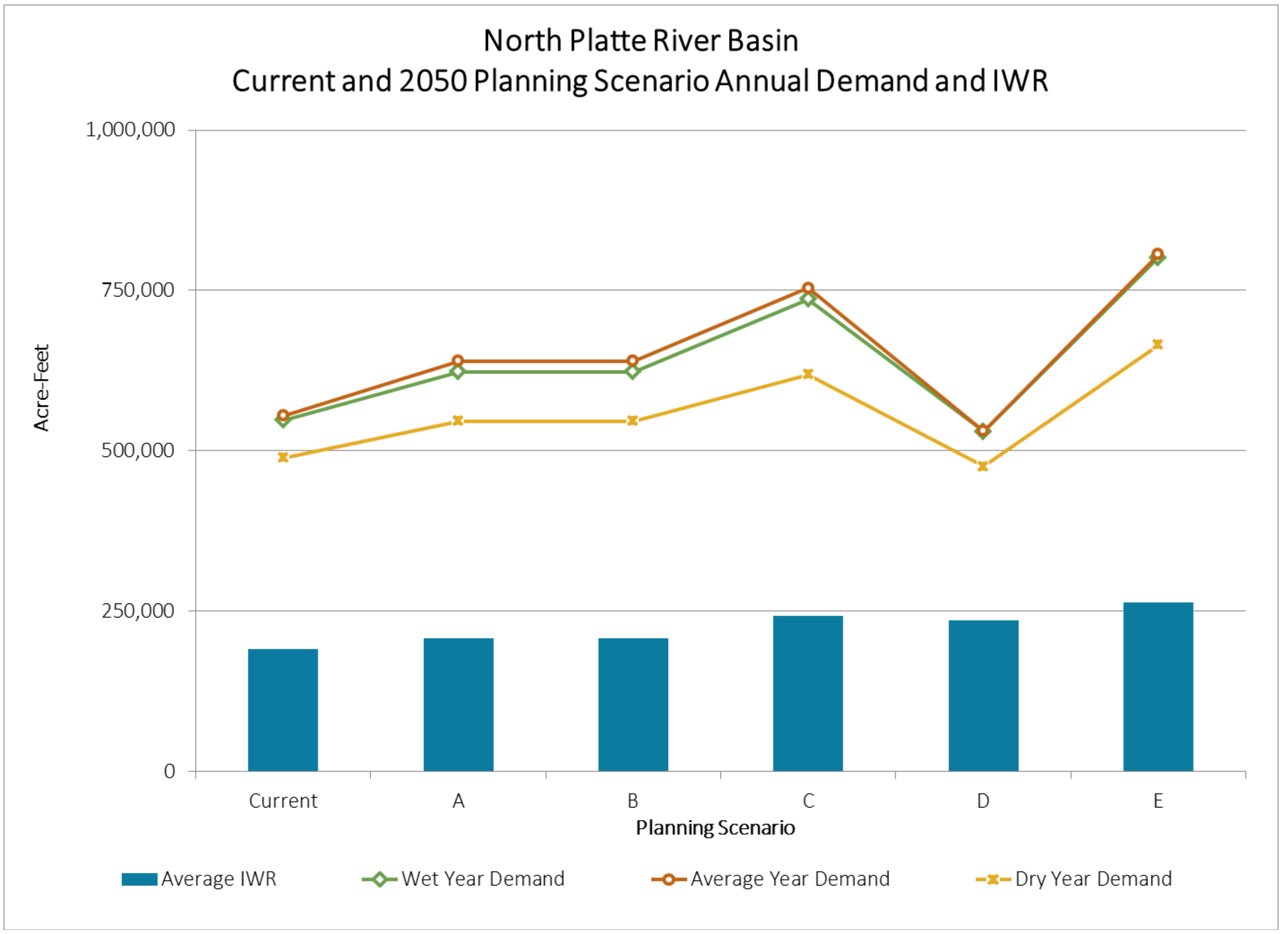


Figure 33: North Platte River Basin Planning Scenario Results

Table 28: Republican River Basin Planning Scenario Results

Planning Scenario	Acreage	Average IWR (acre-feet)	Ground Water Demand Wet Year (acre-feet)	Average Year (acre-feet)	Dry Year (acre-feet)
Current	578,800	837,000	913,000	1,056,000	1,241,000
A	442,000	635,000	681,000	800,000	941,000
B	443,400	636,000	683,000	802,000	943,000
C	442,000	661,000	714,000	833,000	960,000
D	442,000	649,000	695,000	799,000	896,000
E	442,000	721,000	772,000	888,000	995,000

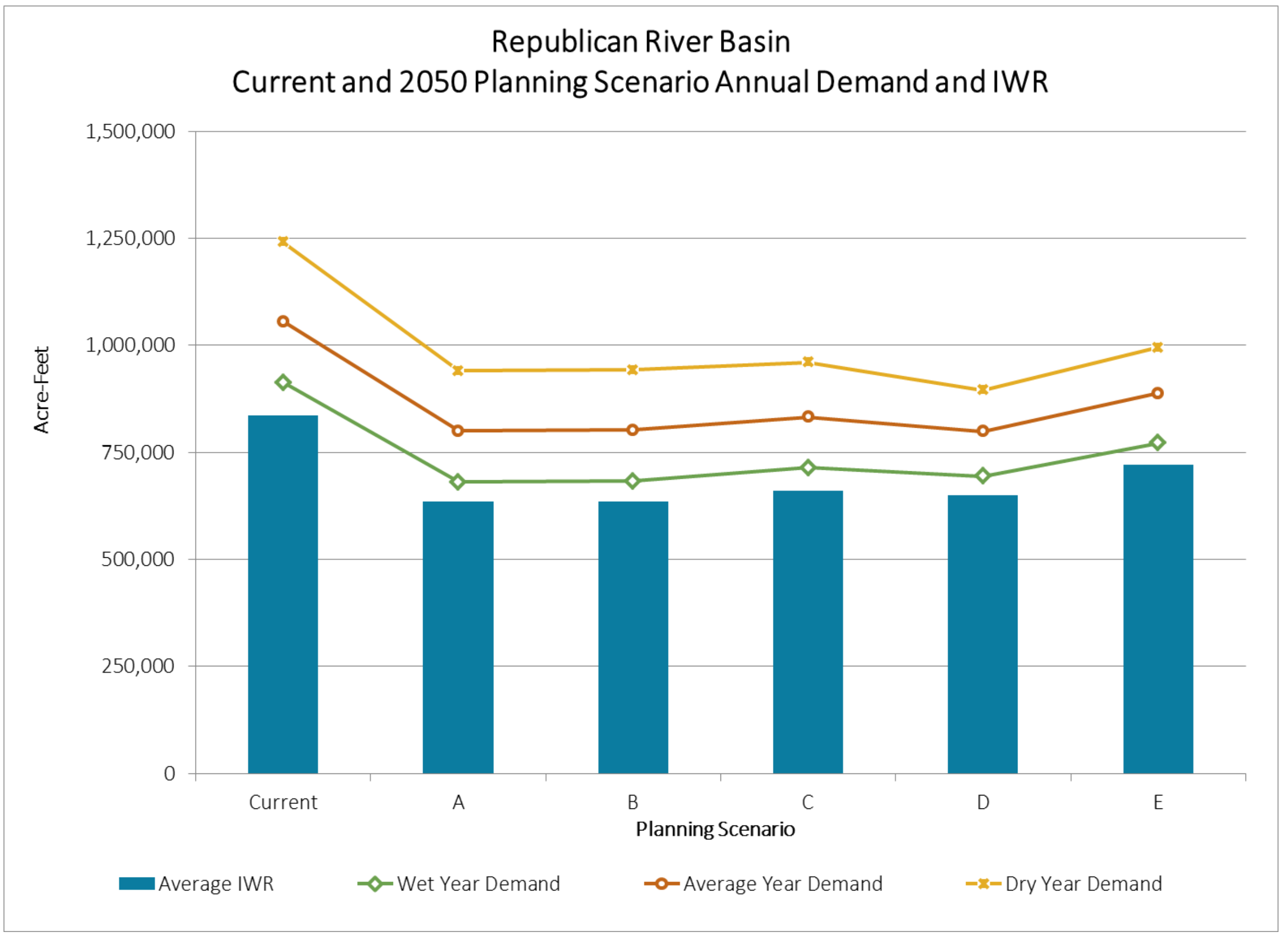


Figure 34: Republican River Basin Planning Scenario Results

Table 29: Rio Grande Basin Planning Scenario Results

Planning Scenario	Acreage	Average IWR (acre-feet)	Total Water Demand Wet Year (acre-feet)	Total Water Demand Average Year (acre-feet)	Total Water Demand Dry Year (acre-feet)
Current	515,300	1,021,000	1,801,000	1,800,000	1,849,000
A	466,300	940,000	1,695,000	1,694,000	1,735,000
B	470,300	949,000	1,712,000	1,712,000	1,754,000
C	396,500	913,000	1,635,000	1,652,000	1,647,000
D	385,200	818,000	1,468,000	1,465,000	1,458,000
E	385,200	909,000	1,635,000	1,632,000	1,625,000

Planning Scenario	Surface Water Demand Wet Year (acre-feet)	Surface Water Demand Average Year (acre-feet)	Surface Water Demand Dry Year (acre-feet)	Ground Water Demand Wet Year (acre-feet)	Ground Water Demand Average Year (acre-feet)	Ground Water Demand Dry Year (acre-feet)
Current	1,237,000	1,172,000	1,195,000	564,000	628,000	654,000
A	1,221,000	1,156,000	1,178,000	474,000	538,000	557,000
B	1,237,000	1,173,000	1,196,000	475,000	539,000	558,000
C	1,182,000	1,139,000	1,120,000	453,000	513,000	527,000
D	1,048,000	999,000	968,000	420,000	466,000	490,000
E	1,186,000	1,135,000	1,104,000	449,000	497,000	521,000

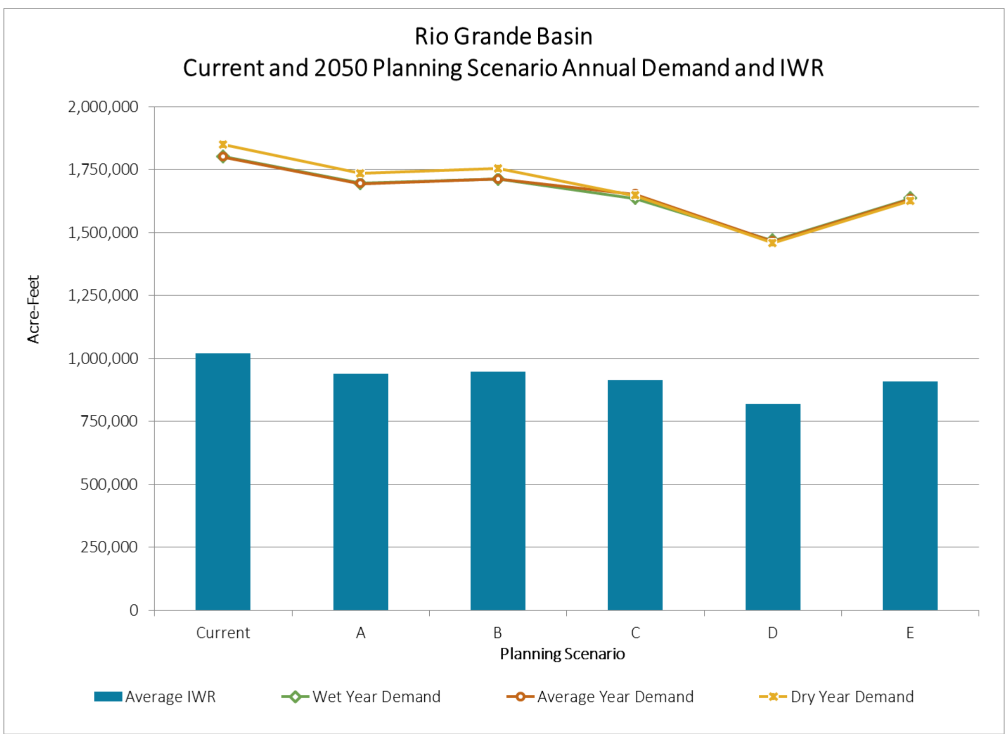


Figure 35: Rio Grande Basin Planning Scenario Results

Table 30: South Platte River Basin Planning Scenario Results

Planning Scenario	Acreage	Average IWR (acre-feet)	Total Water Demand Wet Year (acre-feet)	Total Water Demand Average Year (acre-feet)	Total Water Demand Dry Year (acre-feet)
Current	854,300	1,500,000	2,427,000	2,589,000	2,632,000
A	701,100	1,225,000	1,959,000	2,081,000	2,128,000
B	701,100	1,225,000	1,959,000	2,081,000	2,128,000
C	722,400	1,341,000	2,186,000	2,268,000	2,286,000
D	722,400	1,264,000	1,707,000	1,771,000	1,797,000
E	679,900	1,323,000	2,123,000	2,202,000	2,191,000

Planning Scenario	Surface Water Demand Wet Year (acre-feet)	Surface Water Demand Average Year (acre-feet)	Surface Water Demand Dry Year (acre-feet)	Ground Water Demand Wet Year (acre-feet)	Ground Water Demand Average Year (acre-feet)	Ground Water Demand Dry Year (acre-feet)
Current	2,078,000	2,186,000	2,108,000	349,000	403,000	524,000
A	1,634,000	1,704,000	1,632,000	325,000	377,000	496,000
B	1,634,000	1,704,000	1,632,000	325,000	377,000	496,000
C	1,842,000	1,872,000	1,777,000	344,000	396,000	509,000
D	1,415,000	1,432,000	1,358,000	292,000	339,000	439,000
E	1,768,000	1,796,000	1,681,000	355,000	406,000	510,000

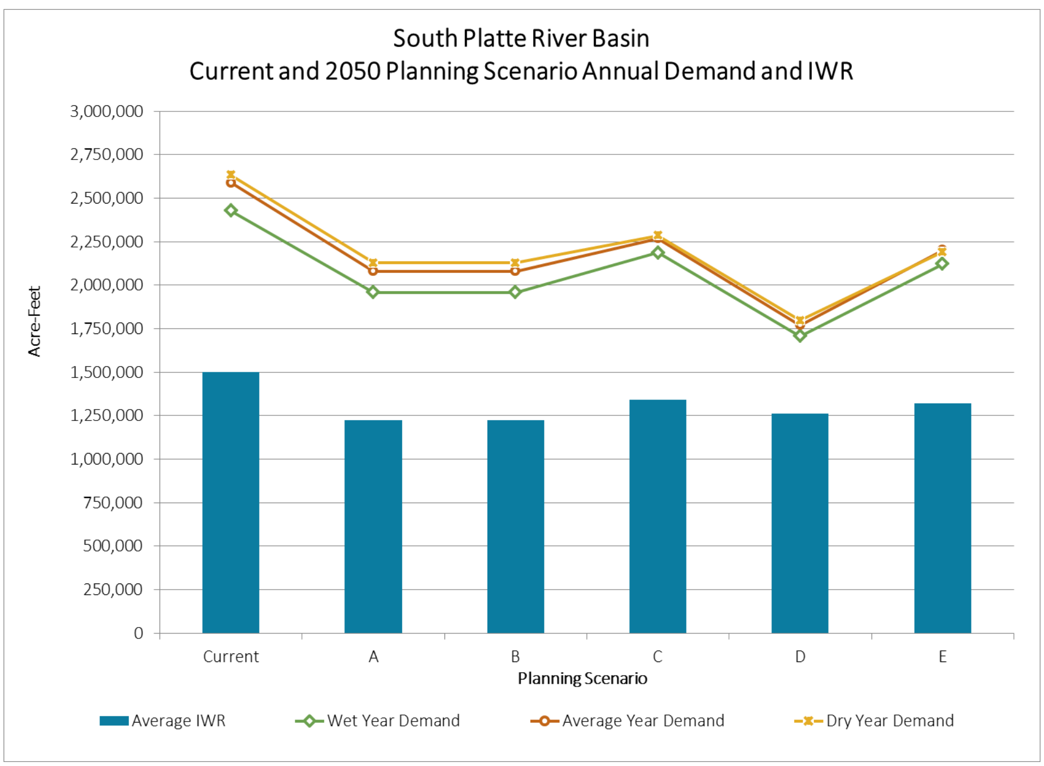


Figure 36: South Platte River Basin Planning Scenario Results

Table 31: Southwest Basin Planning Scenario Results

Planning Scenario	Acreage	Average IWR (acre-feet)	Surface Water Demand		
			Wet Year (acre-feet)	Average Year (acre-feet)	Dry Year (acre-feet)
Current	222,500	474,900	980,000	1,025,000	1,007,000
A	218,800	467,000	962,000	1,005,000	987,000
B	218,800	467,000	962,000	1,005,000	987,000
C	218,800	569,000	1,279,000	1,211,000	1,162,000
D	218,800	537,000	958,000	933,000	883,000
E	218,800	597,000	1,345,000	1,290,000	1,210,000

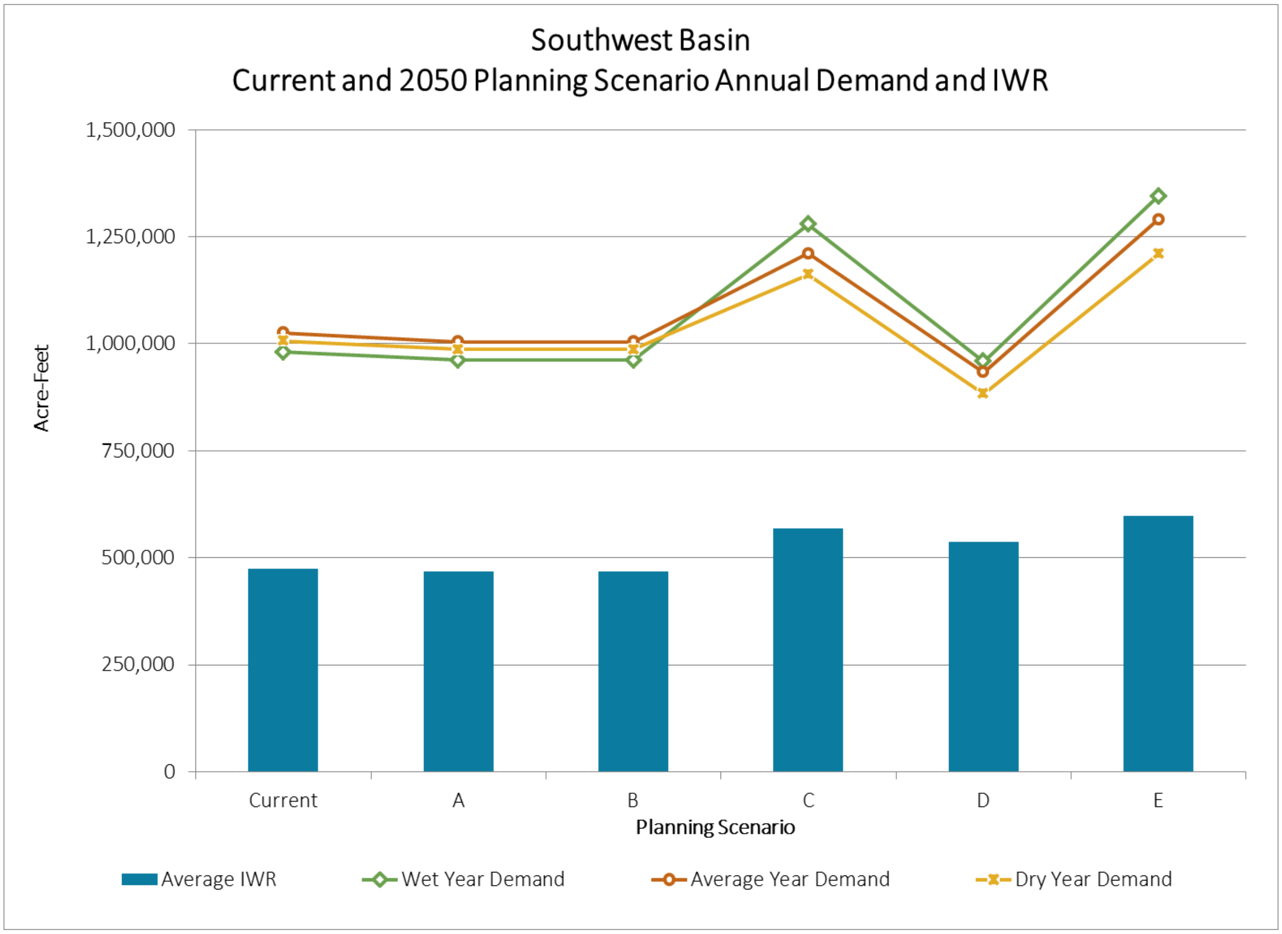


Figure 37: Southwest Basin Planning Scenario Results

Table 32: White River Basin Planning Scenario Results

Planning Scenario	Acreage	Average IWR (acre-feet)	Surface Water Demand Wet Year (acre-feet)	Surface Water Demand Average Year (acre-feet)	Surface Water Demand Dry Year (acre-feet)
Current	28,100	46,400	250,000	243,000	242,000
A	27,700	45,800	246,000	239,000	238,000
B	28,000	46,400	250,000	243,000	242,000
C	27,700	55,700	305,000	293,000	278,000
D	27,700	55,900	186,000	180,000	173,000
E	27,700	62,100	344,000	324,000	306,000

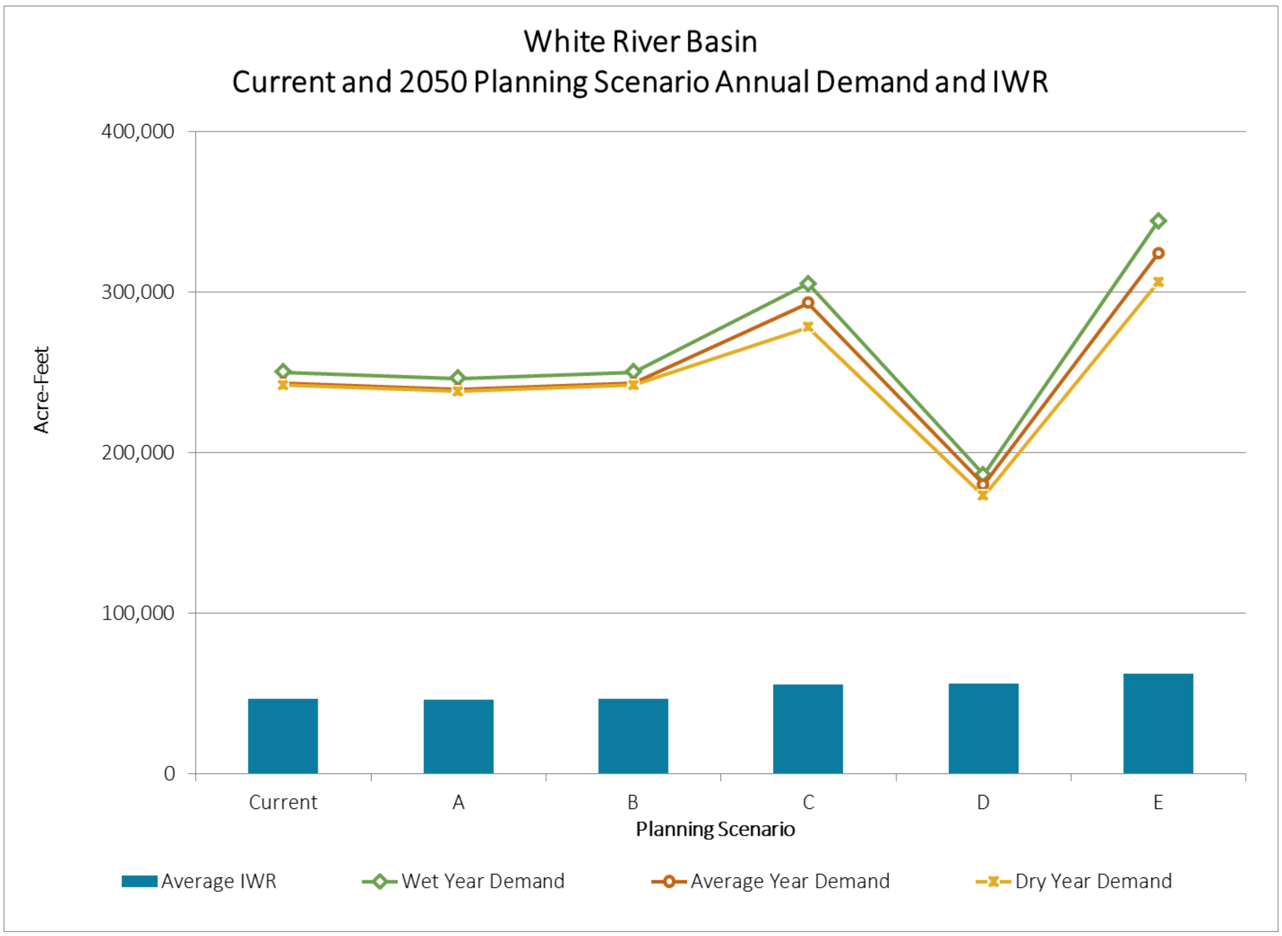


Figure 38: White River Basin Planning Scenario Results

Table 33: Yampa River Basin Planning Scenario Results

Planning Scenario	Acreage	Average IWR (acre-feet)	Surface Water Demand: Wet Year (acre-feet)	Surface Water Demand: Average Year (acre-feet)	Surface Water Demand: Dry Year (acre-feet)
Current	78,900	150,600	387,000	402,000	403,000
A	78,400	150,000	389,000	403,000	404,000
B	78,400	150,000	389,000	403,000	404,000
C	82,400	188,000	518,000	518,000	514,000
D	92,300	209,000	460,000	456,000	447,000
E	92,300	232,000	691,000	679,000	658,000

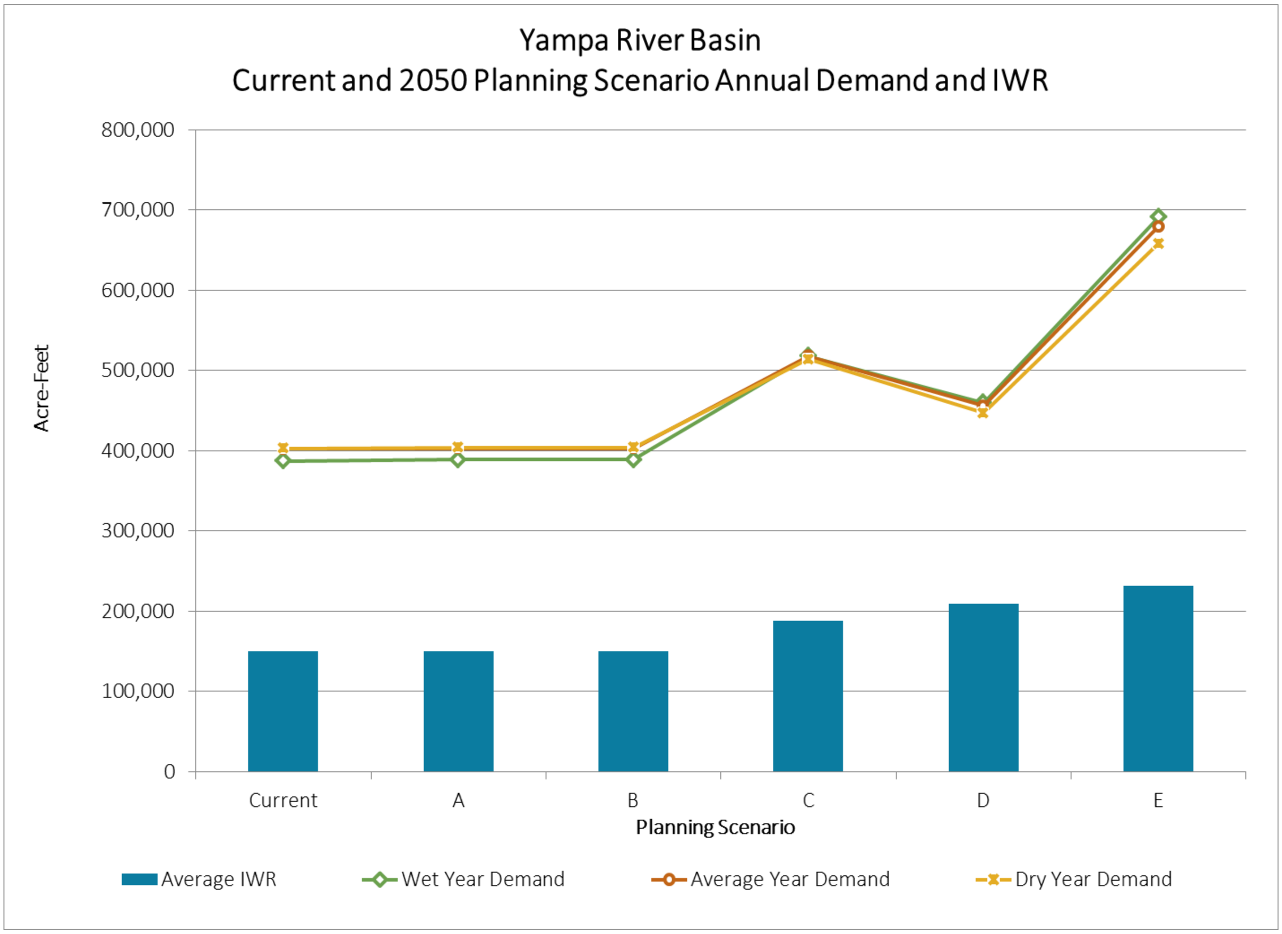


Figure 39: Yampa River Basin Planning Scenario Results

Table 34: Statewide Planning Scenario Results

Planning Scenario	Acreage	Average IWR (acre-feet)	Total Water Demand Wet Year (acre-feet)	Total Water Demand Average Year (acre-feet)	Total Water Demand Dry Year (acre-feet)
Current	3,280,000	6,190,000	12,664,000	12,964,000	13,079,000
A	2,890,000	5,510,000	11,544,000	11,786,000	11,829,000
B	2,890,000	5,520,000	11,559,000	11,802,000	11,846,000
C	2,840,000	5,990,000	13,059,000	13,012,000	12,796,000
D	2,820,000	5,660,000	10,465,000	10,442,000	10,377,000
E	2,780,000	6,210,000	13,736,000	13,561,000	13,163,000

Planning Scenario	Surface Water Demand Wet Year (acre-feet)	Surface Water Demand Average Year (acre-feet)	Surface Water Demand Dry Year (acre-feet)	Ground Water Demand Wet Year (acre-feet)	Ground Water Demand Average Year (acre-feet)	Ground Water Demand Dry Year (acre-feet)
Current	10,511,000	10,502,000	10,199,000	2,153,000	2,462,000	2,880,000
A	9,755,000	9,714,000	9,393,000	1,789,000	2,072,000	2,436,000
B	9,775,000	9,735,000	9,415,000	1,784,000	2,067,000	2,431,000
C	11,226,000	10,899,000	10,369,000	1,833,000	2,113,000	2,427,000
D	8,771,000	8,492,000	8,164,000	1,694,000	1,950,000	2,213,000
E	11,848,000	11,399,000	10,723,000	1,888,000	2,162,000	2,440,000

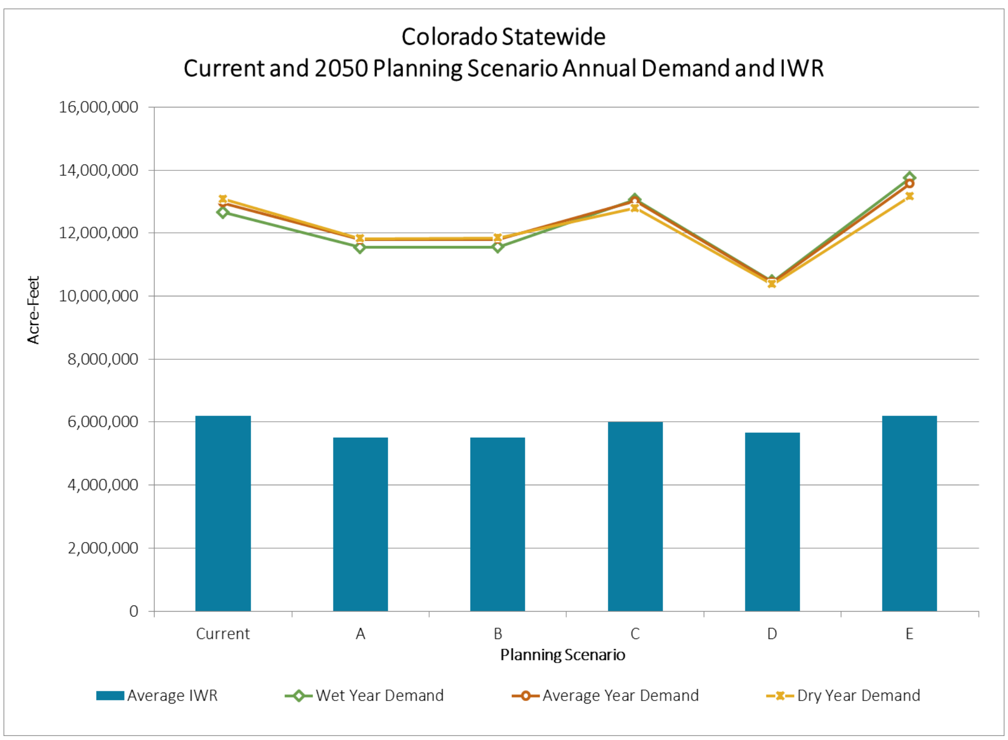


Figure 40: Statewide Planning Scenario Results

Section 10: Comments and Considerations

The following reflects observations and comments that should be considered when reviewing the current and 2050 Planning Scenario agricultural diversion demand results.

- **Comparison to Historical Diversions**. The current agricultural diversion demands are not directly comparable to the historical diversions as the historical diversions reflect changing irrigation practices, crop types, and acreage, as well as physical and legal water availability shortages. A comparison to recent average diversions (2005-2012) can, however, provide perspective on the amount of shortages experienced in a specific area and provide a high-level check on the demand results. In consistently water short basins, such as the Rio Grande basin, the historical diversions are generally significantly less than the diversion demands as reflected in Figure 41.

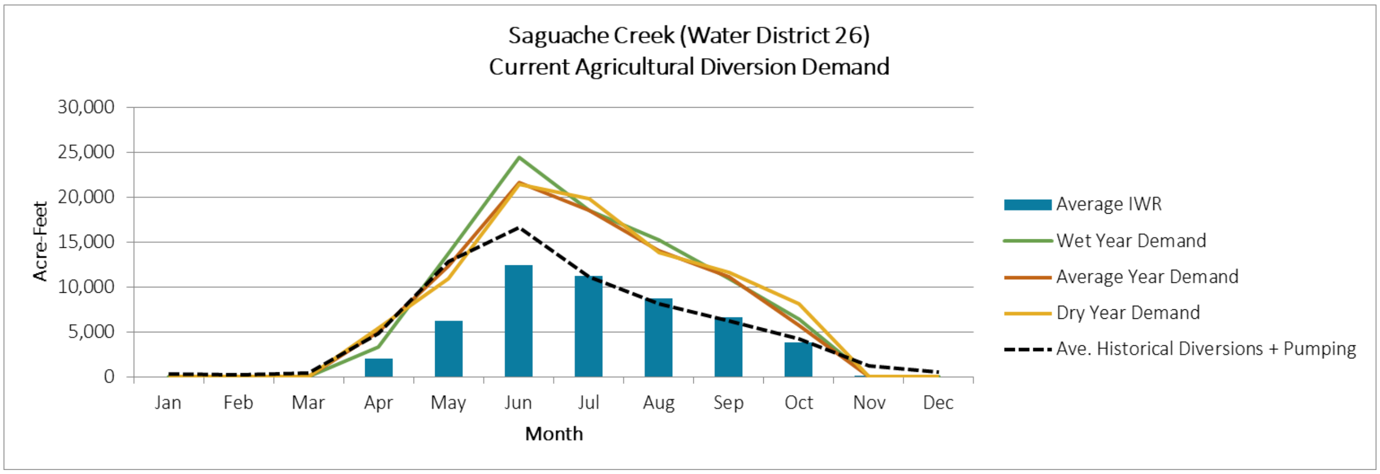


Figure 41: Saguache Creek Current Agricultural Diversion Demand

Conversely, in tributaries with more consistent native supply or supplemental supplies available from storage, the historical diversions more closely match the diversion demands. As reflected in Figure 42, irrigators in the Upper Uncompahgre River basin still experience shortages; however historically diverted supplies more closely mimic the agricultural demand.

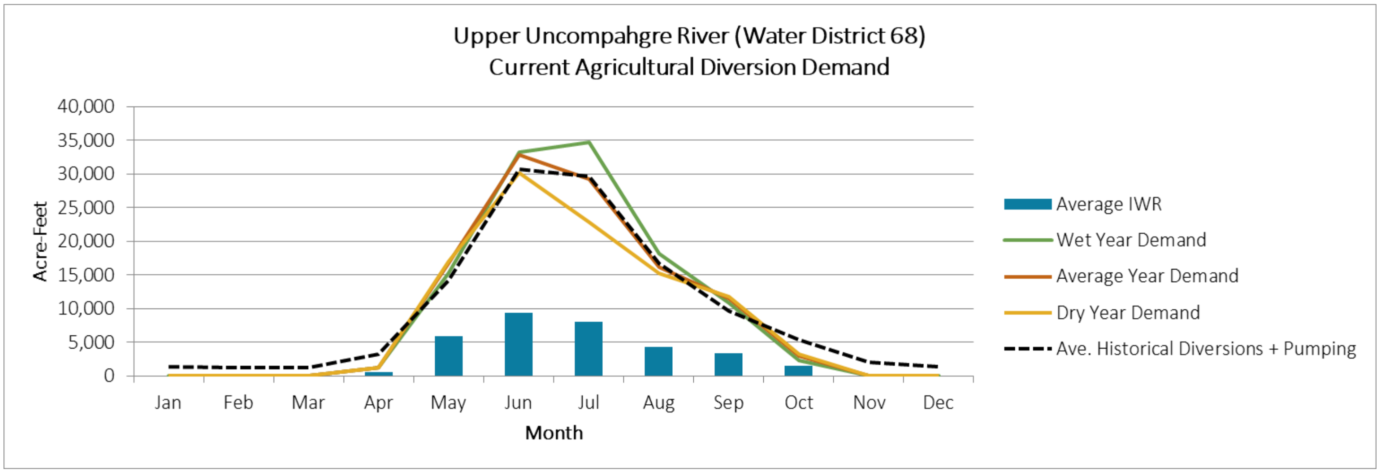


Figure 42: Upper Uncompahgre River Current Agricultural Diversion Demand

In areas that have experienced significant urbanization of irrigated lands including the transfer of water rights from irrigation to municipal uses, the historical diversions are generally larger than the agricultural diversion demand values because the demand values are based on the current (reduced) acreage. This impact is reflected in the Clear Creek River basin agricultural diversion demand results illustrated in Figure 43, where irrigated acreage has been reduced due to water transfers to municipalities and urbanization of crop land.

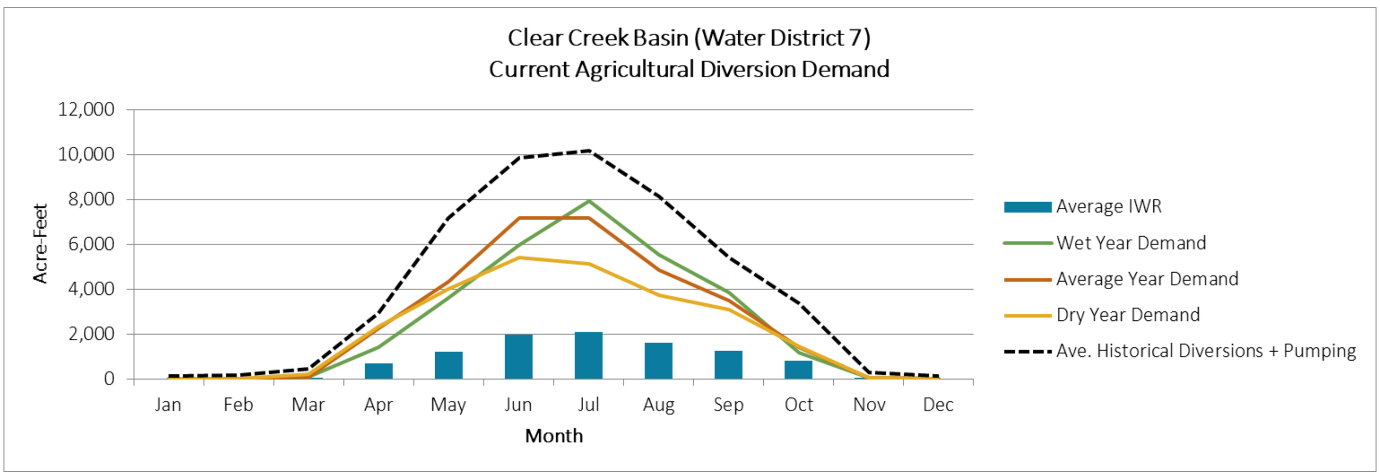


Figure 43: Clear Creek Basin Current Agricultural Diversion Demand

- **Irrigated Acreage Assessments**. The current agricultural diversion demand analysis relies on the irrigated acreage assessments developed by the CWCB and DWR. The assessments are generally performed every 5 years and more frequently in basins where annual acreage assessments are required for Compact reporting or DWR administration. CWCB and DWR staff have continually improved the delineation of parcels, crop assignments, and water supply assignments in these assessments, however there remains areas with acreage delineation inconsistencies.

  - The irrigated acreage assessments are generally not intended to delineate municipal or commercial irrigated parcels. Therefore, parks, cemeteries, golf courses, or small pasture areas (hobby farms) are not delineated in the acreage assessments. Overall, this irrigated acreage is a small component of the basin-wide acreage totals, however, if concentrated in a specific area (e.g. Clear Creek basin or Grand Valley area), it can have a more significant local impact. This acreage was not accounted for or delineated under this Technical Update effort, therefore the current acreage and agricultural diversion demands may be lower in these areas for this analysis.

  - Approximately 20,000 irrigated acres on the Western Slope do not have recent diversion records available in the Historical Dataset and, therefore, system efficiency information could not be calculated. As this acreage represents around 2 percent of the total acreage on the Western Slope, it was not accounted for in the Technical Update effort.

- Recharge Demands. There are a small number of irrigation systems in the Rio Grande basin that have decrees allowing preferential use of ground water supplies while diverting surface water for on-farm aquifer recharge. The RGDSS Phase 6 – Historical Consumptive Use Analysis documentation identified six structures in the basin that operate under this preferential practice, including three of the largest irrigation systems in the basin; Rio Grande Canal, Farmers Union Canal, San Luis Valley Canal Company. The approach outlined above for developing the current agricultural diversion demand for co-mingled structures double-accounted the demand for these structures. Therefore the agricultural diversion demand for these structures was developed using the ground-water only approach outlined above and designated as a ground water demand in the results. Although the structures are legally allowed to use either surface or ground water supplies on their acreage, designating their agricultural diversion demand as a ground water demand for the Technical Update efforts is consistent with their current irrigation practices.

- Shoulder Season Irrigation Practices. The agricultural diversion demand approach outlined above relies on IWR and historical system efficiencies from wet, dry, and average year types to capture the variability of irrigation practices across variability hydrological conditions. As reflected in the summary graphs above, the dry year demand is often greater in the early spring months. This can be attributed to both a higher IWR in the early season due to generally warmer temperatures in dry year types and irrigation practices that reflect higher diversions during the runoff with the knowledge that supplies may not be available later in the irrigation season during dry years.

  Although this approach allows for the estimation of demands that can vary based on IWR, it may not fully capture the agricultural diversion demand associated with irrigation practices during months when the IWR is very low or zero. This issue is generally limited to lower elevation basins with limited water availability (i.e. rely primarily on supplies during runoff, no significant supplemental reservoir supplies or ground water) that rely on filling their soil early in the season. Figure 44 for the La Plata River basin illustrates the issue between the historical diversions in March and April and the resulting current agricultural diversion demand.

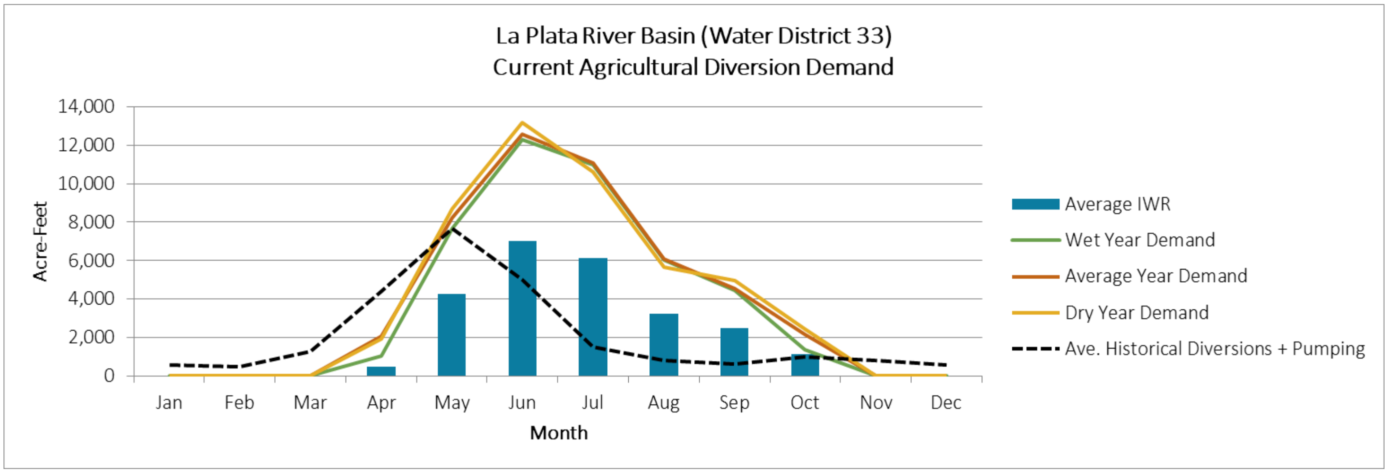


Figure 44: La Plata River Basin Current Agricultural Diversion Demand

- **Agricultural Diversion Demands**. The agricultural diversion demand is defined as the amount of water that would need to be diverted or pumped to meet the full crop irrigation demand. The tables provided herein reflect a summation of agricultural diversion demand across major river basins. The tables do not reflect nor consider the common practice of re-diverting irrigation return flows many times within a river basin. As such, it is not appropriate to assume the total demand reflects the amount of native streamflow that would need to be diverted to meet the full crop irrigation demand.

- **Pumping Estimates**. Ground water withdrawals have been metered and recorded in recent years, but records are generally not available over a long historical period. With rare exceptions, pumping records in the Rio Grande basin have only been available since 2009, and even more recently in the South Platte River basin. As such, it is necessary to estimate ground water only and supplemental irrigation (co-mingled) supplies over a longer period of record. For CDSS basin-planning efforts, pumping is initially estimated based on IWR in the StateCU datasets and then adjusted to account for historical restrictions to pumping. For irrigated lands served by ground water only, pumping is estimated by dividing the IWR by system efficiency, which is usually 80 or 85 percent due to sprinkler application methods. For irrigated lands served by both surface and ground water supplies, the surface water irrigation supplies are applied to the land first and any remaining IWR is assumed to be met by ground water supplies. This remaining IWR is then divided by system efficiency to estimate the supplement pumping supply. Pumping estimates are limited by well development (i.e. estimates are limited historically when fewer wells were developed) and account for the change in sprinkler development over time within the StateCU process. Additionally restrictions to historical pumping vary by basin:
    - Pumping estimates in the Rio Grande basin are adjusted based on historical season of use and calibrated to metered pumping when available.
    - In the South Platte River basin, pumping estimates were limited based on historical quotas imposed by augmentation providers due to lack of augmentation supplies.
    - Pumping within the H-I Model area in the Arkansas River basin was estimated back to 1950 in support of the Arkansas River Compact, and accounted for well development and changes to irrigated acreage due to municipal transfers.

For the Technical Update effort, it was necessary to estimate Current and 2050 Planning Scenario pumping demands. These baseline demands needed to reflect current conditions, without imposing water supply shortages, and respond to changing IWR demand. As outlined above, baseline pumping estimates for irrigated lands served by ground water only were estimated based on Current and 2050 Planning Scenario IWR divided by system efficiency. The process was more difficult for supplemental pumping supplies due to the ability of surface water supplies to meet a portion of the IWR. Stakeholders in basins with ground water pumping indicated both declining ground water availability and declining augmentation supplies, indicating pumping would not likely increase in the future. As such, supplemental pumping estimates that reflected low, high, and average pumping conditions in recent years (i.e. post-2005 to account for administrative changes spurred by the 2002 drought) were selected and correlated to wet, dry, and average year types to create a longer time series of supplemental/co-mingled pumping supplies for the Current and 2050 Planning Scenarios. Years selected for each basin are:

- Arkansas River Basin: 2012 for High, 2013 for Low, 2006 for Average
- Rio Grande Basin: 2006 for High, 2009 for Low, 2010 for Average
- South Platte River Basin: 2006 for High, 2009 for Low, 2011 for Average

This approach holds supplemental/co-mingled pumping to current levels, leaving any change of agricultural diversion demand (positive or negative) in the 2050 Planning Scenarios to be a change in surface water agricultural diversion demand. Refer to the *Technical Update Current and 2050 Planning Scenario Water Supply and Gap* documentation for more information on how the ground water agricultural gap was estimated.

- **Planning Scenario Adjustments**. The Planning Scenarios presented by Colorado's Water Plan describe five plausible futures that each include several adjustments to agricultural diversion demand. Although the individual adjustments are discussed in the Basin Summaries above, it is difficult to completely isolate the impact of a specific adjustment because the adjustments tend to compound within a Planning Scenario. For example, urbanized acreage in the South Platte River basin was removed first, and the acreage adjustments for ground water sustainability were applied to the remaining acreage. These adjustments would have resulted in slightly different values had the adjustments been applied in a different order. If water resources planners are interested in the impact of an individual adjustment, they are encouraged to obtain the consumptive use datasets and implement the adjustments in a step-wise fashion, analyzing the results after each adjustment is implemented.

Section 11: References

Colorado Water Plan

Colorado Water Conservation Board, 2015, Colorado Water Plan Website (www.colorado.gov/cowaterplan)

Basin Implementation Studies

Colorado Water Conservation Board and Basin Roundtables, 2015,
Colorado Water Plan Website (www.colorado.gov/cowaterplan)

Agricultural Water Needs Study

Yampa-White-Green Basin Roundtable, Prepared by CDM, December 2010

Basin Implementation Plan Modeling Phase 3 Final Report
Yampa-White-Green Basin Roundtable, Prepared by Wilson Water Group, April 2018

The Gunnison River Basin, A Handbook for Inhabitants
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Colorado Foundation for Water Education, Prepared by Joshua Zaffos, December 2015

Ground Water Levels in the Southern High Plains Designated Ground Water Basin
Colorado Division of Water Resources, Prepared by Andrew Flor, 2018

Irrigation Improvement Rules in the Arkansas River Basin
AWRA Colorado and Colorado Division of Water Resources, Prepared by Tracy Kosloff

The Contribution of Agriculture to Colorado's Economy: An Executive Summary
Colorado State University and Colorado Department of Agricultural, Prepared by Stephen Davies, Professor, Amalia Davies, Research Associate, Becky Goldbach and Martha Sullins, January 2012

Five Year Average Ground Water Withdrawals in Confined Aquifer Response Areas in Division 3: July 2018 Requirement of Division 3 Ground Water Rules Section 8.1.5
Colorado Division of Water Resources, Prepared by DWR Modeling and Decision Support System Team, June 2018

Five Year Average Ground Water Withdrawals in Confined Aquifer Response Areas in Division 3: July 2018 Requirement of Division 3 Ground Water Rules Section 8.1.5

Analysis and Technical Update to the Colorado Water Plan

Technical Memorandum

Prepared for:

Colorado Water Conservation Board

Project Title:

Current and 2050 Planning Scenario Water Supply and Gap Results

Date: September 18, 2019

Prepared by: Wilson Water Group
Reviewed by: Jacobs, Brown & Caldwell

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Section 1: Introduction

This technical memorandum summarizes the water supply and gap approach and results for the Technical Update effort. The water supply and gap results consider the current and projected 2050 agricultural, municipal and industrial demands associated with each of the Technical Update Planning Scenarios under current or climate-adjusted hydrological conditions. These water supply and gap results are then compared to Baseline results to compare and contrast how the projected water supply and gaps may change in the future under each Planning Scenario. Figure 1 shows the five plausible 2050 Planning Scenarios, as presented in Colorado's Water Plan.

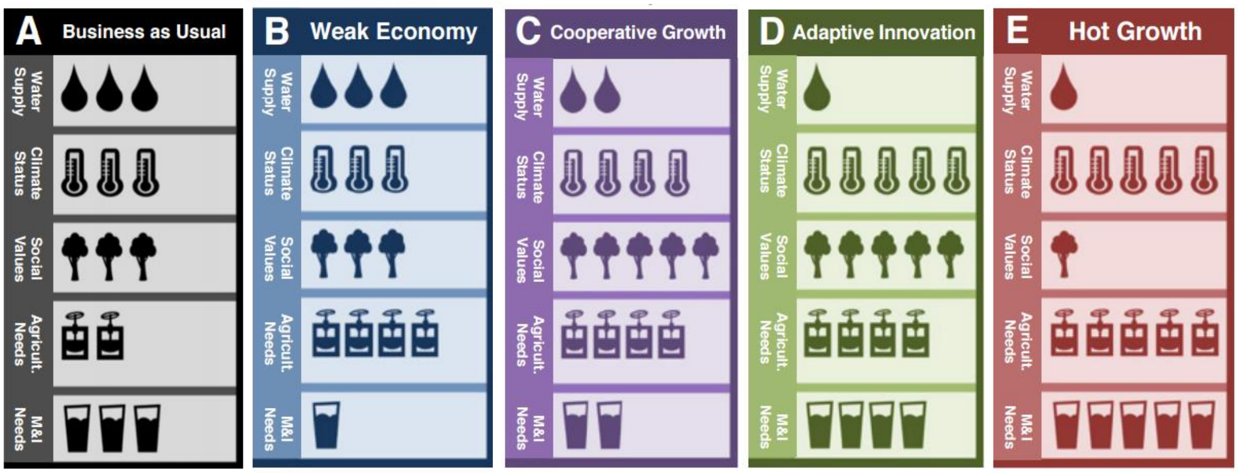


Figure 1: 2050 Planning Scenario Descriptions

The water supply and gap analyses rely heavily on information developed throughout the Technical Update effort, and documented in separate technical memoranda. The approach and resulting agricultural demands for the Baseline and 2050 Planning Scenarios are documented in the *Current and 2050 Planning Scenario Agricultural Diversion Demand* memorandum. Likewise, the approach and resulting municipal and self-supplied industrial (M&SSI) demands for the Baseline and 2050 Planning Scenarios are documented in the *Baseline and Projected 2050 Planning Scenario Municipal and Self-Supplied Industrial Water Demands* memorandum. Climate-adjusted hydrological information was developed through the Colorado River Water Availability Study Phase II (CRWAS-II) effort and documented in *Colorado River Availability Study Phase II Task 7: Climate Change Approach and Results*. The demand and hydrological information were brought together and analyzed using the Colorado Decision Support System (CDSS) water allocation modeling tools, where available. Using Prior Appropriation, these models are able to estimate the amount of water supply and gaps based on the changed demand and hydrology under each Planning Scenario.

This technical memorandum presents the water supply and gap information at a basin-level (Figure 2). Information presented herein generally includes a summary of agricultural and M&SSI demands and gaps by basin. Incremental increases in demand and gap are provided to understand how the results from each Planning Scenario compare relative to the Baseline results and other scenarios. Additionally, the results include projected changes in basin storage, physical streamflow, and water availability.

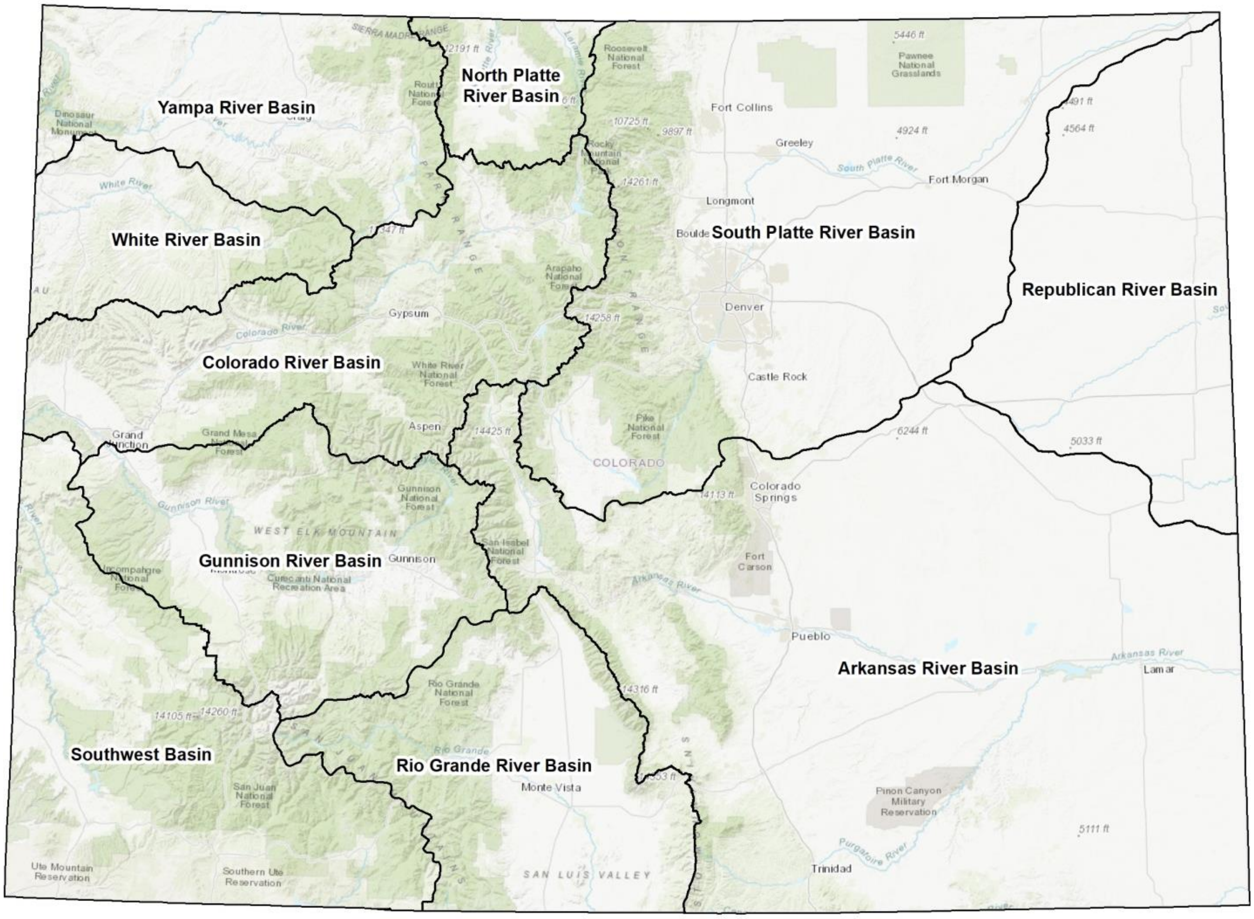


Figure 2: River Basin Boundaries

Section 2: Definitions and Terminology

This section summarizes the definitions and terminology used to discuss water supply components in the Technical Update effort. As discussed in more detail below, there are differences in definitions and terminology between the SWSI 2010 and Technical Update, particularly regarding the definition of agricultural demands and gaps. The summaries below the definitions note legacy definitions from SWSI 2010 as applicable.

- Water Supply Information: Collective term used to describe several pieces of data that characterize the total amount of water in a basin; data includes physical streamflow, reservoir contents, and agricultural and M&SSI gaps.
- Physical Streamflow: The amount of physical water in a stream at any given point in the river, either historical gaged streamflow or simulated streamflow from modeling results.
- Natural Flow: The amount of water supply absent the effect of man, serves as the foundation of the StateMod water allocation models.

- **Unappropriated Available Supply**: The amount of unappropriated streamflow at a specific location that could be developed under a future water right; also referred to as free river conditions.
- **Agricultural Diversion Demand**: The amount of water that needs to be diverted or pumped to meet the full crop irrigation water requirement.
    - *SWSI 2010 defined agricultural demand as the amount of water currently consumed by the crops; not the amount of water that needs to be diverted to meet the current levels of agricultural production.*
- **Irrigation Water Requirement (IWR)**: The amount of water that must be applied to the crop to meet the full crop consumptive use, also referred to as the crop demand. IWR provides an estimate of the maximum amount of applied water the crops could consume if it was physically and legally available.
- **Water Supply Limited (WSL) Consumptive Use**: The amount of applied water consumed by the crop; also referred to as actual crop consumptive use. WSL is the minimum between the IWR and the amount of applied water that reaches the crops.
- **Irrigation System Efficiency**: The percent of diverted or pumped water consumed by the crops or stored in soil moisture; calculated by dividing the sum of WSL and water stored in soil moisture by the total applied water from all sources. System efficiency reflects the losses to applied water due to canal seepage and on-farm application losses.
- **Agricultural Gap**: The difference between the amount of water available to meet the agricultural diversion demand and the full agricultural diversion demand.
    - *SWSI 2010 defined the agricultural gap as the crop shortages, although recognized that diversions and pumping would need to be much larger in order to meet the crop shortage.*
- **Crop Demand Gap**: The difference between the amount of water the crops need to meet full crop consumptive use (IWR) and the amount of applied water the crops consumed (WSL).
- **M&SSI Diversion Demand**: The amount of water that needs to be diverted or pumped to meet the full municipal and self-supplied industrial (M&SSI) demand.
- **M&SSI Gap**: The difference between the amount of water available to meet M&SSI diversion demand and the full M&SSI diversion demand.

Section 3: SWSI 2010 Water Supply Methodology

Basin-wide analyses on water supply and water availability were not completed in the SWSI 2010 effort. Rather SWSI 2010 discussed statewide surface and ground water availability by summarizing results of recent studies completed by CWCB and by individual Basin Roundtables. Additionally, SWSI 2010 summarized the major interstate compacts, decrees, and endangered species programs that impact water availability in each basin. Quantitative analyses completed for the original SWSI 1 effort in 2004 were not updated in the 2010 effort, with SWSI 2010 stating that "future SWSI updates will provide updated water availability analysis in each basin based on additional Colorado Decision Support System (CDSS) modeling tools".

SWSI 2010 reported the following conclusions on water availability, which are consistent with conclusions developed during the SWSI 1 effort:

- There are no reliable additional water supplies that can be developed in the Arkansas and Rio Grande Basins, except in very wet years.

- The North Platte River Basin has the ability to increase both irrigated acres and some additional consumptive uses, consistent with the North Platte Decrees.
- The South Platte River Basin has water that is legally and physically available for development in wet years, although unappropriated water is extremely limited.
- Compact entitlements in the Colorado River Basins are not fully utilized and those basins (Colorado, Gunnison, Southwest, and Yampa-White) have water supplies that are legally and physically available for development given current patterns of water use.

The agricultural gap as defined in the Technical Update (i.e. the water required to meet the full IWR) was not analyzed in the SWSI 2010 effort. The SWSI 2010 effort calculated and reported shortages to the crops (i.e. crop demand gap) based on the most recent 10 years of historical information available, and noted that diversions and pumping would need to be much larger in order to meet the crop shortage.

The SWSI 2010 report provides an extensive summary of the M&SSI gap, defined as the amount of "future water supply need for which a project or method to meet that need is not presently identified". The SWSI 2010 municipal gap was developed by first calculating the 2050 M&SSI water needs corresponding to low, medium, and high growth scenarios; the current M&SSI use; and the anticipated yield from water providers' identified projects and processes (IPP). The gap could then be calculated using these components in the following equation, as documented in Section 5.3.1 of the SWSI 2010 report:

M&I and SSI Water Supply Gap = 2050 Net New Water Needs – 2050 IPPs

Where:

2050 Net New Water Needs =

(2050 low/medium/high M&I baseline demands – high passive conservation - current M&I use) + (2050 low/medium/high SSI demands – current SSI use)

2050 IPPs =

Water Provider Anticipated Yield from: Agricultural Transfers + Reuse + Growth into Exiting Supplies + Regional In-basin Projects + New Transbasin Projects + Firming In-basin Water Rights + Firming Transbasin Water Rights

Specific IPP and estimated yields were obtained from CWCB interviews and data collected from water providers throughout the State (2009-2010); the original SWSI effort (2004); and information from BRT (2008-2010). The overall IPP "success" was then adjusted to create varying levels of M&SSI gap based on the likelihood that a specific IPP would produce its full yield. Table 1 reflects the major categories of IPP and associated yield at 100 percent success rate.

Table 1: SWSI 2010 IPP Category and Yield by Basin

Basin	Agricultural Transfer (AFY)	Reuse (AFY)	Growth into Existing Supplies (AFY)	Regional In-Basin Project (AFY)	New Transbasin Project (AFY)	Firming In-Basin Water Rights (AFY)	Firming Transbasin Rights (AFY)	Total IPPs at 100% Success Rate (AFY)
Arkansas	9,200 – 11,000	23,000 – 32,000	2,300 – 2,600	37,000	0	6,100 – 7,300	10,000 – 11,000	88,000 – 100,000
Colorado	2,900 – 8,000	500	14,000 – 28,000	13,000 – 15,000	0	11,000 – 19,000	0	42,000 – 70,000
Gunnison	400 – 500	0	1,100 – 1,700	11,000 – 15,000	0	900	0	14,000 – 18,000
Metro	20,000 – 33,000	14,000 – 21,000	55,000 – 86,000	34,000 – 39,000	13,000 – 23,000	900 – 1,400	3,500 – 4,800	140,000 – 210,000
North Platte	0	0	100 – 300	0	0	0	0	100 – 300
Rio Grande	0	0	2,900 – 4,300	0	0	3,000 – 4,300	0	5,900 – 8,600
South Platte	19,000 – 20,000	5,000 – 7,000	20,000 – 30,000	37,000 – 39,000	0	22,000 – 26,000	18,000 – 21,000	120,000 – 140,000
Southwest	0	0	5,200 – 7,300	9,000 – 13,000	0	0	0	14,000 – 21,000
Yampa-White	0	0	3,500 – 4,900	6,600 – 9,000	0	0	0	10,000 – 14,000
Total	**51,000 – 73,000**	**43,000 – 61,000**	**100,000 – 160,000**	**150,000 – 170,000**	**13,000 – 23,000**	**44,000 – 58,000**	**32,000 – 37,000**	**430,000 – 580,000**

The SWSI 2010 reported the M&SSI gap ranging from 190,000 to 630,000 acre-feet by 2050, depending on the growth projection and the IPP success rate. This value assumes that the 1.16 million acre-feet of existing M&SSI supply annually will continue to be available into the future and that IPPs will yield between 350,000 and 430,000 acre-feet annually of additional supply to meet the increasedM&SSI demands.

Table 2 provides a summary of the projected 2050 M&SSI gap under the various growth and IPP success scenarios.

Table 2: SWSI 2010 M&SSI Gap

Basin	Increase in M&I and SSI Demand (AFY)			Estimated Yield of Identified Projects and Processes (AFY)			Estimated Remaining M&I and SSI Gap after Identified Projects and Processes (AFY)		
				100% IPP Success Rate	Alternative IPP Success Rates	Status Quo IPP Success Rates	Gap at 100% IPP Success Rate	Gap at Alternative IPP Success Rates	Gap at Status Quo IPP Success Rates
	Low	Med	High	Low	Med	High	Low	Med	High
Arkansas[2]	110,000	140,000	170,000	88,000	85,000	76,000	36,000	64,000	110,000
Colorado	65,000	82,000	110,000	42,000	49,000	63,000	22,000	33,000	48,000
Gunnison	16,000	19,000	23,000	14,000	14,000	16,000	2,800	5,100	6,500
Metro[3]	180,000	210,000	280,000	140,000	97,000	100,000	63,000	130,000	190,000
North Platte	100	200	300	100	200	300	0	20	30
Rio Grande	7,700	9,900	13,000	5,900	6,400	7,700	1,800	3,600	5,100
South Platte	160,000	180,000	230,000	120,000	78,000	58,000	36,000	110,000	170,000
Southwest	20,000	25,000	31,000	14,000	13,000	15,000	5,100	12,000	16,000
Yampa-White	34,000	48,000	95,000	10,000	11,000	13,000	23,000	37,000	83,000
Total	**590,000**	**710,000**	**950,000**	**430,000**	**350,000**	**350,000**	**190,000**	**390,000**	**630,000**

[1] Aggregated basin total values rounded to two significant digits to reflect increased uncertainty at larger geographic scales
[2] Arkansas gaps include additional 13,500 AFY for Urban Counties replacement of nonrenewable groundwater supplies.
[3] Metro gaps include additional 20,850 AFY for South Metro replacement of nonrenewable groundwater supplies.

Section 4: Technical Update Water Supply Methodology

As stated in SWSI 2010, the Technical Update provides a more in-depth analyses of historical and climate-adjusted hydrology and analyses of water availability to meet future projected agricultural and municipal diversion demands. The analyses, discussed in more detail below, relied primarily on water allocation models to simulate how climate-adjusted hydrology impacts future demands, and what unappropriated supplies may be available to meet the future projected demands. These Technical Update analyses will improve upon the SWSI 2010 effort by providing:

- Estimates of current and projected future physical streamflow at key locations.
- Estimates of how much the current and projected future agricultural and M&SSI diversion demands are satisfied on average and in a critically dry year; the remaining unmet diversion demand is considered to be the agricultural and M&SSI gap.
- Revised water allocation models in select basins reflecting the Planning Scenario demands and hydrology that can be used for future analysis of potential projects by Basin Roundtables (BRT) to meet the agricultural and M&SSI gap.

The Technical Update focuses on a basin's water supply under projected demands and hydrological conditions using the current municipal and agricultural operations and infrastructure. This differs from the SWSI 2010 effort because it will not look at the projected yield of a specific IPP or how effective that IPP would be in meeting the agricultural and M&SSI gap under the various Planning Scenarios. This approach is recommended because the BRT have taken on the role of looking at solutions to meet their basin needs through the Basin Implementation Planning effort. The BRT is a more appropriate forum to identify, fully vet, and ultimately analyze the ability of a specific IPP to meet demands in the basin under a variety of scenarios. The Technical Update, however, will provide the BRT with the data, tools, and analyses to support future analysis of an IPP.

The overall Technical Update water supply methodology can be separated into two steps. First, it is necessary to develop information for current conditions, providing a "baseline" comparison point for the Planning Scenario results. Next, the future demands and climate-adjusted hydrology are incorporated into the water allocation models. The Planning Scenario models are then simulated and results are used to develop water supply information, including estimates of physical streamflow and the agricultural and M&SSI gap for Planning Scenarios A through E.

4.1 CURRENT/BASELINE WATER SUPPLY METHODOLOGY

The water supply information for current conditions was developed using a "baseline" representation of the diversion demands and operations. A "baseline" representation means that the current agricultural and municipal diversion demands, operations, and infrastructure are in place as if the historical climatic and hydrological conditions will continue again into the future. Reflecting the current water supply in this way, as opposed to summarizing historical conditions over a recent period, was selected for the following reasons:

- It reflects current conditions over a long hydrologic period.
- It allows for a consistent methodology and comparison between the current and Planning Scenario water supply analyses.
- It is recommended by the CWCB as the starting point for "what if" Planning Scenario modeling.
- It has been previously implemented and vetted through the CDSS efforts.

The available data in each basin necessitates a slightly different methodology for analyzing the water supply information. The bulk of the analysis for the current water supply information relied on models and data developed under the CDSS program. In basins where the CDSS program has not been fully implemented, the methodology for those basins was modified based on water supply information that is available. This section discusses the specific methodologies that were used to develop the current "baseline" water supply information for each basin.

4.1.1 CDSS BASIN WATER SUPPLY METHODOLOGY

CWCB has developed water allocation datasets for use with the StateMod modeling platform for several of the basins in the State through the Colorado Decision Support System (CDSS) program. For basins with full CDSS program development, two water allocation datasets have been developed:

1. **Historical Dataset.** This dataset allocates water to meet the historical agricultural and municipal diversion demands in each basin. It contains historical diversions and pumping that reflect administrative and operational constraints on water supply as they occurred over time. This model is calibrated by comparing historical measured diversions, reservoir contents, and streamflow to simulated results; model adjustments are made until there is good correlation between the measured and simulated data. It is an appropriate dataset to look at historical conditions in the basin over an extended period of time.
2. **Baseline Dataset**. This dataset allocates water to meet the current agricultural and municipal diversion demands as if the historical climatic and hydrological conditions were to continue into the future. It reflects current administrative, infrastructure, and operational conditions over the entire study period (e.g. a reservoir constructed in 1985 would be operational for the 1975 – 2013 modeled period). It is an appropriate dataset to use for "what if" Planning Scenarios.

The State of Colorado's Water Allocation Model (StateMod) is a water allocation and accounting model capable of making comparative analyses for the assessment of various historical and future water management policies in a river basin. It is designed to be applied to any river basin through appropriate input data preparation. Note that information used in the modeling datasets is based on available data collected and developed through CDSS, including information recorded by the State Engineer's Office. The model datasets and results are intended for basin-wide planning purposes. Individuals seeking to use the model dataset or results in any legal proceeding are responsible for verifying the accuracy of information included in the model.

StateMod's operation, like the stream itself, is governed by its hydrology, water rights, demands for water, and infrastructure and operations used to deliver water. It recognizes four types of water rights (direct flow rights, instream flow rights, reservoir storage rights, well rights) and also user-specified operational "priorities or rights". Operational priorities or rights generally pertain to complex operations such as reservoir operating policies, exchanges, carrier ditch systems, augmentation or recharge, and changed water rights with associated terms and conditions. Each of the water rights is given an administration number (i.e. ranking) and location in the stream system. The model then sorts the water rights by priority and simulates their operation according to the Prior Appropriation Doctrine (i.e. first in time, first in right) allocating water until all the demands are satisfied or there is no longer physically or legally available streamflow to meet the demand.

The modeling platform is ideal for running "what-if" scenarios because, after it is properly calibrated, the user can include a "what-if" operation in the Baseline model (e.g. revised hydrology or a new demand) and simulate the model to see how the river regime responds with the future operation over a variable hydrology. The results of the changed model are compared to the results of the original Baseline model to assess the impact of the new operation. Figure 3 illustrates the availability of StateMod datasets in each basin.

Several of the CDSS datasets required refinement and/or extension prior to implementing revisions for the Technical Update effort. The following paragraphs summarize basin-specific revisions necessary to prepare the CDSS datasets for Technical Update modeling efforts.

West Slope Basins

The full CDSS program has been developed for the Western Slope basins (i.e. Yampa River, White River, Colorado River, Gunnison River, and Southwest Basins) and the North Platte River basin. The CDSS datasets for the Western Slope basins are available for the 1950 to 2013 period. The Western Slope datasets are available on the CDSS website; minimal modifications were made to these datasets prior to their use in the Technical Update effort. These modifications include revisions to the total acreage and diversions in the Grand Valley Project area in the Colorado River Model and to Cimarron Canal area in the Gunnison River Basin model; removal of diversions for non-irrigation uses for aggregate structures in all datasets; and revisions to the Yampa River Basin to reflect recent modeling efforts undertaken by the Yampa/White/Green Basin Roundtable.

North Platte River Basin

The North Platte River Basin model had not been updated and/or extended since the previous SWSI effort, therefore the Historical and Baseline datasets were extended through 2016 for this effort. During this effort, a total of six irrigation structures and irrigated acreage assessments from 2005 and 2010 through 2016 were added to the models.

South Platte River Basin

Only the Historical dataset was developed through the CDSS effort in the South Platte River Basin, therefore it was necessary to develop the Baseline StateMod dataset for the Technical Update effort. The Baseline StateMod dataset was developed by revising the Historical StateMod dataset to reflect the most current agricultural and municipal diversion demands, infrastructure, and operations over the entire study period. A significant complication in developing the Baseline dataset in South Platte River basin is the complexity of the municipal operations in the basin, both in terms of the municipalities' water portfolio and the flexibility in how the municipalities use their supplies. The Historical dataset in the basin reflects one representation of these operations, a representation that reflects the common municipal operations but may not capture the full operational flexibility that many municipalities have with their water supplies. The representation of the most current municipal operations, water rights, and infrastructure from the Historical model was implemented in the Baseline dataset[1] over the entire study period. The model extent was not expanded in this effort, however, and both the Historical and Baseline datasets exclude the Cache La Poudre River Basin (Water District 3) due to the on-going permitting efforts for projects in the sub-basin. Refer to the discussion below for more information on how the Cache La Poudre water supply information was developed and integrated into the overall South Platte River basin model.

[1] The South Platte River Historical model extends through 2012, and did not include representation of Aurora Water's Prairie Water Project. The Baseline model was revised to include this project, which increased the amount of return flows re-diverted by the project and used within Aurora Water's system in the model.

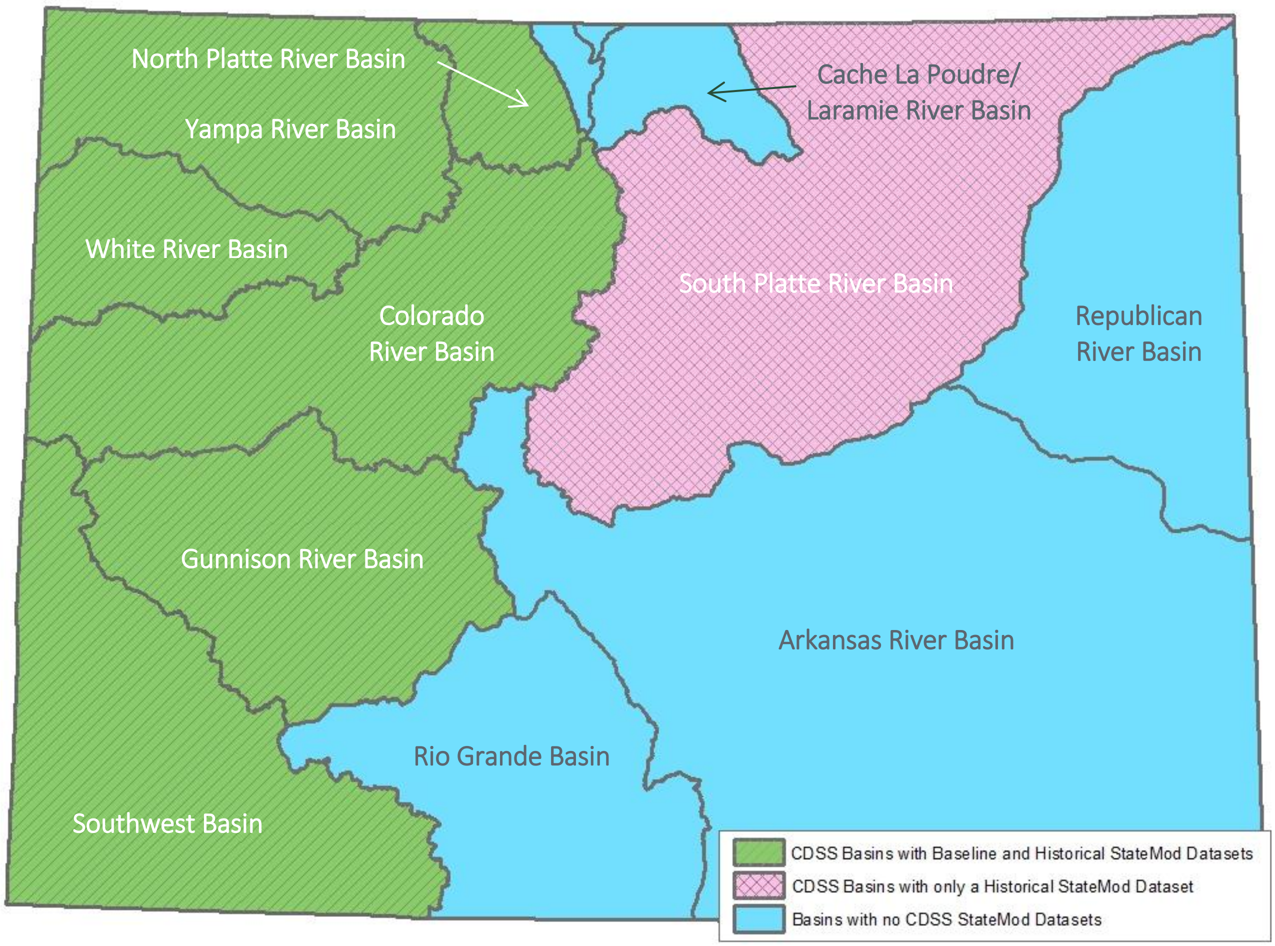


Figure 3: CDSS StateMod Model Availability

Once the CDSS models were refined for the Technical Update effort, the first step was to incorporate the Technical Update current agricultural demands and M&SSI demands into the Baseline Model. These demands were developed by the Technical Update consultant team and documented in the *Current and 2050 Planning Scenario Agricultural Diversion Demand* memorandum and the *Baseline and Projected 2050 Planning Scenario Municipal and Self-Supplied Industrial Water Demands* memorandum, respectively. Refer to Appendix A of this document for more information regarding how the agricultural and M&SSI demands were incorporated into the StateMod datasets. Note that transbasin imports and exports were not revised for the Current or Planning Scenario modeling effort and are represented with their historical records in the model datasets. Additionally, no environmental or recreational "demands" were added to the modeling dataset. The models represent many existing decreed minimum instream flow reach and recreational in-channel diversions (RICD) demands; however those demands were not revised for the Current or Planning Scenario modeling effort.

After incorporating the agricultural and M&SSI demands, the models were simulated over the period beginning in 1975 to the most current year available in the model. The Western Slope datasets extend through 2013, whereas the North and South Platte River Basin datasets extend through 2016 and 2012, respectively. The period of record in all of these basins provides for nearly 40 years of variable hydrology, including the critical drought years of the early and mid-2000s, over which to assess water supply conditions.

Results were extracted from the simulated model datasets and summarized using the standard CDSS data management tools (e.g. TSTool). The following information was extracted from the datasets to reflect current conditions:

1. Simulated monthly physical streamflow at key locations[2] in each basin.
2. Agricultural and M&SSI diversion demands on average and for a critically dry year summarized by Water District and by basin.
3. Agricultural gap and crop demand gap on average and for a critically dry year summarized by Water District and by basin.
4. M&SSI gap on average and for a critically dry year summarized by Water District and by basin.
5. Simulated monthly reservoir contents summarized by Water District and by basin.
6. Simulated unappropriated available supply at key locations in each basin, if the basin is not over-appropriated.

4.1.2 NON-CDSS BASIN WATER SUPPLY METHODOLOGY

There are four basins where a StateMod water allocation model has not been developed; the Arkansas, Republican, Rio Grande, and Cache La Poudre/Laramie River basins. These are also perhaps the four basins with the most limited water availability. As such, a full water allocation model is not necessary to understand the water availability in the basin; historical data can be used to estimate the current water supply information in the basin at a level sufficient for the Technical Update planning effort.

As with the CDSS Basin Water Supply Methodology, the agricultural and M&SSI demands in these basins were developed by the Technical Update consultant team and documented in the *Current and 2050 Planning Scenario Agricultural Diversion Demand* memorandum and the *Baseline and Projected 2050 Planning Scenario Municipal and Self-Supplied Industrial Water Demands* memorandum, respectively. The following sections summarize the approach used in each basin to develop the agricultural and M&SSI gap and water supply information for current conditions.

Republican River Basin

The Republican River basin is subject to the Republican River Compact of 1942, which governs the amount of beneficial consumptive use allowed in the basin. As the basin has almost no surface water diversions or reservoirs, the consumptive use in the basin is a result of irrigation from ground water supplies. Current levels of irrigation in the basin result in consumptive use that exceeds this allocation, therefore the basin is undergoing reductions to pumping and irrigated acreage, and the Compact Compliance Pipeline is being constructed to deliver ground water to the Stateline to bring the basin into compliance. As the basin is already over-appropriated, there is not consistent unappropriated surface or ground water available for a new water right in the basin. Current water supply information in the Republican River basin was developed primarily using historical information available from the Republican River Compact Accounting:

- Current agricultural gap was estimated to be the difference between the current agricultural diversion demand and historical pumping estimates.

[2] Key locations were selected in coordination with the Technical Update Environmental and Recreational consultant team to support analyses of projected streamflow in the Environmental Flow Tool. Refer to the Technical Update Environmental Flow Tool memorandum for more information on how the key locations were selected and environmental and recreational analysis of the resulting streamflow.

- Current crop demand gap was estimated as the difference between the historical IWR and WSL.
- The current M&SSI diversion demand was assumed to be fully satisfied and the current M&SSI gap was set to zero.

Arkansas River and Rio Grande Basins

Water availability in the Arkansas and Rio Grande basins is severely restricted by each basin's interstate agreements and compacts. In the Arkansas River basin the 1948 Arkansas River Compact restricts water use by post-1948 water rights to times when there would be no depletions to the usable Stateline flows. Those times only occur when flows are high enough to cause John Martin Reservoir to spill, which has only occurred 5 years since 1971.

The Rio Grande basin's compacts include the Rio Grande Compact of 1938, the Rio Grande, Colorado, and Tijuana rivers treaty of 1945 between the U.S. and Mexico, and the Amended Costilla Creek Compact of 1963. Although these compacts and agreements are complex, their administration effectively limits unappropriated water in the basin only to times when Elephant Butte Reservoir spills. This has occurred less than 10 times over the past 60 years.

Under these restricted conditions, there is not consistent unappropriated surface or ground water available for a new water right in either the Arkansas or Rio Grande basins. Current water supply information in these basins was developed primarily using historical information:

- Current agricultural gap was estimated to be the difference between the current agricultural diversion demand and the combined historical diversions and pumping.
- Current crop demand gap was estimated as the difference between the historical IWR and WSL.
- The current M&SSI diversion demand was assumed to be fully satisfied and the current M&SSI gap was set to zero.

Cache La Poudre and Laramie River Basins

The Cache La Poudre and Laramie River basins are located in north-central Colorado. The Laramie River basin flows north out of Colorado where it meets the North Platte River in Wyoming. The basin has a relatively small amount of irrigated acreage; however it does export a significant amount of water to the Cache La Poudre River via the Laramie-Poudre Tunnel. Diversions in the basin are limited by the Laramie River Decree of 1957.

The Cache La Poudre River flows southeast to its confluence with the South Platte River near Greeley. There is significant irrigation and municipal development in the basin, including several off-channel storage facilities. These basins were not included in the original South Platte River StateMod modeling effort due to the ongoing planning and permitting efforts of several large storage projects in the basin. Current water supply information in these basins was developed primarily using historical information:

- Current agricultural gap was estimated to be the difference between the current agricultural diversion demand and the combined historical diversions and pumping.
- Current crop demand gap was estimated as the difference between the historical IWR and WSL.
- The current M&SSI diversion demand was assumed to be fully satisfied and the current M&SSI gap was set to zero.

Although the methodologies for developing current water supply information in each of these basins differs from the CDSS basins, they provide an appropriate estimate of physical streamflow, water availability, and agricultural gap for current conditions for comparison to the Planning Scenario results.

4.2 PLANNING SCENARIO A-E WATER SUPPLY METHODOLOGY

The Colorado Water Plan presented five Planning Scenarios designed by the Interbasin Compact Committee (IBCC) to capture how Colorado's water future might plausibly look in 2050. The IBCC used five key drivers to adjust the relative demand and available water supply, as shown in Figure 4 below, to ultimately develop the five Planning Scenarios.

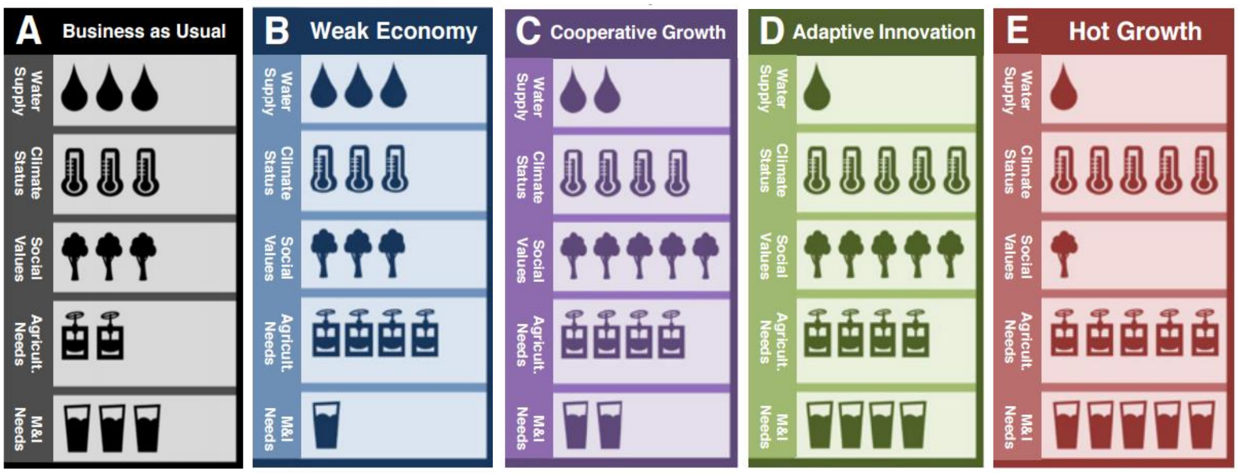


Figure 4: 2050 Planning Scenario Descriptions

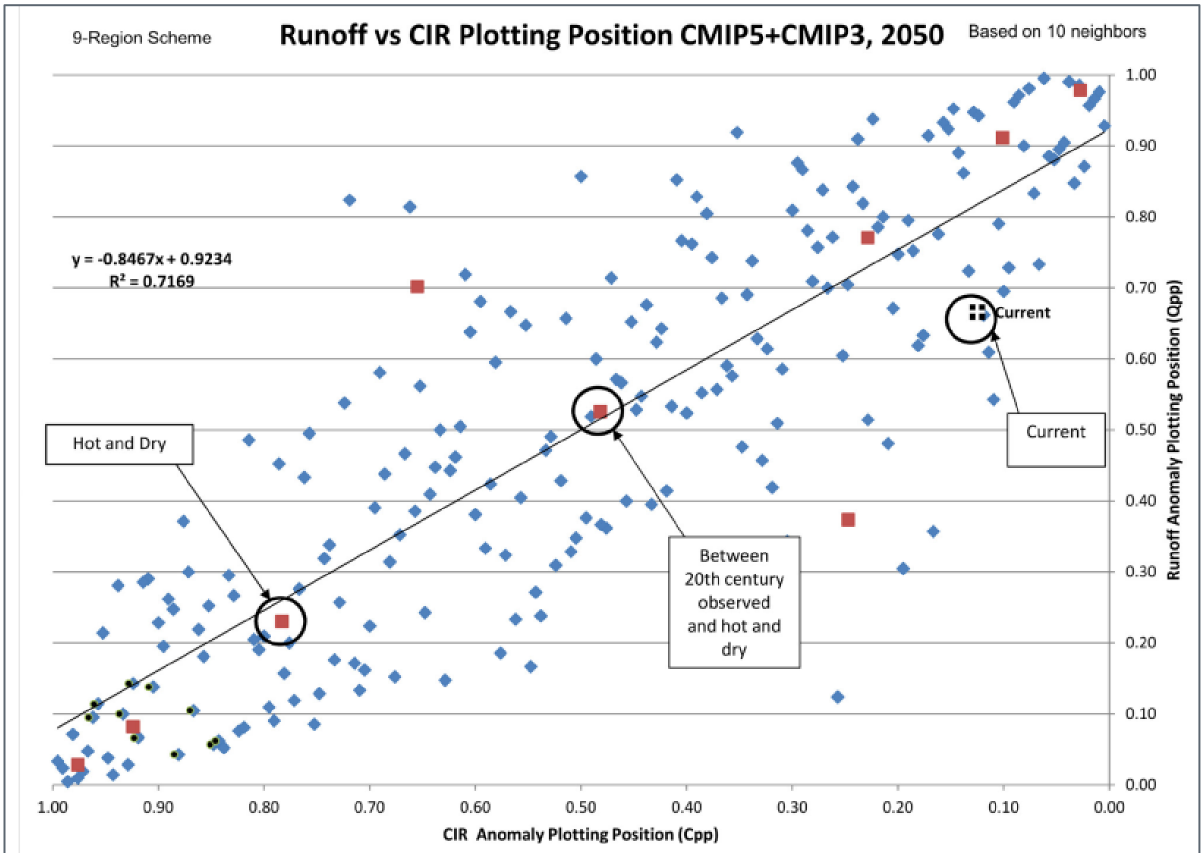
As depicted, "Water Supply" is a key driver in developing the overall Planning Scenarios, and the relative supply associated with this driver varies between each scenario (e.g. five water droplets reflects a larger water supply than two water droplets). Language associated with the graphics in the Colorado Water Plan provides information as to how the IBCC contemplated adjusting the water supply in the Planning Scenarios. The purpose of this section is to discuss how water supply was adjusted in each Planning Scenario and summarize the approach used in developing the projected 2050 water supply information for each Planning Scenario.

4.2.1 PLANNING SCENARIO WATER SUPPLY ADJUSTMENTS

CWCB has undertaken several studies and investigations on the impact of climate projections on the future of water use in Colorado. Most notably was the development of the Colorado Climate Plan (CCP), which focuses on observed climate trends, climate modeling, and climate and hydrology projections to assist with the planning and management of water resources in Colorado. The CCP discusses the most recent global climate projections (CMIP5) and recommends the integration of these results with the previous global climate projections (CMIP3) to provide a representative range of potential future climate and hydrological conditions.

Supported by the information from the CCP, the IBCC chose to incorporate the impact of climate change and selected two future potential climate projections for the Planning Scenarios. As reflected in the graphic below from the Colorado Water Plan (Figure 5), the IBCC selected a group of climate projections representative of "Between 20th Century Observed and Hot and Dry" conditions (referred to as "In-Between") and another group of projections representative of "Hot and Dry" conditions. The climate projections included both projected changes to IWR and changes to hydrology.

Figure 5: Climate Projections selected by IBCC



"Hot and dry" is defined as the 75th percentile of climate projections for crop irrigation requirements (water use), and the 25th percentile for natural flows. In other words, only 25 percent of projections have lower natural flows and 25 percent of projections have higher crop irrigation requirements. "Between 20th century-observed and hot and dry" is defined as the 50th percentile for both natural flows and crop irrigation requirements. This scenario represents the middle of the range in terms of severity. Historical or current conditions, which represents no change in runoff or in crop irrigation requirements, fall at roughly the 9th and 67th percentiles; this means that 91 percent of runs show increases in crop irrigation requirements and about two-thirds show reductions in runoff.

The effort associated with processing the projected climate data and downscaling the information for use at the Water District level was completed through the CRWAS-II project. Refer to the CRWAS-II documentation, including the *Temperature Offsets and Precipitation Change Factors Implicit in the CRWAS-II Planning Scenarios* memorandum and *Colorado River Availability Study Phase II Task 7: Climate Change Approach and Results*, for more information on the projected climate conditions. The CRWAS-II effort resulted in a time series of climate-adjusted hydrology at over 300 streamflow gage locations statewide for each climate projection. The hydrology reflects "natural flow", which is the amount of water in the river absent the effect of man and serves as the foundation of the StateMod water allocation models. Although the impact of the climate projections varies across the state, natural flow under the climate projections generally show an overall decline and shift temporally to reflect earlier runoff periods.

Using the "Water Supply" driver under each Planning Scenario as a guide, Table 3 reflects the recommended assignment of projected climate conditions for Planning Scenarios A-E. The methodology for incorporating the climate-adjusted natural flow in the Planning Scenario allocation models is discussed in more detail below.

Table 3: Climate Projection Assignment to Planning Scenarios

Planning Scenario	A. Business as Usual	B. Weak Economy	C. Cooperative Growth	D. Adaptive Innovation	E. Hot Growth
Climate Projection	Current	Current	In-Between	Hot and Dry	Hot and Dry

4.2.2 CDSS BASIN PLANNING SCENARIO WATER SUPPLY METHODOLOGY

The Planning Scenario water supply information will be developed using an approach similar to that described in Section 4.1, which was used to develop the current water supply information. The Planning Scenario water supply information, however, will be developed using projected 2050 agricultural and M&SSI demands specific to each Planning Scenario and, in some scenarios, climate-adjusted hydrology. Once the Planning Scenario datasets are developed, they can be simulated and the results can be compared to the current water supply information to assess the impact of the projected demands and hydrology. This section outlines the approach that will be used to develop the Planning Scenario A through E StateMod models and water supply information.

The Baseline StateMod datasets developed for the current water supply analysis serve as the starting point for the Planning Scenario datasets. The following steps were taken to develop the Planning Scenario StateMod datasets and ultimately the water supply information:

1. Incorporate the appropriate 2050 Planning Scenario agricultural diversion demands into the Planning Scenario models.
2. Incorporate the appropriate 2050 Planning Scenario M&SSI diversion demands into the Planning Scenario models.
3. Incorporate the appropriate climate-adjusted natural flow into the Cooperative Growth, Adaptive Innovation, and Hot Growth Planning Scenario models; Business as Usual and Weak Economy reflect the current hydrology as if it were to occur again into the future.
4. Simulate the Planning Scenario models.
5. Extract the monthly physical streamflow and water availability at key locations in each basin.
6. Summarize the M&SSI gap by Water District and by basin on average and for critically dry years.
7. Summarize the agricultural gap and crop demand gap by Water District and by basin on average and for critically dry years.
8. Summarize total storage by Water District and by basin over the modeled period.

In select basins, additional information was extracted from the models to provide an estimate of how much water may be available from changed irrigation water rights associated with land undergoing urbanization, and an estimate of how much transbasin water may not be available to be delivered (i.e. transbasin import supply gap) due to changes in physically or legally available supplies in the exporting basin.

Note that the Planning Scenario StateMod datasets incorporate the projected hydrology and demands with the Baseline representation of the basins' infrastructure and operations. Adjustments to other modeling parameters, such as order of supplies used to meet municipal diversion demands or alternative methods for conveying water, were not be made in the Planning Scenario datasets under this effort. This effort will produce a set of Planning Scenario StateMod datasets that can be further refined in subsequent analyses to investigate future projects or operations that may help alleviate agricultural or M&SSI gaps or achieve other river basin goals.

4.2.3 NON-CDSS BASIN PLANNING SCENARIO WATER SUPPLY METHODOLOGY

The absence of basin-wide planning models in these basins limits the options to evaluate the projected demands and hydrology in the non-CDSS basins. Many models that have been created for these basins reflect historical conditions (i.e. point flow models); reflect only a portion of the basin; are proprietary models developed by water users and not available for use; have only been partially calibrated; or do not contain sufficient detail/resolution to evaluate the projected demands and hydrology. As such, these existing models are not conducive to implementing the “what-if” Planning Scenario conditions; however, they do provide information on the basin operations which can be used in developing the Planning Scenario water supply information. An additional consideration is that these basins are generally the most over-appropriated basins in the state. As such, any agricultural or M&SSI demands above and beyond current levels cannot be met from unappropriated supplies in the basin and are considered a gap. The following discussion summarizes how the water supply information was developed in these basins.

Republican River Basin

Development of Planning Scenario water supply information in the Republican River basin is unique in that the general absence of surface water diversions in the basin means that climate-adjusted hydrology will not impact the amount of surface water diverted for agricultural uses. Ground water supplies will be affected by the climate-adjusted hydrology; however, that interaction was not contemplated under this Technical Update effort. Due to the limited streamflow in the basin, specific climate-adjusted hydrology estimates were not explicitly developed for gages in the Republican River basin.

For the Republican River basin, the current levels of ground water supplies serve as the maximum available water supply in the basin into the future and it was assumed that no unappropriated surface or ground water supplies will be available in the future. As such, any projected demands in the basin greater than these supplies are reflected in the gap. Additionally, it was assumed that current irrigation practices, in which irrigators pump less than the full amount needed be the crops (i.e. deficit pumping) will continue into the future, as supported through discussions with stakeholders in the basin. Based on these assumptions, projected water supplies in the Republican River basin were estimated as follows:

- Planning Scenario unappropriated available supply was set to zero.
- Planning Scenario agricultural gap and crop demand gap was estimated as the difference between the Planning Scenario agricultural diversion demand and the current levels of agricultural pumping on average and for critically dry years.
- Planning Scenario municipal gaps were estimated as the difference between the Planning Scenario M&SSI demand and the current M&SSI demand on average and for critically dry years.

Arkansas River and Rio Grande Basins

Development of Planning Scenario water supply information in these basins relied heavily on historical water availability results in the basin, assuming that because the basins are over-appropriated, water availability would continue into the future at similar levels or decline under climate-adjusted Planning Scenarios. As such, agricultural gaps for the Business as Usual and Weak Economy Planning Scenarios were based on shortages experienced historically. For the remaining climate-adjusted Planning Scenarios, the change in hydrology at key locations was used to adjust the historical shortages. For example, the change in hydrology at the Alamosa River above Terrace Reservoir gage location was used to adjust (i.e. increase) the historical shortages to agricultural demands in the Alamosa River sub-basin for the climate-adjusted scenarios.

M&SSI gaps in Planning Scenarios were set equal to the incremental increase of the Planning Scenario demand compared to the Baseline demand, based on the premise no unappropriated supplies would be available in the basin to meet the increased demand.

Change in simulated flow and storage for the Planning Scenarios could not be accurately estimated, however the change in natural flow at key locations throughout the basin was provided to illustrate the potential impact of the changed hydrology to streamflow and storage conditions.

Cache La Poudre and Laramie River Basins

Although these basins do not have the full suite of CDSS modeling tools available, model results from neighboring sub-basins with similar levels of irrigated acreage, municipal demands, storage, and transbasin supplies, can be used to inform and adjust the Planning Scenario results in these basins. This approach allows the Planning Scenario results in these basins to be adjusted in response to the Planning Scenario adjustments, including increased M&SSI demands, reduced agricultural demands, and reduced hydrology, without simulated the full river operations. The following approach was used to develop water supply information in these basins:

- The Planning Scenario agricultural gap was based on the current agricultural gap, and then adjusted based on the gap results from neighboring sub-basins in each Planning Scenario.
- The Planning Scenario M&SSI gap was assumed to be similar to M&SSI gaps experienced in neighboring sub-basins, particularly in sub-basins in which the municipal supplies are similar (e.g. Colorado-Big Thompson supplies, changed water rights, storage).
- The outflow from the Cache La Poudre River to the South Platte River was based on historical streamflow for the Business as Usual and Weak Economy scenarios; and adjusted with the hydrology factors in Planning Scenarios with climate-adjusted hydrology.

The Planning Scenario water supply information from the Cache La Poudre and Laramie River basins was then incorporated into the overall South Platte River and North Platte River basin results, respectively.

4.3 EXPLANATION OF RESULTS

Water supply and gap results from the Baseline and Planning Scenarios are summarized by basin and Statewide in the sections below. The sections provide the results in both graphical and tabular format; additional discussion and observations on the results are also provided. The results are presented in the same order in each basin:

1. Agricultural results (green color-coding)
2. M&SSI results (orange color-coding)
3. Transbasin results (blue color-coding)

Agricultural and M&SSI demand and gap results presented in a tabular format in each section contain the following standard categories. Refer to the explanation for information on how the data in each category was calculated.

Result Table Category	Explanation
Average Annual Demand (ac-ft)	Total annual demand in the basin, averaged over model period of record
Average Annual Demand Increase from Baseline (ac-ft)	Planning Scenario average annual demand minus Baseline demand; set to zero if Planning Scenario demand is less than Baseline demand
Average Annual Gap (ac-ft)	Total annual gap in the basin, averaged over model period of record
Average Annual Gap Increase from Baseline (ac-ft)	Planning Scenario average annual gap minus Baseline gap; set to zero if Planning Scenario gap is less than Baseline gap
Average Annual Percent Gap	Average annual gap divided by the average annual demand
Average Annual CU Gap (ac-ft)	Only available for agricultural demands; average annual amount of shorted IWR; estimate of lost crop yield.
Demand In Maximum Gap Year (ac-ft)	Demand that occurred in the year with the largest gap; note that it may not represent the maximum demand for the entire period of record
Increase from Baseline Demand (ac-ft)	Planning Scenario demand in maximum gap year minus Baseline demand in maximum gap year; set to zero if Planning Scenario demand is less than Baseline demand
Gap In Maximum Gap Year (ac-ft)	Maximum gap volume by basin; may not occur in the same year statewide
Increase from Baseline Gap (ac-ft)	Planning Scenario maximum gap minus Baseline maximum gap; set to zero if Planning Scenario gap is less than Baseline gap
Percent Gap In Maximum Gap Year	Maximum gap divided by demand that occurred in the same year

Transbasin diversions, both imports and exports, are reflected in the model at their historical levels and were not assumed to vary across Planning Scenarios. Understanding how water providers may change their operations under the projected demands or climate-adjusted hydrological conditions was beyond the scope of this effort, therefore historical operations were maintained. The transbasin export demand is included in the total basin demands for basins that export transbasin supplies. In some instances, the full transbasin demand could not be diverted in the source basin due to a physical or legal limitation of water supply at the diverting location. This is caused by changes in water availability, increases in senior demands in the source basin, or a combination of both. When this occurs, the resulting shortage to the demand is reported as a transbasin import supply gap in the destination basin. Similar to the table above, the import supply gap results are summarized both on an average annual basis and for critically dry years. The import supply gap results are provided for informational purposes; the import supply gap would have the effect of increasing the overall gap in the destination basin, however this was not directly applied to the gap values.

All basins are projected to experience urbanization of irrigated acreage, or acreage that is projected to come out of production due to municipal growth, in at least one of the Planning Scenarios. Supplies used to irrigate the urbanized acreage could be considered a new municipal supply if the associated water rights were changed to municipal uses. To capture the amount of water associated with this potential new supply, the average annual consumptive use of the urbanized acreage was estimated and provided for each basin. There are several uncertainties as to whether the urbanized supply would or could directly be used to offset M&SSI demand, therefore the historical consumptive use values were not directly applied to the gap values.

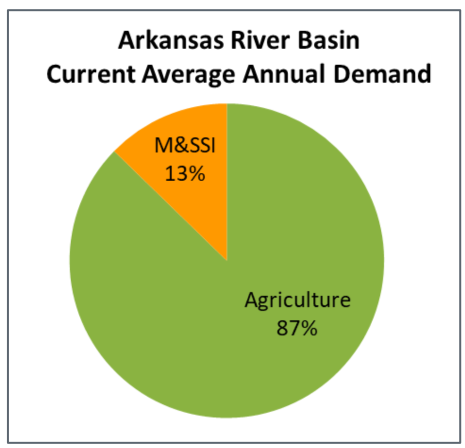
Time series information for the Baseline and Planning Scenarios is primarily presented either on a monthly basis over the model period of record (e.g. storage contents) or as average monthly values (e.g. simulated streamflow). The colors in these graphics used to represent Baseline and Planning Scenario results are consistent throughout the document. As discussed in the basin summaries below, results from the Weak Economy (green line) are often overlapping the Business as Usual (maroon line) and Baseline (black line) results. Note that natural flow information, as opposed to simulated streamflow information, is presented for the Arkansas River and Rio Grande basins. The graphics reflecting these natural flows only include results from the Current, In-Between, and Hot and Dry hydrological conditions and are displayed with a different color scheme.

Section 5: Water Supply and Gap - Basin Summary Results

This section summarizes the water supply and gap results for each basin; refer to Figure 2 for a map of each basin boundary. The total Statewide water supply and gap results are provided in Section 6.

5.1 ARKANSAS RIVER BASIN

The majority of the water in the Arkansas River basin is used to irrigate over 472,000 acres, with nearly half of these acres located along the river between Pueblo Reservoir and the stateline. Many of the large irrigation systems in this area rely on surface water diversions from the mainstem Arkansas River, supplemented with ground water and Fryingpan-Arkansas Project[3] deliveries. The basin also provides water to three of the fastest growing municipalities in the state, Colorado Springs, Aurora, and Pueblo, and competition for water is high. An over-appropriated basin coupled with the constraints of developing new water supplies under the Arkansas River Compact have historically led municipalities to purchase and transfer irrigation water rights to municipal uses to meet their growing needs. In the 1980s, large transfers of irrigation water rights in the Twin Lakes Reservoir and Irrigation Canal Company resulted in the dry up of 45,000 acres in Crowley County alone. More recently, however, the basin has been proactive at looking for solutions to share water supplies and has been one of the front-runners in developing alternative transfer methods, lease/fallow tools, and interruptible supply agreements in which irrigation rights can be temporarily leased to municipalities for a limited number of years (e.g. 3 years out of every 10 years).



The following sections describe the agricultural and M&SSI demands in the Arkansas River basin in more detail. Figure 6 reflects the basin outline, the administrative boundaries of

[3] The Fryingpan-Arkansas Project is a transbasin diversion project that diverts an average of 69,000 acre-feet annually from the Colorado River Basin and delivers water for municipal, industrial, and supplemental irrigation purposes in the Arkansas River Basin.

water districts, and the streamflow gages highlighted in the results section below.

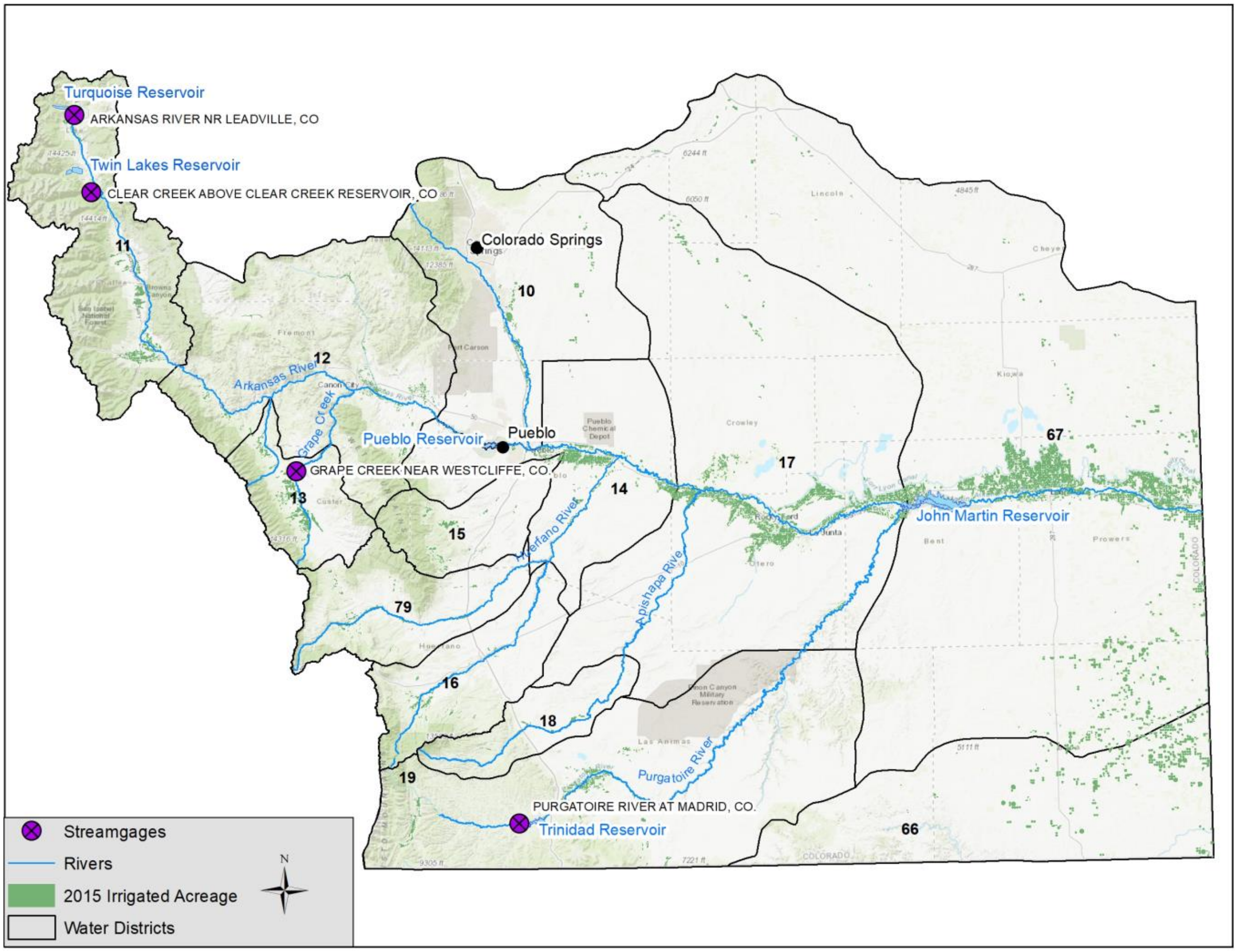


Figure 6: Arkansas River Map with Streamgage Locations

5.1.1 ARKANSAS RIVER BASIN AGRICULTURE WATER SUPPLY AND GAP

As mentioned above, a majority of the irrigated acreage in the basin is located between Pueblo Reservoir and the stateline. The fertile soils in this river valley support a wide variety of crops, including pasture grass, alfalfa, corn, grains, wheat, fruits, vegetables, and the renown Rocky Ford melons. Fields in the area are still predominantly flood irrigated, however producers are converting to drip and sprinkler irrigation methods. Pasture grass is the predominant crop grown outside of the Arkansas River Valley, with concentrated areas of irrigated acreage under the Trinidad Project on the Purgatoire River; along Fountain Creek downstream of Colorado Springs; and in the southeastern corner in the Southern High Plains ground water management area.

The resulting Arkansas River Basin agricultural diversion demands, demand gaps, and consumptive use gap results for the baseline and Technical Update Planning Scenarios are presented in Table 4. As discussed in the *Current and 2050 Planning Scenario Agricultural Diversion Demand* technical memorandum, 2050 agricultural diversion demands are influenced by a number of drivers, including climate, urbanization, and emerging technologies.

Table 4: Arkansas River Basin Agricultural Water Supply and Gap Summary

	Agricultural Results	Baseline	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand (ac-ft)	1,899,894	1,778,323	1,770,230	1,878,883	1,721,160	1,918,022
	Average Annual Demand Increase from Baseline (ac-ft)	-	-	-	-	-	18,128
	Average Annual Gap(ac-ft)	617,289	586,445	585,246	701,659	734,783	819,461
	Average Annual Gap Increase from Baseline (ac-ft)	-	-	-	84,370	117,494	202,172
	Average Annual Percent Gap	32%	33%	33%	37%	43%	43%
	Average Annual CU Gap (ac-ft)	313,135	297,056	296,423	362,464	381,457	425,265
Critically Dry Maximum	Demand In Maximum Gap Year (ac-ft)	2,303,894	2,152,059	2,141,540	2,149,344	1,932,665	2,157,896
	Increase from Baseline Demand (ac-ft)	-	-	-	-	-	-
	Gap In Maximum Gap Year (ac-ft)	1,446,435	1,369,579	1,366,564	1,532,028	1,566,087	1,749,833
	Increase from Baseline Gap (ac-ft)	-	-	-	85,594	119,652	303,398
	Percent Gap In Maximum Gap Year	63%	64%	64%	71%	81%	81%

All of the Planning Scenarios reflect a reduction of approximately 20,000 irrigated acres due to the projected urbanization and/or municipal transfer of water rights; an additional reduction ranging from approximately 7,500 to 26,000 irrigated acres across the Planning Scenarios associated with projected ground water sustainability concerns; and projected sprinkler development in the Arkansas River Valley. These Planning Scenario adjustments lead to a 122,000 ac-ft reduction in average agricultural demand in the Business as Usual Planning Scenario, and an additional 8,000 ac-ft reduction in the Weak Economy scenario compared to the Baseline demand. The impact of reducing irrigated acreage is nearly offset by the climate adjustments to IWR and additional sprinkler development in the southeast corner of the basin in the Cooperative Growth scenario, resulting in an agricultural demand only 2 percent less than the Baseline scenario demand. The Adaptive Innovation Planning Scenario, however, is substantially less than the Baseline scenario despite the projected increase from climate-adjusted IWR factors because of the improved system efficiency adjustment attributable to Emerging Technologies. The combined impact from these factors leads to a 10 percent reduction to agricultural demand in the Adaptive Growth scenario compared to the Baseline scenario. The Hot Growth scenario reflects the largest demand due to the climate adjustments and is the only scenario in which the agricultural demand is greater than the Baseline scenario demand.

Development of the Arkansas River Decision Support System is currently underway and future Technical Updates will have the benefit of using the full suite of models to evaluate water availability in the basin. For this effort, a basin-wide historical and baseline consumptive use model were developed to better understand existing agricultural demands and shortages, however a surface water model was not available. As such, shortages from the consumptive use model were relied upon to inform the gap in the Baseline, Business as Usual, and the Weak Economy Planning Scenarios. The agricultural demands basin-wide have historically experienced a 32 percent gap on average. If current climate conditions occur again in the future as contemplated in the Baseline, Business as Usual and Weak Economy scenarios, the projected gaps for these scenarios are likely to be similar to the historical gap. The gap results for the critically dry year were developed in a similar fashion, however only using gap information for drought years in each Water District, resulting in a basin-wide average gap of 63 percent for the three scenarios.

For the Cooperative Growth, Adaptive Innovation, and Hot Growth scenarios that reflect a change in hydrology, the gap values needed to be further adjusted. In order to capture the combined impact of the climate adjustment in the basin, it would be necessary to simulate the basin operations with the climate-adjusted hydrology in a surface and ground water model. As that level of modeling was beyond the scope of this Technical Update, a simplified approach was developed that captured the change in hydrology and translated the change to a gap value. Refer to the Water Supply Methodology section above for more information on the approach; however, in short, the average decline in runoff at a representative streamflow gage was used to increase the projected gap for these scenarios. This approach assumes that irrigated acreage served by surface and ground water experience a similar shortage due to a decline in runoff volume because a reduction to surface water supplies would result in a reduction of diversions to irrigated land and diversions for augmentation and recharge to offset ground water pumping. On average, the decline in total runoff volume for the Cooperative Growth scenario increases the gap to 37 percent, and to 43 percent for the Adaptive Innovation and Hot Growth scenarios. The following bar graphs reflect the average and maximum gaps in critically dry years for each Planning Scenario. The gaps increase to 71 and 81 percent for the scenarios, respectively, in critically dry years as reflected in the annual agricultural gap time series below (Figure 9).

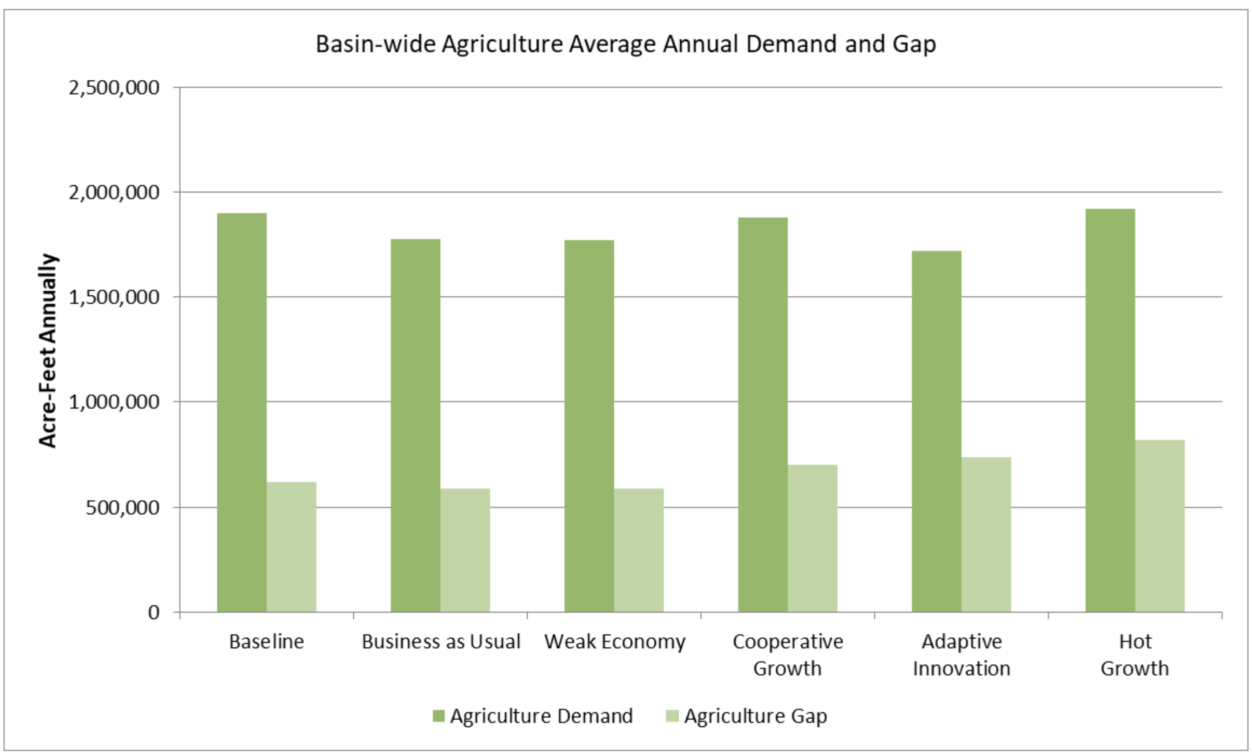


Figure 7: Arkansas River Basin Agriculture Average Annual Demand and Gap

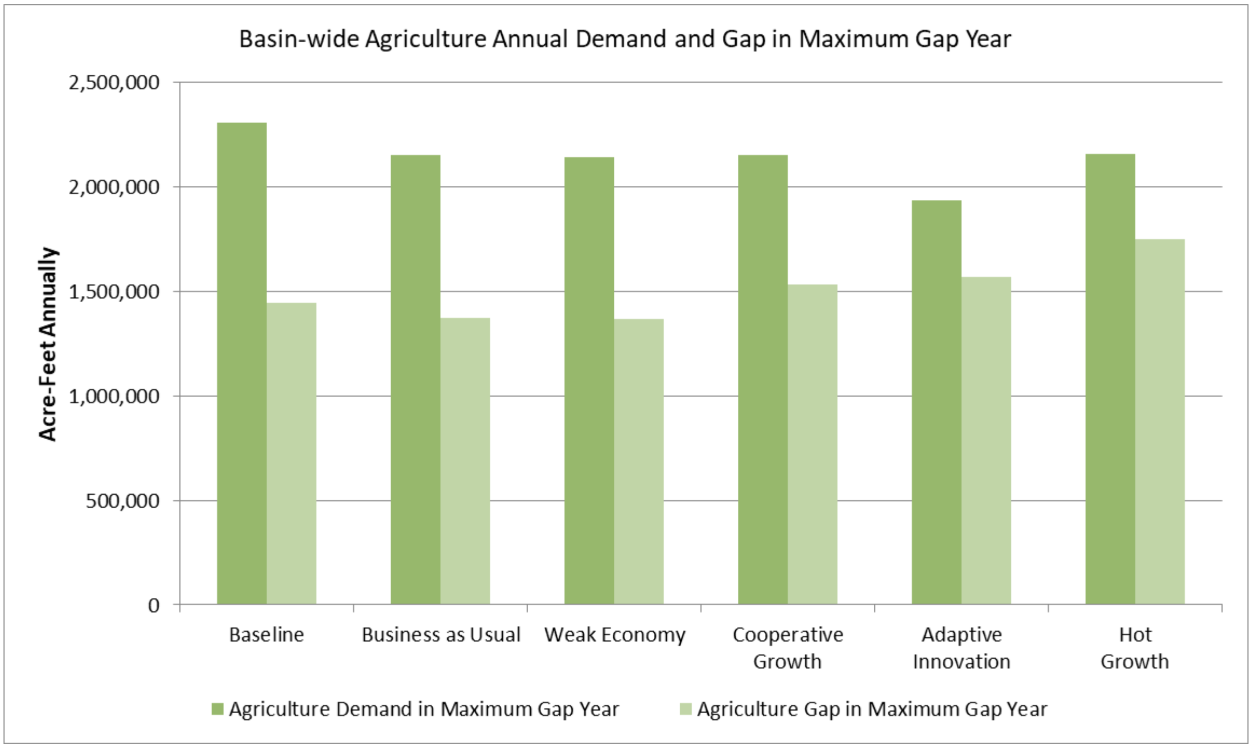


Figure 8: Arkansas River Basin Agriculture Annual Demand and Gap in Maximum Gap Year

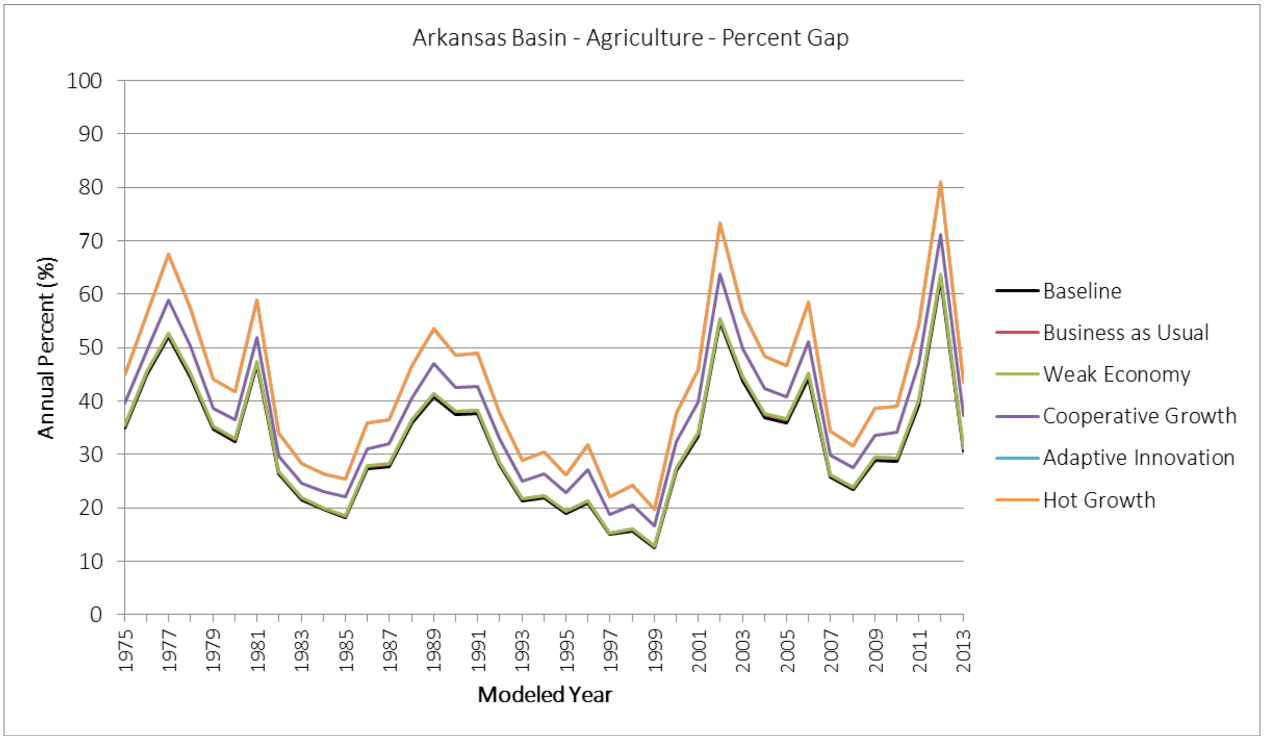


Figure 9: Arkansas River Basin Agriculture Percent Diversion Gap Times Series

5.1.2 ARKANSAS RIVER BASIN M&SSI WATER SUPPLY AND GAP

M&SSI demands in the Arkansas represent approximately 13 percent of the total demand in the basin, substantially lower than agricultural demand. Municipal demands currently account for approximately 80 percent of the total M&SSI demand, with the remaining portion attributable to Large Industrial and Energy Development SSI demands. Municipal demands are largest in El Paso and Pueblo County, and the municipal demand in these counties is projected to significantly grow in the future. Refer to the *Baseline and Projected 2050 Planning Scenario Municipal and Self Supplied Industrial Water Demands* technical memorandum for additional discussion on how the M&SSI demands in the basin were developed. The water supply and gap results for M&SSI in the Arkansas River basin are summarized in Table 5, and graphically reflected in Figure 10 and Figure 11.

Table 5: Arkansas River Basin Municipal and Self Supplied Industrial Water Supply and Gap Summary

	M&SSI Results	Baseline	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand (ac-ft)	276,738	363,259	347,886	353,203	357,647	403,486
	Average Annual Demand Increase from Baseline (ac-ft)	-	86,521	71,148	76,465	80,909	126,748
	Average Annual Gap (ac-ft)	-	68,521	53,148	58,465	62,909	108,748
	Average Annual Gap Increase from Baseline (ac-ft)	-	68,521	53,148	58,465	62,909	108,748
	Average Annual Percent Gap	0%	19%	15%	17%	18%	27%
Critically Dry Maximum	Demand In Maximum Gap Year (ac-ft)	276,738	363,259	347,886	353,203	357,647	403,486
	Increase from Baseline Demand (ac-ft)	-	86,521	71,148	76,465	80,909	126,748
	Gap In Maximum Gap Year (ac-ft)	-	68,521	53,148	58,465	62,909	108,748
	Increase from Baseline Gap (ac-ft)	-	68,521	53,148	58,465	62,909	108,748
	Percent Gap In Maximum Gap Year	0%	19%	15%	17%	18%	27%

Population is projected to increase in the Arkansas River basin in all Planning Scenarios, driven by the increase in population in the two most populous counties, El Paso and Pueblo County. Population is also expected to increase in the headwaters of the basin, but remain relatively constant or decline in counties on the eastern plains. Population increases for municipalities in the basin range from approximately 454,000 to 618,000 people across the Planning Scenarios, with the highest population projected to occur in the Adaptive Innovation scenario. Overall, the population and M&SSI Planning Scenario adjustments, including climate adjustments, captured in each county's projected per capita demand combine to increase the M&SSI demand compared to the Baseline demand.

A simplified approach to estimating the M&SSI gap was taken in the Arkansas River Basin. As neither surface nor ground water supplies are projected to be available to meet increases in demand in the future due to Compact administration and declining aquifer levels, for many M&SSI users the Baseline demand served as the maximum amount of demand expected to be met in the future. Larger M&SSI providers, such as Colorado Springs Utilities, may have additional existing supplies they can reasonably expect to grow into, however these are limited and projected M&SSI gaps in the Planning Scenarios remain. Therefore, any increases to the demand beyond growth into existing supplies[4] can reasonably be

[4] Colorado Springs' current demand was estimated for this effort to be approximately 77,000 ac-ft annually, calculated based on the municipality's current population as a percentage of the total El Paso County population multiplied by the total current El Paso County M&SSI demand. This is less than Colorado Springs Utilities' (CSU) estimated current demand of 88,000 ac-ft annually in the CSU Integrated Water Resources Plan (IWRP), as the assumptions for the IWRP demand differ from those used for the Technical Update. With this consideration in mind, the IWRP indicates CSU's current system can reliably meet 95,000 ac-ft of demand annually; resulting in an estimated 18,000 ac-ft of existing supplies that may be available to meet future demands. Pueblo Board of Water Works did not provide an estimate for growth into existing supplies, and therefore was not accounted for in the gap.

considered an M&SSI gap. This simplified approach does not take into consideration the shift of population and demand within the basin (i.e. decline of population in one county and an increase in population in another county), which may indicate a specific area may experience a larger gap in the future. Additionally, it also does not take into consideration the types of existing supplies that larger providers (e.g. storage, transbasin supplies, changed irrigation water rights) may grow into, and whether those supplies are available in critically dry years or in climate-adjusted Planning Scenarios. As such, the gap may be under-estimated based on this approach.

With this in mind, even the smallest basin-wide gap of approximately 53,000 ac-ft for the Weak Economy scenario is substantial. The M&SSI gaps increase moderately in the Business as Usual, Cooperative Growth, and Adaptive Innovation scenarios, but the M&SSI gaps double in the Hot Growth scenario compared to the Weak Economy scenario.

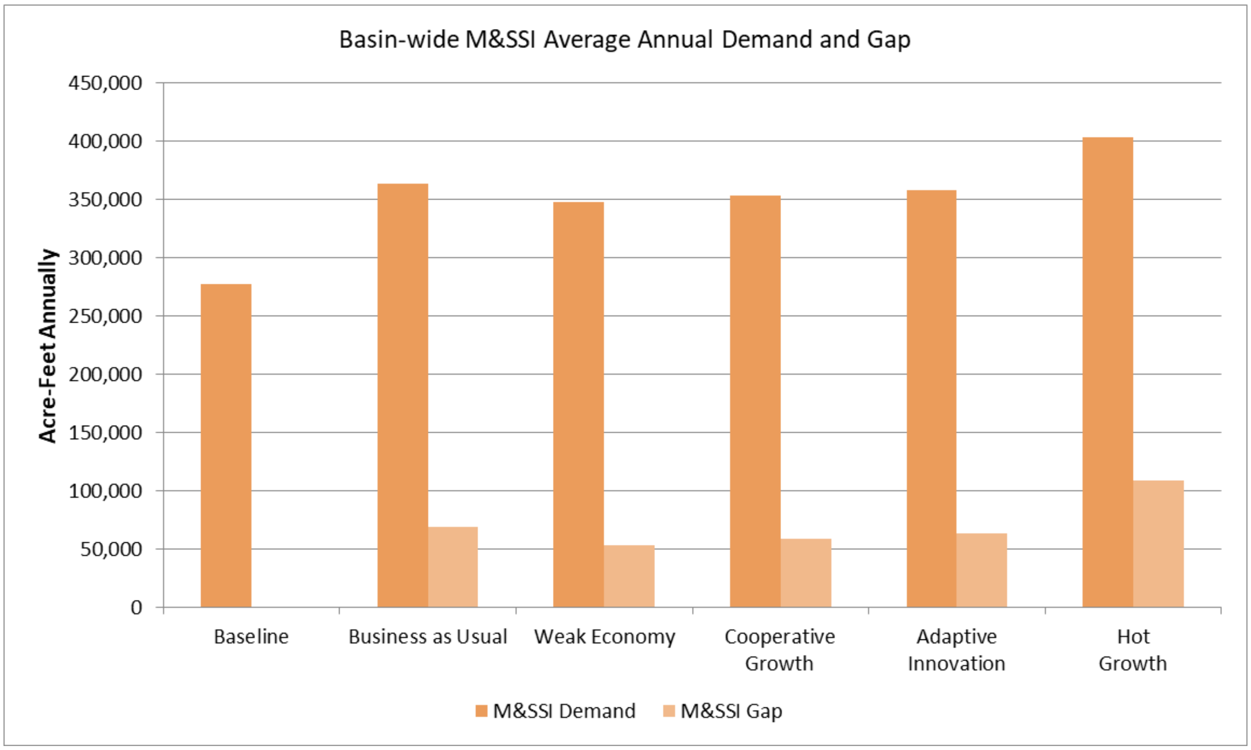


Figure 10: Arkansas River Basin M&SSI Average Annual Demand and Gap

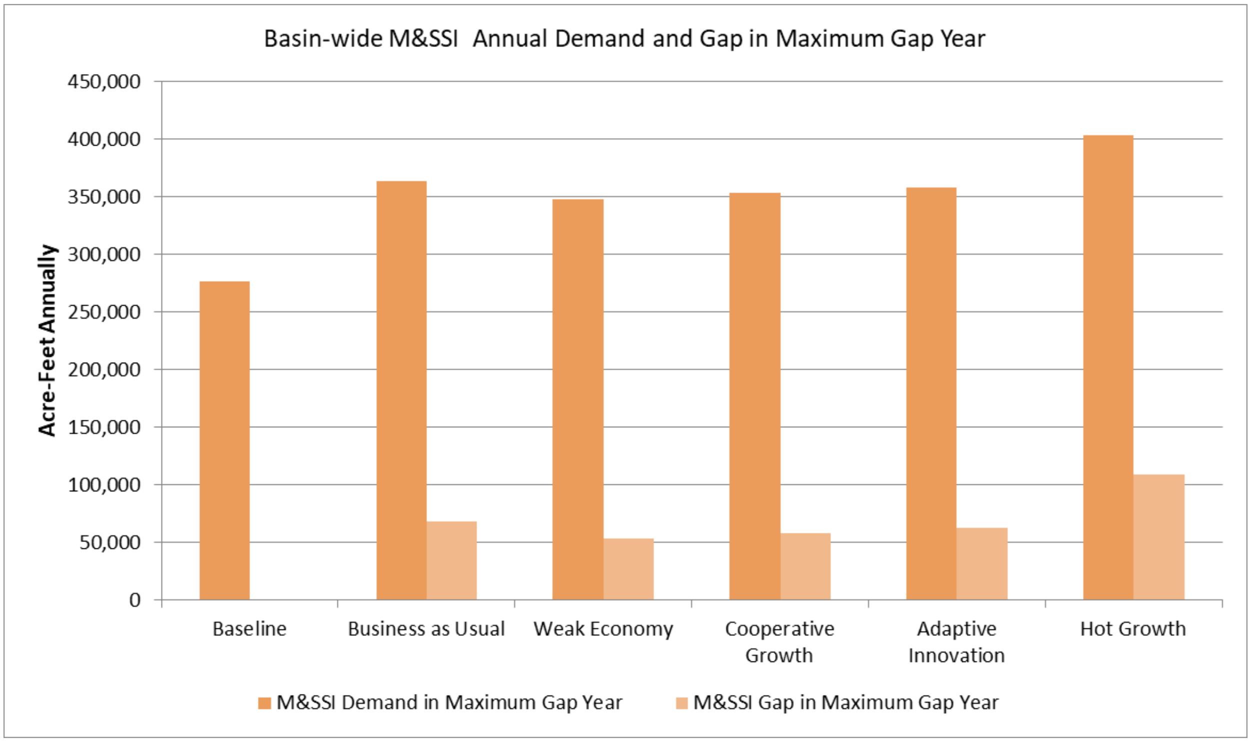


Figure 11: Arkansas River Basin M&SSI Maximum Annual Demand and Gap in Maximum Gap Year

5.1.3 ARKANSAS RIVER BASIN TRANSBASIN EXPORT DEMAND

Aurora Water exports water from the Arkansas River basin into the South Platte River basin through the Otero Pump Station, which it shares with Colorado Springs Utilities. A majority of this water originates in the Colorado River basin and is carried through several tunnels (e.g. Homestake Tunnel, Twin Lakes Tunnel, Busk-Ivanhoe Tunnel, Columbine Ditch) into the Arkansas River basin before being delivered via the Otero Pipeline to Colorado Springs Utilities or exported from the Arkansas River. The transbasin demand for these diversions is included in the Colorado River basin demands. To a lesser degree, the Otero Pipeline also exports native Arkansas River basin water supplies; primarily water from changed irrigation rights on the Rocky Ford Ditch and Colorado Canal. Of the total Otero Pipeline diversions, only Aurora Water's changed irrigation share water can be considered an export demand from the Arkansas River basin, without double-accounting the Colorado River exports. As this amount is relatively small compared to the overall import and exports in the basin; varies depending on exchange potential and storage in Turquoise Reservoir, Twin Lakes, and Pueblo Reservoir; and is not explicitly measured separately by DWR (i.e. not available in HydroBase), the export demand was not developed nor provided for this Technical Update effort.

5.1.4 ARKANSAS RIVER BASIN SUMMARY

The combined agriculture and M&SSI demands and gap summary is provided in Table 6. The results are very similar to the agricultural results in Table 4, because water supplies in the Arkansas River basin are predominantly used for agriculture. Figure 12 reflects the relative size of the agricultural and M&SSI demands in the Arkansas River basin. Due to the projected decline in irrigated acreage and increase in population, the M&SSI demand is projected to increase from 13 percent of the total demand in the basin to 17 percent of the total demand in the 2050 Planning Scenarios. Following the graphic are summaries regarding other considerations that may impact the basin-wide gap, including potential M&SSI supplies from urbanized acreage or transbasin import supply gaps.

Table 6: Arkansas River Basin Water Supply and Gap Summary

	Agricultural and M&SSI Results	Baseline	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand (ac-ft)	2,176,632	2,141,582	2,118,115	2,232,086	2,078,807	2,321,508
	Average Annual Gap (ac-ft)	617,289	654,967	638,394	760,125	797,692	928,209
	Average Annual Percent Gap	28%	31%	30%	34%	38%	40%
Critically Dry Max	Demand In Maximum Gap Year (ac-ft)	2,580,632	2,515,318	2,489,426	2,502,547	2,290,312	2,561,382
	Gap In Maximum Gap Year (ac-ft)	1,446,435	1,438,100	1,419,712	1,590,494	1,628,996	1,858,581
	Percent Gap In Maximum Gap Year	56%	57%	57%	64%	71%	73%

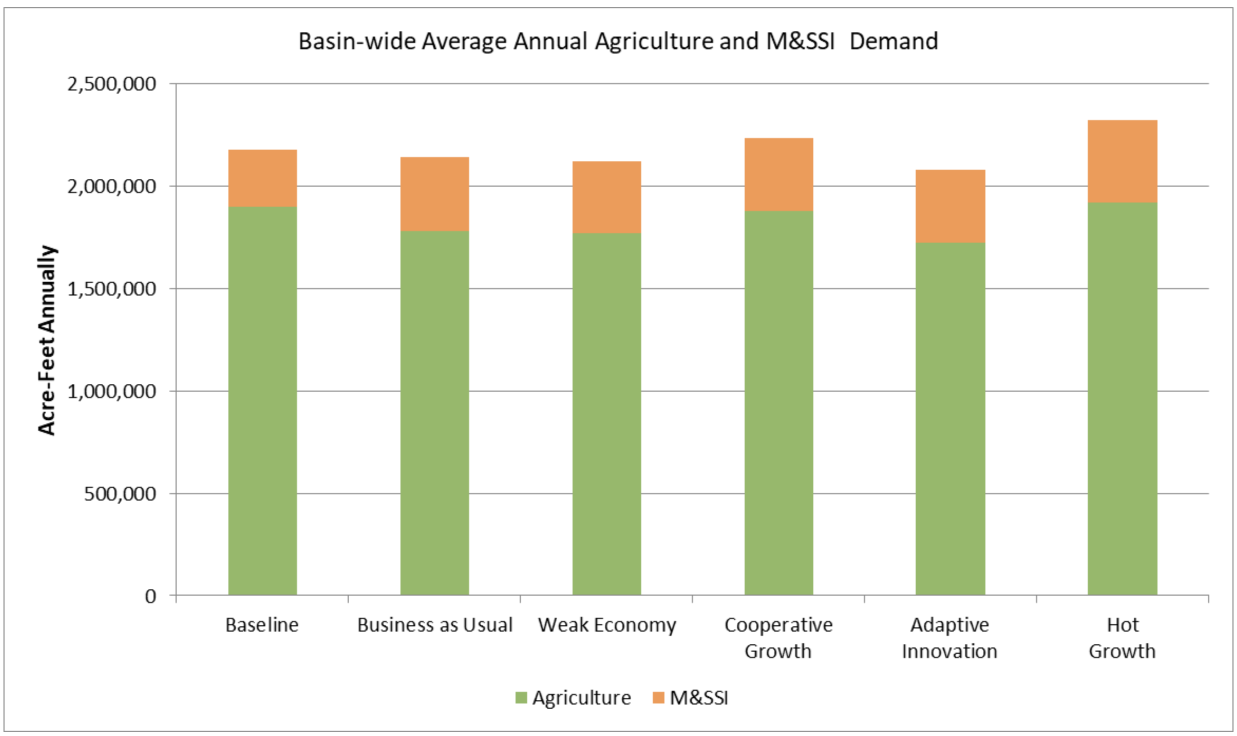


Figure 12: Arkansas River Basin Comparison of Average Agricultural and M&SSI Annual Demands

All scenarios project 19,840 acres of irrigated land will be taken out of production due to urbanization or due to municipal transfers (i.e. buy and dry). Acreage taken out of production for municipal transfers is intended to be used as a future municipal supply, and water used to irrigate the urbanized acreage could be considered a new municipal supply if the associated water rights were changed to municipal uses. To estimate this potential new supply, the average consumptive use of the urbanized acreage by Planning Scenario is reflected in Table 7.

With respect to urbanized acreage, it should be noted that the economy in the basin has historically been heavily reliant on agriculture and to the extent ground water levels decline and land comes out of production, populations of local agricultural communities may also decline over time. Additionally, if the urbanized acreage is supplied by ground water, it is less likely the supply would be used for municipal purposes and instead these supplies may remain in the aquifer for recovery purposes. Additionally, it is unknown if the water rights would be changed to municipal use or whether the supply could directly meet the future municipal demand.

With respect to municipal transfers, this estimate is not intended to replace or supersede any decreed estimates of consumptive use in a specific ditch. Nor is it known which farms and ranches will be directly impacted, or the crop type or specific irrigation practices on this acreage. In light of these uncertainties, the table reflects a planning-level estimate of this potential new supply. Although it has not been applied to the M&SSI gap presented above, it would likely have the effect of decreasing the gap.

Table 7: Potential Water Supply from Urbanized Acreage in the Arkansas River Basin

Urbanized Acreage Results	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Urbanized Acreage	19,840	19,840	19,840	19,840	19,840
Estimated Consumptive Use (ac-ft/year)	29,636	29,673	29,435	25,244	27,939

As noted above, the Arkansas River basin benefits from the delivery of several imported transbasin supplies from the Colorado River basin. These transbasin diversions include:

- The Continental Hoosier Project, or Blue River Project, delivers water from the headwaters of the Blue River for use by Colorado Springs Utilities.
- The Homestake Project delivers water to both the South Platte River Basin for use by Aurora Water, and to the Arkansas River Basin for use by Colorado Springs Utilities. Only the portion delivered to the Arkansas River Basin is accounted for in the results below.
- The Columbine Ditch delivers water from the East Fork of the Eagle River for use by Pueblo Board of Water Works.
- The Ewing Ditch delivers water from Piney Creek, a tributary to the Eagle River, for use by Pueblo Board of Water Works.
- The Wurtz Ditch delivers water from the South Fork of the Eagle River for use by Pueblo Board of Water Works.
- The Twin Lakes Tunnel delivers water from the headwaters of the Roaring Fork River to the Twin Lakes Reservoir and Canal Company in the Arkansas River Basin.
- The Boustead Tunnel, part of the Fryingpan-Arkansas Project, delivers water from the Fryingpan River to Turquoise Reservoir in the Arkansas River Basin.
- The Busk-Ivanhoe Tunnel delivers water to Busk Creek upstream of Turquoise Lake for use by Pueblo Board of Water Works and Aurora Water. Only the portion delivered to Pueblo Board of Water Works is accounted for in the results below.

Table 8 summarizes the total transbasin import volumes and associated import gaps. Note that transbasin imports are the same across the scenarios because they are represented in the model at historical levels, and no Planning Scenario adjustments were applied. A gap indicates that the historical import could not be diverted in the source basin due to a physical or legal limitation of water supply at the diverting location. This is caused by changes in water availability, increases in senior demands in the source basin, or a combination of both.

Ideally the import supply gap in the Baseline scenario would be zero; however the Baseline dataset represents current agricultural and M&SSI demands over the entire model period which can result in minor shortages to junior water rights, including transbasin diversions. With this in mind, the incremental increase in the import gap reflects the increase in gap due to the Planning Scenario adjustments. Under current hydrologic conditions, there was no projected increase in the gap for the Business as Usual and Weak Economy scenarios. The increased demands and changed hydrology in the Cooperative Growth, Adaptive Innovation, and Hot Growth scenarios however resulted in more substantial gaps on average and during critically dry years.

If exports stay the same in the future, the reported import gaps could increase the total Arkansas River basin gaps in these scenarios. As transbasin imported supplies are able to be reused to extinction within the Arkansas River basin, the imported supply gap would have the effect of increasing the total Arkansas River basin gap by more than the values shown in the table.

Table 8: Summary of Transbasin Imports to the Arkansas River Basin

	Transbasin Import Supply Gap Results	Baseline	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Import Supply (ac-ft)	123,244	123,244	123,244	123,244	123,244	123,244
	Average Annual Import Supply Gap (ac-ft)	1,434	1,405	1,412	15,566	27,399	27,632
	Average Annual Import Supply Gap Increase from Baseline (ac-ft)	-	-	-	14,132	25,965	26,198
	Average Annual Import Supply Percent Gap	1%	1%	1%	13%	22%	22%
Critically Dry Maximum	Import Supply In Maximum Gap Year (ac-ft)	154,756	154,756	154,756	154,756	126,528	126,528
	Import Supply Gap In Maximum Gap Year (ac-ft)	8,086	8,086	8,086	35,979	49,602	48,639
	Increase from Baseline Import Supply Gap (ac-ft)	-	0	0	27,893	41,516	40,553
	Import Supply Percent Gap In Maximum Gap Year	5%	5%	5%	23%	39%	38%

Although detailed surface water modeling was not completed in the basin, it is important to understand the potential impact the climate conditions may have on the volume and timing of runoff in the basin.

Figure 13 through Figure 20 reflect the average monthly and time series of annual natural flow runoff at following four gaged locations[5]:

- Arkansas River near Leadville (07081200)
- Clear Creek above Clear Creek Reservoir (07086500)
- Grape Creek near Westcliffe (07095000)
- Purgatoire River at Madrid (07124200)

Note that the graphics reflect *natural flow* or the amount of water in the river absent the effects or impact of man, not simulated streamflow. These streamflow gages are generally located in the headwaters with limited impact from upstream irrigation or municipal uses; however any man-induced effects (e.g. transbasin diversions, irrigation, reservoirs) above the gage locations have been removed so that the climate adjustments could be applied. Additionally, the annual natural flow graphics reflect a stacked volume of runoff compared to the volume of runoff for current conditions. The green band in these graphs reflects the incremental increase in runoff under the In-Between climate conditions compared to the runoff under the Hot and Dry conditions in the blue area.

As reflected, natural flow at the Leadville gage is projected to experience the smallest reduction in volume compared to the other gaged locations, with the In-Between conditions projecting a 6 percent decrease on average and the Hot and Dry conditions projecting a 15 percent reduction on average. There is however a pronounced shift in the peak runoff, projected to occur a month earlier than current conditions, and a reduction to late season flows.

Larger reductions are projected for the Clear Creek gage, which provides nearly the same amount of natural flow runoff as the headwaters of the Arkansas River. Natural flow on Clear Creek is projected to decline by approximately 15 percent on average under the In-Between conditions and 26 percent on average under the Hot and Dry conditions. As reflected in the graph, the reduction to streamflow is projected to occur during years with average and above-average runoff, with smaller reductions projected for years with lower flows. Although there is a projected shift in the runoff, it is not as pronounced as projected shifts at other locations.

Grape Creek and Purgatoire River are projected to have the largest declines in runoff under the climate-adjusted hydrology conditions. Grape Creek is projected to decline 29 percent on average and 38 percent on average under the In-Between and Hot and Dry conditions, respectively. From a volumetric perspective, this is projected annual decline of approximately 12,000 ac-ft and 16,000 ac-ft of runoff in the basin, respectively, compared to the current average annual runoff of 43,000 ac-ft. As reflected in the Figure 18, the decline is projected to occur fairly consistently across several hydrological year types, with only the wettest year projected to have less than average declines.

Hydrology in the Purgatoire River is projected to have the largest decline out of the four gages. Under the In-Between conditions, Purgatoire River is projected to decline 34 percent on average, or approximately 17,000 ac-ft of runoff annually. Under the Hot and Dry conditions, the Purgatoire River is projected to decline 44 percent on average, or approximately 22,000 ac-ft of runoff annually. The average monthly results for May and June indicate a substantial decline in snowpack runoff volume and a shift in the runoff earlier in the year. These inflows can serve as a predictor to the amount of water supplies that may be available in the future for storage in Trinidad Reservoir and irrigation under the Trinidad Project.

[5] A majority of the streamflow results presented in this memorandum reflect information from gages selected to support the Environmental Flow Tool. These gages differ from those selected for the Flow Tool; the streamflow results from these gages are provided to better reflect the impact of climate-adjusted hydrology on the native streamflow in the basin.

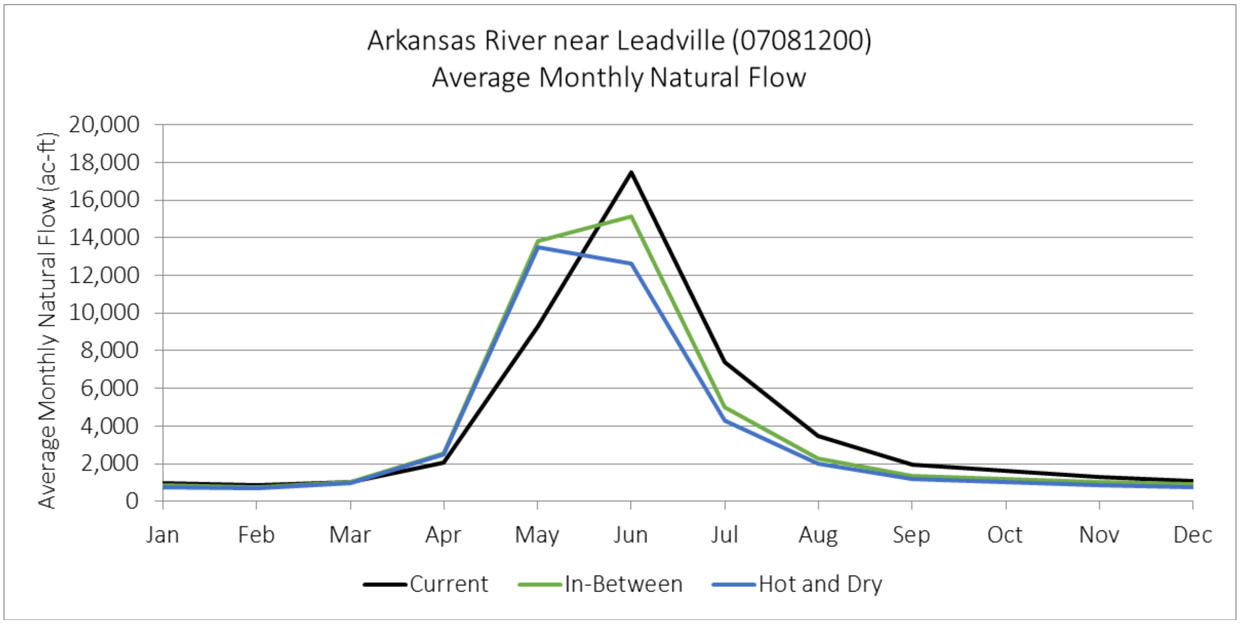


Figure 13: Average Monthly Natural Flow at Arkansas River near Leadville

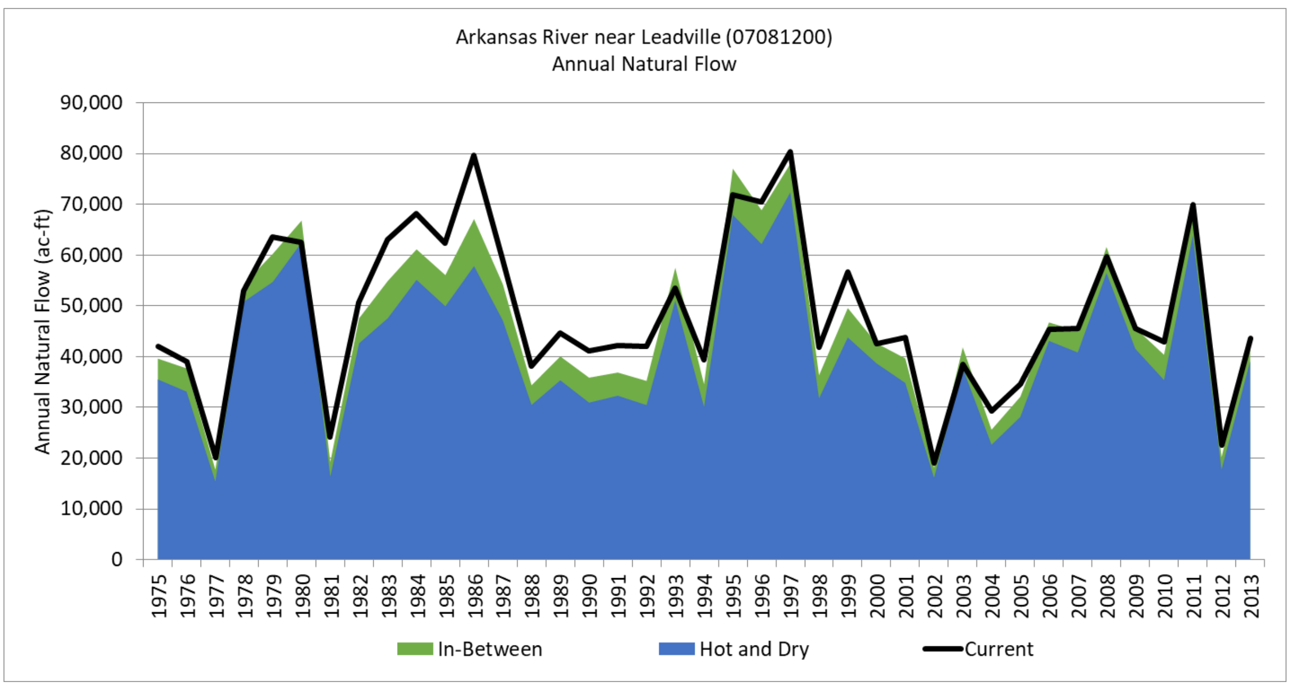


Figure 14: Annual Natural Flow at Arkansas River near Leadville

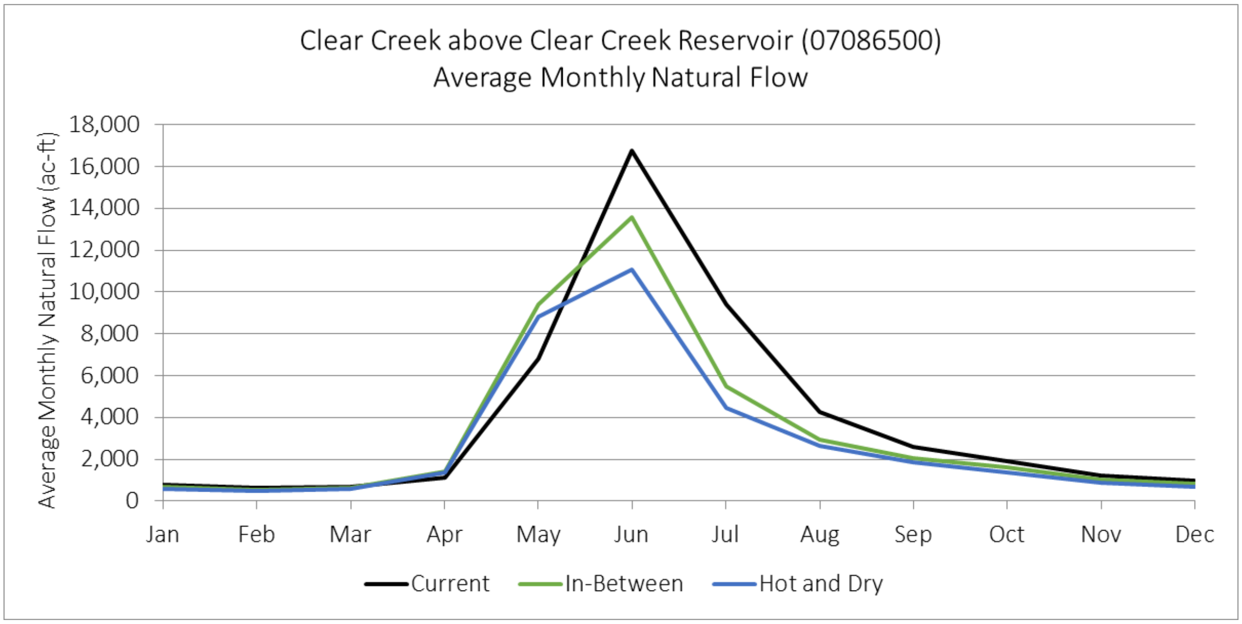


Figure 15: Average Monthly Natural Flow at Clear Creek above Clear Creek Reservoir

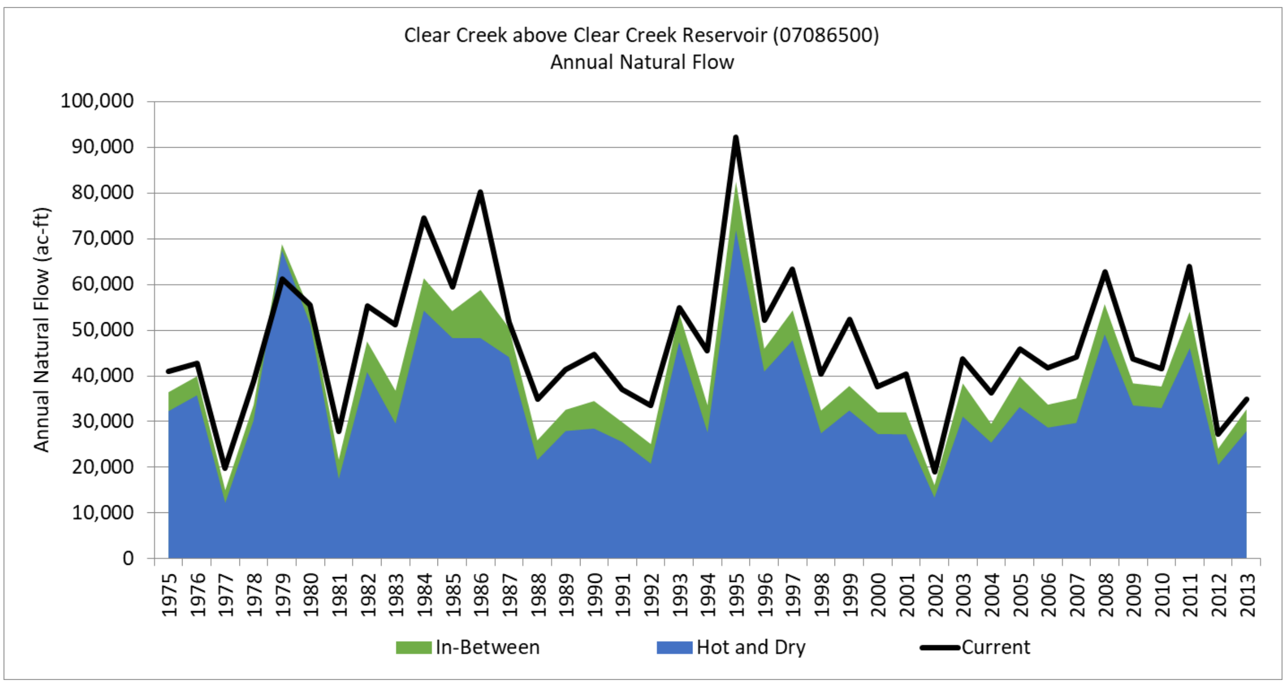


Figure 16: Annual Natural Flow at Clear Creek above Clear Creek Reservoir

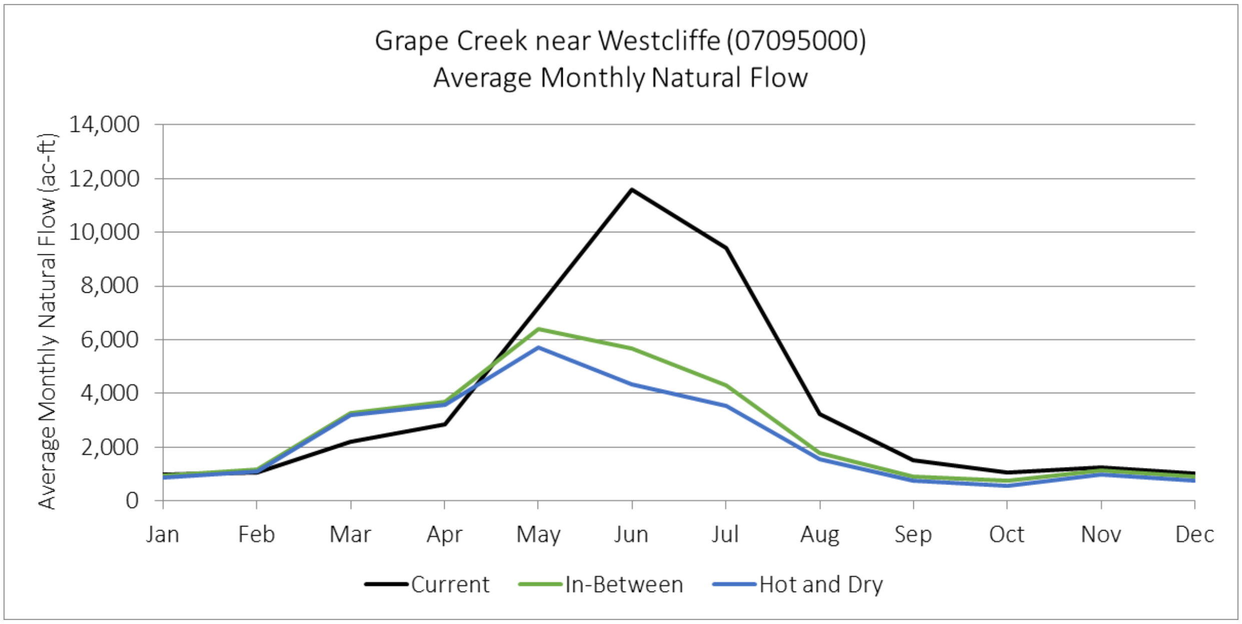


Figure 17: Average Monthly Natural Flow at Grape Creek near Westcliffe

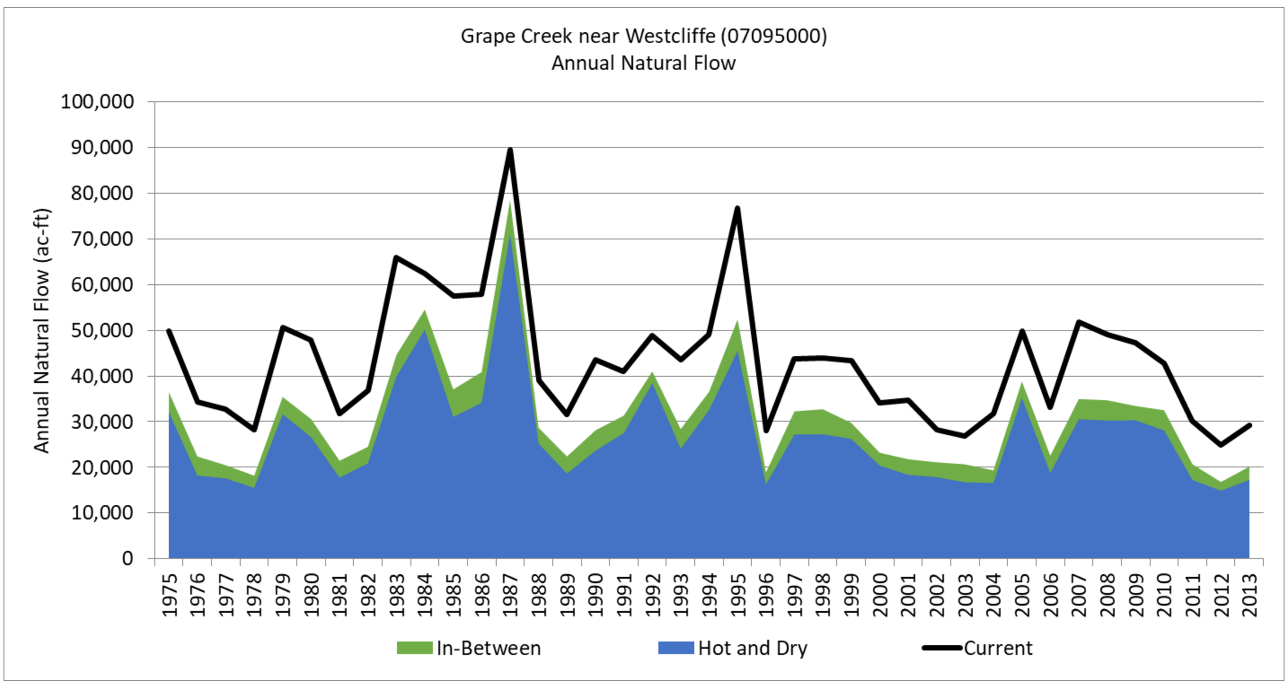


Figure 18: Annual Natural Flow at Grape Creek near Westcliffe

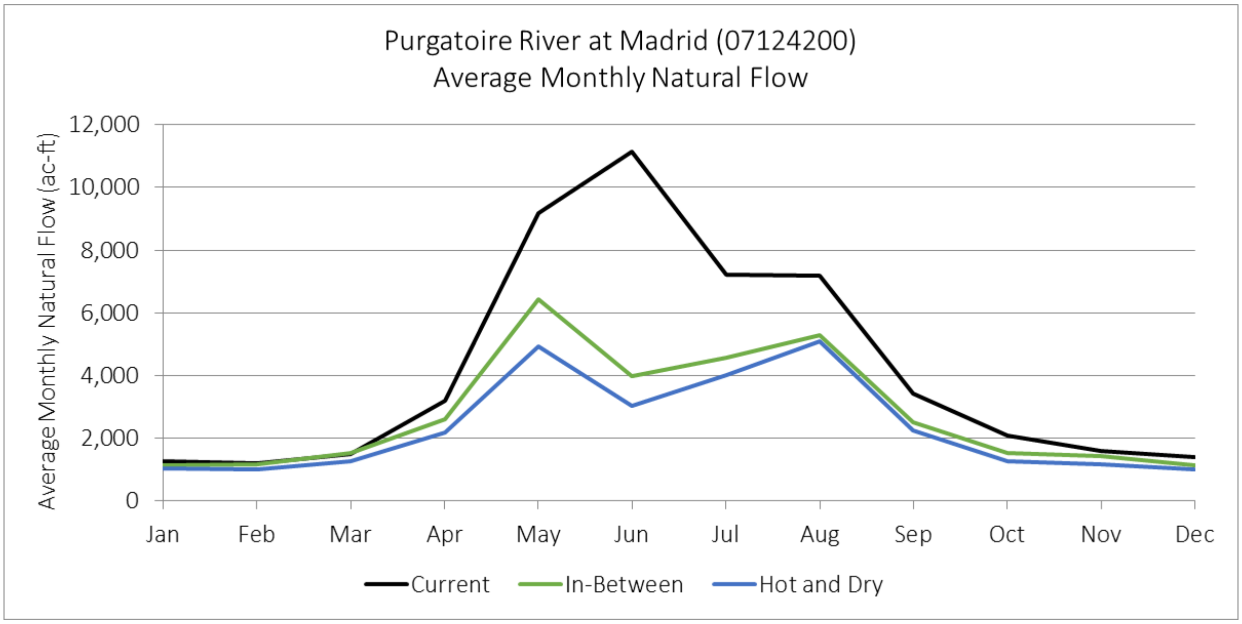


Figure 19: Average Monthly Natural Flow at Purgatoire River at Madrid

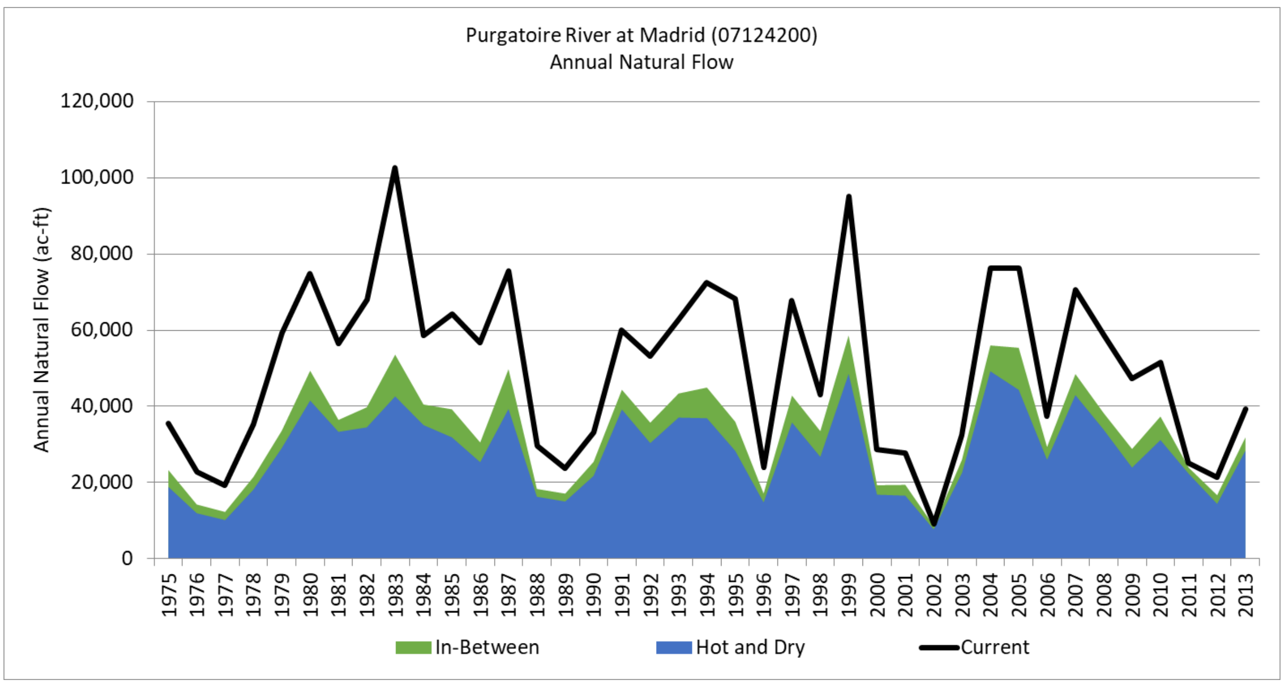
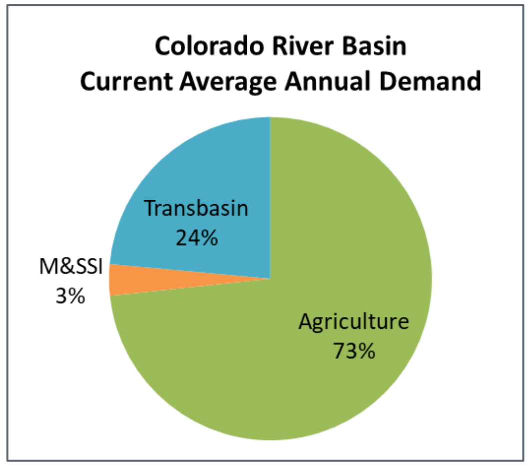


Figure 20: Annual Natural Flow for Purgatoire River at Madrid

5.2 COLORADO RIVER BASIN

The majority of the water in the Colorado River basin is used to irrigate over 206,000 acres, with nearly a quarter of these acres irrigated in and around Grand Junction by the Grand Valley Project. The next largest demand for water supplies in the basin is for transbasin exports. These diversions move water from the headwaters of the Colorado River basin to M&SSI and agricultural users in the South Platte and Arkansas River basins.

Smaller demands are associated with M&SSI uses in the basin. There are a number of growing municipal communities mixed between the agricultural operations. Resort towns such as Aspen, Avon, Breckenridge, Glenwood Springs, Snowmass Village, Winter Park, and Vail are located in the mountains and have economies primarily based on tourism. Agricultural-based communities include Eagle, Fruita, Grand Junction, Palisade, and Rifle. As with other parts of Colorado, people who come to visit the Colorado River Basin enjoy skiing, hiking, camping, rafting, fishing, hot springs, and other outdoor adventures.



The following sections describe the agricultural, M&SSI, and transbasin export demands in the Colorado River basin in more detail. Figure 21 shows the basin outline, the administrative boundaries of water districts, and the streamflow gages highlighted in the results section below.

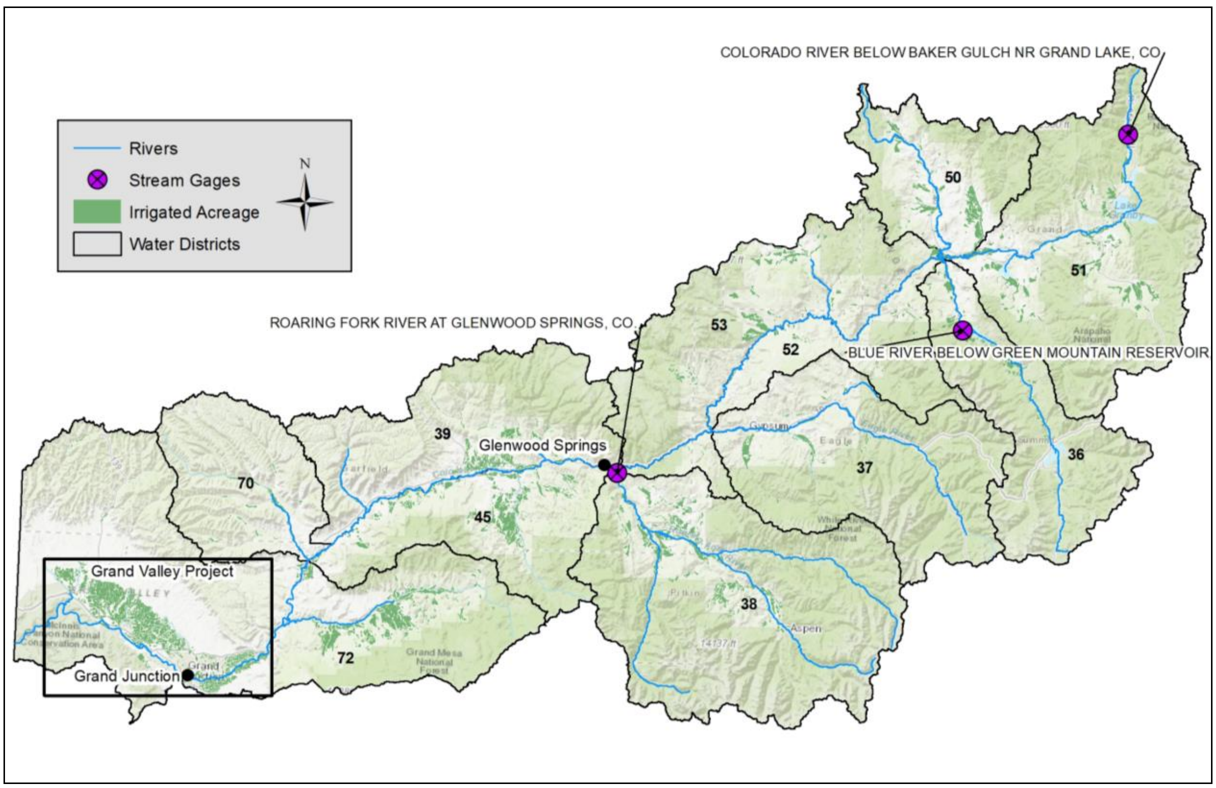


Figure 21: Colorado River Map with Streamgage Locations

5.2.1 COLORADO RIVER BASIN AGRICULTURE WATER SUPPLY AND GAP

There is great diversity in the irrigated agriculture industry across the Colorado River basin. Large ranching operations dominate agriculture in the higher elevations of the basin, particularly around the Towns of Kremmling, Collbran, and Rifle. Farming regions focused on the cultivation of fruits, vegetables, and alfalfa are more prevalent in the lower basin due to a longer growing season and warmer summer temperatures. Large scale irrigation projects built by Reclamation and other entities provide infrastructure and storage facilities to better serve agricultural lands and provide supplemental supplies. The biggest example is the Grand Valley Project and the Grand Valley Irrigation Company, located at the bottom of the Colorado. Together, they irrigate over a quarter of the 206,700 acres irrigated in the entire basin.

The Colorado River Basin agricultural diversion demands, demand gaps, and consumptive use gaps results for the baseline and Technical Update Planning Scenarios are presented in

Table 9. As discussed in the *Current and 2050 Planning Scenario Agricultural Diversion Demand* technical memorandum, 2050 agricultural diversion demands are influenced by a number of drivers[6], including climate, urbanization, planned agricultural projects, and emerging technologies.

Table 9: Colorado River Basin Agricultural Water Supply and Gap Summary

	Agricultural Results	Baseline	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand (ac-ft)	1,598,908	1,476,827	1,476,827	1,663,820	1,294,883	1,751,552
Average	Average Annual Demand Increase from Baseline (ac-ft)	-	-	-	64,911	-	152,644
Average	Average Annual Gap (ac-ft)	45,288	43,994	43,985	76,208	61,498	103,782
Average	Average Annual Gap Increase from Baseline (ac-ft)	-	-	-	30,920	16,209	58,494
Average	Average Annual Percent Gap	3%	3%	3%	5%	5%	6%
Average	Average Annual CU Gap (ac-ft)	25,105	24,400	24,395	42,381	40,368	57,772
Critically Dry Maximum	Demand In Maximum Gap Year (ac-ft)	1,598,822	1,477,522	1,477,522	1,587,174	1,258,020	1,668,295
Critically Dry Maximum	Increase from Baseline Demand (ac-ft)	-	-	-	-	-	69,473
Critically Dry Maximum	Gap In Maximum Gap Year (ac-ft)	147,979	141,118	141,049	166,477	131,445	210,423
Critically Dry Maximum	Increase from Baseline Gap (ac-ft)	-	-	-	18,498	-	62,444
Critically Dry Maximum	Percent Gap In Maximum Gap Year	9%	10%	10%	10%	10%	13%

The average annual agricultural demand decreases from the Baseline to the Business as Usual and Weak Economy Planning Scenarios due to the projected reduction of 13,590 irrigated acres due to urbanization of irrigated lands. As reflected in the table, irrigators in the basin currently experience a relatively small agricultural gap on average and during critically dry years.

[6] As noted in the technical memorandum, structures that carry water both for irrigation and for other purposes (e.g. power operations), such as those within the Grand Valley Project, were not adjusted across Planning Scenarios for changes in system efficiency or increases in agricultural demands.

Demand for the Cooperative Growth scenario incorporates the urbanized acreage as well as the increase in climate change adjustments to IWR, leading to an increase of 187,000 ac-ft of demand basin-wide compared to the Business as Usual scenario. Climate adjustments to hydrology in the Cooperative Growth scenario reduce the magnitude, shift the peak runoff generally from June to May, and reduce the amount of late season supplies. These changes lead to approximately 32,000 ac-ft of increased gap basin-wide on average compared to the Business as Usual and Weak scenarios. Agriculture located on smaller tributaries throughout the basin often has limited or no access to supplemental irrigation supplies from reservoir storage. Increased demands in these areas must be met using water supplies available only during runoff. As such, agricultural demands in this scenario, particularly on smaller tributaries, are often shorted more than the average basin-wide gap.

For the Adaptive Innovation scenario, the average annual demand is less than the Baseline demand, despite reflecting the same reduction to irrigated lands for urbanization and incorporating climate adjustments to IWR under the Hot and Dry conditions. To offset the impact of climate change, the Adaptive Innovation scenario assumes that emerging technologies decrease the IWR and increase irrigation system efficiency for the entire basin. Agricultural demands are highly sensitive to changes in IWR and system efficiency, so the two adjustments result in a net decrease of nearly 182,000 ac-ft of agricultural demands on average compared to the Business as Usual scenario. The average annual gap and the CU gap in the Adaptive Innovation scenario is smaller than the Cooperative Growth scenario, but larger than the Business as Usual scenario, indicating the two adjustments did not fully mitigate the effects of Hot and Dry climate conditions.

Finally, the Hot Growth scenario produces the largest agricultural gaps in the Colorado River Basin. Average annual demands are projected to increase while the runoff is projected to decrease. The annual percent gap is 6 percent on average and 13 percent during critically dry years. These are larger than those currently experienced in the basin on average, but still relatively small compared to gaps projected in other areas in the State.

In general, the Colorado River Basin is projected to experience relatively low agricultural gaps in 2050. The difference between the average annual gap and gaps during critically dry years are highlighted in Figure 22 and Figure 23, which show the relative size of the agricultural demands and gaps. As noted above, agricultural water users are not impacted evenly throughout the basin, depending on the available water supply and the relative seniority of the agricultural water rights. For example, Water District 45 (Divide Creek) has a gap of 47 percent in a critically dry year in the Hot Growth scenario. In contrast, Water District 72 (Lower Colorado River) has a gap of 8 percent in a critically dry year. Irrigation in Water District 45 depends on smaller tributaries to the Colorado River, such as Divide Creek, Beaver Creek, and Battlement Creek, and has no access to storage. In the Hot Growth scenario, runoff declines and is not able to meet the agricultural demand in the late season. Irrigation in Water District 72, primarily under the Grand Valley Project, have senior water rights and are supported by large diversion infrastructure directly from the Colorado River.

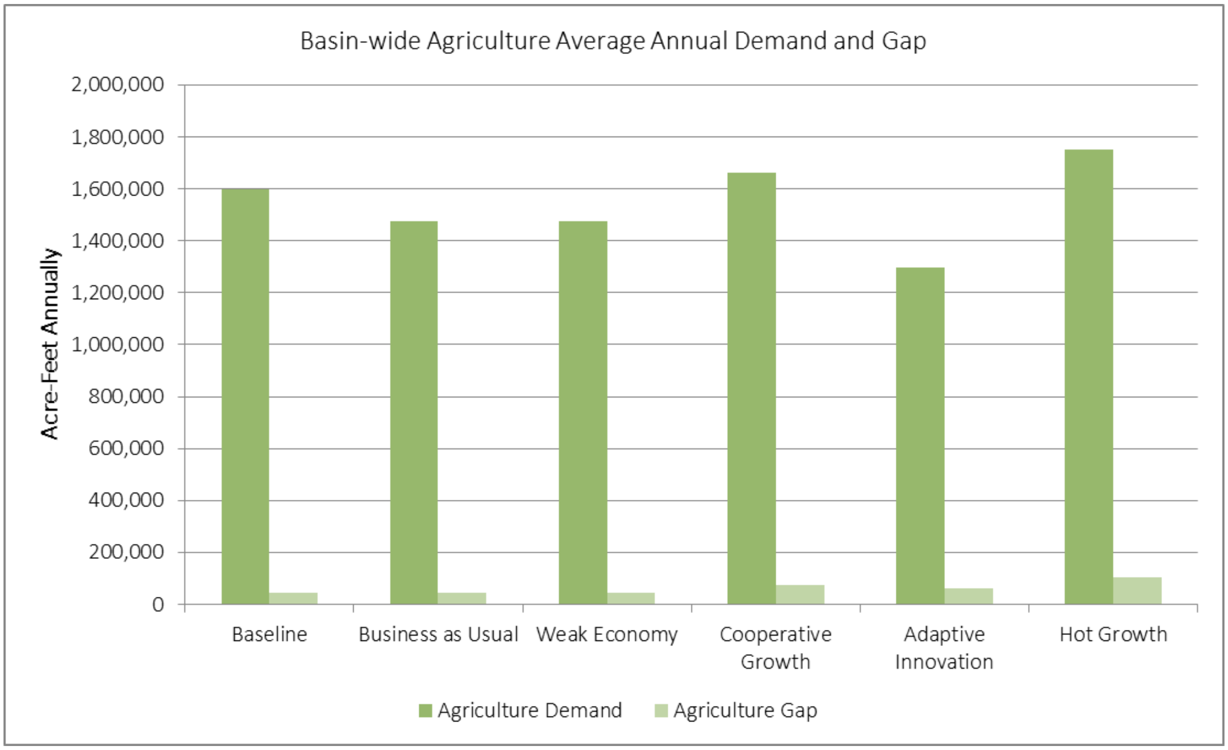


Figure 22: Colorado River Basin Agriculture Average Annual Demand and Gap

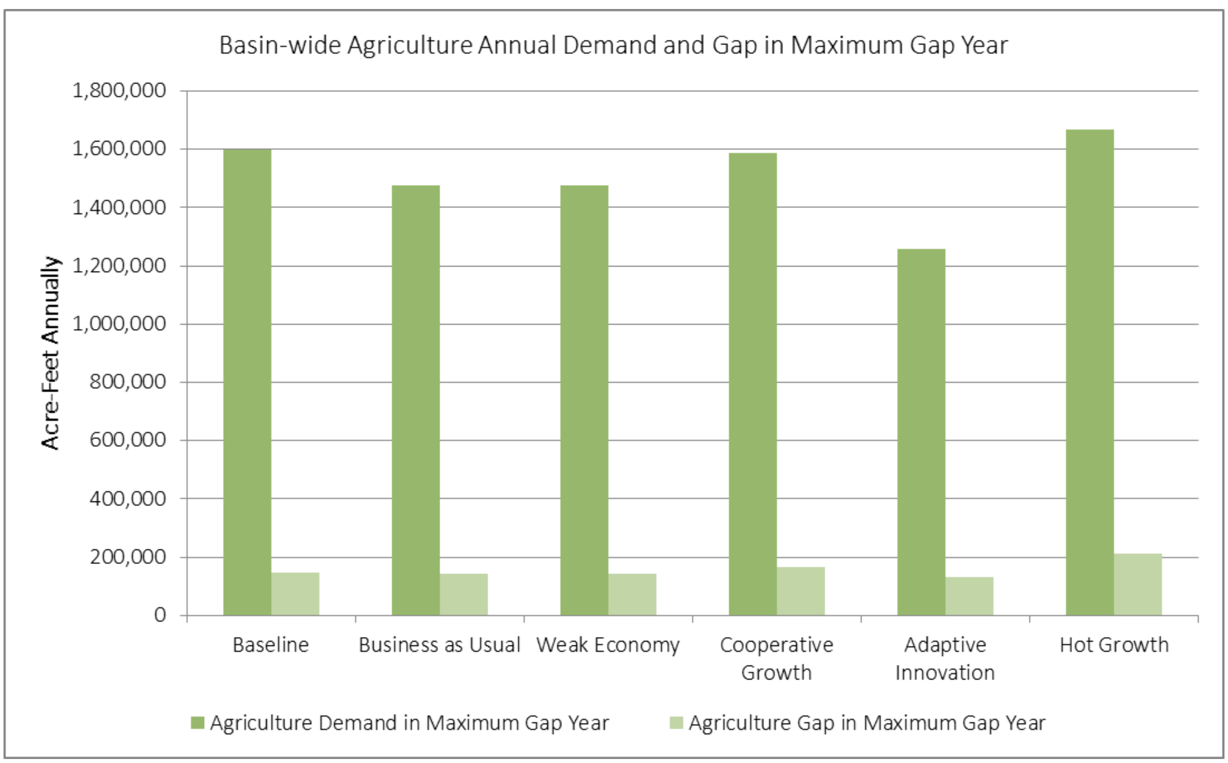


Figure 23: Colorado River Basin Agriculture Annual Demand and Gap in Maximum Gap Year

In addition to the average annual summary, it is important to consider the variability of gaps across wet, average, and dry year types. Figure 24 reflects the average annual percent gap for the modeled years (1975 – 2013). The dry hydrology years of 1977, 2002, and 2012 stand out as the largest gaps in the basin, followed by 1981 and 1990. The Baseline, Business as Usual, and Weak Economy scenarios all produce very similar results, which are often overlapping in the graphic. The Cooperative Growth and the Adaptive Innovation scenarios generally trend together, indicating the emerging technologies adjustments had the effect of partially mitigating the impact of Hot and Dry climate conditions. The Hot Growth scenario consistently produces the largest gaps.

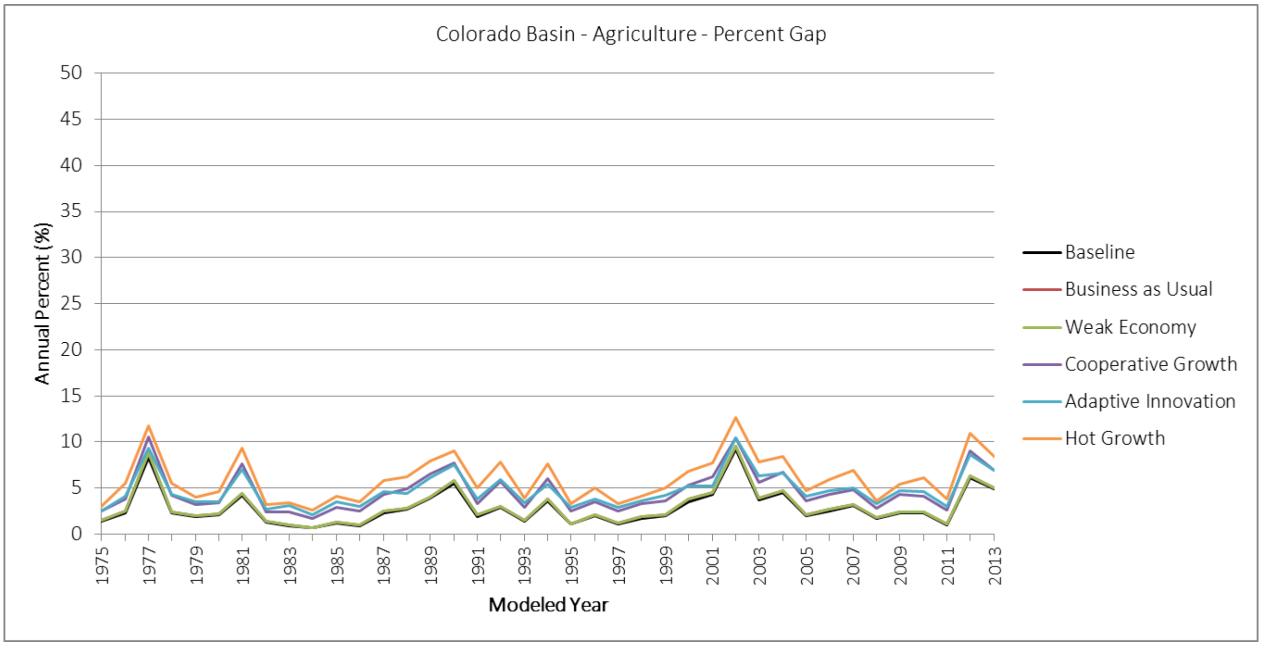


Figure 24: Colorado River Basin Agriculture Percent Diversion Gap Times Series

5.2.2 COLORADO RIVER BASIN M&SSI WATER SUPPLY AND GAP

M&SSI demands are small relative to the other demands in the basin, consisting of approximately 3 percent of the total demands. Of the total M&SSI demand, approximately 90 percent are attributable to municipal demands and the remaining 10 percent are attributable to SSI operations.

The municipal demands are largest in Mesa, Garfield, and Eagle counties, which encompass the municipalities along the I-70 corridor. Population is projected to increase in all Planning Scenarios, driving an increase in municipal demands by 2050. Of the total municipal demands, approximately half are represented in the model at grouped locations and the other half are represented in the model using the municipalities' individual demands, water rights, and operations. Entities represented individually in the model include:

- Aspen
- Breckenridge
- Carbondale
- Dillon Valley Water and Sanitation District

- Glenwood Springs
- Grand Junction
- Keystone
- Rifle
- Snowmass
- Ute Water Conservancy District

The SSI[7] in the basin is predominantly snowmaking; large industry and energy development demands vary depending on the Planning Scenario. Similar to the municipal demands, the SSI demands can be modeled individually or at grouped locations. SSI operations represented individually in the model include:

- Breckenridge Snowmaking
- Copper Mountain Snowmaking
- Henderson Mine
- Keystone Snowmaking
- Ten Mile
- Vail Snowmaking

There are several reservoirs in the Colorado River Basin that currently lease water to M&SSI water providers from contract pools/accounts. These reservoirs include Green Mountain, Wolford Mountain, and Ruedi. For purposes of the Technical Update, it was assumed that these current lease agreements would continue in the future, therefore the model was revised to include releases of contract supplies to grouped M&SSI demands in the basin.

Refer to the *Baseline and Projected 2050 Planning Scenario Municipal and Self Supplied Industrial Water Demands* technical memorandum for additional discussion on how the M&SSI demands in the basin were developed. The water supply and gap results for M&SSI in the Colorado River basin are summarized in

[7] Note that water used for hydropower, such as those operations at the Shoshone Power Plant, are represented in the model but are not included in the SSI demand summaries (i.e. non-consumptive) and are not adjusted between Planning Scenarios.

Table 10, and graphically reflected in Figure 25 through Figure 27.

Table 10: Colorado River Basin M&SSI Water Supply and Gap Summary

	M&SSI Results	Baseline	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand (ac-ft)	68,485	98,415	85,793	95,383	94,490	121,433
Average	Average Annual Demand Increase from Baseline (ac-ft)	-	29,930	17,308	26,898	26,005	52,948
Average	Average Annual Gap (ac-ft)	498	1,207	813	1,865	2,344	4,677
Average	Average Annual Gap Increase from Baseline (ac-ft)	-	709	315	1,368	1,846	4,179
Average	Average Annual Percent Gap	1%	1%	1%	2%	2%	4%
Critically Dry Maximum	Demand In Maximum Gap Year (ac-ft)	68,485	98,415	85,793	95,383	94,490	121,433
Critically Dry Maximum	Increase from Baseline Demand (ac-ft)	-	29,930	17,308	26,898	26,005	52,948
Critically Dry Maximum	Gap In Maximum Gap Year (ac-ft)	2,339	4,238	3,348	5,306	6,595	15,849
Critically Dry Maximum	Increase from Baseline Gap (ac-ft)	-	1,899	1,008	2,967	4,256	13,510
Critically Dry Maximum	Percent Gap In Maximum Gap Year	3%	4%	4%	6%	7%	13%

As reflected in the table, there is an M&SSI gap in the Baseline scenario. Ideally, the Baseline scenario would have no M&SSI gaps because the current conditions in the basin fully satisfy the existing M&SSI demands. This small amount of gap is likely a result of minor calibration issues in the model during low flow years on tributaries supplying small water providers.

The Colorado River Basin is projected to increase in population in 2050; therefore all of the Planning Scenarios reflect an increase to the average annual demands above the Baseline scenario. For the Business as Usual scenario, the average annual demand increase is primarily driven by the increase in municipal demands, although industrial demands also increase modestly. The average annual gap doubles from the Baseline scenario, but still represents about 1 percent of the total demand. The gap during critically dry years is slightly larger; however still only 4 percent of the total M&SSI demand.

The Weak Economy scenario has similar results. The average annual gap increases from the Baseline scenario, but still represents about 1 percent of the total demand. The gap in a critically dry year increases from 3 to 4 percent, compared to the Baseline scenario. These are relatively small gaps and show that under current hydrology, future M&SSI demand increases can generally be met from unappropriated flows in the basin supplemented with contract releases from reservoirs.

The Cooperative Growth and Adaptive Innovation scenarios have a similar increase in demand as the Business as Usual scenario, however have slightly larger gaps. This is due to the climate-adjusted hydrology in these scenarios, which causes the annual streamflow volume to decline and reduces the water available to meet the increased demands. On average, gaps in both scenarios are approximately 2 percent of the total demand, with critically dry years reflecting more substantial gaps of 6 and 7 percent, respectively.

The demands and the gaps are the largest in the Hot Growth scenario. While the average annual gap is a moderate 4 percent on average, the gap is 13 percent of total demand in critically dry years. As noted above with agricultural demands, the average basin-wide gap under-estimates gaps projected for M&SSI water providers reliant on water supplies from smaller tributaries without the benefit of storage.

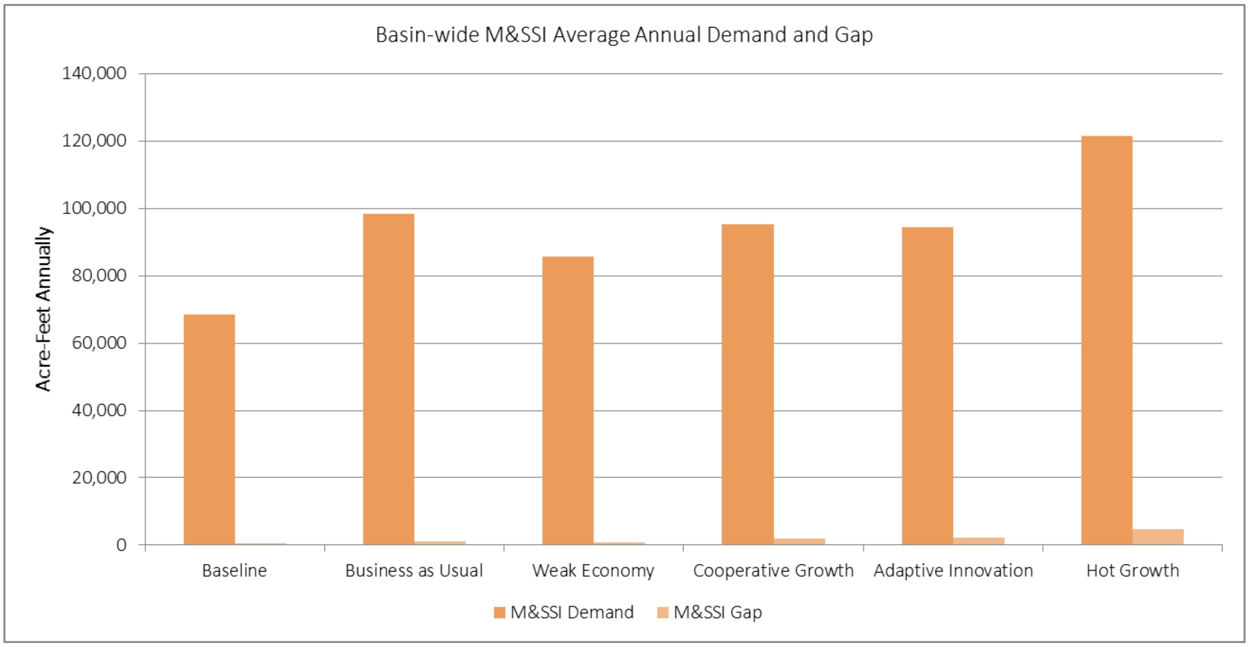


Figure 25: Colorado River Basin M&SSI Average Annual Demand and Gap

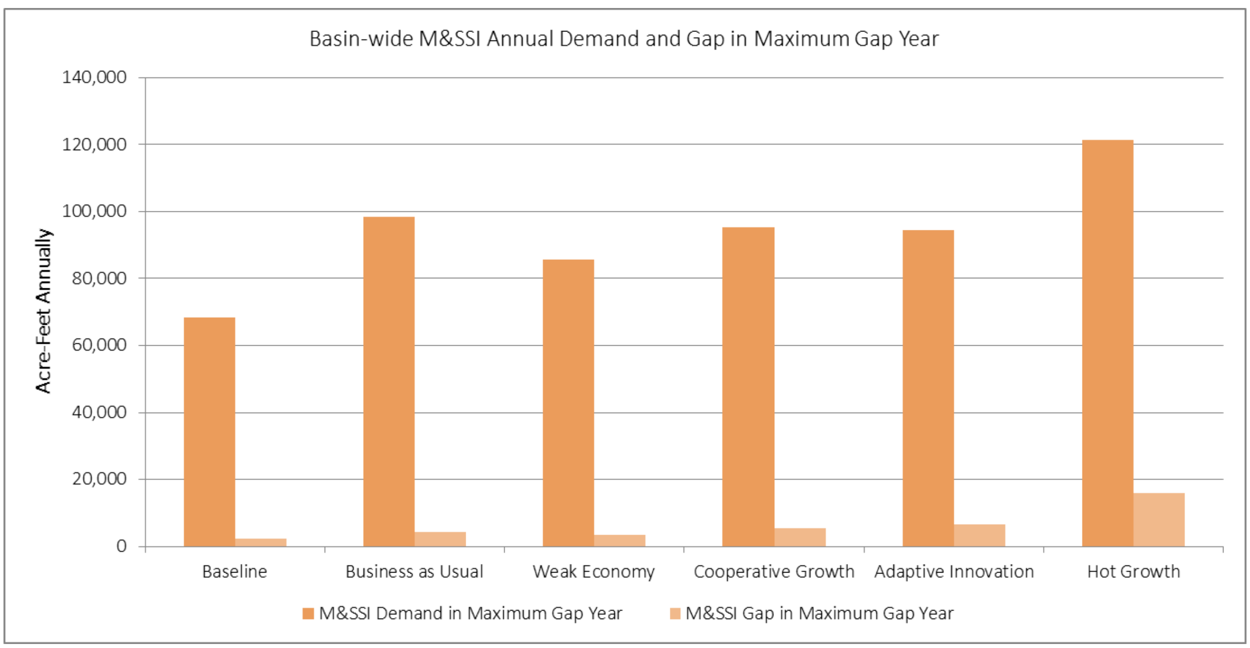


Figure 26: Colorado River Basin M&SSI Maximum Annual Demand and Gap in Maximum Gap Year

Figure 27 reflects the average annual percent gap across a variety of wet, average, and dry year types. The percent gap in the Baseline, Business as Usual, and Weak Economy scenarios generally trend together. For example, these scenarios reach maximum gaps in the dry years of 1977, 2002, and 2013. The Cooperative Growth and Adaptive Innovation scenarios generally have similar gap percentages, but they do not always react to dry years in the same manner. For example, the Adaptive Innovation scenario continues to have relatively large gaps in 2004, 2005, 2006 and 2007 while the Cooperative Growth scenario is projected to recover much more quickly. The Adaptive Innovation scenario uses the Hot and Dry hydrology, which reduces available streamflow and increases the length of time required to refill reservoirs. This further reduces unappropriated flows that some of the M&SSI systems may depend on in the future. The Hot Growth scenario has the largest year to year variability with gaps of near 10 percent for over 3 years.

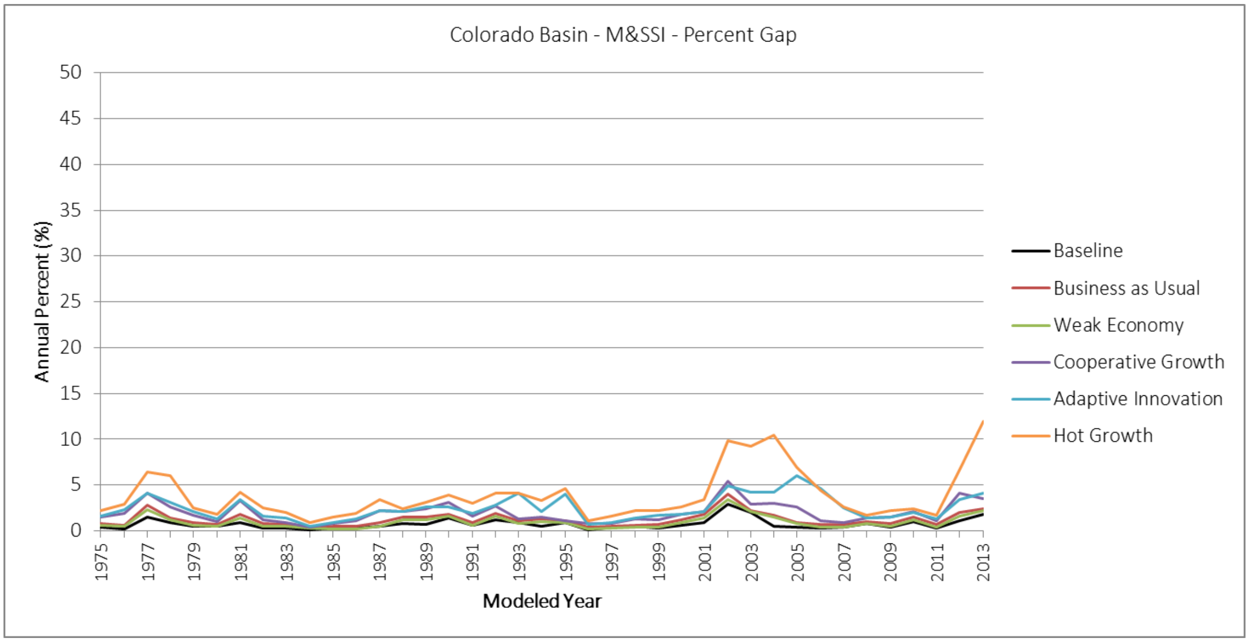


Figure 27: Colorado River Basin M&SSI Average Annual Gap Time Series

5.2.3 COLORADO RIVER BASIN TRANSBASIN EXPORT DEMAND

There are several tunnels and ditches that export water from the Colorado River Basin, delivering water to the South Platte River, Gunnison River, and Arkansas River basins. The model reflects sixteen transbasin diversions; the larger transbasin diversions are:

- Colorado-Big Thompson Project (C-BT) diverts water from the headwaters of the Colorado River through the Alva B. Adams Tunnel for irrigation and municipal use in the South Platte River basin.
- The Moffat Tunnel System diverts water from the headwaters of the Fraser River for Denver Water municipal use.
- Roberts Tunnel System diverts water from the Blue River for Denver Water municipal use.
- Fryingpan-Arkansas Project diverts water from the headwaters of the Roaring Fork through the Charles H. Boustead Tunnel for irrigation and municipal use in the Arkansas River Basin.
- The Twin Lakes Tunnel delivers water from the headwaters of the Roaring Fork River to the Twin Lakes Reservoir and Canal Company in the Arkansas River Basin.

- The Homestake Project diverts water from Homestake Creek and delivers water to both the South Platte River Basin for use by Aurora Water, and to the Arkansas River Basin for use by Colorado Springs Utilities.

On average, the total transbasin export demand from the Colorado River basin is 513,690 ac-ft per year, however this value ranges annually depending availability of water supplies, available storage capacity, and demand in both the Colorado River basin and the destination basins. Note that the transbasin export demand, reflecting approximately 24 percent of the total basin demand, is set to historical levels and the same across all Planning Scenarios. These demands could not be satisfied in all Planning Scenarios; however the shortages are reflected as an import supply gap in the destination basins and not considered a gap in the Colorado River basin.

5.2.4 COLORADO RIVER BASIN SUMMARY

The combined agriculture and M&SSI demands and gaps summary is provided in

Table 11. The summary results are similar to the agricultural results in

Table 9, because M&SSI demands are relatively small compared to the agricultural demands in the Colorado River Basin. As previously discussed, the Colorado River basin is generally able to meet demands in the Baseline, Business as Usual, and Weak Economy scenarios. The gaps increase as the demands increase and/or the hydrology decreases in the Cooperative Growth and the Adaptive Innovation scenarios. The gaps are the largest in the Hot Growth scenario, which combines the largest demands and the smallest streamflow.

Figure 28 shows the relative size of the demands in the Colorado River Basin. Agriculture is the dominant demand, and varies across the Planning Scenarios, whereas the transbasin export demand is constant across all scenarios. While the M&SSI demand does vary, it is difficult to see the changes graphically because it is the smallest demand. Following the graphic are summaries regarding other considerations that may impact the basin-wide gap, including potential M&SSI supplies from urbanized acreage or transbasin import supply gaps.

Table 11: Colorado River Basin Water Supply and Gap Summary

	Agricultural and M&SSI Results	Baseline	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand (ac-ft)	1,667,393	1,575,242	1,562,620	1,759,203	1,389,373	1,872,985
	Average Annual Gap (ac-ft)	45,786	45,200	44,798	78,073	63,841	108,459
	Average Annual Percent Gap	3%	3%	3%	4%	5%	6%
Critically Dry Max	Demand In Maximum Gap Year (ac-ft)	1,667,307	1,575,937	1,563,315	1,682,557	1,352,510	1,789,728
	Gap In Maximum Gap Year (ac-ft)	150,318	145,356	144,397	171,782	138,040	226,271
	Percent Gap In Maximum Gap Year	9%	9%	9%	10%	10%	13%

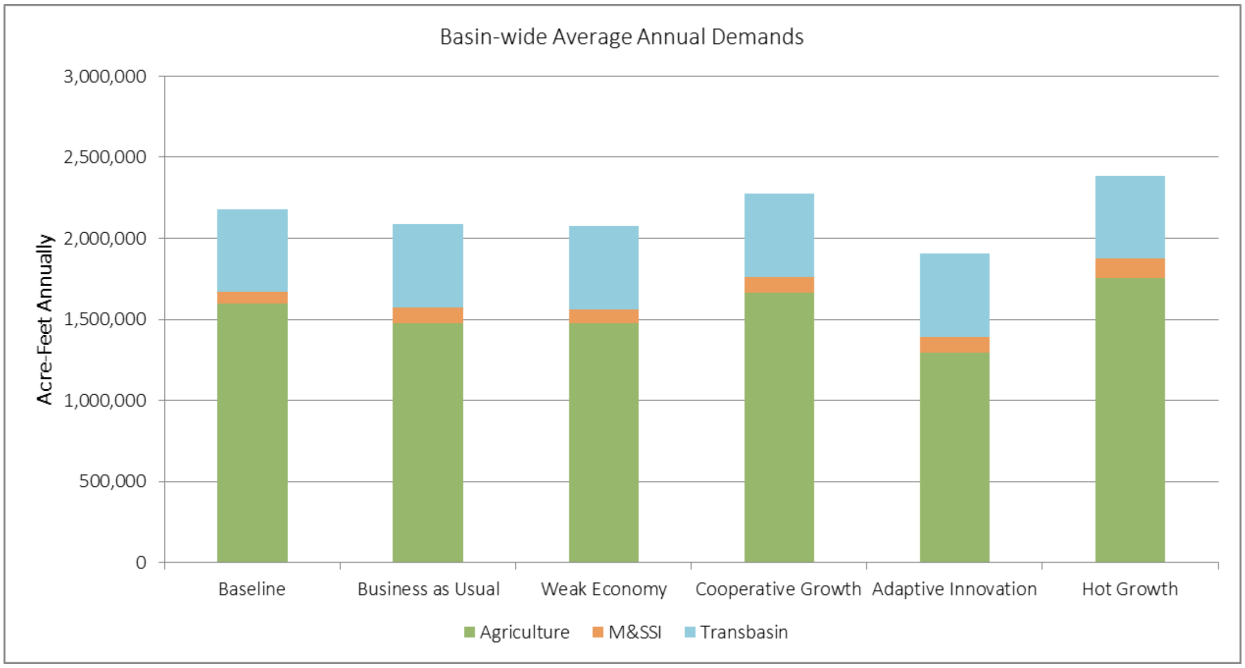


Figure 28: Colorado River Basin Comparison of Average Annual Demands

All of the Planning Scenarios project that 13,590 acres of irrigated land will be taken out of production due to urbanization. Supplies used to irrigate the urbanized acreage could be considered a new municipal supply if the associated water rights were changed to municipal uses. To estimate this new supply, the average consumptive use of the urbanized acreage by Planning Scenario is reflected in Table 12. Note however, it is not known which farms and ranches will be directly impacted; whether the acreage was served by senior/junior direct rights or had supplemental storage supplies; or the crop type or specific irrigation practices on this acreage. Additionally, it is unknown if the water rights would be changed to municipal use, or whether the supply could directly meet the future municipal demand or would require exchange potential. In light of these uncertainties, the table reflects a planning-level estimate of this potential new supply. Although it has not been applied to the M&SSI gap presented above, it would likely have the effect of decreasing the gap.

Table 12: Potential Water Supply from Urbanized Acreage in the Colorado River Basin

Urbanized Acreage Results	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Urbanized Acreage	13,590	13,590	13,590	13,590	13,590
Estimated Consumptive Use (ac-ft/year)	28,264	28,264	30,799	29,744	32,108

The Colorado River Basin benefits from the delivery of a small amount of imported transbasin supplies; these supplies are delivered from the Gunnison River basin for M&SSI purposes in and around the Grand Junction.

Table 13 summarizes the total transbasin import volumes and associated import gap. Note that transbasin imports are the same across the scenarios because they are represented in the model at historical levels, and no Planning Scenario adjustments were applied. A gap indicates that the historical import could not be diverted in the source basin due to a physical or legal limitation of water supply at the diverting location. This is caused by changes in water availability, increases in senior demands in the source basin, or a combination of both.

Ideally the import supply gap in the Baseline scenario would be zero; however the Baseline dataset represents current agricultural and M&SSI demands over the entire model period which can result in minor shortages to junior water rights, including transbasin diversions. With this in mind, the incremental increase in the import gap reflects the increase in gap due to the Planning Scenario adjustments.

Under current hydrology conditions, there was no increase in the gap for the Business as Usual and Weak Economy scenarios. The increased demands and changed hydrology in the Cooperative Growth, Adaptive Innovation, and Hot Growth scenarios however resulted in more substantial gaps on average and during critically dry years. If exports stay the same in the future, the reported import gaps could increase the total Colorado River basin M&SSI gaps in these scenarios.

Table 13: Summary of Transbasin Imports to the Colorado River Basin

	Transbasin Import Supply Gap Results	Baseline	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Import Supply (ac-ft)	6,603	6,603	6,603	6,603	6,603	6,603
	Average Annual Import Supply Gap (ac-ft)	45	45	45	41	88	79
	Average Annual Import Supply Gap Increase from Baseline (ac-ft)	-	0	0	-	43	34
	Average Annual Import Supply Percent Gap	1%	1%	1%	1%	1%	1%
Critically Dry Maximum	Import Supply In Maximum Gap Year (ac-ft)	6,601	6,601	6,601	6,601	6,601	6,601
	Import Supply Gap In Maximum Gap Year (ac-ft)	676	676	676	783	1,123	1,096
	Increase from Baseline Import Supply Gap (ac-ft)	-	0	0	107	448	420
	Import Supply Percent Gap In Maximum Gap Year	10%	10%	10%	12%	17%	17%

The Colorado River Basin has a substantial amount of reservoir storage. As shown in Figure 29, the Colorado River Basin has just under 1.4 million ac-ft of storage. The reservoirs serve agriculture, transbasin exports, M&SSI, recreation, and support the recovery of endangered fish species. The storage capacity helps buffer the basin against periods of drought, but then needs average and wet hydrologic conditions to refill. The large reservoirs individually represented model, organized by their primary purpose, are listed below:

Agriculture Reservoirs:
Harvey Gap (a.k.a. Grass Valley Reservoir)
Monument Reservoir System
Rifle Gap Reservoir
Vega Reservoir
Multi-purpose Reservoirs:
Clinton Gulch Reservoir
Eagle Park Reservoir
Green Mountain Reservoir
Ruedi Reservoir
Williams Fork Reservoir
Wolford Mountain Reservoir

Transbasin Reservoirs:
Dillon Reservoir
Granby Reservoir
Grand Lake/Shadow Mountain Reservoir
Homestake Reservoir
Leon Creek Reservoir
Meadow Creek Reservoir
Upper Blue Reservoir
Willow Creek Reservoir
M&SSI Reservoirs:
Bonham Reservoir
Cottonwood Reservoir
Jerry Creek Reservoir

The largest reservoirs in the basin are Granby Reservoir with over half a million ac-ft of storage for the Colorado-Big Thompson Project; and Dillon Reservoir with over a quarter million ac-ft of storage for transbasin diversion for Denver Water. The next largest reservoirs, Green Mountain, Reudi, and Wolford Mountain Reservoirs, provide compensatory storage for West Slope users to mitigate the impacts of transbasin diversions. In general, active reservoir capacity in the basin is drawn down in dry years in all Planning Scenarios; any remaining storage capacity can be attributed to inactive reservoir storage or capacity maintained for environmental or recreational purposes.

Simulated reservoir storage results for the Baseline, Business as Usual, and Weak Economy scenarios are similar and the results are overlapping in the graphic. The Cooperative Growth scenario uses the In-Between hydrology resulting in reservoir storage that is lower than results for scenarios using the current hydrology. The reservoir storage results are very similar for Adaptive Innovation and Hot Growth scenarios, and produce the lowest reservoir storage results of the Planning Scenarios due to the impact of the Hot and Dry hydrology. The Adaptive Innovation usually has slightly more water in storage than the Hot Growth scenario due to lower demands in the Adaptive Innovation scenario.

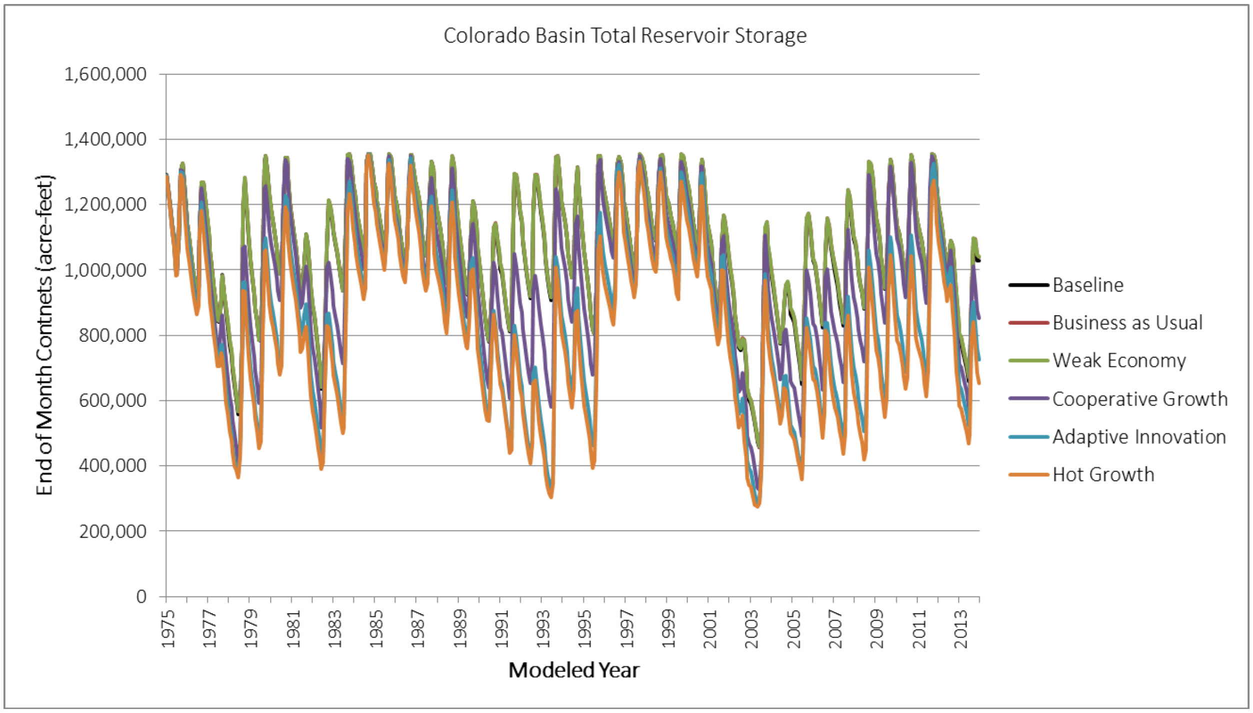


Figure 29: Colorado River Basin Total Reservoir Storage

The following figures reflect average monthly simulated streamflow at key locations across the basin; refer to Figure 21 for the location of the gages. The primary driver of average monthly simulated streamflow across the Planning Scenarios is hydrology. The average monthly streamflow results from Baseline, Business as Usual, and Weak Economy scenarios are often indistinguishable from each other due to their use of current hydrology and only limited differences in demands. In several locations, the results from these scenarios are overlapping. The In-Between hydrology featured in the Cooperative Growth scenario and the Hot and Dry hydrology featured in the Adaptive Innovation and Hot Growth scenarios consistently reduce late season flows across the basin and, in many areas, shift the peak streamflow earlier in the year.

Figure 30 reflects the simulated streamflow results of the Colorado River below Baker Gulch near Grand Lake, which is located high in the headwaters of the Colorado River. The most noticeable impact to streamflow across the scenarios is the shift in peak streamflow from June to May, and the considerable decline in streamflow in July. The average monthly streamflow volume in July under current hydrology is approximately 8,000 ac-ft. For the In-Between hydrology, the streamflow drops to 3,300 ac-ft and for the Hot and Dry hydrology, the streamflow drops to 2,300 ac-ft. This is a significant decline in streamflow during a month which has historically been critical for irrigation water supplies. On an annual basis, the In-Between hydrology has slightly more streamflow volume, but the Hot and Dry hydrology has less streamflow volume than current hydrology. The change in the runoff timing, however, will be challenging in a headwater tributary with limited access to storage.

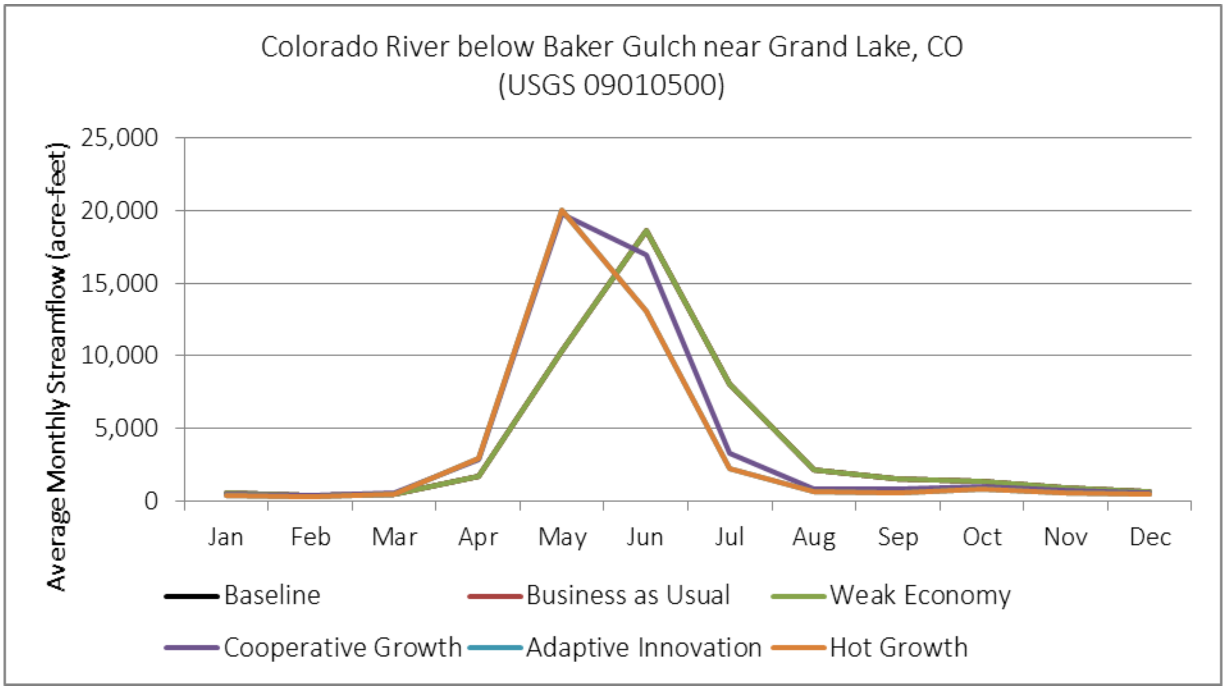


Figure 30: Average Monthly Streamflow for Colorado River below Baker Gulch near Grand Lake

Figure 31 reflects the average monthly simulated streamflow results for the Blue River below Green Mountain Reservoir. The streamflow in this location is projected to have a different response to the In-Between hydrology and the Hot and Dry hydrology compared to streamflow at other locations due to upstream operations. This is because there are two large reservoirs (Green Mountain and Dillon) and several transbasin export diversions upstream of this gage location. Roberts Tunnel is the largest of the transbasin exports above the Blue River below Green Mountain gage location, and its diversions are backed by storage in Dillon Reservoir. The export demand is nearly always satisfied, in some years causing Dillon Reservoir to drop to very low levels. From a streamflow perspective, the reservoirs are storing as much of the peak flow as possible, especially in April and May when the results reflect low levels in all scenarios. During the winter, Green Mountain Reservoir is drawing down for flood control purposes by releasing for hydropower operations. Additionally, Green Mountain releases to contract holders who are called out by senior downstream Shoshone Power Plant. These combined effect of these operations leads to the different streamflow response reflected at this location.

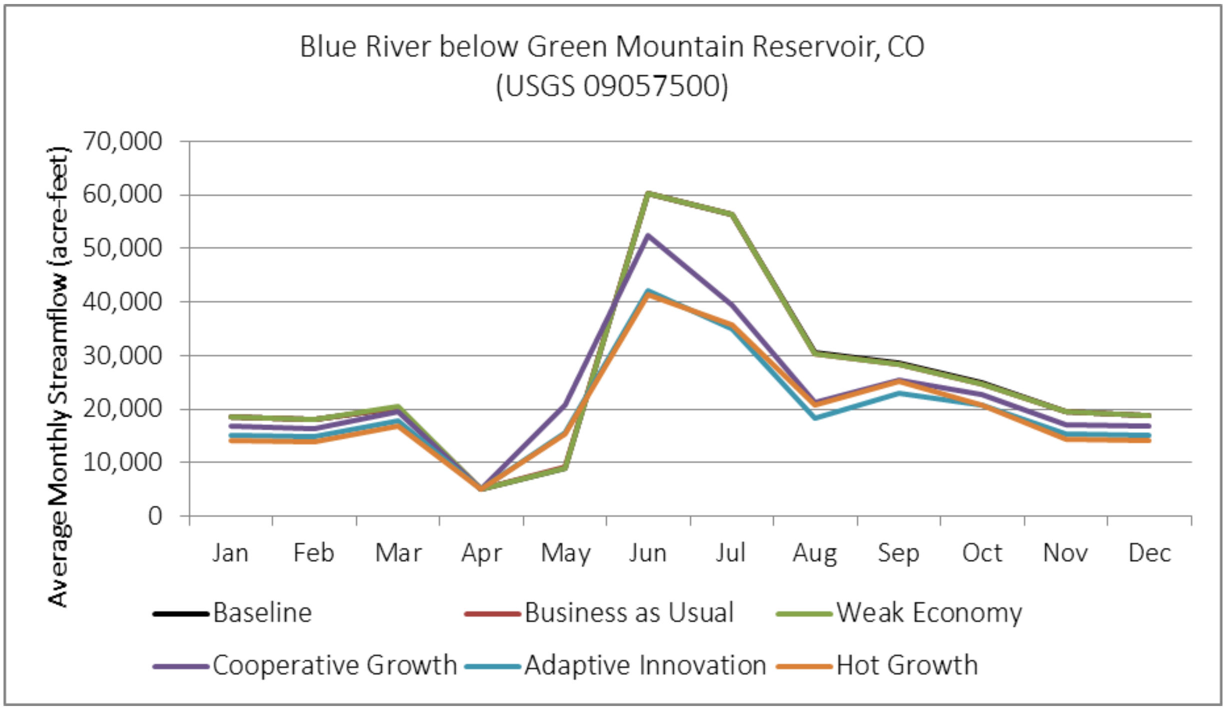


Figure 31: Average Monthly Streamflow for Blue River below Green Mountain Reservoir

The Colorado River near Dotsero average monthly streamflow is shown in Figure 32. This gage is representative of the amount of water available to the Shoshone Power Plant and is located about halfway down the Colorado River Basin. The trends in simulated streamflow across the scenarios are indicative of results at downstream locations. The simulated streamflow is similar between the Baseline, Business as Usual, and the Weak Economy scenarios. Under the In-Between hydrology and the Hot and Dry hydrology, the peak streamflow is shifted from June to May, and there is an overall reduction to streamflow volumes. The annual volume of streamflow is projected to decrease from about 310,000 ac-ft to 274,000 ac-ft for the In-Between hydrology and 238,000 ac-ft for the Hot and Dry hydrology.

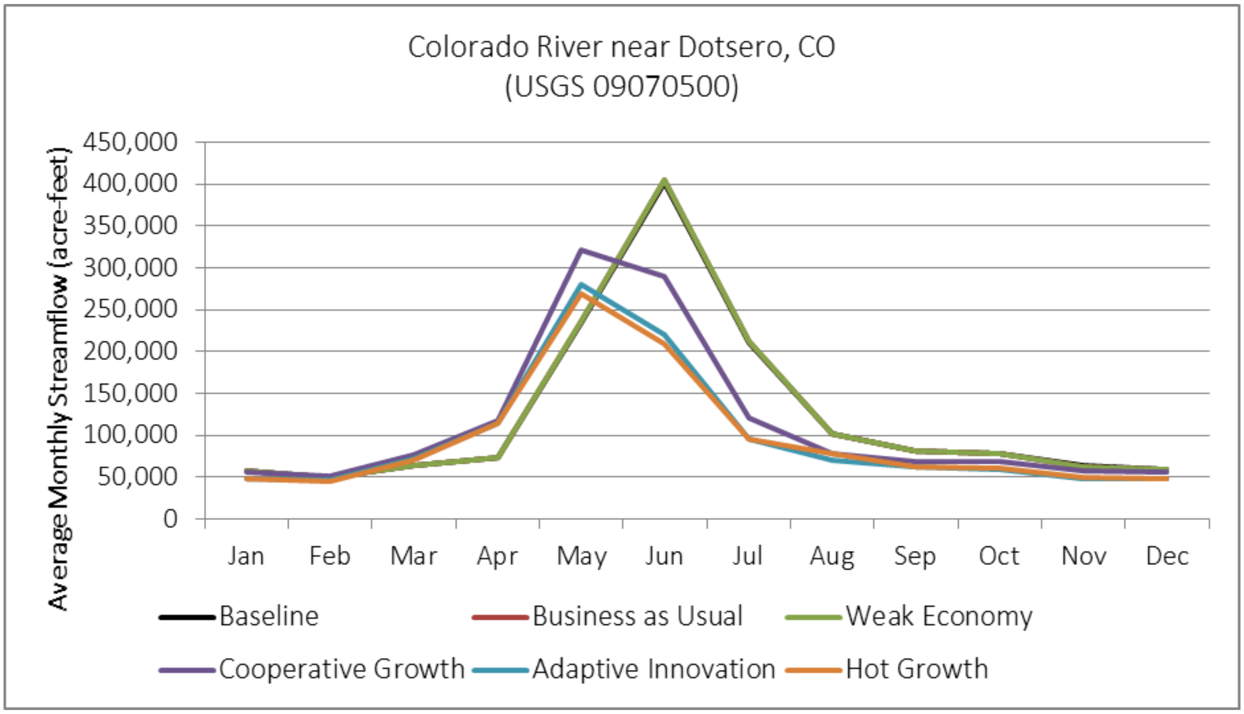


Figure 32: Average Monthly Streamflow for Colorado River near Dotsero

Figure 33 reflects simulated streamflow results for the Roaring Fork River at Glenwood Springs. The streamflow is influenced by upstream transbasin exports, reservoir storage, agricultural use, and M&SSI use. Similar to the Colorado River at Dotsero results, the peak streamflow is shifted from June to May, and the streamflow in July is greatly reduced. The annual streamflow volume is reduced from 870,000 ac-ft under the current hydrology to 822,000 ac-ft in the Cooperative Growth scenario, 730,000 ac-ft in the Adaptive Innovation scenario and 724,000 ac-ft in the Hot Growth scenario.

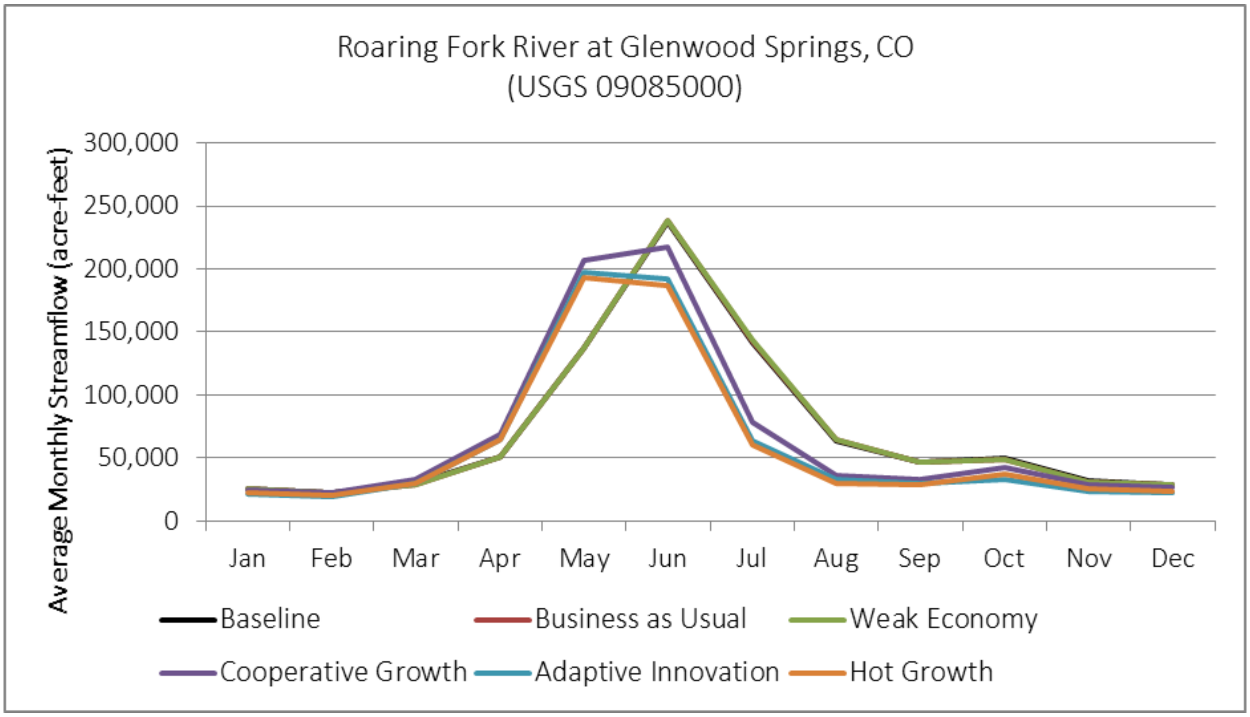


Figure 33: Average Monthly Streamflow for Roaring Fork River at Glenwood Springs

Figure 34 through Figure 37 reflect simulated unappropriated available supply for the Colorado River Basin at locations representative of the Shoshone Power Plant diversion (near Dotsero) and the "Cameo Call", which are generally the controlling rights on the mainstem of the Colorado River. As reflected on the graphics, there is generally unappropriated streamflow available in the Business as Usual and Weak Economy scenarios during runoff, except during critically dry years, when no unappropriated flow is available. Winter-time has severely limited unappropriated streamflow available, as nearly all of the flow is being used to meet existing water rights and demands. Unappropriated available supplies are still available in the climate-adjusted Planning Scenarios during the runoff, but the average volumes are substantially reduced and shifted earlier in the year. Streamflow and unappropriated available flow nearly double between the upstream and downstream locations due to inflows from the Roaring Fork, Parachute Creek, and Rifle Creek. The figures reflect that unappropriated streamflow is available at these locations, but the magnitude and timing vary substantially annually and across the hydrologic year types.

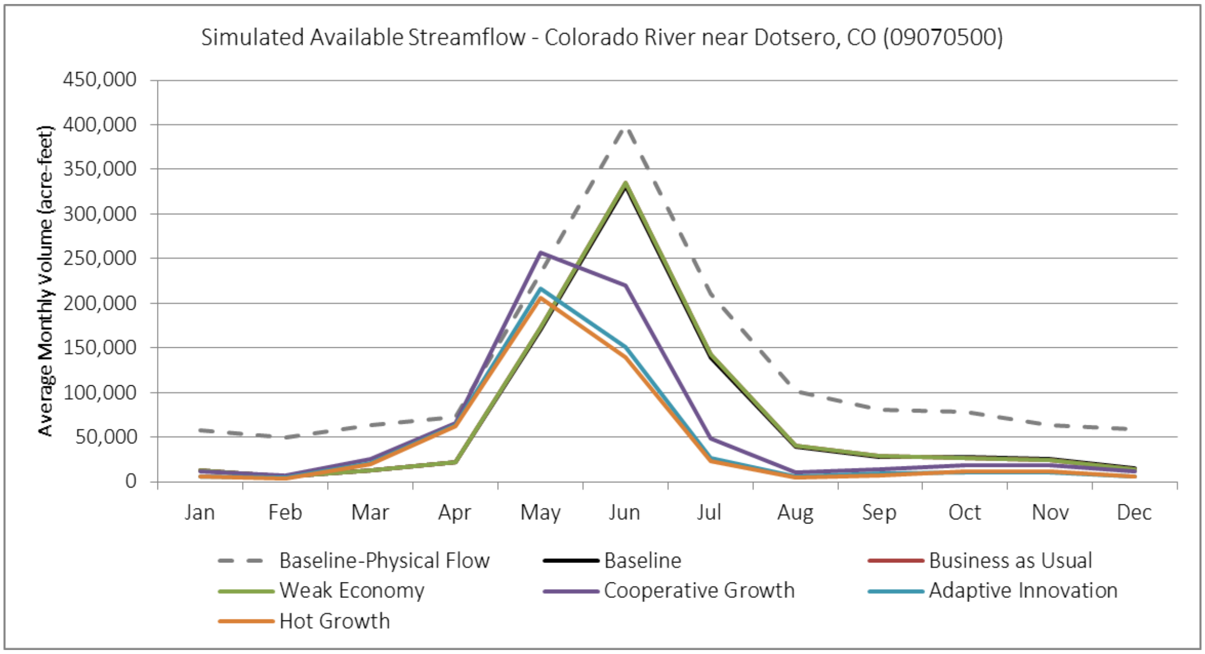


Figure 34: Average Monthly Unappropriated Available Supply at Colorado River near Dotsero

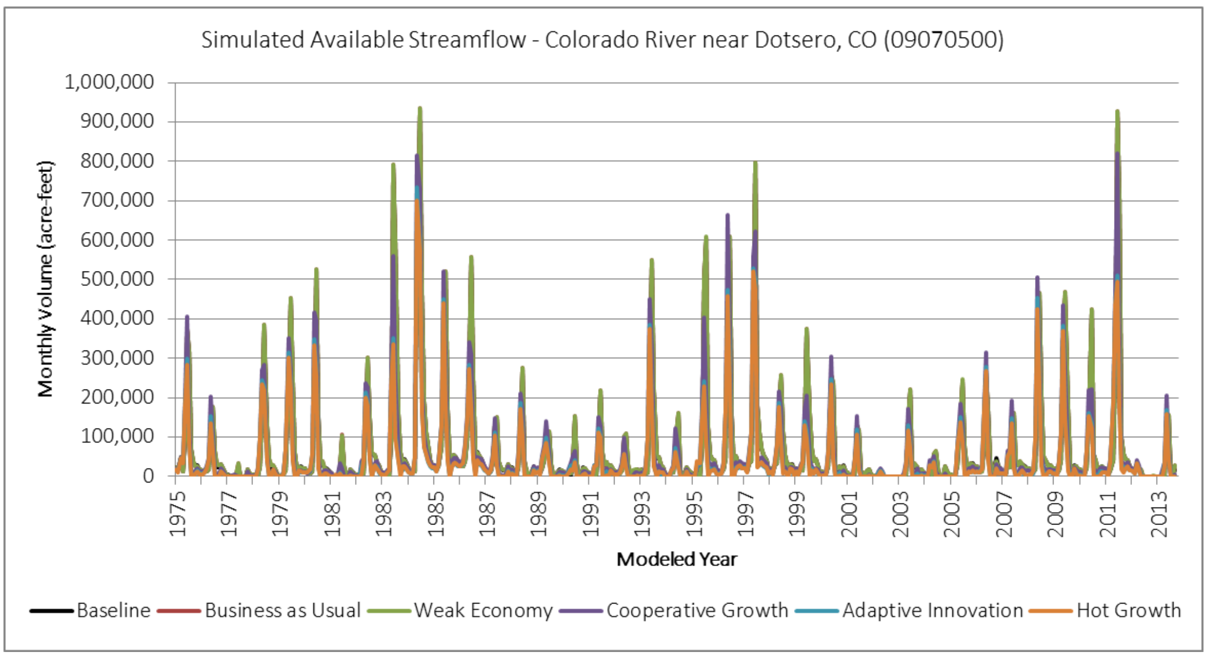


Figure 35: Monthly Unappropriated Available Supply at Colorado River near Dotsero

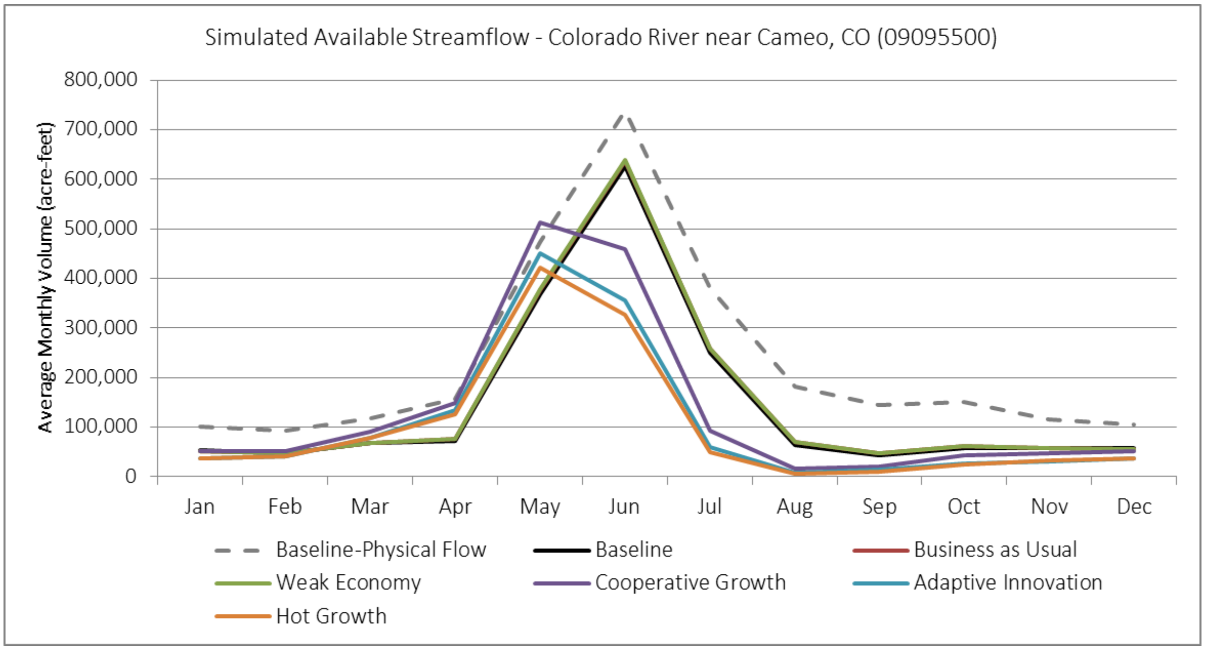


Figure 36: Average Monthly Unappropriated Available Supply at Colorado River near Cameo

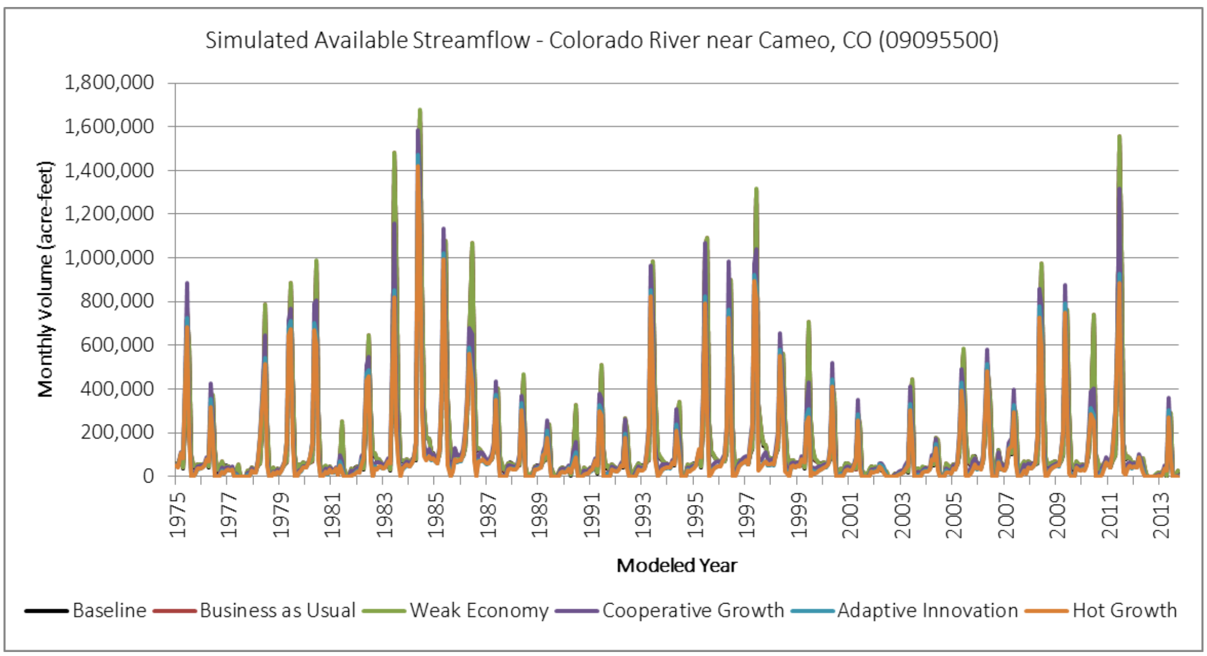


Figure 37: Monthly Unappropriated Available Supply at Colorado River near Cameo

5.3 GUNNISON RIVER BASIN

A vast majority of the water used in the Gunnison River Basin is for agricultural purposes; for mountain ranching at higher elevations and for producing fruits and field crops at lower elevations near the confluence with the Colorado River at Grand Junction. Irrigation in the basin has been supported by several Reclamation projects, including the Uncompahgre Project, which diverts an average of 330,000 ac-ft per year through the Gunnison Tunnel, the Paonia Project, Smith Fork Project, Bostwick Park Project, and the Fruitgrowers Dam Project. In addition to the irrigation projects, the Gunnison River fills the Aspinall Unit, which is comprised of three reservoirs dammed by Blue Mesa Dam, Morrow Point Dam, and Crystal Dam. The three reservoirs are operated in tandem to produce hydropower, provide flood control benefits, support the recovery of endangered fish species, and deliver water to downstream water users.

Several municipal areas are located throughout the Gunnison River Basin, many of which are agricultural communities such as the Delta/Montrose area, Ridgway, and Hotchkiss. Tourism is also an important economic driver in the basin. Recreational opportunities range from the ski resorts in Crested Butte and Telluride to fishing opportunities at the many reservoirs, and the Black Canyon of the Gunnison National Park.

The following sections describe the agricultural, M&SSI, and transbasin export demands in the Gunnison River basin in more detail. Figure 38 shows the basin outline, the administrative boundaries of water districts, and the streamflow gages highlighted in the results section below.

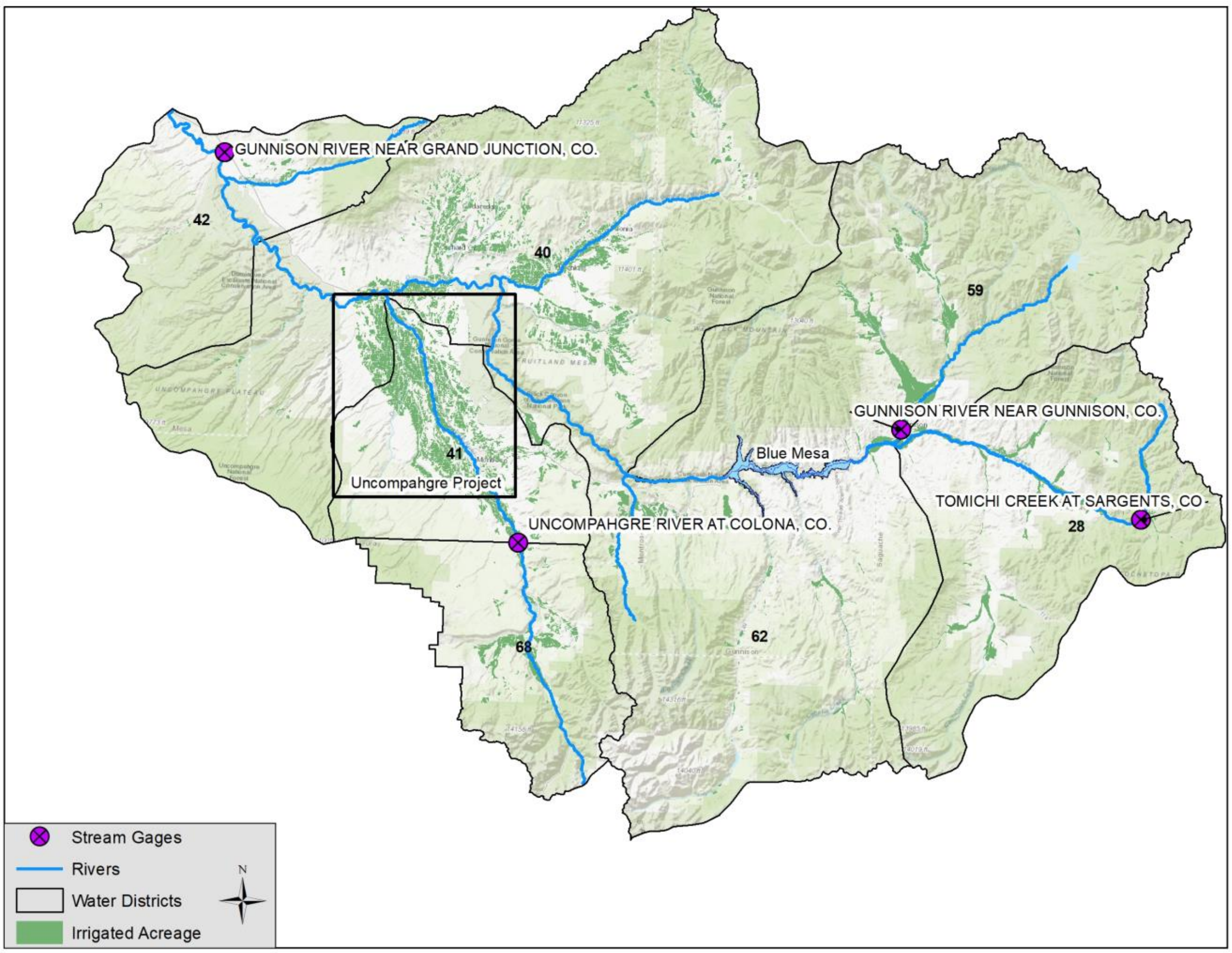


Figure 38: Gunnison River Map with Streamgage Locations

5.3.1 GUNNISON RIVER BASIN AGRICULTURE WATER SUPPLY AND GAP

Agriculture in the Upper Gunnison River Basin, above Blue Mesa Reservoir, is defined by large cattle and sheep ranches located along the tributaries and mainstem river. Ranchers generally rely on flood irrigation to fill the alluvium during the runoff season, as supplies are typically scarce later in the irrigation season. Gravelly soils lead to large diversions and lower efficiencies in the basin, a fact captured in the high duty of water (i.e. water decreed as reasonably necessary to grow and mature a valuable crop) in many of the irrigation decrees. Irrigation in the Lower Gunnison River basin was shaped by several Bureau of Reclamation Projects, which provide supplemental irrigation supplies for much of the irrigated acreage in the area. Due to lower elevations and warmer temperatures, irrigators in the Lower Gunnison River basin cultivate a variety of fruits, vegetables, corn grain, and root crops on over 185,000 acres of the total 234,400 acres irrigated in the basin.

Another notable feature in the Gunnison River basin are operations that help maximize a tributary's yield by rotating diversions among all irrigators, regardless of the priority of water rights. Sometimes referred to as "gentleman's agreements", these informal operations tend to benefit the more junior water users on a tributary and are motivated by lack of storage. For areas without storage, irrigation supplies are generally available only during the runoff, and water users use these informal agreements to allow more of the runoff to be diverted. One of the more important examples of these types of agreements is the operational practice whereby the Gunnison Tunnel abstains from placing a call during dry years. In some instances, the Gunnison Tunnel water users will coordinate with the Upper Gunnison Water Conservancy District to receive water from Taylor Park Reservoir in lieu of placing a call. At other times, the Gunnison Tunnel water users decide to forego diverting their full entitlement, thus allowing upstream irrigators to divert more water.

These types of agreements are discussed herein because the baseline model allocates water based on strict priority, and does not replicate these informal agreements. This approach allows the model to demonstrate conditions in the basin under current administration, which provides the most certainty to water users for planning purposes. This may also overestimate the amount of agricultural gap compared to historical conditions, and may overestimate the amount of diversions through the Gunnison Tunnel.

The Gunnison River Basin agricultural diversion demands, demand gaps, and consumptive use gaps results for the baseline and Technical Update Planning Scenarios are presented

Table 14. As discussed in the *Current and 2050 Planning Scenario Agricultural Diversion Demand* technical memorandum, 2050 agricultural diversion demands are influenced by a number of drivers, including climate, urbanization, planned agricultural projects, and emerging technologies.

Table 14: Gunnison River Basin Agricultural Water Supply and Gap Summary

	Agricultural Results	Baseline	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand (ac-ft)	1,800,163	1,675,496	1,675,496	1,967,156	1,305,708	2,041,502
	Average Annual Demand Increase from Baseline (ac-ft)	-	-	-	166,994	-	241,339
	Average Annual Gap (ac-ft)	87,314	77,167	77,317	157,596	112,632	221,970
	Average Annual Gap Increase from Baseline (ac-ft)	-	-	-	70,282	25,318	134,656
	Average Annual Percent Gap	5%	5%	5%	8%	9%	11%
	Average Annual CU Gap (ac-ft)	43,202	38,195	38,271	74,838	64,720	104,022
Critically Dry Maximum	Demand In Maximum Gap Year (ac-ft)	1,841,123	1,713,899	1,713,899	1,833,551	1,247,621	1,912,658
	Increase from Baseline Demand (ac-ft)	-	-	-	-	-	71,535
	Gap In Maximum Gap Year (ac-ft)	339,679	313,533	314,821	432,633	319,622	590,803
	Increase from Baseline Gap (ac-ft)	-	-	-	92,954	-	251,124
	Percent Gap In Maximum Gap Year	18%	18%	18%	24%	26%	31%

The average annual agricultural demand decreases from the Baseline to the Business as Usual and Weak Economy Planning Scenarios. Both Planning Scenarios assume 14,600 acres of irrigated acreage is removed from production due to urbanization of irrigated lands. The reduction in acreage does not make additional supplies available for the remaining acreage. As reflected in the table, irrigators in the basin currently experience a relatively small agricultural gap on average with a slightly more substantial gap during critically dry years.

Under the Cooperative Growth scenario, 14,600 acres of irrigated acreage is removed from production due to urbanization and the average annual demand increases due to climate adjustments to IWR. These adjustments combine to increase the agricultural demand by approximately 167,000 ac-ft basin-wide compared to the Baseline scenario, noting however that the impact of the climate change adjustments are larger in the upper basin compared to the lower basin. Irrigators in the upper basin have significantly less or no access to reservoir storage compared to ditches in the lower basin. Increased demands in these areas must be met using available water supply from the river. The Cooperative Growth scenario uses the In-Between hydrology, which shifts the peak runoff and reduces streamflow during the late irrigation season; therefore, shortages increase in this scenario compared to the Baseline scenario.

For the Adaptive Innovation scenario, the average annual demand is less than the Baseline demand, despite reflecting the same reduction to irrigated lands for urbanization and incorporating climate adjustments to IWR under the Hot and Dry conditions. To offset the impact of climate change, the Adaptive Innovation scenario assumes that emerging technologies decrease the IWR and increase irrigation system efficiency for the entire basin. Agricultural demands are highly sensitive to changes in IWR and system efficiency, so the two emerging technology adjustments result in a net decrease of nearly 495,000 ac-ft of agricultural demands on average compared to the Baseline scenario. The average annual gap and the CU gap in the Adaptive Innovation scenario is smaller than the Cooperative Growth scenario, but larger than the Business as Usual scenario, indicating the two adjustments did not fully mitigate the effects of Hot and Dry climate conditions. Finally, the Hot Growth scenario produces the largest agricultural gaps in the Gunnison River Basin. Average annual demands have increased while the runoff is projected to decrease. The annual percent gap is 11 percent on average, but increases to 31 percent in critically dry years.

In general, the Gunnison River Basin is projected to experience relatively low agricultural gaps on average, with more pronounced gaps during critically dry years. This is highlighted in Figure 39 and Figure 40, which show the relative size of the agricultural demands and gaps for the average annual and during a critically dry year. As discussed above, the gap is likely larger for irrigators on smaller tributaries without access to storage due to the reduced annual runoff volumes and more pronounced reductions in late season supplies. For example, Water District 28 (Tomichi Creek) has a maximum gap of 46 percent in the Hot Growth scenario compared to a maximum gap of 19 percent in Water District 41 (Lower Uncompahgre River). Agricultural storage in Water District 28 is limited, so irrigators depend on direct diversions whereas Water District 41 benefits from the Uncompahgre Project, which has storage in Blue Mesa Reservoir and Taylor Park Reservoir, and is supplied by the Gunnison Tunnel. These supplemental supplies and infrastructure buffer against declining streamflow.

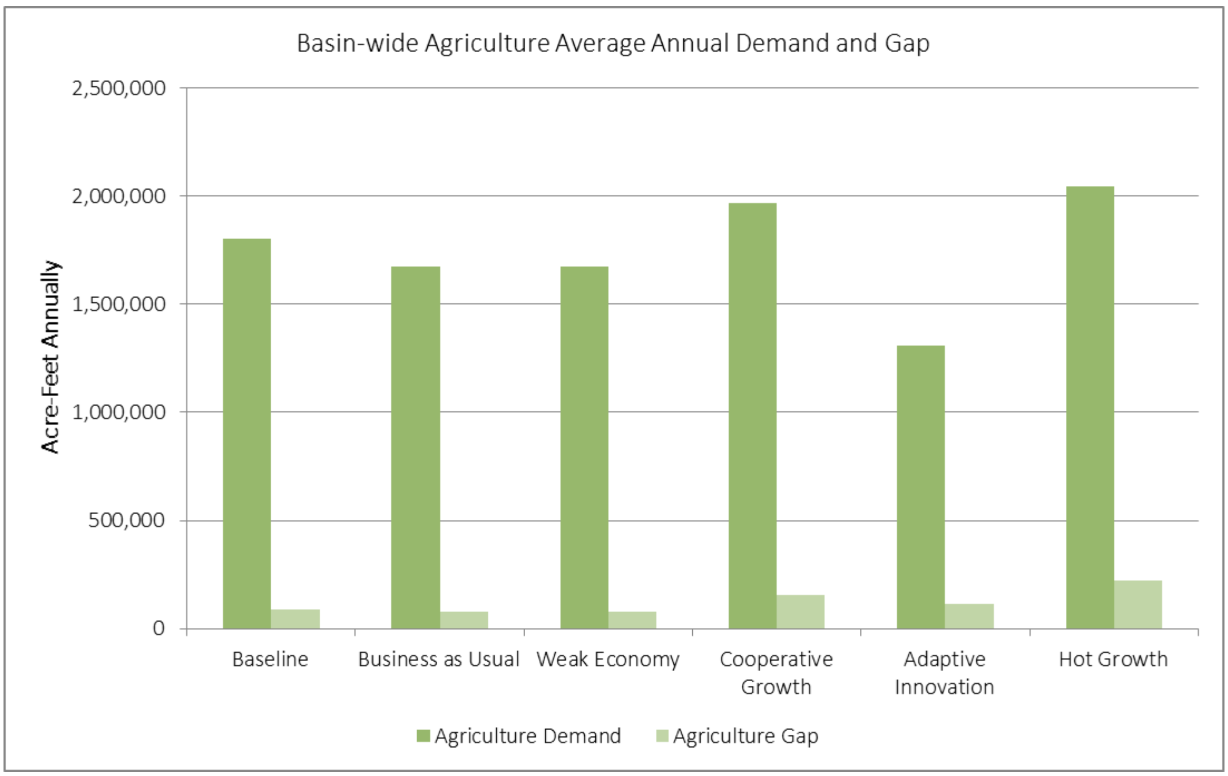


Figure 39: Gunnison River Basin Agriculture Average Annual Demand and Gap

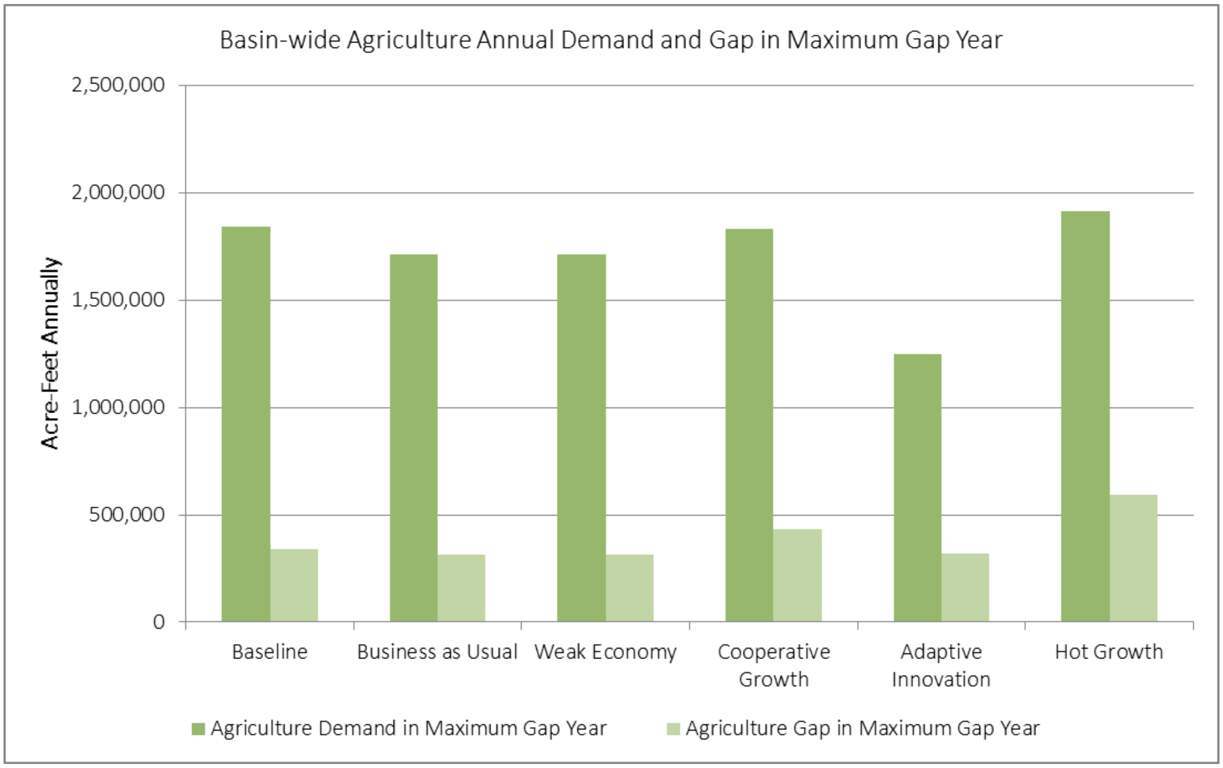


Figure 40: Gunnison River Basin Agriculture Annual Demand and Gap in Maximum Gap Year

In addition to the average annual summary, it is important to consider the variability of gaps across wet, average, and dry year types. Figure 41 reflects the average annual percent gap for modeled years (1975 - 2013). The dry hydrology years of 1977 and 2002 stand out as the largest gaps in the basin, followed by 2012, 1990, and 1981. The Baseline, Business as Usual, and Weak Economy scenarios all produce very similar results and results are often overlapping on the graph. The results for these scenarios indicate that shortages to agriculture, although small, occur in even the wettest years. The Cooperative Growth and the Adaptive Innovation scenarios generally trend together, indicating the emerging technologies adjustments had the effect of partially mitigating the impact of Hot and Dry climate conditions. The Hot Growth scenario produces the largest gaps.

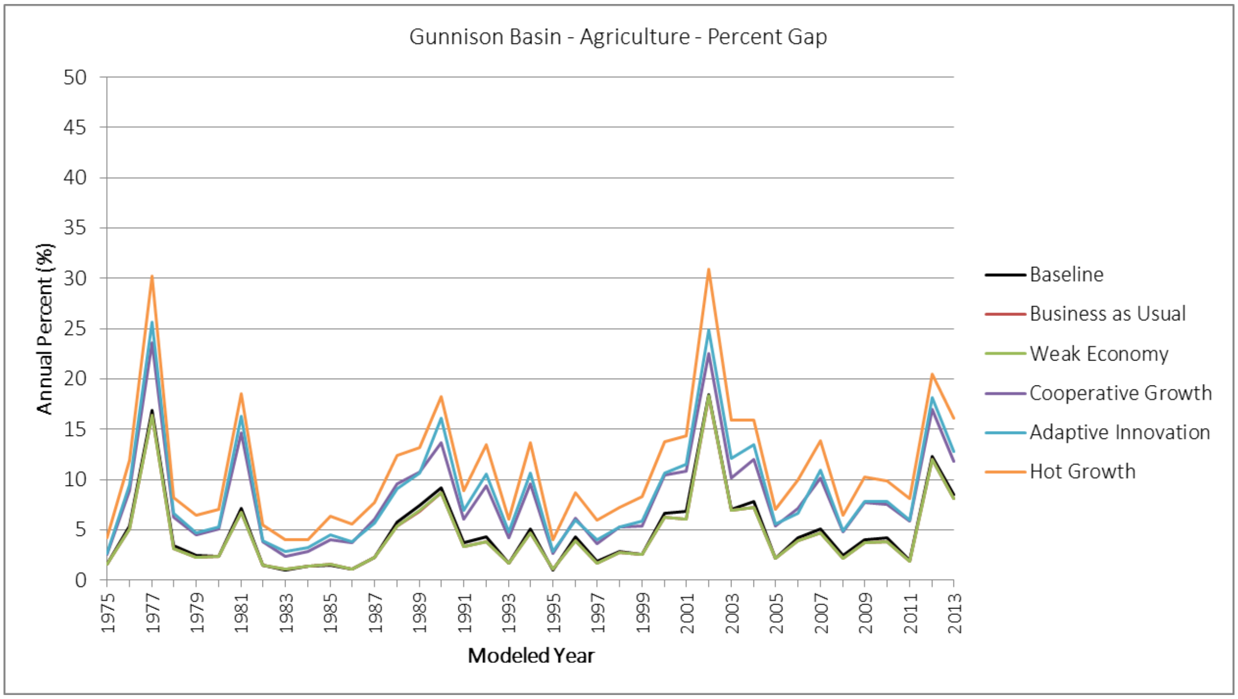


Figure 41: Gunnison River Basin Agriculture Percent Diversion Gap Times Series

5.3.2 GUNNISON RIVER BASIN M&SSI WATER SUPPLY AND GAP

M&SSI demands are small relative to other demands in the basin, consisting of approximately one percent of the total demands. Of the total M&SSI demands, over 99 percent are attributable to municipal demands, with only one percent attributable to SSI demands. Close to half of the municipal demand in the basin occurs in Montrose County, which is projected to increase in all Planning Scenarios. Hinsdale County is projected to have the highest rate of population growth across the Planning Scenarios, whereas Ouray County is projected to have more moderate growth or decrease in population in some Planning Scenarios. Population in the basin overall, however, is projected to increase in all Planning Scenarios, driving increased municipal demands.

In the Gunnison River Basin model, a majority of the municipal demand is represented at grouped locations, with only the Project 7 Water Authority, which provides municipal and domestic water to the Uncompahgre Valley, including the Towns of Montrose and Delta, represented individually as a component of the Dallas Creek Project.

SSI[8] demands in the basin, projected to be less than 700 ac-ft, are attributable to snowmaking operations. These demands are modeled at grouped locations in tributary headwaters. Refer to the *Baseline and Projected 2050 Planning Scenario Municipal and Self Supplied Industrial Water Demands* technical memorandum for additional discussion on how the M&SSI demands in the basin were developed. The water supply and gap results for M&SSI in the Colorado River basin are summarized in Table 15, and graphically reflected in Figure 42 through Figure 44.

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[8] Note that water used for hydropower, such as those operations at the Aspinall Unit, are represented in the model but are not included in the SSI demand summaries (i.e. non-consumptive) and are not adjusted between Planning Scenarios.

Table 15: Gunnison River Basin M&SSI Water Supply and Gap Summary

	M&SSI Results	Baseline	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand (ac-ft)	17,012	24,763	19,133	22,888	26,393	34,057
Average	Average Annual Demand Increase from Baseline (ac-ft)	-	7,751	2,121	5,876	9,381	17,045
Average	Average Annual Gap (ac-ft)	84	980	200	1,372	2,197	5,444
Average	Average Annual Gap Increase from Baseline (ac-ft)	-	896	116	1,288	2,113	5,360
Average	Average Annual Percent Gap	0%	4%	1%	6%	8%	16%
Critically Dry Maximum	Demand In Maximum Gap Year (ac-ft)	17,012	24,763	19,133	22,888	26,393	34,057
Critically Dry Maximum	Increase from Baseline Demand (ac-ft)	-	7,751	2,121	5,876	9,381	17,045
Critically Dry Maximum	Gap In Maximum Gap Year (ac-ft)	409	2,290	700	3,486	4,326	11,465
Critically Dry Maximum	Increase from Baseline Gap (ac-ft)	-	1,881	291	3,077	3,917	11,056
Critically Dry Maximum	Percent Gap In Maximum Gap Year	2%	9%	4%	15%	16%	34%

As reflected in the table, there is an M&SSI gap in the Baseline scenario. Ideally, the Baseline scenario would have no M&SSI gaps because the current conditions in the basin fully satisfy the existing M&SSI demands. This small amount of gap is likely a result of minor calibration issues in the model associated with the representation of the Project 7 Water Authority. Dallas Creek Project operations in dry years differ from those in average and wet years; the model currently represents average year conditions.

The Gunnison River Basin is projected to increase in population in 2050; therefore all of the Planning Scenarios reflect an increase in M&SSI demand compared to the Baseline scenario. The average annual demand increases from the Baseline scenario to the Business as Usual scenario, primarily because of the increase in municipal demands. The average annual gap of 4 percent is relatively small, however the 9 percent gap in critically dry years is more substantial. M&SSI demand in the Weak Economy increases approximately 2,100 ac-ft compared to the Baseline Scenario, and the gap results on average and during critically dry years are similar to those experienced in the Baseline scenario.

The Cooperative Growth scenario has smaller increase in demands than the Business as Usual scenario, but the gaps are larger due to the reduction in streamflow volume reduction in water available in the basin under the In-Between hydrological conditions. The percent gap reaches 6 percent and 15 percent for the average annual and during critically dry years, respectively.

M&SSI demands projected in Adaptive Innovation scenario are considerably larger than the Baseline scenario, driven by projected population growth. In addition to increasing the demands, streamflow is further reduced under the Hot and Dry hydrology. The average annual gap is 8 percent and reaches 16 percent in critically dry years.

Finally, the Hot Growth scenario demand doubles the Baseline M&SSI demand and reduces the available water supply with Hot and Dry hydrological conditions. The average annual gap is nearly 5,500 ac-ft or 16 percent of the demand. The gap in critically dry years reaches 11,000 ac-ft or 34 percent of the total demand.

Overall conclusions on the M&SSI demand and gap in the Gunnison River Basin vary depending on the scenario. Scenarios that incorporate current hydrological conditions have relatively low gaps, indicating that river conditions, even during critically dry years, are sufficient to meet much of the projected demand. Gaps increase, however, once drier hydrological conditions are incorporated alongside the increased gaps, leading to consistent annual gaps on average and larger gaps during critically dry years.

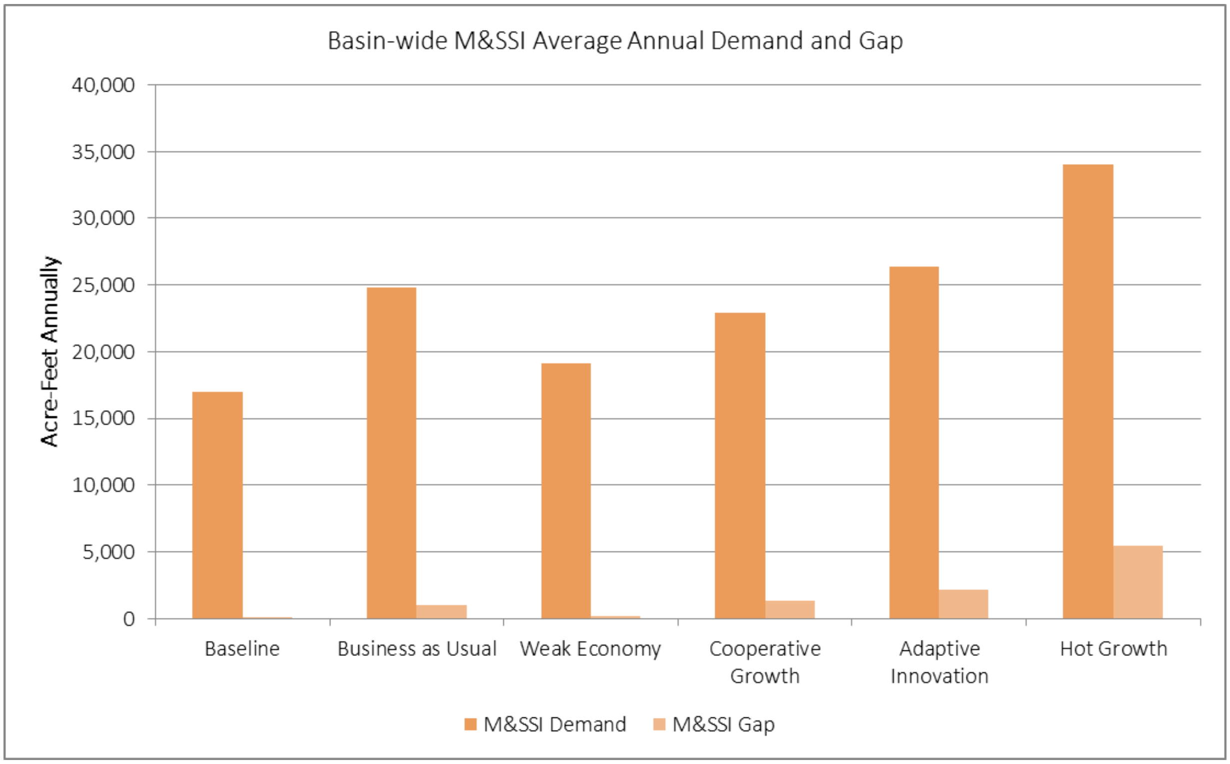


Figure 42: Gunnison River Basin M&SSI Average Annual Demand and Gap

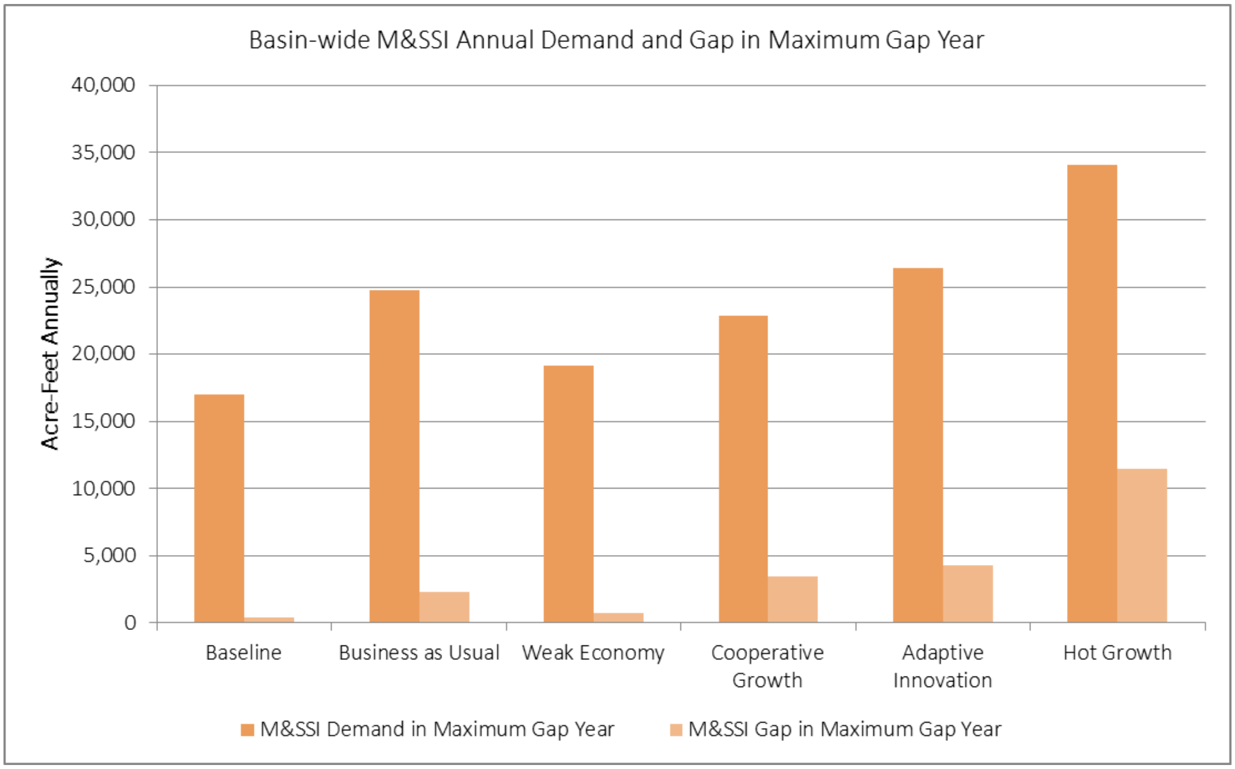


Figure 43: Gunnison River Basin M&SSI Maximum Annual Demand and Gap in Maximum Gap Year

Figure 44 reflects average annual percent gap across a variety of wet, average, and dry year types. The scenarios respond differently to the dry hydrology periods. Due to low water availability, 1977, 1985, 2002, and 2012 stand out as the years with the largest gaps, particularly for the Business as Usual, Cooperative Growth, and Hot Growth scenarios. The Adaptive Innovation scenario gap results appear to have a unique pattern, particularly during drier periods (e.g. 2000 – 2004), despite using the same hydrological conditions as the Hot Growth scenario. This is likely due to the emerging technologies adjustment for the agricultural demands. Improvements to irrigation system efficiency reduce the amount of agricultural demand, and change the amount and timing of irrigation return flows available in the system. In an agriculturally dominated system, these conditions would change water availability for more junior users in the system.

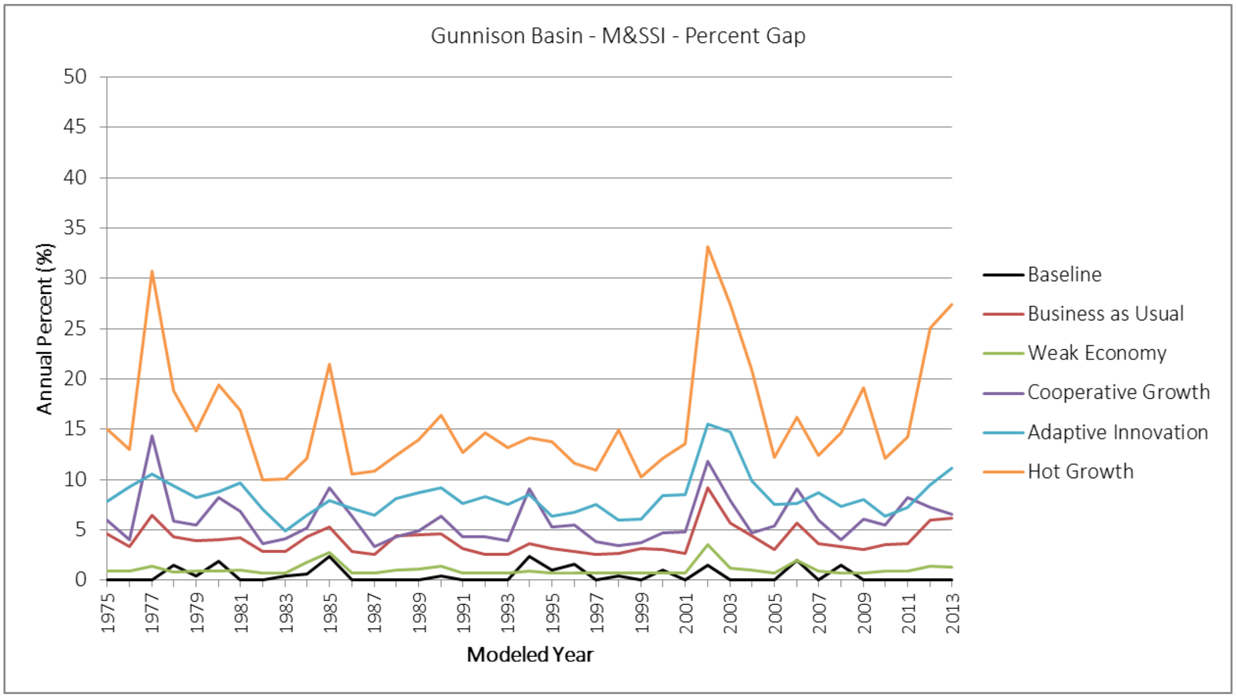


Figure 44: Gunnison River Basin M&SSI Average Annual Gap Time Series

5.3.3 GUNNISON RIVER BASIN TRANSBASIN EXPORT DEMAND

There is one transbasin export reflected in the Gunnison River Basin; a diversion from Kannah Creek for use in Grand Junction's municipal supply. Transbasin exports range depending on the in-basin supplies and the need for supplies at Grand Junction; however, on average the transbasin export demand from the Gunnison River Basin is 6,600 ac-ft. These demands could not be satisfied in all Planning Scenarios; however the shortages are reflected as an import supply gap in the destination basin and not considered a gap in the Gunnison River basin.

5.3.4 GUNNISON RIVER BASIN SUMMARY

The combined agriculture and M&SSI demands and gap summary is provided in Table 16. The results in Table 16 are very similar to the agricultural results in

Table 14, because the Gunnison River Basin is dominated by agriculture uses. The Gunnison River basin is generally able to meet much of the total demand in the Baseline, Business as Usual and Weak Economy scenario, except during critically dry years. The gaps increase as the demands increase and/or the hydrology decreases in the Cooperative Growth and the Adaptive Innovation scenarios. The gaps are largest in the Hot Growth scenario, which has the largest demands and the smallest streamflow.

Figure 45 shows the relative size of the demands in the Gunnison River Basin. Agriculture is the dominate demand; it is difficult to reflect the relative size of the M&SSI and transbasin export demands in the basin. Following the graphic are summaries regarding other considerations that may impact the basin-wide gap, including potential M&SSI supplies from urbanized acreage or transbasin import supply gaps.

Table 16: Gunnison River Basin Water Supply and Gap Summary

	Agricultural and M&SSI Results	Baseline	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand (ac-ft)	1,817,175	1,700,259	1,694,629	1,990,044	1,332,101	2,075,559
	Average Annual Gap (ac-ft)	87,398	78,147	77,517	158,967	114,829	227,414
	Average Annual Percent Gap	5%	5%	5%	8%	9%	11%
Critically Dry Max	Demand In Maximum Gap Year (ac-ft)	1,858,135	1,738,662	1,733,032	1,856,439	1,274,014	1,946,715
	Gap In Maximum Gap Year (ac-ft)	340,088	315,823	315,521	436,119	323,948	602,268
	Percent Gap In Maximum Gap Year	18%	18%	18%	23%	25%	31%

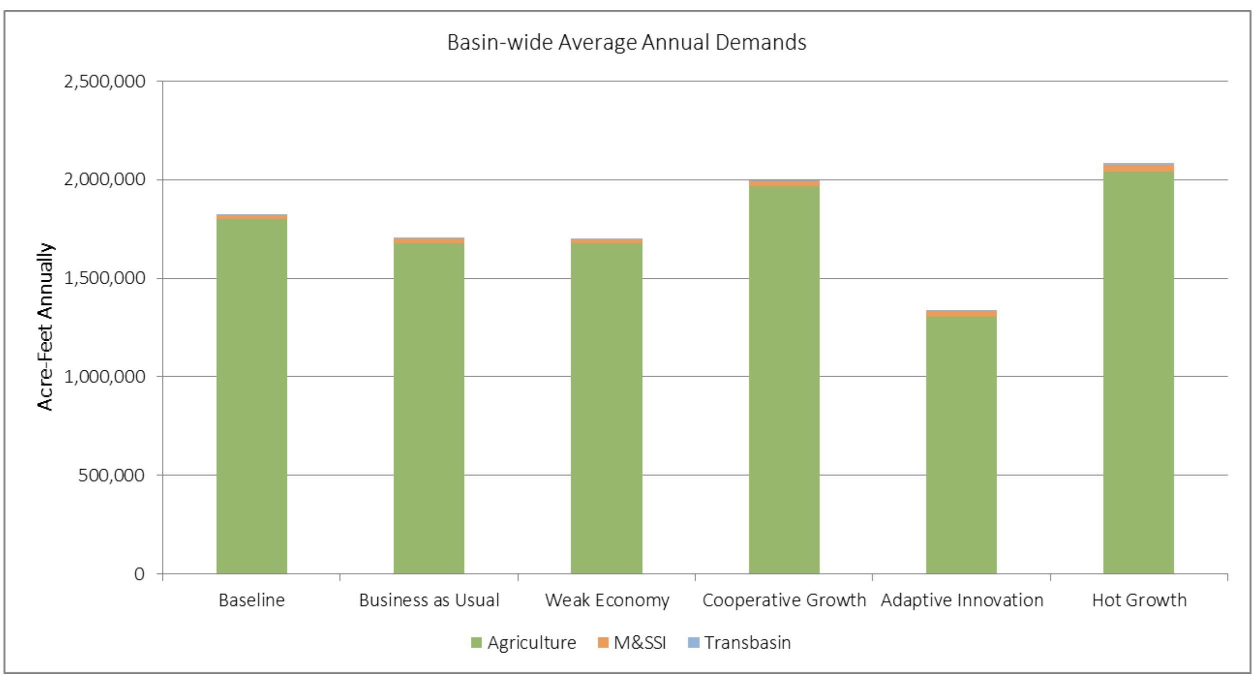


Figure 45: Gunnison River Basin Comparison of Average Annual Demands

All of the Planning Scenarios project 14,600 acres of irrigated agriculture will be taken out of production due to urbanization. Many counties in the basin are projected to have substantial population increases by 2050. Supplies used to irrigate the urbanized acreage could be considered a new municipal supply if the associated water rights were changed to municipal uses. To estimate this new supply, the average consumptive use of the urbanized acreage by Planning Scenario is reflected in Table 17. Note however, it is not known which farms and ranches will be directly impacted; whether the acreage was served by senior/junior direct rights or had supplemental storage supplies; or the crop type or specific irrigation practices on this acreage. Additionally, it is unknown if the water rights would be changed to municipal use, or whether the supply could directly meet the future municipal demand or would require exchange potential. In light of these uncertainties, the table reflects a planning-level estimate of this potential new supply. Although it has not been applied to the M&SSI gap presented above, it would likely have the effect of decreasing the gap.

Table 17: Potential Water Supply from Urbanized Acreage in the Gunnison River Basin

Urbanized Acreage Results	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Urbanized Acreage	14,600	14,600	14,600	14,600	14,600
Estimated Consumptive Use (ac-ft/year)	30,276	30,271	33,090	31,636	33,011

The Gunnison River Basin benefits from the delivery of a small amount of imported transbasin supplies including:

- Leon Tunnel Canal imports water from the Colorado River Basin to Surface Creek for irrigation.
- Mineral Point Ditch and Red Mountain Ditch imports water from the Southwest Basin to high mountain irrigation in the headwaters of the Uncompahgre River.

Ideally the import supply gap in the Baseline scenario would be zero; however the Baseline dataset represents current agricultural and M&SSI demands over the entire model period which can result in minor shortages to junior water rights, including transbasin diversions. With this in mind, the incremental increase in the import gap reflects the increase in gap due to the Planning Scenario adjustments.

Under current hydrology conditions, there was no increase in the gap for the Business as Usual and Weak Economy scenarios. The increased demands and changed hydrology in the Cooperative Growth, Adaptive Innovation, and Hot Growth scenarios however resulted in more substantial gaps during critically dry years. If exports stay the same in the future, the reported import gaps could increase the total Gunnison River basin M&SSI gaps in these scenarios.

Table 18: Summary of Transbasin Imports to the Gunnison River Basin

	Transbasin Import Supply Gap Results	Baseline	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Import Supply (ac-ft)	1,711	1,711	1,711	1,711	1,711	1,711
	Average Annual Import Supply Gap (ac-ft)	1	1	1	24	34	40

	Average Annual Import Supply Gap Increase from Baseline (ac-ft)	-	0	0	24	33	40
	Average Annual Import Supply Percent Gap	0%	0%	0%	1%	2%	2%
Critically Dry Maximum	Import Supply In Maximum Gap Year (ac-ft)	2,455	2,455	2,455	2,082	2,082	2,082
	Import Supply Gap In Maximum Gap Year (ac-ft)	15	15	15	216	368	368
	Increase from Baseline Import Supply Gap (ac-ft)	-	0	0	201	353	353
	Import Supply Percent Gap In Maximum Gap Year	1%	1%	1%	10%	18%	18%

As shown in Figure 46, the Gunnison River Basin has just under 1,400,000 ac-ft of storage. The largest reservoirs are:

- Aspinall Unit, including Blue Mesa Reservoir and smaller reservoirs impounded by Morrow Point Dam, and Crystal Dam
- Taylor Park Reservoir
- Ridgway Reservoir

The Aspinall Unit accounts for about a million ac-ft of the total storage in the basin, with the primary purpose of storing water for the Upper Colorado River Basin states. Secondary purposes include hydropower, delivery of irrigation supplies to the Uncompahgre Project via the Gunnison Tunnel, flood control, and maintaining flows for fish habitat. Blue Mesa Reservoir is the primary operational reservoir in the unit; storage in the two downstream reservoirs does not fluctuate much and used more to re-regulate flows. Due to the size of the Blue Mesa Reservoir, the results in the following graphic largely reflect the simulated reservoir operations of this reservoir. Taylor Park Reservoir is operated for supplemental irrigation water to the Uncompahgre Project and replacement water for irrigation in the Upper Gunnison River basin. Reservoir storage in Taylor Park is heavily used, especially in the Cooperative Growth, Adaptive Innovation, and Hot Growth scenarios. Ridgway Reservoir provides supplemental irrigation water, but only about half of the reservoir is allocated to consumptive uses. The remaining half of the reservoir is either inactive storage or maintained for recreational purposes. Other reservoirs in the basin, including Paonia, Crawford, Silverjack, Gould, Overland and Fruit Growers, are primarily used for irrigation. These irrigation reservoirs generally fill and release their full contents annually with limited carry-over storage, however many of these reservoirs are unable to fill during dry years under the Cooperative Growth, Adaptive Innovation, and Hot Growth scenarios

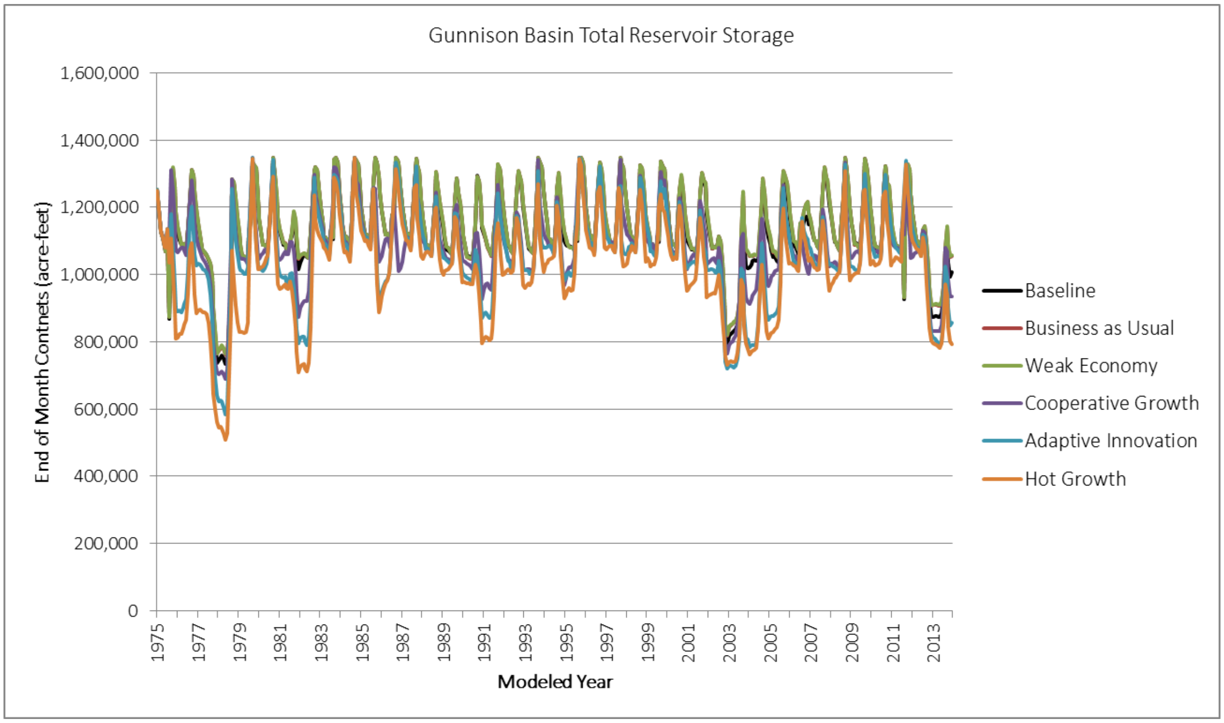


Figure 46: Gunnison River Basin Total Reservoir Storage

The following figures reflect average monthly simulated streamflow at key locations across the basin; refer to Figure 38 for the locations of the gages. The primary driver of average monthly simulated streamflow across the Planning Scenarios is hydrology. The average monthly streamflow results from Baseline, Business as Usual, and Weak Economy scenarios are often indistinguishable from each other because they use current hydrology. In several locations, the results are overlapping. The In-Between hydrology featured in the Cooperative Growth scenario and the Hot and Dry hydrology featured in the Adaptive Innovation and Hot Growth scenarios consistently reduce late season flows across the basin and, in many areas, shift the peak streamflow earlier in the year.

There are limited diversions to agriculture located upstream of the Tomichi Creek at Sargents gage and the average monthly streamflow generally reflects near-natural flow conditions. The In-Between hydrology projects slightly more water than current hydrology in April and May, but significantly less water in June and July. The Hot and Dry hydrology also projects slightly more water in April, but less water in all other months. This projected decline in streamflow causes the agricultural gaps, primarily in late season irrigation demands, in the scenarios that use the climate projections.

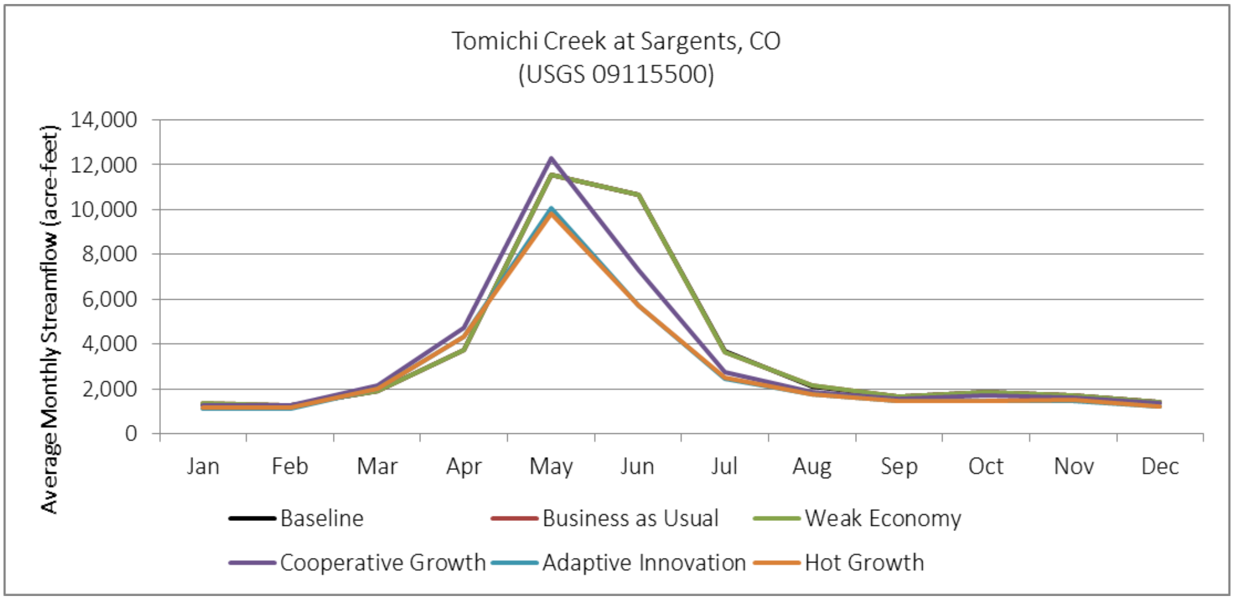


Figure 47: Average Monthly Streamflow for Tomichi Creek at Sargents

The Gunnison River near Gunnison gage is located downstream of Taylor Park Reservoir and a substantial amount of agricultural demand. The Business as Usual and Weak Economy scenarios have slightly more projected streamflow than the Baseline scenario due the reduction in upstream agricultural demand in these scenarios, but in general, mirror the results from the Baseline scenario. A drastic shift in streamflow is projected for the Cooperative Growth, Adaptive Innovation, and Hot Growth scenarios. The peak is shifted from June to May and the peak flow volume is slightly higher than the Baseline scenario flows. However, the annual flow volume is less than the Baseline scenario because of the streamflow decline in most other months. The projected decrease in late season streamflow is the primary cause of the increased agricultural gaps in these climate-adjusted scenarios.

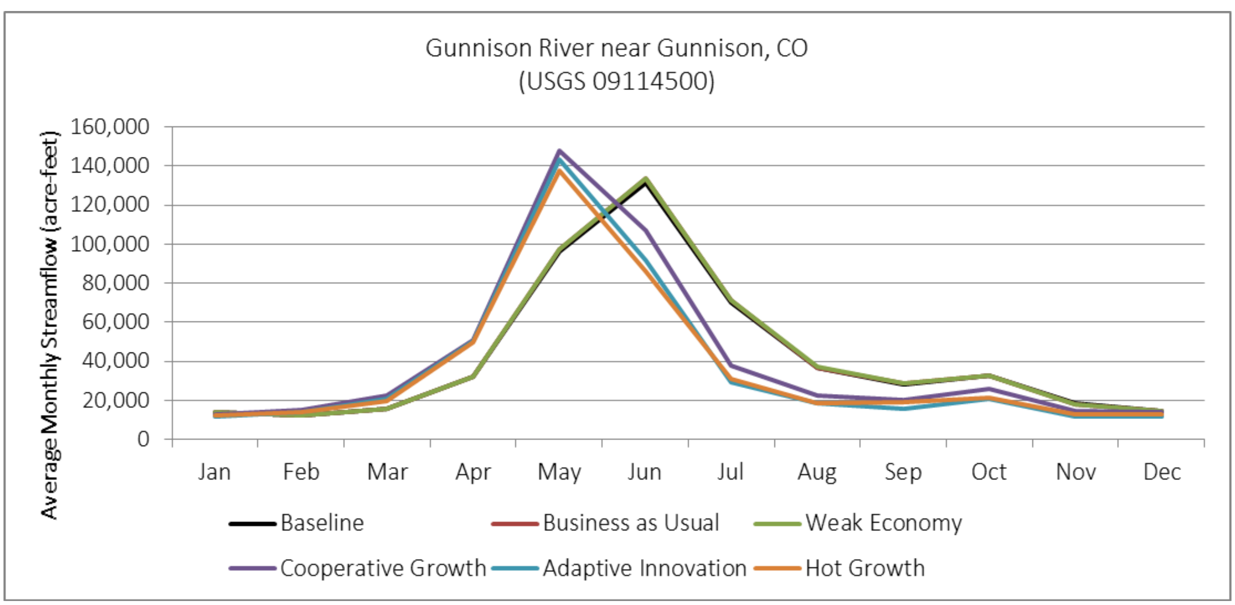


Figure 48: Average Monthly Streamflow for the Gunnison River near Gunnison

The Uncompahgre River at Colona gage is downstream of Ridgway Reservoir and some agricultural demand, but upstream of the majority of the Uncompahgre Project area. The Cooperative Growth, Adaptive Innovation and Hot Growth scenarios are projected to have muted runoff responses in May and June and significantly reduced flows during the late irrigation season. Annual streamflow is projected to experience a 20 percent decline on average in the Cooperative Growth scenario and a 30 to 33 percent decline on average in the Adaptive Innovation and Hot Growth scenarios, respectively.

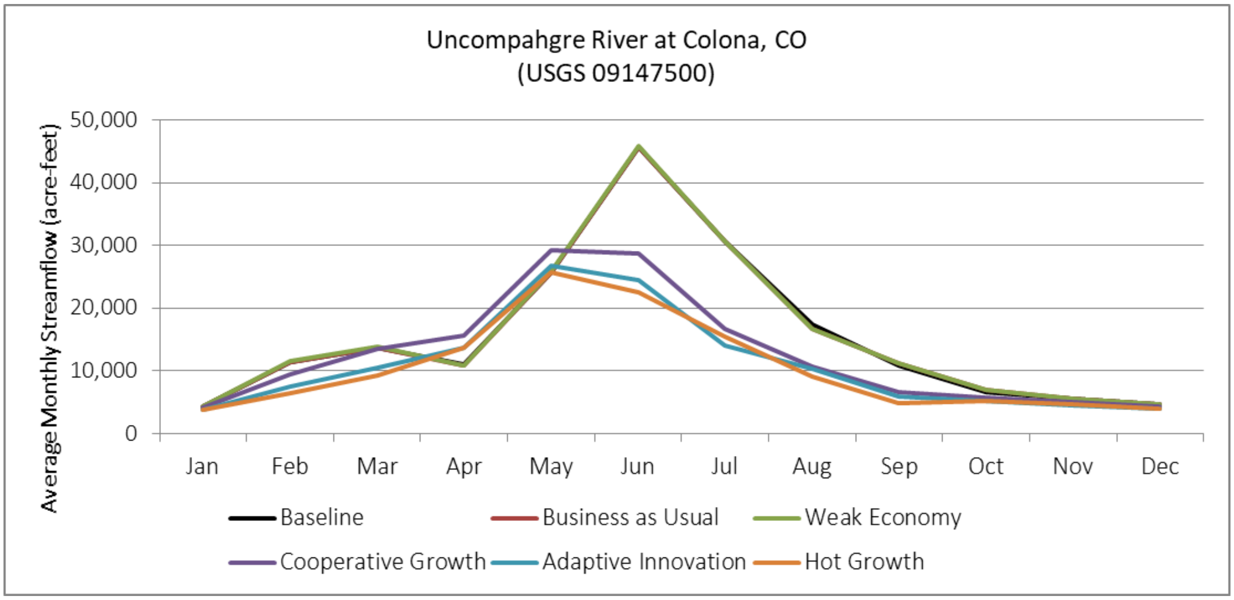


Figure 49: Average Monthly Streamflow for the Uncompahgre River at Colona

The Gunnison River near Grand Junction gage is near the bottom of the river, and provides an estimate of the amount of water that flows into the Colorado River. Streamflow results at the gage reflects the cumulative effect of changed agricultural and M&SSI demands, and climate-adjusted hydrology in the entire Gunnison River basin for each scenario. Overall, the scenarios project similar results for winter and springs months. Larger differences are projected for the late irrigation season, with the climate-adjusted scenarios reflecting a substantial decline in flows. This is consistent with the streamflow results discussed above, and indicates an overall decline on average of late irrigation season flows.

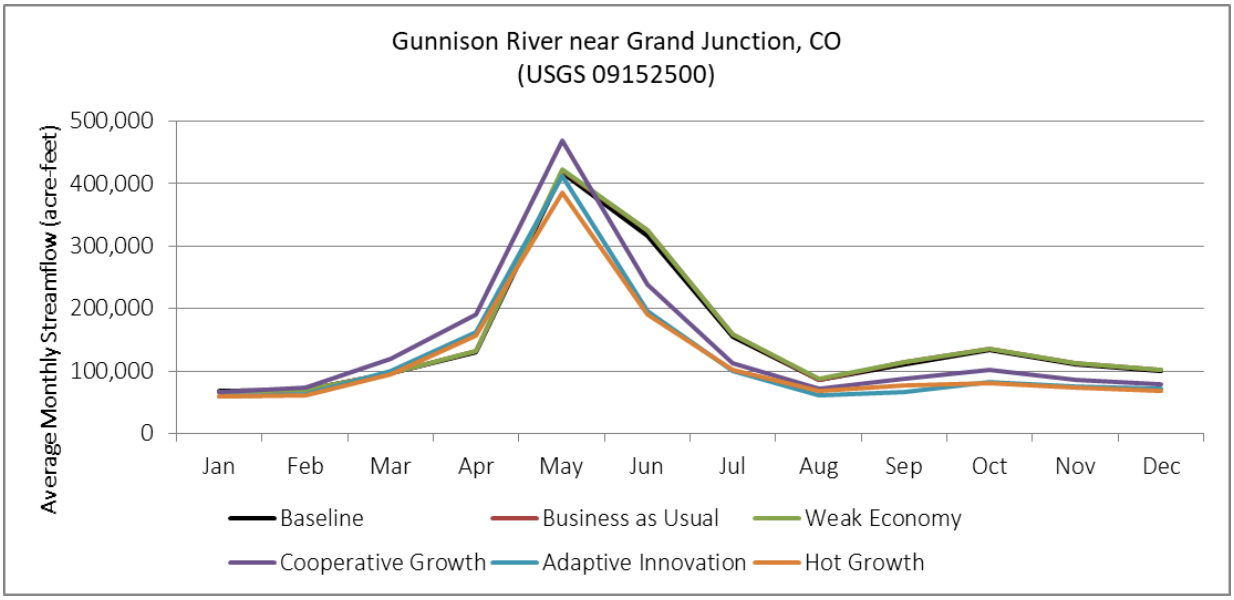


Figure 50: Average Monthly Streamflow for the Gunnison River near Grand Junction

Figure 51 and Figure 52 reflect simulated unappropriated available supply in the Gunnison River at a location downstream of the Aspinall Unit and Gunnison Tunnel diversion but upstream of the Redlands Canal, which is the primary calling right in the lower basin. The canal diverts for power and irrigation, and return flows accrue to the Colorado River Basin, reflecting a total depletion to the Gunnison River. Streamflow, and by extension unappropriated available flow, is heavily influenced by storage and releases from the Aspinall Unit and Gunnison Tunnel diversions located upstream. As reflected on the graphics, there is generally unappropriated streamflow available in the Business as Usual and Weak Economy scenarios except during critically dry years, when no unappropriated flow is available. Unappropriated available supplies are still available in the climate-adjusted Planning Scenarios, but the average volumes are substantially reduced and shifted earlier in the year. The figures reflect that unappropriated streamflow is available at these locations, but the magnitude and timing vary substantially annually and across the hydrologic year types.

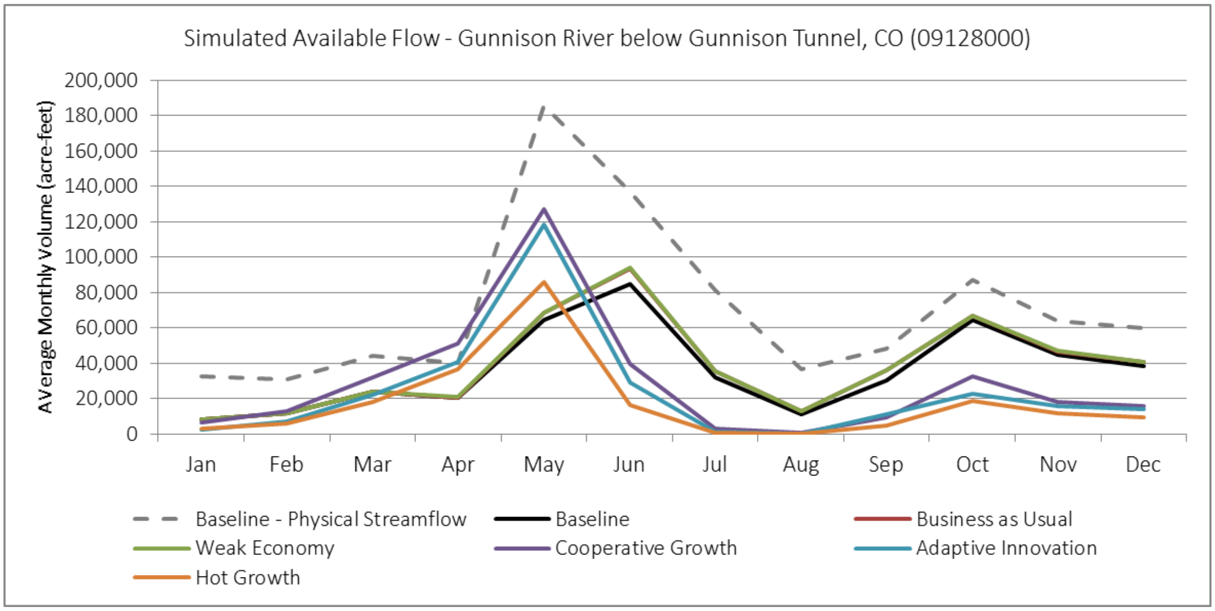


Figure 51: Average Monthly Unappropriated Available Supply at Gunnison River below Gunnison Tunnel

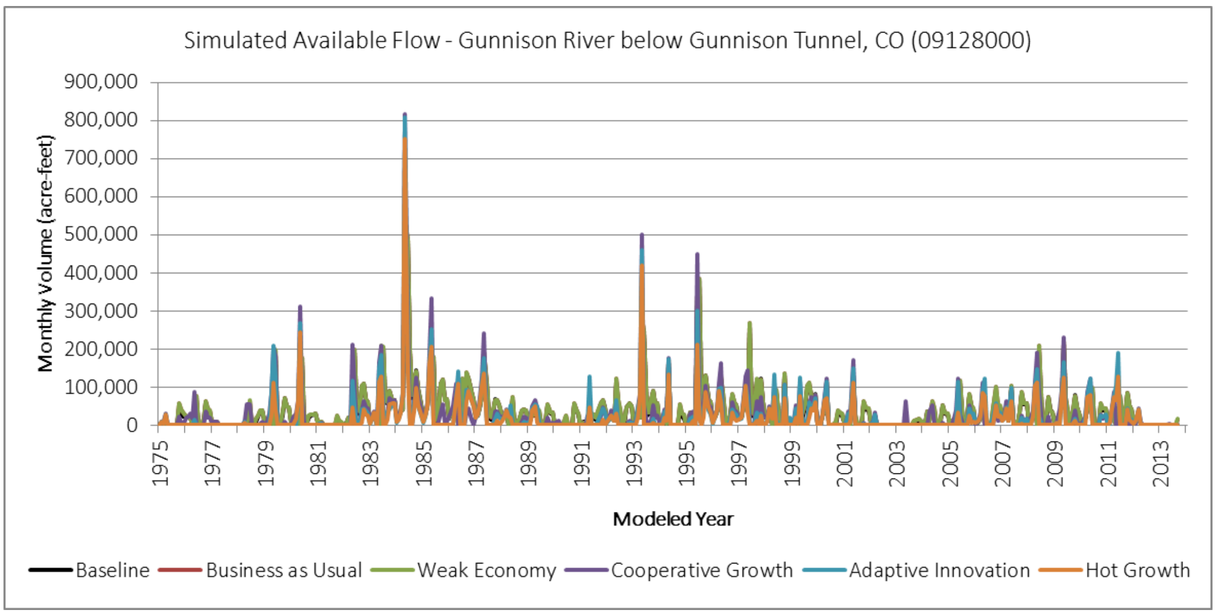


Figure 52: Monthly Unappropriated Available Supply at Gunnison River below Gunnison Tunnel

5.4 NORTH PLATTE RIVER BASIN

Irrigation of high mountain meadows for ranching operations is the largest use of water in the North Platte River basin, accounting for nearly all of total basin demands. These high mountain meadows are generally flood irrigated, and with limited storage in the basin, irrigators rely on diversions of spring and summer runoff for supplies. Water used for M&SSI and transbasin diversions is limited in the basin relative to agricultural use, constituting less than 1 percent of the total demand in the basin.

The following sections describe the agricultural, M&SSI, and transbasin export demands in the North Platte River basin in more detail. Figure 53 reflects the basin outline, the administrative boundaries of water districts, and the streamflow gages highlighted in the results section below.

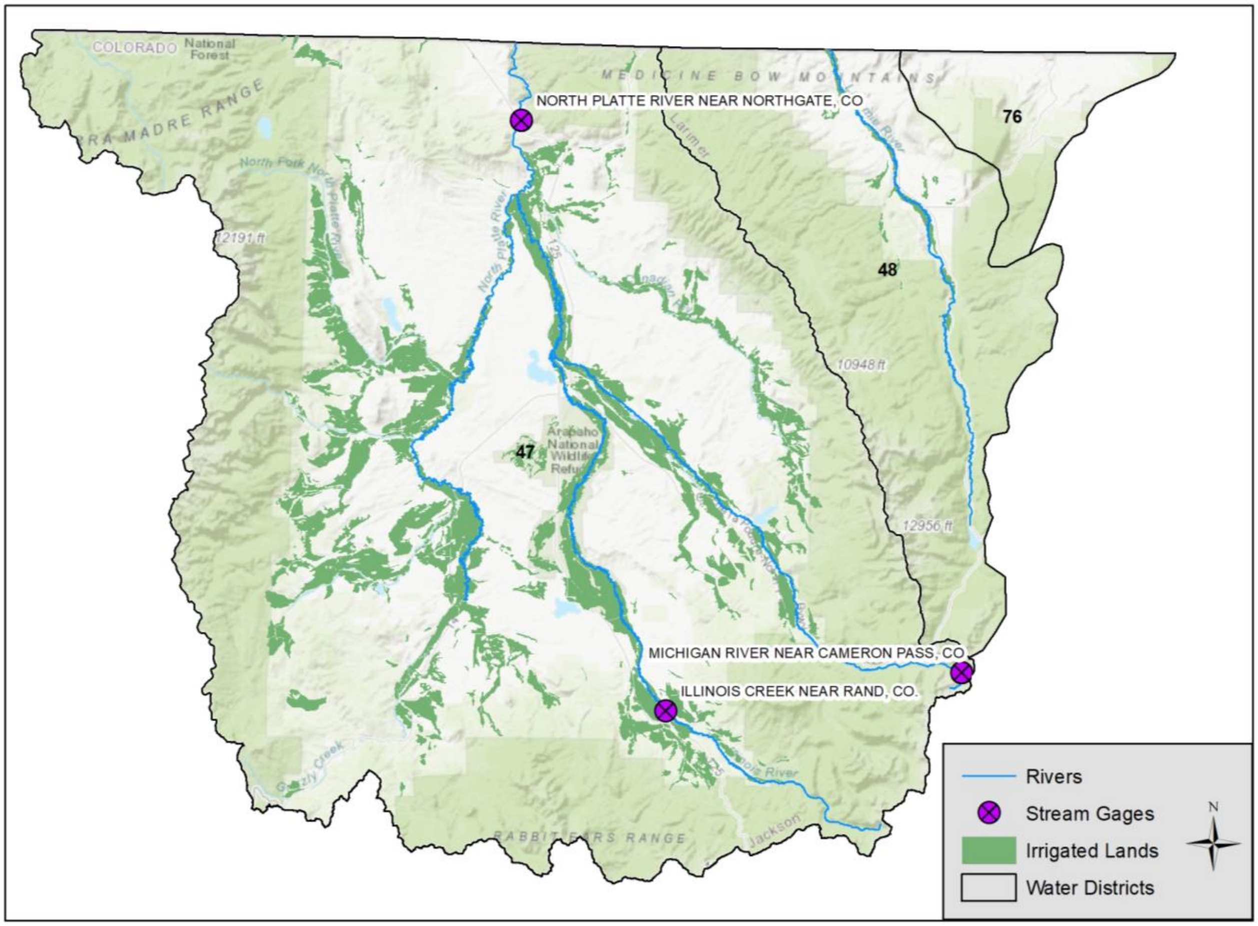


Figure 53: North Platte River Map with Streamgage Locations

5.4.1 NORTH PLATTE RIVER BASIN AGRICULTURE WATER SUPPLY AND GAP

Grass and hay are the primary crops grown in the basin to support numerous calf/cow operations. Irrigators rely on runoff from the snowpack in the late spring and early summer to flood their fields. Relative to the agricultural demand, there is limited storage[9] available to supplement irrigation supplies after the runoff is over. With limited access to supplies later in the irrigation season, irrigators will generally begin to dry out fields for the first hay cutting in late June or early July, and then many choose not to continue irrigating later in the season for a second cutting.

These irrigation practices are not explicitly reflected in the Technical Update models (i.e. the models did not stop allocating water to meet the agricultural demand every year in mid-July). This modeling assumption was made because these current irrigation practices may not be appropriate or continued in the future if climatic, hydrological, or economic conditions in the basin change by 2050. The results

[9] The Equitable Apportionment Decree limits storage for irrigation purposes to 17,000 ac-ft annually in the basin

summarized below reflect the full season agricultural diversion demand; modeled water supplies as if irrigators continued to irrigate as long as water is physically and legally available; and the resulting agricultural gap.

The North Platte River Basin agricultural diversion demands, demand gaps, and consumptive use gap results for the baseline and Technical Update Planning Scenarios are presented in Table 19 and reflected graphically in Figure 54 and Figure 55. As discussed in the *Current and 2050 Planning Scenario Agricultural Diversion Demand* technical memorandum, 2050 agricultural diversion demands are influenced by a number of drivers, including climate, urbanization, planned agricultural projects, and emerging technologies.

Table 19: North Platte River Basin Agricultural Water Supply and Gap Summary

	Agriculture Results	Baseline	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand (ac-ft)	529,204	602,431	602,431	688,308	502,345	733,493
Average	Average Annual Demand Increase from Baseline (ac-ft)	-	73,227	73,227	159,105	-	204,289
Average	Average Annual Gap (ac-ft)	85,733	107,962	107,937	177,854	168,136	231,084
Average	Average Annual Gap Increase from Baseline (ac-ft)	-	22,228	22,204	92,120	82,402	145,351
Average	Average Annual Percent Gap	16%	18%	18%	26%	33%	32%
Average	Average Annual CU Gap (ac-ft)	40,308	50,845	50,833	83,584	91,997	108,494
Critically Dry Maximum	Demand In Maximum Gap Year (ac-ft)	521,572	582,442	582,442	659,426	494,854	693,975
Critically Dry Maximum	Increase from Baseline Demand (ac-ft)	-	60,870	60,870	137,854	-	172,403
Critically Dry Maximum	Gap In Maximum Gap Year (ac-ft)	296,925	336,720	336,654	394,815	320,762	440,981
Critically Dry Maximum	Increase from Baseline Gap (ac-ft)	-	39,795	39,729	97,890	23,837	144,055
Critically Dry Maximum	Percent Gap In Maximum Gap Year	57%	58%	58%	60%	65%	64%

As reflected in the table, irrigators in the basin currently experience a relatively small agricultural gap on average. Considering the irrigation practice discussion above, water users and stakeholders in the basin may consider the average agricultural gap to be over-estimated (i.e. there is not a late season gap if irrigators choose not to irrigate). The current agricultural gap in a critically dry year with low snowpack levels and extremely limited irrigation supplies, however, is substantially greater.

The average annual agricultural demand increases from the Baseline to the Business as Usual and Weak Economy Planning Scenarios by approximately 73,000 ac-ft due to the addition of approximately 10,600 irrigated acres in these scenarios for planned agricultural projects in the basin. The additional acreage leads to an average increase to the agricultural gap of approximately 22,000 ac-ft, indicating the new planned agricultural projects may expect to see an agricultural gap of nearly 30 percent on average in 2050 if developed under the Business as Usual and Weak Economy Planning Scenario conditions.

Results for the Cooperative Growth Planning Scenario incorporate the additional acreage for planned agricultural projects as well as an increase in agricultural demand due to climate change adjustments to IWR and climate-adjusted hydrology associated with the projected In-Between climate conditions. Climate adjustments to IWR in the Cooperative Growth Planning Scenario lead to an increase of nearly 86,000 ac-ft of agricultural demand compared to the Business as Usual and Weak Economy scenarios. Climate adjustments to hydrology shift in the peak runoff, on average, from June to May and reduce the amount of late season supplies. The combined impact of these adjustments is an increase of 70,000 ac-ft of agricultural gap compared to the Business as Usual and Weak Economy scenarios on average.

For the Adaptive Innovation scenario, which includes the additional acreage for planned agricultural projects and a slight decrease in acreage due to urbanization, the average annual demand is approximately 5 percent less than the Baseline demand. In this scenario, emerging technologies are assumed to mitigate approximately 10 percent of the increase in IWR due to projected Hot and Dry climate conditions as well as increase irrigation system efficiency by 10 percent, which results in an overall net decrease in agricultural demand. Despite the reduced agricultural demand, the agricultural gap actually increases by approximately 82,000 ac-ft compared to the Baseline Scenario primarily due to the shifting of the peak runoff month associated with the projected hydrology under the Hot and Dry climate conditions.

The Hot Growth scenario reflects the largest agricultural demand and the largest agricultural gap, driven by the full impact of the projected Hot and Dry climate conditions. In this scenario, the agricultural demand is approximately 204,000 ac-ft greater than the Baseline agricultural demand on average, however approximately 145,000 ac-ft or 70 percent of the increased demand is shorted in the Hot Growth scenario due the climate-adjusted hydrology. The agricultural gap is over 440,000 ac-ft in critically dry years, or 64 percent of the total agricultural demand in the same year. The following figures reflect the agricultural demand and gap on average and in a critically dry year, relative to the demand and across Planning Scenarios.

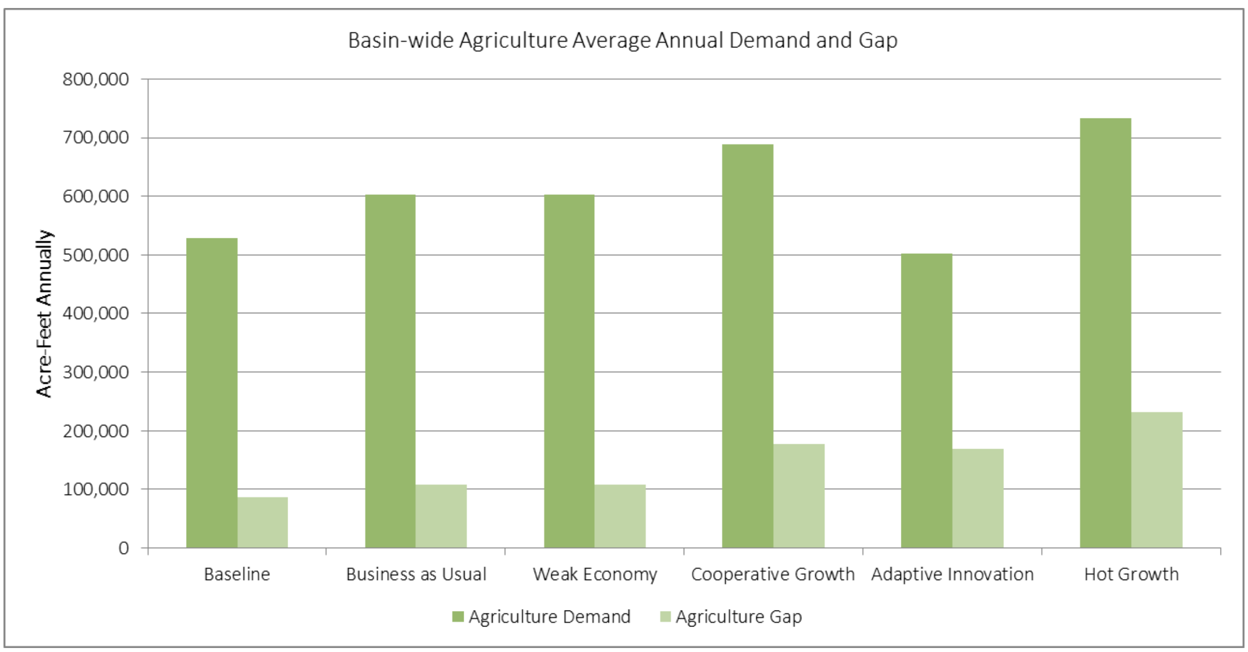


Figure 54: North Platte River Basin Agriculture Average Annual Demand and Gap

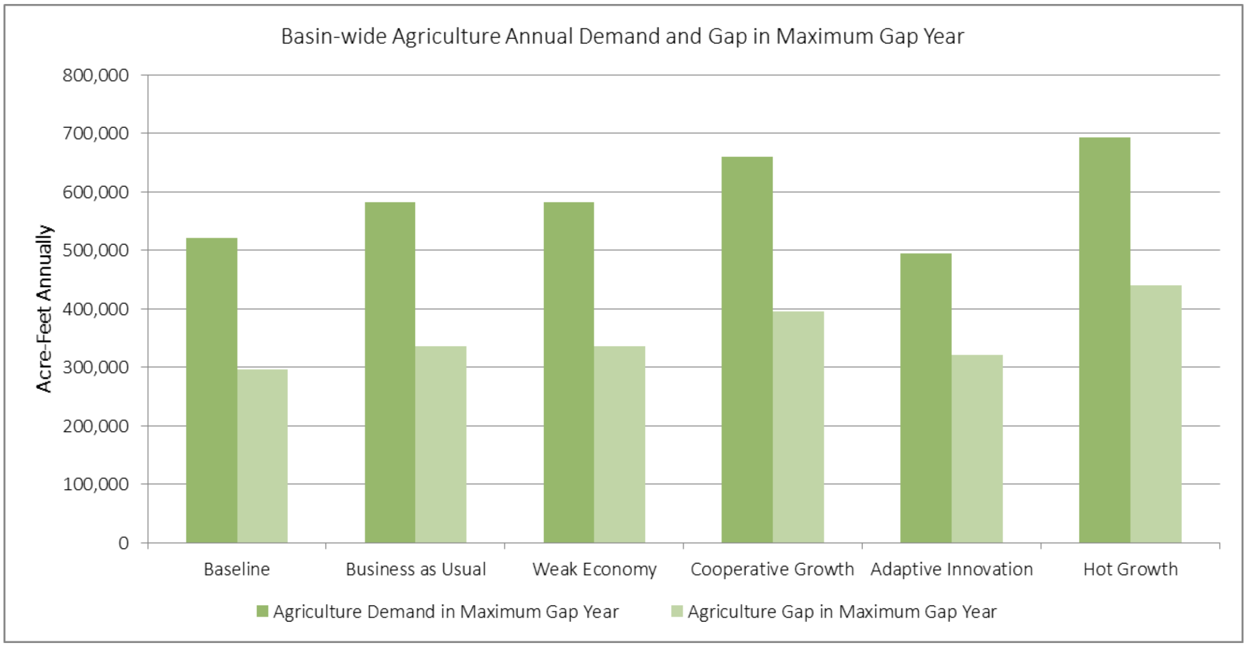


Figure 55: North Platte River Basin Agriculture Annual Demand and Gap in Maximum Gap Year

As reflected in Figure 56, the agricultural gap varies annually based on the demand and the available water supplies in the basin. With only the planned agricultural projects differentiating the Baseline, Business as Usual, and the Weak Economy scenarios, the agricultural gaps are very similar over the study period and the lines on the graph are overlapping. The wet hydrology years of the mid-1980s and the late 1990s reflect minimal shortages across all scenarios, with minimal impacts of the climate adjustments. The average to below average hydrology years from 2004 to 2009 reflect separation between the Baseline agricultural gap and the gaps in the Cooperative Growth, Adaptive Innovation, and Hot Growth scenarios due to the reduction in already limited water supplies. In the critically dry years of 2002 and 2012, only the irrigators with the most senior water rights are able to divert the limited supplies, regardless of climate-adjusted hydrology and the agricultural gaps are similar across all the Planning Scenarios.

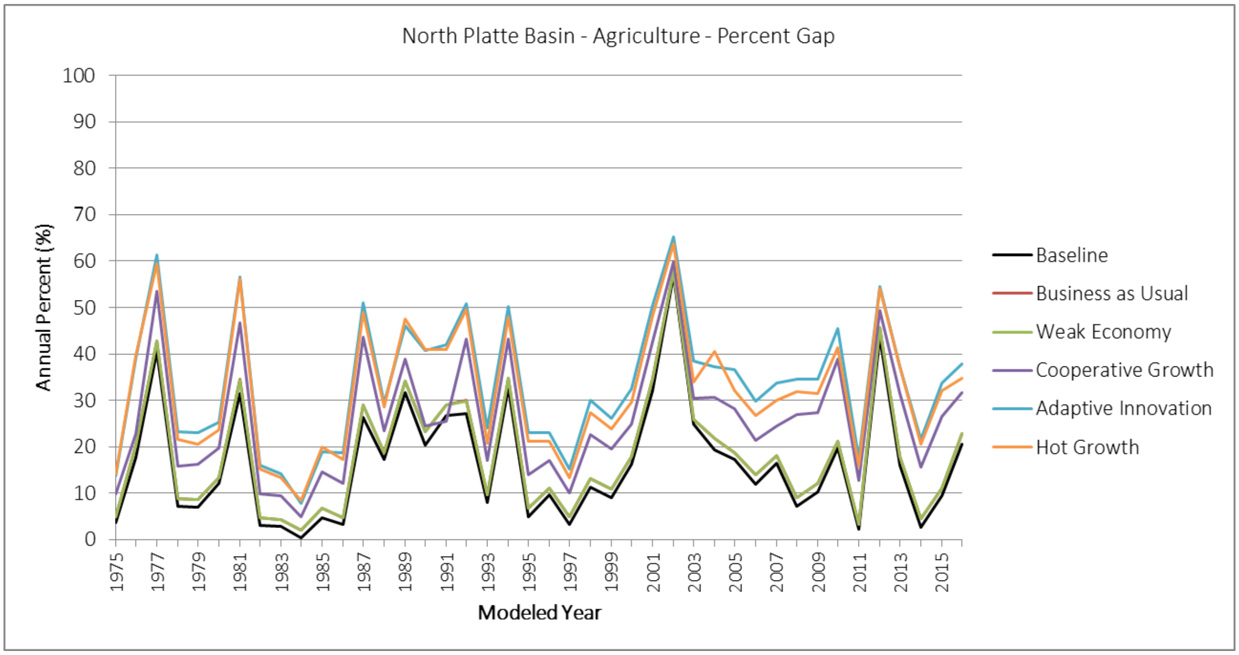


Figure 56: North Platte River Basin Agriculture Percent Diversion Gap Times Series

5.4.2 NORTH PLATTE RIVER BASIN M&SSI WATER SUPPLY AND GAP

A majority of the M&SSI demands in the North Platte River basin are grouped and represented at several general locations throughout the model, with only the Town of Walden's demands and surface water rights modeled individually. The M&SSI demands in the basin are low compared to the agricultural demand, reflecting less than 1 percent of the total demand in the basin. Refer to the *Baseline and Projected 2050 Planning Scenario Municipal and Self Supplied Industrial Water Demands* technical memorandum for additional discussion on how the M&SSI demands in the basin were developed. The water supply and gap results for M&SSI in the North Platte River basin are summarized in

Table 20, and graphically reflected in Figure 57 through Figure 59.

Table 20: North Platte River Basin M&SSI Water Supply and Gap Summary

	M&SSI Results	Baseline	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand (ac-ft)	402	369	311	345	382	458
	Average Annual Demand Increase from Baseline (ac-ft)	-	-	-	-	-	56
	Average Annual Gap (ac-ft)	0	0	0	1	2	21
	Average Annual Gap Increase from Baseline (ac-ft)	-	-	-	1	2	20
	Average Annual Percent Gap	0%	0%	0%	0%	1%	5%
Critically Dry Maximum	Demand In Maximum Gap Year (ac-ft)	402	369	311	345	382	458
	Increase from Baseline Demand (ac-ft)	-	-	-	-	-	56
	Gap In Maximum Gap Year (ac-ft)	17	15	13	13	18	45
	Increase from Baseline Gap (ac-ft)	-	-	-	-	1	28
	Percent Gap In Maximum Gap Year	4%	4%	4%	4%	5%	10%

The M&SSI demand in the basin is projected to decrease in all but the Hot Growth scenarios compared to the Baseline scenario. This projection correlates to population levels that are expected to remain the same or decline by 2050 in the basin in all but the Hot Growth scenario. Population growth in the Hot Growth scenario is modest, with an increase in demand of just over 10 percent compared to the Baseline demand level.

As reflected in the table, the M&SSI demand is fully or nearly satisfied on average in all but the Hot Growth scenario. The demands, however, experience a 4 to 5 percent shortage during critically dry years. Ideally these scenarios would have no M&SSI gaps because the current conditions in the basin should fully satisfy the Baseline demand levels. These shortages are likely due to minor calibration issues stemming from the representation of individual M&SSI demands at a grouped location drawing only from surface water supplies, and not accounting for ground water supplies (i.e. exempt wells) or dispersion of the demands across several tributaries.

The larger M&SSI gap experienced in the Hot Growth scenario may be more indicative of chronic shortages in 2050, as reflected in Figure 59. Gaps tend to range between 2.5 and 10 percent for the full study period, and are caused by climate-adjusted hydrology on smaller tributaries (e.g. Illinois Creek, Canadian River) as opposed to the increase in demand under the Hot Growth scenario.

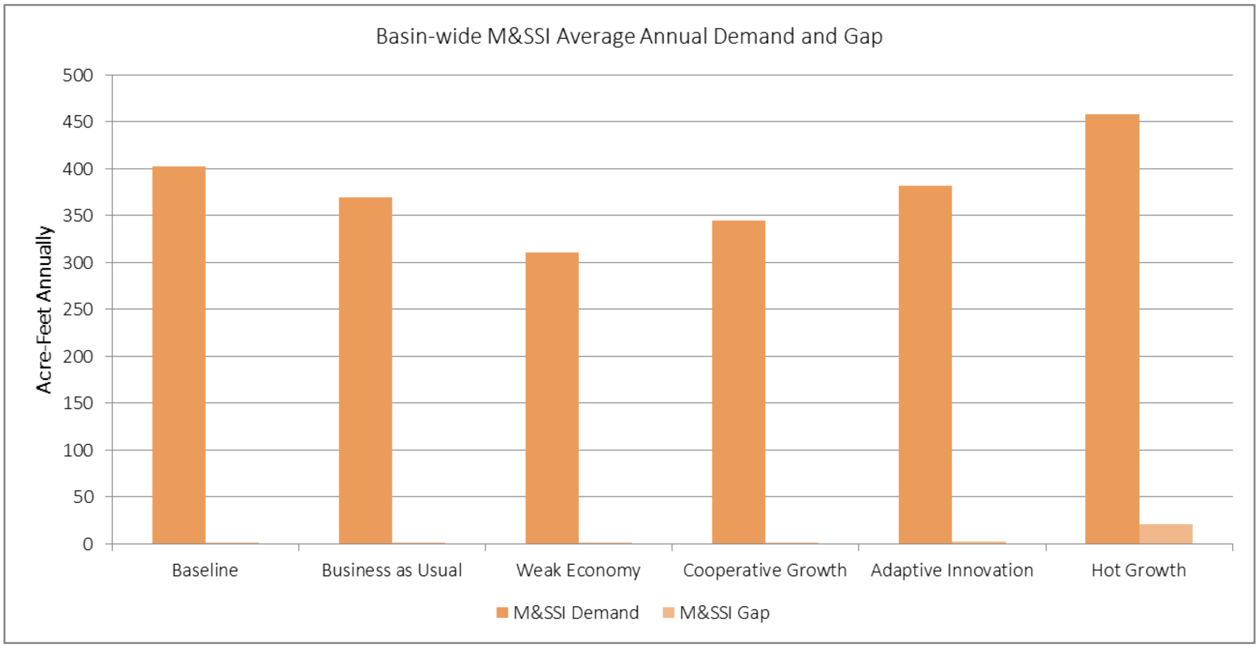


Figure 57: North Platte River Basin M&SSI Average Annual Demand and Gap

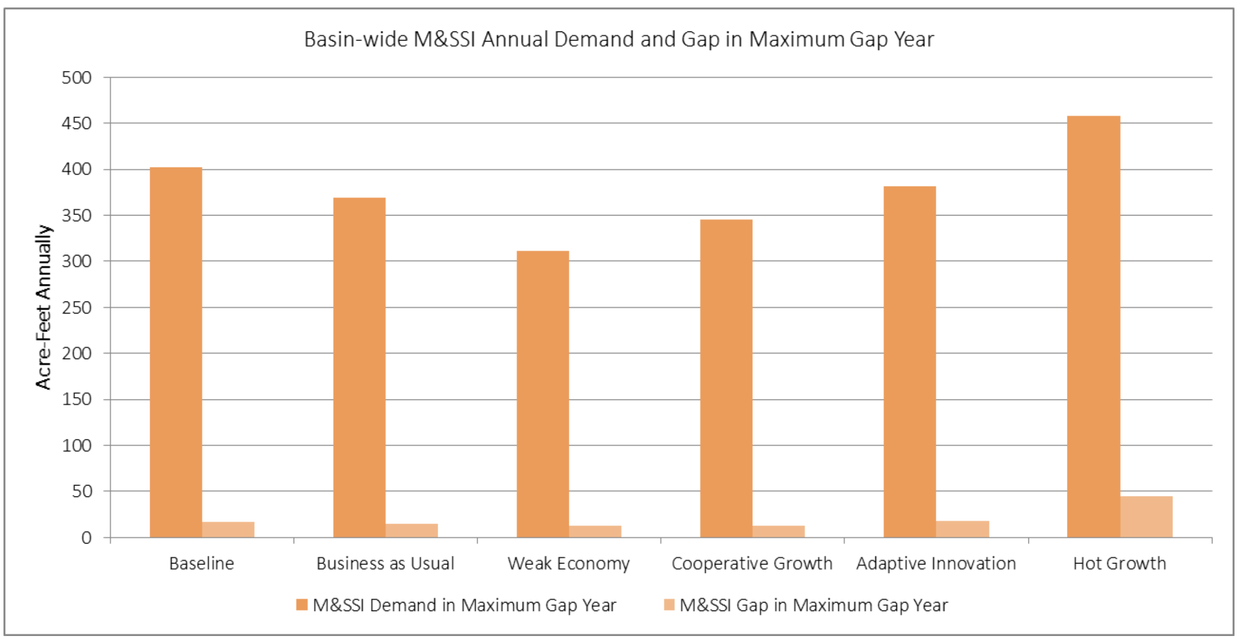


Figure 58: North Platte River Basin M&SSI Maximum Annual Demand and Gap in Maximum Gap Year

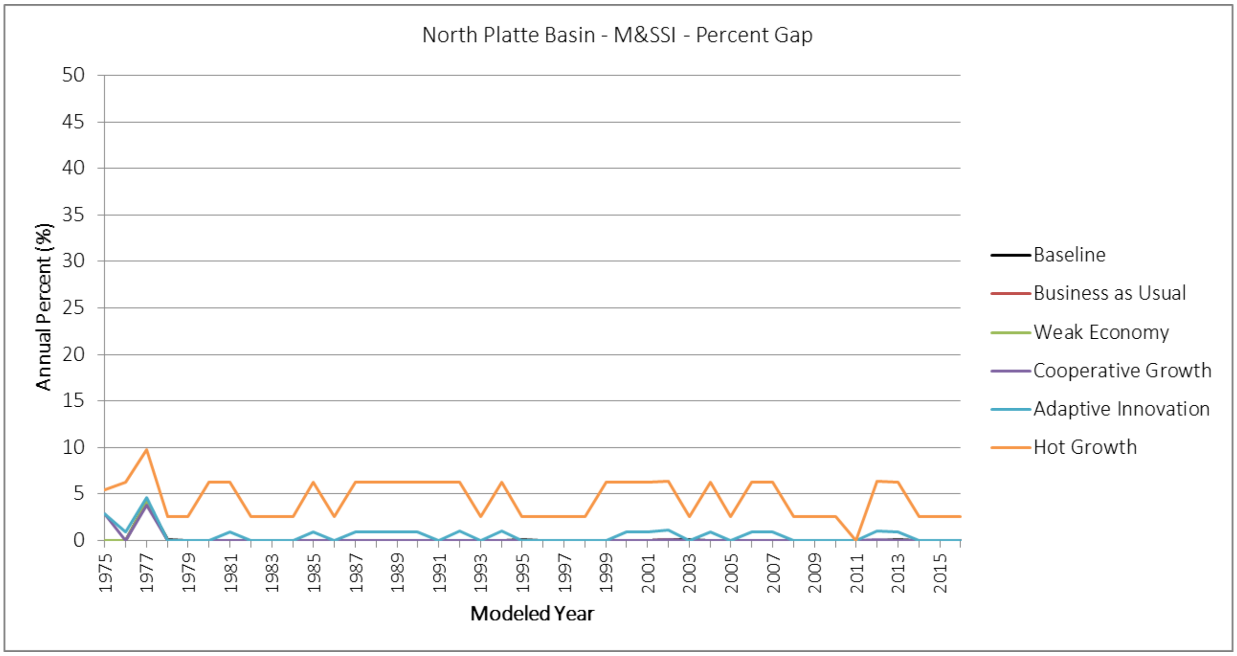


Figure 59: North Platte River Basin M&SSI Average Annual Gap Time Series

5.4.3 NORTH PLATTE RIVER BASIN TRANSBASIN EXPORT DEMAND

There are two transbasin diversions that export water from the Michigan River to the South Platte River basin: Michigan Ditch and Cameron Pass. Transbasin exports range from less than 500 ac-ft to over 6,500 ac-ft annually, depending on availability of in-basin supplies and the need for imported supplies in the South Platte River basin. On average, the transbasin export demand from the North Platte River Basin is 3,265 ac-ft. Note that the transbasin export demand is set to historical levels and the same across all Planning Scenario. These demands could not be satisfied in all Planning Scenarios; however the shortages are reflected as an import supply gap in the destination basin and not considered a gap in the North Platte River basin.

5.4.4 NORTH PLATTE RIVER BASIN SUMMARY

The combined agriculture and M&SSI demands and gap summary is provided in Table 21. The results are very similar to the agricultural results in Table 19, because water supplies in the North Platte River basin are predominantly used for agriculture. As previously discussed, gaps during average years are relatively low in the Baseline, Business as Usual and Weak Economy scenario, particularly considering late season irrigation practices. Gaps during critically dry years, which tend to occur at least once every ten years, are much larger. The gaps increase in the Cooperative Growth and the Adaptive Innovation scenarios as a result of increasing demands and the shift to the peak runoff. The gaps both on average and during critically dry years are largest in the Hot Growth scenario, due to the increased demands and decreased hydrology from the climate projections.

Figure 60 reflects the relative size of the agricultural, M&SSI, and transbasin demands in the North Platte River basin. The M&SSI and transbasin demands are difficult to reflect graphically on the same scale because they are significantly smaller than the agricultural demands. Following the graphic are summaries regarding other considerations that may impact the basin-wide gap, including potential M&SSI supplies from urbanized acreage.

Table 21: North Platte River Basin Water Supply and Gap Summary

	Agriculture and M&SSI Results	Baseline	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand (ac-ft)	529,606	602,800	602,742	688,653	502,727	733,951
	Average Annual Gap (ac-ft)	85,734	107,962	107,937	177,855	168,138	231,105
	Average Annual Percent Gap	16%	18%	18%	26%	33%	31%
Critically Dry Max	Demand In Maximum Gap Year (ac-ft)	521,974	582,811	582,753	659,771	495,236	694,433
	Gap In Maximum Gap Year (ac-ft)	296,942	336,735	336,667	394,828	320,780	441,025
	Percent Gap In Maximum Gap Year	57%	58%	58%	60%	65%	64%

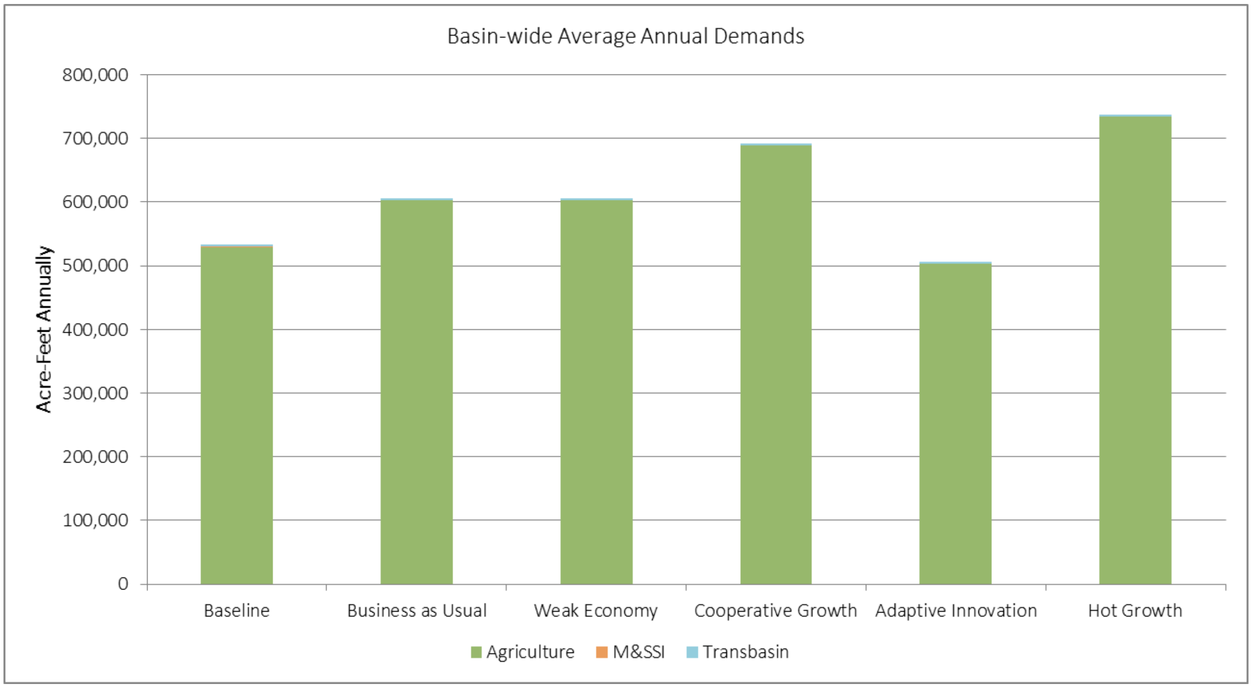


Figure 60: North Platte River Basin Comparison of Average Annual Demands

The Adaptive Innovation and Hot Growth scenarios project 40 acres of irrigated land will be taken out of production due to urbanization as the counties experience municipal growth. Supplies used to irrigate the urbanized acreage could be considered a new municipal supply if the associated water rights were changed to municipal uses. To estimate this new supply, the average consumptive use of the urbanized acreage by Planning Scenario is reflected in Table 22. Note however that it is not known which farms and ranches will be directly impacted; whether the acreage was served by senior/junior direct rights or had supplemental storage supplies; or the crop type or specific irrigation practices on this acreage. Additionally, it is unknown if the water rights would be changed to municipal use or whether the supply could directly meet the future municipal demand or would require exchange potential. In light of these uncertainties, the table reflects a planning-level estimate of this potential new supply. Although it has not been applied to the M&SSI gap presented above, it would likely have the effect of decreasing the gap.

Table 22: Potential Water Supply from Urbanized Acreage in the North Platte River Basin

Urbanized Acreage Results	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Urbanized Acreage	-	-	-	40	40
Estimated Consumptive Use (ac-ft/year)	-	-	-	46	50

The North Platte River basin has approximately 30,000 ac-ft of total storage[10], and approximately half of that storage is used to meet agricultural demands. The remaining half of storage in the basin can be attributed to reservoir supplies owned by Colorado Parks & Wildlife, U.S. Fish and Wildlife, or other governmental entities. These supplies are generally kept in the reservoir in an effort to maintain minimum storage volumes; there are no active releases except to meet environmental demands (e.g. Arapaho National Wildlife Rufuge) in some years. Figure 61 reflects the simulated storage by month for the combined reservoirs in each Planning Scenario. The results reflect very little difference between the Baseline and the Planning Scenario results, primarily because the irrigation reservoirs in the basin generally fill and release supplemental irrigation supplies every year with limited carry-over storage. As the climate-adjusted hydrology shifted runoff volumes in the Cooperative Growth, Adaptive Innovation, and Hot Growth scenarios, the graph reflects slightly more draw-down as compared to the Baseline scenario, but in general, storage across the entire basin is expected to operate at the same levels in all the Planning Scenarios.

[10] Reflects large operational reservoirs in Water District 47; excludes smaller reservoirs used primarily for recreational/piscatorial uses and reservoirs in Water Districts 48 and 76.

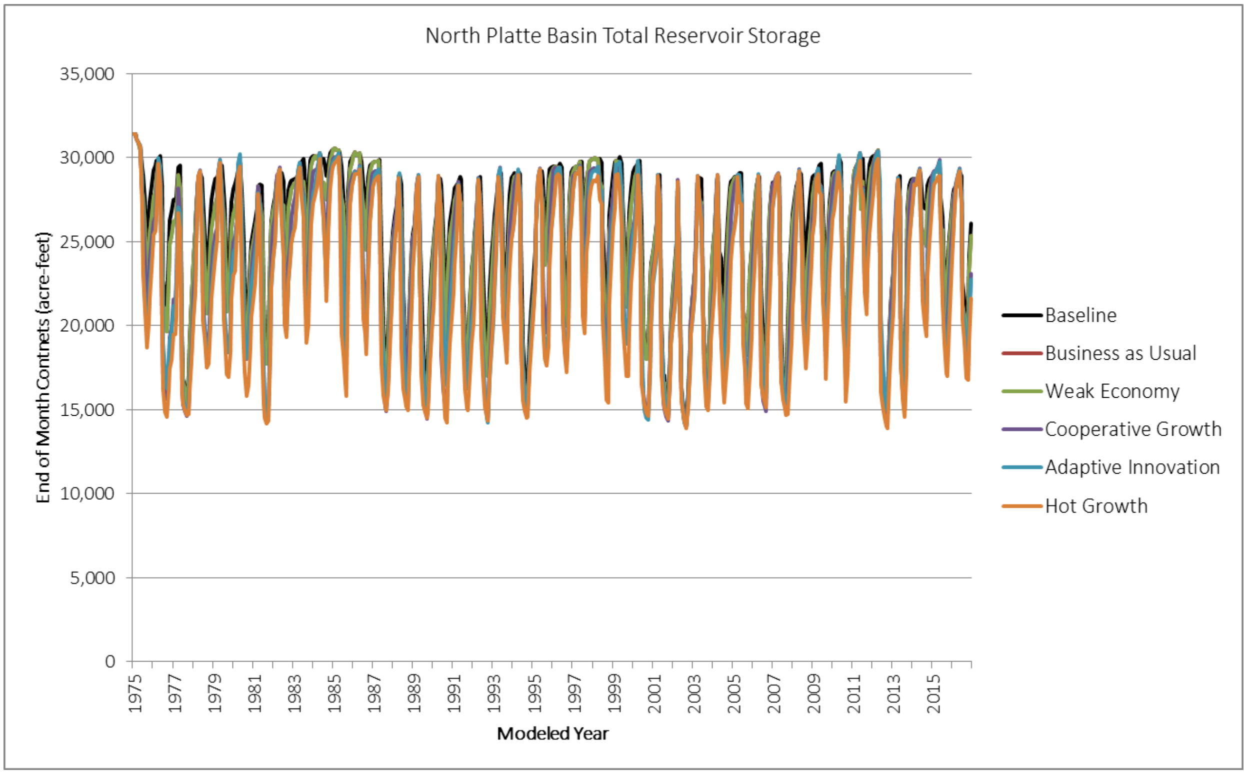


Figure 61: North Platte River Basin Total Reservoir Storage

The following figures show average monthly simulated streamflow at key locations across the basin, as reflected in Figure 53. The primary driver of average monthly simulated streamflow across the Planning Scenarios is hydrology, particularly because the demands were not significantly adjusted across the Planning Scenarios. The average monthly streamflow results from Baseline, Business as Usual, and Weak Economy scenarios are almost indistinguishable from each other because they use the current hydrology. In several locations, the lines graph directly on top of each other. The In-Between hydrology used in the Cooperative Growth scenario reflected a moderate change to total runoff volume, increasing in some areas and decreasing in others. The Hot and Dry hydrology used in the Adaptive Innovation and Hot Growth scenarios further reduces the amount of total runoff volume compared to the In-Between hydrology. This change in runoff is reflected in the Michigan River near Cameron Pass simulated streamflow graph (Figure 62), which is indicative of the supplies available to the transbasin diversions from the basin.

More impactful to the Planning Scenarios with climate-adjusted hydrology was the shift of the peak runoff earlier in the year, leading to the reduction in late irrigation season supplies. Using the Northgate gage (Figure 64) as an indicator of the total cumulative effect, the following can be observed:

- Peak runoff is occurring earlier than the peak irrigation season, therefore less streamflow is diverted for irrigation uses or stored in the soil reservoir during the early irrigation season. As such, the runoff remains in the river and eventually flows out of the basin in April and May at a greater volume than experienced in the Baseline scenario.
- Less streamflow is available during the later irrigation season, leading to increased agricultural gaps and reduced streamflow in June, July, and August compared to the Baseline scenario.

- A reduction in available water supplies and diversions also reduces the amount of lagged irrigation return flows that accrue to the river later in the season, further reducing streamflow during August and September compared to the Baseline scenario

The Illinois Creek near Rand simulated streamflow (Figure 63) reflects a similar impact from the climate-adjusted hydrology, albeit with substantially smaller streamflow volumes. With storage for irrigation purposes limited by the Equitable Apportionment Decree, opportunities to capture the earlier runoff are limited in the basin. Other alternatives to mitigate the impact of this potential future shift in runoff will need to be discussed among water users and stakeholders in the basin.

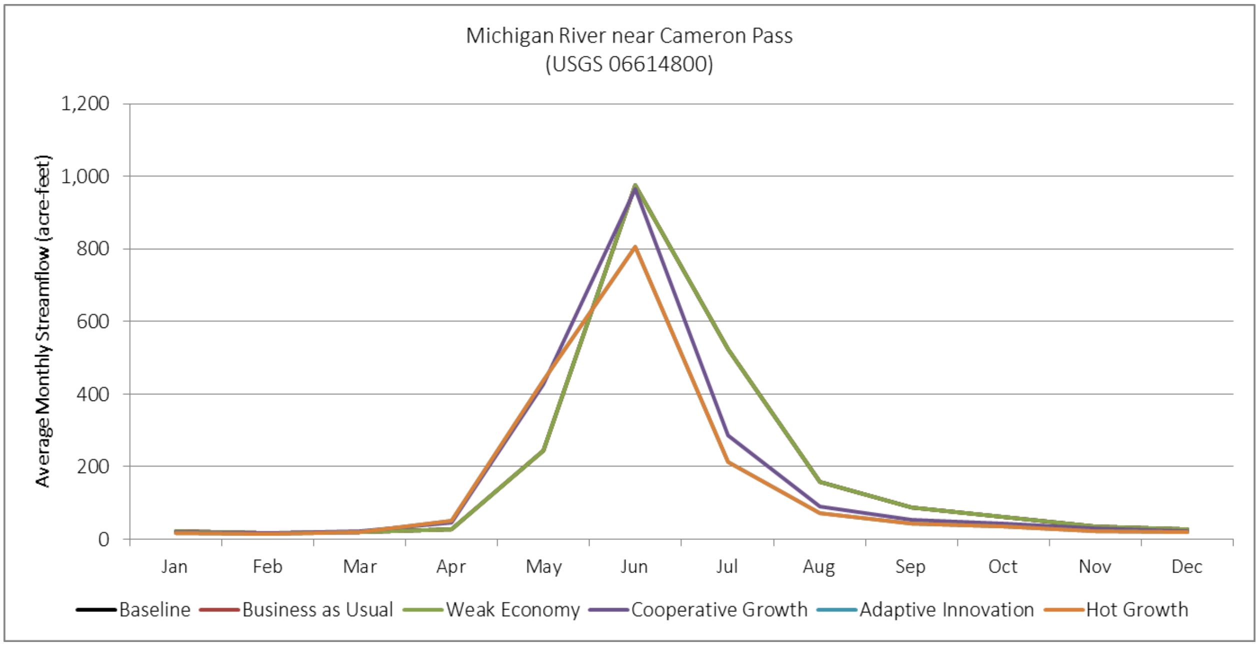


Figure 62: Average Monthly Streamflow for Michigan River near Cameron Pass

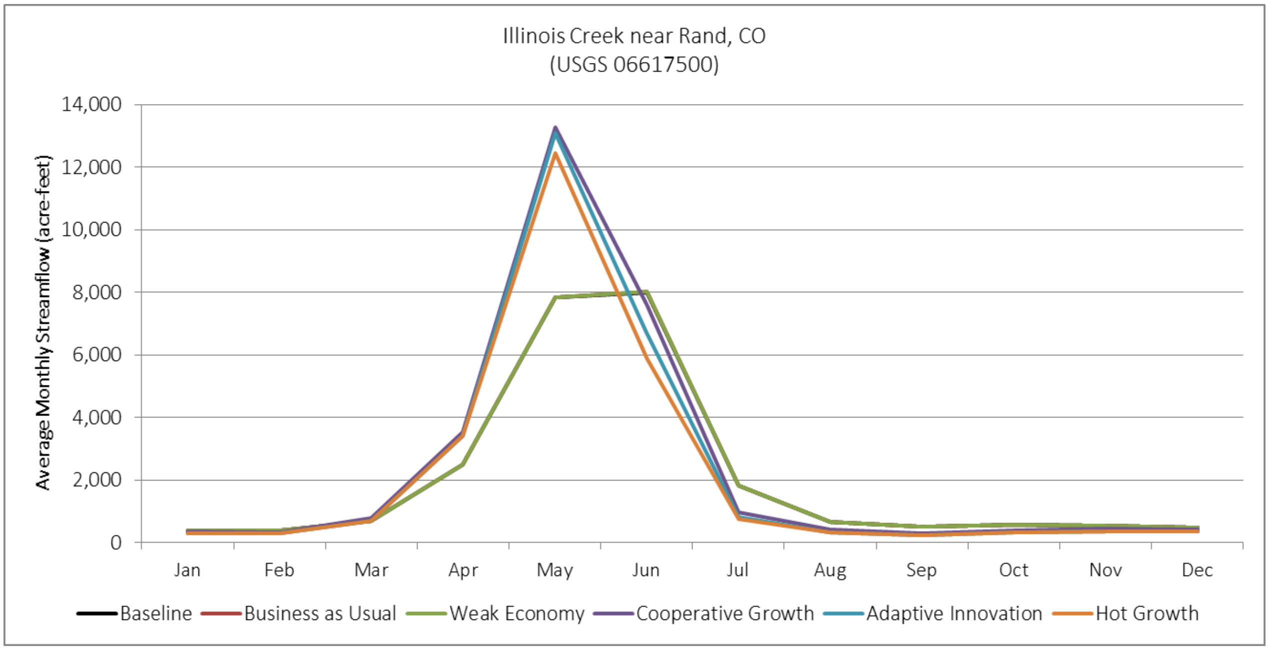


Figure 63: Average Monthly Streamflow for Illinois Creek near Rand

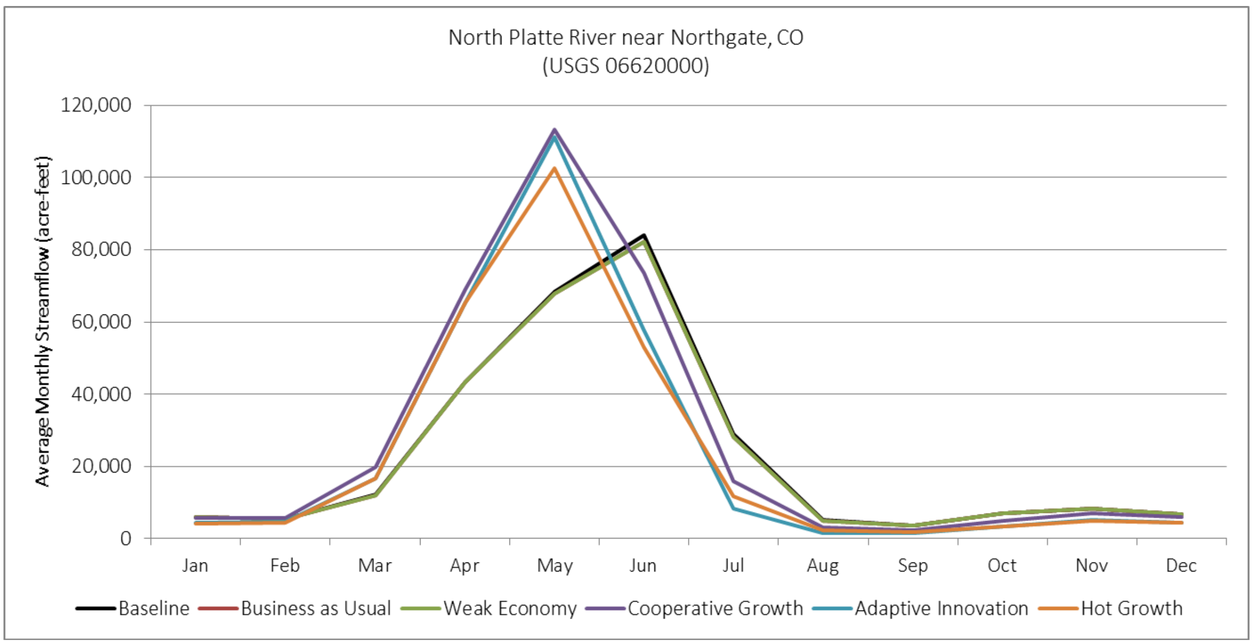


Figure 64: Average Monthly Streamflow for North Platte River near Northgate

Figure 65 and Figure 66 reflect simulated available flow at a location on the Lower Michigan River upstream of the confluence with the North Platte River. The location represents water availability upstream of the primary controlling rights on the tributary, which include the Hiho Ditch, Kiwa Ditch, and diversions to storage in Carlstrom Reservoir. Unappropriated flow availability is only moderately impacted by the calling rights. Flows are projected to be available in most years, except during critically dry years, but vary greatly on an annual basis. Peak flows are projected to increase at this location but could diminish in the late summer in climate-impacted scenarios. As discussed above, by shifting the timing of runoff in the climate-adjusted scenarios, substantially more water is projected to runoff in April and May. This, however, occurs prior to the peak irrigation demands and, without the ability to construct new storage, likely cannot be used to meet projected agricultural gaps in the basin.

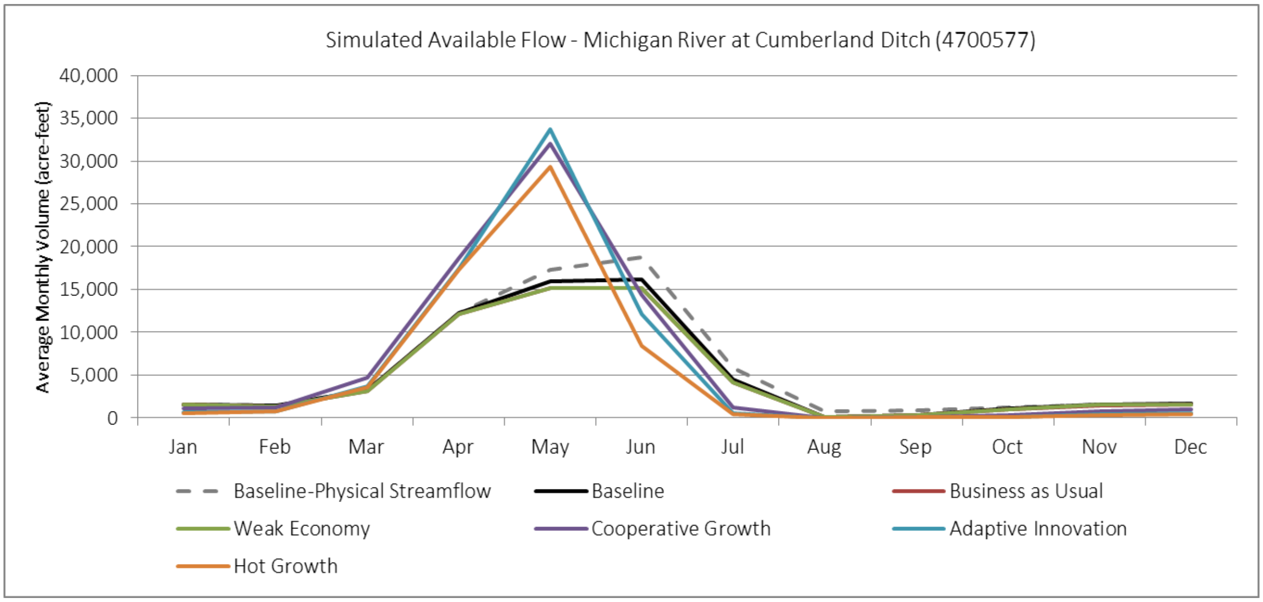


Figure 65: Average Monthly Unappropriated Available Supply at Michigan River at Cumberland Ditch

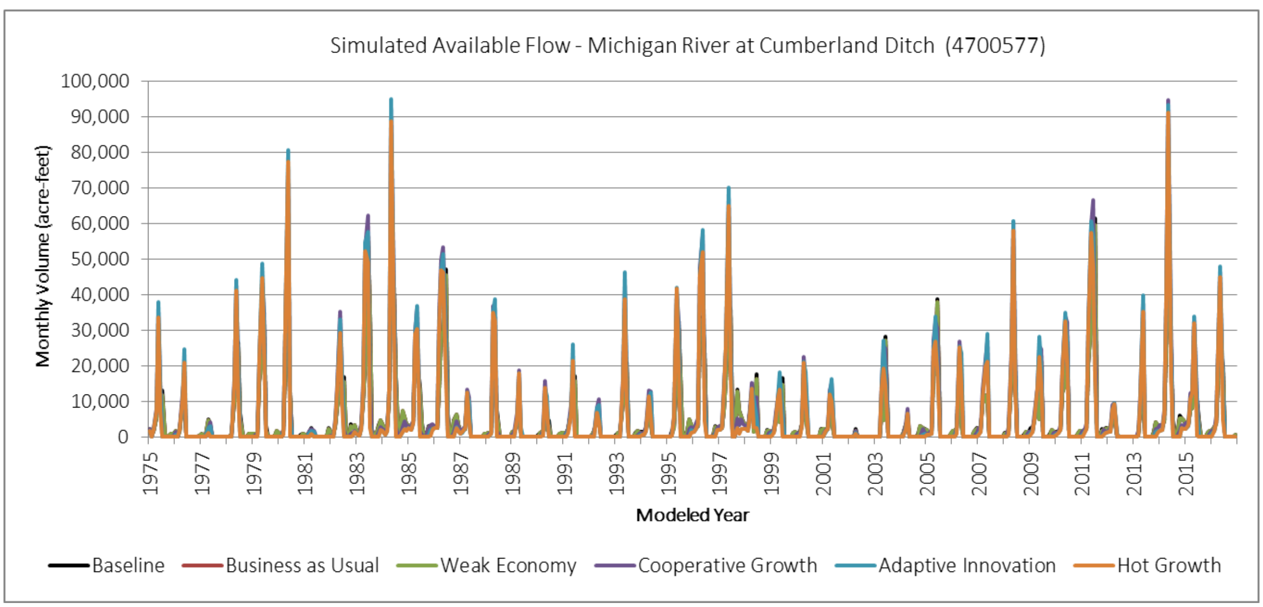


Figure 66: Monthly Unappropriated Available Supply at Michigan River at Cumberland Ditch

5.5 REPUBLICAN RIVER BASIN

Irrigation of nearly 580,000 acres of land is the predominant use of water in the Republican River basin on the eastern Colorado plains. Surface water supplies are scarce in the basin, and irrigators rely on pumping supplies from the High Plains Aquifer (also known as the Ogallala Aquifer). Nearly all of the fields are served by sprinklers, making efficient use of the pumped supplies. The M&SSI use in the basin, accounting for less than 1 percent of the total demand in the basin, can be attributed to the numerous small agricultural towns and communities throughout the basin.

The following sections describe the agricultural and M&SSI demands in the Republican River basin in more detail. Figure 67 reflects the basin outline and administrative boundaries of water districts.

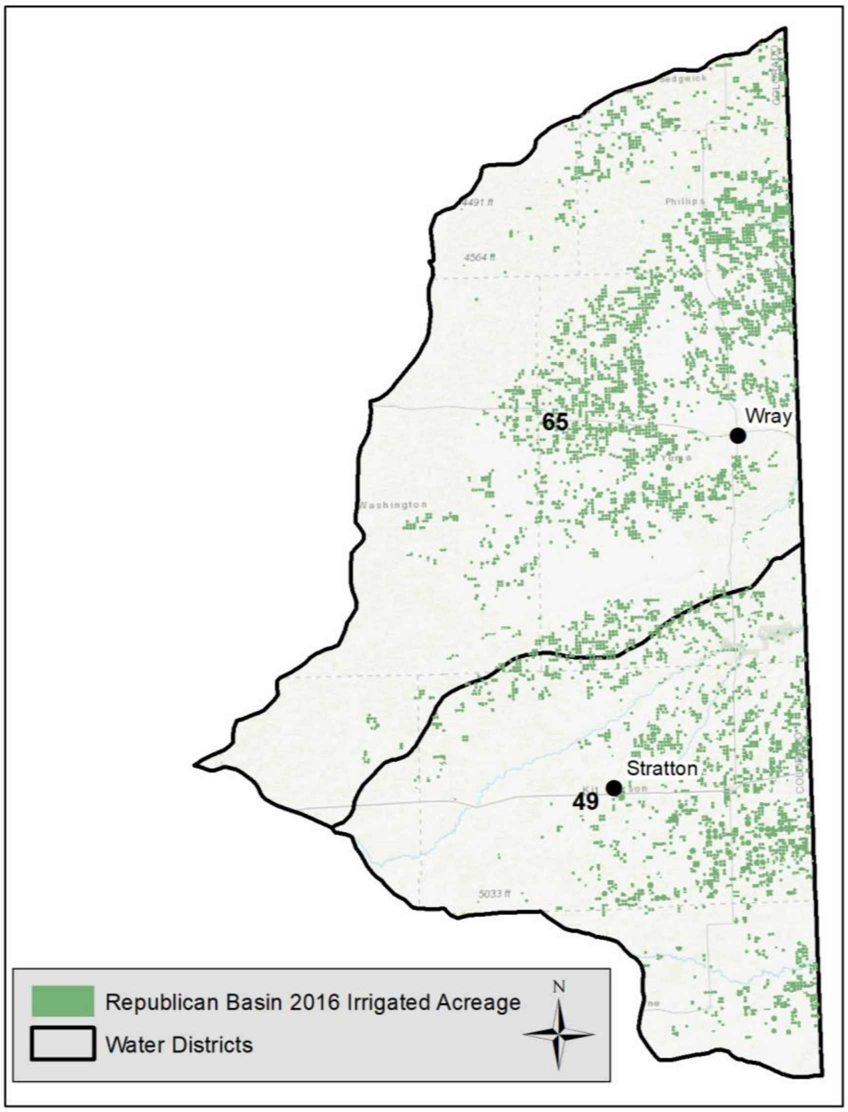


Figure 67: Republican River Map

5.5.1 REPUBLICAN RIVER BASIN AGRICULTURE WATER SUPPLY AND GAP

Corn and wheat are the primary crops grown in the basin, with sorghum, alfalfa, and small grains grown to a lesser degree. With virtually no surface water diversions and no reservoirs, irrigators pump ground water to meet crop demands. Approximately 10 percent of total pumping is subject to the Republican River Compact (RRC) with the remaining 90 percent pumped from "storage" in the High Plains Aquifer. Several efforts have taken place since 2002 to maintain RRC compliance including the establishment of the Republican River Water Conservation District (RRWCD); voluntary retirement of more than 30,000 irrigated acres; draining of Bonny Reservoir; and construction of a Compact Compliance Pipeline to deliver water to downstream states. In addition to RRC compliance, the basin is also experiencing declining thickness of the High Plains Aquifer. Ground water modeling supporting the Republican River Compact Accounting reflects thinning aquifer levels, particularly in the southern and western areas of the basin, and if current pumping rates were to continue into the future the aquifer would be depleted such that irrigation in many of these areas could not continue. These limitations on future pumping were the largest contributing factors on the agricultural pumping demand and gap in the Planning Scenarios. Refer to the *Current and 2050 Planning Scenario Agricultural Diversion Demand* technical memorandum for additional discussion on these and other drivers for the Republican River Basin agricultural demand.

The resulting Republican River Basin agricultural diversion demands, demand gaps, and consumptive use gap results for the baseline and Technical Update Planning Scenarios are presented in Table 23.

Table 23: Republican River Basin Agricultural Water Supply and Gap Summary

	Agriculture Results	Baseline	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand (ac-ft)	1,067,226	805,492	807,481	835,281	797,185	885,762
	Average Annual Demand Increase from Baseline (ac-ft)	-	-	-	-	-	-
	Average Annual Gap (ac-ft)	266,807	201,373	201,870	208,820	199,296	221,440
	Average Annual Gap Increase from Baseline (ac-ft)	-	-	-	-	-	-
	Average Annual Percent Gap	25%	25%	25%	25%	25%	25%
	Average Annual CU Gap (ac-ft)	211,420	159,804	160,196	165,703	161,605	179,561
Critically Dry Maximum	Demand In Maximum Gap Year (ac-ft)	1,445,179	1,113,049	1,114,721	1,113,164	1,014,395	1,127,106
	Increase from Baseline Demand (ac-ft)	-	-	-	-	-	-
	Gap In Maximum Gap Year (ac-ft)	361,295	278,262	278,680	278,291	253,599	281,777
	Increase from Baseline Gap (ac-ft)	-	-	-	-	-	-
	Percent Gap In Maximum Gap Year	25%	25%	25%	25%	25%	25%

As reflected in the table, the average annual demand decreases in all Planning Scenarios as compared to the Baseline scenario. This is caused by a nearly 25 percent reduction to irrigated acreage in the basin by 2050 driven by the RRC compliance and the declining aquifer levels. Within the Planning Scenarios, the Business as Usual and the Weak Economy are fairly similar, with the slight decrease of demands attributable to the urbanization of approximately 1,400 acres in the Business as Usual scenario. The

Cooperative Growth demands are approximately 5 percent greater than the Business as Usual scenario demands due to the In-Between climate adjustments to IWR. Similarly, the Hot Growth demands are approximately 10 percent greater than the than the Business as Usual scenario demands due to the Hot Growth climate adjustments to IWR. The Adaptive Innovation demands are less than the Business as Usual due to the implementation of the Emerging Technologies adjustments. The 10 percent reduction to IWR in this scenario essentially zeros out the increase to IWR from the Hot and Dry conditions.

The agricultural gap was estimated to be 25 percent across all scenarios based on the current pumping practices; review of RRC Accounting; and through discussions with RRWCD and their ground water modeling consultants. Pumping records for wells serving irrigated land in the basin indicate irrigators pump approximately 25 percent less than the agricultural demand (i.e. deficit irrigate), after accounting for sprinkler efficiencies. Although this amount has varied over time, this gap estimate is appropriate for long-term planning efforts and is in line with the RRC Accounting estimates.

Figure 68 reflects the monthly agricultural gap for each Planning Scenario for the most recent 10 years. As shown, the agricultural gap differs depending on the year, driven by temperature and precipitation. In hot and dry years such as 2012, the agricultural gap is nearly 80,000 ac-ft in the peak of the irrigation season compared to 50,000 ac-ft in cooler and wetter years. The following figures reflect the annual agricultural demand and gap on average and in a critically dry year, relative to the demand and across Planning Scenarios.

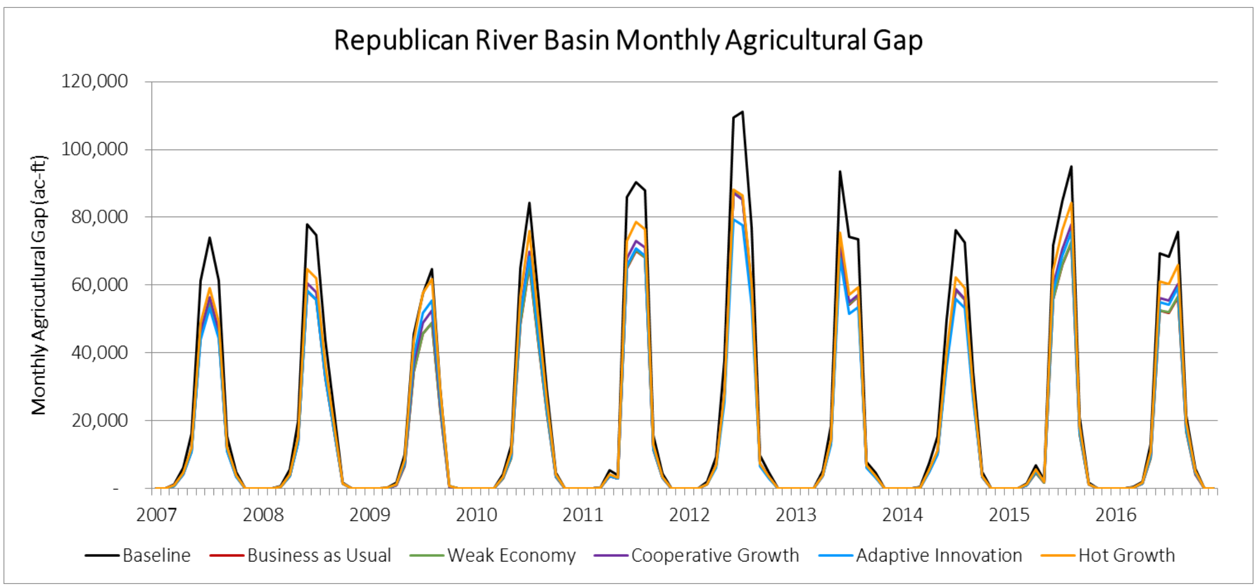


Figure 68: Republican River Basin Monthly Agricultural Gap

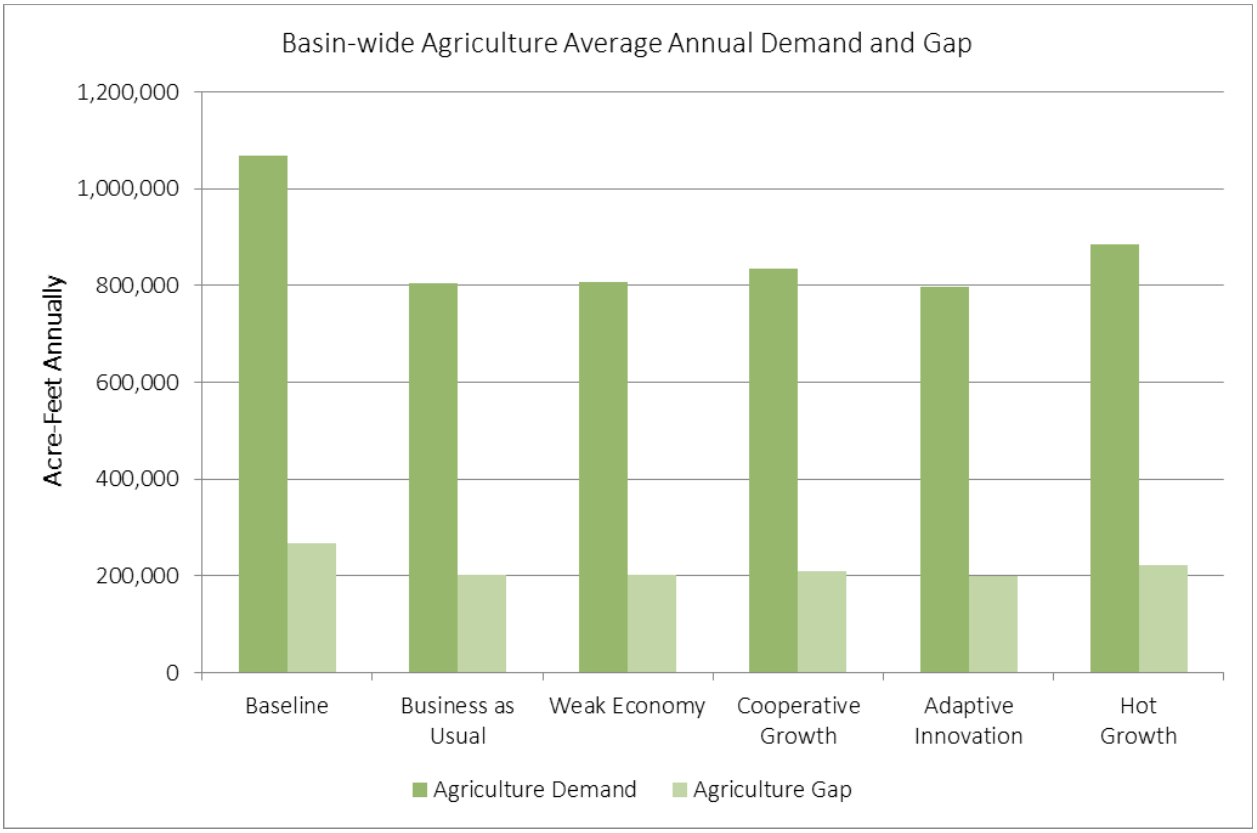


Figure 69: Republican River Basin Agriculture Average Annual Demand and Gap

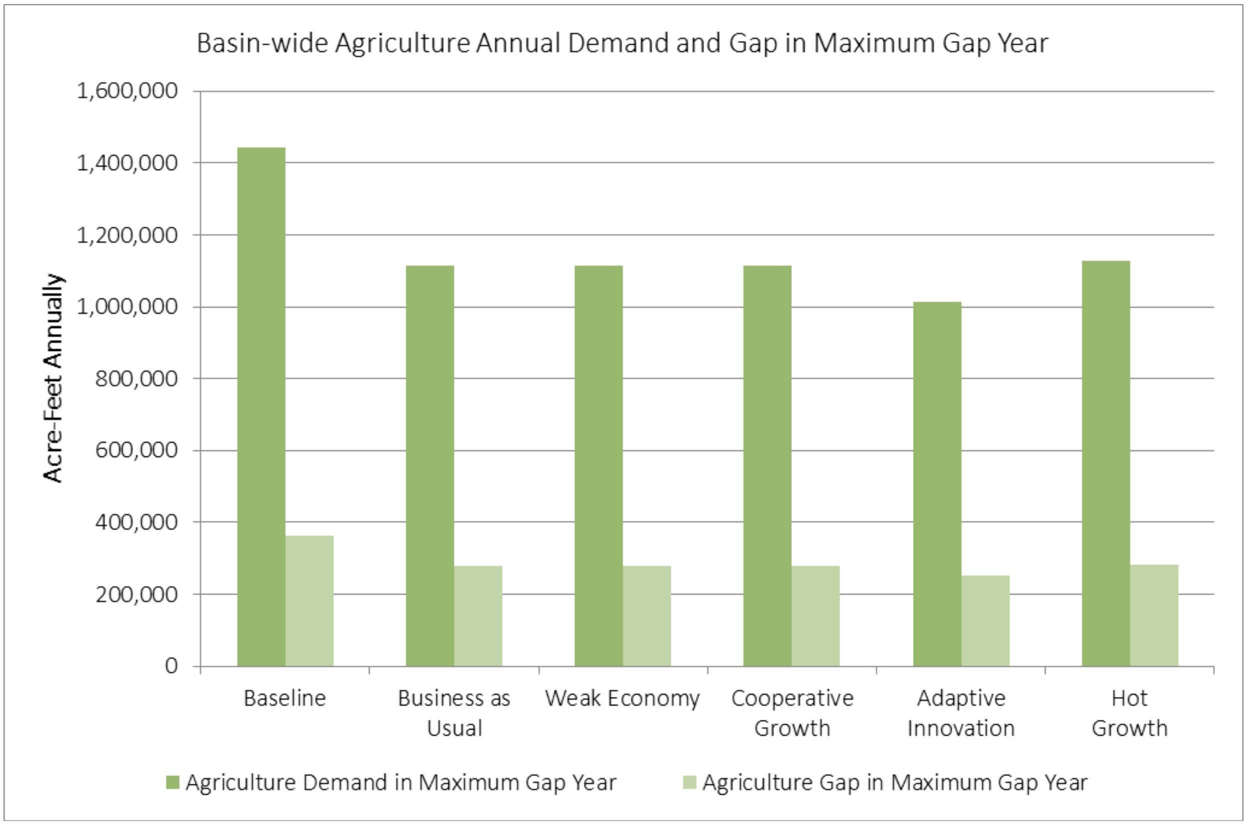


Figure 70: Republican River Basin Agriculture Annual Demand and Gap in Maximum Gap Year

5.5.2 REPUBLICAN RIVER BASIN M&SSI WATER SUPPLY AND GAP

The M&SSI demands in the Republican River Basin consist solely of municipal demands; there are no identified SSI demands in the basin. The municipal demands are dispersed fairly evenly across the counties in the basin, with larger concentrations in and around the agricultural communities in Yuma and Kit Carson counties. The M&SSI demands are low compared to the agricultural demand, reflecting less than 1 percent of the total demand in the basin. Refer to the *Baseline and Projected 2050 Planning Scenario Municipal and Self Supplied Industrial Water Demands* technical memorandum for additional discussion on how the M&SSI demands in the basin was developed. The water supply and gap results for M&SSI in the Republican River basin are summarized in Table 24, and graphically reflected in Figure 71 and Figure 72.

Table 24: Republican River Basin M&SSI Water Supply and Gap Summary

	M&SSI Results	Baseline	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand (ac-ft)	8,403	9,151	7,895	8,134	8,947	11,202
Average	Average Annual Demand Increase from Baseline (ac-ft)	-	748	-	-	545	2,799
Average	Average Annual Gap (ac-ft)	-	748	-	-	545	2,799
Average	Average Annual Gap Increase from Baseline (ac-ft)	-	748	-	-	545	2,799
Average	Average Annual Percent Gap	0%	8%	0%	0%	6%	25%
Critically Dry Maximum	Demand In Maximum Gap Year (ac-ft)	8,403	9,151	7,895	8,134	8,947	11,202
Critically Dry Maximum	Increase from Baseline Demand (ac-ft)	-	748	-	-	545	2,799
Critically Dry Maximum	Gap In Maximum Gap Year (ac-ft)	-	748	-	-	545	2,799
Critically Dry Maximum	Increase from Baseline Gap (ac-ft)	-	748	-	-	545	2,799
Critically Dry Maximum	Percent Gap In Maximum Gap Year	0%	8%	0%	0%	6%	25%

Population is expected to increase in the basin in all but the Weak Economy Planning Scenario. The two most populous counties, Yuma County followed by Kit Carson County, are projected to account for most of the growth and remain the largest population centers in the basin. Lincoln County is projected to have the highest growth *rate* of any county in the basin, however will still only account for approximately 5 percent of the population in the basin. The reduction in population is largely responsible for the decrease in M&SSI demand in the Weak Economy Planning Scenario compared to the Baseline demand. M&SSI Planning Scenario adjustments captured in each county's projected per capita demand offset the population increase and climate adjustments in the Cooperative Growth scenario leading to a small decrease in M&SSI demand compared to the Baseline demand. Increased population, Planning Scenario adjustments, and climate adjustments lead to a moderate increase in M&SSI demand in the Adaptive Innovation scenario, and more substantial increases in the Hot Growth scenario compared to the Baseline demand.

A simplified approach to estimating the M&SSI gap was taken in the Republican River Basin, because water availability to the M&SSI demand is based largely on ground water conditions and ground water modeling was not included in this Technical Update effort. Unlike agricultural wells, M&SSI wells have historically pumped to meet the full M&SSI demand. Understanding neither surface nor ground water supplies are projected to be available to meet any increases in demand in the future due to the RRC and declining aquifer levels, the Baseline demand served as the maximum amount of demand expected to be met in the future. Any increases to the demand, as reflected in the Business as Usual, Adaptive Innovation, and Hot Growth scenarios, can reasonably be considered an M&SSI gap. This simplified approach does not take into consideration the shift of population and demand within the basin (i.e. decline of population in one county and an increase in population in another county), which may indicate a specific area may experience a larger gap in the future. With this in mind, the basin-wide gap of approximately 750 and 550 ac-ft for the Business as Usual and Adaptive Innovation scenarios, respective, is moderate. The M&SSI gap of approximately 2,800 ac-ft in the Hot Growth is much more substantial.

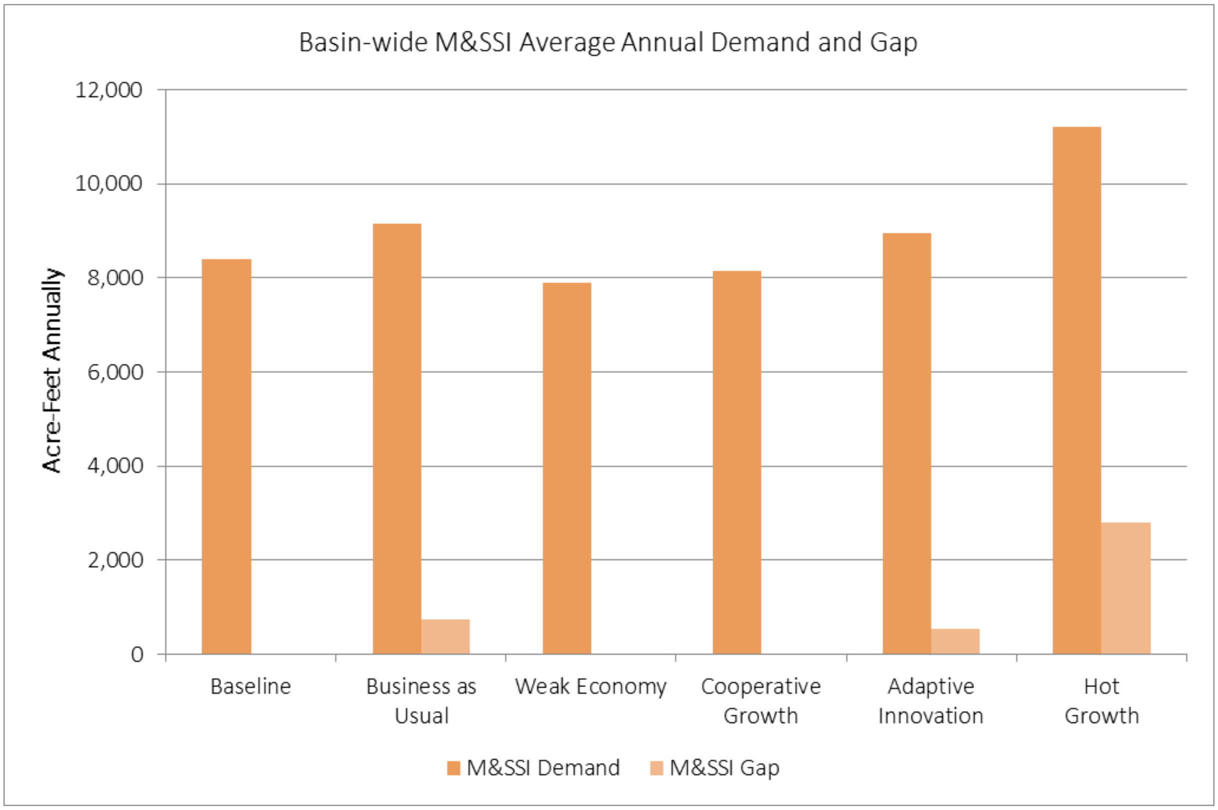


Figure 71: Republican River Basin M&SSI Average Annual Demand and Gap

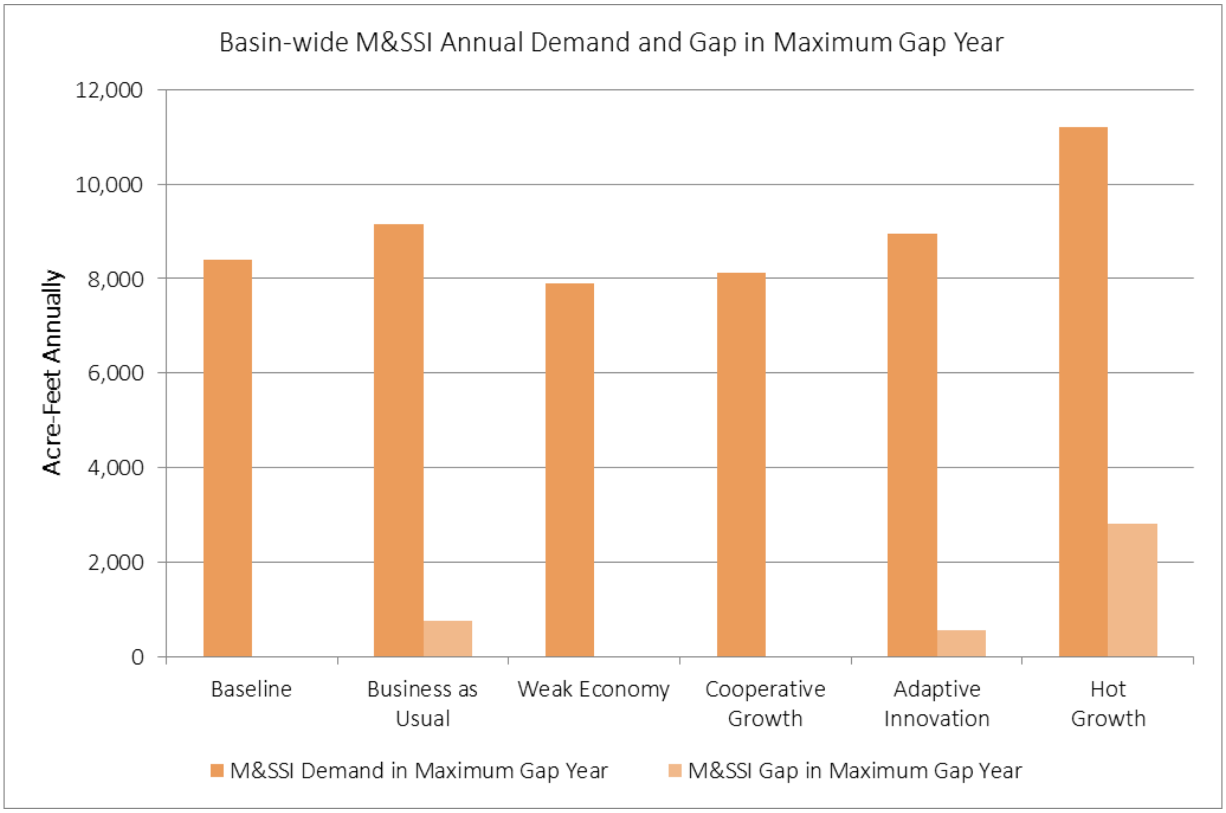


Figure 72: Republican River Basin M&SSI Maximum Annual Demand and Gap in Maximum Gap Year

5.5.3 REPUBLICAN RIVER BASIN SUMMARY

The combined agriculture and M&SSI demands and gap summary is provided in

Table 25. The results are very similar to the agricultural results in Table 23, because water supplies in the Republican River basin are predominantly used for agriculture. Figure 73 reflects the relative size of the agricultural and M&SSI demands in the Republican River basin. The M&SSI demand is difficult to reflect graphically on the same scale because they are significantly smaller than the agricultural demands. Following the graphic are summaries regarding other considerations that may impact the basin-wide gap, including potential M&SSI supplies from urbanized acreage.

Table 25: Republican River Basin Water Supply and Gap Summary

	Agriculture and M&SSI Results	Baseline	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand (ac-ft)	1,075,629	814,642	815,376	843,415	806,133	896,963
	Average Annual Gap (ac-ft)	266,807	202,121	201,870	208,820	199,841	224,240
	Average Annual Percent Gap	25%	25%	25%	25%	25%	25%
Critically Dry Max	Demand In Maximum Gap Year (ac-ft)	1,453,582	1,122,199	1,122,616	1,121,298	1,023,343	1,138,308
	Gap In Maximum Gap Year (ac-ft)	361,295	279,010	278,680	278,291	254,144	284,576
	Percent Gap In Maximum Gap Year	25%	25%	25%	25%	25%	25%

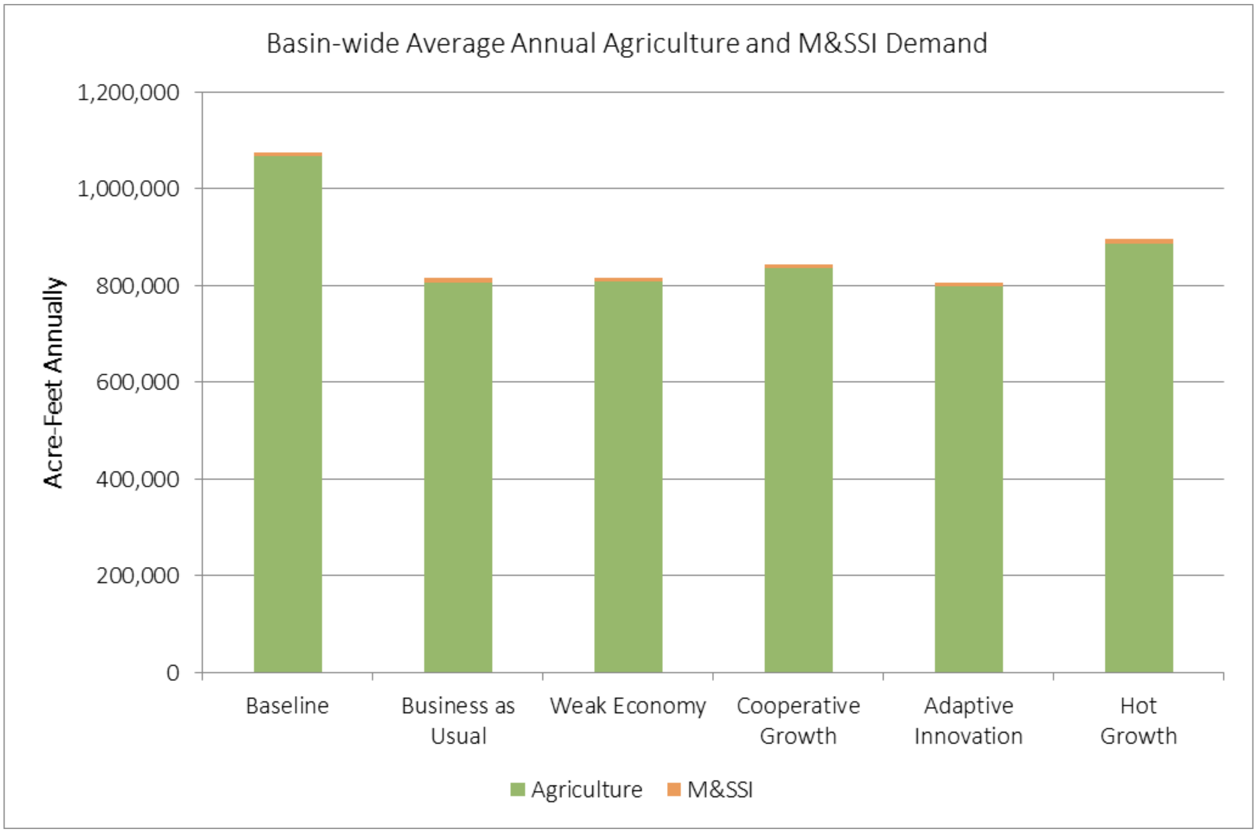


Figure 73: Republican River Basin Comparison of Average Agricultural and M&SSI Annual Demands

All scenarios except the Weak Economy scenario projects 1,410 acres of irrigated land will be taken out of production due to urbanization as the counties experience municipal growth. Supplies used to irrigate the urbanized acreage could be considered a new municipal supply if the associated water rights were changed to municipal uses. It should be noted that the economy in the basin has historically been heavily reliant on agriculture and to the extent ground water levels decline and land comes out of production, populations of local communities may also decline over time.

To estimate this potential new supply, the average consumptive use of the urbanized acreage by Planning Scenario is reflected in Table 22. It is not known which farms and ranches will be directly impacted, or the crop type or specific irrigation practices on this acreage. Additionally, it is unknown if the water rights would be changed to municipal use or whether the supply could directly meet the future municipal demand. In light of these uncertainties, the table reflects a planning-level estimate of this potential new supply. Although it has not been applied to the M&SSI gap presented above, it would likely have the effect of decreasing the gap.

Table 26: Potential Water Supply from Urbanized Acreage in the Republican River Basin

Urbanized Acreage Results	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Urbanized Acreage	1,410	-	1,410	1,410	1,410
Estimated Consumptive Use (ac-ft/year)	1,516	-	1,580	1,555	1,727

5.6 RIO GRANDE BASIN

Water supplies in the Rio Grande Basin are unique, and the development of those supplies to meet M&SSI and agricultural demands has changed significantly over time. Melting snow channeled into streams were first diverted for agricultural and domestic uses by early settlers in the 1850s, leading to the oldest water right in Colorado and the establishment of Colorado's oldest town, San Luis. With the arrival of the railroad in the 1880s, agricultural uses became the dominant economic driver and irrigated acreage increased to 400,000 acres[11]. Surface water supplies in the basin are highly variable from year to year; however newly discovered ground water supplies available through artesian wells provided more reliable and consistent supplies. Agricultural development, construction of ditches and reservoirs, and additional well construction continued through the 1930s. This development led to 700,000 acres[12] of irrigated land, a basin that was over-appropriated, and the Rio Grande Compact.

Fast forward to today, and agriculture is still at the heart of the Rio Grande Basin, and over 99 percent of the total demand for water in the basin can be attributed to agricultural demands. The basin has several small agricultural communities, with M&SSI demands accounting for less than one percent of the total water demand in the basin. Agricultural demands are met from surface water diversions supplemented by reservoir releases, and ground water supplies (i.e. pumping and artesian supplies) withdrawn from stacked aquifers located in the valley floor; the upper unconfined aquifer and the deeper confined aquifer. Although recharge to the unconfined aquifer occurs relatively quickly, decades of withdrawals greater than recharge have left it severely depleted. The deeper confined aquifer supplies fewer wells than the unconfined aquifer due to its depth, however also experiences greater withdrawals compared to recharge. Daily administration of the Rio Grande Compact, which primarily restricts surface water diversions through curtailment to meet Compact deliveries, further impacts water availability in the basin.

The following sections describe the agricultural and M&SSI demands in the Rio Grande Basin in more detail. Figure 74 reflects the basin outline, the administrative boundaries of water districts, and the streamflow gages highlighted in the results section below.

[11] Source: Rio Grande Basin Implementation Plan (April, 2015)

[12] Source: Rio Grande Basin Implementation Plan (April, 2015)

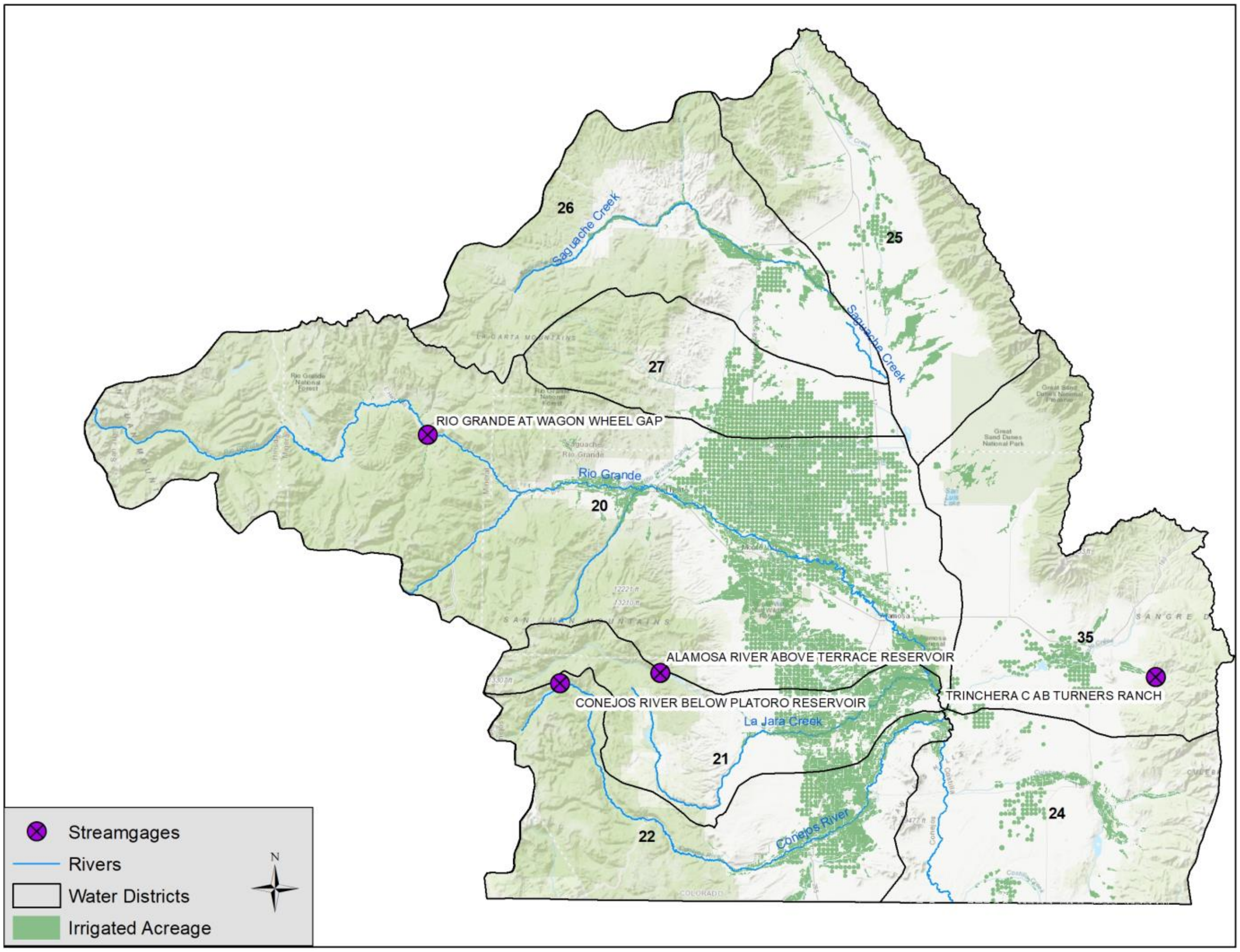


Figure 74: Rio Grande Basin Map with Streamgage Locations

5.6.1 RIO GRANDE BASIN AGRICULTURE WATER SUPPLY AND GAP

There are approximately 515,000 acres of irrigated land in the basin currently, with irrigators predominantly growing grass, alfalfa, small grains, and potatoes. As discussed above, variable surface water supplies, declining aquifer levels, and Compact administration greatly impact water availability in the basin. The basin, through the Rio Grande Water Conservation District (RGWCD), has developed Special Improvement District of the Rio Grande (Subdistrict No. 1) to manage ground water withdrawals and recharge of the aquifers. Subdistrict No. 1 operates on an annual basis to replace injurious stream depletions caused by the wells in the Subdistrict; recover aquifer levels; and maintain a sustainable irrigation supply from the aquifers for the long term. Additional Subdistricts located throughout the basin are currently in various stage of formation. Management of ground water withdrawals and recharge has led to the retirement of irrigated acreage and pumping levels less than the full crop demand in an effort to recover the aquifers in recent years. These management practices, along with the need to mitigate increases in IWR due to climate change in an over-appropriated basin, led to the projected 2050 reductions to irrigated acreage in each Planning Scenario. Refer to the *Current and 2050 Planning*

Scenario Agricultural Diversion Demand technical memorandum for additional discussion on these and other drivers for the Rio Grande Basin agricultural demand.

Table 27: Rio Grande Basin Agricultural Water Supply and Gap Summary

	Agriculture Results	Baseline	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand (ac-ft)	1,825,178	1,717,781	1,735,702	1,656,255	1,471,434	1,638,935
	Average Annual Demand Increase from Baseline (ac-ft)	-	-	-	-	-	-
	Average Annual Gap (ac-ft)	683,881	655,775	661,464	737,365	741,866	826,430
	Average Annual Gap Increase from Baseline (ac-ft)	-	-	-	53,484	57,986	142,549
	Average Annual Percent Gap	37%	38%	38%	45%	50%	50%
	Average Annual CU Gap (ac-ft)	348,288	333,392	336,305	374,561	376,927	419,840
Critically Dry Maximum	Demand In Maximum Gap Year (ac-ft)	2,058,802	1,935,437	1,956,199	1,814,118	1,605,689	1,789,675
	Increase from Baseline Demand (ac-ft)	-	-	-	-	-	-
	Gap In Maximum Gap Year (ac-ft)	1,059,702	1,017,391	1,026,351	1,112,661	1,110,956	1,238,485
	Increase from Baseline Gap (ac-ft)	-	-	-	52,959	51,254	178,783
	Percent Gap In Maximum Gap Year	51%	53%	52%	61%	69%	69%

The average annual agricultural demand decreases from the Baseline to the Weak Economy Planning Scenario by approximately 90,000 ac-ft due to the removal of approximately 45,000 irrigated acres for ground water sustainability efforts in the basin. The Business as Usual agricultural demand is further reduced by 18,000 ac-ft compared to the Weak Economy due to the additional removal of urbanized lands. Larger reductions to acreage were projected for the Planning Scenarios with climate adjustments. To account for this potential future outcome, it was assumed that the percent increase in IWR by Water District would result in the same percent decrease in irrigated acreage. This is potentially an underestimate of the total acreage that may come out of production under potential future climate conditions; however the approach accounts for the potential impact and effectively mitigates the increase in demand due to climate conditions. This approach resulted in the removal of approximately 70,000 acres in the Cooperative Growth scenario and approximately 81,000 acres in the Adaptive Innovation and Hot Growth scenarios across the basin. The Adaptive Innovation demand is further reduced due to Emerging Technology factors.

As discussed in the Water Supply Methodology section above, model development for the Rio Grande Decision Support System has focused on the consumptive use and ground water models and a surface water model was not available for this effort. As such, shortages from the consumptive use model were relied upon to inform the gap in the Baseline, Business as Usual, and the Weak Economy Planning Scenarios. The agricultural demands basin-wide have historically experienced a 37 percent gap on average[13]. If current climate conditions occur again in the future as contemplated in the Baseline, Business as Usual and Weak Economy scenarios, the projected gaps for these scenarios are likely to be similar to the historical gap. Although acreage is removed from the Business as Usual and Weak Economy scenarios, the acreage is served primarily by ground water supplies. The amount of ground water supply not withdrawn due to the removal of acreage is projected to remain in the aquifers and would not available to offset any gaps experienced by the other demands in the basin. The gap results for the critically dry year were developed in a similar fashion, however only using gap information for drought years in each Water District, resulting in a basin-wide average gap of approximately 50 percent for the three scenarios.

For the Cooperative Growth, Adaptive Innovation, and Hot Growth scenarios that reflect a change in hydrology, the gap values needed to be further adjusted. In order to capture the combined impact of the climate adjustment in the basin, it would be necessary to simulate the basin operations with the climate-adjusted hydrology in a surface and ground water model; particularly to understand what surface water supplies may be available under Compact administration to meet agricultural demands, augmentation needs, and aquifer recharge. As that level of modeling was beyond the scope of this Technical Update, a simplified approach was developed that captured the change in hydrology and translated the change to a gap value. In short, the average decline in runoff at a representative streamflow gage was used to increase the projected gap for these scenarios. This approach assumes that irrigated acreage served by surface and ground water experience a similar shortage due to a decline in runoff volume because a reduction to surface water supplies would result in a reduction of diversions to irrigated land and diversions for augmentation and recharge to offset ground water pumping. On average, the decline in total runoff volume for the Cooperative Growth scenario increases the gap to 45 percent, and to 50 percent for the Adaptive Innovation and Hot Growth scenarios. The following bar graphs reflect the average and maximum gaps in critically dry years for each Planning Scenario. The gaps increase to 61 and 69 percent for the scenarios, respectively, in critically dry years as reflected in the annual agricultural gap time series below (Figure 77).

It is difficult to determine if this adjustment over or under estimates the future gaps in the basin due to the Rio Grande Compact requirements. The Rio Grande Compact delivery obligation varies based on the flow at index gages on the Rio Grande and Conejos River. In essence, the lower the streamflow at the index gage, the lower the obligation requirement under the Compact. As such, the reduced streamflow may allow a slight increase in the amount of water available to meet agricultural demands in future Planning Scenarios. Despite this uncertainty, the assumption is appropriate for planning purposes and more detailed modeling is recommended in future Technical Updates.

[13] Source: RGDSS Historical Consumptive Use Modeling Results, 1975 – 2010 (rg2012_FactorSoUMeter; June, 2016 Scenario)

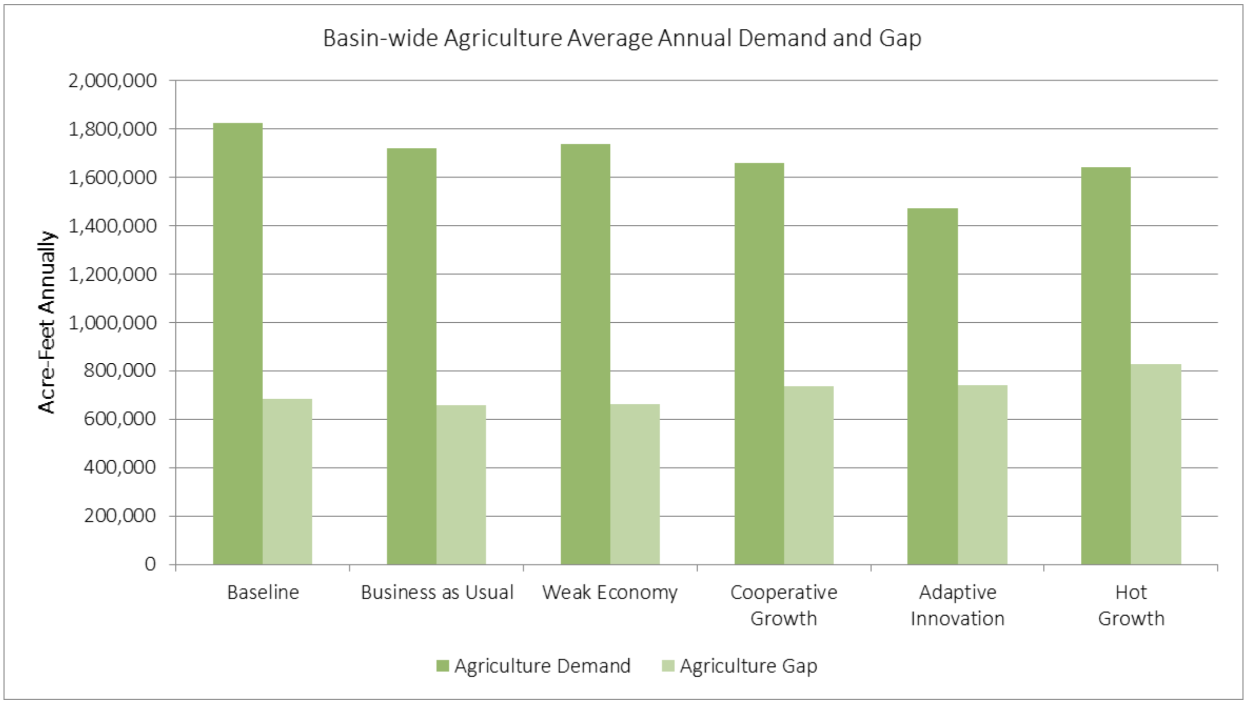


Figure 75: Rio Grande Basin Agriculture Average Annual Demand and Gap

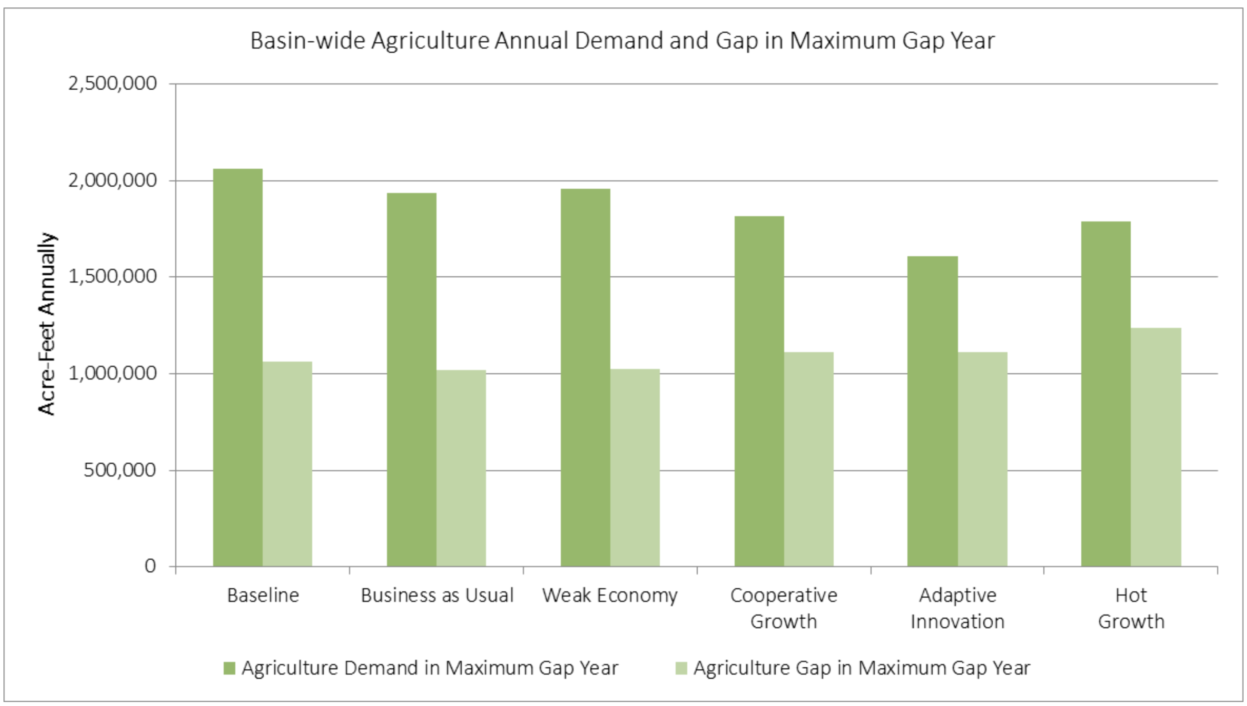


Figure 76: Rio Grande Basin Agriculture Annual Demand and Gap in Maximum Gap Year

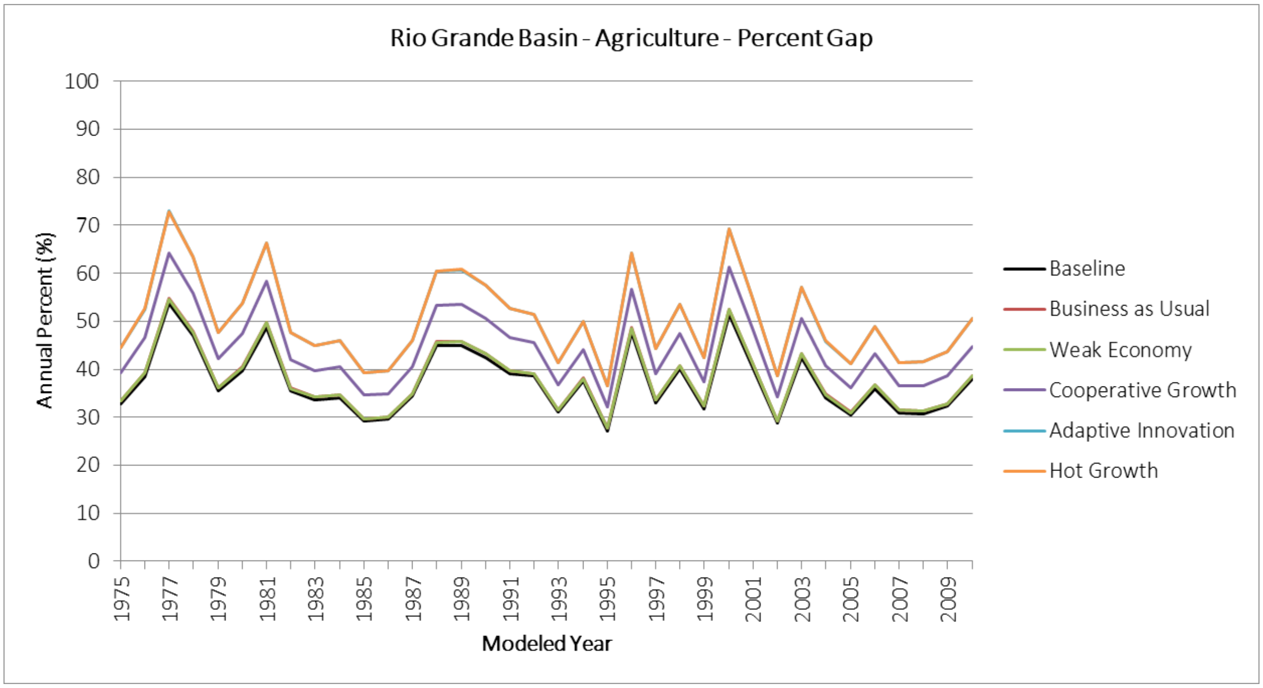


Figure 77: Rio Grande Basin Agriculture Percent Diversion Gap Times Series

5.6.2 RIO GRANDE BASIN M&SSI WATER SUPPLY AND GAP

M&SSI demands in the Rio Grande are low compared to the agricultural demand, accounting for less than one percent of the total demands in the basin. Municipal demands account for approximately 60 percent of the total M&SSI demand, with the remaining portion attributable to Large Industrial and Energy Development SSI demands. Municipal demands are greatest in Alamosa County, which encompasses the Town of Alamosa. Refer to the *Baseline and Projected 2050 Planning Scenario Municipal and Self Supplied Industrial Water Demands* technical memorandum for additional discussion on how the M&SSI demands in the basin were developed. The water supply and gap results for M&SSI in the Rio Grande basin are summarized in

Table 28, and graphically reflected in Figure 78Figure 71 and Figure 79.

Table 28: Rio Grande Basin M&SSI Water Supply and Gap Summary

	M&SSI Results	Baseline	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand (ac-ft)	17,722	21,092	17,653	20,140	21,698	25,786
Average	Average Annual Demand Increase from Baseline (ac-ft)	-	3,370	-	2,418	3,976	8,064
Average	Average Annual Gap (ac-ft)	0	3,370	0	2,418	3,976	8,064
Average	Average Annual Gap Increase from Baseline (ac-ft)	-	3,370	-	2,418	3,976	8,064
Average	Average Annual Percent Gap	0%	16%	0%	12%	18%	31%
Critically Dry Maximum	Demand In Maximum Gap Year (ac-ft)	17,722	21,092	17,653	20,140	21,698	25,786
Critically Dry Maximum	Increase from Baseline Demand (ac-ft)	-	3,370	-	2,418	3,976	8,064
Critically Dry Maximum	Gap In Maximum Gap Year (ac-ft)	0	3,370	0	2,418	3,976	8,064
Critically Dry Maximum	Increase from Baseline Gap (ac-ft)	-	3,370	-	2,418	3,976	8,064
Critically Dry Maximum	Percent Gap In Maximum Gap Year	0%	16%	0%	12%	18%	31%

Population is expected to increase in the basin in all but the Weak Economy Planning Scenario. The most populous county, Alamosa County, is projected to increase under all scenarios and accounts for a majority of the growth. The reduction in population is largely responsible for the decrease in M&SSI demand in the Weak Economy Planning Scenario compared to the Baseline demand. The population and M&SSI Planning Scenario adjustments, including climate adjustments, captured in each county's projected per capita demand combine to increase the M&SSI demand in the remaining scenarios compared to the Baseline demand.

A simplified approach to estimating the M&SSI gap was taken in the Rio Grande Basin, because water availability to the M&SSI demand is based largely on ground water conditions and ground water modeling was not included in this Technical Update effort. Unlike agricultural wells, M&SSI wells have historically pumped to meet the full M&SSI demand. Understanding neither surface nor ground water supplies are projected to be available to meet any increases in demand in the future due to Compact administration and declining aquifer levels, the Baseline demand served as the maximum amount of demand expected to be met in the future. Any increases to the demand can reasonably be considered an M&SSI gap. This simplified approach does not take into consideration the shift of population and demand within the basin (i.e. decline of population in one county and an increase in population in another county), which may indicate a specific area may experience a larger gap in the future. With this in mind, even the smallest basin-wide gap of approximately 2,420 ac-ft for the Cooperative Growth scenario is substantial. The M&SSI gaps increase moderately in the Business as Usual and Adaptive Innovation scenarios, but the M&SSI demands increase by 3.5 times in the Hot Growth scenario compared to the Cooperative Growth gap.

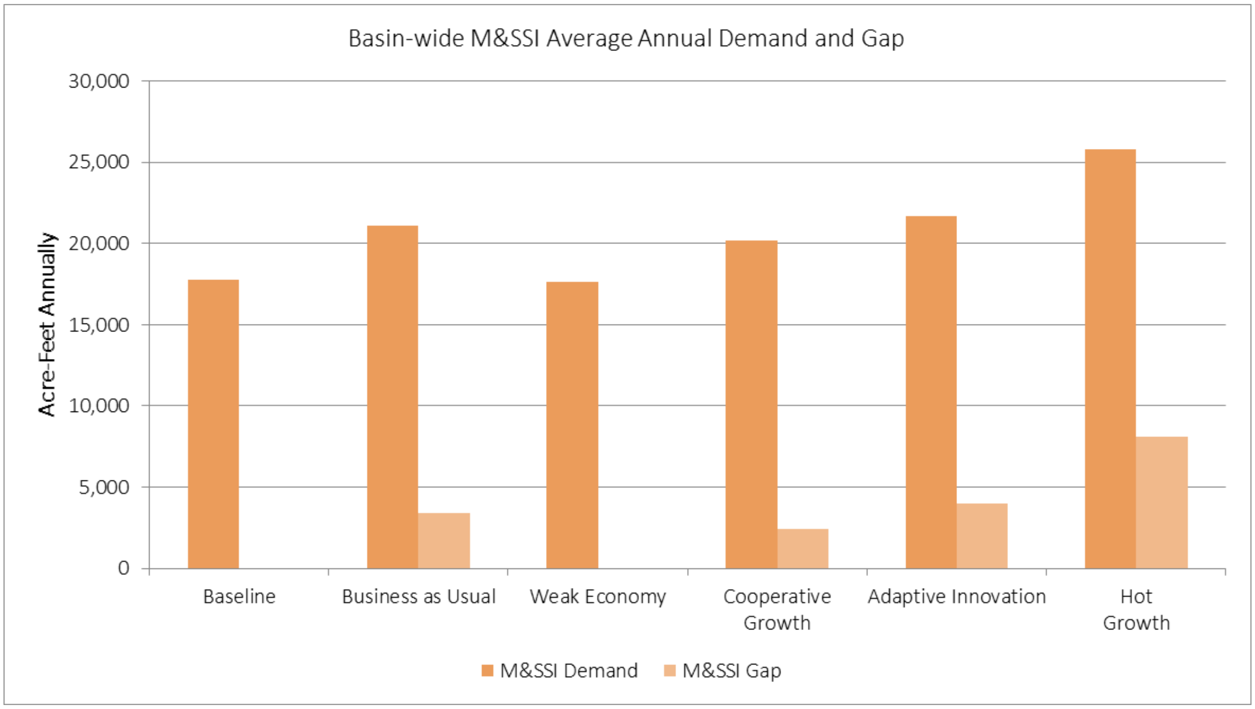


Figure 78: Rio Grande Basin M&SSI Average Annual Demand and Gap

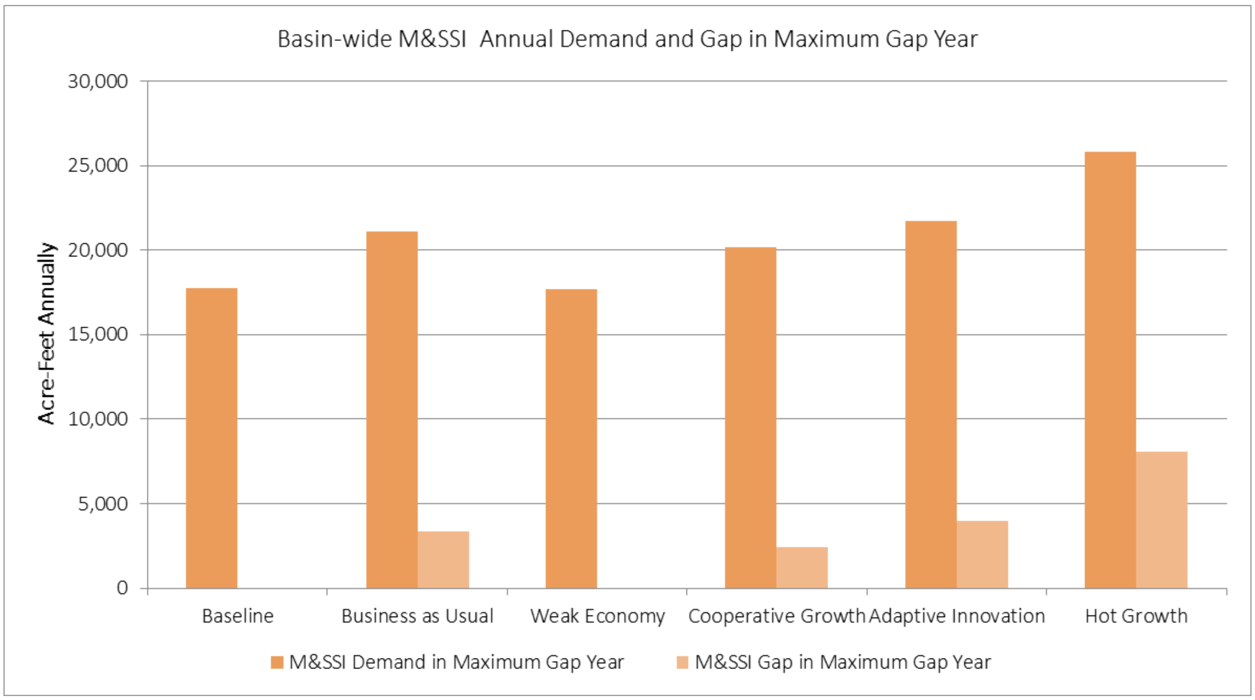


Figure 79: Rio Grande Basin M&SSI Maximum Annual Demand and Gap in Maximum Gap Year

5.6.3 RIO GRANDE BASIN SUMMARY

The combined agriculture and M&SSI demands and gap summary is provided in Table 29. The results are very similar to the agricultural results in Table 27, because water supplies in the Rio Grande basin are predominantly used for agriculture. Figure 80 reflects the relative size of the agricultural and M&SSI demands in the Rio Grande basin. The M&SSI demand is difficult to reflect graphically on the same scale because they are significantly smaller than the agricultural demands. Following the graphic are summaries regarding other considerations that may impact the basin-wide gap, including potential M&SSI supplies from urbanized acreage or transbasin import supply gaps.

Table 29: Rio Grande Basin Water Supply and Gap Summary

	Agriculture & M&SSI Results	Baseline	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand (ac-ft)	1,842,900	1,738,873	1,753,355	1,676,395	1,493,132	1,664,722
	Average Annual Gap (ac-ft)	683,881	659,145	661,464	739,783	745,842	834,494
	Average Annual Percent Gap	37%	38%	38%	44%	50%	50%
Critically Dry Max	Demand In Maximum Gap Year (ac-ft)	2,076,524	1,956,529	1,973,852	1,834,258	1,627,387	1,815,461
	Gap In Maximum Gap Year (ac-ft)	1,059,702	1,020,761	1,026,351	1,115,079	1,114,932	1,246,548
	Percent Gap In Maximum Gap Year	51%	52%	52%	61%	69%	69%

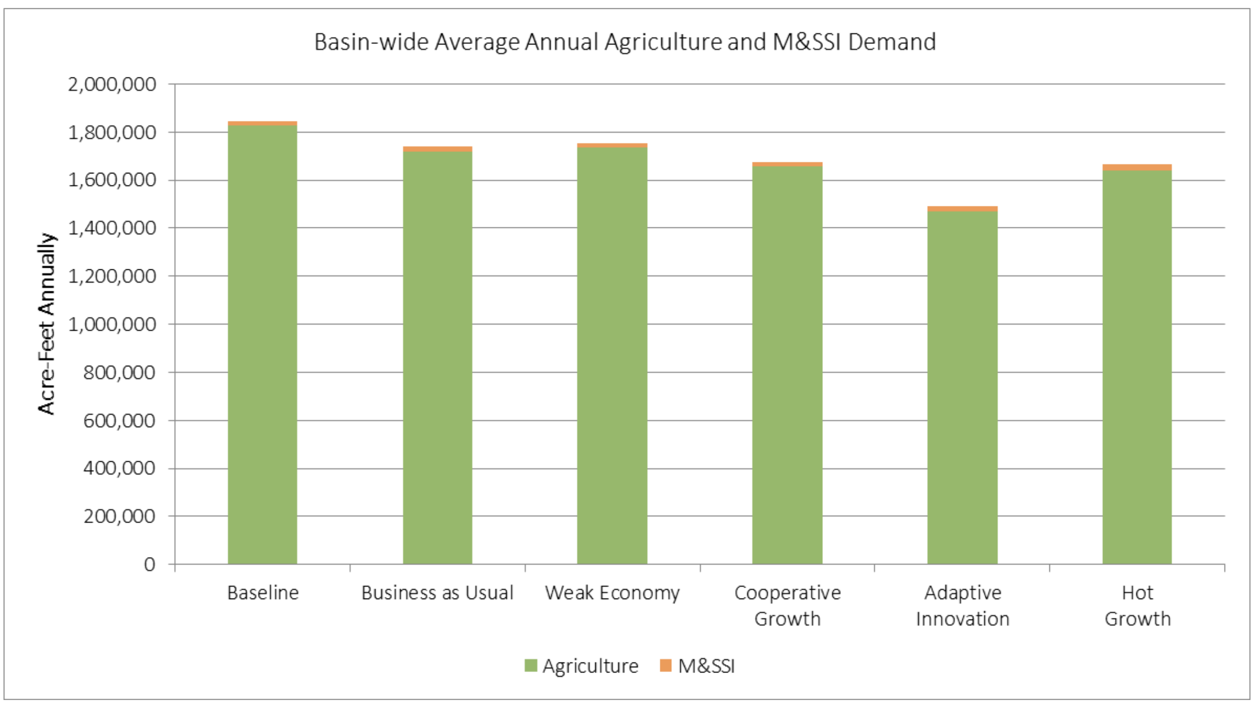


Figure 80: Rio Grande Basin Comparison of Average Agricultural and M&SSI Annual Demands

All scenarios except the Weak Economy scenario projects 4,010 acres of irrigated land will be taken out of production due to urbanization as the counties experience municipal growth. Supplies used to irrigate the urbanized acreage could be considered a new municipal supply if the associated water rights were changed to municipal uses. It should be noted that the economy in the basin has historically been heavily reliant on agriculture and to the extent ground water levels decline and land comes out of production, populations of local communities may also decline over time. Additionally, if the urbanized acreage is supplied by ground water, it is less likely the supply would be used for municipal purposes and instead these supplies may remain in the aquifer for recovery purposes.

To estimate this potential new supply, the average consumptive use of the urbanized acreage by Planning Scenario is reflected in Table 30. It is not known which farms and ranches will be directly impacted, or the crop type or specific irrigation practices on this acreage. Additionally, it is unknown if the water rights would be changed to municipal use or whether the supply could directly meet the future municipal demand. In light of these uncertainties, the table reflects a planning-level estimate of this potential new supply. Although it has not been applied to the M&SSI gap presented above, it would likely have the effect of decreasing the gap.

Table 30: Potential Water Supply from Urbanized Acreage in the Rio Grande Basin

Urbanized Acreage Results	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Urbanized Acreage	4,010	-	4,010	4,010	4,010
Estimated Consumptive Use (ac-ft/year)	5,271	-	5,445	4,592	5,092

The Rio Grande Basin receives imported transbasin supplies primarily from the Southwest Basin. The transbasin imports are diverted at the headwaters of several sub-basins in the Southwest Basin and delivered to the headwaters of the Rio Grande primarily for agricultural purposes. Table 31 summarizes the total transbasin import volumes and associated import gaps. Note that transbasin imports are the same across the scenarios because they are represented in the model at historical levels, and no Planning Scenario adjustments were applied. A gap indicates that the historical import could not be diverted in the source basin due to a physical or legal limitation of water supply at the diverting location. This is caused by changes in water availability, increases in senior demands in the source basin, or a combination of both.

Ideally the import supply gap in the Baseline scenario would be zero; however the Baseline dataset represents current agricultural and M&SSI demands over the entire model period which can result in minor shortages to junior water rights, including transbasin diversions. With this in mind, the incremental increase in the import gap reflects the increase in gap due to the Planning Scenario adjustments. Under current hydrology conditions, there was no increase in the gap for the Business as Usual and Weak Economy scenarios. The increased demands and changed hydrology in the Cooperative Growth, Adaptive Innovation, and Hot Growth scenarios however resulted in more substantial gaps on average and during critically dry years. If exports stay the same in the future, the reported import gaps could increase the total Rio Grande basin gaps in these scenarios. As transbasin imported supplies are generally able to be reused to extinction within the Rio Grande Basin, the imported supply gap would have the effect of increasing the total Rio Grande basin gap by more than the values shown in the table.

Table 31: Summary of Transbasin Imports to the Rio Grande Basin

	Transbasin Import Supply Gap	Baseline	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Import Supply (ac-ft)	2,118	2,118	2,118	2,118	2,118	2,118
	Average Annual Import Supply Gap (ac-ft)	210	211	211	924	1,061	1,198
	Average Annual Import Supply Gap Increase from Baseline (ac-ft)	-	1	1	714	851	989
	Average Annual Import Supply Percent Gap	10%	10%	10%	44%	50%	57%
Critically Dry Maximum	Import Supply In Maximum Gap Year (ac-ft)	4,170	4,170	4,170	5,621	5,621	5,621
	Import Supply Gap In Maximum Gap Year (ac-ft)	1,214	1,214	1,214	2,760	3,384	3,406
	Increase from Baseline Import Supply Gap (ac-ft)	-	0	0	1,546	2,170	2,192
	Import Supply Percent Gap In Maximum Gap Year	29%	29%	29%	49%	60%	61%

Although detailed surface water modeling was not completed in the basin, it is important to understand the potential impact the climate conditions may have on the volume and timing of runoff in the basin, particularly with respect to Compact administration. Figure 81 through Figure 88 reflect the average monthly and time series of annual natural flow runoff at following four gaged locations[14]:

- Rio Grande at Wagon Wheel Gap (08217500)
- Alamosa River above Terrace Reservoir (08236000)
- Trinchera Creek above Turners Ranch near Fort Garland (08240500)
- Conejos River below Platoro Reservoir (08245000)

Note that the graphics reflect *natural flow* or the amount of water in the river absent the effects or impact of man, not simulated streamflow. These streamflow gages are generally located in the headwaters with limited impact from upstream irrigation or municipal uses; however any man-induced effects (e.g. Platoro Reservoir) above the gage locations have been removed so that the climate adjustments could be applied. Additionally, the annual natural flow graphics reflect a stacked volume of runoff compared to the volume of runoff for current conditions. The green band in these graphs reflects the incremental increase in runoff under the In-Between conditions compared to the runoff under the Hot and Dry conditions in the blue area.

As reflected, natural flow at the Rio Grande gage is projected to experience a smaller reduction in volume compared to the other gaged locations, with the In-Between conditions projecting a 7 percent decrease on average and the Hot and Dry conditions projecting a 17 percent reduction on average. There is

[14] A majority of the streamflow results presented in this memorandum reflect information from gages selected to support the Environmental Flow Tool. These gages differ from those selected for the Flow Tool; the streamflow results from these gages are provided to better reflect the impact of climate-adjusted hydrology as it may apply to the Compact Delivery Obligations in 2050. Information from the Los Pinos and San Antonio gages near Ortiz were excluded because their contributing drainage areas are primarily in New Mexico and climate adjustments were not considered for areas outside of Colorado.

however a pronounced shift in the peak runoff, projected to occur a month earlier than current conditions, and a reduction to late season flows. Larger reductions are projected for the Conejos and Alamosa gages, projected to be approximately 15 percent with the In-Between conditions and 25 percent with the Hot and Dry conditions. As reflected in the graphs, the reductions to streamflow are projected to occur during years with average and above-average runoff, with smaller reductions projected for years with lower flows. Similar to the Rio Grande gages, the Conejos and Alamosa natural flow is projected to shift earlier by a month and experience lower late season flows. Trinchera Creek is projected to the largest reduction in flows of all the gaged locations; over 45 percent reduction with In-Between conditions and 55 percent reduction with Hot and Dry conditions.

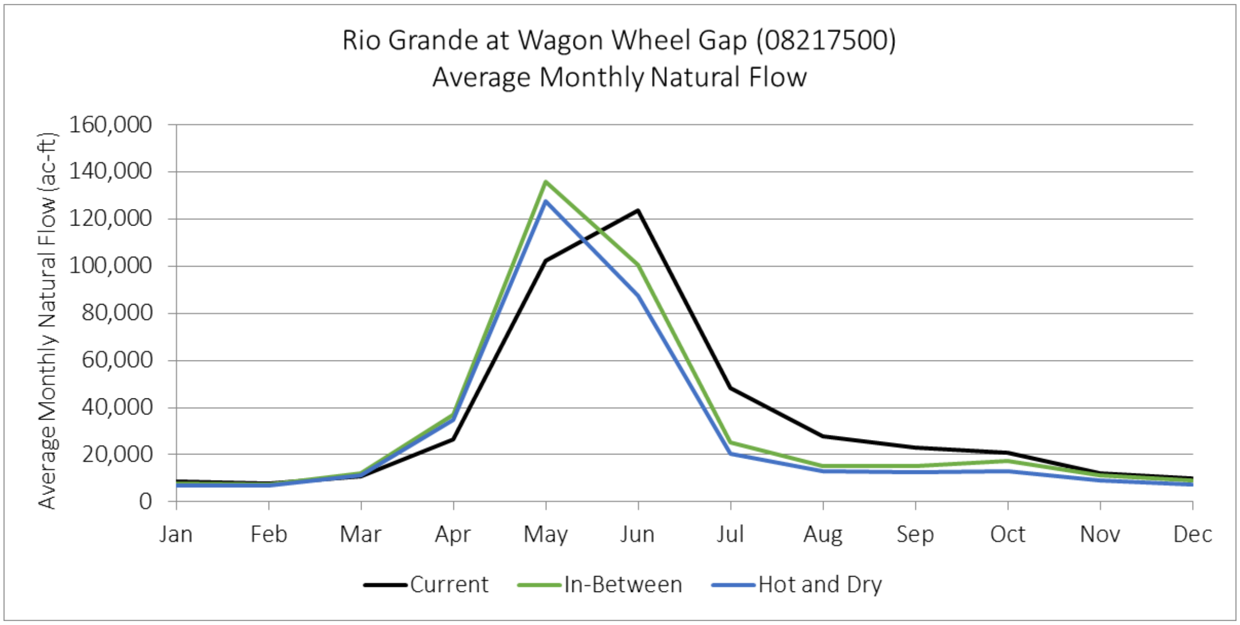


Figure 81: Average Monthly Natural Flow at Rio Grande at Wagon Wheel Gap

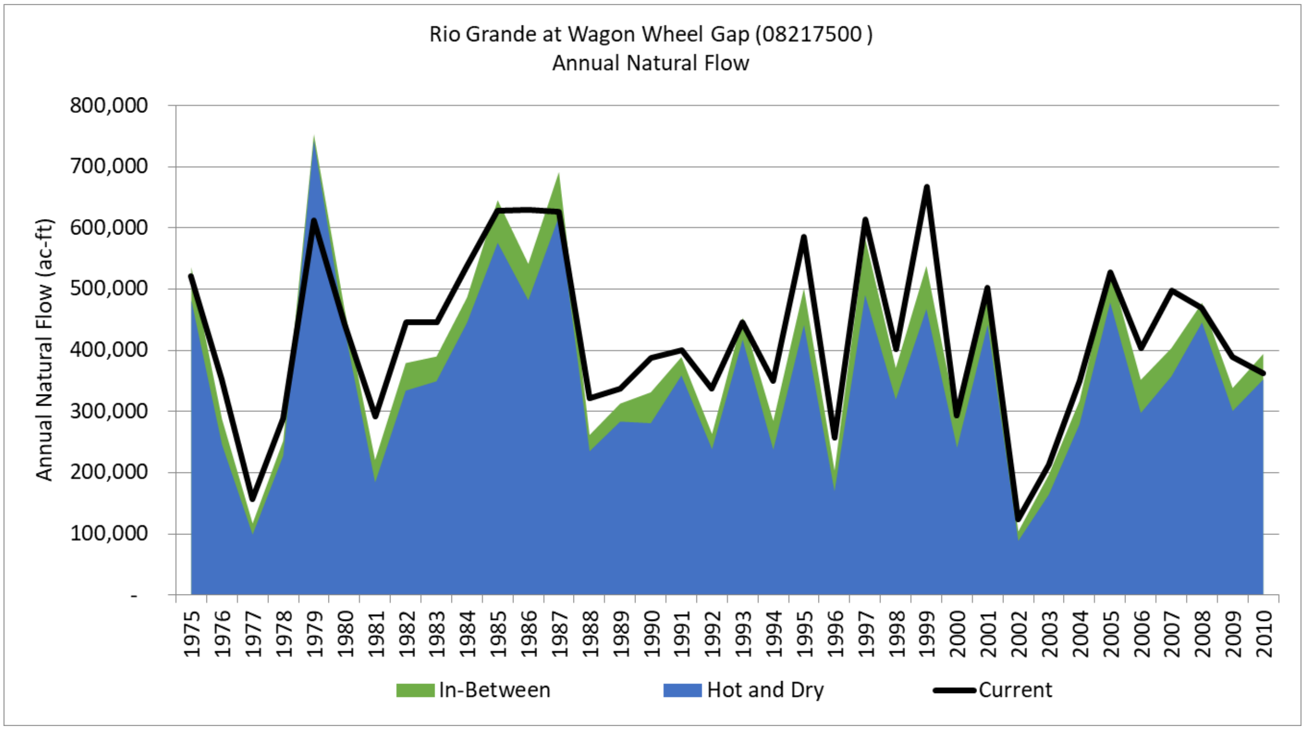


Figure 82: Annual Natural Flow at Rio Grande at Wagon Wheel Gap

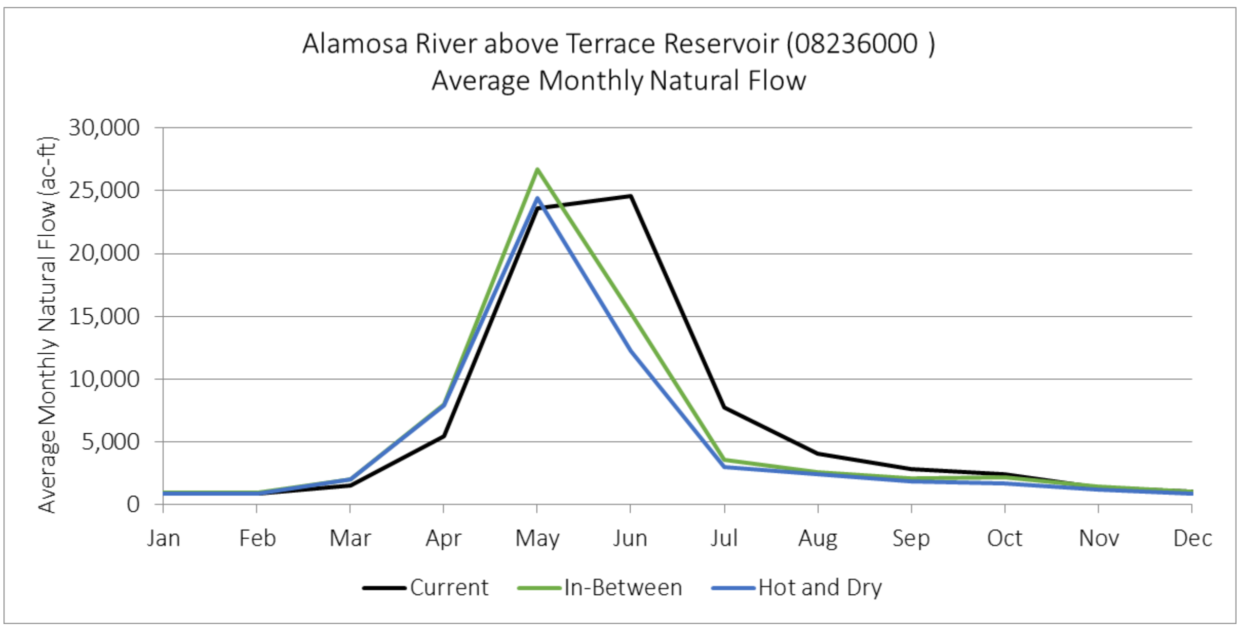


Figure 83: Average Monthly Natural Flow at Alamosa River above Terrace Reservoir

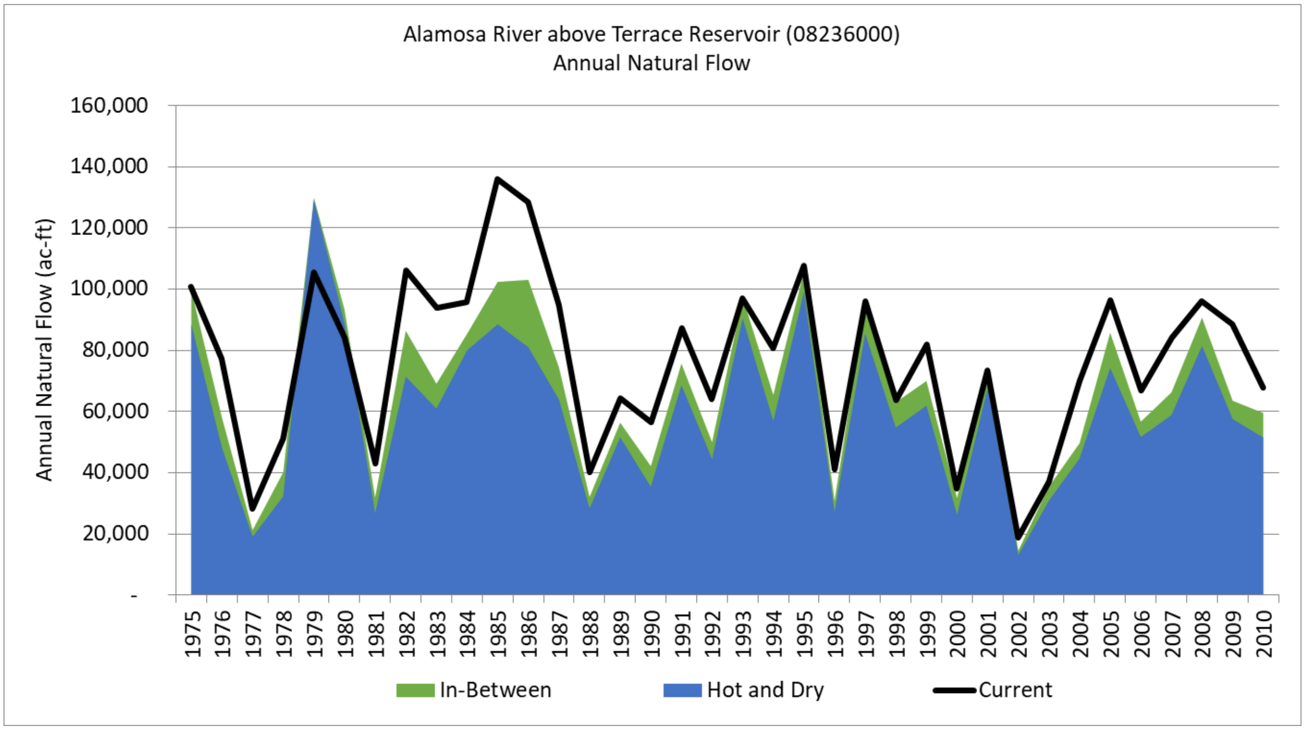


Figure 84: Annual Natural Flow at Alamosa River above Terrace Reservoir

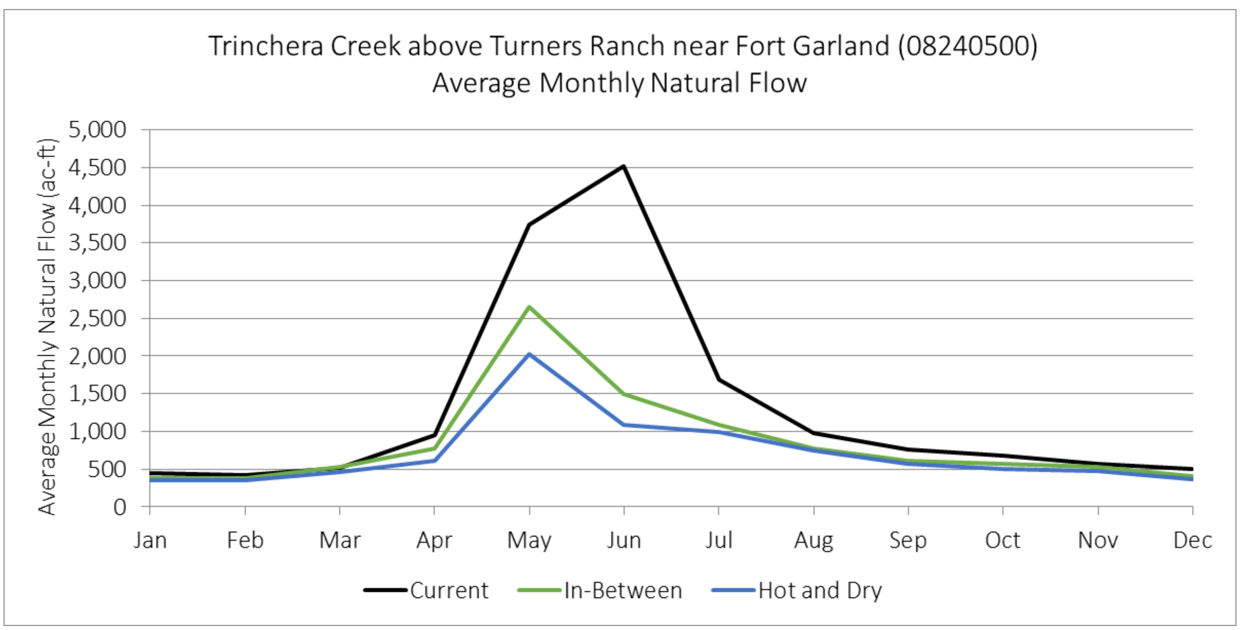


Figure 85: Average Monthly Natural Flow at Trinchera Creek above Turners Ranch near Fort Garland

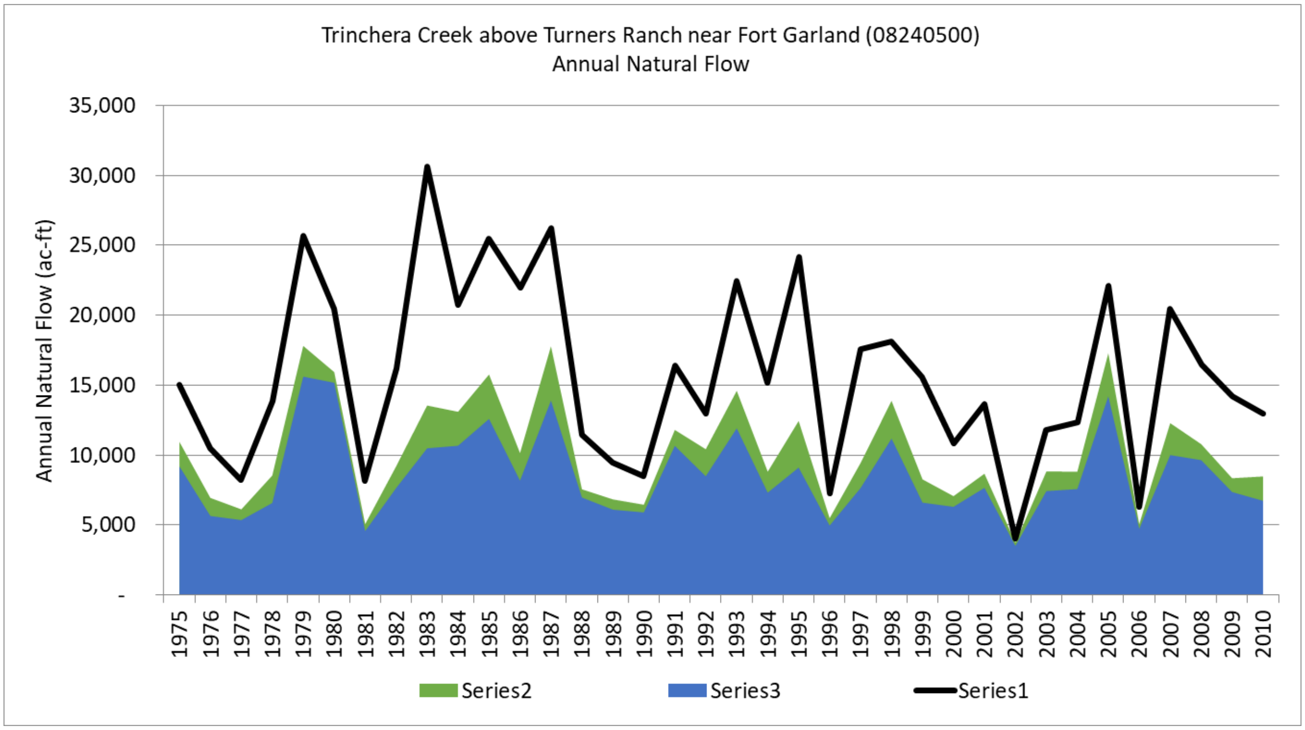


Figure 86: Annual Natural Flow at Trinchera Creek above Turners Ranch near Fort Garland

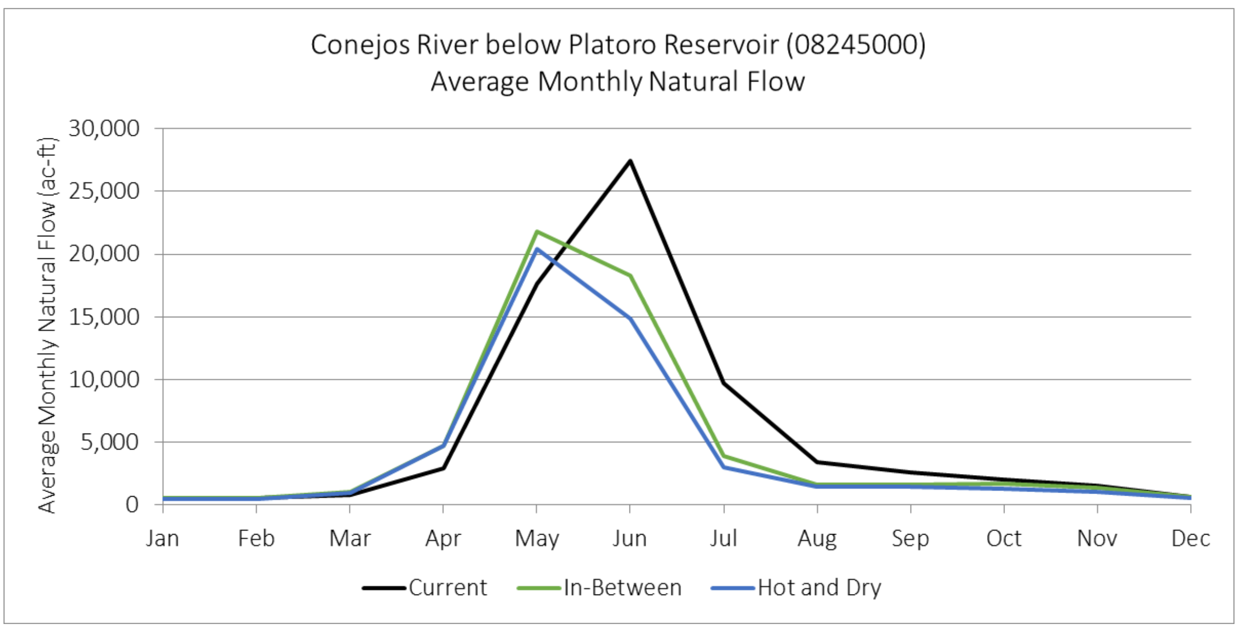


Figure 87: Average Monthly Natural Flow at Conejos River below Platoro Reservoir

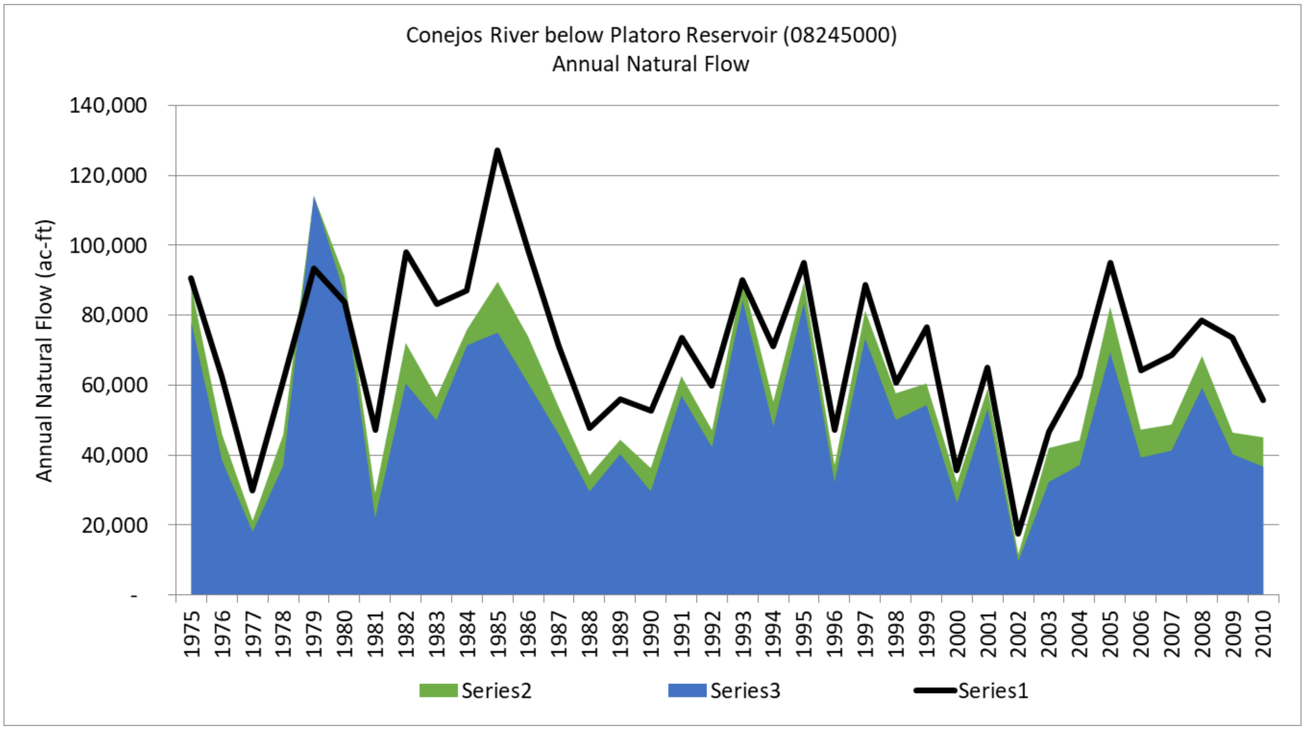
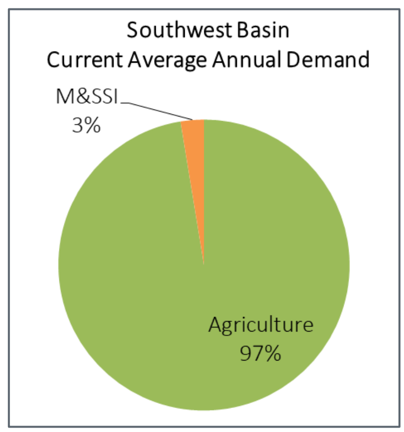


Figure 88: Annual Natural Flow at Conejos River below Platoro Reservoir

5.7 SOUTHWEST BASIN



The Southwest Basin is made up of a series of nine sub-basins, each with their own unique hydrology and demands. The basin is home to a diverse set of demands including several small towns founded primarily due to either mining or agricultural interests; two Native American reservations (Southern Ute Indian Tribe and Ute Mountain Ute Tribe); the San Juan Chama Project[15] to deliver water to New Mexico; several small transbasin diversions; and four major Reclamation Projects (Pine River Project, Dolores Project, Florida Project, and the Mancos Project) that both brought new irrigated acreage under production and provided supplemental supplies to existing lands.

Water demands in the basin are predominantly for agricultural uses, with only 3 percent of the total demand in the basin attributable for M&SSI demands and less than one percent attributable to transbasin demands. The following sections describe the agricultural, M&SSI, and transbasin export demands in the Southwest basin in more detail. Figure 89 reflects the basin outline, the administrative boundaries of water districts, and the streamflow gages highlighted in the results section below.

[15] The San Juan Chama Project, developed by Reclamation under the Colorado River Storage Project (CRSP), delivers water from San Juan tributaries to the Rio Grande basin in New Mexico. The Baseline and Planning Scenario models include the current demand and operations, but the project deliveries are not considered a transbasin export under the Technical Update as the project does not operate under a Colorado water right; cannot call out Colorado water users; and the supply is not delivered to a Colorado entity.

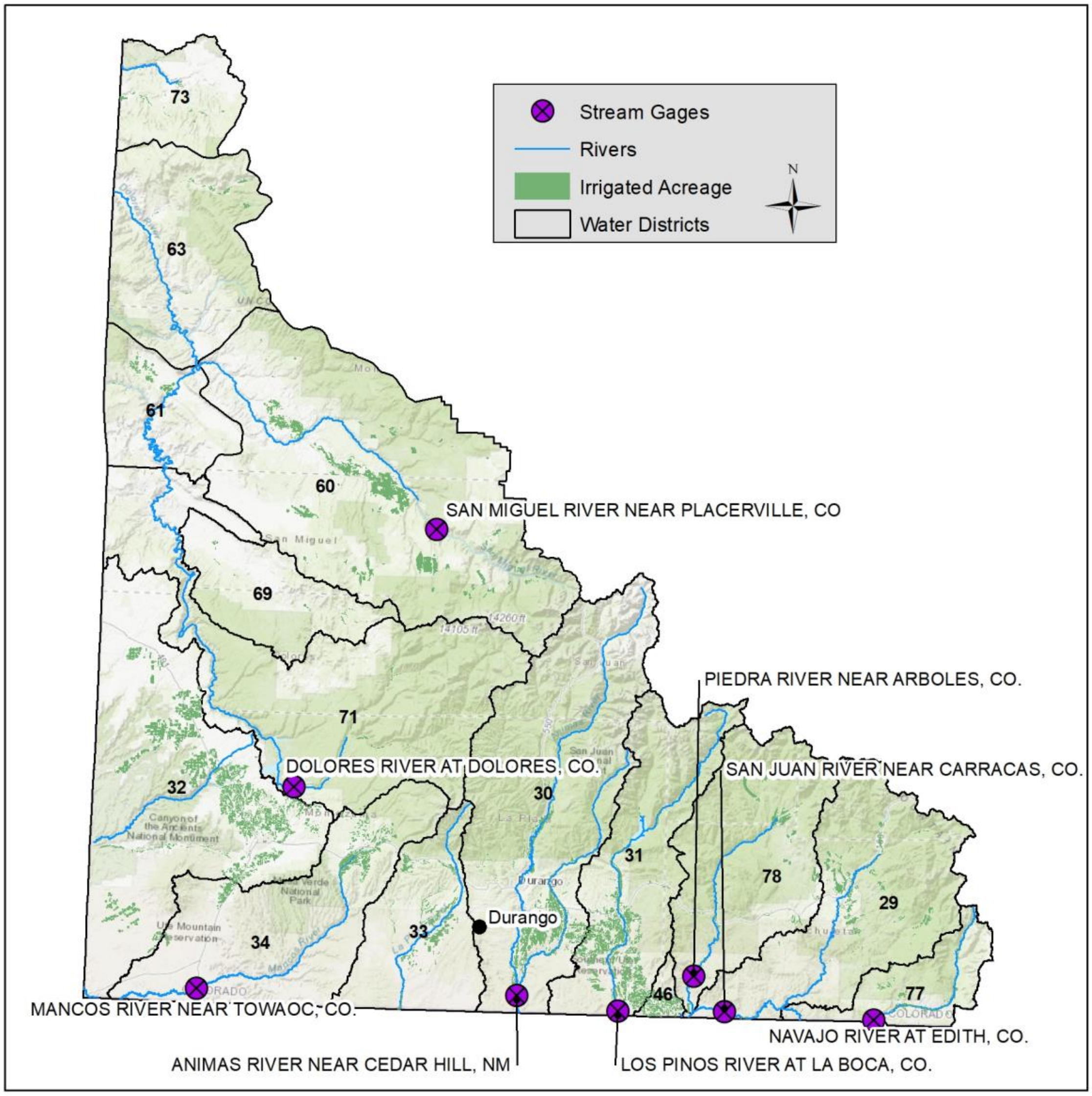


Figure 89: Southwest Basin Map with Streamgage Locations

5.7.1 SOUTHWEST BASIN AGRICULTURE WATER SUPPLY AND GAP

On much of the 222,000 irrigated acres in the basin, producers generally irrigate grass meadows for cattle operations along the rivers and tributaries and rely on supplies available during the runoff season. Reclamation Projects have developed critical supplemental supplies in the basin and producers under these Projects irrigate a wider variety of crops, such as alfalfa and row crops, due to lower elevations, warmer temperatures, and supplemental storage supplies during the later irrigation season.

The Southwest Basin agricultural diversion demands, demand gaps, and consumptive use gaps results for the baseline and Technical Update Planning Scenarios are presented in Table 32. As discussed in Technical Memo *Current and 2050 Planning Scenario Agricultural Diversion Demand*, 2050 agricultural demands are influenced by a number of drivers, including climate, urbanization, and emerging technologies.

Table 32: Southwest Basin Agricultural Water Supply and Gap Summary

	Agricultural Results	Baseline	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand (ac-ft)	1,024,784	1,005,432	1,005,432	1,220,493	923,100	1,271,671
	Average Annual Demand Increase from Baseline (ac-ft)	-	-	-	195,708	-	246,887
	Average Annual Gap (ac-ft)	126,642	120,297	119,760	276,733	219,000	355,081
	Average Annual Gap Increase from Baseline (ac-ft)	-	-	-	150,091	92,357	228,439
	Average Annual Percent Gap	12%	12%	12%	23%	24%	28%
	Average Annual CU Gap (ac-ft)	72,255	68,721	68,393	158,451	147,241	206,411
Critically Dry Maximum	Demand In Maximum Gap Year (ac-ft)	1,152,958	1,131,100	1,131,100	1,215,185	899,260	1,238,203
	Increase from Baseline Demand (ac-ft)	-	-	-	62,227	-	85,245
	Gap In Maximum Gap Year (ac-ft)	517,556	507,371	504,937	679,498	474,012	738,104
	Increase from Baseline Gap (ac-ft)	-	-	-	161,942	-	220,548
	Percent Gap In Maximum Gap Year	45%	45%	45%	56%	53%	60%

The average annual agricultural demand decreases from the Baseline to the Business as Usual and Weak Economy Planning Scenarios by approximately 20,000 ac-ft due to the reduction of irrigated acreage from urbanization. As reflected in the table, irrigators in the basin currently experience a relatively small agricultural gap on average. Runoff and water availability in each of the sub-basins in the Southwest Basin, however, are widely variable. Agricultural gaps under current conditions are much greater than the 12 percent basin-wide average in sub-basins with more limited supplies, particularly on farms and ranches along smaller tributaries to the Mancos, Dolores, and La Plata Rivers. Current agricultural gaps in these areas range from 25 to 45 percent on average, with even larger gaps during critically dry years, and gaps in these areas trend substantially higher than the basin-wide average in all Planning Scenarios. Consideration of this variability across the sub-basins should be noted during review of the basin-wide results.

Demand for the Cooperative Growth scenario incorporates the urbanized acreage as well as the increase in climate change adjustments to IWR, leading to an increase of 20 percent or approximately 195,000 ac-ft of demand basin-wide. Climate adjustments to hydrology in the Cooperative Growth scenario reduce the magnitude, shift the peak runoff generally from June to May, and reduce the amount of late season supplies. These changes lead to an 11 percent increase in gap (approximately 156,000 ac-ft) compared to the Business as Usual and Weak Scenarios. The gap in a critical dry year surpasses 50 percent on average for the Cooperative Growth scenario, indicating that the more water short sub-basins discussed above are projected to experience even higher gaps during critically dry years.

The Adaptive Innovation scenario reflects the decrease in acreage due to urbanization, improved system efficiencies, and the mitigation of approximately 10 percent of the increase in IWR due to projected Hot and Dry climate conditions. These adjustments lead to an agricultural demand that is approximately 100,000 ac-ft or 10 percent less than the Baseline demand. Despite the reduced agricultural demand, the agricultural gap actually increases by approximately 92,000 ac-ft compared to the Baseline Scenario due to both the reduced return flows from the more efficient irrigation practices and the shift of the peak runoff month associated with the projected hydrology under the Hot and Dry climate conditions.

The Hot Growth scenario reflects the largest agricultural demand and the largest agricultural gap, driven by the full impact of the projected Hot and Dry climate conditions. In this scenario, the agricultural demand and gap are approximately 355,000 ac-ft and 228,000 ac-ft greater than the Baseline agricultural demand on average, respectively. As reflected in Figure 92, the 2002 drought conditions exacerbated by the Hot and Dry climate conditions lead to the projected gap results for the critically dry year. The following figures reflect the agricultural demand and gap on average and in a critically dry year, relative to the demand and across Planning Scenarios.

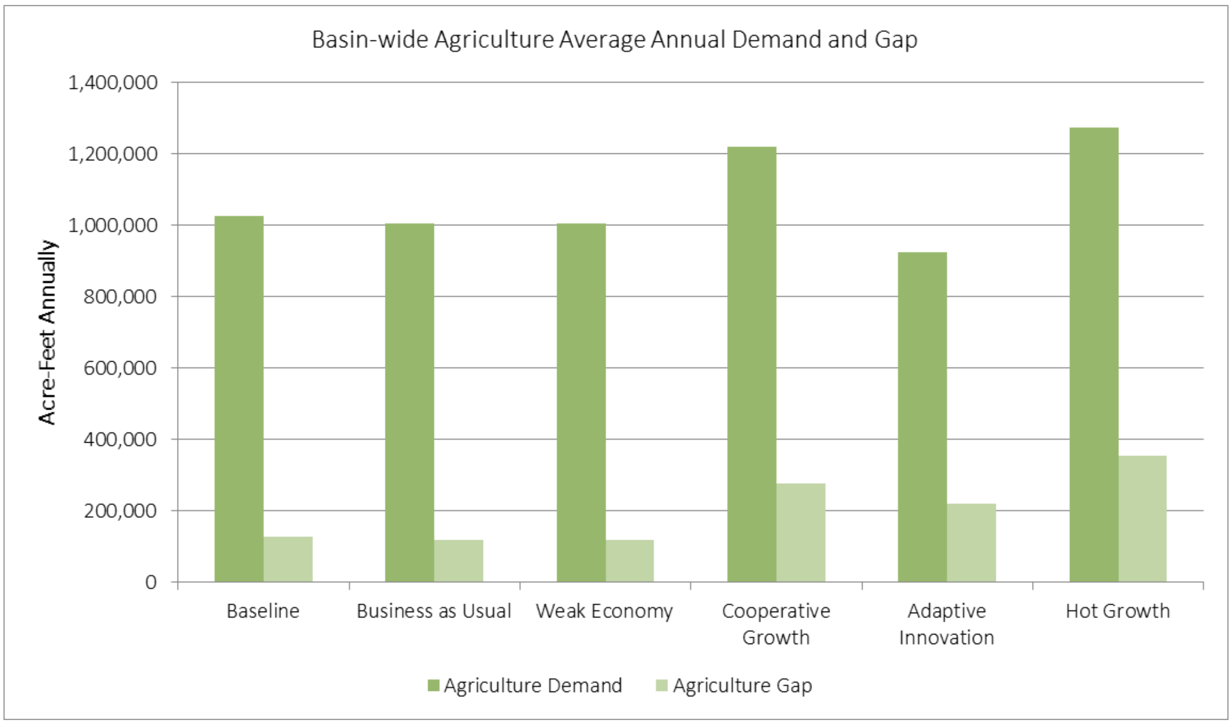


Figure 90: Southwest Basin Agriculture Average Annual Demand and Gap

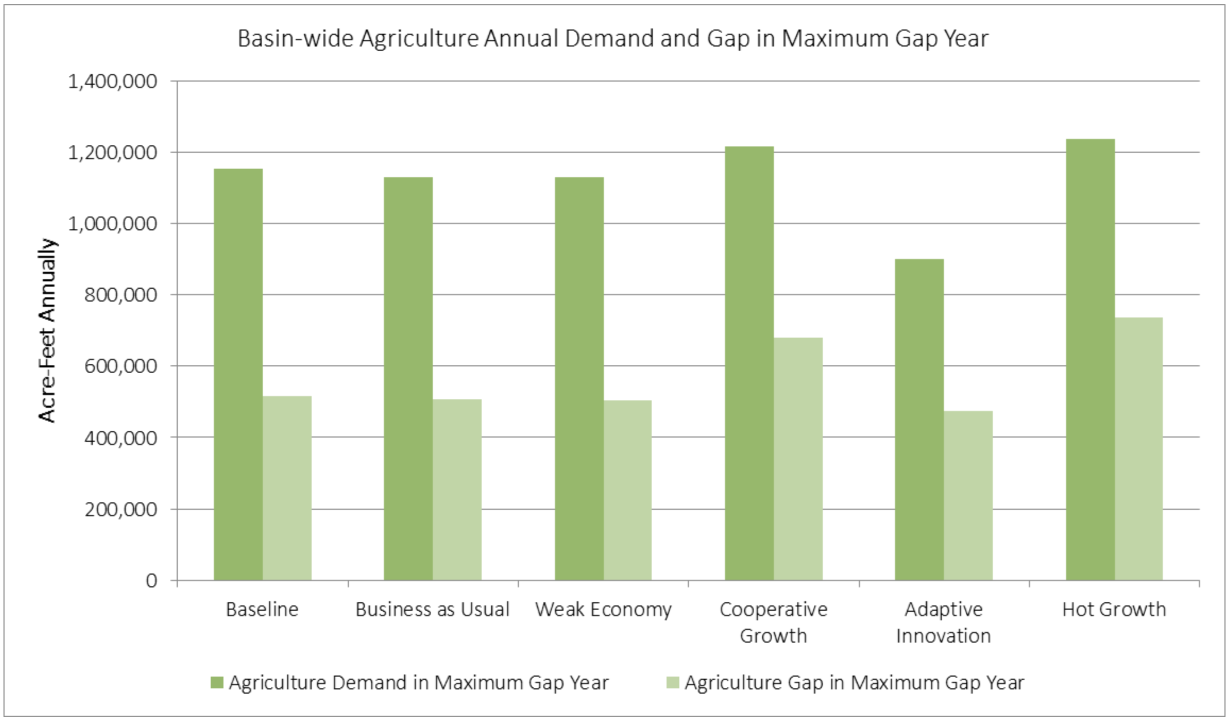


Figure 91: Southwest Basin Agriculture Annual Demand and Gap in Maximum Gap Year

As reflected in Figure 92, the agricultural gap varies annually based on the demand and the available water supplies in the basin. With only the decrease in acreage due to urbanization differentiating the Baseline, Business as Usual, and the Weak Economy scenarios, the agricultural gaps are very similar over the study period and the lines on the graph are overlapping. The impact of climate adjustments is substantial as the agricultural gap from the Cooperative Growth, Adaptive Innovation, and Hot Growth scenarios is doubled in average and above average hydrology years compared to the Baseline values. In the critically dry year of 2002, only the irrigators with the most senior water rights are able to divert the limited supplies, regardless of climate-adjusted hydrology, and the agricultural gaps are similar across all the Planning Scenarios.

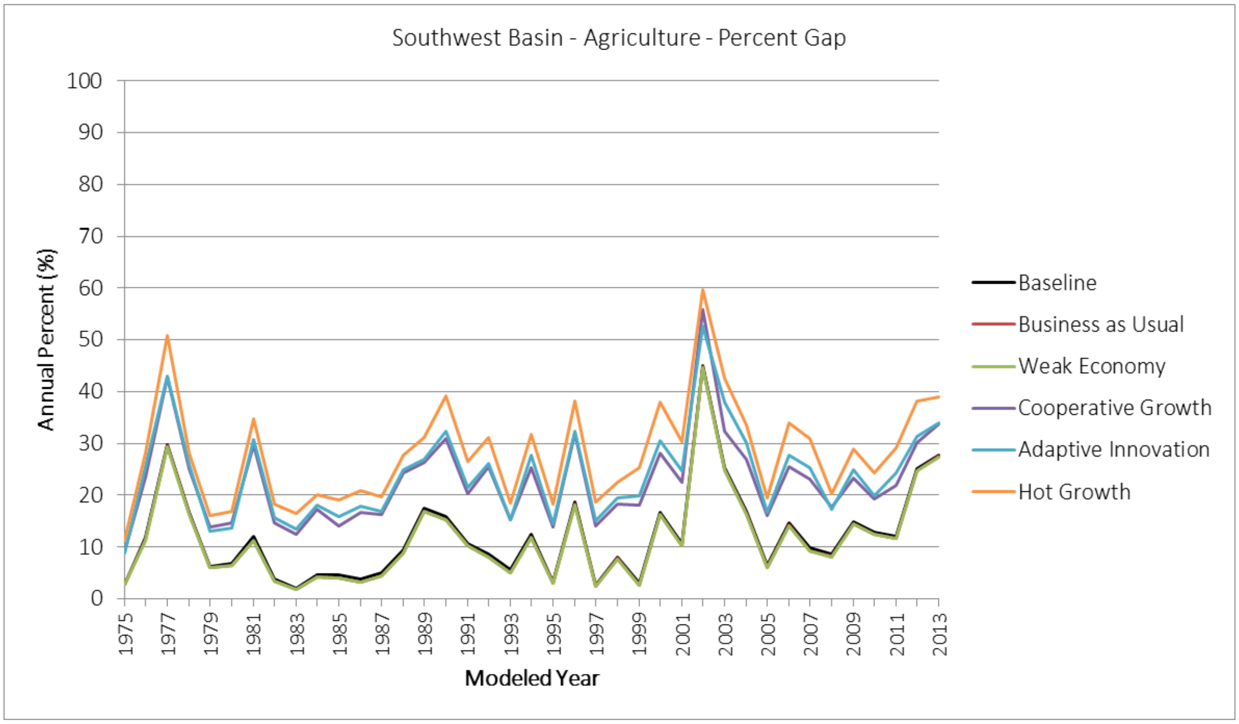


Figure 92: Southwest Basin Agriculture Percent Diversion Gap Times Series

5.7.2 SOUTHWEST BASIN M&SSI WATER SUPPLY AND GAP

Municipal demands in the Southwest Basin account for more than 90 percent of the total M&SSI demand in the basin, with the remaining 10 or less percent attributable to SSI demands in the basin. The SSI[16] in the basin is predominantly thermo-electric demands, with smaller snowmaking demands. From a percentage basis, the Southwest Basin has the largest projected increase in population of all basins throughout the state, ranging from 16 to 161 percent across Planning Scenarios. Much of this growth is projected to occur in La Plata County, which encompasses the larger communities of Durango, Bayfield, and Ignacio.

A majority of the M&SSI demands in the Southwest Basin are grouped and represented in the model at several general locations throughout the model. Municipal demands and surface water supplies, however, are modeled individually for the City of Durango, and the Towns of Rico, Mancos, Cortez, and Dolores. The M&SSI demands in the basin are low compared to the agricultural demand, reflecting 3 percent of the total demand in the basin. Refer to the *Baseline and Projected 2050 Planning Scenario Municipal and Self Supplied Industrial Water Demands* technical memorandum for additional discussion on how the M&SSI demands in the basin was developed. The water supply and gap results for M&SSI in the Southwest basin are summarized in Table 33, and graphically reflected in Figure 93 through Figure 95.

[16] Note that water used for hydropower, such as those operations at Cascade Reservoir, Ames Hydro Project, and Nucla Power Diversion, are represented in the model but are not included in the SSI demand summaries (i.e. non-consumptive) and are not adjusted between Planning Scenarios.

Table 33: Southwest Basin M&SSI Water Supply and Gap Summary

	M&SSI Results	Baseline	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand (ac-ft)	27,182	44,760	30,238	43,267	53,968	69,464
	Average Annual Demand Increase from Baseline (ac-ft)	-	17,578	3,056	16,085	26,786	42,282
	Average Annual Gap (ac-ft)	40	3,325	385	4,100	7,770	13,438
	Average Annual Gap Increase from Baseline (ac-ft)	-	3,286	346	4,060	7,730	13,399
	Average Annual Percent Gap	0%	7%	1%	9%	14%	19%
Critically Dry Maximum	Demand In Maximum Gap Year (ac-ft)	27,182	44,760	30,238	43,267	53,968	69,464
	Increase from Baseline Demand (ac-ft)	-	17,578	3,056	16,085	26,786	42,282
	Gap In Maximum Gap Year (ac-ft)	799	7,477	1,820	7,686	13,795	24,811
	Increase from Baseline Gap (ac-ft)	-	6,679	1,022	6,888	12,997	24,013
	Percent Gap In Maximum Gap Year	3%	17%	6%	18%	26%	36%

The M&SSI demand in the basin is projected to increase in all scenarios compared to the Baseline scenario due a projected increase in population by 2050 in the basin. Echoing the population projections, M&SSI demand is projected to increase moderately in the Weak Economy scenario compared to the Baseline demand but increase by nearly 60 percent in the Business as Usual and the Cooperative Growth scenarios and double and more in the Adaptive Innovation and Hot Growth scenarios.

As reflected in the table and graphics below, the M&SSI demand under the Baseline scenario experiences a gap in the critically dry years of 2002 and 2012, which is then reflected as a small gap on average. Ideally this scenario would have no M&SSI gaps because the current water supply should fully satisfy the Baseline level demands. These shortages are due to minor calibration issues potentially stemming from the representation of individual M&SSI demands at a grouped location; not accounting for ground water supplies (i.e. exempt wells); or drought restrictions imposed by the towns in the basin.

The M&SSI gap in the Weak Economy scenario is small, but consistent during average and below-average dry year types; the demand is fully satisfied during above-average wet years. The M&SSI gap for the Business as Usual and the Cooperative Growth scenarios vary based on year type as well, reflecting a 5 percent gap during wet years but significantly more gap during average and dry years. The M&SSI gap for the Adaptive Innovation and Hot Growth show chronic shortages for the entire study period indicating the decreased hydrology is not sufficient to meet the increased demands in even the wettest years.

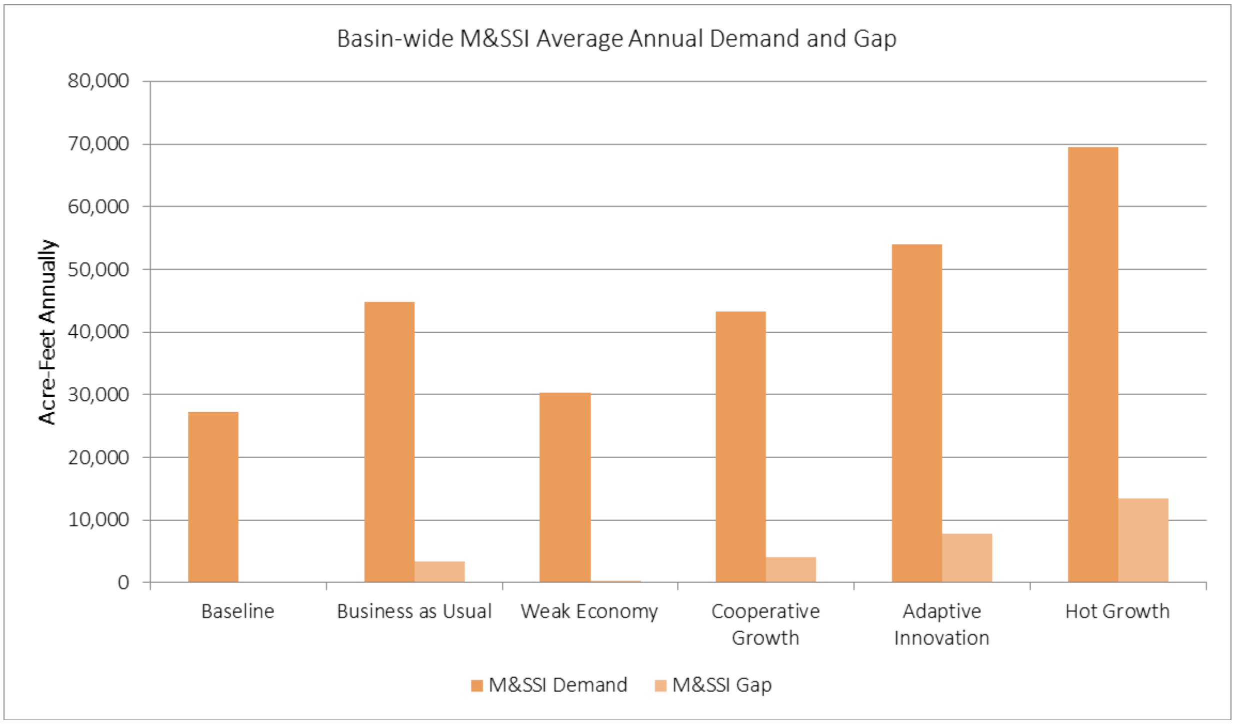


Figure 93: Southwest Basin M&SSI Average Annual Demand and Gap

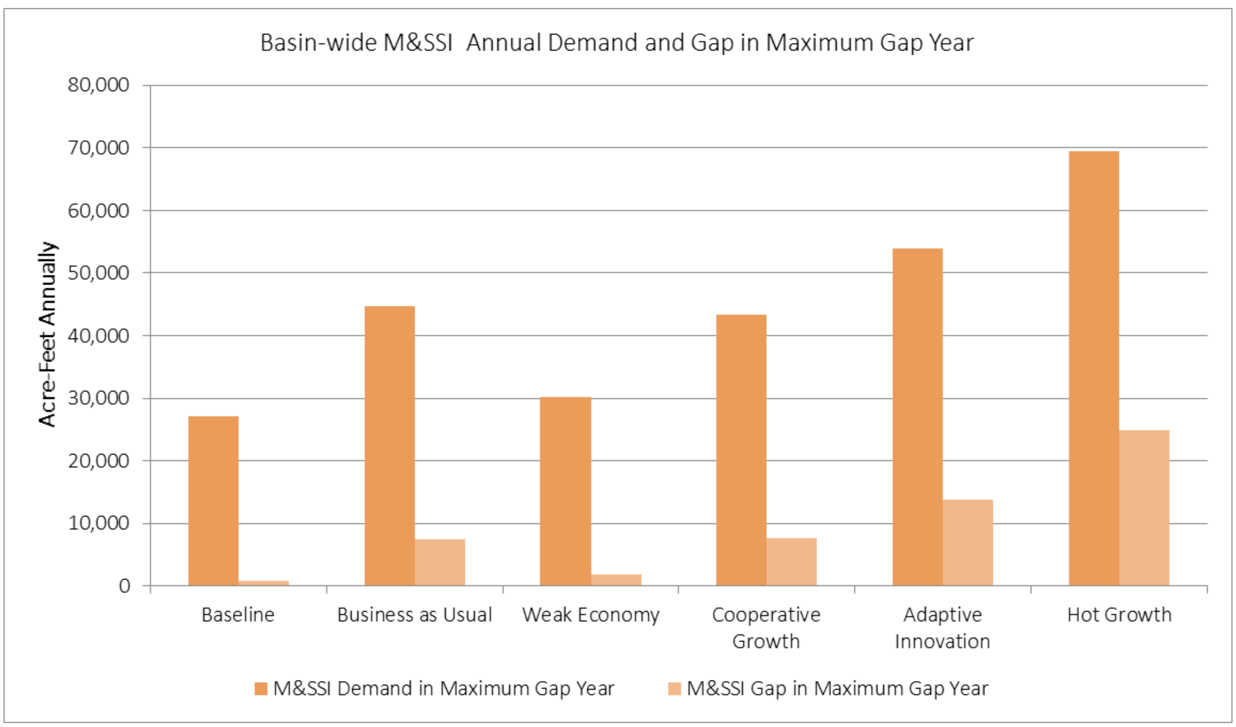


Figure 94: Southwest Basin M&SSI Maximum Annual Demand and Gap in Maximum Gap Year

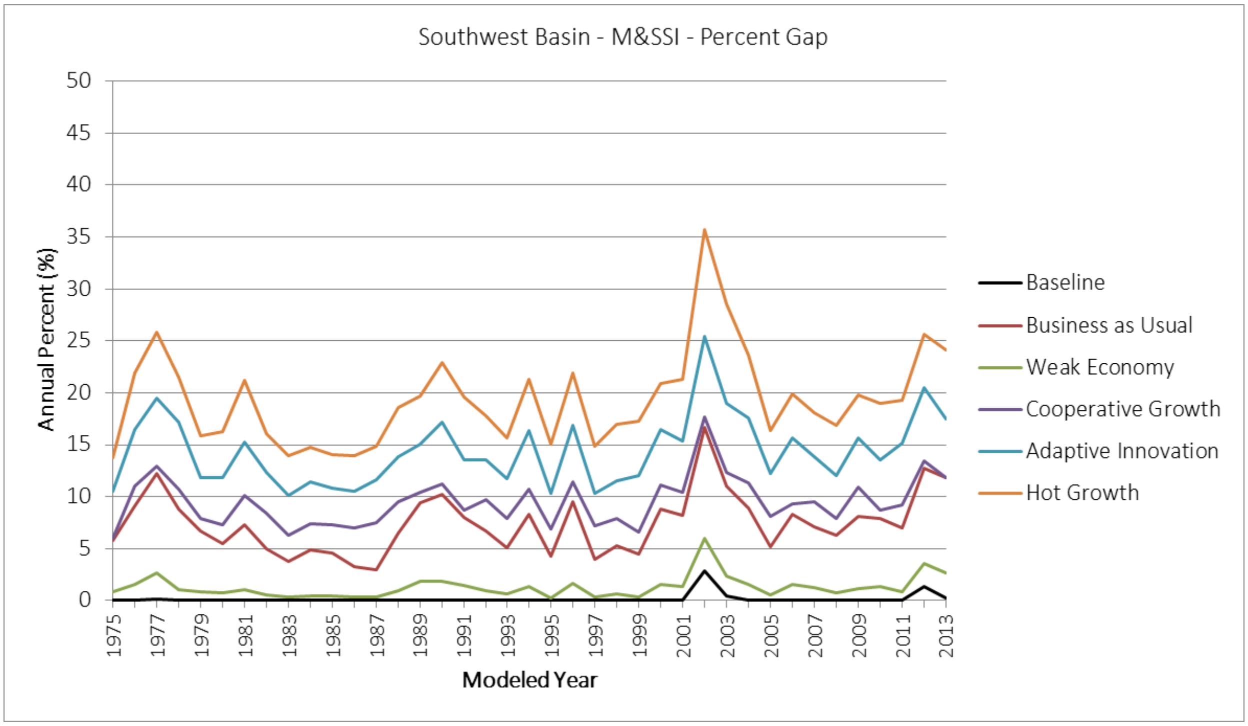


Figure 95: Southwest Basin M&SSI Average Annual Gap Time Series

5.7.3 SOUTHWEST BASIN TRANSBASIN EXPORTS

There are several transbasin diversions that export water from the headwaters of the San Juan, Piedra, Los Pinos, and Animas Rivers to the Gunnison and Rio Grande Basins. Total transbasin exports range from less than 200 ac-ft to nearly 5,800 ac-ft annually, depending on availability of in-basin supplies and the need for imported supplies in the Gunnison River and Rio Grande basins. On average, the transbasin export demand from the Southwest Basin is 2,245 ac-ft. These demands could not be satisfied in all Planning Scenarios; however the shortages are reflected as an import supply gap in the destination basin and not considered a gap in the Southwest Basin.

As noted above, the San Juan Chama Project delivers water from San Juan tributaries to the Rio Grande basin in New Mexico. The Baseline and Planning Scenario models include the current demand and operations, but the project deliveries are not considered a transbasin export under the Technical Update as the project does not operate under a Colorado water right; cannot call out Colorado water users; and the supply is not delivered to a Colorado entity.

5.7.4 SOUTHWEST BASIN SUMMARY

The combined agriculture and M&SSI demands and gap summary is provided in Table 34. The results are very similar to the agricultural results in Table 19, because water supplies in the Southwest Basin are predominantly used for agriculture. As previously discussed, water availability in the basin is widely variable from one sub-basin to the next, and the average basin results may not be indicative of conditions in more water short basins. With that in mind, the M&SSI gaps are relatively low on average in the Baseline, Business as Usual, and Weak Economy scenarios, however, become more substantial in critically dry years. The gaps both on average and during critically dry years become much larger for the Cooperative Growth, Adaptive Innovation, and Hot Growth scenarios, due to the climate-adjusted hydrology, particularly as the Adaptive Innovation demand actually decreases compared to the Baseline demand.

Figure 96 reflects the relative size of the agricultural, M&SSI, and transbasin demands in the Southwest Basin. The M&SSI and transbasin demands are difficult to reflect graphically on the same scale because they are significantly smaller than the agricultural demands. Following the graphic are summaries regarding other considerations that may impact the basin-wide gap, including potential M&SSI supplies from urbanized acreage.

The Colorado River Basin Ten Tribes Partnership Tribal Water Study (TWS), completed in December, 2018, summarizes current tribal water use, projects future development of tribal water under a variety of growth scenarios and timeframes, and identifies tribal challenges and opportunities associated with the development of tribal water. The report indicated both municipal and agricultural growth for the Southern Ute Indian Tribe (SUIT) and the Ute Mountain Ute Tribe (UMUT) under the Current Water Development Trends for the 2040 and 2060 scenarios. The municipal growth projected in the TWS is captured in the M&SSI projections for the La Plata and Montezuma County demands. The agricultural growth from the TWS, however, was not represented in the Technical Update agricultural demands. The Technical Update relied on Basin Implementation Plans (BIP) to identify new irrigation projects. The agricultural growth projections in the TWS were developed after the completion of the Southwest BIP and after the agricultural demands were completed for Technical Update. The State recognizes the Tribes intent to fully develop their reserved water rights in the future, part of which may be used for agriculture. Future Tribal use should be incorporated into future Southwest BIP and subsequent Technical Updates.

Table 34: Southwest Basin Water Supply and Gap Summary

	Agricultural and M&SSI Results	Baseline	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand (ac-ft)	1,051,966	1,050,192	1,035,670	1,263,760	977,068	1,341,135
	Average Annual Gap (ac-ft)	126,682	123,622	120,145	280,833	226,769	368,520
	Average Annual Percent Gap	12%	12%	12%	22%	23%	27%
Critically Dry Max	Demand In Maximum Gap Year (ac-ft)	1,180,140	1,175,860	1,161,338	1,258,452	953,228	1,307,667
	Gap In Maximum Gap Year (ac-ft)	518,355	514,849	506,757	687,185	487,808	762,916
	Percent Gap In Maximum Gap Year	44%	44%	44%	55%	51%	58%

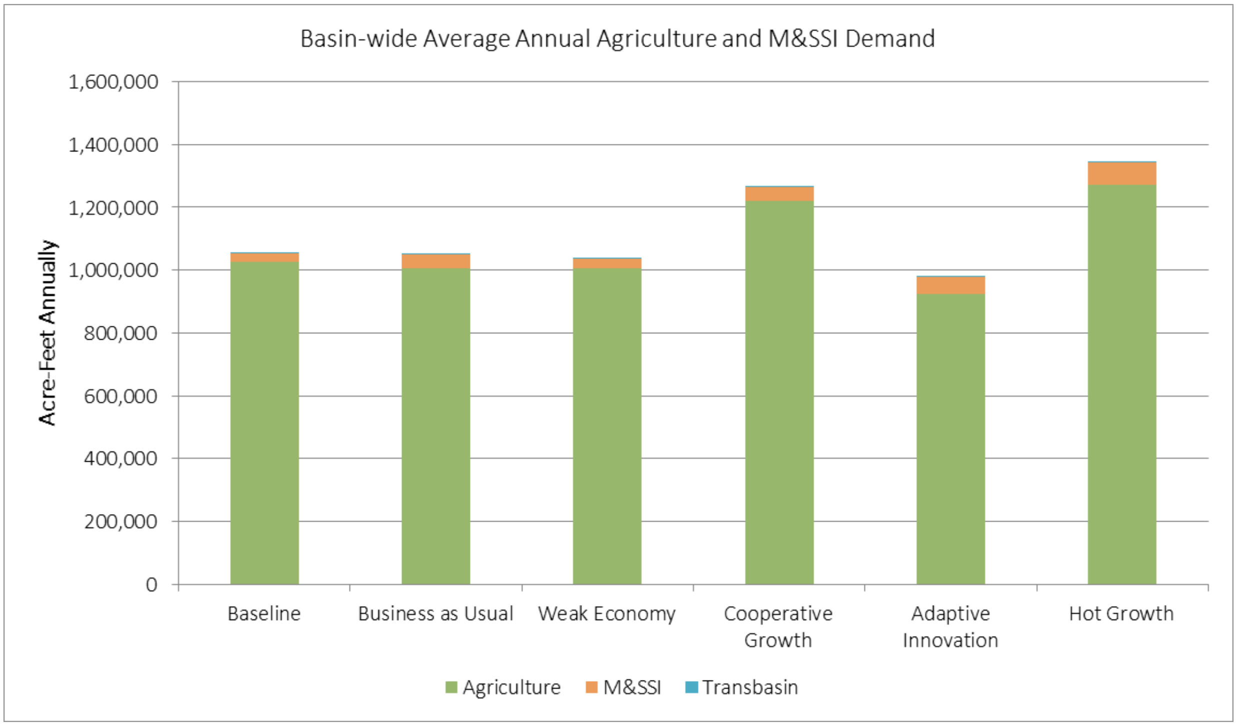


Figure 96: Southwest Basin Comparison of Average Agricultural, M&SSI and Transbasin Annual Demands

All Planning Scenarios project 3,800 acres of irrigated land will be taken out of production due to urbanization, as counties are projected to have municipal growth. Supplies used to irrigate the urbanized acreage could be considered a new municipal supply if the associated water rights were changed to municipal uses. To estimate this new supply, the average consumptive use of the urbanized acreage by Planning Scenario is reflected in Table 35. Note however that it is not known which farms and ranches will be directly impacted; whether the acreage was served by senior/junior/Tribal rights or had supplemental storage supplies; or the crop type or specific irrigation practices on this acreage. Additionally, it is unknown if the water rights would be changed to municipal use or whether the supply could directly meet the future municipal demand or are located in a different sub-basin compared to the demand. In light of these uncertainties, the table reflects a planning-level estimate of this potential new supply. Although it has not been applied to the M&SSI gap presented above, it would likely have the effect of decreasing the gap.

Table 35: Potential Water Supply from Urbanized Acreage in the Southwest Basin

Urbanized Acreage Results	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Urbanized Acreage	3,800	3,800	3,800	3,800	3,800
Estimated Consumptive Use (ac-ft/year)	6,917	6,923	7,130	6,769	6,784

The Southwest Basin has approximately 700,000 ac-ft of total storage[17] used primarily to meet agricultural and M&SSI demands. Reservoirs represented individually in the model are listed below by sub-basin; the simulated contents of these reservoirs are reflected in Figure 97.

- San Miguel River basin: Gurley Reservoir, Miramonte Reservoir, Trout Lake, Lilylands Reservoir, Lone Cone Reservoir, and Lake Hope
- Dolores River basin: Groundhog Reservoir , McPhee Reservoir , Summit Reservoir, and Narraguinnep Reservoir
- San Juan River basin: Jackson Gulch Reservoir, Cascade Reservoir, Vallecito Reservoir, Lemon Reservoir, Ridges Basin Reservoir, Long Hollow Reservoir

As reflected, approximately 300,000 ac-ft of storage in the basin is not drawn down in any of the Planning Scenarios. This storage volume is largely attributable to inactive storage in the basin (e.g. 151,000 ac-ft in McPhee Reservoir) and the newly constructed Lake Nighthorse. Lake Nighthorse Reservoir, completed in 2012, was constructed to meet the requirements of the 1988 Colorado Ute Indian Water Rights Settlement Act and the Colorado Ute Settlement Act Amendment of 2000 by delivering water to both Colorado Ute Tribes as well as several non-tribal participants. The reservoir will be used to meet M&SSI demands for the Tribes, the City of Durango, and other water providers in Colorado and New Mexico in the future and infrastructure is being constructed to improve the delivery of those supplies. However, these operations are not reflected in the baseline model dataset. It is recommended that future analysis of potential solutions to the meet the gap incorporate Lake Nighthorse Reservoir operations.

The results reflect very little difference between the Baseline, Business as Usual, and the Weak Economy Planning Scenarios and the reservoir content results are overlapping in the graphic below. As the climate-adjusted hydrology decreased runoff volumes and increases agricultural demand in the Cooperative Growth, Adaptive Innovation, and Hot Growth scenarios, the graph reflects more draw-down compared to the Baseline scenario. In addition to more draw-down, the reservoirs in the climate-adjusted scenarios have slightly longer post-drought recovery (e.g. early 1990s) and are not able to fully refill to the same content reached in the non-adjusted scenarios (e.g. late 2000s). As reservoirs are generally able to store water even if the peak runoff is shifted earlier in the year, these decreased reservoir contents are more indicative of the decreased runoff in the climate-adjusted scenarios.

[17] Total storage represents the total reservoir capacity for large operational reservoirs located within Colorado in the Southwest Basin. Therefore, Navajo Reservoir with a 1.7 million ac-ft capacity located primarily in New Mexico is excluded from this summary.

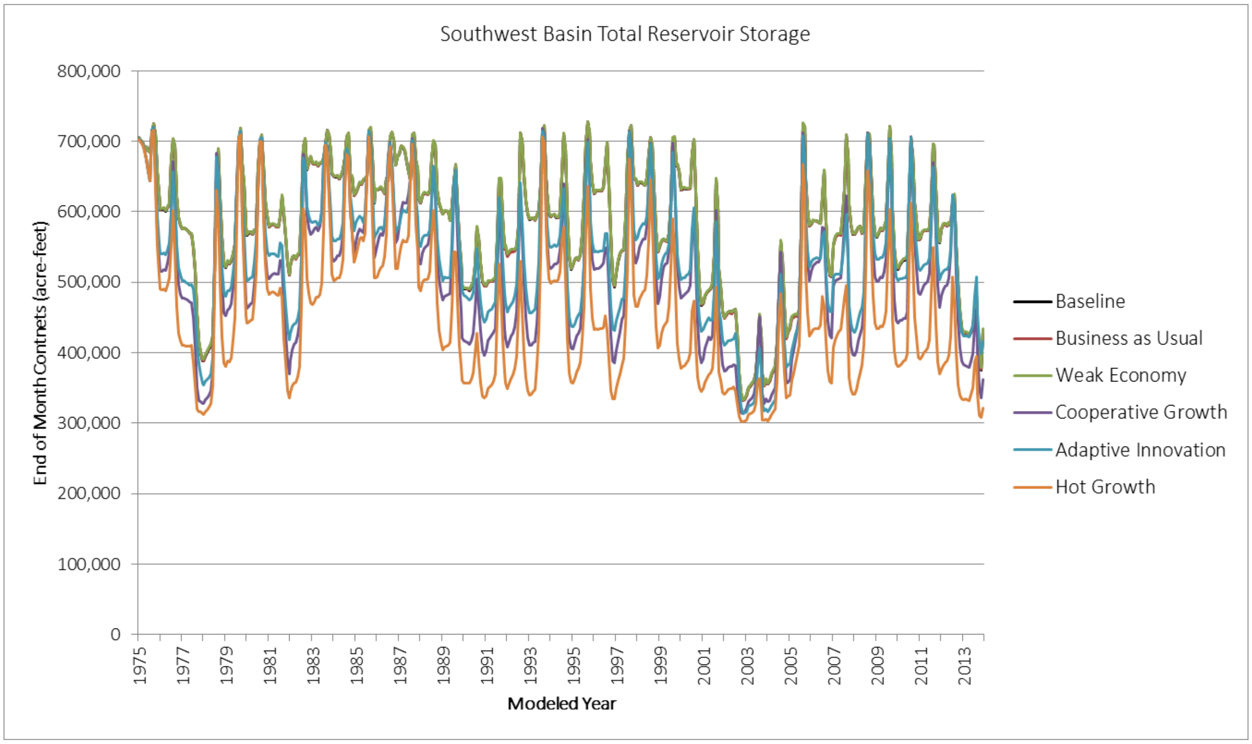


Figure 97: Southwest Basin Total Reservoir Storage

Figure 98 through Figure 105 reflect the simulated streamflow results for each Planning Scenario at key locations reflected on the basin map above. There are no significant differences in streamflow between the Baseline, Business as Usual, and the Weak Economy Planning Scenarios at the key locations, and the results are overlapping on the graphics. This result is expected due to relatively small changes in demands and no change in hydrology for these scenarios.

There are also limited differences between the Adaptive Innovation and Hot Growth scenarios, as the climate-adjusted hydrology is the same in these scenarios and serves as the primary driver on streamflow results in basins with limited changes in demands. The Los Pinos gaged location reflects the largest difference between these two scenarios, likely due to increased agricultural demands in the Pine River Irrigation District and storage operations of Vallecito Reservoir, which is an on-channel reservoir located in the headwaters of the tributary. The Cooperative Growth scenario results tend to track with the other climate-adjusted scenario results with slightly higher streamflow volumes. All the climate-adjusted scenarios reflect a substantial shift in the peak runoff, from June to May, at all locations except the Dolores River and Piedra River gages.

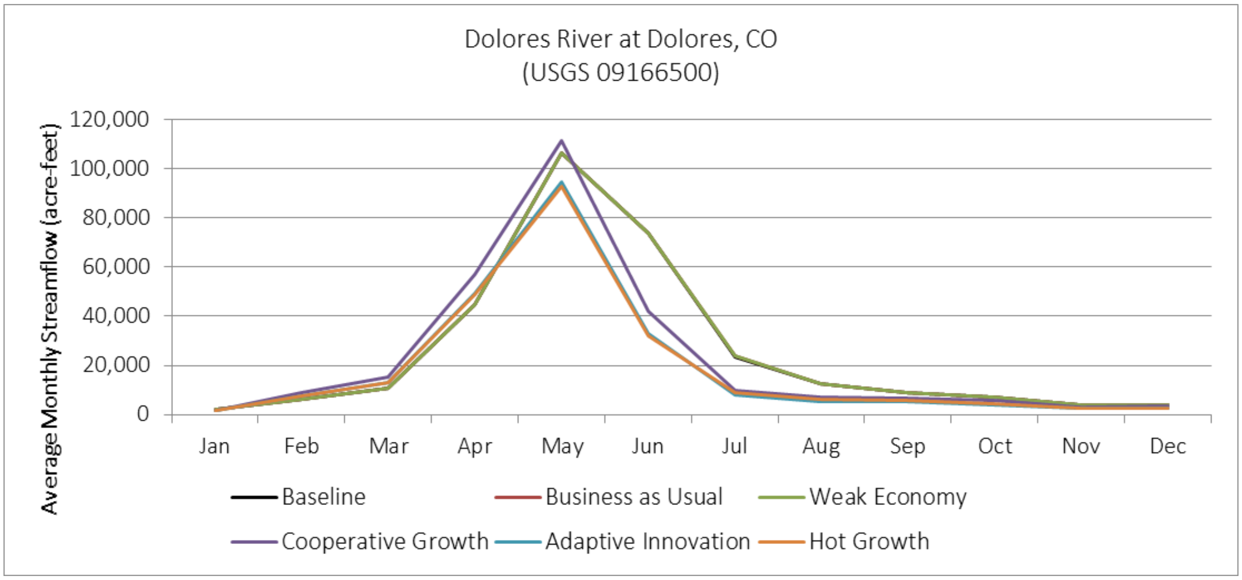


Figure 98: Average Monthly Streamflow at Dolores River at Dolores

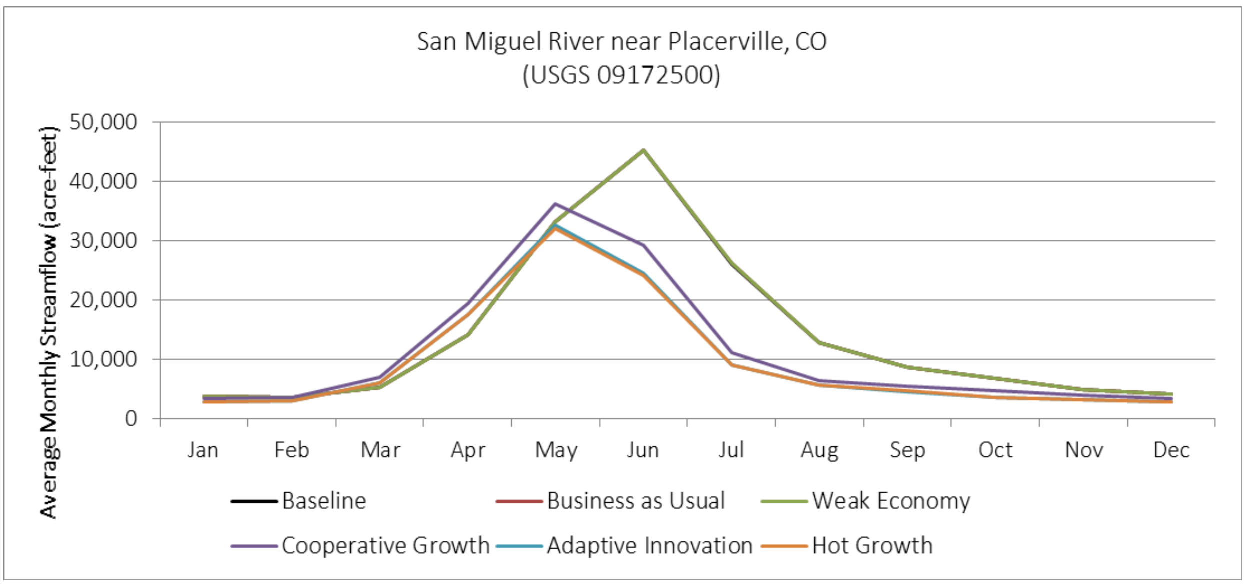


Figure 99: Average Monthly Streamflow at San Miguel River near Placerville

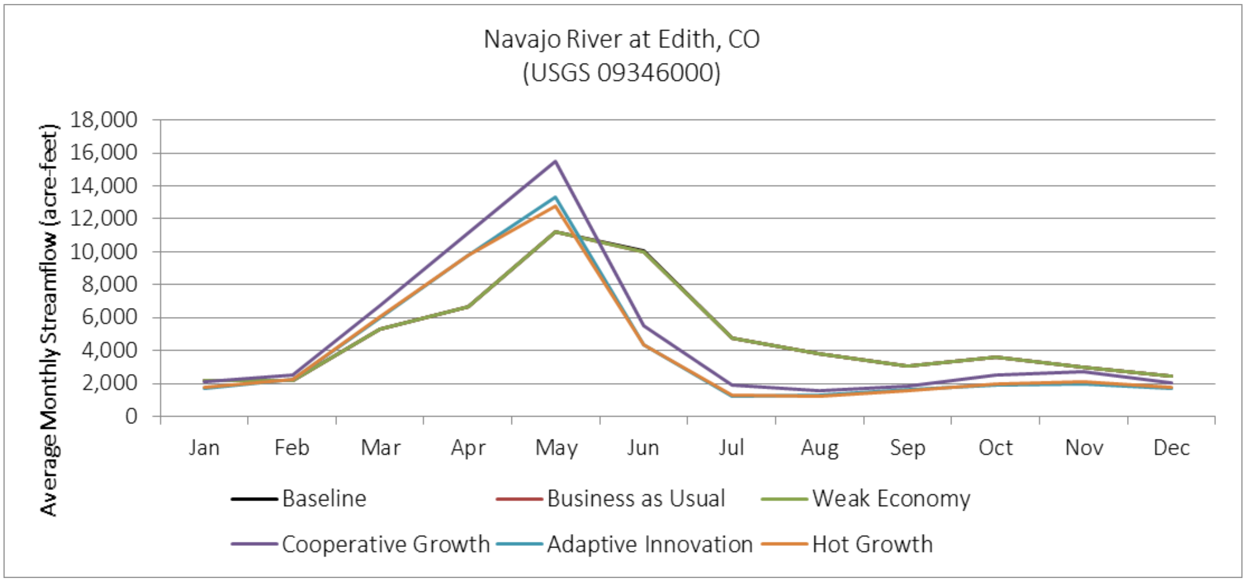


Figure 100: Average Monthly Streamflow at Navajo River at Edith

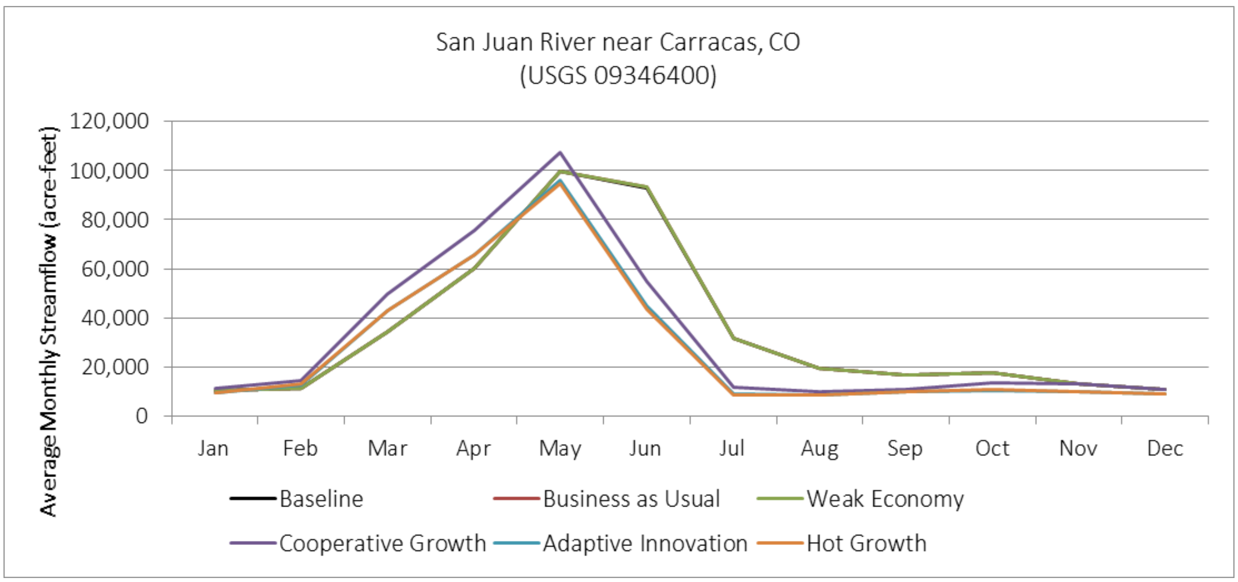


Figure 101: Average Monthly Streamflow at San Juan River near Carracas

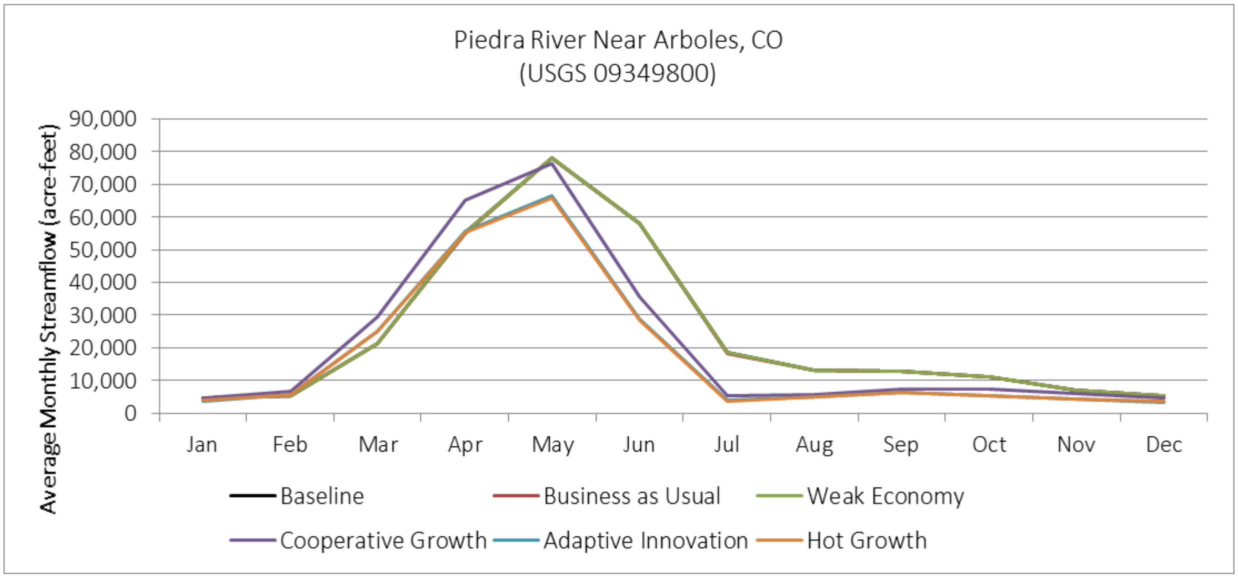


Figure 102: Average Monthly Streamflow at Piedra River Near Arboles

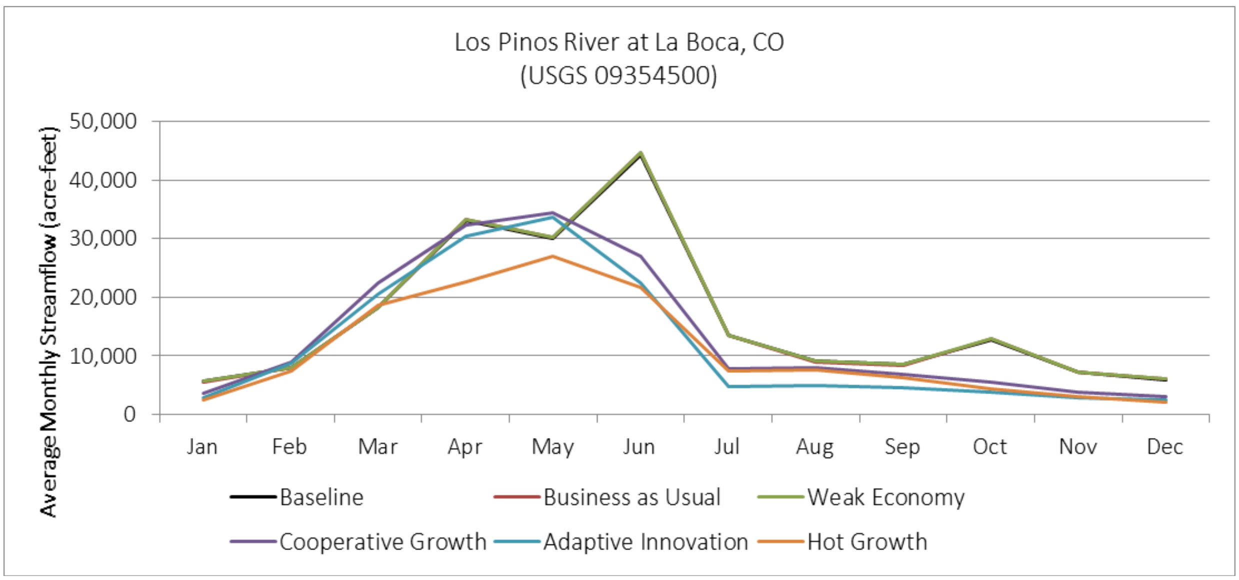


Figure 103: Average Monthly Streamflow at Los Pinos River at La Boca

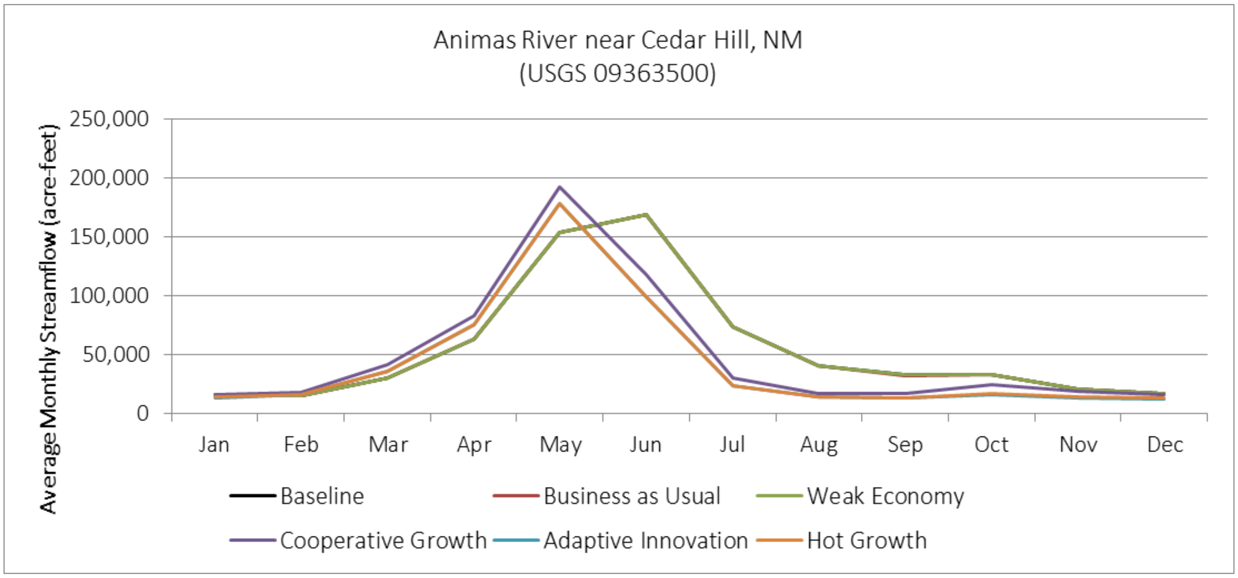


Figure 104: Average Monthly Streamflow at Animas River near Cedar Hill

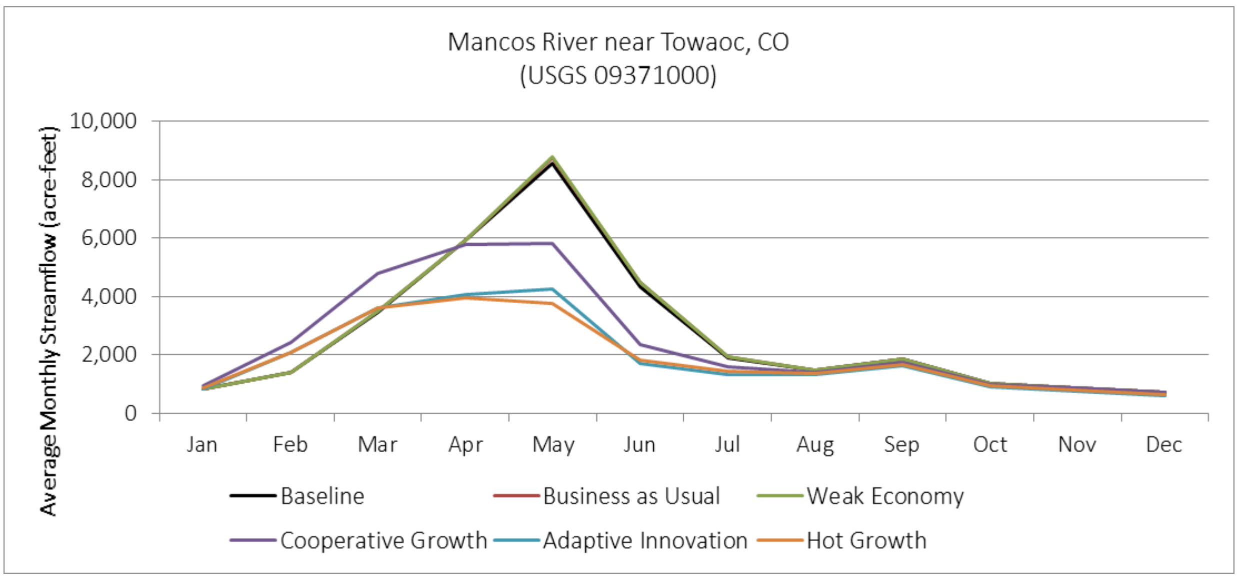


Figure 105: Average Monthly Streamflow at Mancos River near Towaoc

Figure 106 through Figure 109 reflect simulated unappropriated available supply for the Southwest Basin at two locations to illustrate the difference in hydrology and water availability across the multiple sub-basins. The Animas River at Durango gage is located just upstream of the Durango Boating Park, which is a recreational instream flow water right and demand of 1,400 cfs. Available flow greatly increases downstream of the Boating Park reach. Conversely, the La Plata River produces very little runoff and demands on the river chronically experience shortages due to physical flow limitations and curtailment due to the La Plata Compact. At both of the locations, unappropriated available supply are projected to diminish and peak flows are projected to occur earlier in the runoff season under climate-adjusted Planning Scenarios. Unappropriated available supply is limited or essentially zero during the winter months and during critically dry years at both locations.

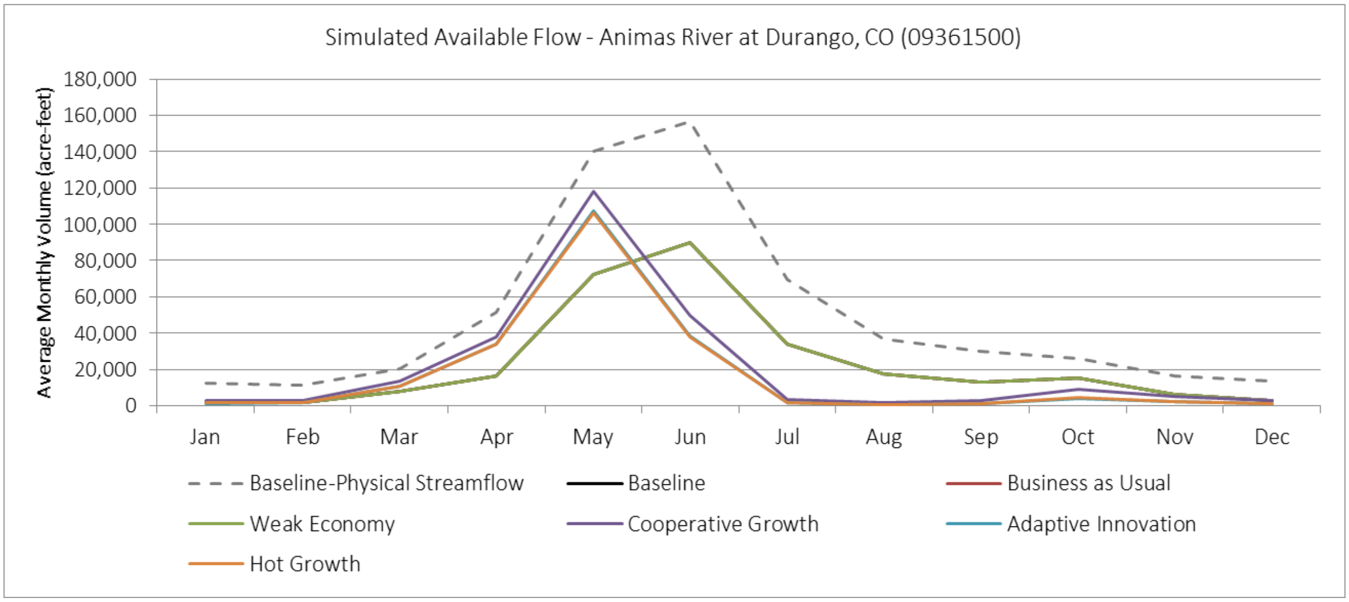


Figure 106: Average Monthly Unappropriated Available Supply at Animas River at Durango

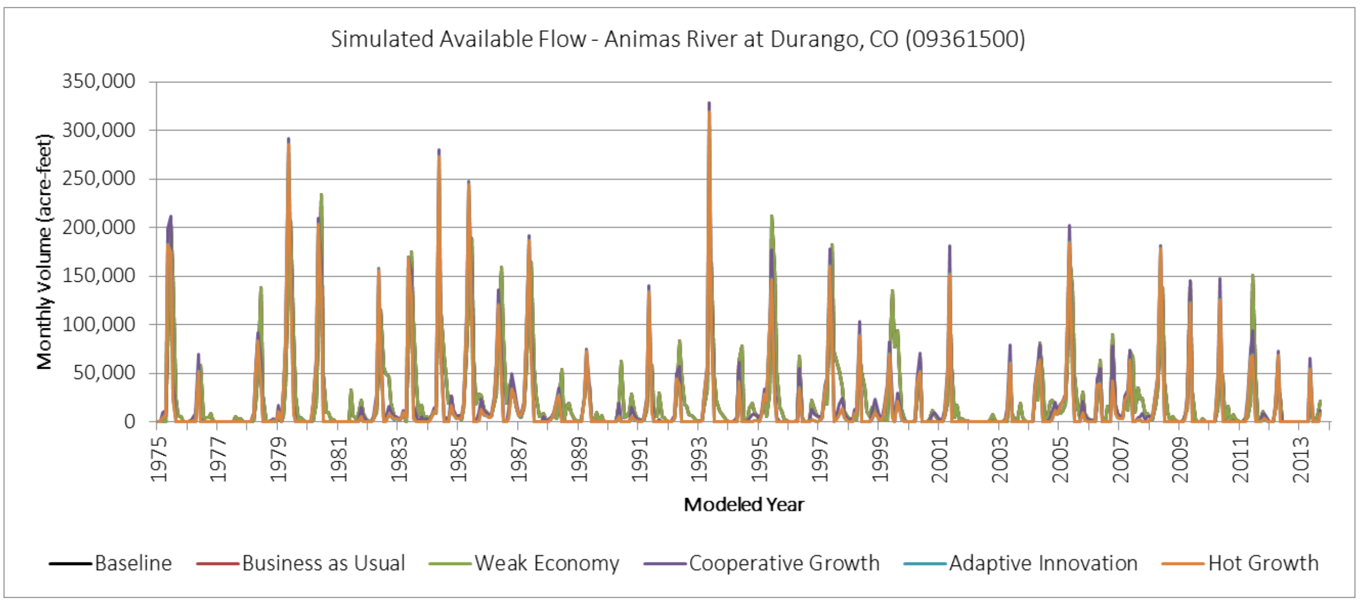


Figure 107: Monthly Unappropriated Available Supply at Animas River at Durango

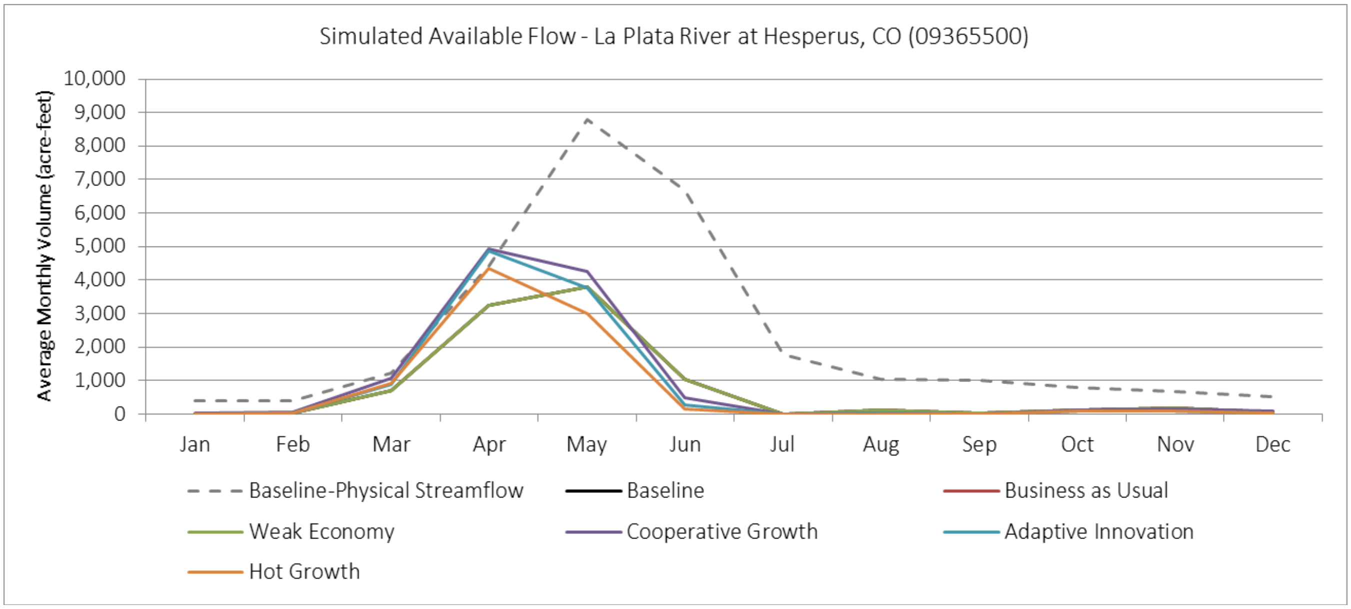


Figure 108: Average Monthly Unappropriated Available Supply at La Plata River at Hesperus

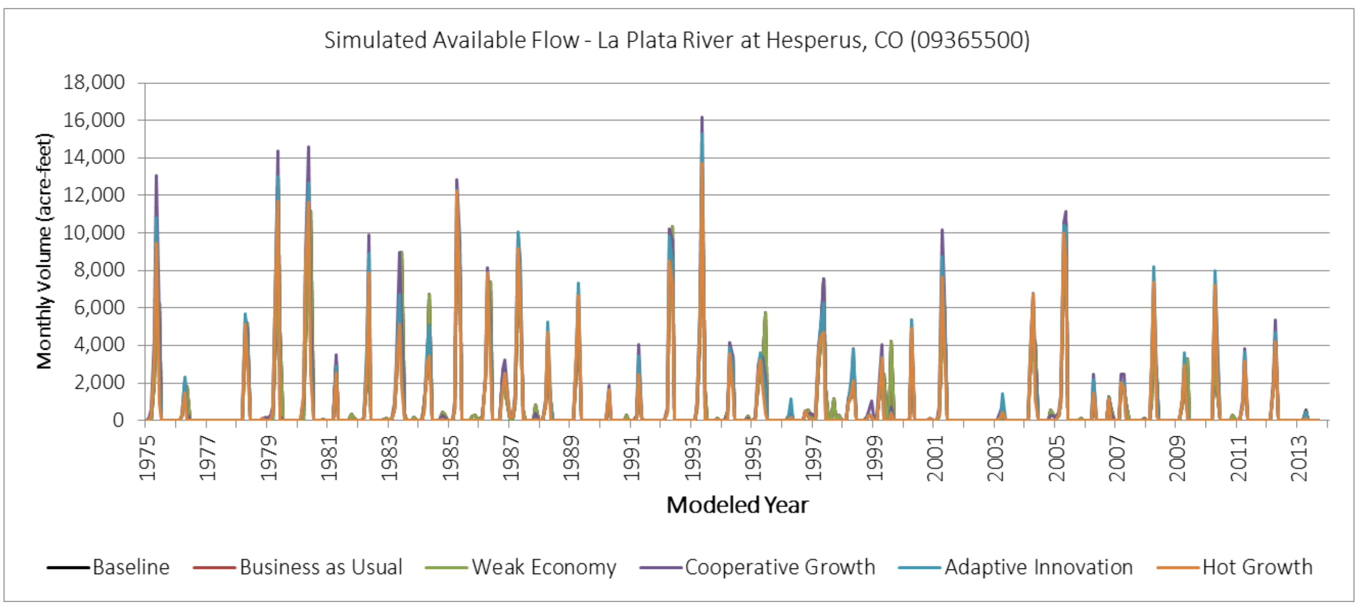
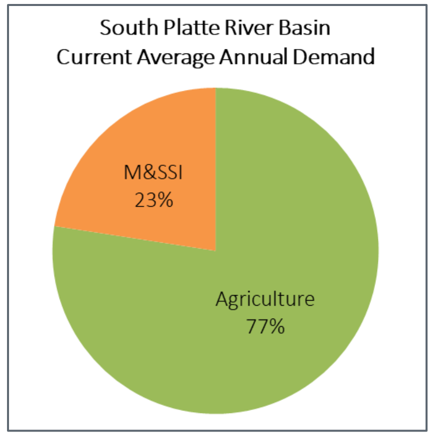


Figure 109: Monthly Unappropriated Available Supply at La Plata River at Hesperus

5.8 SOUTH PLATTE RIVER BASIN

The South Platte River basin is home to the vast majority of Colorado's population and has more irrigated acreage than any other basin. The South Platte River starts in the high mountain meadows of South Park, fueled by snowmelt. The river flows out of the mountains and heads north as it runs through the Front Range metropolitan corridor. Along the way, it is fed by several large tributaries, including Clear Creek, Boulder Creek, St. Vrain Creek, Big Thompson River, and Cache La Poudre River. The South Platte River then turns east and crosses the plains before leaving the northeast corner of Colorado to Nebraska. The natural hydrology of the river is highly variable, and the growing demands in the basin turned to transbasin supplies and ground water resources to supplement supplies from the river.



Over three-quarters of the total demand in the South Platte River is associated with irrigated agriculture, with the remaining quarter of demand tied to M&SSI uses. There are over 850,000 acres of irrigated land in the basin, located both in the tributary sub-basins and along the mainstem, primarily downstream of the Denver metropolitan area. Irrigators along the tributaries rely on surface water supplies and reservoir storage to meet agricultural demand, with limited ground water supplies. Acreage lower in the basin is served by surface water supplies, several large agricultural reservoirs, and supplemental ground water supplies. Agricultural and, recently to a larger extent, M&SSI users along the Big Thompson River, Cache La Poudre River, St. Vrain Creek, Boulder Creek, and South Platte River mainstem also benefit from transbasin supplies from the Colorado-Big Thompson (C-BT) Project.

Several major municipal areas are located in the South Platte River Basin, with the largest being the City of Denver and the surrounding metropolitan area. Other larger municipalities along the Front Range corridor include Boulder, Loveland, Longmont, Fort Collins, and Greeley. The basin is projected to have the largest M&SSI growth in the State, with a majority of this growth projected within this I-25 corridor. M&SSI water providers in the basin rely on surface and ground water supplies, several municipal reservoirs, and are supplemented with transbasin supplies.

Similar to the Arkansas, Republican, and Rio Grande Basins, ground water supplies are an important source of supply in the South Platte River basin. Relatively shallow wells pump ground water supplies from the alluvial aquifer, largely along the mainstem of the lower South Platte River. Alluvial supplies are generally pumped under junior water rights and depletions must be augmented to avoid injuring the senior water right holders. Maintaining sufficient augmentation supplies in the future will be critical for continued use of alluvial ground water. Deeper wells higher up in the basin pump water from the Denver Basin aquifer system, a series of stacked aquifer layers that are largely disconnected from the overlying river system. This disconnection means that the pumped supplies do not have to be augmented to the same degree as alluvial supplies, but also means that recharge of the aquifer is limited and depletions have exceeded recharge rates.

The following sections describe the agricultural and M&SSI demands in the South Platte River basin in more detail. Figure 110 reflects the basin outline, the administrative boundaries of water districts, and the streamflow gages highlighted in the results section below.

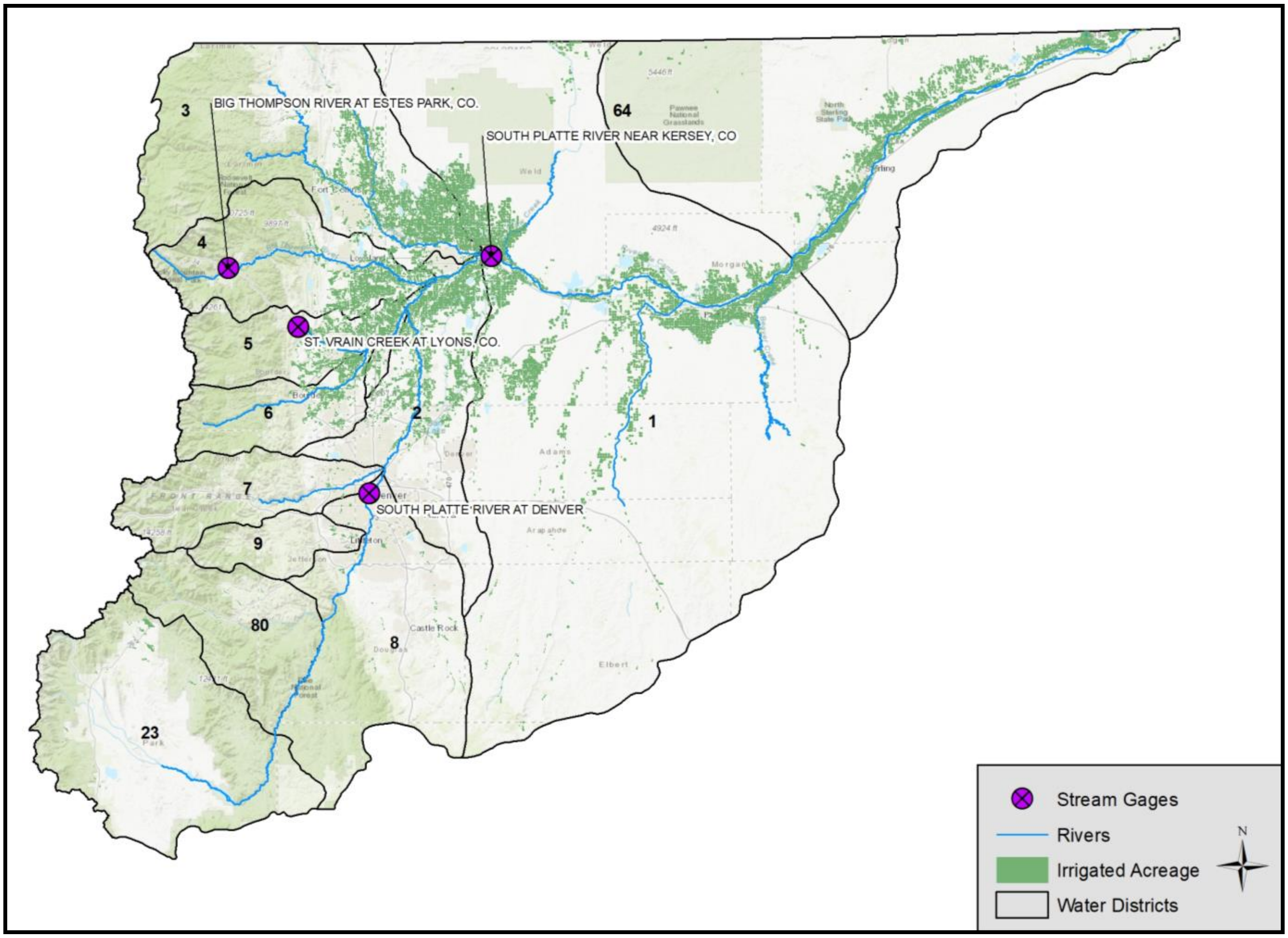


Figure 110: South Platte River Map with Streamgage Locations

5.8.1 SOUTH PLATTE RIVER BASIN AGRICULTURE WATER SUPPLY AND GAP

Irrigated agriculture varies across the basin. High elevation ranches grow hay and alfalfa to support cattle operations. Lower in the basin, agriculture benefits from warmer temperature and a longer growing season and crops include corn, beans, vegetables, potatoes, sugar beet, and various grains. Irrigated agriculture benefits from the most senior water rights in the basin, however native South Platte River supplies are often not sufficient to meet the crop demand for the full irrigation season. As such, surface water supplies are supplemented by releases from reservoirs, ground water supplies, and transbasin supplies.

Irrigated acreage in the basin steadily increased between the 1950s to the 1980s, driven by the development of supplemental transbasin and ground water supplies, reaching over 1 million acres. Irrigated acreage in the basin then began to decline, due in part to the transfer of agricultural water rights over to municipalities (i.e. “buy and dry”). The drought of the mid-2000s resulted in another decline in irrigated acreage as augmentation supplies were not sufficient to cover well depletions and acreage served solely by ground water were taken out of production. Current levels of irrigation are near 850,000 acres, although this projected to substantially decline by 2050.

The South Platte River Basin agricultural diversion demands, demand gaps, and consumptive use gaps results for the baseline and Technical Update Planning Scenarios are presented in Table 36. As discussed in the *Current and 2050 Planning Scenario Agricultural Diversion Demand* technical memorandum, 2050 agricultural diversion demands are influenced by a number of drivers, including climate, urbanization, planned agricultural projects, and emerging technologies.

Table 36: South Platte River Basin Agricultural Water Supply and Gap Summary

	Agricultural Results	Baseline	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand (ac-ft)	2,465,767	1,988,661	1,988,661	2,157,439	1,696,494	2,063,094
Average	Average Annual Demand Increase from Baseline (ac-ft)	-	-	-	-	-	-
Average	Average Annual Gap (ac-ft)	506,724	404,936	402,121	402,055	378,256	444,016
Average	Average Annual Gap Increase from Baseline (ac-ft)	-	-	-	-	-	-
Average	Average Annual Percent Gap	21%	20%	20%	19%	22%	22%
Average	Average Annual CU Gap (ac-ft)	277,969	220,376	218,718	220,309	237,796	247,633
Critically Dry Maximum	Demand In Maximum Gap Year (ac-ft)	2,982,292	2,411,177	2,411,177	2,419,670	2,006,209	2,360,925
Critically Dry Maximum	Increase from Baseline Demand (ac-ft)	-	-	-	-	-	-
Critically Dry Maximum	Gap In Maximum Gap Year (ac-ft)	1,206,124	978,381	960,652	901,935	824,750	1,064,020
Critically Dry Maximum	Increase from Baseline Gap (ac-ft)	-	-	-	-	-	-
Critically Dry Maximum	Percent Gap In Maximum Gap Year	40%	41%	40%	37%	41%	45%

The average annual agricultural demand decreases approximately 477,000 ac-ft from the Baseline to the Business as Usual and Weak Economy Planning Scenarios. Both Planning Scenarios assume 148,400 acres of irrigated land is taken out of production due to urbanization basin-wide and “buy and dry” practices in the Lower South Platte. Additionally, 20 percent or 4,800 acres of ground water irrigated acreage is projected to be taken out of production because of lack of augmentation supplies. This is a total reduction of 153,200 acres. Total agricultural demand also declines due to projected sprinkler development in the basin. The agricultural gaps on average are substantial, estimated to be 400,000 ac-ft, and are projected to more than double during critically dry years. Note however, that despite the decline in agricultural demand, the percent gap in these two scenarios is similar to Baseline conditions, indicating the remaining irrigated acreage projected gap levels are consistent with currently experienced shortages.

The Cooperative Growth scenario is projected to have the largest agricultural demand compared to all Planning Scenarios, however it is still substantially less than the Baseline demand. The Cooperative Growth scenario assumes a total of 127,100 acres of irrigated land is taken out of production due to urbanization and projected “buy and dry” trends, with an additional 4,800 acres removed because of lack of augmentation supplies. This scenario also projects sprinkler development, further reducing the agricultural demand. Adjustments to IWR under the In-Between climate conditions, however, increase the crop demand of the remaining acreage, moderately increasing the agricultural demand in the scenario. The average annual gap volume is about the same as the previous scenarios. Adjustments to hydrology under the In-Between climate conditions do not generally result in lower annual streamflow volumes. Rather, the average annual streamflow at many locations is projected to slightly increase compared to current hydrology. The pattern of streamflow throughout the year shifts at some locations, however agricultural and M&SSI storage in the basin largely mitigates the effect of this shift in timing.

The Adaptive Innovation scenario is projected to have the lowest agricultural demand. The projected reduction to irrigated acreage is the same as that projected in the Cooperative Growth scenario. The emerging technology factors in this scenario substantially reduce the agricultural demand by partially mitigating the effects of the Hot and Dry climate conditions on crop demand and improving irrigation system efficiency. The projected agricultural demand in the scenario is nearly 1,700,000 ac-ft annually, or approximately 770,000 ac-ft less than the Baseline demand. Volumetrically, the agricultural gap in the Adaptive Innovation scenario is less than all other scenarios. The percent gap, however, is similar to the percent gap projected for other basins, indicating that despite the lower demand, irrigated acreage is still projected to experience similar patterns of shortages (e.g. late irrigation season shortages, larger gaps during dry years) largely due to the reduced hydrology under the Hot and Dry climate conditions.

The Hot Growth scenario is projected to have the greatest amount of irrigated acreage removed due to urbanization and “buy and dry” trends, resulting in an agriculture demand of approximately 2.06 million ac-ft annually. Similar to other Planning Scenarios, this scenario projects 105,900 acres will be removed from production due to urbanization and 4,800 acres of ground water irrigated acreage will be taken out of production because of lack of augmentation supplies. This scenario also projects 63,700 acres served by surface water will be removed due to “buy and dry” trends in the Lower South Platte, bringing the total reduction in the basin to 174,400 acres. This reduction, along with sprinkler development in the Lower South Platte River basin, offsets the increase in demand due to the climate adjustment to IWR under the Hot and Dry conditions. Streamflow is projected to decline under the Hot and Dry hydrology, resulting in the largest gaps on average, and gaps in critically dry years that exceed 1 million ac-ft. Despite the significant reduction to demand, the gaps are nearing those currently experienced by producers in the basin.

The average gap and gap during critically dry years relative to the demand is reflected in Figure 111 and Figure 112. The Planning Scenario results, both demand and gap values, do not substantially differ across the Planning Scenarios, largely due to the substantial reductions to irrigated acreage across all scenarios. Figure 113 reflects the percent of basin-wide agricultural gap across a variety of wet, average, and dry year types. As reflected, the drought beginning in the early 2000s produces the largest percent gaps in all scenarios. The separation of results following the peak in 2002 is largely due to hydrological conditions; slightly increased hydrology in the Cooperative Growth scenario leads to a smaller gap, particularly compared to the climate-adjusted Adaptive Innovation and Hot Growth scenarios. Gap results are also impacted by the availability of supplemental storage, ground water, and transbasin supplies, discussed in more detail Section 5.8.3. The largest separation of results across the Planning Scenarios is experienced by the Adaptive Innovation and Hot Growth, which tend to project larger gaps during the average to above-average hydrological year types in the early and late 1990s due to the climate-adjusted hydrology.

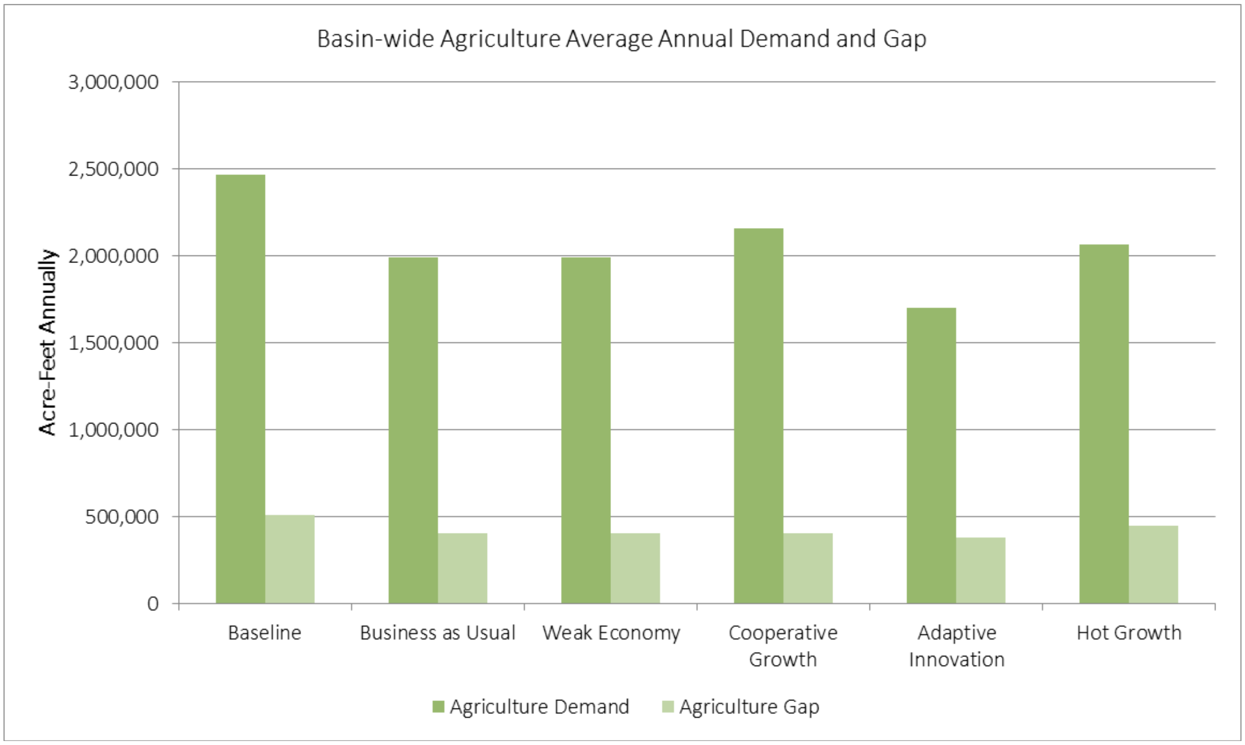


Figure 111: South Platte River Basin Agriculture Average Annual Demand and Gap

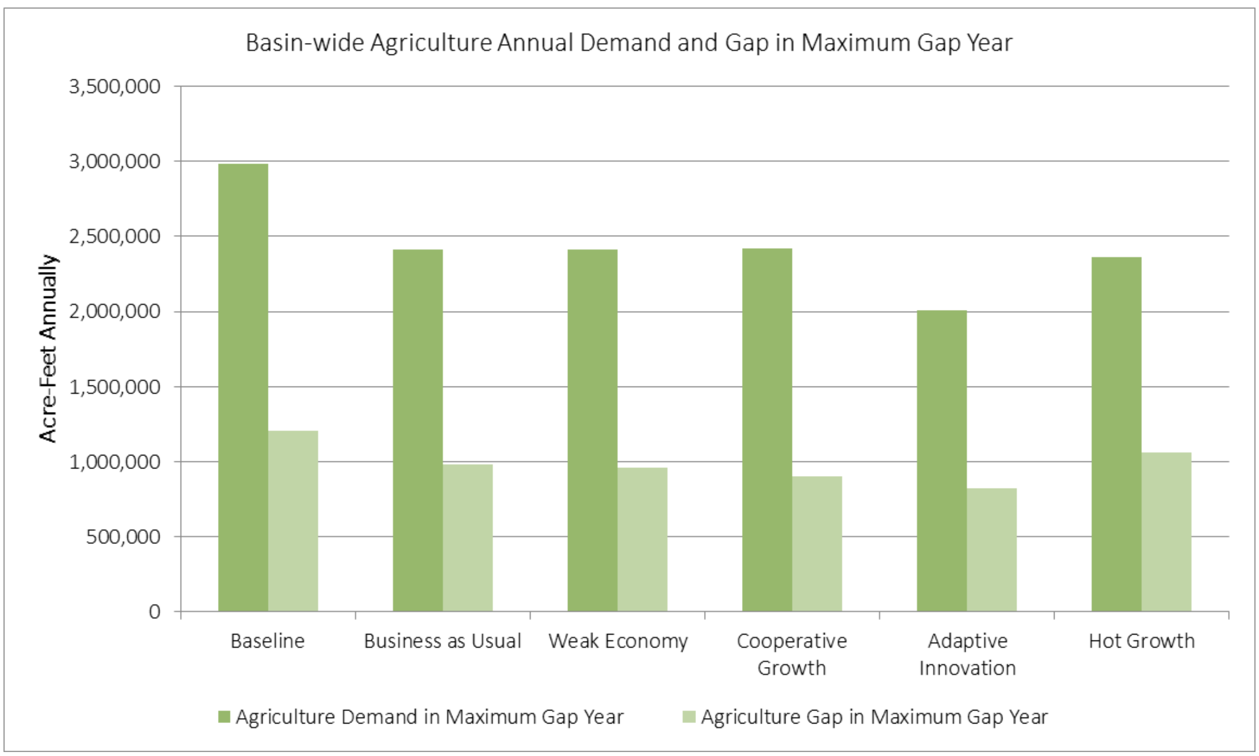


Figure 112: South Platte River Basin Agriculture Annual Demand and Gap in Maximum Gap Year

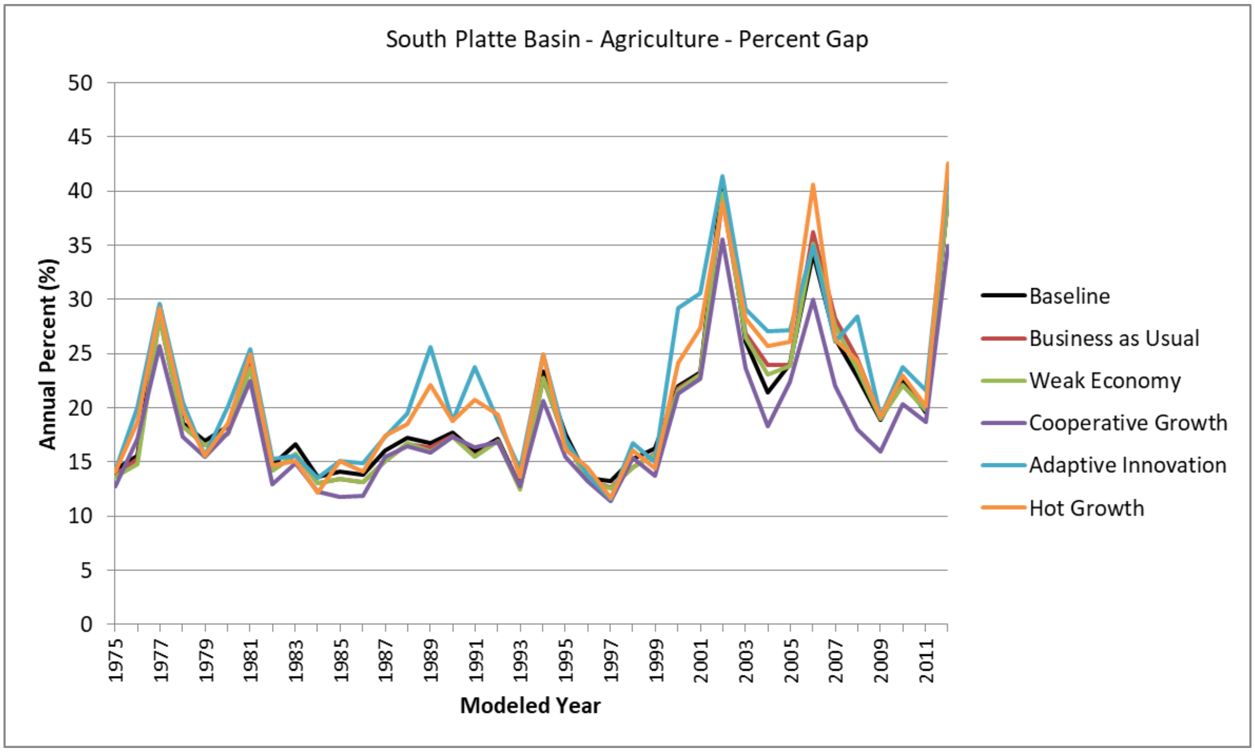


Figure 113: South Platte River Basin Agriculture Percent Diversion Gap Times Series

5.8.2 SOUTH PLATTE RIVER BASIN M&SSI WATER SUPPLY AND GAP

The South Platte River basin currently has the largest M&SSI demand of any basins in the state, representing nearly a quarter of the total demand for water in the basin. Of the total demands, approximately 90 percent can be attributed to municipal demands, with the remaining 10 percent attributable to SSI demands in the basin.

The municipal demands are largest in counties which encompass the larger cities along Front Range corridor, including Adams, Arapahoe, Denver, Jefferson, Larimer, and Weld. Population is projected to substantially increase in all Planning Scenarios, driving an increase in municipal demands by 2050. Of the total municipal demands, approximately 40 percent are represented in the model at grouped locations and the remaining 60 percent is represented in the model using the municipalities' individual demands, water rights, and operations. Entities represented individually in the model include:

- City of Arvada
- Aurora Water
- Denver Water
- City of Englewood
- Town of Estes Park
- Town of Fort Morgan
- City of Golden
- City of Lafayette
- City of Longmont

- City of Loveland
- City of Louisville
- City of Northglenn
- South Adams County Water and Sanitation District Boulder
- Town of Sterling
- City of Thornton
- City of Westminster

The SSI[18] in the basin is predominantly large industry and thermos-electric demands, with smaller demands for snowmaking. Similar to the municipal demands, the SSI demands can be modeled individually or at grouped locations. SSI operations represented individually in the model include:

- Arapahoe Power Plant
- Cherokee Power Plant
- Coors Brewery
- Eldora Ski Resort
- St. Vrain Power Plant
- Loveland Ski Area
- Valmont Power Plant
- Metropolitan Golf Courses

As discussed in the Water Supply Methodology section, the baseline model reflects one representation of the current water rights portfolio, infrastructure, available storage, and operations for the individually represented M&SSI entities. This representation does not capture the full flexibility of the water resources operations available to the entities, and in some cases, may not represent all of the entities' currently owned supplies if they have yet to be developed. The model representation was developed to capture the predominant operations that typically occur during average years. As such, this model may not fully capture operations the M&SSI entities may use during drought years.

Refer to the *Baseline and Projected 2050 Planning Scenario Municipal and Self Supplied Industrial Water Demands* technical memorandum for additional discussion on how the M&SSI demands in the basin were developed. The water supply and gap results for M&SSI in the South Platte River basin are summarized in Table 37, and graphically reflected in Figure 114 through Figure 116.

[18] Note that water used for hydropower, such as those operations for the Colorado-Big Thompson Project, are represented in the model but are not included in the SSI demand summaries (i.e. non-consumptive) and are not adjusted between Planning Scenarios.

Table 37: South Platte M&SSI Water Supply and Gap Summary

	M&SSI Results	Baseline	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand (ac-ft)	718,737	1,073,023	968,879	1,002,775	1,070,141	1,257,699
	Average Annual Demand Increase from Baseline (ac-ft)	-	354,286	250,142	284,038	351,405	538,962
	Average Annual Gap (ac-ft)	1,882	192,812	136,573	159,843	221,361	390,565
	Average Annual Gap Increase from Baseline (ac-ft)	-	190,930	134,692	157,961	219,479	388,683
	Average Annual Percent Gap	0%	18%	14%	16%	21%	31%
Critically Dry Maximum	Demand In Maximum Gap Year (ac-ft)	720,019	1,074,305	970,162	1,004,057	1,070,160	1,257,717
	Increase from Baseline Demand (ac-ft)	-	354,286	250,142	284,038	350,141	537,698
	Gap In Maximum Gap Year (ac-ft)	17,323	256,318	184,473	213,331	333,157	540,743
	Increase from Baseline Gap (ac-ft)	-	238,995	167,150	196,008	315,834	523,420
	Percent Gap In Maximum Gap Year	2%	24%	19%	21%	31%	43%

As reflected in the table, the Baseline scenario reflects a small M&SSI gap. Ideally, the Baseline scenario would have no M&SSI gaps as the current conditions in the basin satisfy the existing M&SSI demands. As these gaps only occur during dry years, the small amount of shortages is likely due to the representation of average year operations that may not account for watering restrictions or other drought operations implemented by municipal entities.

The average annual demand increases from the Baseline scenario to the Business as Usual scenario by approximately 354,000 ac-ft annually, primarily due to the increase in municipal demands driven by substantial population growth. The annual gap is 18 percent on average and increases to 24 percent, or 256,000 ac-ft annually, during critically dry years. This indicates that approximately 70 percent of the total increased M&SSI demand could not be satisfied under drought conditions. There is limited unappropriated flow in the South Platte River basin on average, and generally no unappropriated flow during dry years. As such, it is expected that any increased demands that could not be met under an entities' existing water rights portfolio and operations, would be significantly shorted.

The Weak Economy scenario reflects the smallest increase in M&SSI demand of any Planning Scenario, however the scenario still reflects a 25 percent increase compared to the Baseline demand. The corresponding gaps are also the smallest of any Planning Scenario, but still substantial. Similar to the Business as Usual scenario, more than 50 percent of the increased M&SSI demand is shorted on average and over 70 percent is shorted during critically dry years.

The Cooperative Growth scenario projects an increase to M&SSI demand of approximately 284,000 ac-ft annually, again driven largely by population growth in the basin. The Planning Scenario also reflects the climate-adjusted hydrology under the In-Between conditions. Recall from the agricultural results discussion that the In-Between hydrology increases the average annual streamflow volume in some locations. Therefore, the gaps are more similar to the scenarios using the current hydrology.

The level of M&SSI demand in the Adaptive Innovation scenario is very similar to the Business as Usual scenario. Recall that the agricultural demands are smaller in the Adaptive Innovation scenario, allowing more water available to the M&SSI demands on average. Even with the climate-adjusted hydrology under Hot and Dry conditions, the average annual gap is only slightly larger than the Business as Usual scenario gap. The Adaptive Innovation scenario reflects more a substantial gap during critically dry years, in which 95 percent of the increased M&SSI demand was shorted. This maximum gap is related to the decline in hydrology under the Hot and Dry hydrology.

The Hot Growth has both the largest M&SSI demand and gap compared to any other scenario. M&SSI demand increases by approximately 539,000 ac-ft. The demand is again driven primarily by population growth, but also reflects moderate increases to SSI demands and to the per-capita municipal demand. The streamflow declines under the Hot and Dry conditions, which coupled with the increased demands, leads to a 31 percent gap on average. The gap during critically dry years exceeds 540,000 ac-ft, larger than the increased M&SSI demand projected for the scenario. This indicates that from a basin-wide perspective, all of the projected increased demand as well as a small amount of existing demand may not be satisfied under this scenario in 2050.

As reflected in the Figure 114 and Figure 115, the M&SSI demand in the South Platte River basin is projected to experience substantial gaps under many of the Planning Scenarios, particularly those with climate-adjusted hydrology. There is essentially no unappropriated flow available in the South Platte River during drought years; however, municipal entities' existing water supply portfolios and storage were able to meet a portion of the increased demand during critically dry years. In many areas, these basin-level results cannot be translated to a sub-basin or entity level, as M&SSI water providers are impacted differently throughout the basin. On a percentage basis, municipal water providers with water supplies in Water Districts 4 and 5 are projected to have the lowest average annual gap, whereas providers with water supplies in Water Districts 2 and 7 have the highest average annual gap in the Hot Growth scenario. Systems that depend on ground water supplies are also particularly vulnerable to gaps in the Planning Scenarios due to limited augmentation supplies.

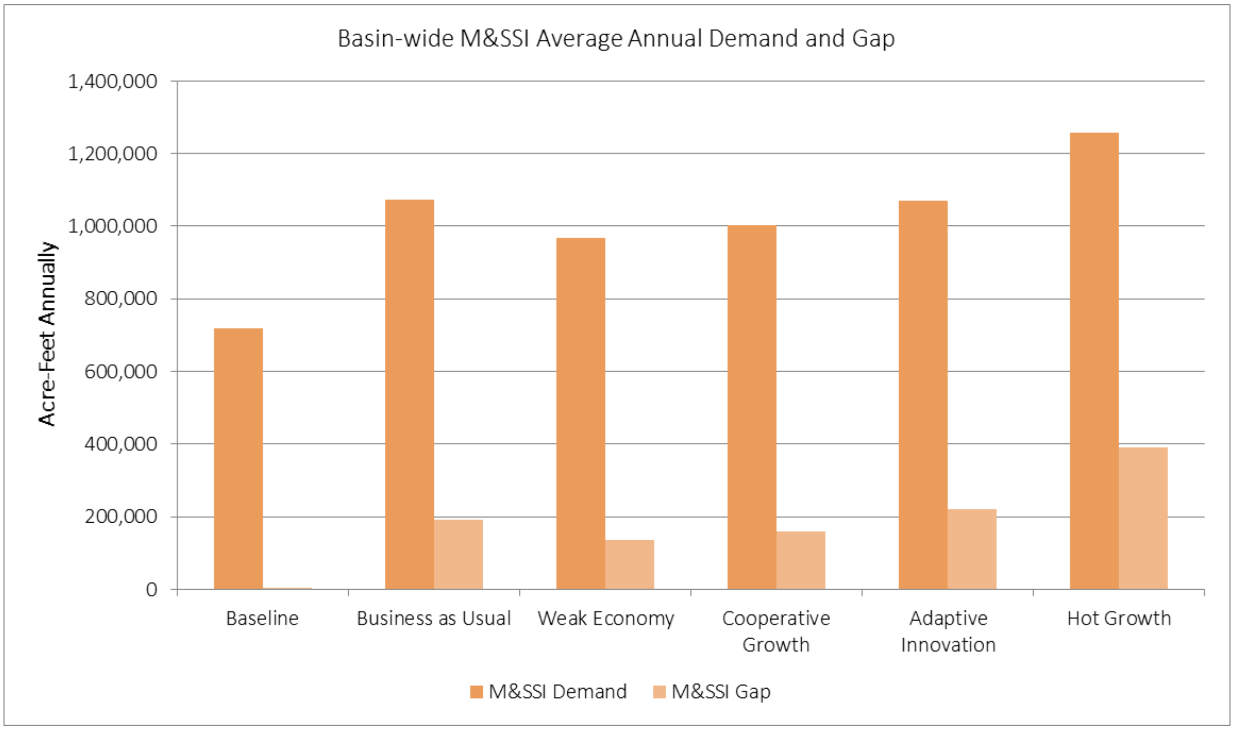


Figure 114: South Platte M&SSI Average Annual Demand and Gap

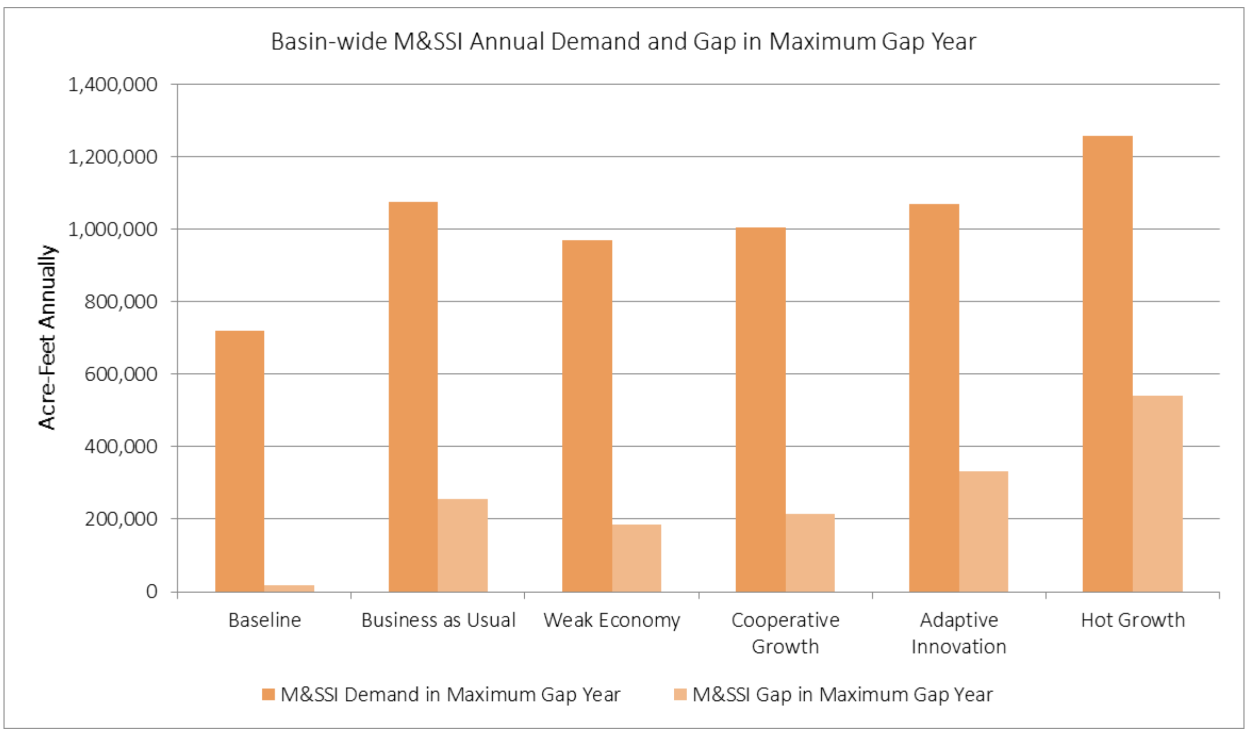


Figure 115: South Platte M&SSI Maximum Annual Demand and Gap in Maximum Gap Year

Figure 116 reflects the average annual percent gap across a variety of wet, average, and dry year types. The percent gap in the Business as Usual, Weak Economy, and Cooperative Growth scenarios generally trend together, reflecting consistent shortages that range between 10 and 20 percent. The graphic reflects a consistent systematic shortage of approximately 20 percent for the Adaptive Innovation scenario, with larger gaps during the dry hydrology years of 1977 and 2002. The Hot Growth scenario, however, reflects more variability than other scenarios depending on year type, with gaps reaching or exceeding 40 percent during dry years. In general, however, the scenarios show less year-to-year variability than other basins. This indicates that a portion of the average annual gap is a systematic shortage to the water supply needs of the M&SSI demands, and not strictly driven by annual variability in hydrology.

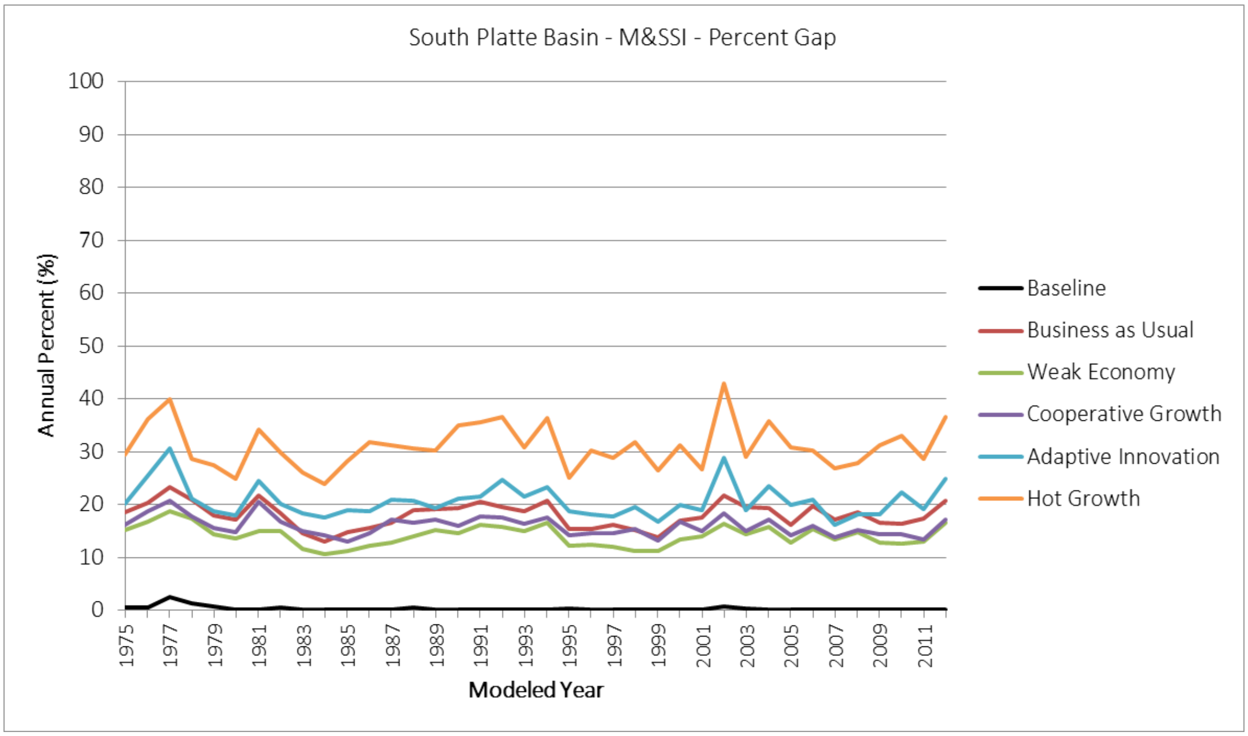


Figure 116: South Platte River Basin M&SSI Average Annual Gap Time Series

5.8.3 SOUTH PLATTE RIVER BASIN SUMMARY

The combined agriculture and M&SSI demands and gaps summary is provided in Table 38. Figure 117 reflects the relative size of the basin-wide average annual demand for the agriculture and M&SSI components, while Figure 118 reflects the relative size of the gaps of each component. The South Platte River Basin differs from the rest of the state in that M&SSI demands are a substantial portion of the total basin demand, and are projected to have gaps on par with agricultural gaps. Following the graphic are summaries regarding other considerations that may impact the basin-wide gap, including potential M&SSI supplies from urbanized acreage or transbasin import supply gaps.

Table 38: South Platte River Basin Water Supply and Gap Summary

	Agricultural and M&SSI Results	Baseline	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand (ac-ft)	3,184,504	3,061,684	2,957,540	3,160,214	2,766,635	3,320,793
	Average Annual Gap (ac-ft)	508,606	597,748	538,694	561,898	599,617	834,581
	Average Annual Percent Gap	16%	20%	18%	18%	22%	25%
Critically Dry Max	Demand In Maximum Gap Year (ac-ft)	3,702,311	3,485,482	3,381,339	3,423,728	3,076,369	3,618,642
	Gap In Maximum Gap Year (ac-ft)	1,223,447	1,234,699	1,145,125	1,115,266	1,157,907	1,604,763
	Percent Gap In Maximum Gap Year	33%	35%	34%	33%	38%	44%

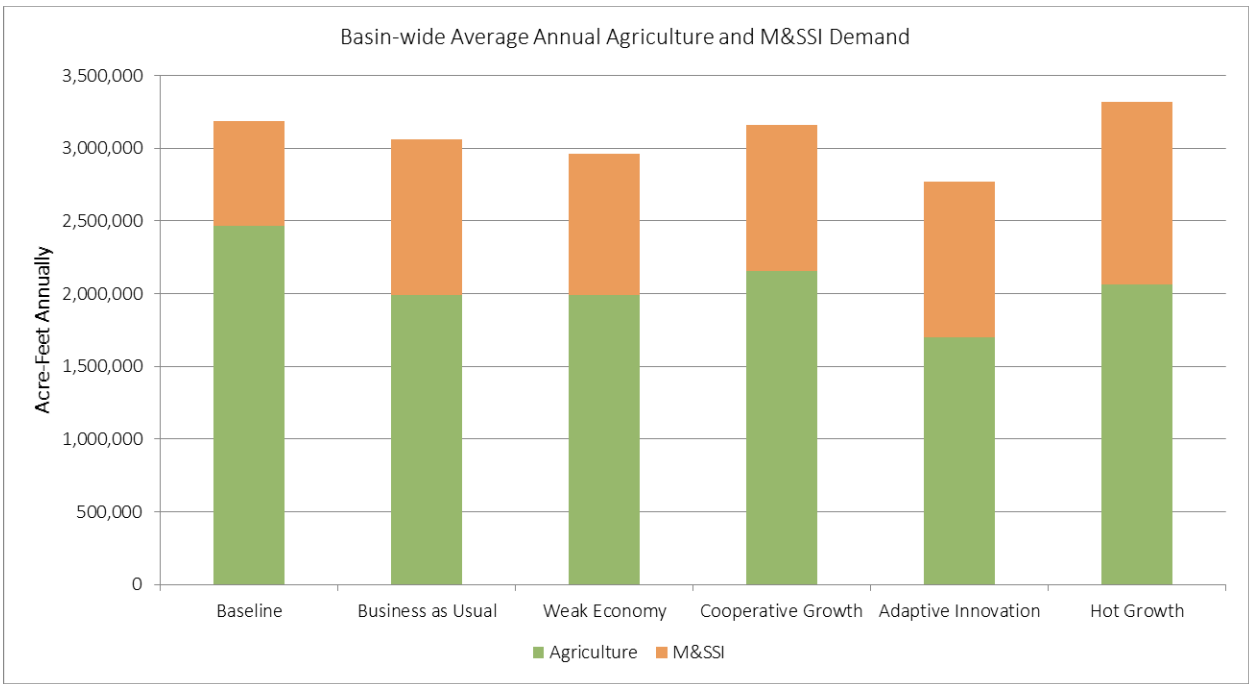


Figure 117: South Platte River Basin Comparison of Average Annual Demands

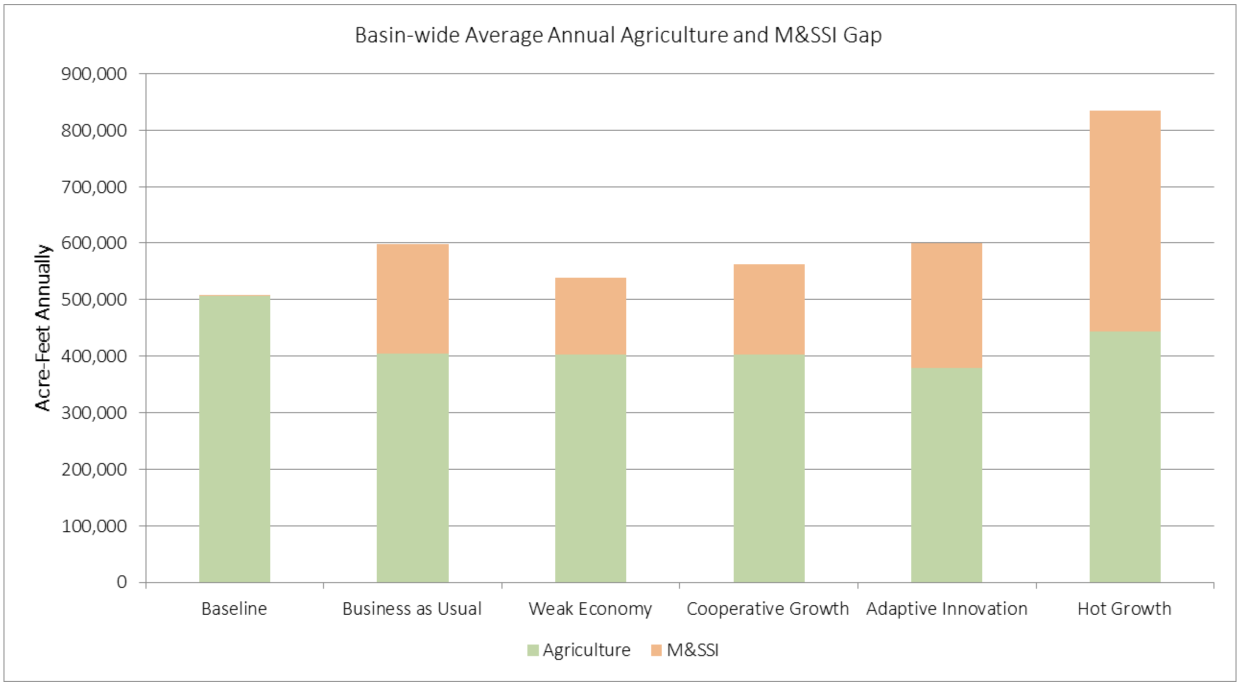


Figure 118: South Platte River Basin Comparison of Average Annual Gaps

The Planning Scenarios project 127,100 to 169,600 acres of irrigated agriculture will be taken out of production due to urbanization or for "buy and dry". Supplies used to irrigate the urbanized acreage could be considered a new municipal or SSI supply if the associated water rights were changed. Note that these acreage values do not include acreage served by ground water removed due to lack of augmentation water, as the junior water supply would likely not provide a reliable new supply.

To estimate this potential new supply, the consumptive use of the urbanized acreage by Planning Scenario is reflected in Table 39. Note however, it is not known which farms and ranches will be directly impacted; whether the acreage was served by senior/junior direct rights or had supplemental ground water or storage supplies; or the crop type or specific irrigation practices on this acreage. Additionally, it is unknown if the water rights would be changed to municipal use, or whether the supply could directly meet the future M&SSI demand or would require exchange potential. In light of these uncertainties, the table reflects a planning-level estimate of this potential new supply. Although it has not been applied to the M&SSI gap presented above, it would likely have the effect of decreasing the gap[19].

[19] Unlike models in other basins, the projected urbanized and buy and dry irrigated acreage in the South Platte River Basin consumes a substantial amount of water. As it was unknown where and how these supplies would be used in the future (i.e. IPP), and the water supply associated with this acreage could not just be left in the river to be diverted by senior users, the irrigated acreage was kept in the South Platte River basin model dataset. The demand and gap results in the basin summaries removed the impact from this acreage, and were instead used for the potential urbanized supply summary. Future BIP modeling efforts will need to address where and how this potential supply may be used in the future.

Table 39: Potential Water Supply from Urbanized Acreage in the South Platte River Basin

Urbanized Acreage Results	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Urbanized Acreage	148,400	148,400	127,100	127,100	169,600
Estimated Consumptive Use (ac-ft/year)	209,754	210,229	179,360	172,709	238,572

As noted above, the South Platte River basin benefits from the delivery of several imported transbasin supplies from the Colorado River and North Platte River basins. These transbasin diversions include:

- Vidler Tunnel diverts water for the City of Golden via Guanella Pass.
- Roberts Tunnel, part of the Blue River Diversion Project, delivers water via Dillon Reservoir to Denver Water's system.
- Boreas Pass Ditch diverts water for the City of Englewood.
- Grand River Ditch delivers water to irrigators along the Cache La Poudre River.
- Berthoud Pass Ditch delivers water to the Cities of Golden and Northglenn.
- Adams Tunnel delivers Colorado-Big Thompson Project water from the collection system in the Colorado River Basin to water users inside the Northern Colorado Water Conservancy District boundaries.
- Moffat Tunnel delivers water to Denver Water's Gross Reservoir.
- The Homestake Project delivers water to both the South Platte River Basin for use by Aurora, and to the Arkansas River Basin for use by Colorado Springs. Only the South Platte deliveries are accounted for in this section.
- The Busk-Ivanhoe Tunnel delivers water to Busk Creek upstream of Turquoise Lake for use by Pueblo Board of Water Works and Aurora Water. Only the portion delivered to Aurora is accounted for in the results below.
- Cameron Pass Ditch diverts water from the North Platte River Basin and supplies irrigators along the Cache La Poudre River.
- Michigan Ditch diverts water from the North Platte River Basin and supplies the City of Fort Collins.

Table 40 summarizes the total transbasin import volumes and associated import gaps. Note that transbasin imports are the same across the scenarios because they are represented in the model at historical levels, and no Planning Scenario adjustments were applied. A gap indicates that the historical import could not be diverted in the source basin due to a physical or legal limitation of water supply at the diverting location. This is caused by changes in water availability, increases in senior demands in the source basin, or a combination of both.

Ideally the import supply gap in the Baseline scenario would be zero; however the Baseline dataset represents current agricultural and M&SSI demands over the entire model period which can result in minor shortages to junior water rights, including transbasin diversions. With this in mind, the incremental increase in the import gap reflects the increase in gap due to the Planning Scenario adjustments.

Under current hydrologic conditions, there is essentially no projected increase in the gap for the Business as Usual and Weak Economy scenarios. The climate-adjusted hydrology in the Cooperative Growth scenario led to a relatively small projected increase in gap on average and during critically dry years. The climate-adjusted hydrology in the Hot Growth scenario, however, projected substantial gaps to transbasin import supplies. There were projected shortages each year in these scenarios, generally ranging from 5 to 10 percent annually during average hydrological year types. Peak shortages occur during the 2003 to 2006 drought period, reaching to more than 20 and 30 percent in the two scenarios, respectively.

If exports stay the same in the future, the reported import gaps could increase the total South Platte River basin gaps in these scenarios. As transbasin imported supplies are able to be reused to extinction either by the importing entity or by downstream users within the South Platte River basin, the imported supply gap would have the effect of increasing the total South Platte River basin gap by more than the values shown in the table.

Table 40: Summary of Transbasin Imports to the South Platte River Basin

	Transbasin Import Supply Results	Baseline	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Import Supply (ac-ft)	392,126	392,126	392,126	392,126	392,126	392,126
	Average Annual Import Supply Gap (ac-ft)	1,155	1,102	1,101	9,730	22,654	27,252
	Average Annual Import Supply Gap Increase from Baseline (ac-ft)	-	-	-	8,575	21,500	26,098
	Average Annual Import Supply Percent Gap	0%	0%	0%	2%	6%	7%
Critically Dry Maximum	Import Supply Demand In Maximum Gap Year (ac-ft)	339,871	339,871	339,871	405,267	339,871	339,871
	Import Supply Gap In Maximum Gap Year (ac-ft)	5,336	5,560	5,543	21,364	71,879	109,405
	Increase from Baseline Import Supply Gap (ac-ft)	-	224	208	16,028	66,543	104,069
	Import Supply Percent Gap In Maximum Gap Year	2%	2%	2%	5%	21%	32%

The South Platte River Basin has approximately 1.2 million ac-ft of reservoir storage (excluding Water District 3 reservoirs), used for both agricultural and M&SSI purposes. A substantial number of agricultural users own and operate off-channel reservoir storage to provide supplemental irrigation or augmentation supplies. Municipal water providers have networks of reservoirs, both on-channel and off-channel, to store in-basin and transbasin supplies. A smaller number of SSI entities also own and operate smaller reservoirs throughout the basin to re-regulate variable river supplies. Several reservoirs also operate for flood control purposes, such as Cherry Creek and Bear Creek Reservoirs. The storage capacity helps buffer the basin against periods of drought, but then requires wet hydrologic conditions to refill.

Figure 119 reflects the aggregated simulated monthly reservoir contents for 67 individually represented reservoirs in the South Platte River basin model. Note that the model does not include Cache La Poudre operations, therefore the reservoir content summary excludes the reservoirs in this sub-basin.

The graphic indicates that storage is used more frequently in all Planning Scenarios compared to the Baseline scenario results, and that additional use is not isolated to just dry periods. Reservoir contents are consistently lower than the Baseline scenario results for the entire study period.

While the reservoir storage in the Business as Usual, Weak Economy, and Cooperative Growth scenarios is projected to experience significant use, these scenarios have years when the reservoirs across the basin are generally able to refill, although wetter conditions are needed to do so. The Adaptive Innovation and Hot Growth scenarios, however, project reservoir storage across the basin cannot fully recover or refill following drought periods. Increased demands in these scenarios places more demands on reservoir storage continuously and the climate-adjusted hydrology reduces the hydrological conditions such that even the wetter hydrological years are not sufficient to allow all the reservoirs to refill. Although this is the case, it does not indicate that future storage projects are not warranted in the South Platte Basin since the existing storage may not be located in locations where water may still be available, such as the lower reaches of the basin.

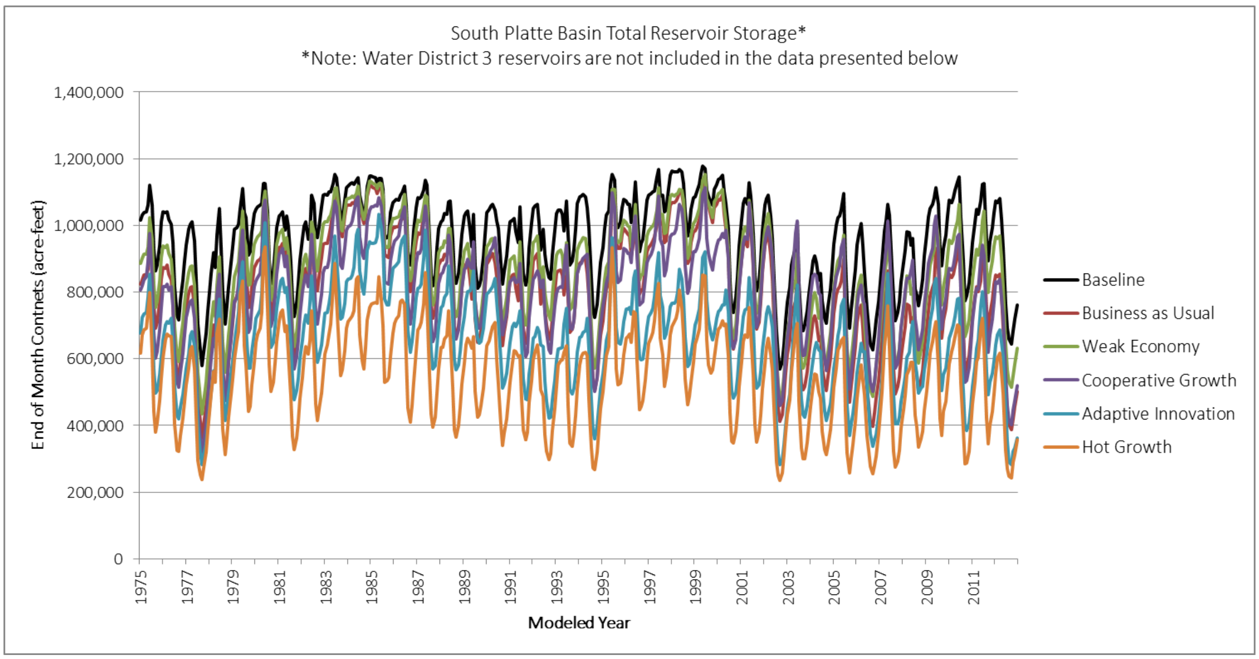


Figure 119: South Platte River Basin Total Reservoir Storage

The following figures reflect average monthly simulated streamflow at key locations across the basin; refer to Figure 110 for the location of the gages. The streamflow conditions vary substantially across the basin due to impacts from natural hydrology and upstream agricultural and M&SSI diversions, storage, and transbasin import supplies.

The average monthly simulated streamflow of the South Platte River at Denver is reflected in Figure 120. This streamgage is located in the City of Denver and represents the combined upstream influence of several on-channel reservoirs owned and operated by Denver Water and Aurora Water along the upper South Platte River before the river benefits from several tributary inflows. The simulated streamflow through the city is projected to be substantially lower in all Planning Scenarios as the municipal demand increases and more water is needed to meet those demands. The Business as Usual and Cooperative Growth scenarios project a 24 percent reduction in total annual flow, whereas the Weak Economy projects an 18 percent reduction. The Adaptive Innovation and Hot Growth scenarios project a larger reduction to annual streamflow of 42 percent. Additionally, note that the peak flows in the Cooperative Growth, Adaptive Innovation, and Hot Growth scenarios have been shifted forward to the month of May. This is a common trend projected for the climate-adjusted hydrology across the state.

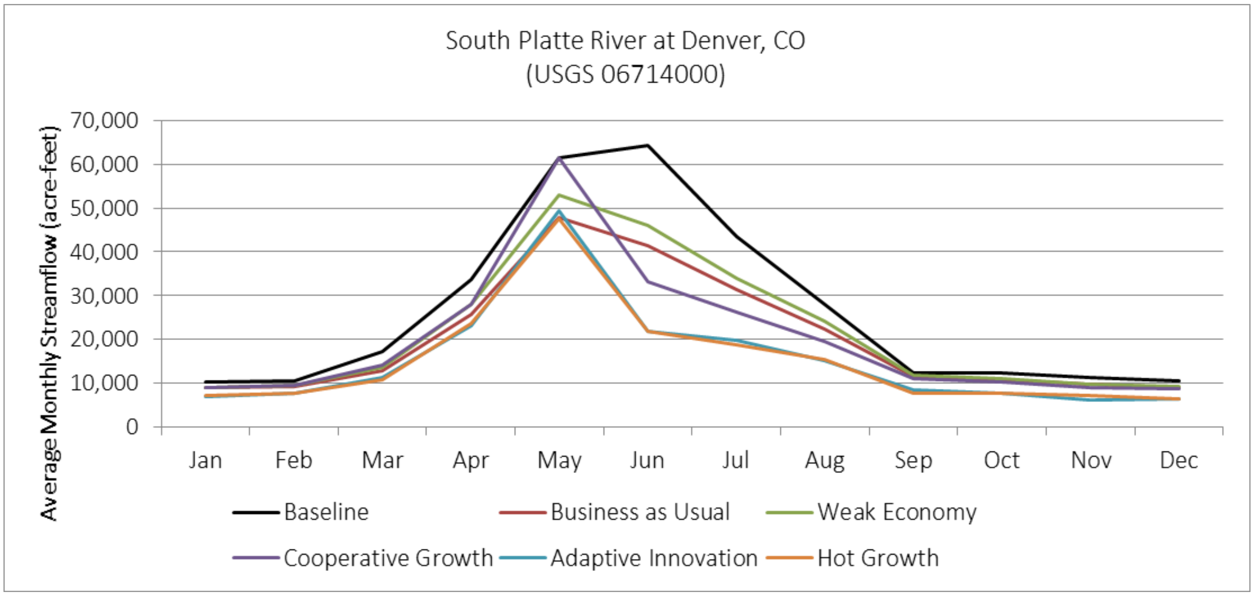


Figure 120: Average Monthly Streamflow for South Platte River at Denver

Figure 121 shows the average monthly simulated streamflow for St. Vrain Creek at Lyons. This location is high in the headwaters of the basin and represents near-natural flow conditions. The largest upstream operations are driven by the City of Longmont, which operates diversion pipelines and Button Rock Reservoir. Additionally, the Left Hand Ditch Company has a diversion point upstream of the gage to serve irrigated acreage lower in the basin. Much of the agricultural diversions in the basin, along with the delivery of transbasin supplies from the C-BT Project occur downstream of the reservoir. The Business as Usual and Weak Economy scenarios are projected to have slightly lower streamflow than the Baseline scenario. On an annual basis, the streamflow volume declines from about 91,600 ac-ft in the Baseline scenario to 86,000 and 89,000 ac-ft in the Business as Usual and the Weak Economy scenarios, respectively. This change is likely caused by the increase in M&SSI demands, including City of Longmont.

The Cooperative Growth streamflow primarily reflects increased M&SSI demands and a change in the runoff due to the climate-adjusted hydrology under the In-Between conditions. The scenario projects less than a 10 percent reduction in streamflow, but shifts that streamflow forward to the month of May. The Adaptive Innovation and the Hot Growth scenarios have overlapping results on the graphic, which are dominated by the Hot and Dry climate-adjusted hydrology. These scenarios also reflect a shift in streamflow forward to the month of May, but project a 30 percent decline overall in streamflow at this location on average.

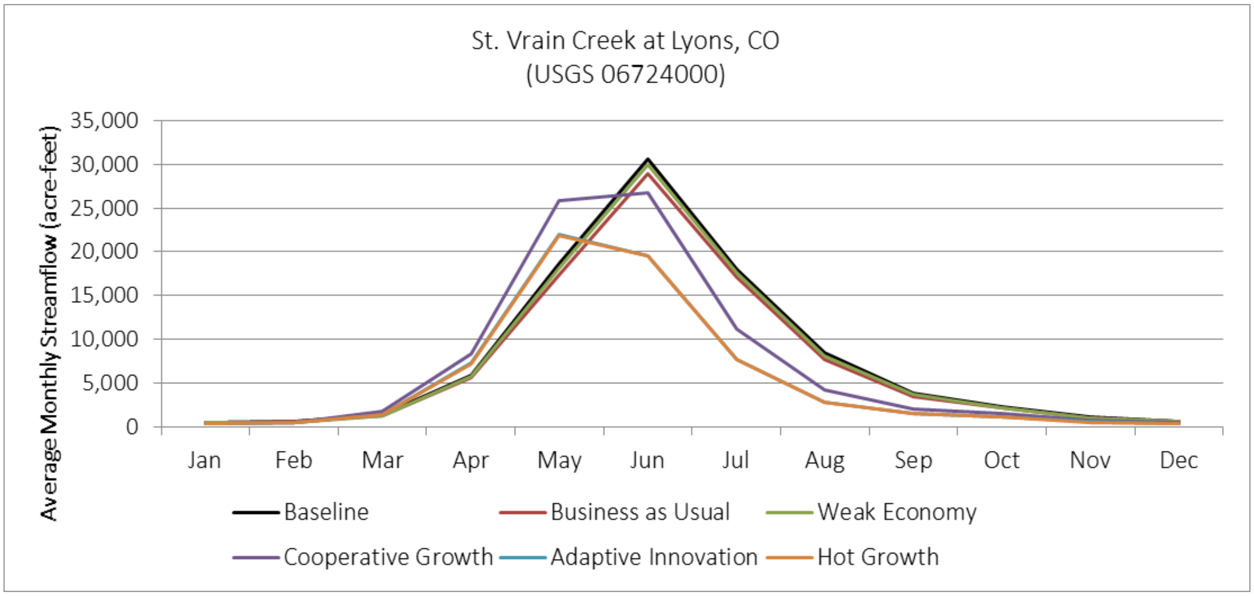


Figure 121: Average Monthly Streamflow for St. Vrain Creek at Lyons

The average monthly simulated streamflow on the Big Thompson River at Estes Park streamflow gage, reflected in Figure 122, represents natural conditions in the basin as there are no upstream diversions or reservoirs in the model. The total volume of natural flow at the gaged location is approximately 88,200 ac-ft, however substantial transbasin supplies are imported via Adams Tunnel directly downstream of the gage, resulting in a much larger water supply for the tributary.

The climate-adjusted hydrology in the Cooperative Growth scenario does not project a decline in overall streamflow volume, but does reflect a shift in runoff and a substantial reduction to late irrigation season streamflow supplies. A similar trend is projected for the Adaptive Innovation and Hot Growth scenarios, which both reflect the Hot and Dry natural flow. These scenarios do, however, project an 11 percent reduction to overall streamflow. For a system like the South Platte River Basin, which has significant reservoir storage, the shift in streamflow timing can be buffered by reservoir storage. However, as projected in the reservoir storage graph in Figure 119, the total reservoir storage in these climate-adjusted scenarios does not refill as frequently as scenarios using the current hydrology.

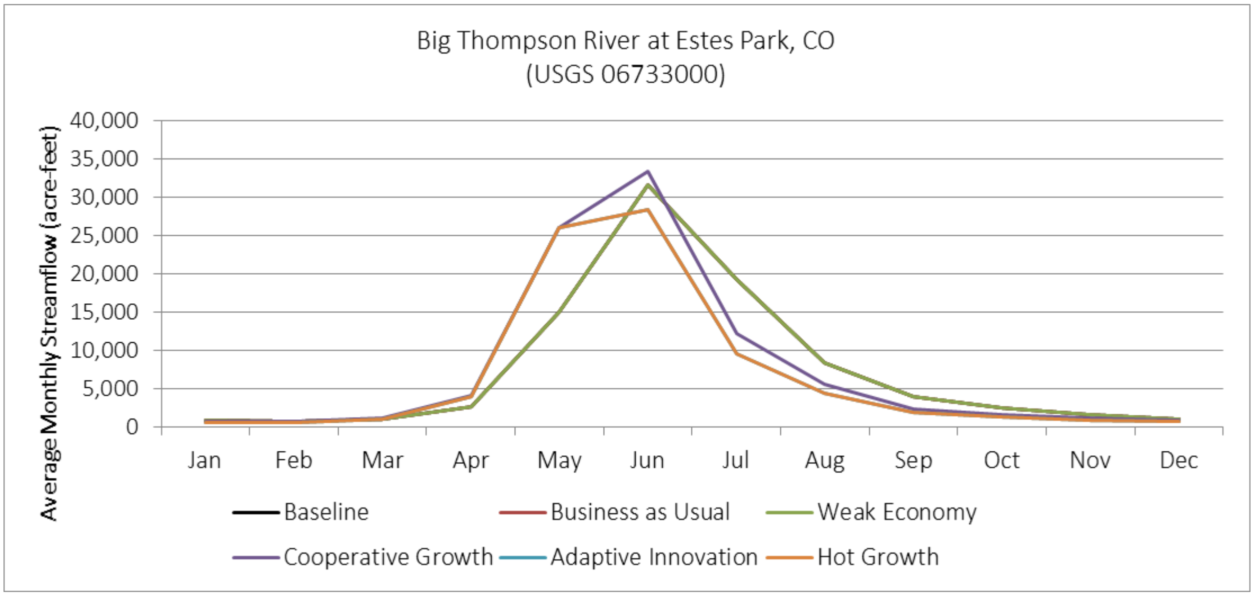


Figure 122: Average Monthly Streamflow for Big Thompson River at Estes Park

Finally, the average monthly simulated streamflow at the South Platte River near Kersey gaged location is shown in Figure 123. This location is downstream of a majority of the Front Range M&SSI demands, includes contributions from all the major tributaries and transbasin import supplies to the South Platte River. This represents the amount and pattern of streamflow projected to be available to large irrigation operations in the lower South Platte River Basin. The Business as Usual and the Weak Economy scenario project lower streamflow than the Baseline scenario. This is due to the increase in municipal demands, most of which are located upstream of Kersey.

The Cooperative Growth, Adaptive Innovation, and Hot Growth scenarios continue the trend of shifting the peak flow into the month of May. At this location, the Cooperative Growth scenario projects the overall streamflow will be very near Baseline scenario conditions, benefitting from an increase in runoff from tributaries feeding into the South Platte River. The Hot and Dry climate-adjusted hydrology used by the Adaptive Innovation and Hot Growth scenarios, along with larger M&SSI demand combine to project an approximately 20 percent reduction in streamflow on average, or a reduction of about 150,000 ac-ft on average annually. The shift in streamflow timing combined with the decline in streamflow during July, August, and September places more demands on reservoir storage during the late season. As shown in Figure 119, reservoir storage in the Adaptive Innovation and Hot Growth scenarios is lower than other Planning Scenarios and the basin-wide storage never refills.

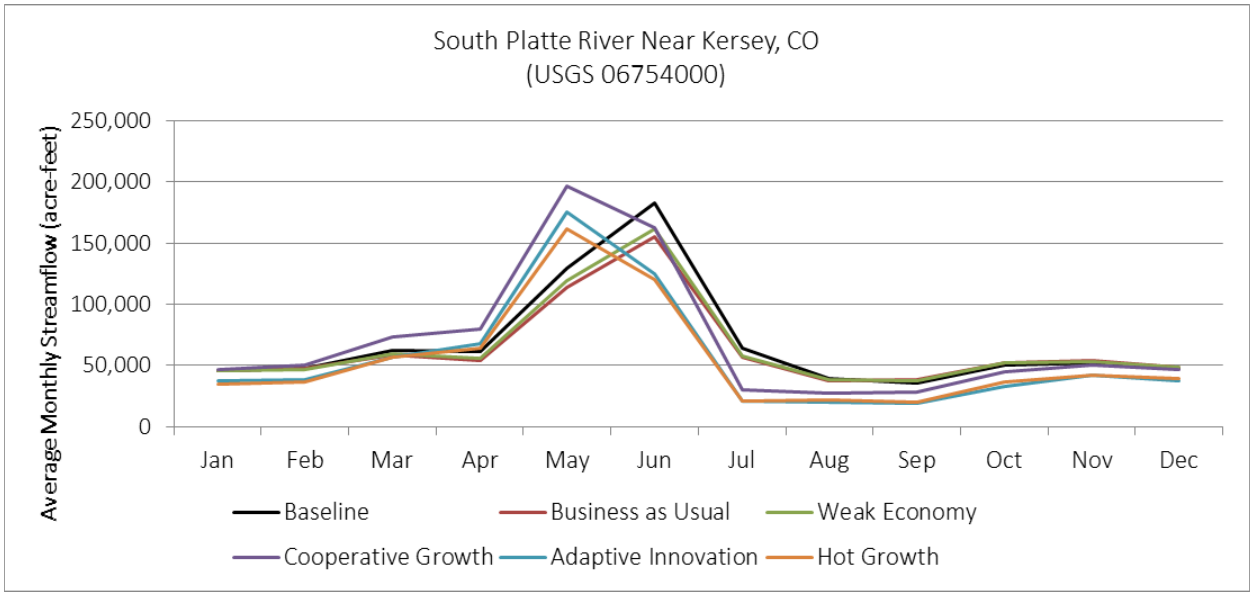


Figure 123: Average Monthly Streamflow for South Platte River near Kersey

The South Platte River basin is over-appropriated, and demands far exceed the native supply in the river. That being said, there are limited times when unappropriated supply are available, however these supplies are generally only available during above-average hydrological conditions and for a couple weeks or even days. Flooding conditions on tributaries and the mainstem do produce large volumes of unappropriated flows, however the high flow rates prohibit substantial diversions during this time for many water users, except those with on-channel reservoirs high up in the basin. The Planning Scenarios project the already limited unappropriated available supplies will be further reduced due to increasing M&SSI demands and climate-adjusted hydrology.

Figure 124 through Figure 127 reflect simulated unappropriated available supply at two locations on the South Platte River, the South Platte River at Denver and South Platte River at Kersey gaged locations. The Denver gage is located upstream of the Burlington Canal, the primary calling right on the mainstem of the Upper South Platte River. The Kersey gage reflects the impact to available flow downstream of the confluence with the Cache La Poudre River and the Lower South Platte River calling rights for storage and irrigation. As reflected in the graphics, available flow at both locations is generally only available during high flow years and for relatively short periods of time. In climate-adjusted scenarios, available flows are projected to diminish, and peak flows are projected to occur earlier in the runoff season.

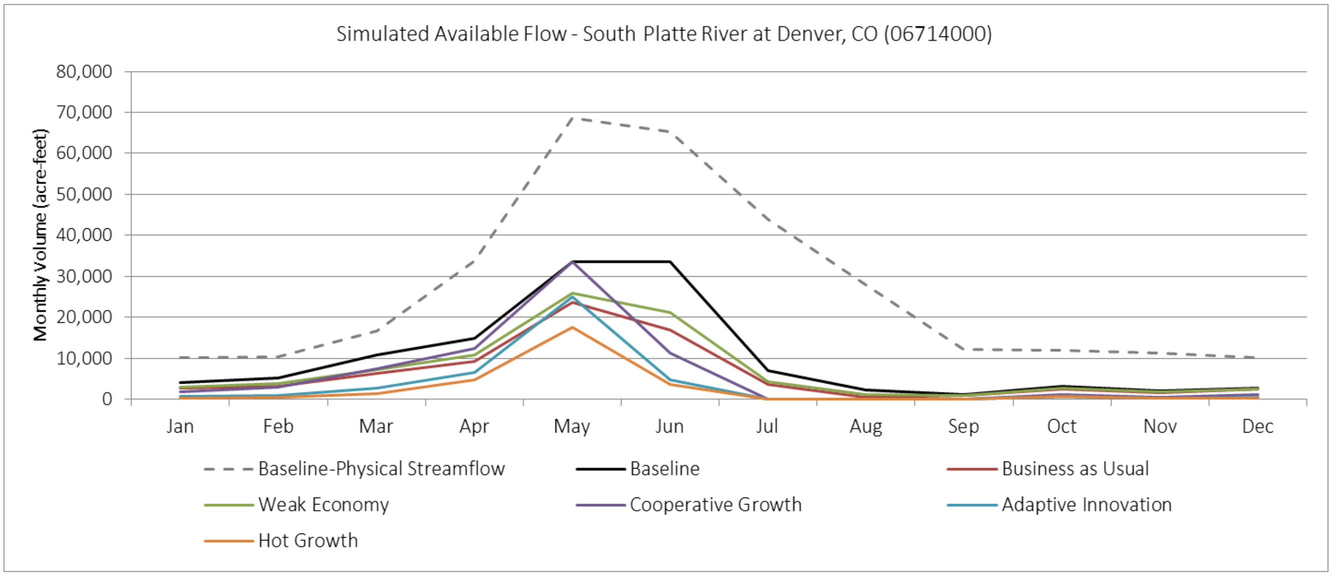


Figure 124: Average Monthly Unappropriated Available Supply at South Platte River at Denver

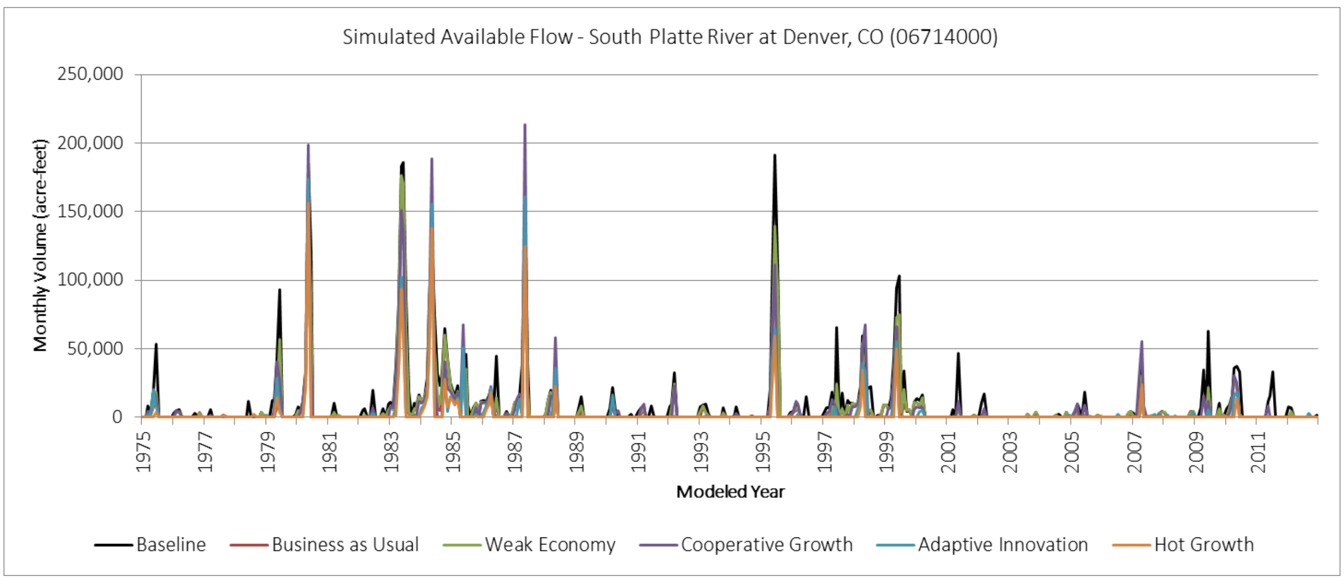


Figure 125: Monthly Unappropriated Available Supply at South Platte River at Denver

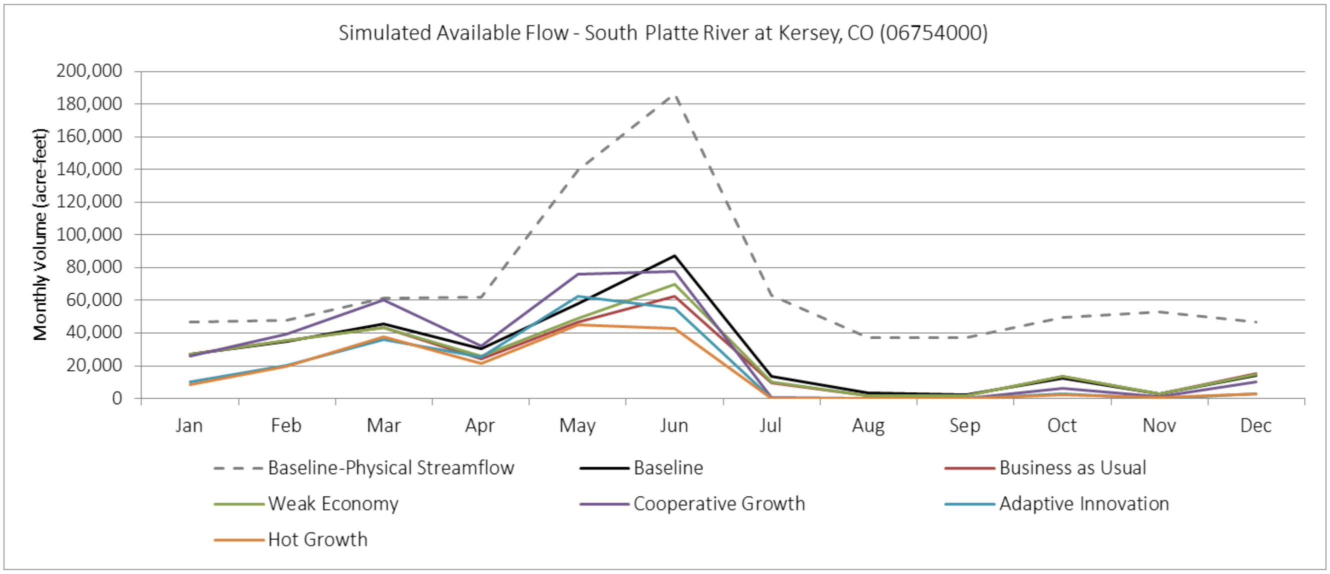


Figure 126: Average Monthly Unappropriated Available Supply at South Platte River at Kersey

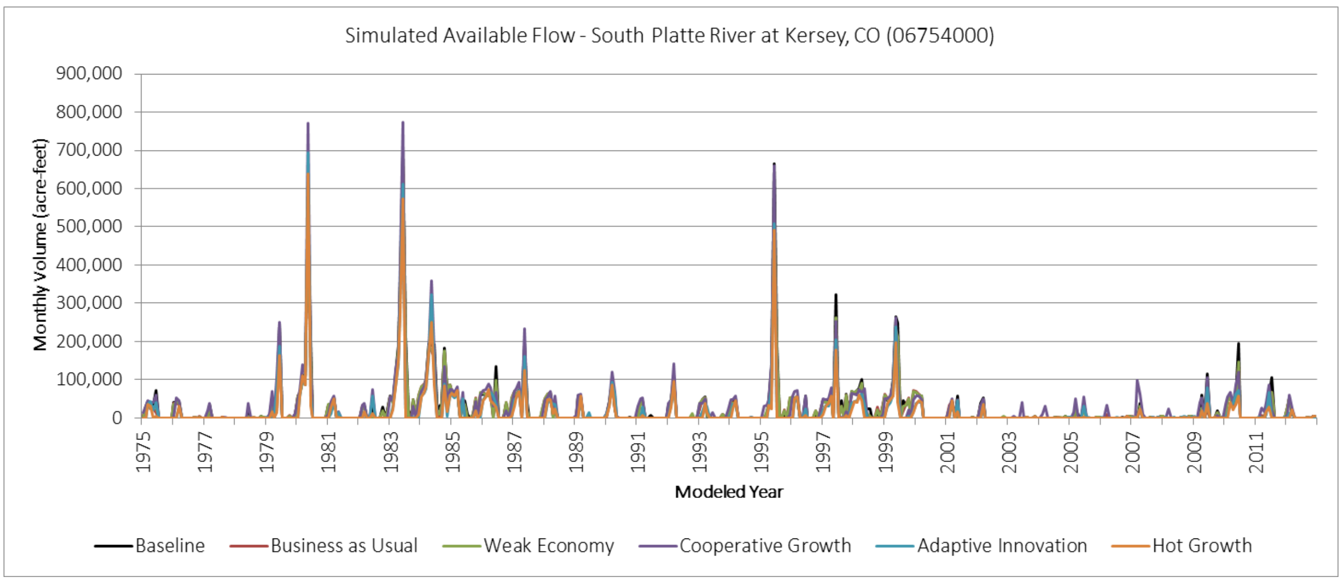


Figure 127: Monthly Unappropriated Available Supply at South Platte River at Kersey

5.9 WHITE RIVER BASIN

Irrigation for ranching operations is the largest demand for water in the White River basin, accounting for approximately 98 percent of total basin demands. These mountain ranches are generally flood irrigated, and with no storage in the basin for agricultural uses, irrigators rely on diversions of runoff for supplies.

Water used to meet M&SSI demands is limited in the basin relative to agricultural use, constituting less than 2 percent of the total demand in the basin. The two municipal areas in the White River Basin are the Town of Rangely and the Town of Meeker. Both towns are popular with outdoor enthusiasts as they offer access to a variety of destinations, from Dinosaur National Monument, Kenney Reservoir, or the Flattops

Wilderness. The region also benefits from large natural gas deposits in the Piceance Basin, which have driven several boom-and-bust cycles of development in the basin over the past several decades.

The following sections describe the agricultural and M&SSI demands in the White River basin in more detail. Figure 128 reflects the basin outline encompassing all of Water District 43 and the streamflow gages highlighted in the results section below.

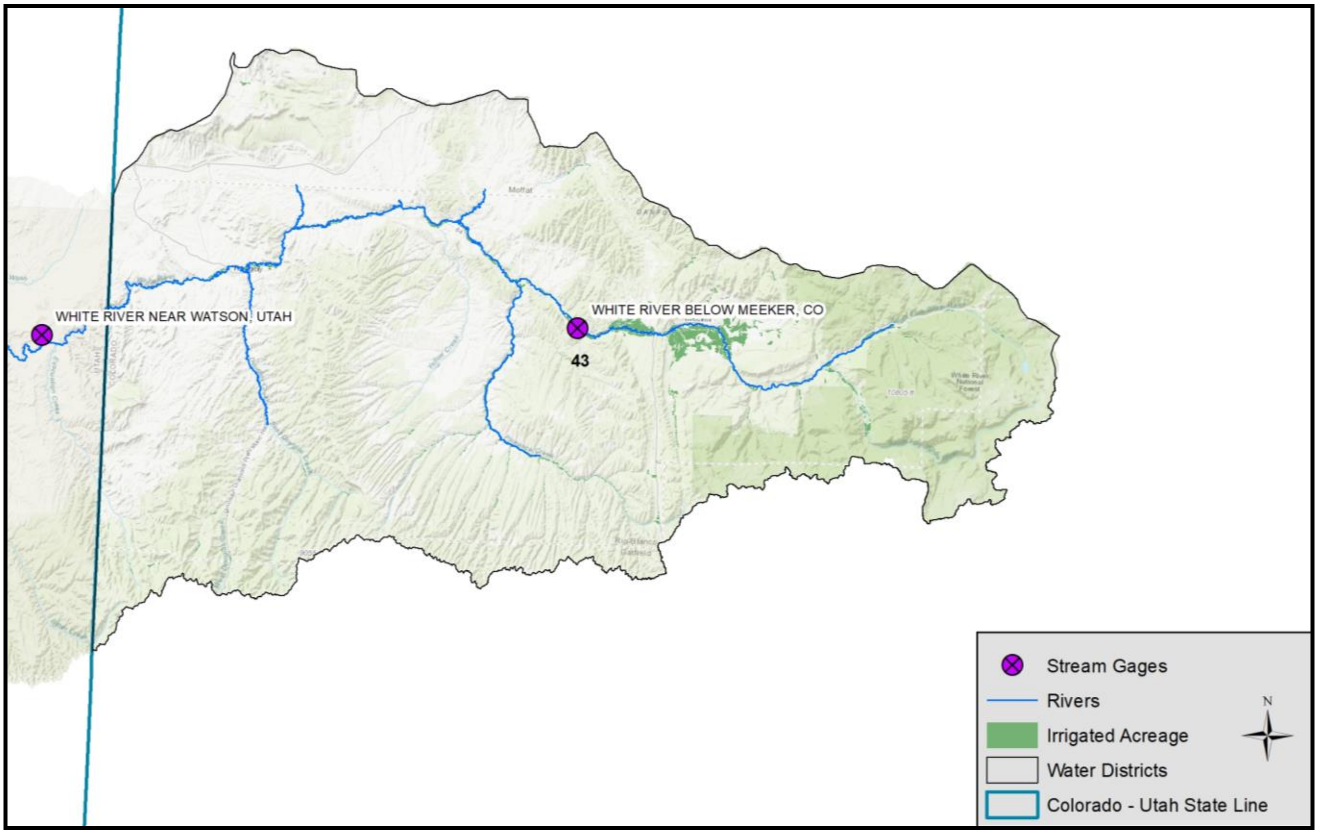


Figure 128: White River Map with Streamgage Locations

5.9.1 WHITE RIVER BASIN AGRICULTURE WATER SUPPLY AND GAP

The majority of irrigation is for grass pasture fields, concentrated in the tributary and river valleys, that are able to produce a single cutting of hay before turning the fields over for grazing cattle. Due to warmer temperatures, the lower portion of the basin is able to produce two cuttings and has more alfalfa fields. Flood irrigation is common and irrigators depend on late-season irrigation return flows because there is no storage for agriculture in the basin. There are no Reclamation or other large-scale irrigation projects in the basin. In areas where it is economically feasible, some ranchers are switching to sprinkler irrigation. Agriculture was identified as a priority for the White River Basin in the Basin Implementation Plan and water users in the basin hope to keep current irrigated acreage in production.

The White River Basin agricultural diversion demands, demand gaps, and consumptive use gaps results for the baseline and Technical Update Planning Scenarios are presented in Table 41. As discussed in Technical Memo *Current and 2050 Planning Scenario Agricultural Diversion Demand*, 2050 agricultural demands are influenced by a number of drivers, including climate, urbanization, and emerging technologies.

Table 41: White River Basin Agricultural Water Supply and Gap Summary

	Agricultural Results	Baseline	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand (ac-ft)	246,744	242,917	246,744	293,889	177,755	319,741
	Average Annual Demand Increase from Baseline (ac-ft)	-	-	-	47,146	-	72,998
	Average Annual Gap (ac-ft)	1,219	1,221	1,222	3,163	3,367	5,829
	Average Annual Gap Increase from Baseline (ac-ft)	-	3	4	1,945	2,149	4,611
	Average Annual Percent Gap	0%	1%	0%	1%	2%	2%
	Average Annual CU Gap (ac-ft)	658	660	660	1,715	2,162	3,163
Critically Dry Maximum	Demand In Maximum Gap Year (ac-ft)	242,254	238,492	242,254	281,374	174,299	307,552
	Increase from Baseline Demand (ac-ft)	-	-	-	39,120	-	65,298
	Gap In Maximum Gap Year (ac-ft)	6,017	6,029	6,029	9,493	8,525	12,199
	Increase from Baseline Gap (ac-ft)	-	12	12	3,475	2,508	6,182
	Percent Gap In Maximum Gap Year	2%	3%	2%	3%	5%	4%

As reflected in the table, irrigators in the basin currently experience a gap, however the gap is relatively small and occurs during drier years. The average annual agricultural demand decreases slightly from Baseline to the Business as Usual Planning Scenario due to the projected urbanization of approximately 360 irrigated acres. The Weak Economy Planning Scenario assumes no acreage is removed for urbanization and agricultural demands are the same as Baseline. Despite having slightly lower agricultural demands, the Business as Usual Planning Scenario has a slightly higher percent gap than the Baseline and Weak Economy scenarios. This is due to the higher future M&SSI demands, as a large portion of the projected M&SSI demands are met by existing municipal water rights portfolios that in some cases are senior or the same priority as irrigation rights. More details on M&SSI demands and gaps are discussed in the next section.

Under the Cooperative Growth scenario, the agricultural demands are projected to increase approximately 22 percent compared to Baseline scenario due to the climate-adjustment to IWR under the In-Between conditions. Additionally, the hydrology under the In-Between conditions is predicting snowmelt runoff will occur earlier in the year. There is no agricultural reservoir storage available in the White River Basin, so the general irrigation practice is to fill the soil moisture and narrow alluvial aquifers during the runoff and use the soil moisture and lagged return flows to meet crop demands during the late irrigation season, when streamflow is low. When the runoff occurs earlier in the year as projected, there are fewer lagged return flows later in the summer and soil moisture supplies are used earlier in the year. This, in combination with larger agricultural demands, causes a moderate increase in agricultural gaps. The streamflow supplies, however, still appear to be sufficient to meet a majority of the agricultural demand in the basin.

For the Adaptive Innovation scenario, the average annual demand is approximately 30 percent less than the Baseline demand. In this scenario, emerging technologies are assumed to mitigate approximately 10 percent of the increase in IWR due to projected Hot and Dry climate conditions as well as increase irrigation system efficiency by 10 percent, which results in an overall net decrease in agricultural demand. While the demand has decreased, the average annual gap and the average annual CU gap have increased under this scenario. The increased system efficiency reduces the demands; however, it also causes return flows to decrease. The White River Basin is highly dependent on return flows, and coupled with the decrease in streamflow under Adaptive Innovation scenario, the result is an increase in the agricultural gap.

The Hot Growth scenario projects the largest volume of agricultural gaps in the White River Basin. Average annual diversion demands have increased compared to all previous scenarios due to the Hot and Dry climate conditions. Overall, the Hot Growth scenario projects an increase of approximately 73,000 ac-ft of agricultural demand compared to the Baseline scenario, with only a 4,600 ac-ft increased gap. This indicates that although the Hot and Dry hydrological conditions reduce streamflow and shift the peak runoff in the basin, the decreased streamflow is still sufficient to meet a majority of the increased agricultural demand.

Agricultural demands in the White River Basin are projected to experience small increases in gaps, despite large increases to demands, as reflected in Figure 129 and Figure 130. As with other basins, it should be noted that agricultural water users are not impacted to the same degree throughout the basin. For example, the White River Basin average annual agricultural gap in the Hot Growth scenario is only two percent, but the agricultural gap in the Piceance River basin is closer to 16 percent. While this is a relatively low gap compared to other basins, it is significantly higher than other areas of the White River Basin.

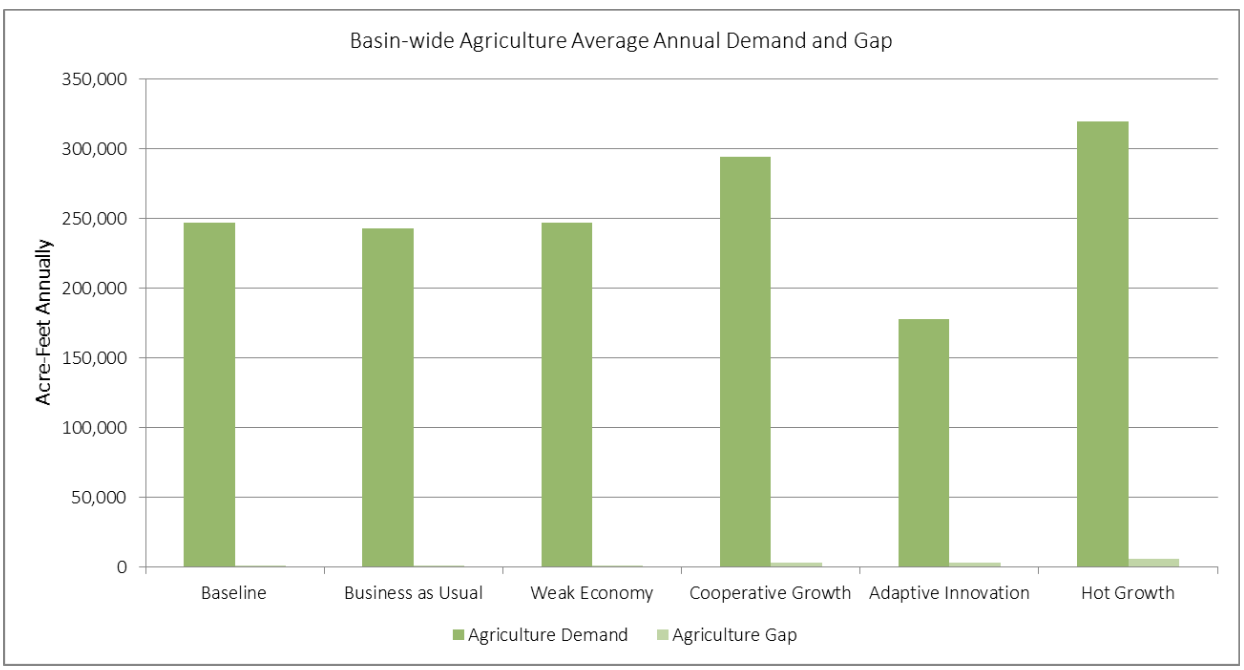


Figure 129: White River Basin Agriculture Average Annual Demand and Gap

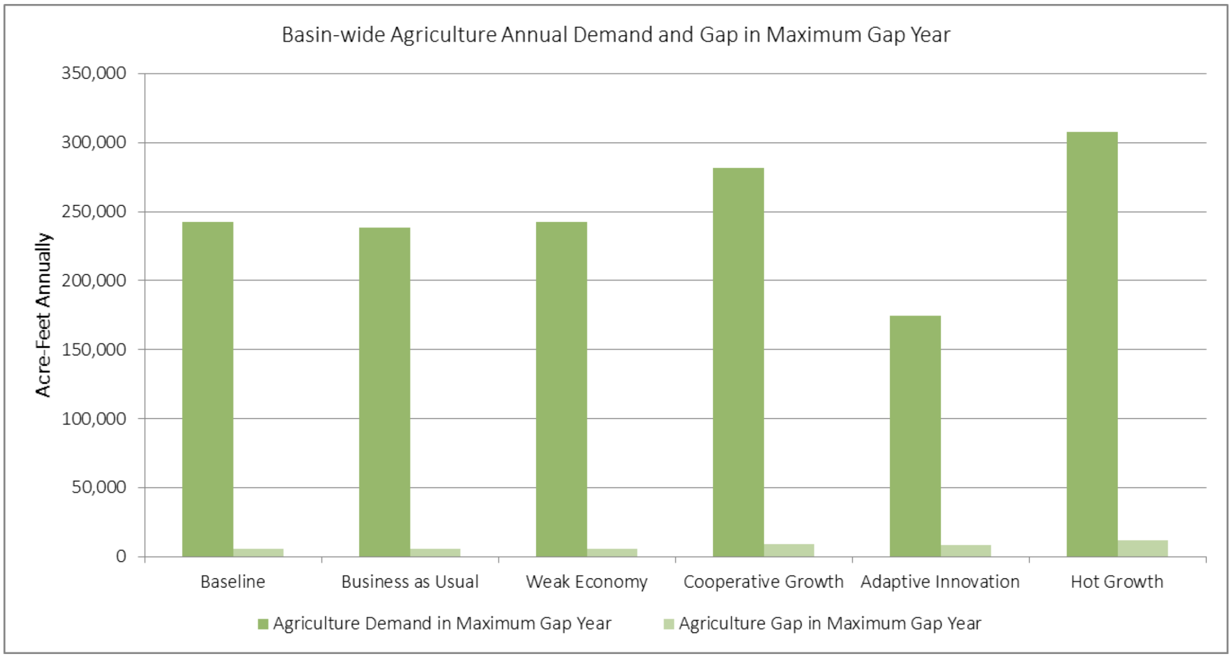


Figure 130: White River Basin Agriculture Annual Demand and Gap in Maximum Gap Year

The annual agricultural gap variability over the model study period is reflected in Figure 131. Note that the years with the largest percent gaps do not necessarily align with the “typical” dry years. For example, the largest percent gap occurs in 2004, after continually growing during the drought of the early 2000s. Given the high dependency on late season return flows and soil moisture in the White River basin, the last year in a series of dry years produces the largest gap, due to the lack of moisture from previous years build up. In generally, the scenarios have very similar results over the study period. As discussed above, the Adaptive Innovation scenario projects the largest gap during the 2002 to 2013 period due to the increased irrigation system efficiency and reduction to late season return flows.

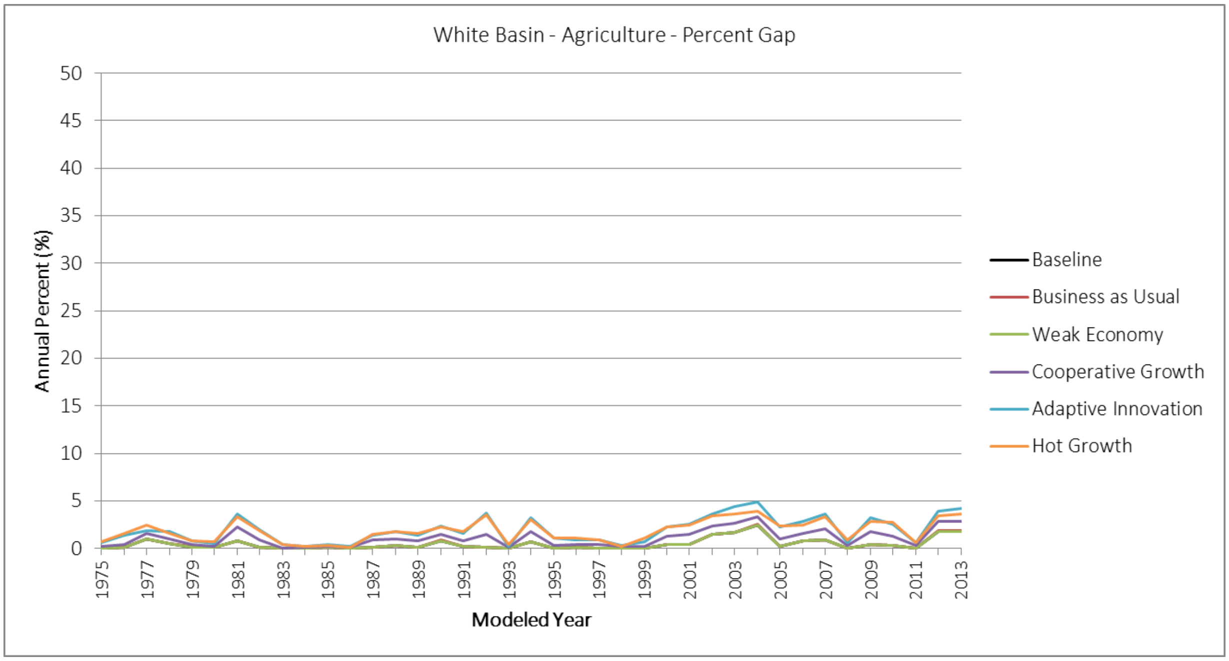


Figure 131: White River Basin Agriculture Percent Diversion Gap Time Series

5.9.2 WHITE RIVER BASIN M&SSI WATER SUPPLY AND GAP

Population in Rio Blanco County is projected to increase in all scenarios except the Weak Economy scenario, leading to moderate increases to the municipal demand in the basin in many scenarios. The SSI demand[20] is projected to have moderate increases in all scenarios except the Hot Growth scenario, in which the SSI demand is projected to increase nearly twenty-five times the Baseline demand. This large increase in the Hot Growth demand is attributable to the projected increase of energy development in the Piceance River basin.

A majority of the municipal demand is grouped and represented in the model at a general location, with only the Town of Rangley and Town of Meeker's demands and surface water rights modeled individually. For the SSI demands, the individual operations and demands associated with the California Co Water Pipeline are included in the model and the remaining SSI demand is represented at two grouped locations. A quarter of the future SSI demands are represented on the Piceance River and the remaining three quarters of the SSI demand is represented on the mainstem of the White River. Although there are several large conditional water rights for energy development in the White River Basin, these were not included in the water right assignment for this effort. Refer to Appendix A for more information on how water rights were assigned to grouped SSI demands in the model; future analyses may consider incorporating these water rights with the projected demand.

Refer to the *Baseline and Projected 2050 Planning Scenario Municipal and Self Supplied Industrial Water Demands* technical memorandum for additional discussion on how the M&SSI demands in the basin were developed. The water supply and gap results for M&SSI in the White River basin are summarized in Table 42, and graphically reflected in Figure 132 and Figure 133.

[20] Note that water used for hydropower, such as those operations at Kenney Reservoir, are represented in the model but are not included in the SSI demand summaries (i.e. non-consumptive) and are not adjusted between Planning Scenarios.

Table 42: White River Basin M&SSI Water Supply and Gap Summary

	M&SSI Results	Baseline	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand (ac-ft)	5,265	10,015	6,086	6,936	7,658	40,960
	Average Annual Demand Increase from Baseline (ac-ft)	-	4,750	821	1,671	2,393	35,695
	Average Annual Gap (ac-ft)	0	3,048	704	708	788	27,498
	Average Annual Gap Increase from Baseline (ac-ft)	-	3,047	704	708	788	27,498
	Average Annual Percent Gap	0%	30%	12%	10%	10%	67%
Critically Dry Maximum	Demand In Maximum Gap Year (ac-ft)	5,265	10,015	6,086	6,936	7,658	40,960
	Increase from Baseline Demand (ac-ft)	-	4,750	821	1,671	2,393	35,695
	Gap In Maximum Gap Year (ac-ft)	0	3,934	910	934	1,282	33,465
	Increase from Baseline Gap (ac-ft)	-	3,934	910	934	1,282	33,465
	Percent Gap In Maximum Gap Year	0%	39%	15%	13%	17%	82%

The average annual demand increases from the Baseline scenario to the Business as Usual scenario, primarily due to the increase in SSI demands. The average annual gap is 30 percent, with gaps increasing 39 percent in critically dry years. The gap is driven by primarily by legal water availability. Projected increases in energy development are represented in the model with a priority that is junior to the hydropower production at Taylor Draw Dam (Kenney Reservoir). As such, the large hydropower demand calls down much of the streamflow outside of the peak runoff, thus shorting nearly all of the increased M&SSI demand in the Business as Usual scenario. This is one representation of water rights priorities and operations, and can be changed in the future based on stake holder input.

The Weak Economy, Cooperative Growth, and Adaptive Innovation scenarios have modest increases in the average annual demands and experience similar levels of gaps on average and during critically dry years. Although each scenario reflects different demands and climate-adjusted hydrological conditions, the average annual gap is approximately the same amount. Similar to the Business as Usual scenario, this is caused by a lack of legally available flow during months outside of the peak runoff, as the water is called down by the hydropower production at Taylor Draw Dam (Kenney Reservoir). There is slightly more water available in the Adaptive Innovation scenario primarily due to the reduction in agricultural demands.

The Hot Growth scenario has a large increase in average annual M&SSI demand caused by the projected energy development average annual demand reaching 35,340 ac-ft. This represents a large-scale build out of oil and gas extraction and energy development in the basin. As with previous scenarios however, much of the increased demand is shorted. This is again caused by the hydropower production at Taylor Draw Dam (Kenney Reservoir), but can also be attributed to substantially larger agricultural demands in the scenario. These combine with the overall reduction to and shift of streamflow under the Hot and Dry conditions to produce substantial projected gaps.

The overall picture for M&SSI in the White River Basin varies greatly depending on energy development assumptions, both magnitude and priority of water supplies. Figure 132 and Figure 133 reflect the relative size of the M&SSI demands and gaps on average and during critically dry years. The Business as Usual and Hot Growth scenarios experience the largest increases in demands, driven by energy development. The gaps increase as the energy demand increases indicating the water supplies are not sufficient to reliably meet the projected M&SSI demands while still meeting the hydropower demands.

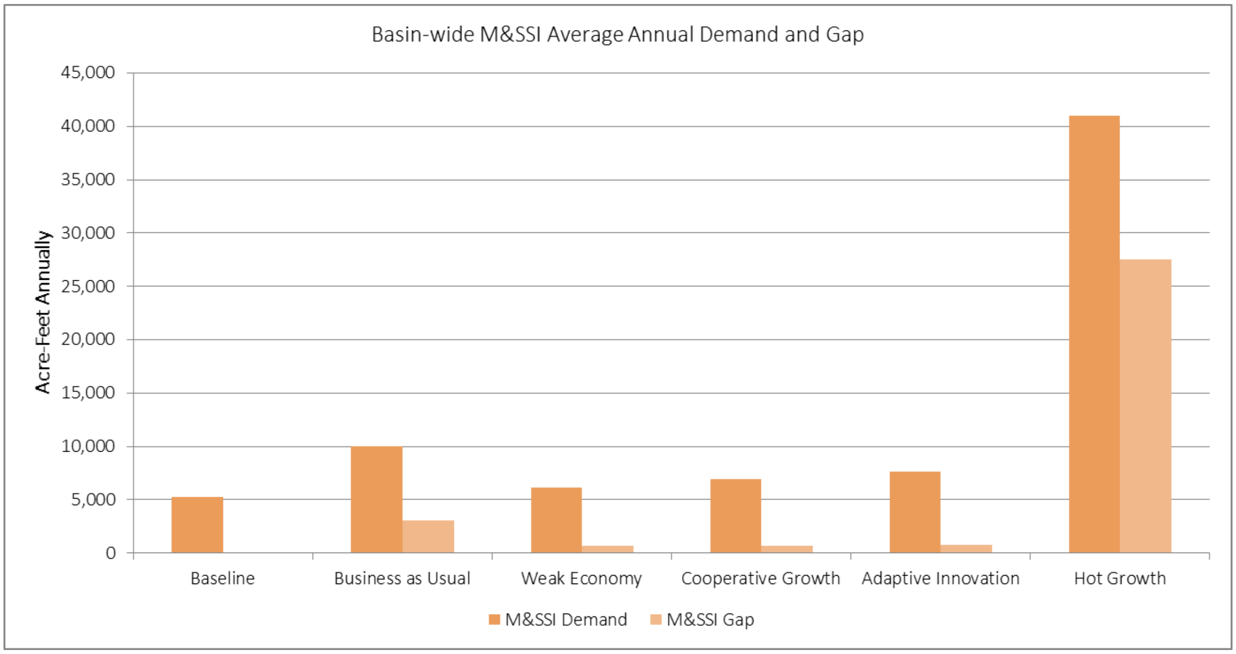


Figure 132: White River Basin M&SSI Average Annual Demand and Gap

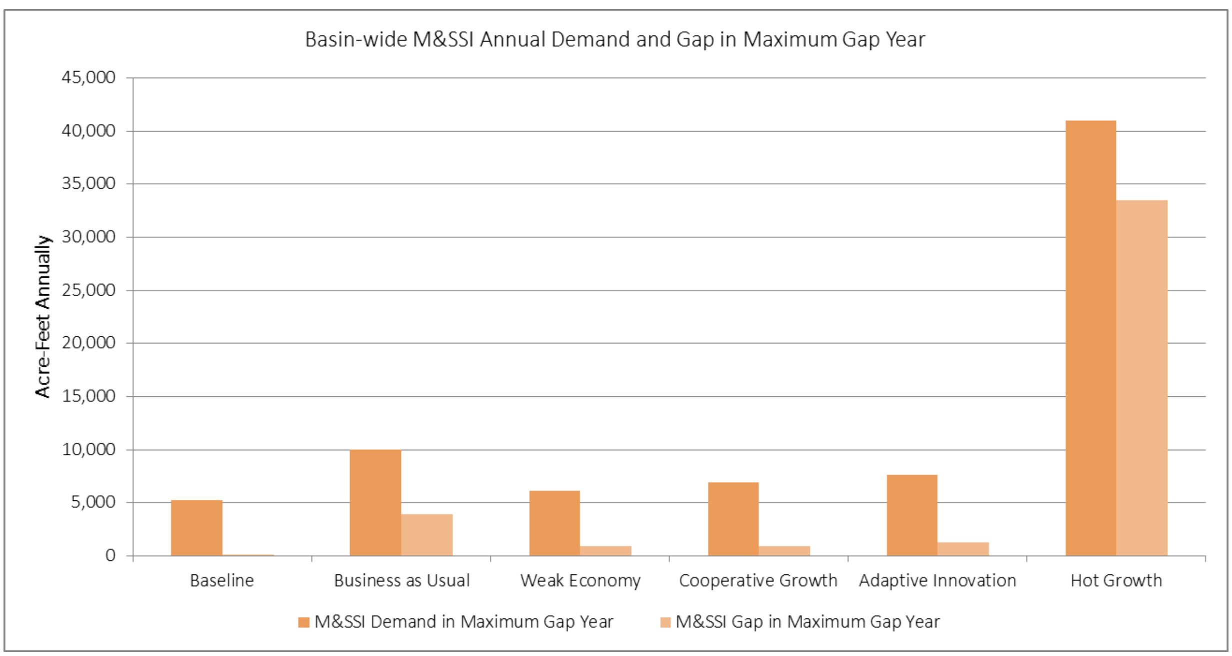


Figure 133: White River Basin M&SSI Maximum Annual Demand and Gap in Maximum Gap Year

Figure 134 reflects average annual percent gap across a variety of wet, average, and dry year types. The graphic reflects relatively consistent shortages of 10 percent for the Weak Economy, Cooperative Growth, and Adaptive Innovation scenarios, regardless of year type. The Business as Usual and Hot Growth scenario results have similar trends and responses to different year types, separated by the magnitude of their demands.

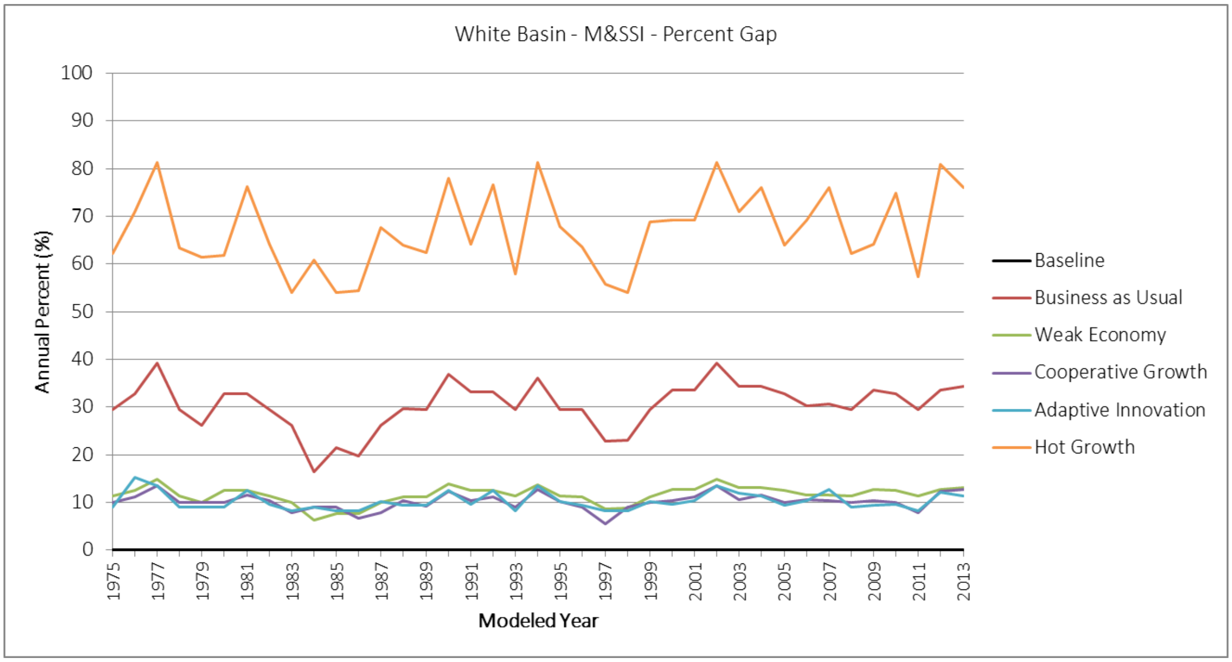


Figure 134: White River Basin M&SSI Average Annual Gap Time Series

5.9.3 WHITE RIVER BASIN SUMMARY

The combined agriculture and M&SSI demand and gap summary is provided in Table 43. While the White River Basin is dominated by agricultural demands (Figure 135), the following Figure 136 reflects that the gaps are a mix of agriculture and M&SSI growth. As previously discussed, agricultural demands in the basin are generally satisfied across all Planning Scenarios. The largest gaps are projected for increased M&SSI demands due to limited legal water availability, with the largest gaps occurring in the Business as Usual and Hot Growth scenarios. Summaries regarding other considerations that may impact the basin-wide gap, including potential M&SSI supplies from urbanized acreage, are provided below the table and graphics.

Table 43: White River Basin Water Supply and Gap Summary

	Agricultural and M&SSI Results	Baseline	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand (ac-ft)	252,009	252,932	252,830	300,825	185,413	360,701
	Average Annual Gap (ac-ft)	1,219	4,269	1,927	3,871	4,155	33,327
	Average Annual Percent Gap	0%	2%	1%	1%	2%	9%
Critically Dry Max	Demand In Maximum Gap Year (ac-ft)	247,519	248,507	248,340	288,310	181,957	348,512
	Gap In Maximum Gap Year (ac-ft)	6,018	9,963	6,939	10,426	9,807	45,664
	Percent Gap In Maximum Gap Year	2%	4%	3%	4%	5%	13%

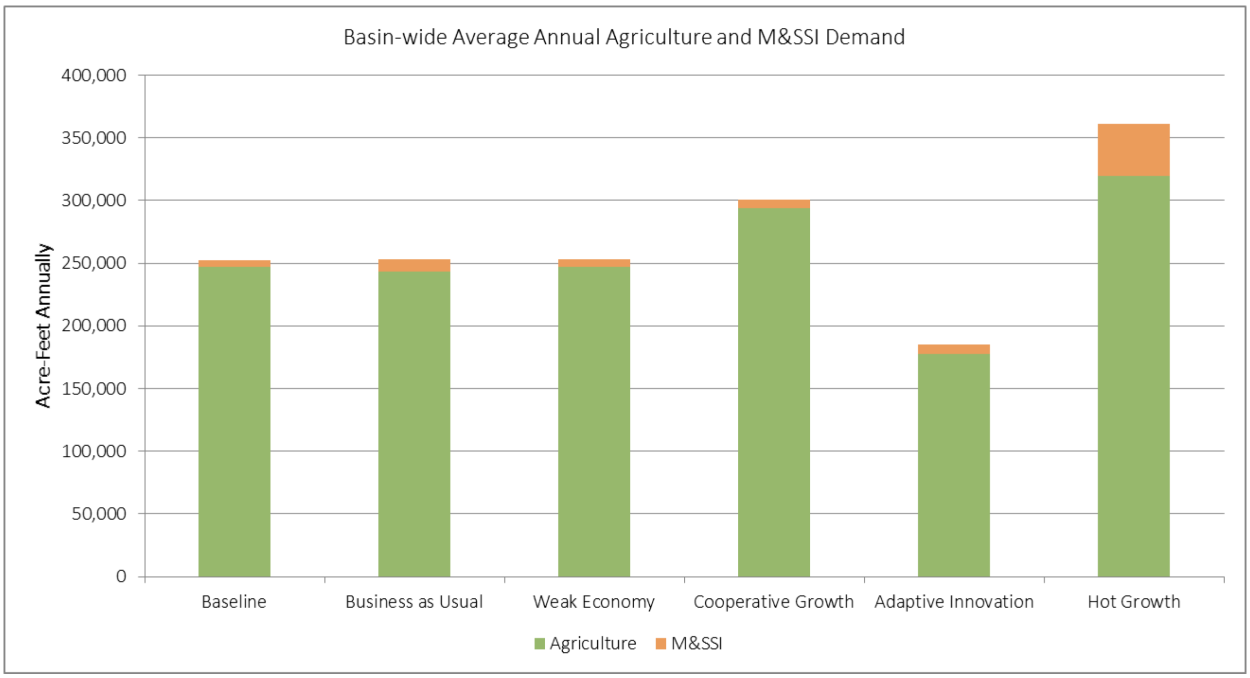


Figure 135: White River Basin Comparison of Average Annual Demands

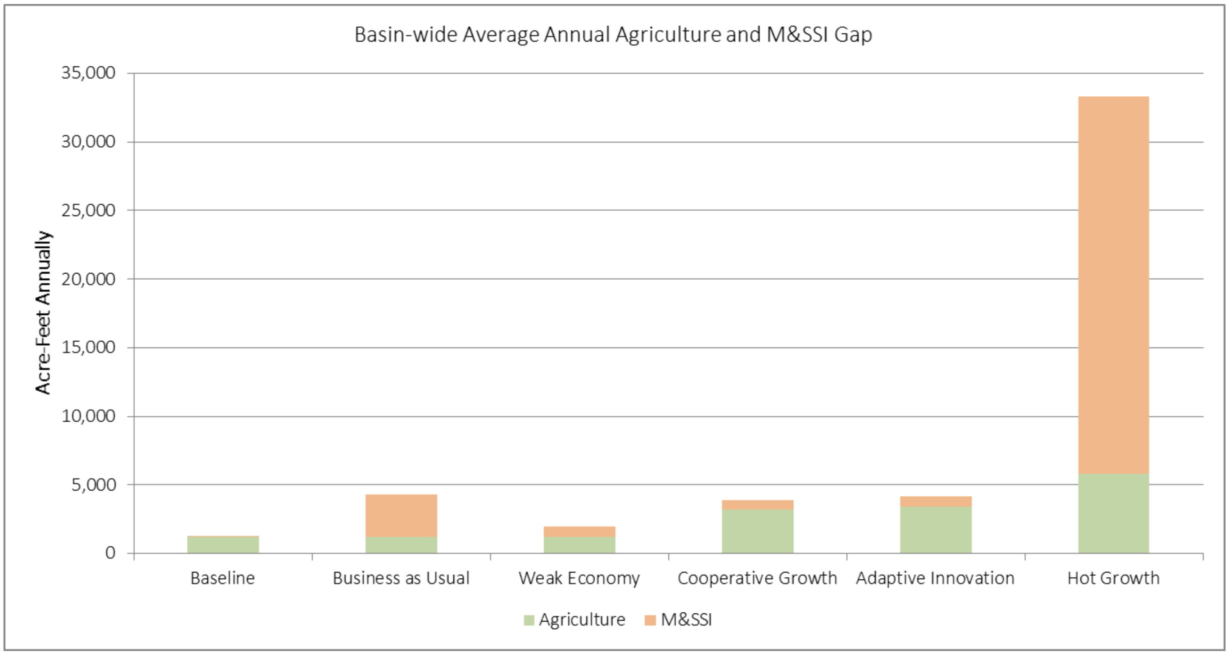


Figure 136: White River Basin Comparison of Average Annual Gaps

All Planning Scenarios, except the Weak Economy, project up to 360 acres of irrigated acreage will be taken out of production due to urbanization. Supplies used to irrigate the urbanized acreage could be considered a new municipal or SSI supply if the associated water rights were changed. To estimate this new supply, the average consumptive use of the urbanized acreage by Planning Scenario is reflected in Table 44. Note however, it is not known which farms and ranches will be directly impacted; whether the acreage was served by senior/junior direct rights or had supplemental storage supplies; or the crop type or specific irrigation practices on this acreage. Additionally, it is unknown if the water rights would be changed to municipal use, or whether the supply could directly meet the future M&SSI demand or would require exchange potential. In light of these uncertainties, the table reflects a planning-level estimate of this potential new supply. Although it has not been applied to the M&SSI gap presented above, it would likely have the effect of decreasing the gap.

Table 44: Potential Water Supply from Urbanized Acreage in the White River Basin

Urbanized Acreage Results	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Urbanized Acreage	360	-	360	360	360
Estimated Consumptive Use (ac-ft/year)	587	-	702	698	766

Reservoir storage is very limited in the White River Basin, and available reservoir storage is not operated for agricultural uses. As shown in Figure 137, the entire basin only has about 22,000 ac-ft of storage and it generally remains full. Lake Avery is operated for wildlife habitat. Colorado Parks and Wildlife has recently explored releasing water from Lake Avery to support streamflow for the mountain white fish, but this is a pilot experiment that has not be incorporated into the modeling. Kenney Reservoir is operated as a run-of-the-river hydropower facility and provides flat-water recreation. It can supply emergency supply to the Town of Rangely, but this is rarely used in any of the scenarios.

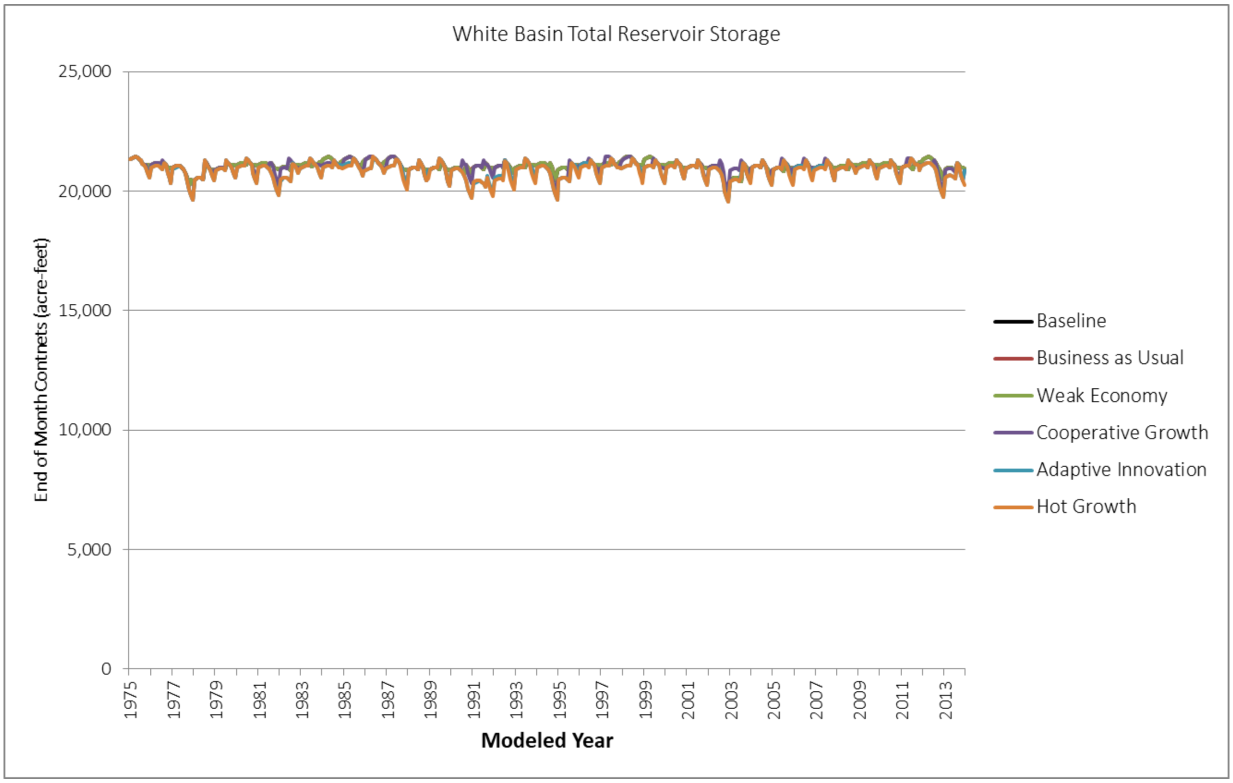


Figure 137: White River Basin Total Reservoir Storage

The following figures show average monthly simulated streamflow at key locations across the basin, as reflected in Figure 128. The primary driver of average monthly simulated streamflow across the Planning Scenarios is hydrology. The average monthly streamflow results from Baseline, Business as Usual and Weak Economy scenarios are almost indistinguishable from each other because they use current hydrology. At both gaged locations, the lines graph directly on top of each other. The modest changes in demands for agriculture and M&SSI result in very similar streamflows.

The In-Between hydrology incorporated in the Cooperative Growth scenario and the Hot and Dry hydrology incorporated in Adaptive Innovation and Hot Growth scenarios consistently reduce late season flows across the basin. The change in streamflow during the month of July is particularly dramatic. For example, Figure 138 reflects the streamflow volume decrease from about 45,000 ac-ft in July under current hydrology to 18,000 ac-ft under the In-Between hydrology and 11,500 ac-ft under the Hot and Dry hydrology. Simulated streamflow results in August through December also reflect consistently lower streamflow under the two climate projections.

Note that although the climate-adjusted scenarios experience a similar or larger peak runoff volume than current conditions, the annual streamflow volume is less than the current annual volume. This indicates that the climate-adjusted hydrological conditions are significantly shifting the streamflow pattern, which may present as many challenges as the decline in streamflow.

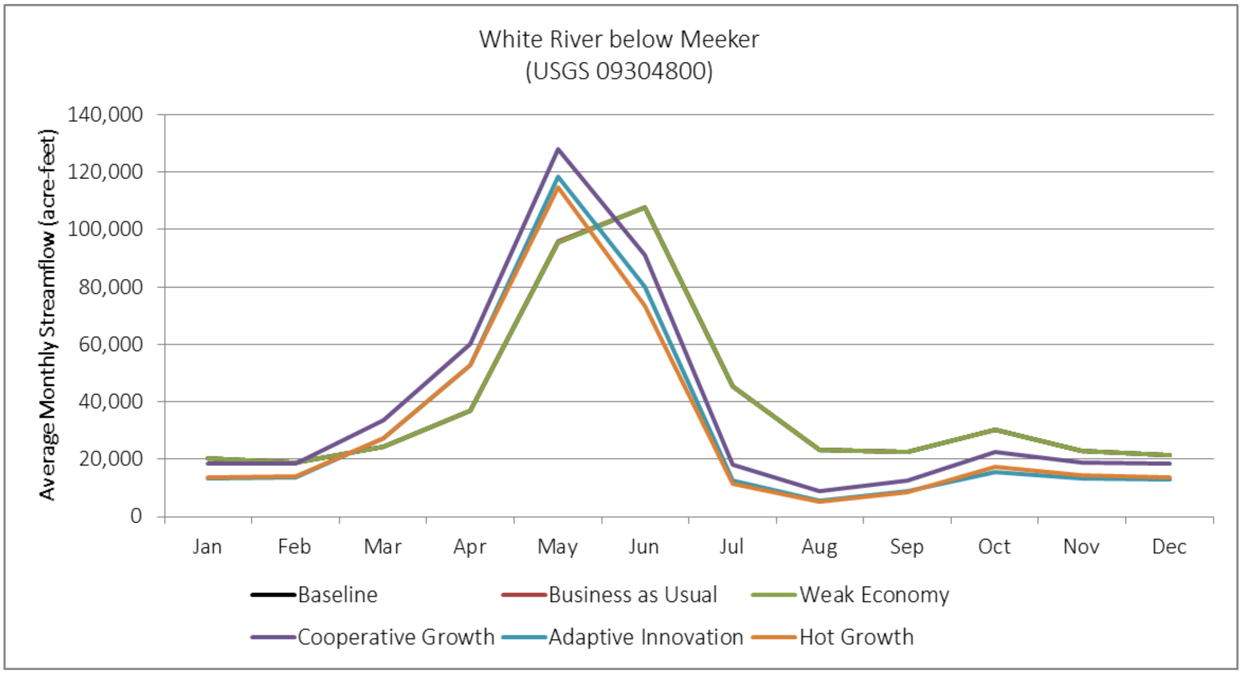


Figure 138: Average Monthly Streamflow for the White River below Meeker

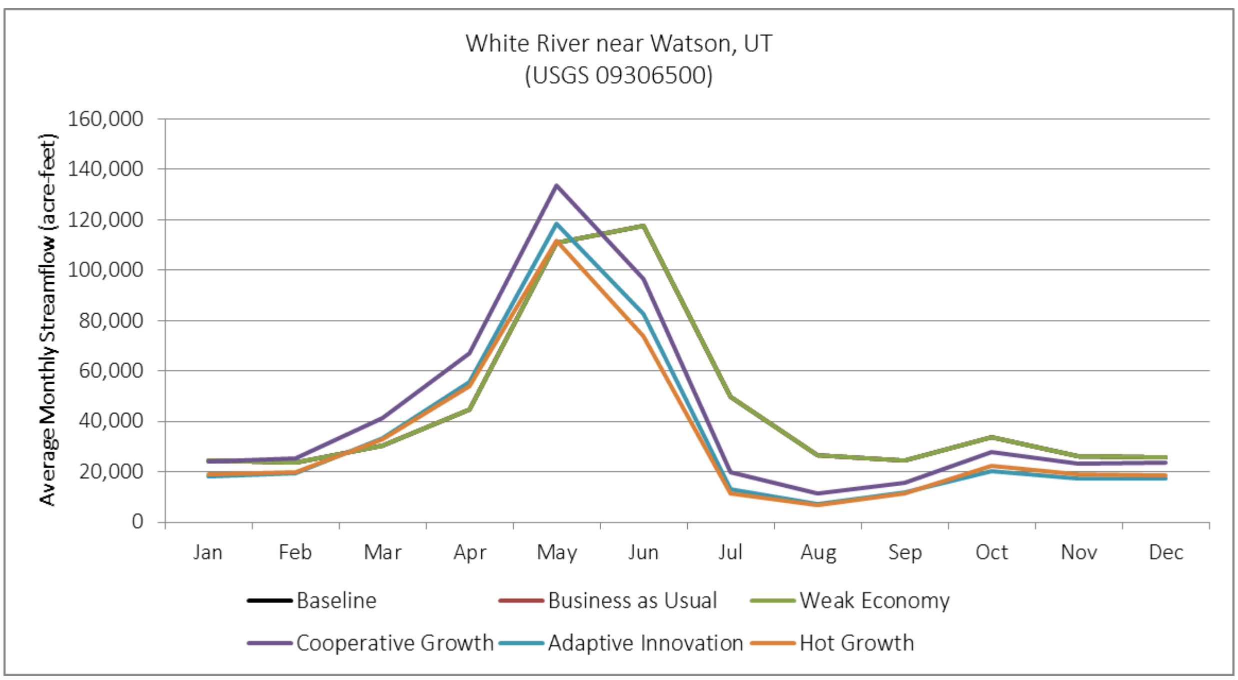


Figure 139: Average Monthly Streamflow for the White River near Watson, UT

Figure 140 and Figure 141 reflect the simulated monthly available flow on the White River below Boise Creek, which is located above Kenney Reservoir. The reservoir has a hydropower water right that is not fully satisfied and serves as the controlling right in the model. The figures reflect that unappropriated flows are projected to be available in most years, though the amounts will vary annually and across scenarios. In some years, very little to no flow is available under current and future conditions at this location, particularly during the winter and during critically dry years. Unappropriated available supply under climate-adjusted Planning Scenarios is projected to decline and to occur earlier in the year.

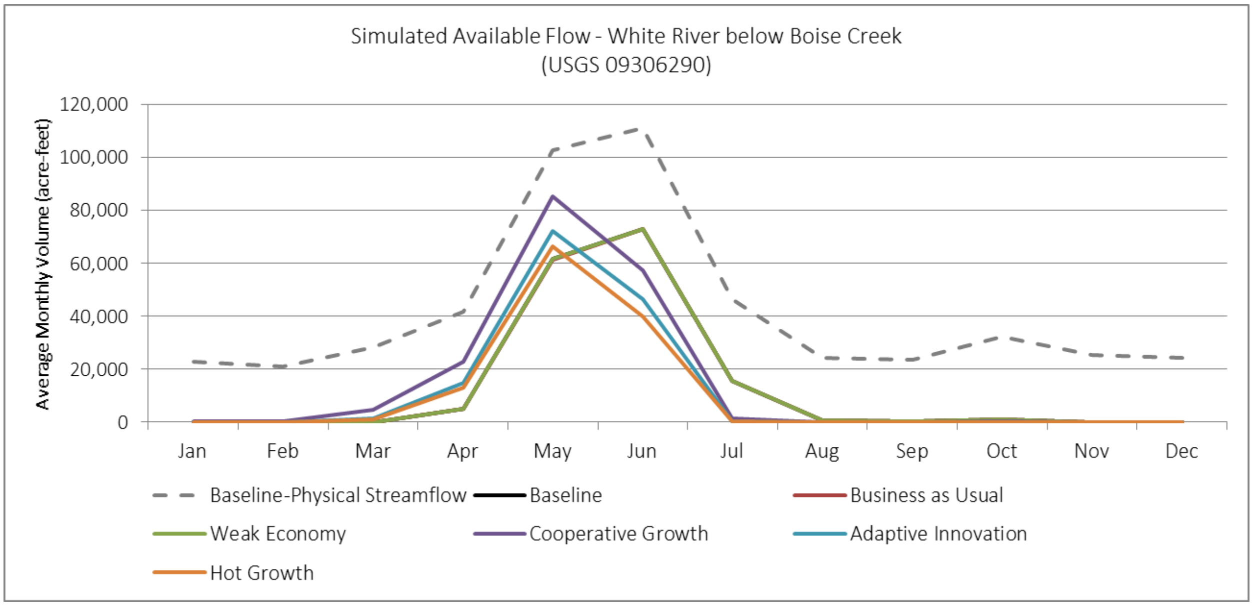


Figure 140: Average Monthly Unappropriated Available Supply at White River below Boise Creek

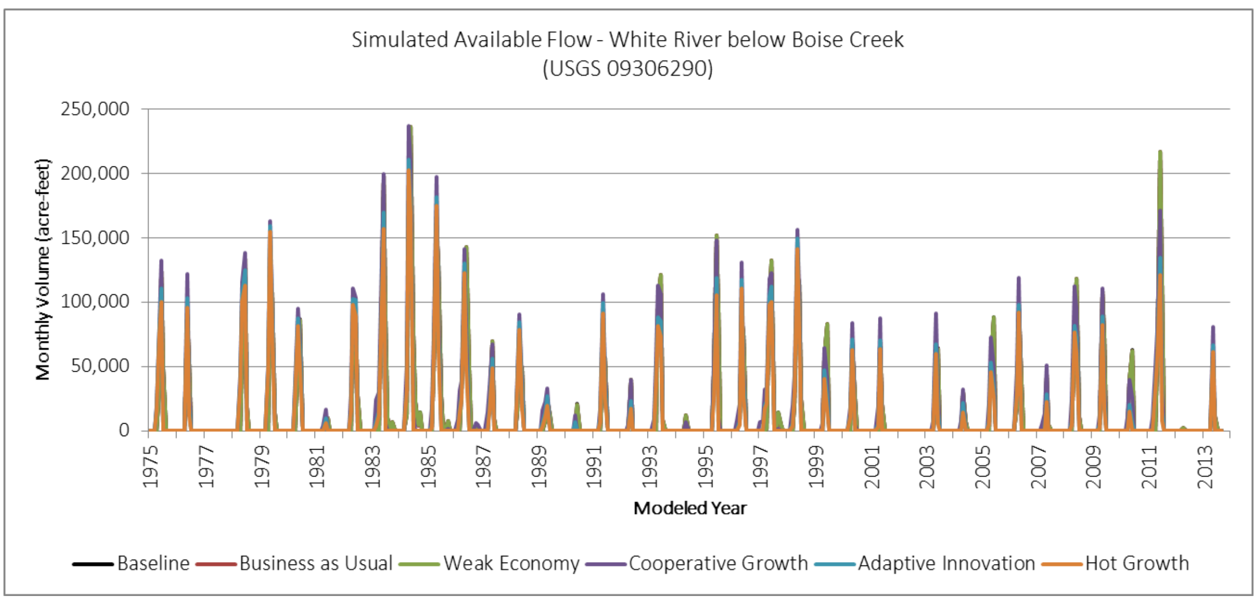
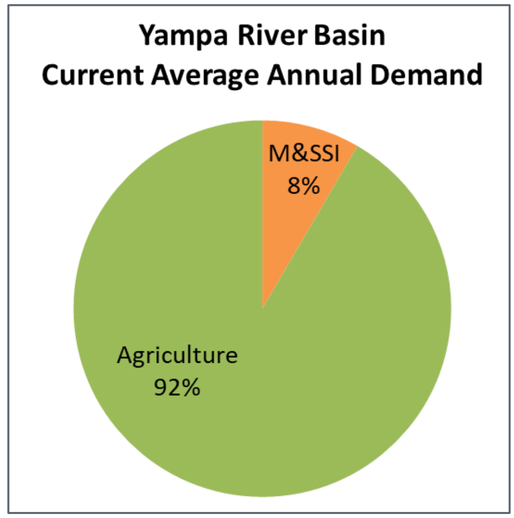


Figure 141: Monthly Unappropriated Available Supply at White River below Boise Creek

5.10 YAMPA RIVER BASIN



Irrigation for ranching operations is the largest demand for water in the Yampa River basin, accounting for over 92 percent of total demand basins. Mountain ranches produce hay and alfalfa to support cow/calf operations, with irrigators generally flood irrigating their fields.

Water used to meet M&SSI demands in the basin is relatively small compared to agricultural uses, accounting for approximately 8 percent of the total current demand in the basin. The two major municipal areas in the Yampa River Basin are the City of Steamboat Springs and the City of Craig. These population centers have a strong tourist economy, driven by Steamboat Springs resort, Dinosaur National Monument, boating, fishing and hunting.

One unique feature of the Yampa River is the amount of unappropriated streamflow compared to other basins in the state. The Yampa River mainstem only recently experienced a call in 2018, a critically dry year, however tributaries throughout the Yampa River Basin experience local calls more frequently.

The following sections describe the agricultural and M&SSI demands in the Yampa River basin in more detail. Figure 142 shows the basin outline, the administrative boundaries of the water districts, and the streamflow gages highlighted in the results section below.

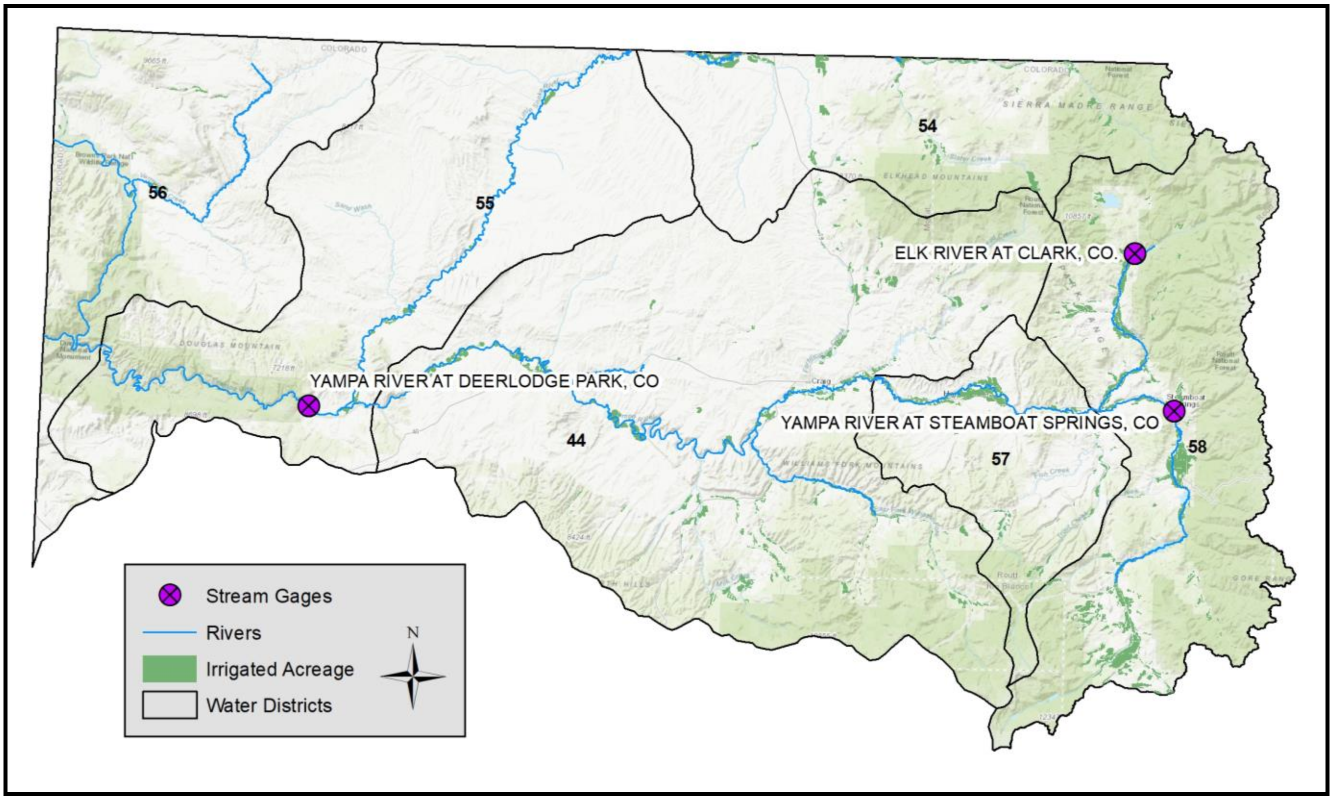


Figure 142: Yampa River Map with Streamgage Locations

5.10.1YAMPA RIVER BASIN AGRICULTURE WATER SUPPLY AND GAP

Irrigated acreage in the Yampa River Basin consists primarily of high mountain meadows and cattle ranches in the upper reaches of the basin along Elk Creek and the Yampa River. Water users also irrigate acreage along the Little Snake River as it meanders between Colorado and Wyoming. Irrigated fields are concentrated in the tributary and river valleys, and are able to produce a single cutting of hay before turning the fields over for grazing cattle. Due to warmer temperatures, the lower portion of the basin is able to produce two cuttings and can support more fields of alfalfa. Flood irrigation is common, especially in the upper portions of the basin. In areas where it is economically feasible, some ranchers are switching to sprinkler irrigation. The Yampa River Basin is an agricultural-focused basin; producers in the basin desire to maintain and increase irrigated acreage along the Yampa River mainstem.

The Yampa River Basin agricultural diversion demands[21], demand gaps, and consumptive use gaps results for the baseline and Technical Update Planning Scenarios are presented in Table 45. As discussed in Technical Memo *Current and 2050 Planning Scenario Agricultural Diversion Demand*, 2050 agricultural diversion demands are influenced by a number of drivers, including climate, urbanization, planned agricultural projects, and emerging technologies.

[21] There are a few small transbasin diversions from the Yampa River basin that are used on irrigated fields just outside of the basin boundaries. These diversions are reported under the agricultural sector, and not reflected as transbasin exports herein.

Table 45: Yampa River Basin Agricultural Water Supply and Gap Summary

	Agricultural Results	Baseline	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand (ac-ft)	402,488	403,627	403,627	522,453	460,985	684,260
	Average Annual Demand Increase from Baseline (ac-ft)	-	1,139	1,139	119,965	58,497	281,772
	Average Annual Gap (ac-ft)	13,254	13,609	13,588	63,053	58,948	150,012
	Average Annual Gap Increase from Baseline (ac-ft)	-	354	333	49,799	45,694	136,757
	Average Annual Percent Gap	3%	3%	3%	12%	13%	22%
	Average Annual CU Gap (ac-ft)	7,394	7,585	7,574	34,422	37,840	81,475
Critically Dry Maximum	Demand In Maximum Gap Year (ac-ft)	448,870	450,513	450,513	532,972	463,792	667,456
	Increase from Baseline Demand (ac-ft)	-	1,643	1,643	84,102	14,922	218,586
	Gap In Maximum Gap Year (ac-ft)	55,578	55,354	55,219	123,445	97,729	246,537
	Increase from Baseline Gap (ac-ft)	-	-	-	67,867	42,151	190,958
	Percent Gap In Maximum Gap Year	12%	12%	12%	23%	21%	37%

As reflected in the table, irrigators in the basin currently experience a relatively small gap on average, but a more substantial gap during critically dry years. There are several small tributaries in the Yampa River basin that currently experience physical water shortages, such that streamflow is not sufficient to meet the crop demand for the full growing season. Gaps are typically experienced during the late irrigation season, after runoff has occurred.

The average annual agricultural demand increases slightly from Baseline to the Business as Usual and Weak Economy Planning Scenarios. Both the Business as Usual and Weak Economy scenarios assume 1,500 acres of agriculture is removed from production due to urbanization. At the same time, the scenarios project 1,000 acres of new alfalfa fields are put into production. The reduction in demand due to urbanization of primarily grass pasture fields is offset by the increase in alfalfa acreage, which has a higher crop demand compared to grass pasture. Despite having the same agricultural demands and hydrology, the Business as Usual scenario has slightly more shortages than the Weak Economy scenario. This is due to the slightly higher projected M&SSI demands in the Business as Usual scenario; more details on M&SSI demands and gaps are discussed in the next section.

The Cooperative Growth Planning Scenario projects additional irrigated acreage will be put into production, as well as incorporates an increase in agricultural demand due to climate change adjustments to IWR and climate-adjusted hydrology associated with the projected In-Between climate conditions. The hydrological conditions at many locations predict limited reductions to total runoff in the basin, but do reflect a substantial shift in the peak streamflow. There is very limited agricultural reservoir storage available in the Yampa River Basin, so the general irrigation practice is to fill the soil moisture during the runoff and use the soil moisture to meet crop demand during the late irrigation season, when the streamflow is low. When the runoff occurs earlier in the year as projected, there are fewer lagged return flows later in the summer and soil moisture supplies are used earlier in the year. This, in combination with larger agricultural demands, causes an increase in agricultural gaps.

For the Adaptive Innovation scenario, the average annual demand is greater than the Baseline scenario demand, but less than the Cooperative Growth scenario demand. This is due to a combination of adjustments, including the removal of urbanized acreage; the addition of 14,805 irrigated acres; climate-adjustments to IWR under the Hot and Dry conditions; and adjustments for emerging technologies. The overall effect of these adjustments is an agricultural demand approximately 60,000 ac-ft greater than the Baseline demand. Agricultural gaps in the scenario, which are moderate on average but more substantial in critically dry years, can be attributed to the shift in peak runoff due to climate-adjusted and improved system efficiencies that reduce late irrigation season return flows.

The Hot Growth scenario projects the largest volume of agricultural gaps in the Yampa River Basin. Average annual diversion demands have increased compared to all previous scenarios due to the Hot and Dry climate conditions. Overall, the Hot Growth scenario projects an increase of approximately 282,000 ac-ft of agricultural demand on average compared to the Baseline scenario, with a 137,000 ac-ft increased gap on average. This indicates that approximately half of the increased demand could be met under the Hot and Dry hydrological conditions.

The overall picture for agriculture in the Yampa River Basin shows relatively low average annual percent gaps, with gaps in critically dry years projected to be more severe. This is highlighted in Figure 143 and Figure 144, which show the relative size of the agricultural demands and gaps on average and for critically dry years. As with other basins, agricultural water users are not impacted evenly throughout the basin, depending on the available water supply and relative seniority of the agricultural water rights. For example, the Yampa River Basin average annual agricultural gap in the Hot Growth scenario is 22 percent, the agricultural gap in Water District 44 (Lower Yampa River) is 35 percent on average. The largest gaps are found on smaller tributaries to the Yampa River because of physical shortages, but irrigators with more junior water rights on the mainstem are also projected to have gaps. The 14,805 acres of new irrigated land put under production is projected to experience an average annual gap of 56 percent in the Hot and Dry scenario.

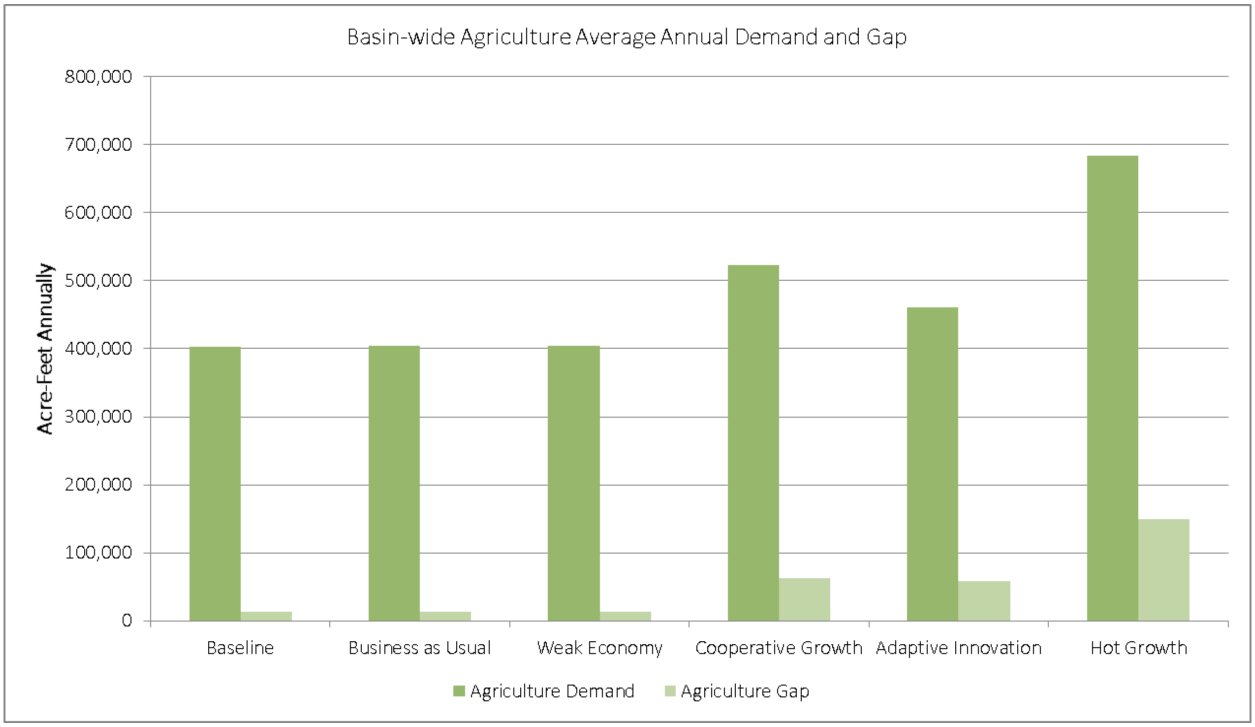


Figure 143: Yampa River Basin Agriculture Average Annual Demand and Gap

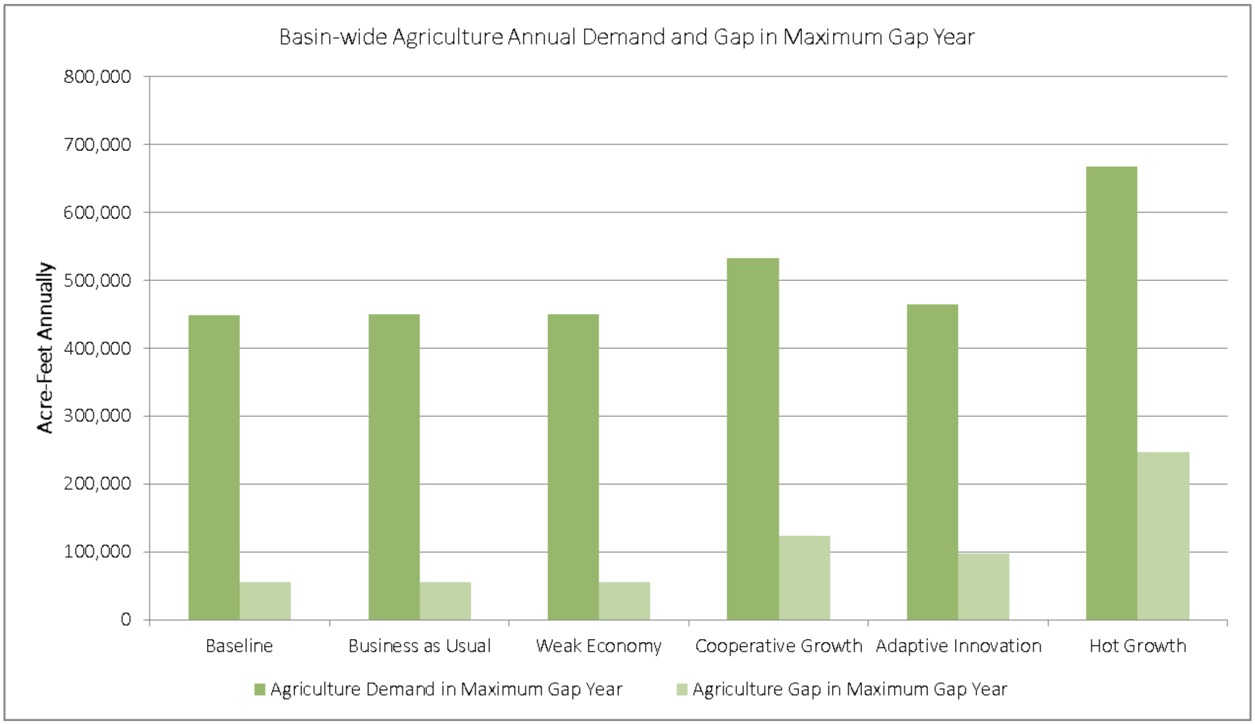


Figure 144: Yampa River Basin Agriculture Annual Demand and Gap in Maximum Gap Year

The annual agricultural gap variability over the model study period is reflected in Figure 145. As expected, the dry hydrology years of 1977, 2002, and 2012 produce the largest gaps regardless of scenario. The Baseline, Business as Usual, and Weak Economy scenarios use current hydrology and the results are very similar on the graph, with results often overlapping. Gaps in these three scenarios are minimal in years with wetter hydrology; however a gap is projected in all years in the study period. Gaps increase as the agricultural demand increases and hydrology is adjusted. Despite differences between projected hydrology, the changes to IWR and irrigation system efficiency in the Adaptive Innovation scenario compensate for the decline in streamflow and the gap results are very similar to the Cooperative Growth scenario gap results. With increased demands and climate-adjusted hydrology, the Hot Growth scenario is projected to have the largest agricultural gaps.

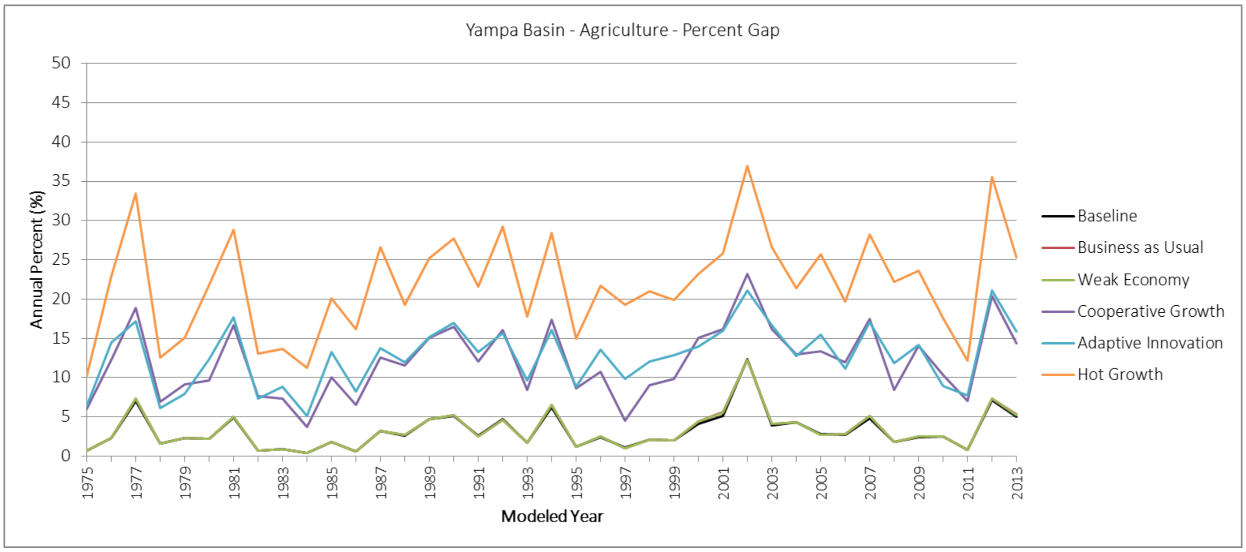


Figure 145: Yampa River Basin Agriculture Percent Diversion Gap Times Series

5.10.2 YAMPA RIVER BASIN M&SSI WATER SUPPLY AND GAP

There is currently approximately 36,000 ac-ft of M&SSI demand in the Yampa River basin; approximately a quarter of the demand is attributable to municipal demands and the remaining three quarters is attributable to SSI demands. Population in the Yampa River basin is projected to increase in all scenarios except the Weak Economy scenario, leading to moderate increases to the municipal demand in the basin in many scenarios. The SSI demand is projected to increase in all scenarios, nearly doubling by the Hot Growth scenario.

Approximately 60 percent of the municipal demand is grouped and represented in the model at several locations throughout the model. The remaining 40 percent is associated with two municipal entities, City of Steamboat Springs (Mt. Werner Water District) and the City of Craig. The demands and surface water rights for these municipalities are represented individually in the model. Approximately 25 percent of the total SSI demand is grouped and represented at several locations in the model. The remaining 75 percent of the SSI demand is attributable to the following entities, which are represented individually in the model:

- Craig Station
- Maybell Mills Pipeline
- Colowyo Mine

- Hayden Station
- Steamboat Resort Snowmaking

Refer to the *Baseline and Projected 2050 Planning Scenario Municipal and Self Supplied Industrial Water Demands* technical memorandum for additional discussion on how the M&SSI demands in the basin were developed. The water supply and gap results for M&SSI in the Yampa River Basin are summarized in Table 46, and graphically reflected in Figure 146 and Figure 147.

Table 46: Yampa River Basin M&SSI Water Supply and Gap Summary

	M&SSI Results	Baseline	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand (ac-ft)	36,894	53,346	46,664	48,914	52,970	68,306
	Average Annual Demand Increase from Baseline (ac-ft)	-	16,452	9,770	12,020	16,076	31,412
	Average Annual Gap (ac-ft)	105	573	217	849	1,407	4,813
	Average Annual Gap Increase from Baseline (ac-ft)	-	468	112	744	1,302	4,708
	Average Annual Percent Gap	0%	1%	0%	2%	3%	7%
Critically Dry Maximum	Demand In Maximum Gap Year (ac-ft)	36,894	53,346	46,664	48,914	52,970	68,306
	Increase from Baseline Demand (ac-ft)	-	16,452	9,770	12,020	16,076	31,412
	Gap In Maximum Gap Year (ac-ft)	397	1,634	684	1,642	2,548	8,190
	Increase from Baseline Gap (ac-ft)	-	1,237	287	1,245	2,151	7,793
	Percent Gap In Maximum Gap Year	1%	3%	1%	3%	5%	12%

Ideally, the Baseline scenario would have no gaps however a small baseline gap is reported. This is due to the model representation of the tributary that supplies water to Colowyo Mine diversion. The mine sources water from pumps on several tributaries, some of which are small and difficult to represent in the model due a runoff signature that differs from other streams in the area. It is difficult to estimate the runoff on this small tributary without measured streamflow information.

The average annual demand increases from the Baseline scenario to the Business as Usual scenario, primarily due to an increase in SSI demand. The annual gap on average and during critically dry years is small, only 1 percent and 3 percent respectively. This indicates that the projected M&SSI demands can largely be satisfied from the entities' existing water rights portfolio and unappropriated flows in the Yampa River basin in the Business as Usual scenario.

The Weak Economy, Cooperative Growth, and Adaptive Innovation scenarios have smaller increases in average annual demand than the Business as Usual scenario and the gaps are also small. Note that even with the climate-adjusted agricultural demands and hydrology in the Cooperative Growth and Adaptive Innovation scenario, the average gap is 2 to 3 percent and the gap in critically dry years is 3 to 5 percent. As with the Business as Usual scenario, the projected M&SSI demands can largely be satisfied from the entities' existing water rights portfolio and unappropriated flows in the Yampa River basin in these scenarios.

The M&SSI demand in the Hot Growth scenario is nearly double the Baseline demands, driven by substantial increases in both municipal and SSI demands. This increase, in combination with increased agricultural demands and reduced hydrology under the Hot and Dry climate conditions, results in larger gaps, with the average annual gap reaching 7 percent and the gap in critically dry years reaching 12 percent. The impact of the Hot and Dry conditions in this scenario is a decline in unappropriated flows available to meet projected M&SSI demands throughout the basin, as a result of both the climate-adjusted hydrology and increased agricultural demand in the basin

In general, M&SSI in the Yampa River Basin is projected to experience relatively low gaps both on average and during critically dry years, as highlighted in Figure 146 and Figure 147. As with other basins, M&SSI water users are not impacted equally throughout the basin, with entities represented individually having far less shortages than those demands represented at grouped locations. For example, the Yampa River Basin average annual M&SSI gap in the Hot Growth scenario is 7 percent. The municipal entities represented with their existing water rights and operations are projected to have no gaps and the individually modeled SSI entities are projected to have a 2 percent gap. Conversely, the demand represented at grouped municipal locations is projected to have an 18 percent gap on average and grouped SSI demand is projected to have a 14 percent gap. The individually modeled entities have robust water rights portfolios capable of meeting a large part of their projected growth and generally have access to reservoir storage. It is likely the demands at grouped locations would have smaller gaps if their water rights portfolios and operations (e.g. reservoir releases) were reflected in the model; it is recommended the representation of these grouped demands is refined in future modeling efforts.

Figure 146: Yampa River Basin M&SSI Average Annual Demand and Gap

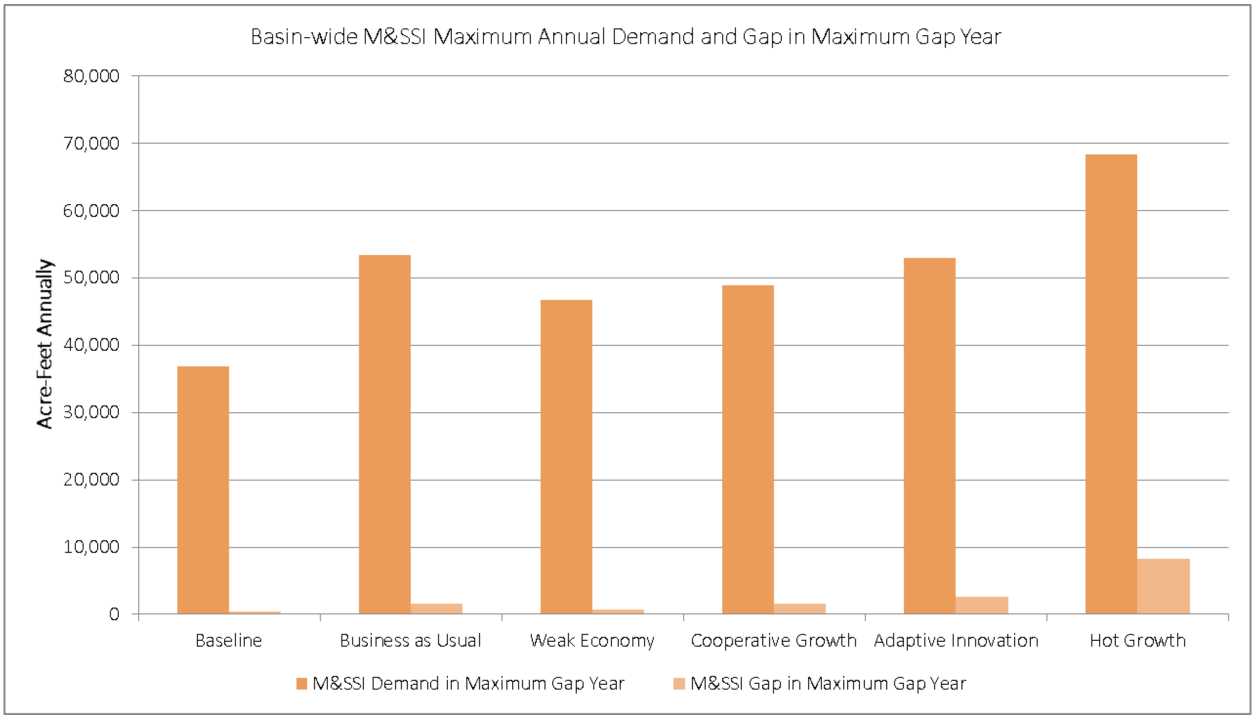


Figure 147: Yampa River Basin M&SSI Maximum Annual Demand and Gap in Maximum Gap Year

Figure 148 reflects the average annual percent gap across a variety of wet, average, and dry year types. The dry hydrology years of 1977 and 2002 produce the largest gaps, regardless of scenario. Note that 2012, despite being an extremely dry year, does not produce as large a gap as other similar dry years. This is because the majority of the M&SSI structures have access to storage, which was filled during the preceding wet year of 2011. The primary drivers of gap appear to be a combination of demand and hydrology.

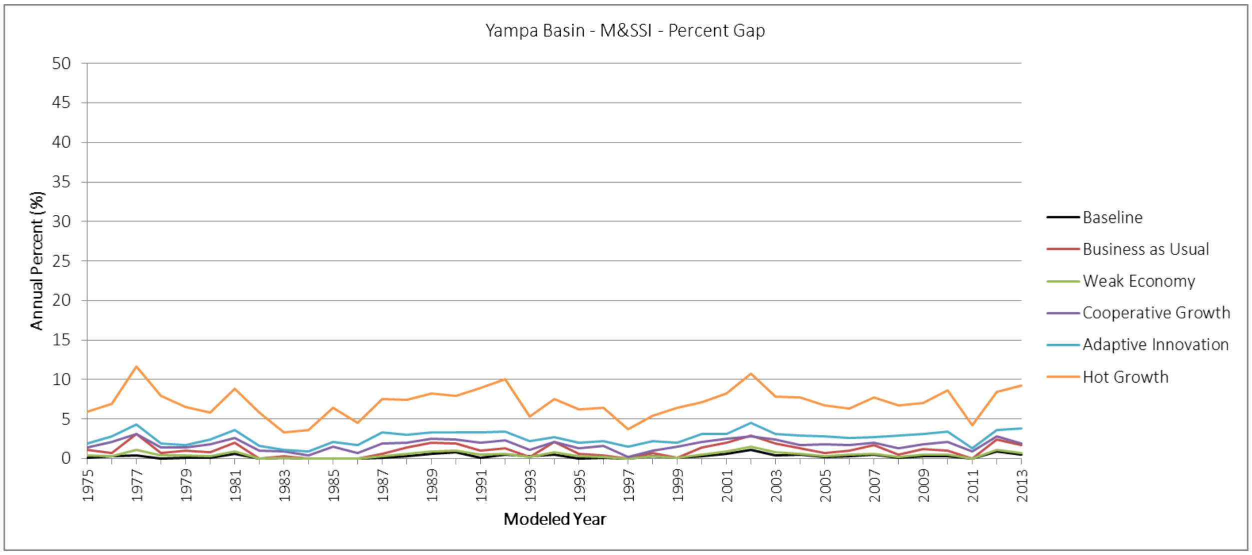


Figure 148: Yampa River Basin M&SSI Average Annual Gap Time Series

5.10.3 YAMPA RIVER BASIN SUMMARY

The combined agriculture and M&SSI demands and gap summary is provided in Table 47. The results are very similar to the agricultural results in Table 45 because water supplies in the basin are predominantly used for agriculture. As previously discussed, gaps are relatively low in the Baseline, Business as Usual and Weak Economy scenarios. Gaps during critically dry years, which occur during drier years, are projected to be more substantial. The gaps increase in the Cooperative Growth and the Adaptive Innovation scenarios as a result of increasing demands and a shift in hydrology. The gaps, both on average and during critically dry years, are largest in the Hot Growth scenario, due to the increased demands and decreased hydrology from the climate projections.

Figure 149 reflects the relative size of the agricultural and M&SSI demands in the Yampa River basin. Following the graphic are summaries regarding other considerations that may impact the basin-wide gap, including potential M&SSI supplies from urbanized acreage.

Table 47: Yampa River Basin Water Supply and Gap Summary

	Agricultural and M&SSI Results	Baseline	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand (ac-ft)	439,382	456,973	450,291	571,367	513,955	752,566
	Average Annual Gap (ac-ft)	13,359	14,182	13,805	63,902	60,354	154,825
	Average Annual Percent Gap	3%	3%	3%	11%	12%	21%
Critically Dry Max	Demand In Maximum Gap Year (ac-ft)	485,764	503,859	497,177	581,886	516,762	735,762
	Gap In Maximum Gap Year (ac-ft)	55,975	56,988	55,903	125,087	100,277	254,727
	Percent Gap In Maximum Gap Year	12%	11%	11%	21%	19%	35%

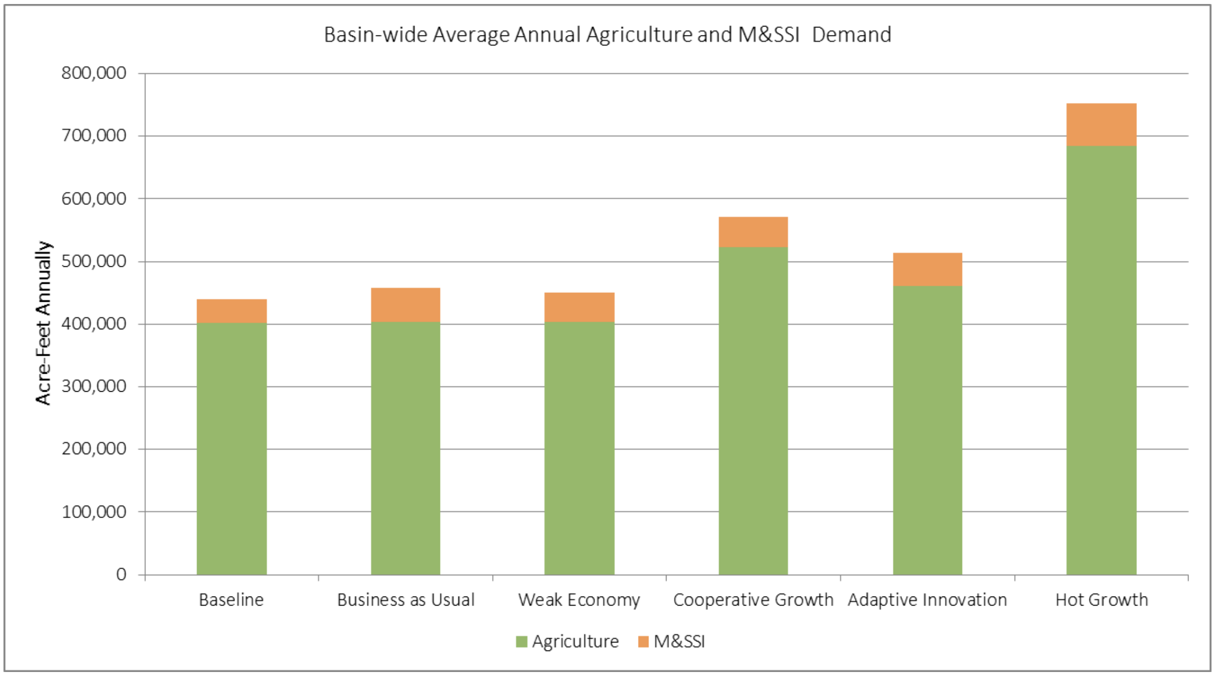


Figure 149: Yampa River Basin Comparison of Average Annual Demands

The Planning Scenarios project 1,500 acres of irrigated agriculture will be taken out of production due to urbanization. Supplies used to irrigate the urbanized acreage could be considered a new municipal supply if the associated water rights were changed to municipal uses. To estimate this new supply, the average consumptive use of the urbanized acreage by Planning Scenario is reflected in Note however that it is not known which farms and ranches will be directly impacted; whether the acreage was served by senior/junior direct rights or had supplemental storage supplies; or the crop type or specific irrigation practices on this acreage. Additionally, it is unknown if the water rights would be changed to municipal use or whether the supply could directly meet the future municipal demand or would require exchange potential. In light of these uncertainties, the table reflects a planning-level estimate of this potential new supply. Although it has not been applied to the M&SSI gap presented above, it would likely have the effect of decreasing the gap.

Table 48. This water could be used to help close the M&SSI gap. Note however that it is not known which farms and ranches will be directly impacted; whether the acreage was served by senior/junior direct rights or had supplemental storage supplies; or the crop type or specific irrigation practices on this acreage. Additionally, it is unknown if the water rights would be changed to municipal use or whether the supply could directly meet the future municipal demand or would require exchange potential. In light of these uncertainties, the table reflects a planning-level estimate of this potential new supply. Although it has not been applied to the M&SSI gap presented above, it would likely have the effect of decreasing the gap.

Table 48: Potential Water Supply from Urbanized Acreage in the Yampa River Basin

Urbanized Acreage Results	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth

Urbanized Acreage	1,500	1,500	1,500	1,500	1,500
Estimated Consumptive Use (ac-ft/year)	2,725	2,725	2,796	2,782	2,446

The Yampa River basin has approximately 120,000 ac-ft of storage, as reflected in the simulated reservoir storage results in Figure 150. Many of the larger reservoirs are for multiple purposes, including flatwater recreation, emergency drought supplies, municipal and industrial storage, and Endangered Fish Recovery Program water (e.g. Elkhead Reservoir). Only the smaller reservoirs, which are concentrated in the upper Yampa, provide water to agriculture, including Stillwater, Yamcolo, Allen Basin, and a portion of Stagecoach Reservoir. The reservoir storage results reflect the portion of storage used annually for agricultural demands; with the majority of the reservoir storage across the basin remains relatively full in all scenarios. Even in scenarios with the Hot and Dry hydrology, the agricultural supplies in the reservoirs are able to recover and refill the majority of study period.

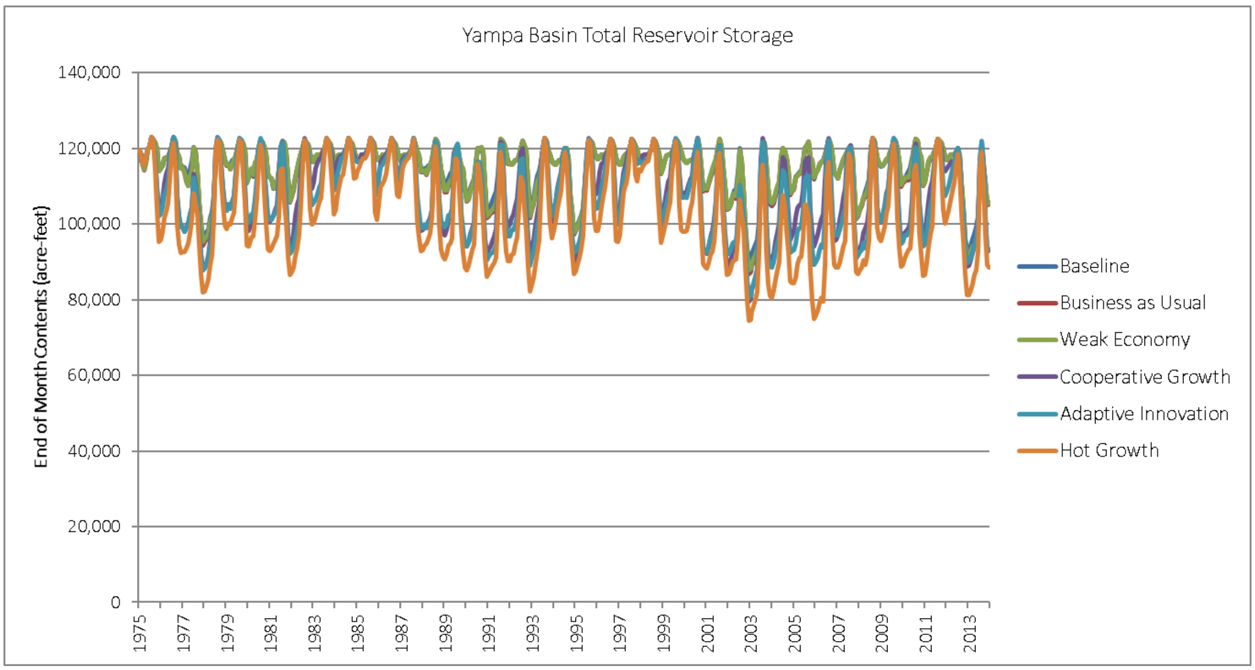


Figure 150: Yampa River Basin Total Reservoir Storage

The following figures show average monthly simulated streamflow at key locations across the basin, as reflected in Figure 142. The primary driver of average monthly simulated streamflow across the Planning Scenarios is hydrology. The average monthly streamflow results from Baseline, Business as Usual, and Weak Economy scenarios are almost indistinguishable from each other because they use the current hydrology. In several locations, the lines graph directly on top of each other. The In-Between hydrology used in the Cooperative Growth scenario reflected a moderate change to total runoff volume, increasing in some areas and decreasing in others. The Hot and Dry hydrology used in the Adaptive Innovation and Hot Growth scenarios further reduces the amount of total runoff volume compared to the In-Between hydrology.

The average streamflow results for gaged locations higher up in the basin best reflect the impact of the climate-adjusted hydrology, particularly the more pronounced peak runoff projected to occur in May and the sharp reduction to streamflow June, July, and August. The total annual volume of flow is actually projected to slightly increase under the In-Between conditions at both the Elk Creek and upper Yampa River locations; however the shift in streamflow availability leads to larger gaps later in the irrigation season. The climate-adjusted hydrology under the Hot and Dry conditions project a one percent decline to total annual streamflow volume for the Elk Creek location and a 9 percent decline for the Steamboat location.

The Yampa River at Deerlodge gage (Figure 153) is the most downstream gage in the basin, and is a good indicator of the total impact of the increased demands and the climate-adjusted hydrology. The simulated streamflow results indicate larger streamflow in March and April for scenarios with climate-adjusted hydrology, primarily because the upper basins projected an earlier runoff. Diversions to the increased demands and reservoir storage deplete the large peak runoff in May under the climate-adjusted hydrology, resulting in similar results between all scenarios for May. The scenario results separate again in the late irrigation season due to the climate-adjusted hydrology, leading to a 13 to 17 percent reduction in total annual streamflow at this location in the Adaptive Innovation and Hot Growth scenarios, respectively.

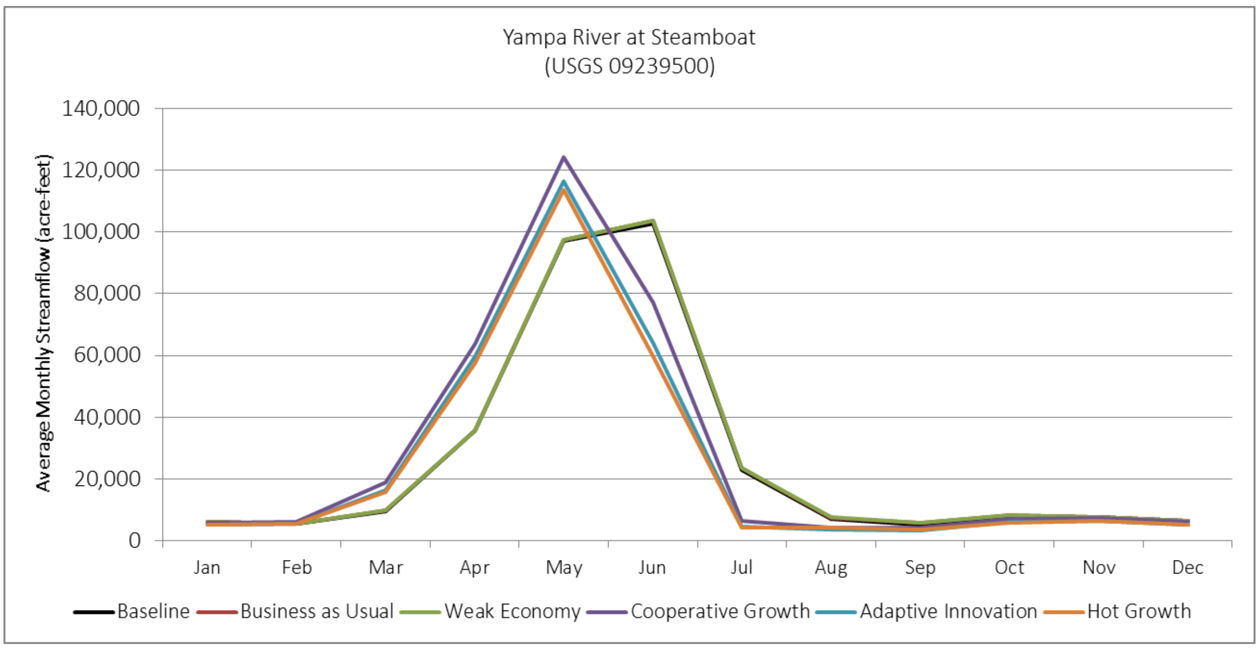


Figure 151: Average Monthly Streamflow for the Yampa River at Steamboat

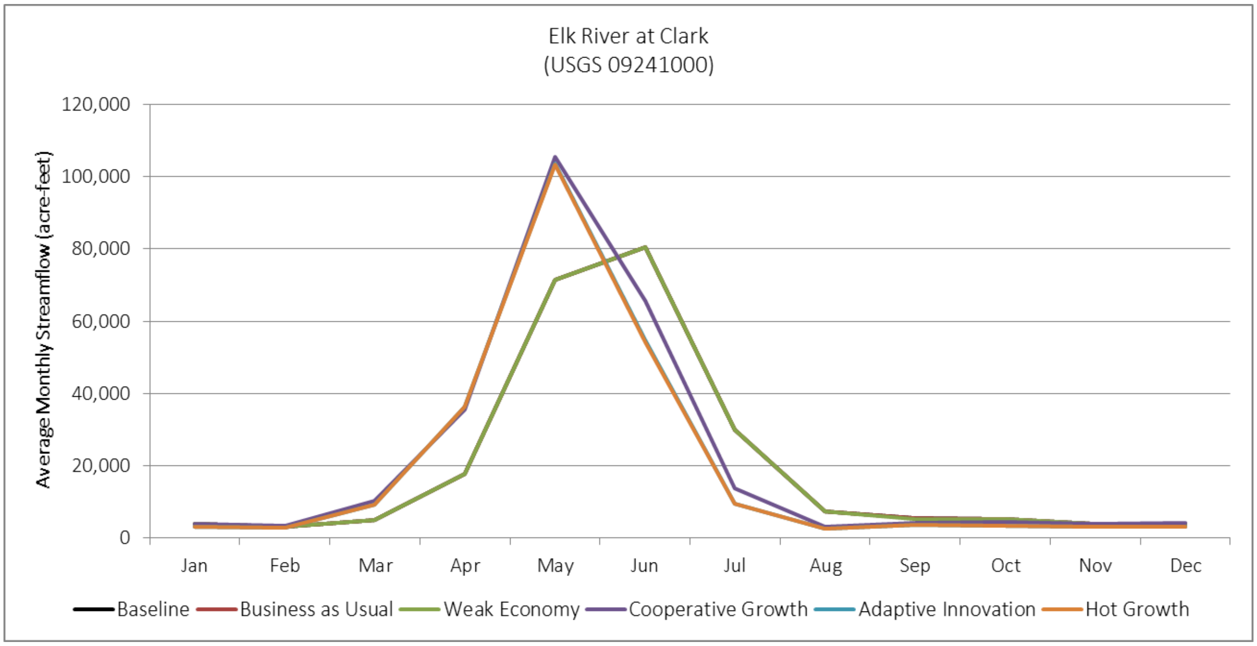


Figure 152: Average Monthly Streamflow for the Elk River at Clark

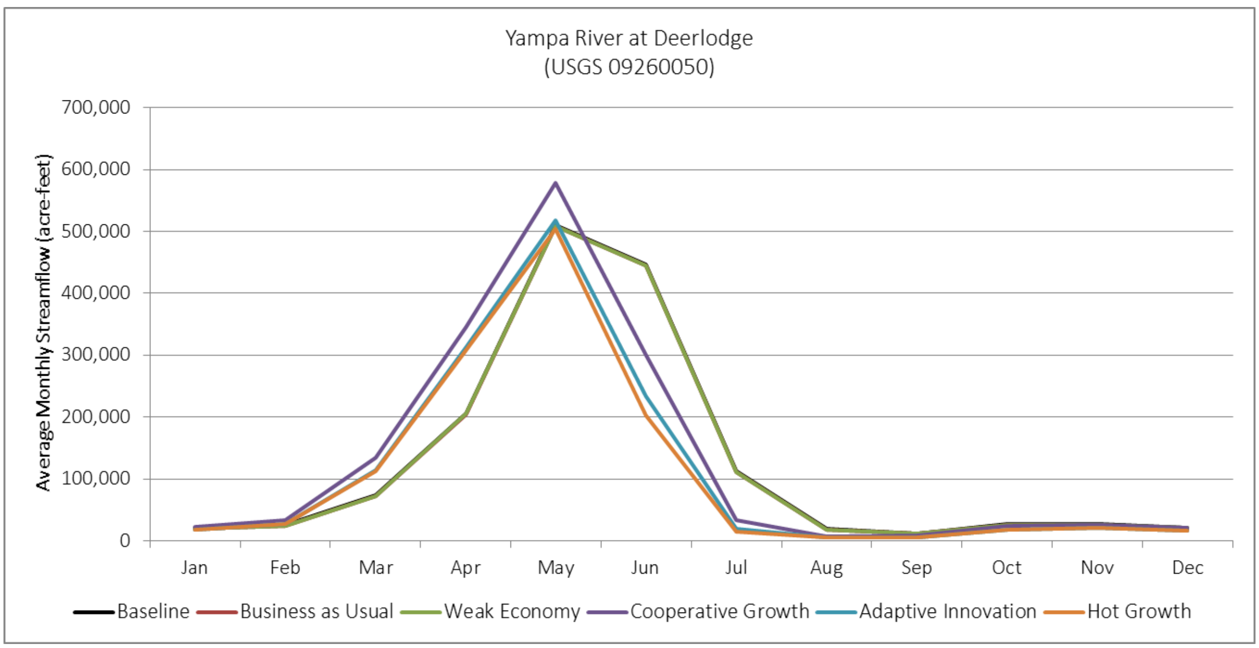


Figure 153: Average Monthly Streamflow for the Yampa River at Deerlodge

Figure 154 and Figure 155 reflect simulated unappropriated available flow for the Yampa River Basin near the Maybell Canal, which is typically the senior calling right in the basin. Available supplies at this location are very near to the physical flow in the stream, indicating that the Maybell Canal does not have a large impact on the available flow upstream. In general, there are substantial unappropriated available supplies throughout the Yampa River basin under current hydrological conditions, particularly on the mainstem which first went under administration during the late irrigation season in 2018. Climate-adjusted hydrology shifts both the streamflow (refer to graphics above) and the unappropriated available supply earlier in the year, leading to lower available supplies during June and July. The figures reflect that available supplies will continue to be available each year, though the amounts will vary annually and across scenarios.

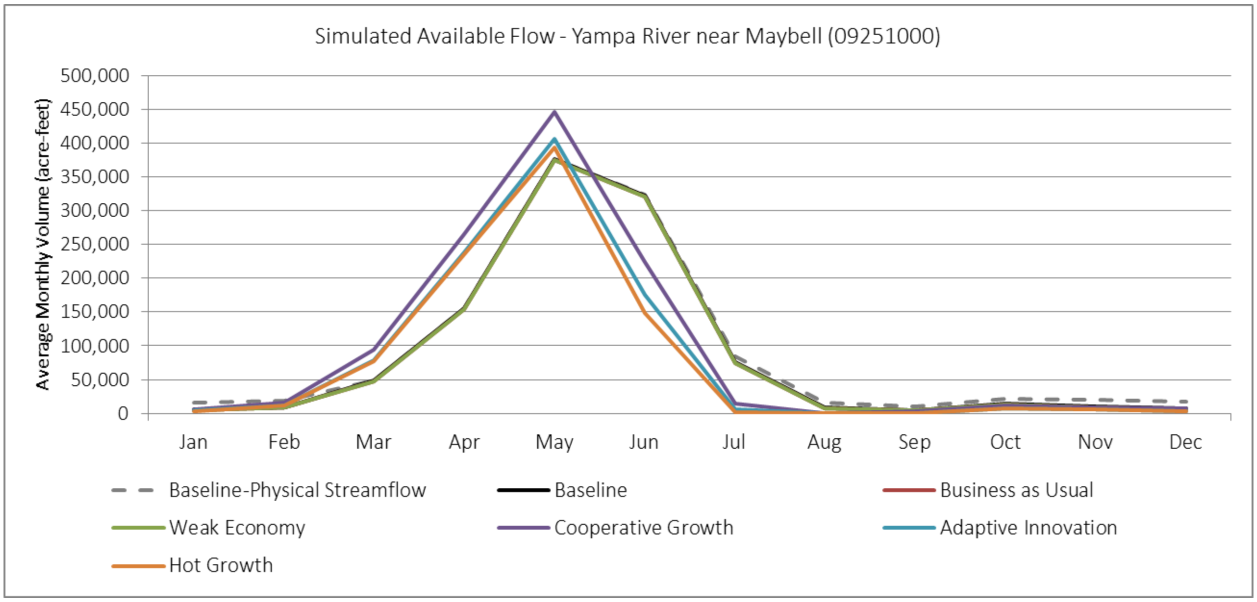


Figure 154: Average Monthly Unappropriated Available Supply at Yampa River near Maybell

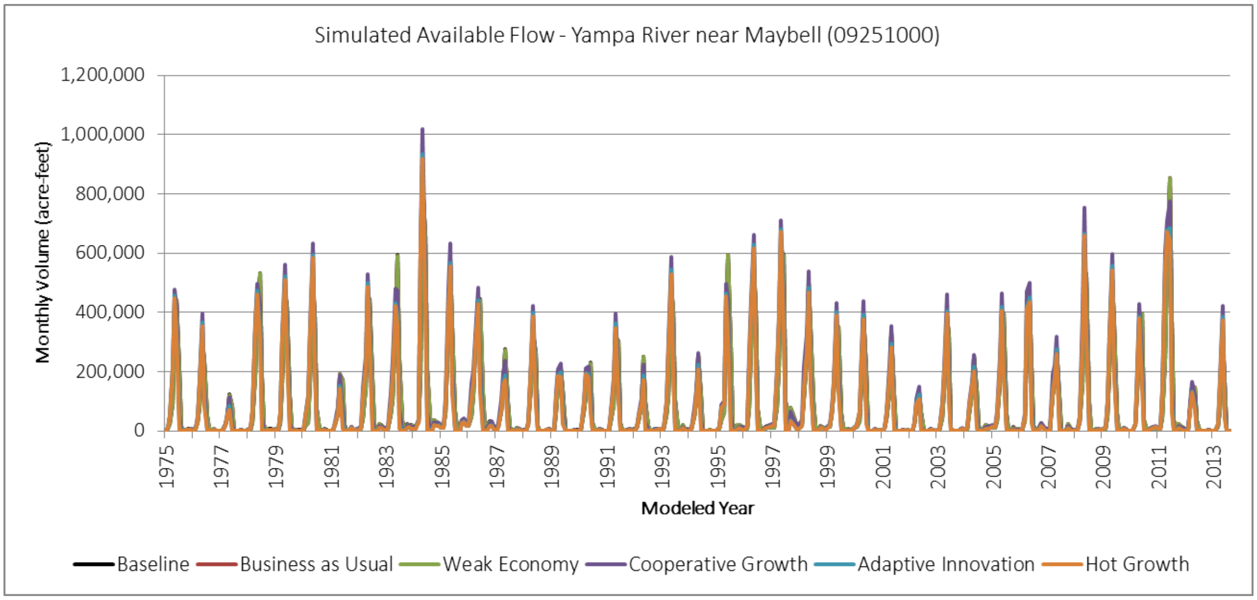


Figure 155: Monthly Unappropriated Available Supply at Yampa River near Maybell

Section 6: Statewide Water Supply and Gap Results

The following graphics and tables reflect the total demand and gap results at a statewide level projected for the 2050 Planning Scenarios. Total demand for water in the state ranged from 12.6 million ac-ft in the Adaptive Innovation scenario to 15.9 million ac-ft in the Hot Growth scenario, compared to the Baseline demand of 14.6 million ac-ft. Agricultural demands are the largest component of the total demand, currently accounting for approximately 88 percent of the statewide demand for water supplies. M&SSI demands are the next largest component of total demand, currently accounting for approximately 8 percent of the total demand. The remaining 4 percent of demand is attributable to transbasin diversions.

Agricultural users also experience the largest gap, both currently and in the 2050 Planning Scenarios. Average annual statewide gaps range from 2.4 million ac-ft in the Weak Economy scenario to 3.9 million ac-ft in the Hot Growth scenario. During critically dry years, however, the statewide gap essentially doubles in magnitude when compared to the average gap for each scenario. Although a smaller component of the overall Planning Scenario demand, M&SSI demands are projected to experience substantial gaps, particularly in dry years.

Similar to the basin summaries, the individual agricultural and M&SSI demand and gap results are presented, followed by the combined total statewide demand and gap results.

6.1 STATEWIDE AGRICULTURAL DEMAND AND GAP RESULTS

Table 49 reflects the total statewide agricultural demand and gap results; the following figures graphically illustrate the information in the table. As shown, the agricultural demand ranges from 10.3 million ac-ft in the Adaptive Innovation scenario to 13.3 million ac-ft in the Hot Growth scenario, an increase of nearly a half million ac-ft of demand over current levels. This increase in demand is largely due to projected climate adjustments to IWR because the total irrigated acreage in the State is projected to decline by approximately 400,000 to 500,000 acres depending on the scenario. As reflected, basins with the most irrigated acreage have the largest agricultural demands. The South Platte River, Arkansas River, and Rio Grande basins currently experience, and are projected to continue experiencing, the largest agricultural gaps. Conversely, the Colorado and Gunnison River basins have the smallest agricultural gap relative their agricultural demand.

Table 49: Statewide Agricultural Water Supply and Gap Summary

	Statewide Agricultural Results	Baseline	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand (ac-ft)	12,860,355	11,696,986	11,712,629	12,883,977	10,351,049	13,308,032
	Average Annual Gap (ac-ft)	2,434,152	2,212,779	2,214,511	2,804,507	2,677,782	3,379,106
	Average Annual Percent Gap	19%	19%	19%	22%	26%	25%
Critically Dry Max	Demand In Maximum Gap Year (ac-ft)	14,595,766	13,205,689	13,221,367	13,605,979	11,096,804	13,923,741
	Gap In Maximum Gap Year (ac-ft)	5,437,291	5,003,738	4,990,958	5,631,276	5,107,488	6,573,161
	Percent Gap In Maximum Gap Year	37%	38%	38%	41%	46%	47%

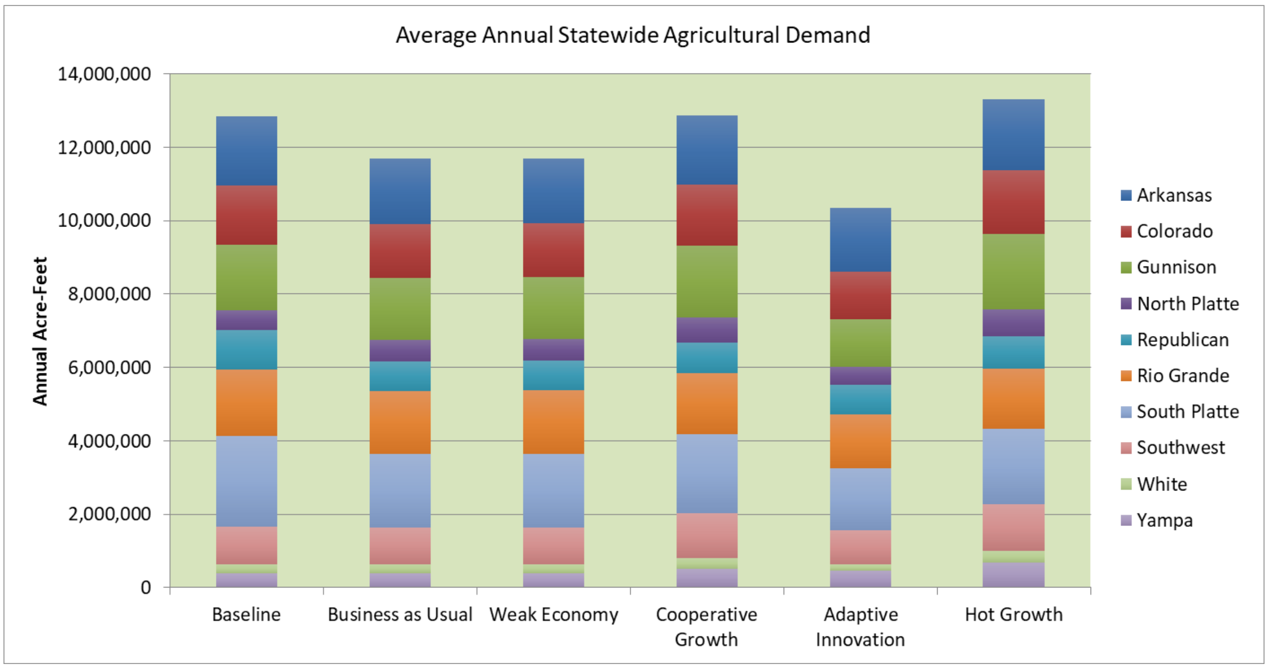


Figure 156: Average Annual Statewide Agricultural Demand

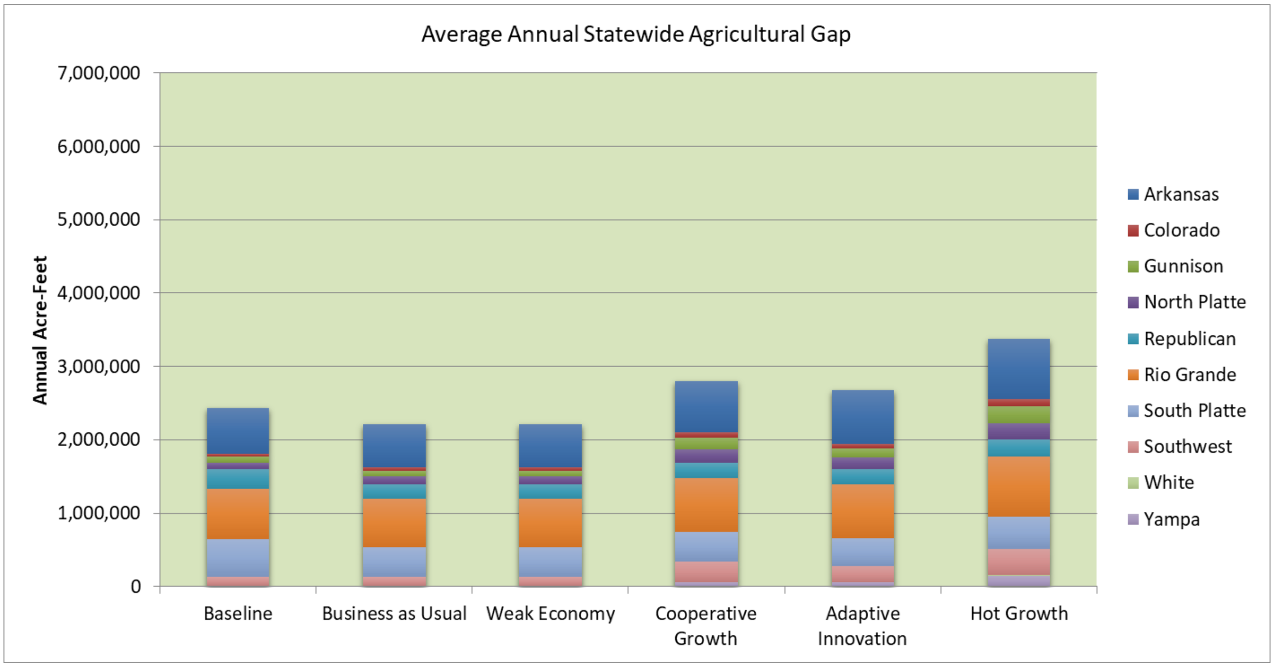


Figure 157: Average Annual Statewide Agricultural Gap

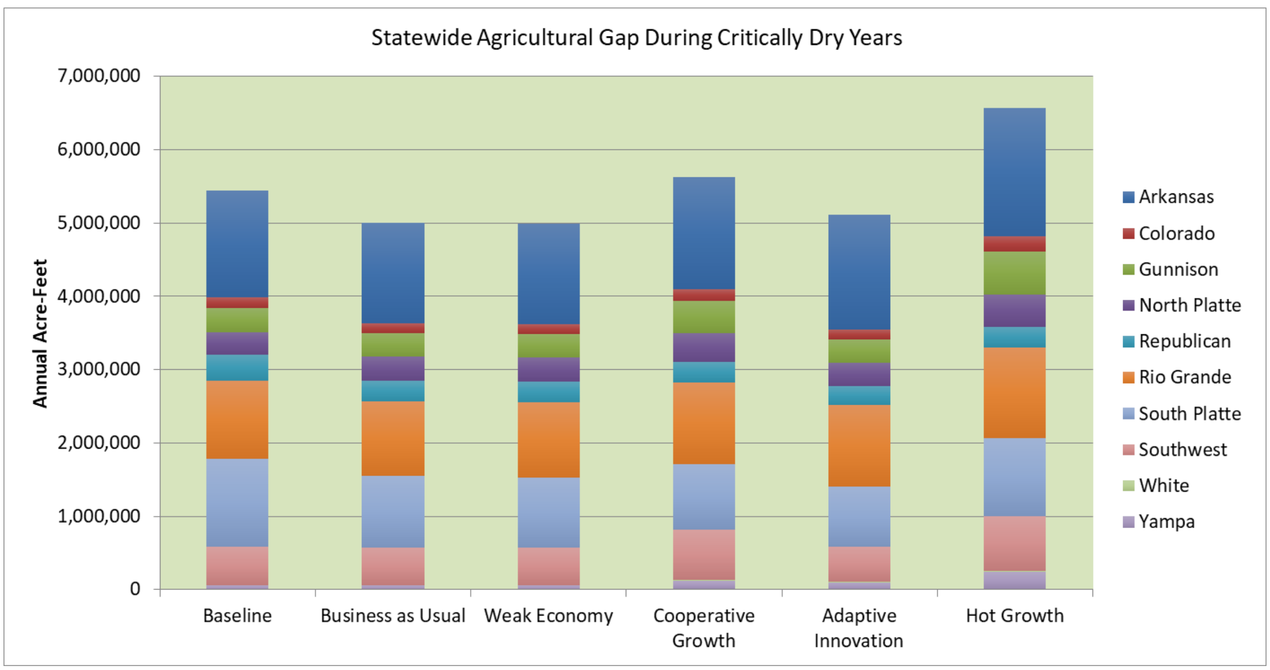


Figure 158: Statewide Agricultural Gap During Critically Dry Years

6.2 STATEWIDE M&SSI DEMAND AND GAP RESULTS

Table 50 reflects the total statewide M&SSI demand and gap results; the following figures graphically illustrate the information in the table. As shown, the M&SSI demand ranges from 1.5 million ac-ft annually in the Weak Economy scenario to over 2 million ac-ft annually in the Hot Growth scenario, an increase of 350,000 to 850,000 ac-ft annually, respectively, over Baseline demands. This projected increase is driven by population growth, primarily in the South Platte and Arkansas River basins. As the demand in these basins already exceeds available supplies, it is expected that these basins are also projected to experience the largest M&SSI gaps. The average annual M&SSI gap ranges from 192,000 to 566,000 ac-ft across the Planning Scenarios, however maximum gap information is used more frequently in planning efforts by M&SSI water providers. Gaps in critically dry years range between 245,000 to 754,000 ac-ft annually depending on the Planning Scenario, with over 85 percent of that gap projected to occur in the South Platte and Arkansas River basins.

Table 50: Statewide M&SSI Water Supply and Gap Summary

	Statewide M&SSI Results	Baseline	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand (ac-ft)	1,176,840	1,698,192	1,530,538	1,601,985	1,694,295	2,032,851
	Average Annual Gap (ac-ft)	2,608	274,583	192,041	229,620	303,297	566,066
	Average Annual Percent Gap	0%	16%	13%	14%	18%	28%
Critically Dry Max	Demand In Maximum Gap Year (ac-ft)	1,178,122	1,699,475	1,531,820	1,603,268	1,694,313	2,032,869
	Gap In Maximum Gap Year (ac-ft)	21,284	348,546	245,095	293,282	429,150	754,178
	Percent Gap In Maximum Gap Year	2%	21%	16%	18%	25%	37%

As noted throughout this report, the gaps presented above do not take into account potential future water supplies from urbanized irrigated acreage nor the potential impact from a reduction to transbasin supplies in climate-adjusted scenarios. Refer to the basin sections above for more information on the modeling assumptions regarding these drivers.

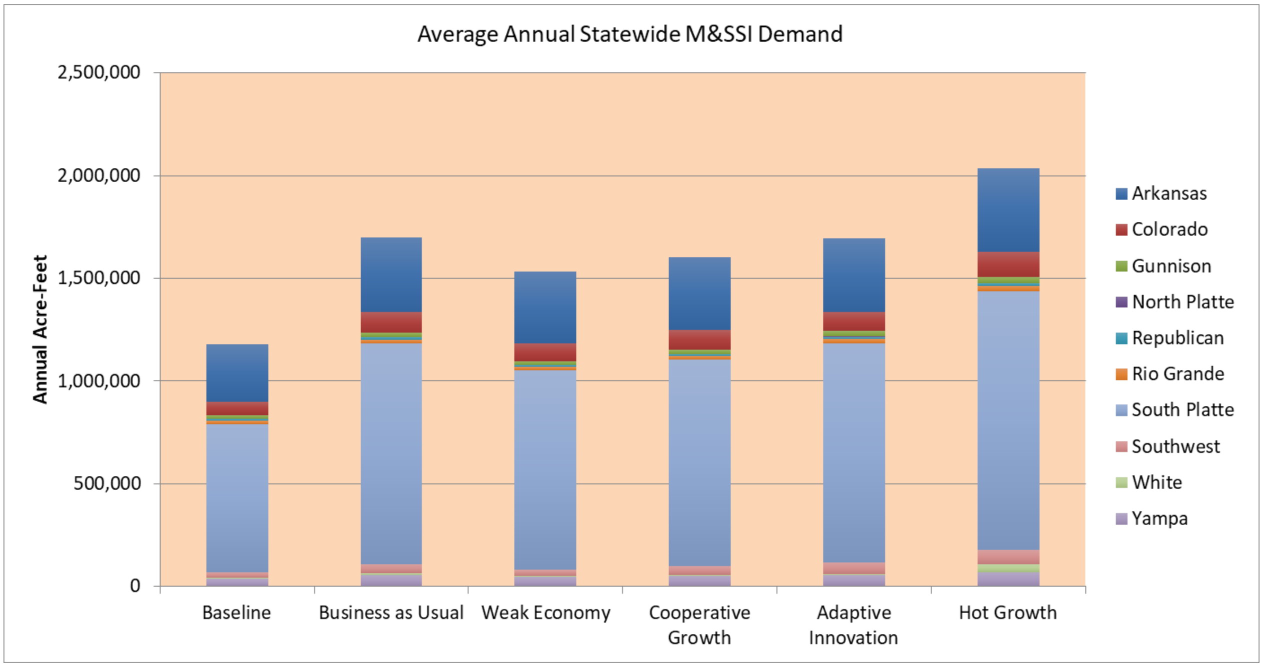


Figure 159: Average Annual Statewide M&SSI Demand

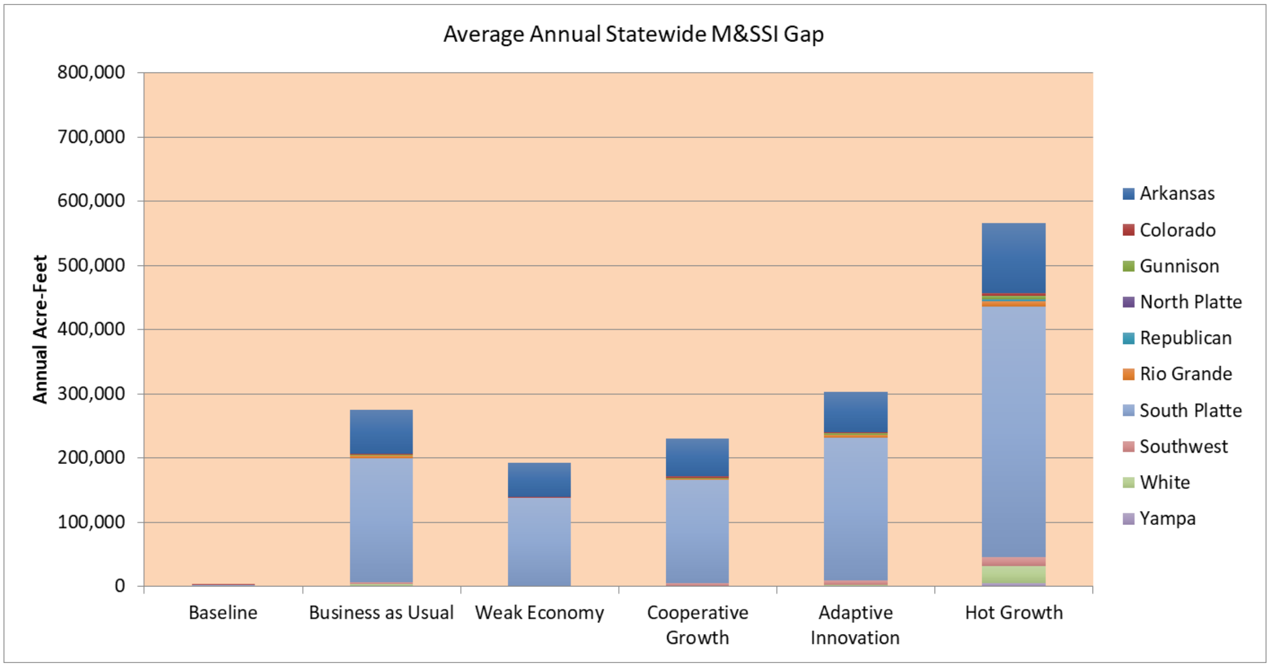


Figure 160: Average Annual Statewide M&SSI Gap

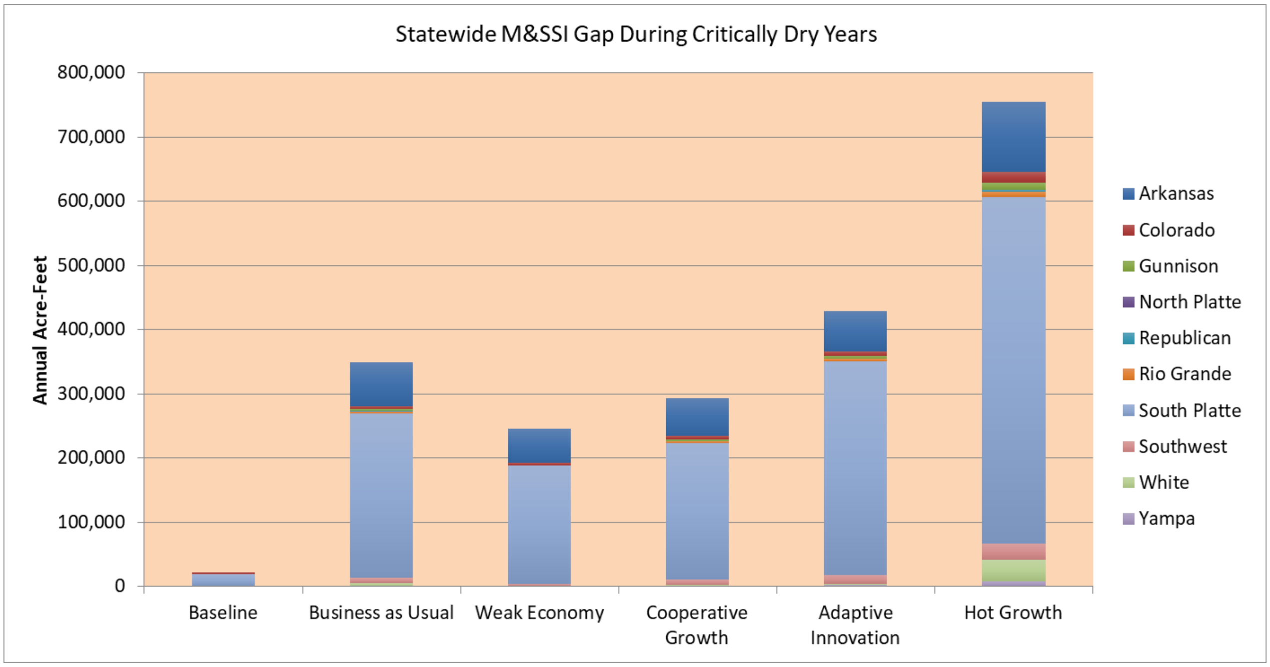


Figure 161: Statewide M&SSI Gap During Critically Dry Years

6.3 STATEWIDE TOTAL DEMAND AND GAP RESULTS

Table 51 reflects the total statewide demand and gap results; the following figures graphically illustrate the information in the table. The total statewide demand values include the agricultural and M&SSI demand summarized above plus approximately 530,000 ac-ft of transbasin demand. The agricultural component of the demand and gap dominate the statewide results, therefore the results look very similar to those presented in Table 49.

As shown, the statewide demand for water ranges from 12.6 million ac-ft annually in the Adaptive Innovation scenario to 15.9 million ac-ft annually in the Hot Growth scenario. Three out of the five Planning Scenarios reflect a decrease in statewide demand, largely due to the projected reduction in irrigated acreage and associated reduction in agricultural demand. The Cooperative Growth and Hot Growth scenarios reflect a moderate increase in demand compared to Baseline levels. Over 20 percent of the statewide demand is projected to occur in the South Platte River basin, the largest of any basin.

The average statewide gap increases in all Planning Scenarios, except the Weak Economy scenario, which shows a modest decline of approximately 30,000 ac-ft annually. Gaps during critically dry years essentially double in magnitude compared to the average values. During these dry years, one-third of total statewide demand is shorted in the Business as Usual and Weak Economy scenarios, with this increasing in the remaining climate-adjusted scenarios to reach 45 percent of shorted demand in the Hot Growth scenario.

Statewide gaps provide a broad overview of how the demands and water supply may react under the Planning Scenarios drivers. It is important to remember that local water supply conditions are impacted by hydrology, demands, and operations within a stream reach and that more detailed analysis on a sub-basin level is necessary to further understand and begin planning for the mitigation of future shortages.

Table 51: Statewide Water Supply and Gap Summary

	Statewide Results	Baseline	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand (ac-ft)	14,562,997	13,920,980	13,768,969	15,011,764	12,571,146	15,866,684
	Average Annual Gap (ac-ft)	2,436,760	2,487,362	2,406,551	3,034,127	2,981,079	3,945,173
	Average Annual Percent Gap	17%	18%	17%	20%	24%	25%
Critically Dry Max	Demand In Maximum Gap Year (ac-ft)	16,304,295	15,435,571	15,283,594	15,892,849	13,268,079	16,433,571
	Gap In Maximum Gap Year (ac-ft)	5,458,575	5,352,284	5,236,053	5,924,558	5,536,638	7,327,339
	Percent Gap In Maximum Gap Year	33%	35%	34%	37%	42%	45%

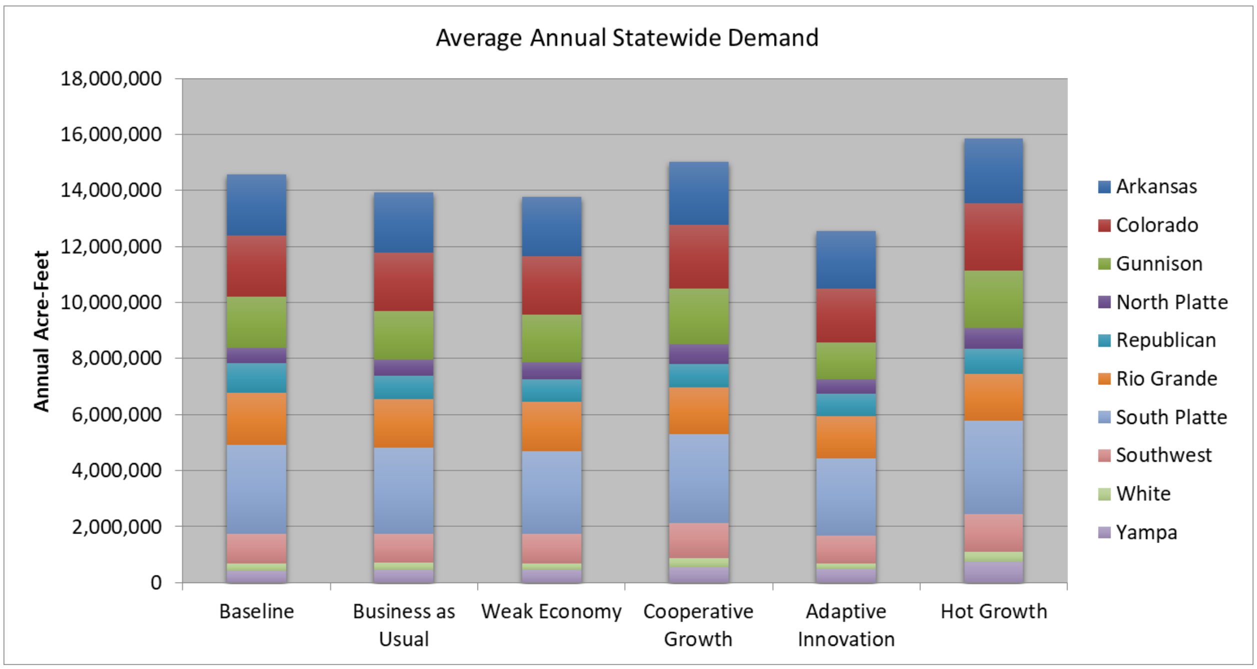


Figure 162: Average Annual Statewide Demand

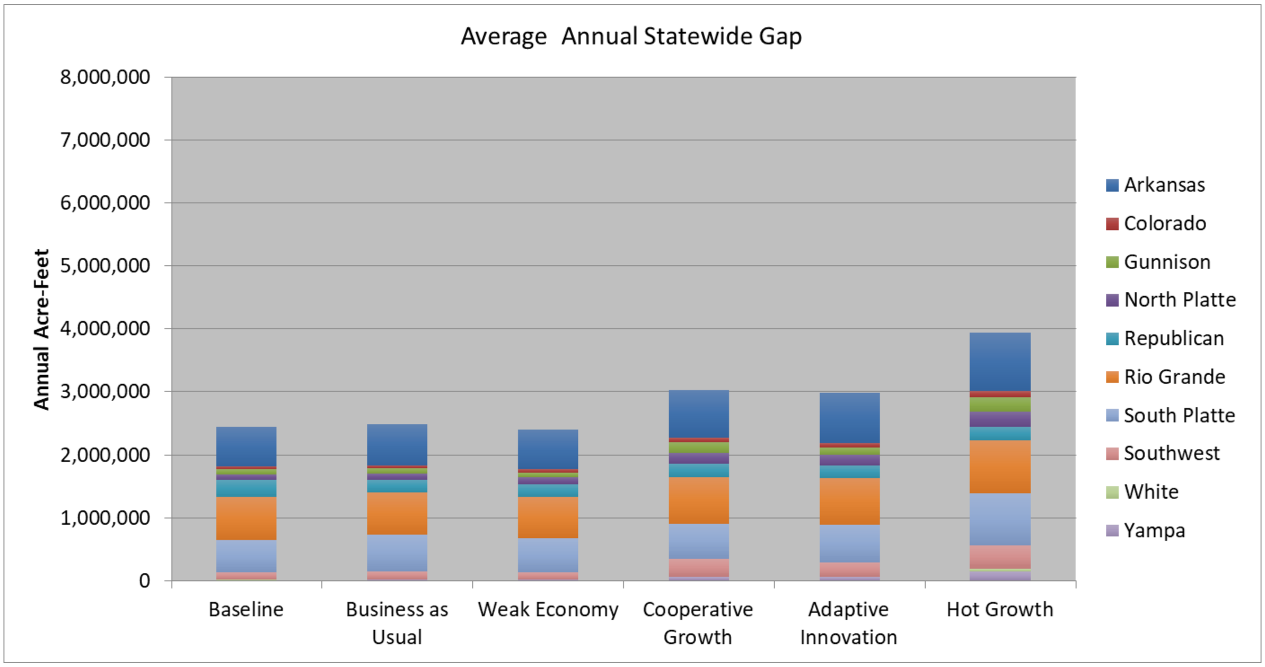


Figure 163: Average Annual Statewide Gap

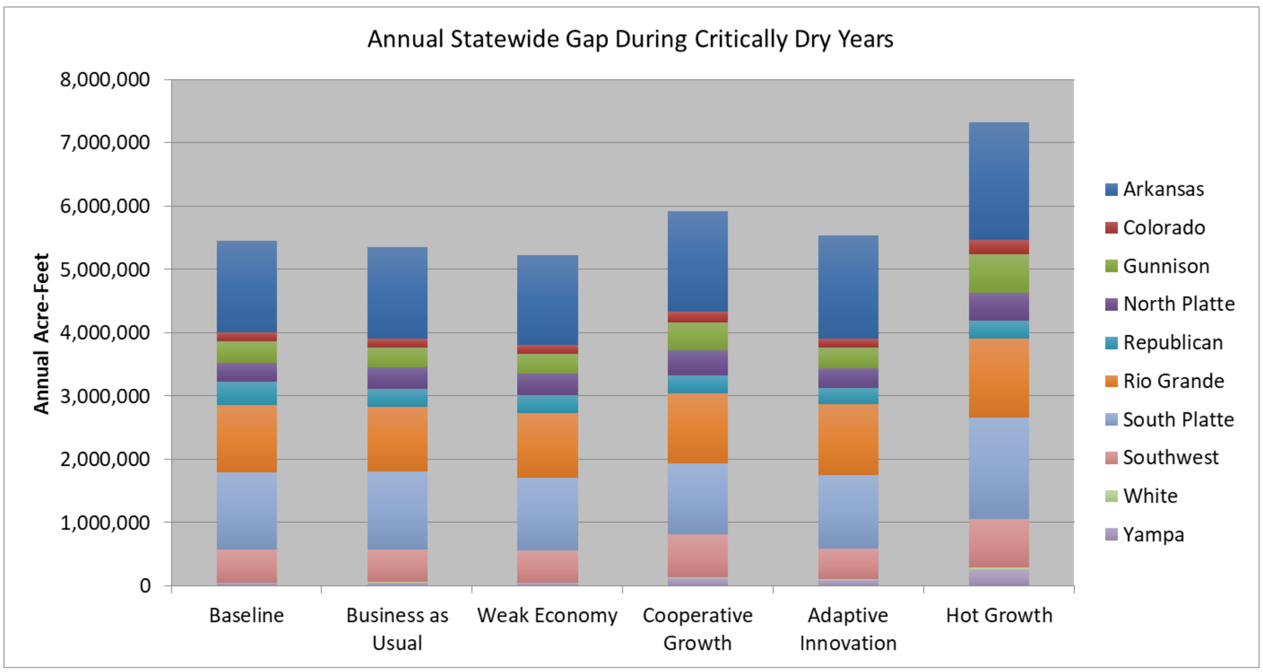


Figure 164: Annual Statewide Gap During Critically Dry Years

Section 7: Comments and Concerns

The following reflects observations and comments that should be considered when reviewing the current and 2050 Planning Scenario water supply and gap results.

- Agricultural Diversion Demands. The agricultural diversion demand is defined as the amount of water that would need to be diverted or pumped to meet the full crop irrigation demand but does not reflect nor consider the common practice of re-diverting irrigation return flows many times within a river basin. As such, it is not appropriate to assume the total demand reflects the amount of native streamflow that would need to be diverted to meet the full crop irrigation demand. Additionally, the current agricultural diversion demands are not directly comparable to historical diversions, because historical diversions reflect changing irrigation practices, crop types, and acreage, as well as physical and legal water availability shortages.
- Planning Scenario Adjustments. The five planning scenarios describe plausible futures with characteristics that require several adjustments to demands. It is difficult to isolate the impact of a specific adjustment because the adjustments tend to compound and overlap within a planning scenario. If water resources planners are interested in the impact of an individual adjustment, they are encouraged to obtain the model datasets and implement the adjustments in a stepwise fashion, analyzing the results after each adjustment is implemented.
- Basin-wide Planning Models. A primary objective of CDSS is to develop water allocation models that can be used to evaluate potential future planning issues or management alternatives based on Colorado Water Law at a regional level. The level of detail regarding representation of hydrology, operations, and demands in the model is appropriate for the Technical Update efforts. The models operate on a monthly time-step, therefore do not capture daily changes in streamflow, routing of reservoir releases, or daily accretions or depletions to the river system. One hundred percent of the consumptive use demands are represented in the model, and many are represented with their individual water rights and operations. Smaller streams are not individually represented in the model; rather the demands and contributing inflow from those tributaries are grouped and represented on larger tributaries in the model. Information used in the modeling datasets is based on available data collected and developed through CDSS, including information recorded by the State Engineer's Office. The model datasets and results are intended for basin-wide planning purposes. Individuals seeking to use the model dataset or results in any legal proceeding are responsible for verifying the accuracy of information included in the model.
- Representation of Water Supplies and Operations. The Baseline models reflect one representation of water user's operations associated with their current infrastructure. The representation in the model is intended to capture their typical operations; however they are simplified and do not reflect the full suite of operations generally available to larger water providers. This representation may not capture operational adjustments or agreements implemented during drought conditions, or the maximum operational flexibility of using water supplies from multiple sources. In addition, the model allocates water according to prior appropriation and non-decreed "gentlemen's agreements" are generally not represented in the models.
- Compacts in Model. The Technical Update analysis did not contemplate the potential impacts of a Colorado River Compact call. To do so in a defendable way would have required the use of a linked model that accounts for actions and conditions in other states; this level of analysis was beyond the scope of the Technical Update study. Interstate compact requirements in other

basins (e.g. South Platte River, La Plata) are reflected in the modeling or other analyses that were used to evaluate gaps and available water supplies.

- **Solutions/Projects.** The Technical Update is intended to develop water supply and gap information that can be used by basin roundtables for future planning efforts, including the development of potential solutions to mitigate gaps. The models can be used to evaluate the effectiveness of a future solution, though future projects and/or solutions are not currently included in the models.
- **Model Calibration**. Each water allocation model undergoes calibration, in which the model developer adjusts model inputs to achieve better agreement between the simulated and measured streamflow, diversions, and reservoir contents. The model builds on historical water supply information, and if information is missing, errant, or there are data inconsistencies, the model cannot be well calibrated and cannot accurately predict future conditions. The models are only as good as the input. The following graphic reflects an area in the South Platte Model that will require additional winter-time calibration in the future. The South Platte River at Julesburg gage is located just upstream of the Colorado-Nebraska stateline on the mainstem of the South Platte River. Simulated streamflow at this location is an accumulation of all of the operations in the South Platte River, but is heavily influenced by well pumping, storage, and augmentation operations in the Lower South Platte. As discussed above, ground water pumping levels are estimated as long term pumping records were not available. Additionally, at the time of the South Platte River model development, only a couple years of records were available for the relatively new practice of making diversions to recharge pits where the lagged return flow from those pits meet future augmentation requirements. These records were used to inform the model calibration, however the records were not available for a long enough period for the model to be fully calibrate over a variety of hydrological conditions. The models are continually improved and calibrated as they are used, and it is recommended the South Platte River basin roundtable improve the model calibration and operations in this area prior to using it in future BIP efforts.

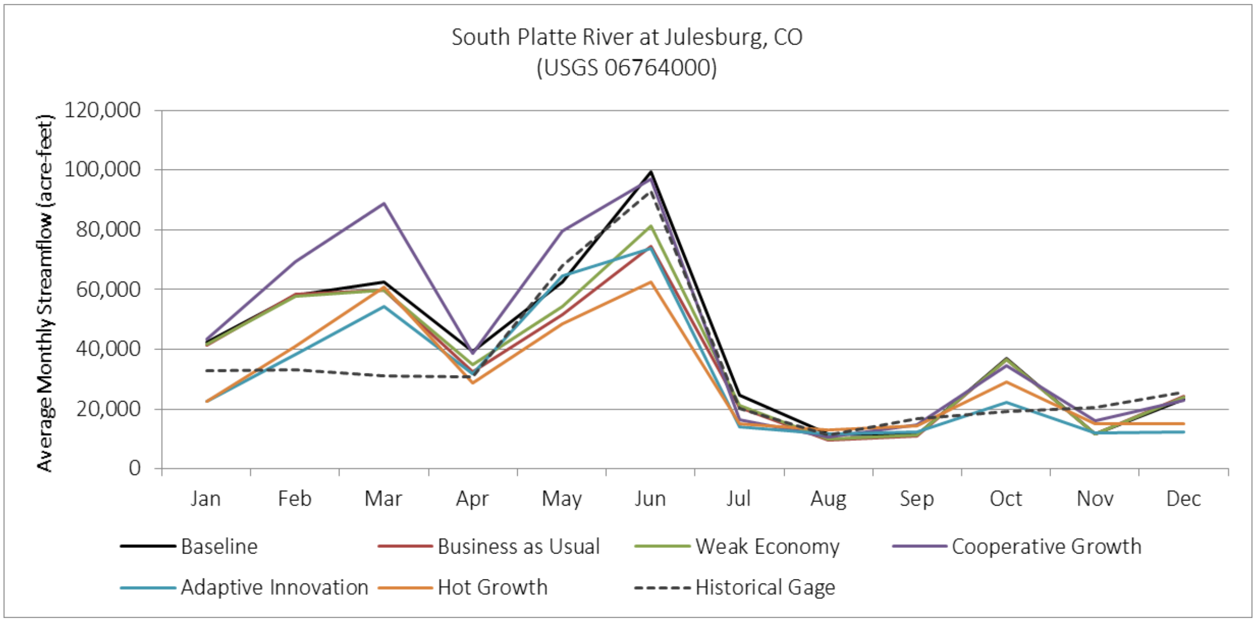


Figure 165: South Platte River at Julesburg Calibration Example

- **Groundwater Pumping Levels/ Transbasin Diversions**. The models reflect current levels of groundwater pumping and transbasin diversions. Noting that administration of groundwater pumping shifted due to the mid-2000s drought, post-drought groundwater pumping levels were used in the baseline and planning scenario models. Similarly, the historical transbasin diversions were used in the baseline and planning scenario models. Transbasin diversions are based on many factors; including water availability and storage in the source and destination basins, demands, other water supplies available to the water provider, and other operational considerations like water quality. Projecting how these factors may change under the 2050 planning scenarios was beyond the Technical Update scope, therefore transbasin diversions were set to historical levels.

Section 8: References

Colorado Water Plan

Colorado Water Conservation Board, 2015, Colorado Water Plan Website (www.colorado.gov/cowaterplan)

Basin Implementation Plans

Colorado Water Conservation Board and Basin Roundtables, 2015, Colorado Water Plan Website (www.colorado.gov/cowaterplan)

The Administration of the Rio Grande Compact in Colorado

Steve Vandiver, Division of Water Resources, WRRI Conference Proceedings, 1999 New Mexico Water Resources Research Institute Website (https://nmwrri.nmsu.edu/wp-content/uploads/2015/watcon/proc44/vandiver.pdf)

Current and 2050 Planning Scenario Agricultural Diversion Demand

Colorado Water Conservation Board Technical Update, Prepared by Wilson Water Group and Jacobs Engineering Group, 2019, Colorado Water Plan Website (www.colorado.gov/cowaterplan)

Baseline and Projected 2050 Planning Scenario Municipal and Self-Supplied Industrial Water Demands

Colorado Water Conservation Board Technical Update, Prepared by Element Water Consulting and Jacobs Engineering Group, 2019, Colorado Water Plan Website (www.colorado.gov/cowaterplan)

Temperature Offsets and Precipitation Change Factors Implicit in the CRWAS-II Planning Scenarios

Colorado Water Conservation Board Technical Update, Prepared by Lynker Technologies, 2019, Colorado Water Plan Website (www.colorado.gov/cowaterplan)

Temperature Offsets and Precipitation Change Factors Implicit in the CRWAS-II Planning Scenarios

Colorado Water Conservation Board Technical Update, Prepared by Lynker Technologies and Wilson Water Group, 2019, Colorado Water Conservation Board website (http://cwcb.state.co.us/technical-resources/colorado-river-water-availability-study/Pages/CRWASSupportingDocuments.aspx)

The Gunnison River Basin, A Handbook for Inhabitants

Gunnison River Basin Roundtable, Prepared by Public Education and Outreach Committee of the Roundtable and Colorado Mesa University, 2013-2014, Upper Gunnison River Water Conservancy District Website (www.ugrwcd.org)

Appendix A: Incorporation of Agricultural and M&SSI Diversion Demands

Current and 2050 Planning Scenario M&SSI demands were developed by the Technical Update municipal demand technical consultant (Element Water Inc.) based on current and projected population and daily per capita demands. The methodology for developing these demands, including discussion on drivers used to adjust demands across Planning Scenarios, is documented in the *Baseline and Projected 2050 Planning Scenario Municipal and Self-Supplied Industrial Water Demands* memorandum. Annual municipal and SSI demands were developed and provided at a county level. This appendix summarizes how the M&SSI demands were disaggregated to a monthly time-step, converted from a county to Water District level, and incorporated into the water supply modeling efforts.

Municipal Demands

Annual indoor and outdoor municipal demands were primarily grouped at the county level, with demands for larger cities provided separately in order to represent them individually in the model. The following approach was used to process the individual and grouped municipal demands for use in the baseline and 2050 Planning Scenario models:

- Annual indoor demands for residential and non-residential were summed to develop a single annual indoor demand for an individual city or county.
- Outdoor and non-revenue demands were summed to produce a single annual outdoor demand for an individual city or county.
- Annual indoor and outdoor demands were disaggregated to a monthly time-step.
    - Indoor demands were assumed to be constant throughout the year.
    - Outdoor demands were distributed to a monthly time-step based on a representative IWR demand curve (i.e. percent of total IWR demand each month) for bluegrass. A bluegrass demand curve was developed using the Modified Blaney-Criddle equation with climate information from a representative weather station in each basin. Table 52 reflects the monthly factors used in each basin, note that winter months have no outdoor demands.

Table 52: Outdoor Demand Disaggregation Curves

Basin	Apr	May	Jun	Jul	Aug	Sep	Oct
Arkansas River Basin	10%	14%	20%	20%	17%	14%	5%
Colorado River Basin	10%	14%	20%	21%	16%	12%	7%
Gunnison River Basin	10%	14%	20%	21%	17%	13%	5%
North Platte River Basin	2%	19%	29%	28%	18%	4%	0%
Republican	10%	13%	19%	21%	18%	14%	5%
Rio Grande Basin	8%	17%	22%	23%	19%	11%	-
South Platte River	9%	15%	19%	20%	17%	13%	7%
Southwest Basin	10%	14%	21%	21%	17%	13%	4%
White River Basin	8%	15%	22%	24%	19%	11%	1%
Yampa River Basin	5%	17%	25%	27%	20%	6%	-

- County monthly indoor and outdoor demands were distributed to Water Districts so they could be included on a representative tributary in the model. A spatial process was used to calculate the percent area of each county in a Water District. The demands were grouped by Water District by first multiplying the percent of county area in a Water District by the county demand and then summing the portions of the demand in each Water District to create one grouped municipal indoor and outdoor demand by basin. This process assumes that grouped municipal demands occur uniformly across each county and/or Water District.
    - An exception to the process above was made for Water Districts 76 and 48. These Water Districts are located in Larimer County and are included within the North Platte River basin results. Larimer County is expected to experience large population growth, which is likely to occur in and around Fort Collins. Water Districts 76 and 48 are unlikely to see large population growth and are more likely to grow at rates similar to neighboring Water District 47 (Jackson County). Therefore, grouped municipal demands for the two Water Districts were added to the Water District 3 grouped demands.
- Grouped monthly indoor and outdoor demands were assigned to either a diversion structure or well structure in the model, depending on the source of supply generally used to meet municipal demands in the basin[22]. Grouped municipal structures were placed near cities and towns not represented individually in the model to mimic the current municipal use. Particularly large Water District demands, such as Water District 1 in the South Platte River basin, were divided and modeled at two different locations, so as not to overestimate demands at a particular location on the river.
- Grouped monthly indoor demands were reflected as 10 percent consumptive and outdoor demands were reflected as 80 percent consumptive in the model.
- Monthly indoor and outdoor demands for cities and towns modeled individually were assigned to their existing structures in the basin models; no adjustments to currently-modeled efficiencies were made.
- Grouped monthly indoor and outdoor demands were assigned a senior water right sufficient to meet their baseline demand, acknowledging that the full baseline demand is assumed to be currently satisfied. For projected increases in demand from the baseline scenario, junior water rights were assigned to the structures. Note that agricultural diversions were given first chance to divert unappropriated streamflow, with any additional streamflow beyond the agricultural needs available to meet the projected increase in grouped municipal demands under the junior water rights.
    - In addition to assigning the water rights described above, operations were included in the Colorado River Basin that would release contract supplies from Green Mountain Reservoir, Ruedi Reservoir, and Wolford Mountain Reservoir to meet the current and Planning Scenario grouped municipal structures in the basin. These reservoirs currently

[22] Grouped municipal demands in the West Slope and North Platte River Basin were assumed to be met by surface water supplies, while the demands in the Rio Grande and Arkansas were assumed to be met by ground water supplies. Grouped municipal demands for higher elevation Water Districts in the South Platte River basin were assumed to met by surface water supplies, whereas the Water District demands in the plains were assumed to be met by ground water supplies.

release contract supplies (i.e. supplies available for lease on a contract basis) to meet smaller municipal and/or augmentation demands in the basin, and these operations were assumed to continue into the future.

- Indoor and outdoor demands for an individually represented city in the model are met by water supplies available under the city's current water rights portfolio, operations, and infrastructure. No additional water rights, capacity, or operations were added to meet projected increases in demand.
- Refer to the basin summaries above for more information on how municipal demands and gaps were accounted for in basins without the full suite of CDSS models.

SSI Demands

Annual SSI demands were provided by county and for facilities (i.e., powerplants, ski resorts, etc.) currently represented individually in the models. The SSI demands were divided into five categories

1. Energy Development
2. Large Industry
3. Snowmaking
4. Thermoelectric
5. Hydropower

The following approach was used to process the individual and grouped SSI demands for use in the baseline and 2050 Planning Scenario models:

- Annual SSI demands for each scenario were first disaggregated to a monthly time-step using distribution factors provided by the municipal demand technical consultant. Energy Development and Large Industry were assumed to have constant demands every month, while Snowmaking, Thermoelectric, and Hydropower demands were assumed to vary monthly within the year. Since Energy Development and Large Industry had the same monthly disaggregation factors, the demands were combined and represented in the model together. Table 53 reflects the monthly disaggregation curves for each SSI category.

Table 53: SSI Demand Disaggregation Curves

Month	Energy Development	Large Industry	Snowmaking	Thermoelectric	Hydropower
Jan	8.3%	8.3%	14.8%	7.9%	7.2%
Feb	8.3%	8.3%	11.8%	6.7%	7.0%
Mar	8.3%	8.3%	0.1%	6.3%	7.7%
Apr	8.3%	8.3%	0.2%	7.8%	7.6%
May	8.3%	8.3%	0.0%	9.2%	9.7%
Jun	8.3%	8.3%	0.0%	10.5%	11.3%
Jul	8.3%	8.3%	0.0%	10.4%	10.5%
Aug	8.3%	8.3%	0.3%	9.7%	9.2%
Sep	8.3%	8.3%	0.1%	7.7%	8.5%
Oct	8.3%	8.3%	5.5%	8.3%	7.8%

Month	Energy Development	Large Industry	Snowmaking	Thermoelectric	Hydropower
Nov	8.3%	8.3%	35.4%	7.8%	6.4%
Dec	8.3%	8.3%	31.8%	7.7%	7.2%

- County SSI demands for each category were distributed to the Water District level using the same spatial method described above for the municipal county demands. The same consideration for Water Districts 48 and 76 discussed above was made for the SSI demands in those areas as well.
- Grouped monthly SSI demands for each category were assigned to either a diversion structure or well structure in the model, depending on the source of supply generally used to meet SSI demands in the basin. Grouped SSI demands were placed at locations in the model representative of where the demand may currently exist; for example, snowmaking structures were placed in the headwaters of tributaries. Similar to the municipal demands, if the demand was large it was split into two nodes and modeled in different locations.
    - Note that Hydropower was only considered a demand for facilities currently represented individually in the model; there are no grouped Hydropower demands.
- Grouped SSI demands were assigned efficiencies based on Table 54. Efficiencies were based on efficiencies of currently modeled facilities or feedback from the M&SSI Technical Advisory Group.

Table 54: SSI Demand Modeled Efficiencies

SSI Category	Efficiencies
Energy Development	100%
Large Industry	100%
Snowmaking	47%
Thermoelectric	91%
Hydropower	0%

- Grouped SSI demands were assigned a senior water right sufficient to meet their baseline demand, acknowledging that the full baseline demand is assumed to be currently satisfied. For projected increases in demand from the baseline scenario, junior water rights were assigned to the structures. Note that agricultural diversions were given first chance to divert unappropriated streamflow, with any additional streamflow beyond the agricultural needs available to meet the projected increase in group SSI demands under the junior water rights. Assumptions regarding contract deliveries in the Colorado River basin discussed above also apply to the grouped SSI structures.
- SSI demands for facilities represented individually in the model are met by water supplies available under the facility's current water rights portfolio, operations, and infrastructure. No additional water rights, capacity, or operations were added to meet projected increases in demand.

- Refer to the basin summaries above for more information on how SSI demands and gaps were accounted for in basins without the full suite of CDSS models.

The total M&SSI demand summarized by basin herein differs from the basin-wide totals presented in the *Baseline and Projected 2050 Planning Scenario Municipal and Self-Supplied Industrial Water Demands* memorandum. This is due to differing approaches used to estimate the portion of each county in each basin. The approach discussed above relied on a spatial process to distribute county demands first to a Water District level, then summed to a basin-wide level. The M&SSI Demand memorandum relied on an estimate of each county in a basin. For example, Rio Blanco County is almost completely encompassed by the White River basin (Water District 43). The M&SSI Demand memorandum included only the demands from Rio Blanco County in the total White River basin demand. The spatial process outlined above, however, accounts for the demand associated with the small portion of Rio Blanco County that falls outside of the White River Basin, and the demand associated with the small portion of Moffat County that falls inside the White River Basin. The total M&SSI demand is represented in the models, however the reporting of where that demand is located differs between this memorandum and the M&SSI Demand memorandum due to this differing approach.

Analysis and Technical Update to the Colorado Water Plan

Technical Memorandum

Prepared for:

Colorado Water Conservation Board

Project Title:

Colorado Water Project Cost Estimating Tool Documentation

Date: May 21, 2019

Prepared by: Lauren Starosta, Eli Gruber, and Devin Schultze, CDM Smith
Reviewed by: Sue Morea and Becky Dunavant, CDM Smith

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List of Acronyms

ac-ft	Acre-feet
ASR	Aquifer Storage and Recharge or Recovery
BIP	Basin Implementation Plan
BRT	Basin Roundtable
CCI	CDM Constructors, Inc.
CDSS	Colorado Decision Support System
cfs	Cubic feet per second
CO DNR	Colorado Department of Natural Resources
CWCB	Colorado Water Conservation Board
DIP	Ductile Iron Pipe
E&R	Environment and Recreation
ENR CCI	Engineering News-Record Construction Cost Index
EPA	Environmental Protection Agency
fps	Feet per second
ft	Feet
ft-msl	Feet above mean sea level
GAC	Granular Activated Carbon
GIS	Geographic Information Systems
gpm	Gallons per minute
Horse Power	Hp
hr	Hour
in	Inches
kW	Kilowatts
lf	Linear feet
MF	Membrane Filtration
MG	Million gallons
mgd	Million gallons per day
NF	Nanofiltration
NRCS	Natural Resources Conservation Service
NWQMC	National Water Quality Monitoring Council
O&M	Operations and maintenance
PF	Peaking Factor
psi	Pounds per square inch

PVC	Polyvinyl Chloride
RO	Reverse Osmosis
STORET	EPA STOrage and RETrieval
SWSI	Statewide Water Supply Initiative
TOC	Total Organic Compounds
TSS	Total Suspended Solids
UCM	Texas Unified Cost Model
UF	Ultrafiltration
USDA	United States Department of Agriculture
USGS	United States Geologic Survey
UV	Ultraviolet
yr	Year

Executive Summary

The Colorado Water Project Cost Estimating Tool (Cost Estimating Tool) was developed for the Statewide Water Supply Initiative (SWSI) update to provide a common framework for the basin roundtables (BRTs) to develop planning-level project cost estimates. The tool may be used to develop costs for the following types of projects:

- Water transmission pipeline projects for transporting raw or treated water supplies
- Well field projects for public water supply, irrigation or aquifer storage and recovery (ASR)
- New reservoir or reservoir expansion projects
- Water treatment projects
- New ditches or ditch rehabilitation projects with or without a diversion structure
- Stream and habitat improvement or restoration projects

The Cost Estimating Tool is available to assist the BRTs in the development of Basin Implementation Plans (BIPs). The tool provides a baseline cost estimate for use in the planning process and serves as a mechanism to collect useful information for additional planning and tool refinement in future iterations. Its targeted use is for project concepts for which cost estimates have not yet been developed.

The tool development and use are documented herein with the following sections:

- **Section 1: Introduction** – This section discusses why the tool was developed, how it is to be used and provides further description of the report organization.
- **Section 2: Methodology** – Each component of the tool is described including calculations, user inputs and outputs, and assumptions. This is the main documentation of the overall tool development.
- **Section 3: Implementation** – Included in this section are recommendations for future updates and improvements. Also discussed are some of the data limitations that could be improved upon with future iterations.
- **Appendix A: User Guide** that can be provided as a stand-alone document with the tool.
- **Appendix B: Documentation** of the various data sources used for developing the cost curves for each type of project

Section 1: Introduction

This memorandum presents the objective, development documentation, user guide and cost data for the Colorado Water Project Cost Estimating Tool (Cost Estimating Tool) developed for the Statewide Water Supply Initiative (SWSI) update. The intent of the Cost Estimating Tool is to provide a common technical framework for the basin roundtables (BRTs) to develop planning-level project cost estimates. The cost estimates developed with the tool may be used to support decision-making and to provide consistent project data to the Colorado Water Conservation Board (CWCB). The Basin Implementation Plans (BIPs) submitted in 2015 provided cost data for basin water projects that varied greatly in detail and consistency.

1.1 INTENDED USE

The Cost Estimating Tool was developed out of a need to have planning-level project cost estimates for all proposed projects. During BIP development, BRTs were tasked with identifying completed, ongoing, and proposed projects and methods for addressing water supply needs. While all basins but one identified project cost as a key component of project execution, presentation of estimated costs for projects was not consistent among basins. **Table 1-1** provides a summary of projects with listed costs by basin.

Table 1-1 Basin Project Cost Summary

Basin	Number of Projects	Projects with Costs	Percent of Projects with Costs
Arkansas	185	17	9%
Colorado	31	14	45%
Gunnison	214	112	52%
North Platte	77	1	1%
Rio Grande	110	30	27%
South Platte & Metro	214	0	0%
Southwest	217	1	0%
Yampa	48	4	8%
Total	**1,096**	**179**	**16%**

As **Table 1-1** shows, only 16% of presented projects throughout the eight BIPs provided any estimate of project costs. This demonstrated a need for an accessible costing tool for basins to use during subsequent development of BIPs to determine potential funding needs. This information is also useful to CWCB for determining available funds through programs such as the Water Supply Reserve Fund (WSRF). Of the 1,096 inventoried projects, 117 identified the WSRF program as a current or planned funding source.

The resulting Cost Estimating Tool serves two functions: 1) it provides a tool for basins to estimate and report planning-level costs for proposed projects, and 2) allows CWCB to make like-for-like comparisons of proposed project costs across the state. The BRTs may also use the tool for financial reporting of project cost estimates during the next round of BIPs.

It is important to understand the purpose and limitations of this tool:

- The tool does **NOT** replace cost estimates that have already been developed for projects.
- The tool should **NOT** be used in place of more detailed cost estimates that could be developed if enough information is available.
- The tool is **NOT** an automated process. Review and understanding of the costs calculated is needed.
- The tool **IS** to be used by BRTs when developing cost estimates for project concepts that are to be included in a BIP so that CWCB has an approximate cost to use in planning.
- The calculated costs are very high-level and **only useful for planning purposes**. More detailed cost estimates based on site-specific information will yield different results.

1.2 TOOL AND REPORT ORGANIZATION

The Cost Estimating Tool is organized by Project Modules, with each module representing a different type of water supply project. The organization of this report correlates with the Project Modules; each having its own section. **Section 2** describes the overarching methodology used to develop the tool and details the methodology for creating the individual Project Modules and associated costs. Section 2 is organized uniformly for each module as described below:

- **Section 2.X** gives an overview of the specific Project Module
- **Section 2.X.1** presents the calculations and tools or models that are used in the Project Module
- **Section 2.X.2** discusses module inputs, outputs and costing data
- **Section 2.X.3** describes significant assumptions

Data from each Project Module is synthesized in the Costing Module and Cost Summary Sheets to develop the overall cost estimate.

It is understood that the Cost Estimating Tool is a dynamic resource that should be revisited and updated; therefore, **Section 3** discusses considerations for future updates to the tool's functionality and cost data. To assist the BRTs to best use the tool, a User Guide was developed and is included as **Appendix A.** Details regarding the development of the cost curves for each type of project are available in **Appendix B**.

Section 2: Cost Estimating Tool Methodology

The Cost Estimating Tool is an excel-based tool that guides users through a process for developing planning-level cost estimates for water supply projects within Colorado. The tool consists of the following main components: 1) eight Project Modules that collect project information significant to project costs from the user, and 2) a Costing Module that uses the output from the Project Modules and calculates construction costs by applying unit costs or cost curves developed for each project type. A Cost Summary Sheet synthesizes the cost information calculated in the Costing Module for easy reporting and includes ancillary project costs for project development and annual costs.

For ease of navigation, the tool components are presented on an Overview Page which provides links to all Project Modules and some tool instructions and disclaimers. **Figure 2-1** is a schematic of the tool organization shown on the Overview Page.

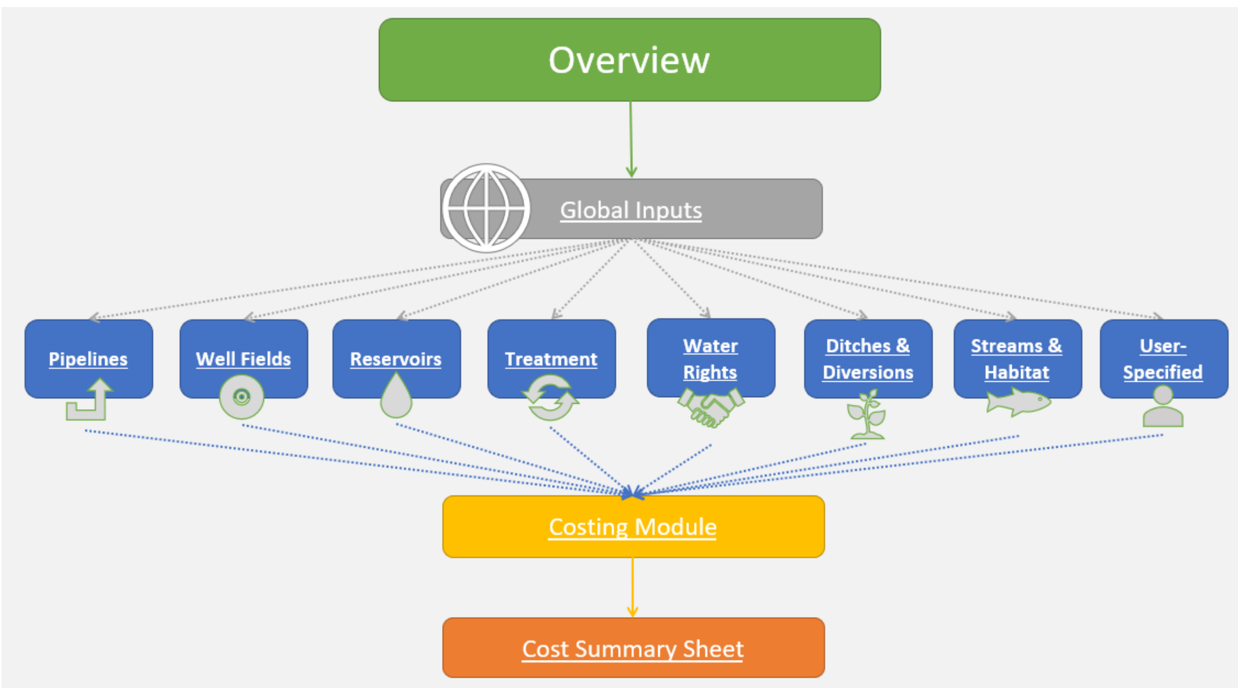

Figure 2-1 Cost Estimating Tool Schematic

To avoid duplicative entry of information, and garner basic details about projects, a Global Inputs tab collects general project information that is used for project development costs and most notably, cost escalation for future projects. More detailed instructions are provided in the Cost Estimating Tool User Guide, which is included as **Appendix A**.

The individual Project Modules prompt the user to input the necessary information to estimate construction costs using the tool. Module complexity varies by project type due to the number of elements a project requires to estimate costs. **Table 2-1** summarizes each Project Module by the type of project and the general inputs used to characterize project components that affect cost.

Table 2-1 Summary of Project Modules

Project Module	Types	Components	General User Inputs
Pipelines	Raw, Treated	Pipelines, Pump Stations, Storage	Project Yield and Peaking Factor, Pipeline Profile Components, Pipe Size and Length, Pump Type
Well Fields	Public Supply, Aquifer Storage and Recovery, Injection, Irrigation Wells	Wells, Booster Pumps, Pipe Network	Water Table Characteristics, Project Yield and Peaking Factor, Transmission Pipeline Profile Components, Number of Wells and Average Production, Well Depth and Capacity, Transmission Pipe Size and Length, Booster Pump Capacity
Reservoirs	New Reservoir, Reservoir Expansion, Reservoir Rehabilitation	Reservoir, Reservoir Rehab, Hydropower Production	Project Type, New Storage Volume, Reservoir Rehab Project Description, Cost of Rehabilitation, Height of Falling Water, Discharge through Hydropower Station
Treatment	Various Treatment Types	Treatment	Average Day Demand and Peaking Factor, Treatment Type
Water Rights	Instream Flow Requirements, Recreational In-Channel Diversion, Water Supply	Cost	Total Capital Cost of Water Right Purchase
Ditches and Diversion	New Ditch, Ditch Rehabilitation	Diversion Structure, Headgate Structure, Ditch	Type of Diversion Structure, Type of Headgate Structure, Maximum Diversion Discharge/Ditch Capacity, Type of Ditch, Ditch Length
Streams and Habitat	Stream Restoration, Conservation, Habitat Restoration/Species Protection, Acid Mine Drainage Water Treatment	Land Acquisition, Channel Improvements, Channel Structures, Channel Realignment	Stream Width Range, Length of Restoration, Level of Restoration
User-Specified Project	Project Types not represented by other modules	User-specified	Project Description, Total Capital Costs, Total Operations & Maintenance Costs

The inputs provided by the user are used to calculate cost-significant project elements. The module outputs are carried over into the Costing Module where unit costs or cost curves, developed for each module, are applied. The development of the cost curves for the eight Project Modules are based on the best available data for that project type. When available, costing information from recent Colorado projects were used to develop cost curves. All cost curves are representative of 2017 dollars. More information on cost curve development is available in Appendix B.

Other project costs, including project development and annual costs, are calculated and presented in the Cost Summary Sheet.

2.1 PIPELINES MODULE METHODOLOGY

The Pipelines Module may be used to cost different types of projects that include a pipeline component. Types of pipeline projects may include transmission of finished or raw water for potable or non-potable uses. The main components of a pipeline project include the pipeline itself, pump stations, and storage at the pump stations. The user may develop parameters for up to three pipe segments of differing diameter, length and project yield.

The inputs include information about the pipeline profile and anticipated project yield, which is used to calculate the pipeline diameter and pumping requirements. The outputs for developing the costs are the pipeline diameters and lengths and the pump station power and energy use. The following sections provide additional details on the process, user inputs, outputs, and assumptions.

2.1.1 CALCULATION PROCESSES

The module calculates pipeline and pump station parameters relevant to establishing construction and operations and maintenance (O&M) costs. Units for each value are converted in the module as needed.

Peak flow is calculated using Equation 1. If the pipeline is providing uniform delivery (i.e., the peaking factor is equal to 1), a percent downtime for maintenance is applied to the peak flow to account for a greater maximum flow needed throughout the year to meet the project annual yield.

Equation 1. $$q_{peak} = q_{average} * PF$$

where q_{peak} = peak flow in cubic feet per second (cfs)

$q_{average}$ = average day flow in (cfs) corresponding to the total project annual yield

PF = peaking factor

Pipeline diameter is calculated using the Continuity equation expanded and rearranged to solve for diameter. The resulting equation is shown as Equation 2.

Equation 2. $$D = \left(\frac{4q}{V\pi}\right)^{1/2}$$

where D = diameter in feet (to be converted to inches),

q = flow in cubic feet per second (cfs), and

V = velocity in feet per second (ft/s)

Total dynamic head and flow are needed to determine the necessary pump station power. Total dynamic head is the static head (total lift) plus the friction head. The friction head is calculated using the Hazen-Williams equation rearranged to solve for the friction head. The equation for total dynamic head is shown as **Equation 3**.

Equation 3. $$h_t = h_s + \frac{10.4LQ^{1.85}}{C^{1.85}D^{4.8655}}$$

where h_t = total dynamic head in feet (ft)

h_s = static head in ft

L = pipe length in ft

Q = flow in gallons per minute (gpm)

C = the Hazen-Williams friction factor

D = pipe diameter in inches (in)

Total required power is calculated in terms of Horse Power (Hp) using the desired flow rate and total dynamic head as shown in **Equation 4**.

Equation 4. $$P = \frac{(h_t)Q}{3960\mu}$$

where P = power in Hp

h_t = total dynamic head in ft

Q = flow in gpm

μ = efficiency as a fraction

The number of pump stations needed is estimated based on the maximum allowable pipeline pressure. An additional pump station is needed when the total pumping head exceeds the maximum allowable pipeline pressure.

Finally, pumping energy required to pump the annual flow rate is calculated to determine the annual cost of pumping. Energy use is assumed to be constant over the year except for specified pump downtime. Total pumping energy per year is calculated by converting Hp to kilowatts (kW) and multiplying by the hours of pumping in the year.

2.1.2 INPUTS, OUTPUTS AND SOURCE DATA

The Pipeline Module requires several inputs that are either required to be supplied by the user, adjustable by the user, or optionally supplied by the user. There are no inputs that are hard-coded. Default typical values are included for those inputs that are adjustable by the user. There are also lists of typical values and ranges of values from which the user can select. This puts the responsibility on the user to appropriately design the pipeline system that is being costed.

The outputs used to develop construction costs include pipe diameter, pipe length, pump station(s) power, and storage volume. This information is applied to the cost curves, which were mostly developed from Denver Water cost data.

Specifics of the inputs and outputs are described in tables in the Pipelines Module section of **Appendix A**. Details regarding development of the cost curves are available in **Appendix B**.

2.1.3 ASSUMPTIONS

The Pipelines Module assumes the following:

- Use of multiple segments is not required and only necessary if there is a change in project yield, peaking factor or diameter along the pipeline length. Multiple segments may also be used if the user wants to control the number and distribution of pump stations along the project. Inputs or calculations do not transfer from one segment to another. They can, however, be used as independent calculations that combine into a single, total cost estimate.
- Based on typical water composition, terrain, and use in Colorado, ductile iron pipe is assumed for all pipeline costs.
- Calculations and costs assume an average of 6 feet of cover over the length of the pipeline.
- Calculations and costs assume an average of 2,500 feet between valves in the pipeline. Bends are not considered.
- The number of pump stations needed is estimated based on the total dynamic head over the entire pipeline divided by the maximum allowable head, and the power required is evenly divided over the number of pump stations.
- If user selects "Intake" as pump type, the first pump is assumed to be intake and any additional required pumps for the segment are assumed to be booster pumps
- Storage requirements are provided by the user, but a recommended value is 10% of the average daily flow.

2.2 WELL FIELD MODULE

The Well Field Module includes wells, pumps, and the main transmission line through a well field. Types of well field projects include public water supply, irrigation, or aquifer storage and recharge or recovery (ASR). Rehabilitation of wells or a well field or conversion of existing wells to ASR wells are not included for this module. Those types of projects require more detailed information for which more detailed cost estimates could be developed.

The types of user inputs for this module include well hydraulic information, well production parameters, and well field transmission pipeline information. These inputs are used to calculate the number of the wells, depth and capacity of each well, transmission pipeline diameter, and transmission pumping needs. The Well Field Module outputs for developing the costs are the individual well capacity and depth, pipeline diameter and length, transmission system pumping requirements (total dynamic head and capacity), and total well field power and energy use (well and transmission). The following sections provide additional details on the process, inputs, outputs, and assumptions.

2.2.1 CALCULATION PROCESSES

This section describes each calculation used in the Well Fields Module. The first set of calculations are for the well field and related hydraulics. **Figure 2-2** depicts a simplified schematic of the well hydraulics inputs and calculations. Elevation is in feet above mean sea level (ft-msl). Units are converted in the module as needed and not explicitly documented here.

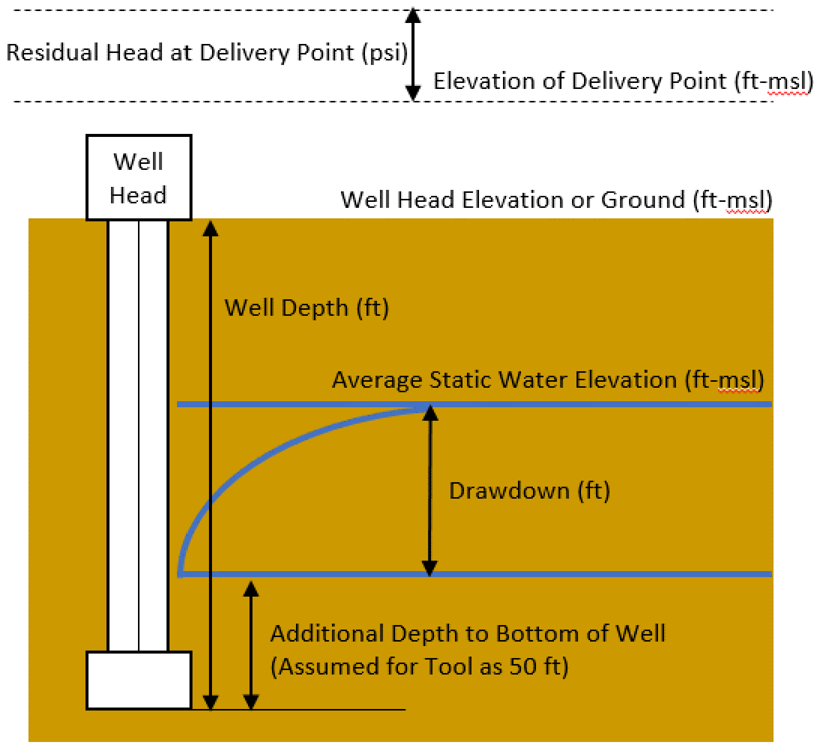

Figure 2-2 Well Hydraulics Schematic

Peak flow is calculated using **Equation 1** (previously presented in the Pipelines Module). The number of required active wells are calculated per **Equation 5**.

Equation 5. $$N_{wells} = \left\lceil \frac{q_{peak\ yield}}{q_{peak\ well}} \right\rceil$$

where N_{wells} = total number of wells needed, rounded up to the nearest whole number

$q_{peak\ yield}$ = total project yield converted to a peak yield (**Equation 1**) in gpm

$q_{peak\ well}$ = peak flow per well in gpm

The module then lists each well in the "Calculated Well Parameters" where the user must supply the well head elevation (or approximate ground elevation) in ft-msl for each well. The well depth is then calculated per **Equation 6**.

Equation 6. $$d_{well} = (z_{well\ head} - z_{static\ water}) + d_{drawdown} + 50ft$$

where d_{well} = the average depth of a well in ft

$z_{well\ head}$ = the well head elevation in ft-msl

$z_{static\ water}$ = the average static water elevation in ft-msl

$d_{drawdown}$ = drawdown depth in ft

An assumed additional depth of 50 feet is added for calculating the total depth. The peak capacity is calculated assuming the same peak flow per well in gpm. The user may keep the calculations for the number of wells, the depth per well and peak capacity as calculated, or the user can input specific information for each well.

The operating time is the fraction of the operating time over a year of operation calculated per **Equation 7** and is used to estimate annual energy use.

Equation 7. $$t_{fraction} = \frac{q_{average\ yield}}{(N_{wells}) * q_{peak\ well}}$$

where $t_{fraction}$ = fraction of time during a year that the entire well field is operating

$q_{average\ yield}$ = total project average annual yield in gpm

N_{wells} = total number of wells in the well field

$q_{peak\ well}$ = peak flow per well in gpm

Average values were calculated for the overall well field to simplify some of the hydraulic equations. For example, the user inputs a well head elevation for each of the wells, but an average of those inputs is used in the calculations for estimating energy use for all the wells in the well field. The average (i.e., average over the well field) total dynamic head for the well field is expressed using **Equation 8**.

Equation 8. $$TDH_{well\ field} = (Z_{well\ head} - z_{static\ water}) + d_{drawdown} + h_{well\ column}$$

where $TDH_{well\ field}$ = the average well field total dynamic head under peak flow conditions in ft

$Z_{well\ head}$ = the average well field head elevation in ft-msl

$z_{static\ water}$ = the average static water elevation in ft-msl

$d_{drawdown}$ = drawdown depth in ft

$h_{well\ column}$ = the average well column frictional losses in the well column in ft

The well column losses (or $h_{well\ column}$ in **Equation 8**) are calculated by rearranging Equation 2 and Equation 3 (refer to Pipelines Module) as shown in **Equation 9**.

Equation 9. $$h_{well\ column} = \frac{10.4 D_{well}\, q_{peak\ well}{}^{1.85}}{C^{1.85}\left[\frac{12\ in}{ft}\left(4\frac{q_{peak\ well}}{V\pi}\right)^{1/2}\right]^{4.8655}}$$

where $h_{well\ column}$ = the average well column frictional losses in the well column in ft

D_{well} = average well depth from the well head elevation to the well bottom in ft

$q_{peak\ well}$ = peak flow per well in gpm

C = the Hazen-Williams friction factor

V = velocity in ft/s

An estimate of total required power is calculated in terms of Hp using the average day flow and total dynamic head per well as shown in Equation 4, previously presented in the Pipelines Module. Then, energy use is calculated per well and for the entire well field to determine the annual cost of well operation. Energy use is assumed to be constant over the year. Total pumping energy per year is calculated by converting Hp to kW and multiplying by the hours of pumping in the year.

The remainder of the module includes calculations for the main transmission line and booster pump stations. These calculations are the same as in the Pipelines Module. Differences in how the pipeline outputs are developed include the following:

- A well field transmission pipeline is set up to determine diameters for multiple segments that account for the connectivity of the well field.
- Pumping related to each well is included in the cost of the well, but the need for additional booster pumps is included along the transmission line. Based on those calculations the user then chooses the number of pumps to include, their capacity and total dynamic head.
- Each well is assumed to be in series along the transmission line, so the required TDH is calculated between each well based on the user-specified well head elevation and head loss through the pipeline.

2.2.2 INPUTS, OUTPUTS AND SOURCE DATA

The Well Fields Module process requires several inputs that are supplied by the user or adjustable by the user. Default values for Well Column Velocity, Mechanical and Electrical Efficiency, and Hazen Williams C values are provided in the tool, but are adjustable by the user. In addition to the required user inputs that feed the calculations, the user has the option to use calculated values for well and booster pump parameters that feed the Costing Module, or they can enter their own specific information. This provides flexibility and puts the responsibility on the user to appropriately design the system that is being costed.

The outputs used to develop construction costs include the same items as in the Pipelines Module. In addition to these, well depth and capacity for each well are used and applied to the cost curves, which were mostly developed from cost data from the Texas Unified Cost Model (UCM) adjusted with information on recent well field projects in the southwest.

Specifics of the inputs and outputs are described in tables in the Well Fields Module section of Appendix A. Details regarding development of the cost curves are available in Appendix B.

2.2.3 ASSUMPTIONS

The Well Fields Module assumes the following:

- Operational parameters are not considered.
- The well field layout is simplified and assumes a main transmission line with wells connecting individually to that line. The pipelines from the well to the main transmission line are assumed short enough to be negligible in the costs. If the user requires costs for these lines, the Pipelines Module may be used, or additional external costs may be added in the Costing Module.
- The calculations for booster pumps include one at each transmission line node (or where a well is added) unless the power needed is zero.
- Calculated well depth assumes an additional 50 feet below the drawdown level; this value is hard-coded in the calculations and is not adjustable by the user.
- Calculations regarding capacity and depth per well assume uniformity across the well field, but the user may input more detailed information if available.

- ASR well fields are included and assumed to be constructed like other well fields. Greater cost curves are used to differentiate the cost of an ASR project. Additional assumptions for ASR well fields include the following:
  - Transmission of the water to be injected from the source to the well field is not included. This may be costed separately using the Pipelines Module.
  - The tool only includes the costs for new wells. Retro-fitting existing wells to be used for ASR has a lower cost and should be considered on a case-by-case basis.
  - Pre- or post-treatment costs are not included. User may consider using the Treatment Module for additional treatment costs.
  - Recharge is assumed as a gravity feed into the well. Additional cost of pumps and operations would need to be added if recharge water must be pumped into the well under pressure.

2.3 RESERVOIRS MODULE

The Reservoirs Module includes projects for construction of a new reservoir, reservoir expansion and reservoir rehabilitation. Hydropower generation may be calculated but the cost of the infrastructure required is not necessarily included in the cost estimate. This module only includes costs related to the reservoir itself and does not include variations for on- or off-channel reservoirs. Conveyance or transmission of water to and from a reservoir is not included, and the Ditches and Diversions or Pipelines Module may be used for that aspect of a reservoir project.

As reservoir rehabilitation can vary greatly depending on the condition, age, location, use and water/soil composition of the reservoir, input data describing these characteristics and corresponding calculations were not included for these types of projects. Future iterations of the tool should consider collecting a larger data set of reservoir rehabilitation projects and costs to develop this module element further.

2.3.1 CALCULATION PROCESSES

This module includes a basic-level process that incorporates cost curves using inputs on the type of reservoir project and reservoir volume. The cost curves include the cost of the dam, spillway, outlet works, and costs related to the impacted area. No calculations are involved. The user inputs are supplied directly to the Costing Module where cost is calculated based on reservoir volume using the appropriate cost curve for reservoir project type (new reservoir or expansion).

Hydropower calculations are optional for estimating energy production. Power production is calculated using **Equation 10**.

Equation 10. $$P = \frac{(h_W)Q}{3960\mu}$$

Where P = power in Hp

h_w = height of falling water in ft

Q = flow in gpm

μ = efficiency as a fraction

The power generated is converted to an annual amount of energy produced based on user input regarding the frequency of production over a typical year. Energy production per year is calculated by converting Hp to kW and multiplying by the hours of generation in the year.

2.3.2 INPUTS, OUTPUTS AND SOURCE DATA

The Reservoirs Module process requires minimal inputs. Inputs required to be supplied by the user include the project type (new reservoir or expansion) and the new or additional storage volume. If the user is rehabilitating an existing reservoir, they are encouraged to provide details regarding the rehabilitation activities taking place and the estimated cost. Other inputs are optional for the user to supply. Values related to hydropower efficiency are included as defaults that are adjustable by the user.

The outputs used to develop construction costs are the inputs, which apply directly to the cost curves. The cost curves are based on data provided by the Colorado School Mines (Burrow, 2014) and the South Platte Storage Study Final Report (Stantec & Leonard Rice, 2015).

Specifics of the inputs and outputs are described in tables in the Reservoirs Module section of Appendix A. Details regarding development of the cost curves are available in Appendix B.

2.3.3 ASSUMPTIONS

The Reservoirs Module assumes the following:

- Module does not include cost variations for on- or off-channel reservoirs. For off-channel reservoirs the Pipelines or Ditches & Diversions modules may be used to estimate costs for conveyance to an off-channel reservoir.
- Transmission of water from a natural source to the basin is not included. Users may cost out a project requiring reservoir transmission by combining costs from the Pipelines Module with the cost of reservoir construction.
- Land acquisition is estimated by the user in the Global Inputs Module. Most reservoir projects will require land acquisition. The user should include an estimate of land area required in the Global Inputs Module.
- Only New Storage Volume is used for cost estimation.
- Hydropower does not affect total project cost.

2.4 TREATMENT MODULE

Water treatment projects may be operated to provide water for potable or non-potable uses. The principal guidelines for determining the appropriate water treatment technology is the source water quality and required effluent water quality, which is dictated by the intended effluent use. The Treatment Module was designed to address these two factors through a qualitative self-assessment of source water characteristics by the user as a tool for determining the best-suited treatment type.

Colorado is characterized by both high-density urban centers and rural communities. With a myriad of environments and industries, water quality in these areas may vary from pristine to significantly impaired. The eight conventional treatment technologies included in the Treatment Module were selected based on their representation of the broad range of source waters and socioenvironmental settings found in Colorado. This module allows for a wide variety of source water quality to be considered using a table of indicator parameters identified as drivers/thresholds for treatment.

2.4.1 CALCULATION PROCESSES

The two main components of the Treatment Module are treatment type and capacity. Selecting the appropriate water treatment type of a community is dictated by source water quality, effluent use, and required capacity. The treatment types included in the module are summarized in **Table 2-2** in terms of source water types.

Table 2-2 Source Water Characterization versus Applicable Treatment Types

Treatment Type	Source Water Quality Characterization
Direct Filtration	Pristine water quality
Conventional	Moderate-high water quality
Conventional + Enhanced Coagulation	High natural organic matter (NOM) May result in disinfection by-products (DBPs)
Conventional + Lime Softening	High hardness (CaCO3) Commonly includes high NOM and turbidity source water
Conventional + Ozone/UV	High NOM Presence of pathogens Bromide and taste and odor issues Potentially includes contaminants of emerging concern (CECs)
Conventional + GAC	High NOM Low risk of pathogens Bromide and taste and odor issues Potentially includes contaminants of emerging concern (CECs)
Conventional + Membranes	High NOM High risk of pathogens
Conventional + Nanofiltration/Reverse Osmosis	Treats all characteristics listed for other treatment types, plus salinity removal (Note: less effective for taste and odor)

The second component of the module is treatment plant capacity. This module calculates the required capacity using **Equation 11**.

Equation 11. $$Q_{required} = Q_{average} * PF$$

where $Q_{required}$ = required peak day capacity in million gallons per day (mgd)

$Q_{average}$ = average day demand in (mgd)

PF = peaking factor

2.4.2 INPUTS, OUTPUTS AND SOURCE DATA

The Treatment Module requires minimal inputs including treatment type, the planned treatment average day demand, and peaking factor. There are no default values or optional inputs.

Treatment type and required capacity are the output used to determine the appropriate point on the cost curve to return a construction cost for the treatment facility type. In addition, the capacity is applied to the O&M cost curve of the treatment technology. In lieu of calculating the required energy for the proposed plant capacity per treatment type, cost curves were developed that account for energy costs in annual maintenance costs.

The cost curves for the Treatment Module were developed using the Cost Estimating Manual for Water Treatment (McGivney and Kawamura, 2008).

Specifics of the inputs and outputs are described in tables in the Treatment Module section of **Appendix A** along with reference material to aid in the selection of treatment type. Details regarding development of the cost curves are available in **Appendix B**.

2.4.3 ASSUMPTIONS

The Treatment Module assumes the following:

- There are eight water treatment technologies provided in the tool. While the tool provides references to aid the user in determining the appropriate technology, it is assumed the user will be able to identify the appropriate technology for their community. The reference table is not intended for final treatment technology decision-making, but as a guiding tool for planning-level cost estimating.
- Reference Table treatment thresholds were developed assuming end use of treated water is for potable uses. The tool may be used for the purposes of planning a non-potable reuse project; however, the water quality requirements for non-potable uses vary significantly depending on the industry. The most typical use of water treatment facilities is to meet municipal water need, and therefore was assumed to be the end-use for the purposes of this tool.
- O&M Costs are calculated for each type of treatment and include an estimation of energy requirements, therefore energy for treatment is not calculated separately
- Treatment costs were created assuming a range of accuracy of +50% and -30%.

2.5 WATER RIGHTS MODULE

The Water Rights Module requires user input on the cost of acquiring a water right. This may include water rights for any type of use including water supply, instream flow requirements, or recreational in-channel diversions. Although no calculations are included, this module exists to provide an input for what can be a significant cost when using the tool to develop costs for other components of a water supply project. **Appendix A** provides some additional resources regarding water rights and water right administration in Colorado.

This module assumes the water rights costs entered by the user are all-inclusive. The cost input in the tool should include all capital, legal, administrative and labor costs involved in the process of negotiating and purchasing the water right. The cost should also be entered in the same year dollars desired by the user for the total project costs. In other words, the tool does not adjust these costs in any way.

2.6 DITCHES AND DIVERSIONS MODULE

The Ditches and Diversions Module is intended for diversion structures and irrigation ditches for agricultural use. Types of ditch and diversion projects may include:

- Ditch or canal construction
- Ditch or canal rehabilitation
- In-channel diversion structures

The most common type of ditch and diversion project among the current BIPs involves rehabilitation or improvements to existing ditches and canals through ditch relining. Historically, many irrigation ditches were earthen or concrete lined. Earthen ditches can easily erode and lose diverted water through infiltration. Recent improvements in ditch lining materials have led agricultural producers to re-line existing channels with synthetic, closed conduit or improved concrete liners. Cost estimating options are included for various lining types and include associated earthwork and labor if a new ditch is being constructed. Development of these costs is discussed in Appendix B.

Diversion projects are reliant on several variables including channel geometry, discharge through the diverting stream and required ditch capacity (i.e. variables that are very project-specific and can vary widely). To aid users in developing their diversion structure costs, a list of existing diversion structure projects, diverted quantity and approximate diversion structure cost is provided in Appendix B and as a reference in the tool. Future iterations of the tool should consider further data collection to refine development of diversion costs, as discussed in Section 3.

In some cases, a ditch and/or diversion project may be one component of a larger water supply project; therefore, it may be appropriate to utilize additional modules such as Streams and Habitat, Reservoirs and Well Fields.

2.6.1 CALCULATION PROCESSES

This module incorporates cost curves using inputs regarding diversion structure type, ditch type, project type (new or rehabilitation), length and capacity. Each user input, except length, is supplied directly to the Costing Module to determine the appropriate cost curve in terms of dollars per linear foot. Cost is then calculated by multiplying length by the unit cost. There are no other calculations.

2.6.2 INPUTS, OUTPUTS AND SOURCE DATA

The Ditches and Diversions Module requires inputs that are mostly informational and are the outputs supplied to the Costing Module to determine the appropriate cost curve (described in Appendix B). The module focuses on characterizing the ditch or diversion project by requesting information on the components included in construction (diversion structure, ditch, or both), type of project (new ditch or rehabilitation) and type of ditch lining. For capacity, the user inputs the maximum desired diversion capacity, which is also assumed to be the capacity of the diversion structure and headgate. Ditch length is used as a multiplier as the cost curves are in dollars per linear foot. The cost curves were developed using a ditch construction cost estimating tool developed by the United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS, 2011).

Because diversion and headgate structure costs are highly variable based on the characteristics of the diverted stream, a reliable cost curve could not be developed. The user is directed to provide inputs; however, these are either optional or informational and are intended to capture information useful in future tool iterations. Specifics and further guidance for ditch and diversion inputs and outputs can be found in the Ditches and Diversions Module section of Appendix A.

2.6.3 ASSUMPTIONS

The Ditches & Diversions Module assumes the following:

- Ditch Rehabilitation projects are characterized by installation of upgraded or improved lining material and do not incorporate changes to ditch capacity. If the user intends to increase ditch capacity in the process of channel lining installation, the New Ditch project type should be selected.
- Recommended Diversion Structure Cost is developed based on limited data points, varying diversion structure types and geometries, and diversion structure capacities are estimated based on peak diversion structure capacity from the Colorado Decision Support System (CDSS) website. These costs are only recommended and require discretion before using the recommended cost. The user should review the Reference Table for actual project costs used to develop the curve to determine if the cost is appropriate for their proposed project.

- A tool developed by the NRCS was used to develop costing curves for ditch discharge versus cost of material per linear foot. The use of this tool required the following assumptions:
  - For ditches with trapezoidal geometry: (1) Ditch side slopes are consistently 2 ft/ft, (2) Trapezoidal ditches include a 0.5-foot freeboard, and (3) The average slope over the length of the ditch is 0.15 percent.
  - For closed conduit ditches: (1) Conduits have 4 feet of soil cover, and (2) The average slope over the length of the conduit is 0.15 percent.
  - Manning's roughness values are as follows:
    - Concrete: 0.013
    - Synthetic: 0.022
    - Ductile Iron Pipe: 0.013
    - PVC: 0.009

2.7 STREAMS AND HABITAT MODULE

The Streams and Habitat Module includes projects related to improving the environment, preserving or improving flow regimes, and sustaining an area for recreational purposes. These types of projects may vary greatly, which makes developing a cost estimating tool to fit all projects complicated. To address this, projects were tiered into four levels of restoration essentially starting with work outside of the channel banks and working inward toward the channel centerline. This is discussed further in **Section 2.7.2** and **Appendix A**.

Examples of stream restoration projects, or projects where stream restoration may provide a benefit, include fire protection or post-fire mitigation, improvement of water quality or invasive species removal. Stream restoration projects are most beneficial when specific environmental attributes served by the stream are identified and considered during project design.

2.7.1 CALCULATION PROCESSES

This module incorporates cost curves using inputs regarding stream width, environment, length of restoration and level of restoration. Each user input, except length, is supplied directly to the Costing Module to determine the appropriate cost curve in terms of dollars per linear foot. Cost is then calculated by multiplying length by the unit cost. There are no other calculations.

2.7.2 INPUTS, OUTPUTS AND SOURCE DATA

Module inputs focus on characterization of the stream environment and restoration level to determine the appropriate cost curve. Users should be aware that inputs for this module may require, at a minimum, an aerial analysis of the project area to determine the stream environment as urban or rural.

Cost of stream restoration projects can vary greatly depending on project location, size (mainstem vs. tributary) and condition; therefore, the tool defines stream restoration at varying levels. Costs for each level of restoration are described below:

- **Level 1 - Riparian habitat restoration:** Addresses ecological-based improvements within the riparian buffer such as vegetation reestablishment, improvement of soil conditions, and regrading to restore natural hydrologic conditions in the floodplain.

- **Level 2 - Level 1 plus bank stabilization:** Includes riparian habitat restoration and addresses work along banks such as bank erosion prevention or bank rebuilding using regrading, armoring, or bioengineering.
- **Level 3 - Levels 1 and 2 plus in-channel restoration:** Includes bank stabilization and riparian and aquatic habitat restoration through in-channel structures such as riffles, rock vanes, or weirs. Such structures can create habitats for aquatic life, improve water quality through stream mixing, and prevent unnatural bank erosion by reestablishing natural flow regimes.
- **Level 4 - Levels 1, 2 and 3 plus channel-realignment**: Achieves the goals of riparian, aquatic and reestablishment of natural flow regimes by reconstructing the channel and banks.

This module additionally collects information on stream width and environment (rural vs. urban) to determine the appropriate cost curve. Output to the Costing Module is the cost of restoration per linear foot. The user input of restoration length is used as a multiplier in the Costing Module. More detailed information on the inputs and outputs is provided in **Appendix A,** while cost curve development is discussed in **Appendix B**.

2.7.3 ASSUMPTIONS

The Streams and Habitat Module assumes the following:

- Urban environments are considered those where the stream restoration takes part within an incorporated area and commercial or residential development has occurred adjacent to the riparian buffer. It is assumed that a few homes along a stream may not constitute an urban setting.
- Streams and Habitat costs compound with Level of Restoration. For example, Level 3 costs include Level 1 and Level 2 costs. The cost curves assume total cost of the project with all components of the lower levels of restoration included.
- Restoration level is categorized based on typical components of a restoration project. If a project incorporates only some levels of restoration, the user may perform multiple analysis to best represent costs. For example, if a project incorporates Level 3 and Level 1 components, but not Level 2, the user may perform multiple cost estimates and remove the calculated costs for Level 2. The new costs may be directly input into the Costing Module.

2.8 USER-SPECIFIED PROJECTS MODULE

This module is for projects that already have cost estimates for construction that may go beyond what can feasibly be calculated with the Cost Estimating Tool. Alternatively, this module could be used to capture a portion of project costs that do not fit within other modules but are included in a multi-component project. The user can input the information on construction costs, which are supplied to the Costing Module to calculate project development, annual, and other costs described in **Section 2.9**. Additional inputs beyond construction costs may be required by the user to perform these other calculations. For example, to calculate normalized cost, the average annual water supply produced by the project is needed.

The User-Specified Project Module assumes the following:

- Users with projects that do not fit into the category of the provided modules may submit their project through the User-Specified Project Module.
- The user is assumed to either have procured a professional to develop a project cost or has used a different costing mechanism to develop planning-level, or better, costs.

- In the Project Description field, the user should provide a description of the project, what needs are met by the project, total yield and any major project components that contribute to cost. It is assumed the user has a project that has been previously developed enough to provide a detailed description of project elements that affect cost.

2.9 COSTING MODULE AND COST SUMMARY

Project costs are developed separately in the Costing Module, which brings together the information supplied or calculated from the Project Modules to develop planning-level cost estimates in an overall Cost Summary sheet. The costs are broken out into construction, project development, and annual costs. The construction costs are developed using the output from the Project Modules (described in the preceding sections) and applying cost curves. These cost curves are adjusted to account for current market conditions based on the year input by the user. Project development and annual costs are developed using percent mark-ups and other inputs that can be adjusted by the user as needed.

The final Cost Summary Sheet is a summary outline of all the costs by type along with an annual cost calculation and a normalized cost that can be used for project comparison.

2.9.1 CALCULATION PROCESSES

The process for the Costing Module and Cost Summary Sheet includes calculating construction, project development, annual, and normalized costs as described in the following sections.

2.9.1.1 CONSTRUCTION COSTS

The construction costs of each component of a module are calculated using a cost curve or multiple cost curves representing different variables of the component. Each type of cost and the variables used are outlined in Table 2-3.

Table 2-3 Summary of Variables Used to Cost Infrastructure Types

Infrastructure/Project Type	Required Variable(s) for Cost Estimate	Optional Additional Information
Pipelines	Length (ft), Diameter (in), Environment	Water Delivered
Intake or Booster Pump Stations	Power (HP)	
Storage Tanks	Volume (MG)	
Wells (including the well pump)	Type, Depth (ft), Capacity (gpm)	
Reservoirs	Type, New Storage Volume (ac-ft)	Height of Falling Water (ft) and Discharge (gpm) for Hydropower Calculations
Treatment	Type, Capacity (mgd)	
Diversion Structure	None*	Type
Ditch	Project Type, Ditch Type, Capacity (cfs), Length (ft)	
Stream Restoration	Level of Restoration, Environment, Width Range (ft)	Constructability
Water Rights and User-Specified Projects	User-Supplied Cost ($)	

*Cost of a diversion structure is flat cost with no variables required

2.9.1.2 COST ADJUSTMENTS FOR CONSTRUCTION COSTS

The Cost Estimating Tool calculates costs that represent the market value for the year selected by the user. The cost curves developed and programmed into the Costing Module are based on year 2017 dollars, but the tool adjusts those costs to represent a year specified by the user based on **Equation 12**.

Equation 12. $$F = \mathrm{P}(1+i)^{n}$$

where F = future cost

P = present cost (specifically in 2017 dollars)

i = escalation rate

n = difference in years from 2017 to the year selected by the user

The method for adjusting costs to the current or desired year uses an escalation rate of 3.5 percent based on the rolling average of historical prices. This is different from using other cost indices that look at comparative escalation to obtain a more precise adjustment for the selected year. The method employed in this tool is smoothing out the variability in escalation rates from year to year because the level of accuracy in the cost estimate is not high enough to warrant a more precise escalation rate for the desired year costs. If the user feels that the current-market rate is significantly different, they may change the value for the escalation rate used in the tool.

Costs entered in the Water Rights or User-Specified Project Modules and any other direct cost inputs must be entered in the year dollars desired for the end project costs as these costs are not converted via **Equation 12**.

2.9.1.3 PROJECT DEVELOPMENT COSTS

The project development costs, also referred to as associated project costs or soft costs, include other types of costs related to constructing the project. These costs include the following:

- Land Acquisition
- Engineering Services
- Surveying
- Legal Services
- Financing and Bond Assistance
- Environmental and Cultural Studies
- Permitting
- Interest During Construction
- Power Connection Costs for Pump Stations

Most of these project development costs are calculated as a percentage of capital construction costs. Default percentage values are provided. Exceptions include land acquisition and permitting. Land acquisition is calculated based on the total acreage and a cost per acre, or the user may input a total cost. The user must supply such values in the global inputs. Permitting costs may vary based on the type of project. The user must consider an appropriate percentage of the capital cost to include based on the project type.

2.9.1.4 ANNUAL COSTS

The annual costs are the costs that continue beyond project completion and include the following:

- Debt service: calculated using the annual cost equation with user input on interest and duration (See **Equation 13** below)
- O&M: for some projects, calculated as a percent of the capital cost of the facility or project
- Pumping energy costs: the energy use calculated in applicable modules multiplied by the cost of energy per unit

The annual cost equation for calculating debt service is shown as **Equation 13**.

Equation 13. $$A = \frac{i(1+i)^n}{(1+i)^n - 1}$$

where A = annual cost (in current-market dollars)

i = interest rate

n = the duration of the debt service in years

The variables for calculating annual costs may vary for different types of projects; therefore, the tool provides various inputs for debt service and O&M based on the type of project.

2.9.1.5 NORMALIZED COST

Normalized cost converts the project cost to a unit cost for the purposes of comparison. For water projects, normalized cost typically divides the total cost by the amount of water produced by the project. For this Cost Estimating Tool, normalized cost may be presented using different units or project yield amounts to give the user flexibility in comparing project costs.

Normalized cost might not be applicable for certain projects included in this tool, thus it will be calculated if the appropriate inputs are supplied by the user. These inputs include the total project yield and the project peaking factor.

2.9.1.6 COST SUMMARY SHEET OUTLINE

The Cost Summary Sheet summarizes the capital costs and outlines the project development, annual and normalized costs discussed in the previous sections.

2.9.1.7 SOURCE DATA AND INFORMATION

Source data and information include unit costs and cost curves in 2017 dollars for capital costs. These inputs were developed from several sources including bid tabs available from CWCB, project experience and input from CDM Smith's construction group. The development of the unit costs or cost curves for each Project Module are documented in **Appendix B**.

Default values for percentages for project development costs and interest rates were developed from project experience but may be changed by the user in the Global Inputs tab.

2.9.2 ASSUMPTIONS

The cost data were developed from several sources of data. As these are planning-level costs, there are several assumptions associated with each Project Module as previously discussed. See **Appendix B** for any specific assumptions regarding the cost curves.

Section 3: Tool Recommendations

It is recommended that the tool be reviewed and updated on a regular basis (for example, whenever Water Plan data sets are updated). This section provides considerations for review and future iterations of the tool in the following areas; (1) cost data, (2) tool functionality, and (3) basin implementation.

3.1 COST DATA LIMITATION AND RECOMMENDATIONS

The cost datasets presented and explained in Appendix B should be reevaluated during every update of the Cost Estimating Tool. Cost curves embedded in the tool during its creation should be compared against project cost data from sources such as the forthcoming BIP updates, updated projects from CWCB or Colorado Department of Natural Resources (CO DNR), new publications, and/or other resources on cost data for water supply projects. The Cost Estimating Tool cost curves should either be adjusted to fit the updated data, or new cost curves developed. The applicability of the escalation rate should also be revisited in future iterations.

Several modules were identified as having limitations in accuracy, region-specific data, or the quantity of available cost information. Table 3-1 provides a list of each module, data limitations and additional data collection points for updating the cost curves. Specifically, several modules referenced the Texas UCM cost curves. The State of Texas maintains a database of unit costs for various project types, and Colorado does not have such a database. It is recommended that CWCB begin to track unit costs/project costs for those cost curves developed based on Texas UCM data. As stated above, updated cost data may be collected from several sources including the next round of BIPs. When providing guidance to BRTs for BIP updates, these data points should be suggested as components of project descriptions.

An aspect of cost not addressed in the Cost Estimating Tool is avoided cost. There are alternative water supply solutions and technologies that may have a higher capital cost but have other benefits or avoided costs that may outweigh the additional cost of an advanced solution compared to a traditional solution. For example, the potential avoided cost of installing a hydropower system at a reservoir to produce energy could offset some of the annual O&M costs related to energy. While the tool includes an informational calculation of the potential revenue that could be produced for installing such a feature, these costs are not included in the overall cost summary. Another example would be the avoided costs related to implementing a water conservation program.

Table 3-1 Cost Data Limitations and Recommended Cost Data Development

Module	Data Limitations for SWSI 2017 Update	Recommended Data Collection or Updates
Pipelines	- Pump Station and Storage Tank cost curves derived from Texas UCM - The ability to select source water is provided for the user; however, no cost data are available specific to pipeline projects based on raw vs. treated water	- Collect cost data for pump stations and storage tanks specific to Colorado - Compile pipeline project data for various water supply uses (potable vs. non-potable or raw vs. treated) to determine if there is a need to provide different cost curves based on source water type
Well Fields	Well Type cost curves derived from Texas UCM	- Collect cost data for well drilling and construction specific to Colorado - Collect additional ASR well field cost data
Reservoirs	- Limited data for reservoir expansion. Cost curve uses median cost per acre-foot of storage - Reservoir rehabilitation cost data does not provide enough detail on types or design details of rehabilitation activities - No consideration of credits or avoided costs included for hydropower projects	- Compile and extract reservoir expansion projects. Projects should include information on amount of added storage and land acquisition - Compline and extract additional data on reservoir rehabilitation. Projects should include reservoir size, rehabilitation activities (dam improvements, outlet works, fish ladders, etc.) as well as any design details (geometry, size, mechanical details, etc.) - Costs for constructing hydropower facilities should be researched or compiled from submitted project data - Energy or power savings provided due to use of hydropower could be developed and included as an annual credit in the Cost Summary sheet
Treatment	For treatment types where cost data were lacking, cost curves were interpolated between treatment types expected to have higher and lower construction costs	Compile further cost information for: - Conventional plus Enhanced Coagulation - Conventional plus Ozone/UV - Conventional plus GAC
Water Rights	Water Right costs are highly variable depending on the administrative/legal process. This should remain a user-input.	None

<table>
<tr><th>Module</th><th>Data Limitations for SWSI 2017 Update</th><th>Recommended Data Collection or Updates</th></tr>
<tr><td>Ditches and Diversions</td><td>- Ditch Rehabilitation cost data were limited. Cost curves currently only consider the cost of lining materials for ditch rehabilitation projects
- Diversion structure costs were limited. A cost curve based on total diversion structure cost and diversion capacity was developed, but does not account for source stream size, diversion type, and may include other activities not associated with the diversion structure
- The user is required to know the diversion capacity for new ditches</td><td>- Compile additional data for ditch rehabilitation projects. Project data should include:
· Rehabilitation activities (re-lining, length of re-lining, channel enlargements, etc.)
· Lining type, for lining rehabilitation
· Closed conduit ditches should include piping material and size
· Open channel should include details on channel geometry and capacity
· Ditch use (type of agriculture using the water supply)
- Compile additional data for only diversion structure construction. Diversion structures should be itemized on the project cost estimate and include:
· Diversion type
· Diversion capacity and/or geometry
· Size, flow, and/or geometry of source stream
· Type of agriculture using water supply in the diverted ditch
- Future iterations may consider calculating a suggested ditch capacity based on characteristics of agriculture being served. Projects submitting ditch and diversion components should include details regarding:
· Acres served
· Type of agriculture (crops, livestock, etc.)
· Months of irrigation</td></tr>
<tr><td>Streams and Habitat</td><td>- Lack of data points in each of the 16 groupings based on width class (4), level of restoration (4) and environment (2).
- Costs for the 20-50- and 50-100-foot width classes are very similar and were grouped together due to limited data.
- Riparian restoration is included in stream restoration because projects did not separate out riparian restoration activities
- Restoration projects lacked detail on project elements and design details, therefore levels of restoration were developed</td><td>- Tool preserved the option to select the 20-50- and 50-100-foot width classes for future tool iterations. Additional stream restoration data should be compiled for various stream sizes and locations, particularly basins outside of the South Platte and Metro area
- Projects including riparian/wetland restoration should include:
· Acres of restoration
· Restoration activities (regrading, seeding) and quantities
- Future tool updates may include costs for specific restoration elements. Projects should include line-item costs for:
· In-channel structures
· Quantity (cubic yards, etc.) of earthwork
· Quantity of lining or armoring materials
· Length of restoration
· Characteristics of stream prior to restoration
· Restoration objectives for stream characteristics post-restoration</td></tr>
</table>

Module	Data Limitations for SWSI 2017 Update	Recommended Data Collection or Updates
User-Specified	User-Specified Module prompts the user to submit projects not represented in the tool	Users should submit as much design detail as possible and tool updates should include additional modules or updates to existing modules based on user-specified projects

3.2 TOOL FUNCTIONALITY RECOMMENDATIONS

The following are recommendations for improving or expanding the capabilities of this tool per module. A general functionality update to consider is integrating the tool into a web-based platform where information can be directly entered through the CWCB website and documented in an online database. This would remove the need for users to download the tool and the need for manual maintenance of an off-line database for tracking project components and costs.

The following recommendations are based on review of the current projects used to develop the Project Modules. Most of these updates could not be included in the current version of the Cost Estimating Tool due to data limitations. To effectively implement these recommendations, cost data required to develop these updates should be identified and requested in the next round of BIPs. Furthermore, a method of collecting and organizing such data should be implemented. Functionality updates that require additional cost details, as listed in Table 3-1, are noted for each module.

3.2.1 PIPELINES MODULE

Updates to cost data may be made per Table 3-1, which discusses the potential to develop separate curves for raw versus treated water. Regarding functionality, this module simplifies the process for developing and costing a water supply pipeline project. A more advanced tool can be developed that gives the user flexibility in developing a profile and choosing where booster pump stations are placed.

3.2.2 WELL FIELD MODULE

ASR well fields include additional components and complexity not considered in this version of the Cost Estimating Tool. Future iterations may consider either developing a separate module for ASR wells that accounts for the other aspects of ASR, such as piping from the source water to the ASR well, additional energy requirements to introduce the water into the aquifer if under pressure, and the ability to rehabilitate existing wells for ASR. This will require further development and may require additional cost curves for the specific project components relating to ASR well fields.

3.2.3 RESERVOIRS MODULE

The Reservoirs Module simplifies the costing of reservoirs based on a given reservoir storage capacity or volume. While the tool is meant to help the BRTs develop planning-level costs where minimal design parameters are known, for some users, a more complex module may be beneficial. For those with a more detailed understanding of project location, available area, or geometry of the proposed new or expanded reservoir, a more accurate cost estimate could be developed. Reservoir costs may be developed based on a conceptual understanding of reservoir embankment height, dam type (material) slopes, and required freeboard as well as spillway and outlet works details. This would require the development of additional cost information for earthwork and specific components of reservoir design.

3.2.4 TREATMENT MODULE

The Treatment Module assumes all treatment projects are intended to have an end-use of potable water; however, there are instances where the end-use may require a lower or higher standard than potable water standards for Colorado. Additionally, the tool currently prompts the user to select a treatment type, meaning it is assumed the user knows what treatment type is appropriate for their circumstance. While a reference table is provided to help guide the user to select the appropriate treatment type, future tool iterations could include functionalities to recommend appropriate treatment types.

This process may require additional cost curves if the treatment types provided are not applicable to some source water or end-uses typical of Colorado.

Currently, there is no costing options for remediation treatment activities, such as acid-mine drainage remediation, which is included in the list of projects in the current BIPs. Future iterations of the tool may consider developing a separate module or module component to address the arduous processes for acid-mine drainage using conventional treatment or passive treatment processes. This will require identification and development of additional cost-curves specific to the processes for completing acid-mine drainage remediation.

3.2.5 DITCHES AND DIVERSION MODULE

The Cost Estimating Tool currently assumes the user will understand the required capacity of the irrigation ditch. Water needs for irrigation ditches are likely associated with a volume of water needed to meet a crop-irrigation requirement. Future development of this module may include an option to estimate a required ditch capacity based on: (1) the quantity of irrigated acres, (2) the agricultural commodity, and (3) the months of irrigation. To include this additional functionality, the module should also require the user to characterize the source water stream to ensure that it can meet the diverted capacity required by the agricultural operation to be served by the ditch. The module would then be able to estimate both the required ditch capacity to meet the water supply need and the maximum ditch capacity that can be drawn off the source stream.

The NRCS tool used to develop the cost curves in the current tool estimates costs based on channel geometry. This tool was adjusted to estimate costs based on a channel capacity; however, elements of the NRCS tool could be incorporated into future tool iterations to allow users to more accurately estimate costs based on the specific geometry of their ditch channel.

3.2.6 STREAMS AND HABITAT MODULE

The Streams and Habitat Module simplifies stream restoration activities by grouping restoration into four levels. This removes the requirement that the user have full knowledge or specific design details for their restoration project. Some users may know more about the current condition of the stream and the desired condition of the stream/habitat; therefore, more accurate costing may be achieved by identifying key characteristics that are addressed by stream restoration. The module may be updated to prompt the user to characterize the pre-project condition and the desired post-project characteristics of the stream. This update may also separate the riparian restoration component and estimate the cost of riparian/wetland restoration based on the acres of restored habitat rather than by stream-mile.

The module could also provide suggestions for the types of restoration activities that may meet the post-project parameters. The development of this functionality would require research into pre- and post-stream and habitat characteristics to identify common elements used to address particular restoration objectives. Including this update may also provide an opportunity to tie together the Cost Estimating Module and the Environmental and Recreation Flow Tool.

To fully effectuate this module update, more cost data for individual elements of a stream restoration project (e.g., in-channel structures, regrading, seeding, etc.) would have to be developed in place of grouped (i.e., levels of restoration) cost curves.

3.3 BASIN IMPLEMENTATION

The Cost Estimating Tool is available to assist the BRTs in the development of BIPs. The tool provides a baseline cost estimate for use in the planning process and serves as a mechanism to collect useful information for additional planning and tool refinement in future iterations.

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Analysis and Technical Update to the Colorado Water Plan

Technical Memorandum

Prepared for:

Colorado Water Conservation Board

Project Title:

Colorado Water Project Cost Estimating Tool
Appendix A: User Guide

Date: May 21, 2019

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Appendix A: Colorado Water Project Cost Estimating Tool User Guide

This User Guide is intended to supplement the Colorado Water Project Cost Estimating Tool and provide users with additional guidance for use of the tool. Attached to this guide are details regarding the cost data used within the tool to develop total project costs from module inputs (Attachment 1). This information may be used by the user to assess the applicability of the data for their specific project and adjust as necessary in the Costing Module.

The Colorado Water Project Cost Estimating Tool is an Excel-based tool comprised of eight project modules intended for developing planning-level cost estimates. The outputs of each module are summarized in the Costing Module where cost curves are applied to module outputs to calculate total project costs. The total costs are then summarized and uniformly formatted in the Cost Summary Sheet, which can be exported and submitted with grant applications.

The Overview page of the tool provides general structure and easy navigation to any module within the tool (**Figure A-1**Figure A-1 Colorado Water Project Cost Estimating Tool Organization**)**.

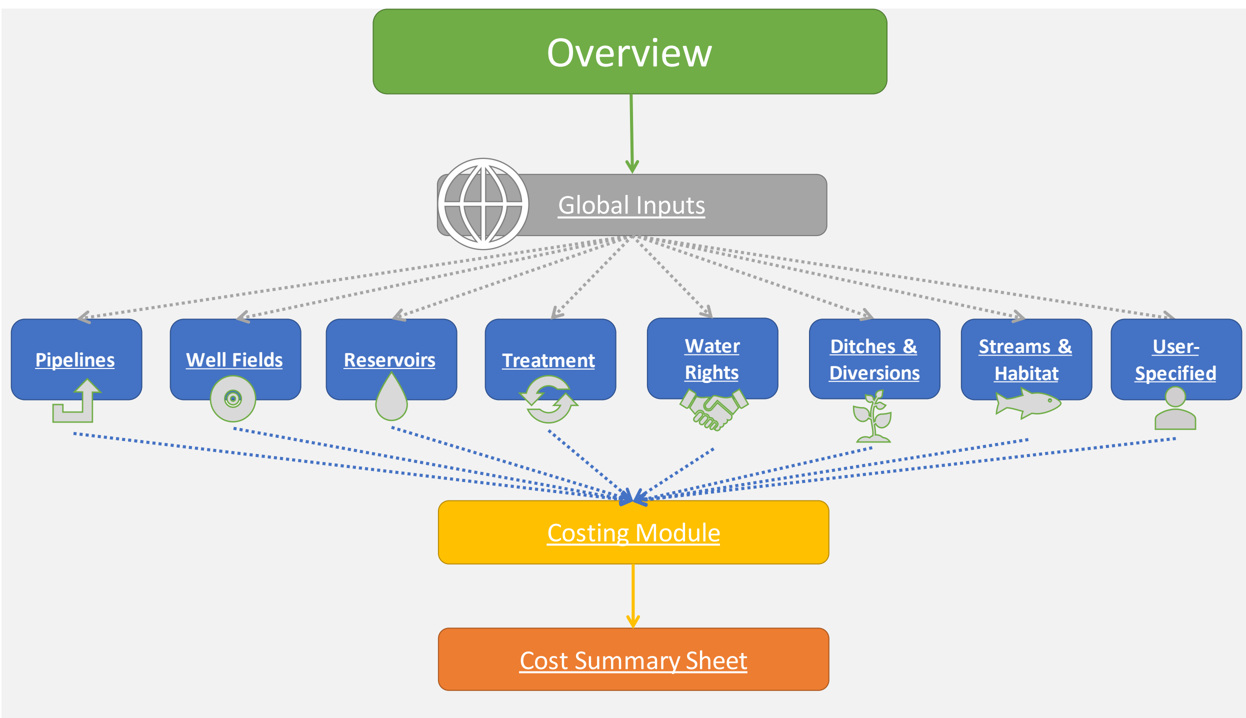

Figure A-1 Colorado Water Project Cost Estimating Tool Organization

On the Overview page, the user can navigate to any module by clicking on the module name. Because the tool is Excel-based, the user can also navigate through the tool using the Excel tabs at the bottom of the interface. When working within a module there are two buttons located in the upper corners for navigation either back to the Overview page or to the Costing Module.

The Overview page also provides brief instructions for tool use with the following introduction:

Introduction
The Colorado Water Project Cost Estimating Tool is intended to provide a common technical framework for basin roundtables (BRTs) to utilize when developing their Basin Implementation Plans. This tool builds on previous Colorado water project cost estimation methods as well as other tools developed for planning-level cost estimation to provide an accessible and user-friendly tool for basin roundtables to use in developing high-level cost estimates of projects and methods.

In addition, the use of this tool provides costs presented in a manner that enables easy comparison by the Colorado Water Conservation Board. As this tool is used, it may be adjusted over time to improve the function and costs databases as more project information and costs are collected. Each project module varies in complexity and level of detail based on the amount of data available to support development of cost curves and the required input information to define specific project-type characteristics.

User Note: For the tool to function properly, user must enable Macros in Excel. Sheets are locked to prevent user-adjustment of calculations. Password for sheet protection is SWSI 2017.

For help navigating the tool, user should refer to the Quick Reference Guide.

Instructions for Enabling Macros: Microsoft Office Support - Enable or Disable Macros in Office Files

The following disclaimer is included at the bottom of the Overview page, which users should consider while using the tool, and information included in the tool, for further development of projects:

Disclaimer
This tool was developed for the purpose of preparing regional water planning level cost estimates only. It is not intended to be used in lieu of professional engineering design or cost estimation. Results of this tool should be carefully reviewed by construction professionals, professional engineers or other knowledgeable professionals prior to implementation of a project.

Any use of the Colorado Water Project Cost Estimating Tool and results will be at the user's own risk and without liability of legal exposure to the Colorado Water Conservation Board and/or CDM Smith, Inc.

A.1: GLOBAL INPUTS MODULE

The Global Inputs Module collects general project information from the user which may be commonly referenced throughout several modules or pertains to project development, administration or annual costs.

A.1.1 INPUT KEY

The user should refer to the Input Key provided at the top of the Global Inputs Module, as shown in **Figure A-2**, when using any of the modules.

Input Key	
0	User Input
0	Informational Data*
0	Default Value, Adjustable by User
0	**Calculated Values, Not to be Adjusted**

Figure A-2 Water Cost Estimating Tool Input Key

The user should take care to only directly input values in white and green cells and review project data before adjusting default values provided in blue cells. Cells highlighted in green should be filled in as accurately as possible; however, the values do not influence project cost. The purpose of collecting informational data via the green cells is for tool improvement during future iterations. Users should not adjust grey cells as they calculate values required for project costing; grey cells are locked to prevent user-adjustment.

Throughout the tool, there are “Reset” and “Restore” buttons. The “Reset” buttons will set all user input cells (white cells) on the page back to blank. The “Restore” buttons will change back all default values (blue cells) on the page to their original values.

A.1.2 PROJECTION INFORMATION SECTION

The Project Information Section (Figure A-3) records important project identification data, water supply need(s) addressed by the project, and project costing reference information.

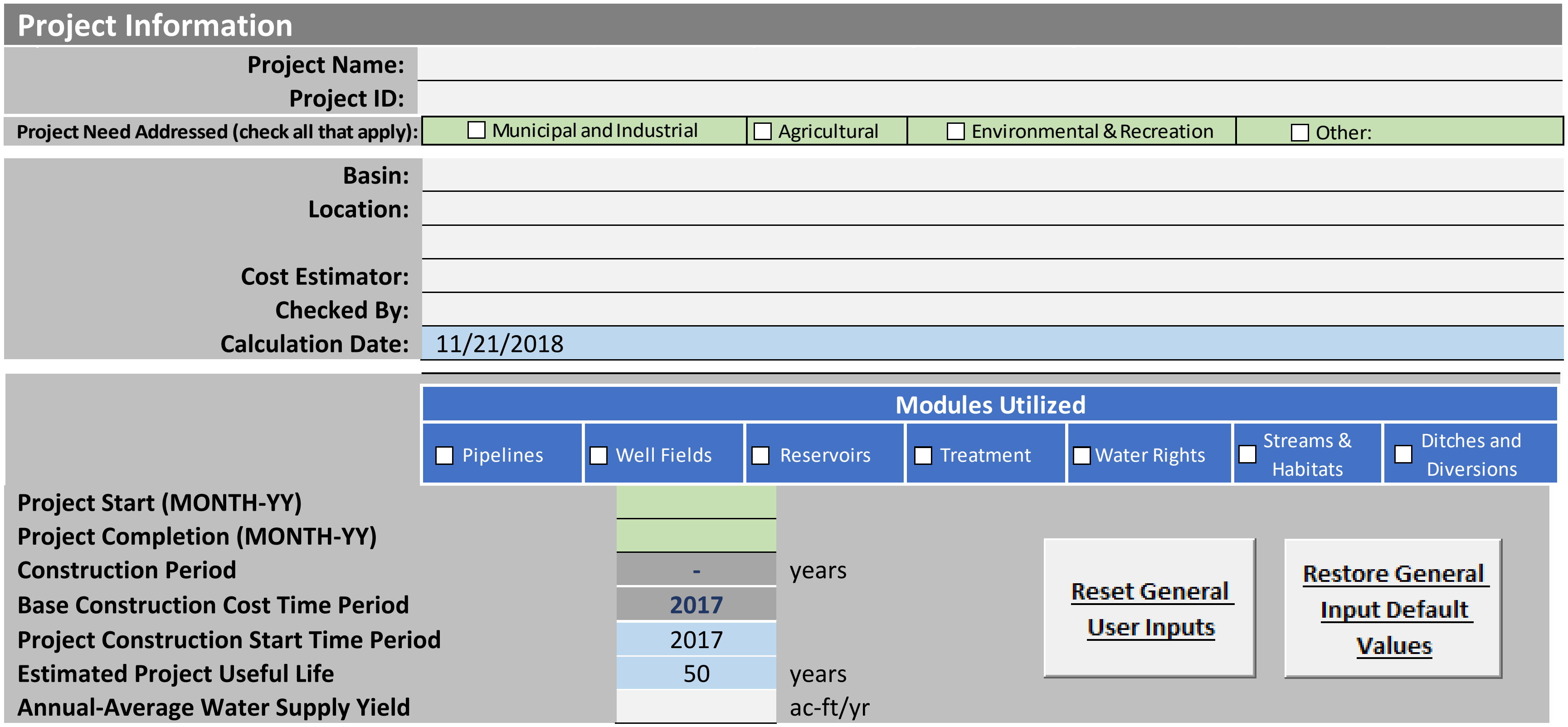

Figure A-3 Project Information Inputs

The user may provide an assumption of project construction timeframe, but the Project Construction Cost Index Time Period is the critical input for adjusting the calculated cost estimate to account for price escalation over time. The cost curves used to generate project costs are based on 2017 dollars; however, understanding that the tool may be used for costing projects that will not break ground for several years, and that costing data within the tool may not be updated until the next iteration of the Statewide Water Supply Initiative (SWSI), the tool is designed to project future costs using a fixed 3.5 percent inflation rate. This rate was based on long-term inflation rate trends provided by the Colorado Water Conservation Board (CWCB). Note that in fields where the user specifies a cost, this inflation rate will **not be applied**, and costs are assumed to be in the year construction will take place.

Project useful life represents the amount of time the user expects the project, as designed, to be operational. The user may also consider this to be the amount of time the project will be in effect before a significant retrofit, capacity increase, or update is required. For example, a treatment plant may have a peak capacity to meet the current population and, based on a 50-year population projection, it is possible that capacity will need to be increased in 50 years. Thus, the project useful life is 50-years. This may be used to estimate total maintenance costs over the life of the project.

The Annual-Average Water Supply Yield represents the additional new supply yield per year the project being costed with the Colorado Water Project Cost Estimating Tool will provide. This value is used in the Project Summary Sheet to calculate the normalized cost of the project.

A.1.3 PROJECT DEVELOPMENT COSTS

Project Development Cost inputs address the overall project administration, engineering design, and oversight costs. The default values, as shown on **Figure A-4**, are consistent with industry standards for project development but may be changed by the user. Required Land Acquisition must be input by the user if the cost of land is to be calculated based on dollars per acre. It is assumed that most project types will require the purchase of land. Note that in fields where the user specifies a cost, the inflation rate will **not be applied**, and costs are assumed to be in the year construction will take place. The Project Development Costs input allows the user to either input the total cost for acquisition of all acres or provide a cost per acre, which is multiplied by the Required Land Acquisition value provided by the user.

Project Development Costs		
Engineering Services	20.0%	% of Capital Costs
Surveying	1.0%	% of Capital Costs
Legal Service	10.0%	% of Capital Costs
Financing and Bond Assistance	1.0%	% of Capital Costs
Environmental and Cultural Studies	1.0%	% of Capital Costs
Required Land Acquisition		acres
Land Acquisition Cost		$ per acre
Permitting	1.0%	% of Capital Costs
Interest During Construction	4.0%	

Figure A-4 Project Development Inputs

A.1.4 ANNUAL COSTS AND PUMPS

The user should review the default values for calculating annual costs associated with project development, capital investment, and operations and maintenance (O&M). Each is shown on **Figure A-5**.

Annual Costs		
Debt Service	5.5%	% of Capital Costs
Debt Service (Non-Reservoirs) Period	20	Years
Debt Service (Reservoirs) Period	40	Years
Operations & Maintenance (Pipelines)	1.0%	% of Capital Costs
Operations & Maintenance (Pump Stations)	2.5%	% of Capital Costs
Operations & Maintenance (Reservoirs)	1.5%	% of Capital Costs
Rate of Return on Investments	1.0%	
Annual Interest Rate (Non-Reservoirs)	5.5%	
Annual Interest Rate (Reservoirs)	5.5%	
Power Costs	0.11	$ per kilowatt-hour
Pumps		
Power Connection Costs - Pump Stations	150	$ per horsepower

Figure A-5 Annual Costs and Pump Power Connection Costs

Debt Service refers to the quantity of money required (per year) to repay loans or external capital investment towards the proposed project. Default values assume 20 years for non-reservoir projects and 40 years for reservoir projects. Interest over the term of the loan is included with a credit for Rate of Return on Investment.

O&M costs are assumed to represent costs of monitoring, labor, equipment, and repairs of facility components. If users wish to adjust default values provided in the Global Inputs Module, they are encouraged to research similar projects completed in their basin or community. When adjusting default values within the Global Inputs Module, the user should refer to projects completed recently (within the last 5 years) throughout their basin or community. The default values are considered representative for the entire state and may vary based on region or basin.

A.2: PROJECT MODULES OVERVIEW

Most project modules are designed for developing planning-level cost estimates. As such, detailed project components are either generalized or assumed because the user is not expected to know all project details at this level. In general, modules are organized where high-level project inputs and outcomes are considered first (e.g., desired total yield). The user then works through more detailed components of the project, keeping high-level project goals in mind.

The header of each module includes the module name and intended use as well as project information, assumptions, and abbreviations.

Pipeline and Pump Station Parameters
Pipeline Module should be used for all projects with a pipeline component. The main elements of a pipeline project include the pipeline, pump stations and storage at the pump station. Three segments are available to cost out different pipe/pump parameters.
Project Information
Enter Project Name in Global Inputs
Enter Project ID in Global Inputs
Enter Basin Name in Global Inputs
Enter Cost Estimator in Global Inputs
Assumptions
Based on typical water composition, terrain and use in Colorado, Ductile Iron Pipe is assumed for all pipeline calculations and costing.

Calculations and costs assume an average of 6ft of cover over the length of the pipeline.

Calculations and costs assume an average of 2500ft between valves in the pipeline. Bends are not considered.

Storage requirements are provided by the user, but a recommended value is 10% of the average daily flow.

Abbreviations

ac-ft/yr	-	acre-feet per year
cfs	-	cubic feet per year
ft	-	feet
ft-msl	-	feet - mean sea level
fps	-	feet per second
HP	-	horsepower
HGL	-	Hydraulic Grade Line
in	-	inches
kW-hr	-	kilowatt-hour
MG	-	million gallons
mgd	-	million gallons per day
psi	-	pounds per square inch
TDH	-	Total Dynamic Head

Figure A-6 provides an example of this header.

Pipeline and Pump Station Parameters		
Pipeline Module should be used for all projects with a pipeline component. The main elements of a pipeline project include the pipeline, pump stations and storage at the pump station. Three segments are available to cost out different pipe/pump parameters.		
Project Information		
Enter Project Name in Global Inputs		
Enter Project ID in Global Inputs		
Enter Basin Name in Global Inputs		
Enter Cost Estimator in Global Inputs		
Assumptions		
Based on typical water composition, terrain and use in Colorado, Ductile Iron Pipe is assumed for all pipeline calculations and costing.		
Calculations and costs assume an average of 6ft of cover over the length of the pipeline.		
Calculations and costs assume an average of 2500ft between valves in the pipeline. Bends are not considered.		
Storage requirements are provided by the user, but a recommended value is 10% of the average daily flow.		
Abbreviations		
ac-ft/yr	**-**	**acre-feet per year**
cfs	**-**	**cubic feet per year**
ft	**-**	**feet**
ft-msl	**-**	**feet - mean sea level**
fps	**-**	**feet per second**
HP	**-**	**horsepower**
HGL	**-**	**Hydraulic Grade Line**
in	**-**	**inches**
kW-hr	**-**	**kilowatt-hour**
MG	**-**	**million gallons**
mgd	**-**	**million gallons per day**
psi	**-**	**pounds per square inch**
TDH	**-**	**Total Dynamic Head**

Figure A-6 Example Project Module Header

The Project Information section is carried over into every module from the Global Inputs tab. The user should read and understand the assumptions for each module and refer to the main report for further guidance on the assumptions prior to completing the module inputs.

A.3: PIPELINES MODULE

The Pipelines Module may be used to cost projects that transport finished or raw water for potable or non-potable uses. The costs developed for the total project include the pipeline, pump stations, and storage at the pump stations (if required). The module assumes that the user has minimal information regarding the route; therefore, the number and size of pump stations and storage tanks needed is estimated. If the user is aware of a difference along the route that should be considered in the calculations, the module is divided up into multiple pipe segments that may be used.

A.3.5 MODULE ORGANIZATION

Each pipe segment is organized into four main components: Pipeline Information, Pipeline Diameter, Pipe Hydraulics and Pump Station Hydraulics. Each component is shown on Figure A-7 through Figure A-10.

These components are included in three separate pipe segment calculations. Use of multiple segments is not required and only necessary if there is a change in project yield, peaking factor or diameter along the pipeline length. Multiple segments may also be used if the user wants to control the number and distribution of pump stations along the project. Inputs or calculations do not transfer from one segment to another. They can, however, be used as independent calculations that combine into a single, total cost estimate. The inputs and each component are described further in the following sections.

A.3.6 MODULE INPUTS AND OUTPUTS

The inputs, calculations and source data for the Pipelines Module are described in the following sections for each of the four components. The overall module outputs that feed into the Costing Module are also described.

A.3.6.1 PIPELINE INFORMATION

This component, as shown on **Figure A-7,** requires the inputs described in **Table A-1**. Many of these inputs are used in calculations in the subsequent components. The input for Environment dictates the cost curve used for costing the pipeline project. The user specifies if the area of the pipeline project will take place in a rural or urban environment. For the purposes of this tool, urban environments are considered those within an incorporated area where commercial or residential development has occurred adjacent to the planned project site. Rural environments should be reserved for those projects planned in areas with minimal development or human influence on the natural habitat. The user should conduct site assessments either through site visits or aerial imagery analysis to determine the best characterization of the project environment. Water Delivered is for informational/data collection purposes and not included in any calculations within the tool.

Pipeline Information

	Ground Elevation (ft-msl)	Environment		Water Delivered	Desired Head at End of Pipe (psi)	Maximum Pipeline Pressure (psi)
Pipeline Start				Raw		
Pipeline End						

Figure A-7 Pipeline Information Component

Table A-1 Pipelines Module Inputs - Pipeline Information

Input	Units	Description
Pipeline Start/End Elevation	ft-msl	Elevation in feet, relative to sea level, of upstream and downstream nodes for pipeline segment
Environment	-	Condition of area where pipeline is installed: Urban or Rural
Water Delivered	-	Characterization of raw or treated water through pipeline. Input is informational only
Residual Head at End of Pipe	psi	Required pressure at pipe end node
Maximum Pipeline Pressure	psi	Greatest allowable pressure through the pipeline. Also known as pipeline pressure class

ft-msl = feet – mean sea level; psi = pounds per square inch

A.3.6.2 PIPELINE DIAMETER

This component calculates the required pipeline diameter based on a maximum allowable velocity given project yield and peaking factor. A screenshot is shown on **Figure A-8.** Each input is described in Error! Reference source not found.. The user may change the default value provided for velocity.

Pipeline Diameter *If desired discharge and velocity are known and required diameter is unknown*		
Total Project Yield		ac-ft/yr
Peaking Factor, PF		
Peak Flow through Pipeline, q	**0.0**	**cfs**
Velocity of Flow, V	5	fps
Required Diameter	**0.00**	**in**

Figure A-8 Pipeline Diameter Calculator Component

Table A-2 Pipeline Module Inputs - Pipeline Diameter

Input	Units	Description
Total Project Yield	ac-ft/yr	Average annual water delivered through the pipeline in acre-feet/year
Peaking Factor	-	Ratio of peak flow to average flow through the pipeline
Velocity of Flow	fps	Default value of 5 feet per second (fps) represents typical maximum velocity through pressurized pipes in a transmission system

ac-ft/yr = acre feet per year; fps = feet per second

A.3.6.3 PIPE HYDRAULICS

The inputs for this component, shown on

Pipe Hydraulics		
Nominal Pipe Size, d		in
Pipeline Length, L		ft
Hazen-Williams C Factor	120	(Roughness)
Maintenance Downtime	5.0%	for Uniform Delivery

Flow				
Average Flow (mgd)	**Average Flow (cfs)**	**Peak Flow (mgd)**	**Peak Flow (cfs)**	**Velocity (fps)**
0.00	**0.00**	**0.00**	**0.00**	**-**

Figure A-9, are used in the hydraulic calculations and described in

Table A-3. The user selects the nominal pipe diameter based on the required diameter calculated in the previous component. Average flow, peak flow, and velocity are calculated to be used in the subsequent component (Pump Station Hydraulics). The calculated velocity is based on peak flow.

Pipe Hydraulics				
Nominal Pipe Size, d				in
Pipeline Length, L				ft
Hazen-Williams C Factor			120	(Roughness)
Maintenance Downtime			5.0%	for Uniform Delivery
Flow				
Average Flow (mgd)	**Average Flow (cfs)**	**Peak Flow (mgd)**	**Peak Flow (cfs)**	**Velocity (fps)**
0.00	**0.00**	**0.00**	**0.00**	**-**

Figure A-9 Pipeline Hydraulics Component

Table A-3 Pipeline Module Inputs - Pipe Hydraulics

Input	Units	Description
Nominal Pipe Size	in	The Pipeline Diameter calculator provides a minimum required diameter for the pipeline. The user selects a standard pipe size diameter greater than the required diameter
Pipeline Length	ft	The length of the pipeline segment from start to end
Hazen-Williams C Factor	-	Roughness coefficient used in pipeline calculations. Default value of 140 is representative of Ductile Iron Pipe
Maintenance Downtime	%	Percent of time over the year to shut down the pipeline and pumps for maintenance. Only applied if the pipeline is providing uniform delivery (i.e., the peaking factor is equal to 1) to account for a greater maximum flow needed throughout the year to meet the project annual yield.

in = inches ft = feet % = percent

The default value for the Hazen-Williams C Factor is 140, representing Ductile Iron Pipe. However, understanding that the source water, use, and soil composition may require alternate pipe materials, Error! Reference source not found. provides a reference table of various pipe materials and respective H azen-Williams C Factors, should the user wish to adjust the default value.

Table A-4 Hazen-Williams Constants for Various Water Pipe Materials

Type of Pipe or Surface	range	clean	design
steel			
welded and seamless	150–80	140	100
interior riveted, no projecting rivets		139	100
projecting girth rivets		130	100
projecting girth and horizontal rivets		115	100
vitrified, spiral-riveted, flow with lap		110	100
vitrified, spiral-riveted, flow against lap		100	90
corrugated	80–40	80	60
mineral			
concrete	150–60	120	100
cement-asbestos	160–140	150	140
vitrified clays			110
brick sewer			100
iron			
cast, plain	150–80	130	100
cast, tar (asphalt) coated	145–50	130	100
cast, cement lined		150	140
cast, bituminous lined	160–130	148	140
ductile iron	150–100	150	140
cement lined	150–120	150	140
asphalt coated	145–50	130	160
wrought, plain	150–80	130	100

Type of Pipe or Surface	range	clean	design
miscellaneous			
aluminum, irrigation pipe	135–100	135	130
copper and brass	150–120	140	130
wood stave	145–110	120	110
transite			
lead, tin, glass	150–120	140	130
plastic (PVC, ABS, and HDPE)	150–120	155	150

[a] C values for sludge pipes are 20% to 40% less than the corresponding water pipe values

[b] The following guidelines are provided for selecting Hazen-Williams coefficients for cast-iron pipes of different ages. Values for welded steel pipe are similar to those of cast-iron pipe five years older. New pipe, all sizes: C = 130.5 yr old pipe: C = 120 (d < 24 in); C = 115 (d ≥ 24 in). 10 yr old pipe: C = 105 (d = 4 in); C = 110 (d = 12 in); C = 85 (d ≥ 30 in). 40 yr old pipe: C = 65 (d = 4 in); C = 80 (d = 16 in).

Table Referenced from PE Civil Reference Manual, Sixteenth Edition, Appendix 17.A Specific Roughness and Hazen-Williams Constants for Various Water Pipe Materials

A.3.6.4 PUMP STATION HYDRAULICS

The inputs for this component are shown on

Pump Station Hydraulics							
Pump Type			Booster				
Pump Efficiency			0.7	(Mechanical & Electrical)			
Pump Requirements							
Static Head (ft)	**Total Dynamic Head (ft)**	**Total Power Needs (HP)**	**Number of Pump Stations Needed**	**HP per Pump Station**	**HP Needed for Average Flow**	**Total Pumping Energy (kW-hr)**	**Storage Volume Requirement (MG)**
1115.5	**1120.5**	**1252.1**	**2**	**626.1**	**633.1**	**3,929,021**	**0.22**

Figure A-10 and described in **Table A-5**. Values from the previous three components are used to calculate power needs, number of pump stations, energy use, and storage volume required. The number of pump stations is a simplified calculation based on the maximum pipeline pressure. It is assumed that a pump station is needed at each point along the pipeline when the maximum pipeline pressure will be exceeded. Total horsepower is then distributed evenly over the number of pump stations needed. To estimate total pump energy needed, the average annual flow is used to calculate overall power needs. Finally, storage is assumed to be needed at 10 percent of the average annual flow.

Pump Station Hydraulics							
Pump Type			Booster				
Pump Efficiency			0.7	(Mechanical & Electrical)			
Pump Requirements							
Static Head (ft)	**Total Dynamic Head (ft)**	**Total Power Needs (HP)**	**Number of Pump Stations Needed**	**HP per Pump Station**	**HP Needed for Average Flow**	**Total Pumping Energy (kW-hr)**	**Storage Volume Requirement (MG)**
1115.5	**1120.5**	**1252.1**	**2**	**626.1**	**633.1**	**3,929,021**	**0.22**

Figure A-10 Pump Station Hydraulics

Table A-5 Pipeline Module Inputs – Pump Station Hydraulics

Input	Units	Description
Pump Type	-	Pump type used for water transmission through the pipeline; may be Intake or Booster
Pump Efficiency	HP/HP	The ratio of output power from the pump to the shaft horsepower input for the pump; default efficiency is 0.7

HP = horsepower

A.3.6.5 PIPELINE MODULE OUTPUTS

The outputs from the Pipeline Module that feed into the Costing Module are described in **Table A-6**. Some outputs are user-provided information while other outputs are calculated in one of the components described previously.

Table A-6 Pipeline Module Outputs to Costing Module

Output	Units	Description
Nominal Pipe Size	in	User selected pipeline diameter
Length	ft	Pipeline length as input by user
Environment	-	Condition of area where pipeline is installed: Urban or Rural
Pump Station Facility Size	HP	Calculated power per pump station
Number of Pump Stations	#	Ratio of pipeline pressure to maximum allowable pipeline pressure needed to convey water through the pipeline
Total Pumping Energy	kW-hr	Energy required based on average annual flow
Storage Volume Requirement	MG	Estimated onsite storage requirement for pump station

in = inches; ft = feet; HP = horsepower; # = number; kW-hr = kilowatt-hour; MG = million gallons

A.4: WELL FIELD MODULE

Well field projects that may be costed using the Well Fields Module include public supply wells, aquifer storage and recovery (ASR) wells, and irrigation wells. Additionally, the module provides the user with options regarding the number of wells, well capacity, and distribution system. The module assumes uniform capacity and depth for each well in the well field or allows the user to specify capacity per well. Similar options are available for the booster pumps stations within the well field.

The well field lay-out is simplified and assumes a main transmission line with each well connecting at a point along the line from the furthest upstream well to the delivery point as shown on **Figure A-11**. The well collector pipeline for each well is assumed to be short enough that the cost of that line in relation to the rest of the project components is negligible. The user can input additional external costs as needed at the bottom of the Costing Module if needed for the well collector pipelines.

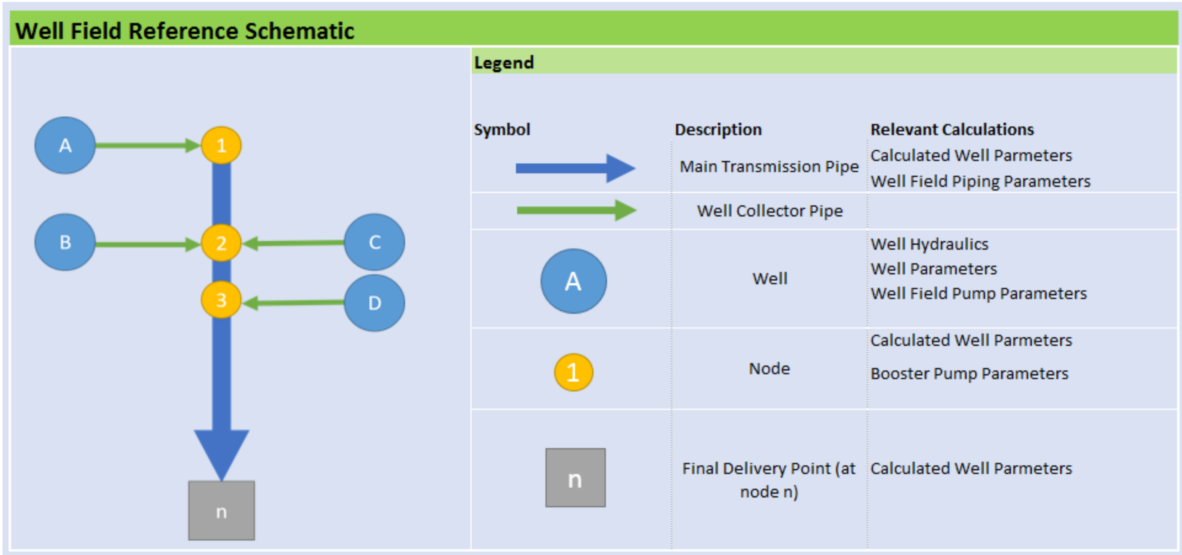

Figure A-11 Well Field Schematic

A.4.1 MODULE ORGANIZATION

The Well Fields Module is organized into three main components: Well and Pump Calculator and Cost Inputs, Pipeline Calculator and Cost Inputs, and Booster Pump Calculator and Cost Inputs. Each represents a separate component of a potential well field project. The well and pump parameters are required to generate well field project costs, but the pipeline and booster pump parameters are not necessary if the user does not need costs for those components.

A.4.2 MODULE INPUTS, OUTPUTS AND SOURCE DATA

The inputs, calculations, and source data for the Well Fields Module are described in the following sections for each of the three components. The overall module outputs that are fed into the costing module are also described.

A.4.2.1 WELL AND PUMP CALCULATOR AND COST INPUTS

The user provides well field information including: the type of well, hydraulic information, and flows. These inputs determine the required well parameters, including energy requirements to extract water to the top of the well. Additional booster pump requirements to convey water through well field transmission line piping are calculated separately in the Booster Pump Calculator and Cost Inputs component. Based on user input for average flow per well, the tool calculates the number of wells needed in the well field to meet the desired total project yield assuming the same capacity at each well. To help the user conceptualize the inputs, Figure A-12 is a schematic of a well showing the various depths and elevations. All of the inputs are shown on Figure A-13 and Figure A-14 and described in Table A-7.

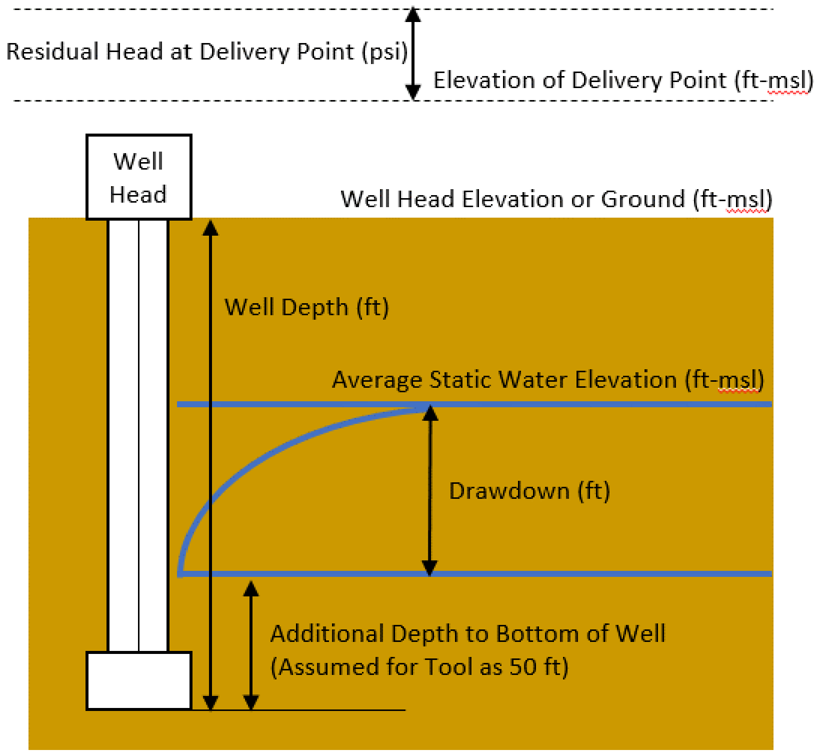

Figure A-12 Well Hydraulics Schematic

User must address all input boxes for the entire section of this module for all values to calculate. User will need to scroll to the right to see all inputs. Specific items to note when supplying inputs include the following:

- Once "Number of Required Active Wells" calculates, the user must input the "Well Head Elevation (ft-msl)" for each of the wells before additional values will calculate.
- The next inputs required to finish the calculations in "Well and Pump Hydraulics" come from "Well Parameter Cost Inputs," which are copied over using the supplied button or can be input by user.

Well Field Information	
Well Type:	
Average Static water elevation (ft-msl):	
Drawdown (ft):	
Total Project Yield (ac-ft/yr):	
Average Daily Well Field Yield (mgd):	0.00
Peaking Factor:	
Well Column Velocity (fps):	8
Elevation of Delivery Point (ft-msl):	
Residual Head at Delivery Point (psi):	
Efficiency (Mechanical & Electrical):	0.7
Hazen Williams C Factor:	140
Click Here for C Factor Roughness Reference Table	
-	

Well and Pump Hydraulics	
Average Flow Per Well (gpm):	
Peak Flow Per Well (gpm):	-
Average Flow Per Well (cfs):	-
Peak Flow Per Well (cfs):	-
Number of Required Active Wells:	0
% Operating Time:	-
Average Well Head Elevation (ft-msl):	-
Average Depth to GW (ft):	-
Well Column Losses (ft):	-
Average TDH (ft):	-
Average Well Pump Requirement (HP):	-
Total Well Pump Requirement (HP):	-
Average Energy Usage per Well (kW-hr):	-
Total Energy Usage for All Wells (kW-hr):	-

Figure A-13 Well & Pump Calculator – Well Field Information and Hydraulics

Calculated Well Parameters

Required Wells	Well Head Elevation (ft-msl)	Calculated Depth (ft)*	Calculated Peak Capacity (gpm)

*Assumes 50 feet below the drawdown level

Copy Calculated Well Cost Inputs

Well Parameter Cost Inputs
User inputs can use calculated parameters or be user defined, but should match or exceed the calculated capacity requirements

Well Number	Calculated Depth (ft)*	Calculated Peak Capacity (gpm)	Quantity
1			1
2			1
3			1
4			1
5			1
6			1
7			1
8			1
9			1
10			1
Total Well Field Capacity (gpm)			-
Total Required Well Field Capacity (gpm)		-	

Figure A-14 Well Parameters

Table A-7 Well Field Module Inputs - Well and Pump Calculator and Cost Inputs

Input	Units	Description
Well Type	-	Public Supply, Aquifer Storage Recovery, or Irrigation Wells
Average Static Water Elevation	ft-msl	The average groundwater elevation, relative to mean sea level, across the well field without the influence of well pumping
Drawdown	ft	Difference in elevation between average static water level and water level immediately adjacent to the well during active pumping
Total Water Production	ac-ft/yr	The anticipated total annual water production of the well field
Peaking Factor	-	Ratio of maximum flow to average flow for an individual well
Well Column Velocity	fps	Typical velocity of 8 fps used to calculate losses in the well column when calculating TDH
Elevation of Delivery Point	ft-msl	Elevation, relative to sea level, at the final delivery point for well field water supply
Residual Head at Delivery Point	psi	Pressure at end of well field transmission pipe
Efficiency (Mechanical & Electrical):	HP/HP	The ratio of output power from a well or pump to the horsepower input; default efficiency is 0.7
Hazen-Williams C Factor	-	Roughness coefficient used in pipeline calculations. Default value of 120 is representative of Ductile Iron Pipe
Average Flow per Well	gpm	Average production of each individual well
Well Head Elevation	ft-msl	Elevation, relative to mean sea level, of top of well (ground elevation); enter an elevation for every well
Calculated Depth	ft	Calculated values if user chooses to utilize the calculations; alternatively, user enters more specific data for each well
Calculated Peak Capacity	gpm	Calculated values if user chooses to utilize the calculations; alternatively, user enters more specific data for each well

ft-msl = feet – mean sea level ft = feet ac-ft/yr = acre-feet per year fps = feet per second psi = pounds per square inch
gpm = gallons per minute

A.4.2.2 PIPELINE CALCULATOR AND COST INPUTS

This component is similar to the Pipelines Module but uses the calculated flow from the Well and Pump Calculator component to determine the cumulative flow through each segment of the transmission line. The module only accounts for the main transmission line (no well field collector piping) and assumes that all wells are in series, increasing in flow based on the calculated peak capacity for each well. The components are shown on Figure A-15 and Figure A-16, and the inputs are described in Table A-8. For Selected Diameter, the user selects a nominal pipe diameter for each pipe segment based on the minimum required diameter computed based on the default maximum velocity. The Selected Diameter and user-input Pipe Length are carried through to the Costing Module. The input for Environment dictates the cost curve used for costing the well field project. For the purposes of this tool, Urban environments are considered those where the planned project takes place within an incorporated area where commercial or residential development has occurred adjacent to the project site. Rural environments should be reserved for projects planned in areas with minimal development or human influence on the natural habitat. The user should conduct site assessments either through site visits or aerial imagery analysis to determine the best characterization of the project site.

Well Field Piping Parameters

Calculates required pipe diameter and booster pump capacity for conveying water along main well field transmission line to delivery point

US Node/ Pipe Number	Flow (gpm)	Peak Flow (cfs)	Computed Diameter for 5 fps (in)	Selected Diameter (in)	Velocity (fps)	Length (ft)
1	400	0.9	5.7	6	4.5	200
2	800	1.8	8.1	10	3.3	300
3	1200	2.7	9.9	10	4.9	50
4	1600	3.6	11.4	12	4.5	400
Totals						950

Figure A-15 Well Field Pipeline Calculator

Well Field Piping Parameter Cost Inputs

Pull from user inputs in Well Field Piping Parameters table

Pipe Size (in)	Environment	Pipe Length (ft)
6	Urban	200
10	Urban	300
10	Urban	50
12	Urban	400

Figure A-16 Well Field Pipeline Cost Inputs

Table A-8 Well Field Module Inputs - Pipeline Calculator and Cost Inputs

Input	Units	Description
Selected Diameter	in	Diameter of each transmission pipe segment for delivery from well field to final delivery point
Length	ft	Length of transmission pipe segment
Environment	-	Condition of area where pipeline is installed: Urban or Rural

in = inches ft = feet

A.4.2.3 BOOSTER PUMP CALCULATOR AND COST INPUTS

Booster pump stations are added along the well field transmission line in this component using the values from the previous components to calculate the number, capacity, and power for each pump station. The component is shown on Figure A-17 and Figure A-18. The inputs for this component are described in Table A-9. The calculations assume a booster pump station for each segment (between each well) with head and power needs calculated for each individual booster pump. If the system uses gravity, the head and power requirements will be zero.

The user is required to enter the Well Head Elevation of each well and select the booster pumps. Well Head Elevation should either be the same as previously entered in the “Calculated Well Parameters” component or specific elevations related to the user’s selected wells in the “Well Parameter Cost Inputs”. For the booster pumps, the user may choose to use the calculated pump capacity and total dynamic head by using the “Copy Calculated Booster Pump Cost Inputs” button. Alternatively, there is the option to manually input a selected number of booster pumps with varying capacities and head requirements. These inputs generate the required pump power and energy, which are carried through to the Costing Module.

Well Field Pipeline Booster Pump Requirements *Calculates required booster pump capacity for conveying water along main well field transmission line to delivery point*										
US Node/ Pipe Number	Capacity (gpm)	Well Head Elevation (ft-msl)	DS Well/ Pipe Node	DS Elevation Well/Pipe (ft)	Elevation Delta (ft)	HGL Slope (ft/100ft)	Segment Pipe Head Loss	TDH (ft)	Power (HP)	Energy (kW-hr)
1	400	100	2	200	100	15.9	3.17	103.2	14.9	37,683
2	800	200	3	300	100	4.8	1.43	101.4	29.3	74,089
3	1200	300	4	400	100	10.1	0.50	100.5	43.5	110,124
4	1600	400	5	500	100	7.1	2.82	102.8	59.3	150,218
Totals					100			407.9	147.0	372,114

Maximum Pipeline Pressure (psi)	226.6
Calculated Number of Booster Pumps	1

Figure A-17 Well Field Pipeline Booster Pump Calculator

Booster Pump Parameters ***User inputs can use Calculated Booster Pump Inputs or be User-defined, but should match or exceed the Total Required Capacity and TDH requirements***				
Pump Number	**Pump Capacity (gpm)**	**Pump TDH (ft)**	**Power (HP)**	**Energy (kW-hr)**
1				-
2				-
3				-
4				-
5				-
6				-
7				-
8				-
9				-
10				-
Total	-	-	-	-
Total Required	-	-		

Figure A-18 Well Field Booster Pump Parameters

Table A-9 Well Field Module Inputs - Booster Pump Calculator and Cost Inputs

Input	Units	Description
Well Head Elevation	ft-msl	Elevation, relative to mean sea level, of top of well (ground elevation); enter an elevation for every well. Values should be the same as entered in "Calculated Well Parameters" unless user chose to enter specific well information in "Well Parameter Cost Inputs".
Capacity (optional)	gpm	Cumulative flow rate through transmission line booster pump for each transmission line segment
Total Dynamic Head (TDH) (optional)	ft	Required pressure resistance pump needs to overcome to convey water through the pipeline

gpm = gallons per minute ft = feet

A.4.2.4 WELL FIELDS MODULE OUTPUTS

The outputs from the Well Fields Module that feed into the Costing Module are described in Table A-10. Some outputs are user-provided information while other outputs are calculated in one of the components described previously.

Table A-10 Well Field Module Outputs to Costing Module

Output	Units	Description
Well Type	-	Public Supply, Aquifer Storage Recovery, or Irrigation Wells
Calculated Depth	ft	Tool-generated depth of individual wells
Calculated Peak Capacity	gpm	Tool-generated capacity for each well based on total well field yield, peaking factor, and average flow per well
Energy	kW-hr	Total energy required for well and booster pumps to extract water and convey to the delivery point
Selected Diameter	in	Diameter of each transmission pipe segment for delivery from well field to final delivery point
Length	ft	Length of transmission pipe segment
Environment	-	Condition of area where pipeline is installed: Urban or Rural
Pump Station Power	HP	Power calculated for a pump station at each transmission line segment

ft = feet gpm = gallons per minute kW-hour = kilowatt-hour in = inch HP = horsepower

A.5: RESERVOIRS MODULE

The Reservoirs Module includes new reservoirs or reservoir expansions. This module simply uses cost curves for developing construction costs of a new reservoir or expansion based on the new or added storage volume. A calculation of energy provided from hydropower is provided for information purposes and is not accounted for in the cost summary.

A.5.1 MODULE ORGANIZATION

The Reservoir Module is organized into two main components: Reservoir Parameters and Hydropower. These are shown on **Figure A-19**.

Reservoir Project Parameters			
Project Type			
New Storage Volume		ac-ft	
Existing Storage (enter 0 if New Reservoir project)		ac-ft	
Total Storage (informational)	**0**	ac-ft	
Reservoir Rehabilitation Project Parameters			
Reservoir Rehabilitation Project Description			
User-Defined Reservoir Rehabilitation Cost		**Click Here for Reservoir Rehab Cost Data Table**	
Hydropower Option *Not factored into cost estimation*			
Height of Falling Water		ft	
Discharge		gpm	
Turbine Efficiency	0.9		*Encompasses mechanical and electrical efficiency used in calculating power and energy production*
Power	**0**	**HP**	
Annual Turbine Use Percentage	60%		*Percent of time over the year that a hydropower generation station will be utilized*
Estimated Annual Energy Production	**0**	**kW-hrs**	

Figure A-19 Reservoir Module Organization

A.5.2 MODULE INPUTS, OUTPUTS AND SOURCE DATA

The inputs, calculations and source data are described in the following sections for each of the components. The overall module outputs that are fed into the Costing Module are also described.

A.5.2.1 RESERVOIR PROJECT PARAMETERS

The inputs required for Reservoir Project Parameters are described in Table A-11. New storage volume applies to a new reservoir or a reservoir expansion in that it is the additional storage added by the project. Existing storage can be added by the user for informational purposes and the module will calculate the total storage of the reservoir.

Table A-11 Reservoir Module Inputs - Reservoir Project Parameters

Input	Units	Description
Project Type	-	New reservoir construction or expansion of existing reservoir
New Storage Volume	ac-ft	Volume of water to be stored in the reservoir in excess of existing storage

ac-ft = acre-feet

A.5.2.2 RESERVOIR REHABILITATION PROJECT PARAMETERS

The reservoir rehabilitation component of the Reservoir Module provides users who intend to complete significant maintenance or repair projects. Reservoir rehabilitation encompasses a variety of activities that may affect the reservoir outfall, outlet works, dredging, water quality, or embankment. Because rehabilitation does not have any defined characteristics, the user is encouraged to provide a detailed description of the rehabilitation activities taking place, as detailed in Table A-12.

Table A-12 Reservoir Module Inputs - Reservoir Rehabilitation Project Parameters

User-Specified Reservoir Rehabilitation Project Description	-	Provide project characteristics to define type of rehabilitation activities taking place. (e.g., spillway expansion/improvement, outlet-works improvements, embankment stabilization, dredging, among others)
User-defined Cost	-	User-provided cost of reservoir rehabilitation activities

To help the user estimate a reasonable cost for reservoir rehabilitation activities, a PDF reference table (Table B-1 Estimated Reservoir Rehabilitation Costs from 2015 Basin Implementation Plan) is provided with actual or estimated reservoir rehabilitation project costs from the April 2015 Basin Implementation Plans. This table is further discussed in Appendix B.

A.5.2.3 HYDROPOWER OPTIONS

This component is provided for informational purposes with the inputs described in Table A-13. Estimated annual energy production is calculated using the inputs and the default values for efficiency and percent annual use.

Table A-13 Reservoir Module Inputs - Hydropower

Input	Units	Description
Height of falling water	ft	Height difference between water surface elevation and outlet into hydropower station
Discharge	gpm	Flow rate over hydropower dam

Ft = feet gpm = gallons per minute

A.5.2.4 RESERVOIR MODULE OUTPUTS

The outputs from this module that feed into the Costing Module are direct inputs from the user and are those previously described in Table A-11.

A.6: TREATMENT MODULE

Water treatment projects may be operated to provide water for potable or non-potable uses. The principal guidelines for determining the appropriate water treatment technology is the source water quality and required effluent water quality, which is dictated by the intended effluent use. The Treatment Module was designed to address these two factors through a qualitative self-assessment of source water characteristics by the user for determining the best-suited treatment type.

The module allows the user to select a treatment type, the planned treatment average day demand, and peaking factor. A wide variety of source water quality may be considered by using the provided table of indicator parameters identified as drivers/thresholds for treatment and discussed in more detail in Section A.6.3.

A.6.1 MODULE ORGANIZATION

The Treatment Module includes two module components for the user to complete: Treatment Type and Treatment Capacity as shown on Figure A-20.

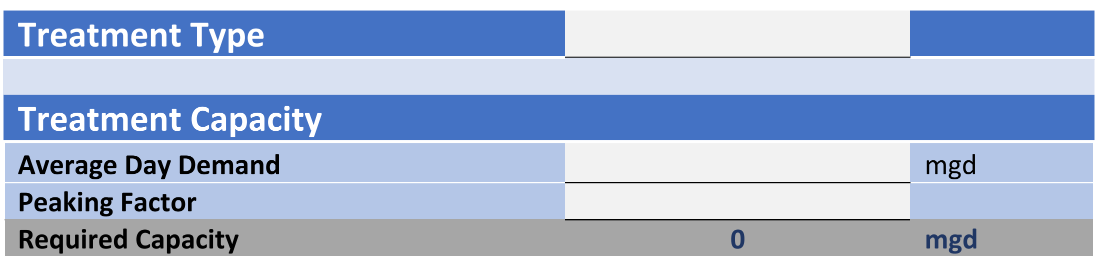

Figure A-20 Treatment Module Organization

There is no specified order in which the user should complete the module components. The “Clear Treatment Parameters” button removes all user inputs from the module, should the user wish to start over.

A.6.2 MODULE INPUTS, OUTPUTS AND SOURCE DATA

The inputs required for estimating treatment costs include water treatment type and plant design capacity. The inputs required for the Treatment Module are provided in Table A-14.

Table A-14 Treatment Module Inputs

Input	Units	Description
Water Treatment Type	-	Treatment technology selected based on source water quality and user-identified treatment needs
Average Day Water Demand	mgd	The average annual demand ultimately planned for the treatment plant
Peaking Factor	-	Used to determine a maximum day capacity

mgd = million gallons per day

A.6.2.1 TREATMENT TYPE

Treatment type should consider source water quality and the desired treated water quality.

If the user does not have a treatment type predetermined, the tool provides a reference table to aid in determining an appropriate treatment type. The reference table, shown on Figure A-21, requires that the user have, at a minimum, a qualitative understanding of the source water influent to the proposed facility. Typical water quality parameter ranges are provided for different source water types such as snow melt, reservoirs, or brackish groundwater, et al. may be used to characterize source water through a qualitative assessment (Driver/Thresholds for Treatment) or a basic quantitative assessment (Drivers/Approximate Numeric Thresholds for Treatment).

Treatment Type	Drivers/Thresholds for Treatment							Drivers/Approximate Numeric Thresholds for Treatment							Source Water Characteristics
	Pathogens	TOC	Suspended Solids & Turbidity	Salinity	Hardness	Nutrients/Taste & Odor	Emerging Contaminants	Cryptosporidium (oocysts/L)	TOC (mg/L)	Turbidity (NTU)	Chloride (mg/L)	Hardness as $CaCO_3$ (mg/L)	Threshold Odor Number	Emerging Contaminants	
Direct Filtration[1]	LOW	LOW	LOW	LOW	LOW	LOW	LOW	< 0.075 (Bin 1)	≤ 3	≤ 10	< 250	≤ 150	≤ 3	Not Detected or < Action Levels/MCLs	Pristine water quality, consistent with few excursions.
Conventional[1]	MED	MED	MED	LOW	LOW	LOW	LOW	< 0.075 to < 1.0 (Bins 1 or 2)	> 3	> 10	< 250	≤ 150	≤ 3	Not Detected or < Action Levels/MCLs	Moderate-high quality water, moderate to high frequency of excursions.
Conventional + Enhanced Coagulation	MED	MED-HIGH	MED-HIGH	LOW	LOW	LOW	LOW	<0.075 to < 1.0 (Bins 1 or 2)	> 3	> 10	< 250	≤ 150	≤ 3	Not Detected or < Action Levels/MCLs	High natural organic matter (NOM is precursor material to disinfection by-products, aka DBPs).
Conventional + Lime Softening	MED	MED-HIGH	MED-HIGH	LOW	HIGH	LOW	LOW	<0.075 to < 1.0 (Bins 1 or 2)	> 3	> 10	≥ 250	> 150	≤ 3	Not Detected or < Action Levels/MCLs	High hardness in source water, often accompanied by high NOM, turbidity, and other treatment challenges.
Conventional + Ozone/UV	MED-HIGH	MED-HIGH	MED-HIGH	LOW	LOW	MED-HIGH	MED-HIGH	< 0.075 to ≥ 3.0 (Bins 1 thru 4)	> 3	> 10	< 250	≤ 150	> 3	Detected ≥ MCLs or Action Levels	High natural organic matter (precursors to DBPs), high NOM and/or increased levels of pathogens, increased levels of bromide, moderate to severe taste and odor, potential for contaminants of emerging concern (CECs).
Conventional + GAC	MED	MED-HIGH	MED-HIGH	LOW	LOW	MED-HIGH	MED-HIGH	< 0.075 to < 1.0 (Bins 1 or 2)	> 3	> 10	< 250	≤ 150	≤ 3	Detected ≥ MCLs or Action Levels	Similar to Conventional + Ozone, but with lower risk of pathogens in source water.
Conventional + Membranes	MED-HIGH	MED-HIGH	MED-HIGH	LOW	LOW	LOW	LOW	< 0.075 to ≥ 3.0 (Bins 1 thru 4)	> 3	> 10	< 250	≤ 150	≤ 3	Not Detected or < Action Levels/MCLs	High pathogens and/or NOM.
Conventional + Nanofiltration/Reverse Osmosis	MED-HIGH	MED-HIGH	MED-HIGH	MED-HIGH	MED-HIGH	MED-HIGH	MED-HIGH	< 0.075 to ≥ 3.0 (Bins 1 thru 4)	> 3	> 10	≥ 250	> 150	> 3	Detected ≥ MCLs or Action Levels	Treats all of the challenging characteristics listed above for NOM removal, disinfection, softening, CECs, and salinity removal. Not always effective for taste and odor issues.

Figure A-21 Treatment Type Reference Table based on Source Water Characteristics

The applicable water quality parameters for treatment are:

- Pathogen concentration
- Total Organic Compounds (TOC)
- Total Suspended Solids (TSS) and Turbidity
- Salinity
- Hardness
- Nutrients/Taste and Odor, and
- Emerging Contaminants

The approximate numeric thresholds provide the user the option for a more detailed source water characterization by providing reasonable ranges for parameter indicators. The user should consult water quality data from sources such as USGS Water-Quality Data website, the National Water Quality Monitoring Council (NWQMC) Water Quality Portal, EPA STOrage and RETreival (STORET) data warehouse, or similar sources, or conduct a baseline water quality assessment of their source water to most accurately use the numeric thresholds.

Once the user has characterized the source water, the most appropriate treatment technology should be selected in the tool. However, it is understood that the basins understand their specific needs and available resources for developing water treatment projects. The most appropriate treatment type for a community may differ from the treatment type suggested by the reference table; therefore, the user should select the treatment type that best suits the needs of their community. The end use of the treated water is also a factor in determining the appropriate treatment technology. While the tool may be used to calculate non-potable use projects, for the purposes of tool simplicity, it was assumed that all end use is potable drinking water.

A.6.2.2 TREATMENT CAPACITY

The user must input the capacity for the treatment facility. Treatment facilities for potable drinking water are designed for anticipated peak day demands. The user inputs the average annual demand and a peaking factor to account for seasonal peaking.

If the user has not yet determined the capacity of the proposed water treatment facility, resources that may be useful for estimating the required capacity of a water treatment facility include American Society of Civil Engineers (ASCE) publications and EPA resources.

The outputs of the Treatment Module, which are summarized in the Costing Module of the tool, are listed in Table A-15. These parameters are used to calculate the appropriate point on the cost curve to represent a planning-level cost for constructing a treatment facility.

Table A-15 Treatment Module Outputs to Costing Module

Input	Units	Description
Water Treatment Type	-	Treatment technology selected based on source water quality and user-identified treatment needs.
Total Required (Peak) Design Capacity	mgd	The required capacity (peak day demand) of the water treatment facility

mgd = million gallons per day

A.7: WATER RIGHTS

Water rights in Colorado are administered by the Colorado Division of Water Resources. Water rights pertain to both surface and groundwater sources and are typically defined in Colorado by a process known as prior appropriations (first in time, first in right). For more information regarding water rights and water right administration in Colorado, the user should refer to the resources provided by the Colorado Department of Natural Resources (CO DNR) - Colorado Division of Water Resources.

Water Rights may be required for some projects costed using the Water Cost Estimating Tool. Water rights may be purchased for permanent or leased uses. Projects which may require the purchase of a water right or leasing include groundwater wells, in-stream channel work, and agricultural diversions. The process of converting a water right from one user to another typically requires both a lawyer and water resource engineer. Before beginning project design, users should investigate the need and feasibility of obtaining the necessary water rights.

A.7.1 MODULE ORGANIZATION

The Water Rights Module is organized for direct user input of the project description and cost information. Figure A-22 shows the Water Rights Module organization. The user should note that in fields where the user specifies a cost, such as in this module, it must be entered in the year dollars desired and selected in the Global Inputs for the project construction start time period. These costs are not converted from 2017 dollars to the selected year.

Water Rights Inputs		
User Cost Input		*Total cost of water right*

Figure A-22 Water Rights Module Organization

A.7.2 MODULE INPUTS, OUTPUTS AND SOURCE DATA

The only input required for the Water Rights Module is provided in Table A-16. Before beginning the process of designing a project relating to water supply, the user should check that the proper water rights have been procured. The module prompts the user to input the total cost of the water right (including all capital, legal and administrative costs).

Table A-16 Water Rights Module Inputs

Input	Units	Description
User Cost Input	$	Total cost of water right (in year dollars selected by user)

$ = dollars

A.8: DITCHES AND DIVERSIONS

The Ditches and Diversions Module uses high-level design considerations for the construction of a new irrigation ditch or rehabilitation of an existing one. Research into modern irrigation ditches and canals showed that ditch lining is the most variable factor in designing a ditch. In addition, it is a common rehabilitation practice to install or upgrade lining material for existing ditches. To complete the module, the user must have an estimate of the total flow the ditch should deliver to meet their water supply needs and the length of the ditch from the diversion structure to the delivery point.

A.8.1 MODULE ORGANIZATION

The Ditches and Diversions Module contains three components: Project Options, Diversion and Headgate Structure, and Diversion Structure, which focuses on characterization of ditch components and quantification of ditch capacity and length. Figure A-23 shows these components.

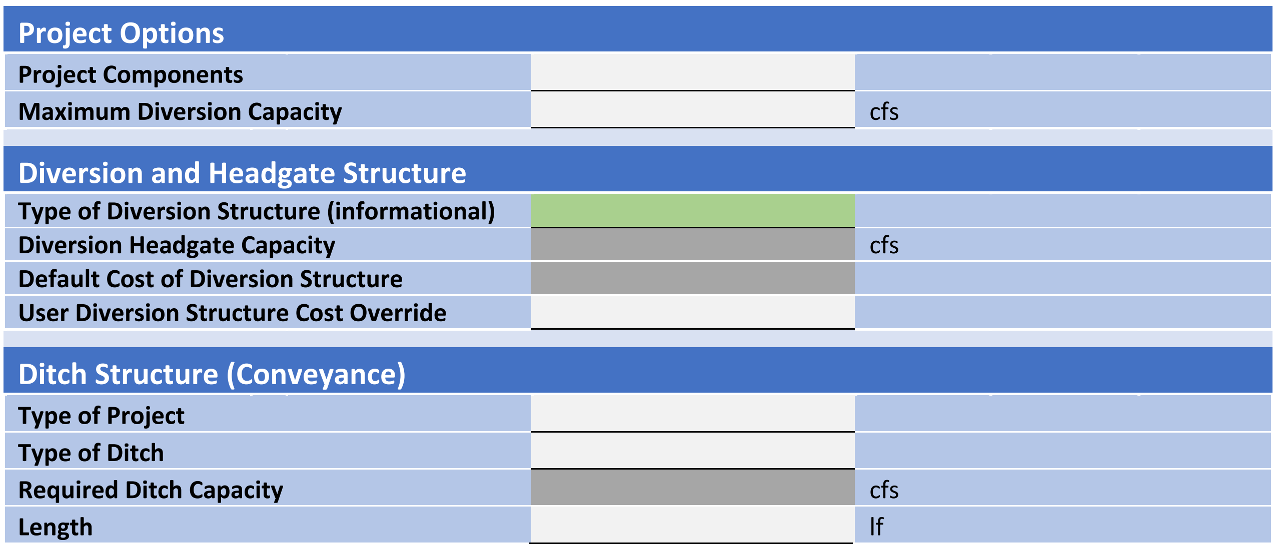

Figure A-23 Ditches and Diversions Module Organization

There is no specified order in which the user should complete the module components. The Reset Ditches and Diversions Inputs button removes all user inputs from the module, should the user wish to start over.

A.8.2 MODULE INPUTS, OUTPUTS AND SOURCE DATA

The inputs required by the Ditches and Diversions Module are provided in Table A-17. The inputs are focused on simplifying ditch characterization by only requiring basic design requirements from the user. It is assumed that the user will have quantified the amount of water required by the project and be able to convert the required yield into a ditch capacity. In addition, the user should know the type of ditch for their needs. If cost is a factor in determining ditch lining material, the user may utilize this module as a tool for determining the best suitable lining type.

Table A-17 Ditches and Diversions Module Inputs

Input	Units	Description
Project Components	-	Project may include a diversion structure, ditch, or both
Maximum Diversion Capacity	cfs	Maximum capacity diverted by the structure and/or conveyed through the ditch
Type of Diversion Structure	-	Characterization of diversion structure; captured for informational purposes only
Selected Cost of Diversion Structure	-	User-supplied cost for diversion structure construction
Type of Project	-	Construction of new ditch or ditch rehabilitation
Type of Ditch	-	Type of ditch lining or construction method
Length	lf	Length of the ditch from intake point at river to delivery point

cfs = cubic feet per second lf = linear feet

It is assumed that the user knows the basic design components of the proposed ditch project. These inputs are used directly in the Costing Module and therefore the module inputs and outputs are the same.

A.8.2.1 PROJECT OPTIONS

Project options provides general information for the project to be constructed. As some projects will only require the construction of a diversion structure or a ditch, the user may elect to cost only those components. However, for either component a capacity is required. The ditch capacity directly relates to both the amount of water diverted by the structure and the total flow conveyed through the ditch. This value will carry over to the Diversion and Headgate Structure and Ditch Structure components, as applicable.

A.8.2.2 DIVERSION AND HEADGATE STRUCTURE

The cost of a diversion structure depends on several variables relating to diversion use, type, capacity, and construction methods. This component collects the type of diversion structure and diversion structure cost installed by the user for informational purposes. This is intended to capture data to improve cost data in future iterations of the tool. The Recommended Diversion Structure Cost estimates a cost for the diversion structure, however, this curve is based on limited data points and several assumptions, discussed in the Ditches and Diversions Section of Appendix B. For these reasons, the cost is only recommended, and the user is encouraged to review the data points provided in the Ditches and Diversions Project Cost Reference (Table B-2 Estimated Ditch and Diversion Costs from Various CO DNR Projects) to determine a reasonable cost for their diversion structure. The user will input their diversion structure cost into Selected Diversion Structure Cost. The user should note that in fields where the user specifies a cost this inflation rate will not be applied and costs are assumed to be in the year construction will take place.

A.8.2.3 DITCH STRUCTURE (CONVEYANCE)

Project components relevant to designing and costing an irrigation ditch begin with understanding the type of project. Costs vary significantly for projects requiring construction of a new ditch, versus installing or re-lining an existing ditch. If the user has a ditch already constructed but knows that significant earthwork or ditch realignment will occur as part of the rehabilitation efforts, the New Ditch option may be selected, as the Rehabilitation option only accounts for lining material costs. In addition, if the project is ditch rehabilitation, it is assumed that a diversion structure is already constructed, and the user may elect not to include a diversion structure. For new ditch projects, the user should select the type of diversion structure included in the project to divert flow into the new ditch.

Type of Ditch pertains to lining material installed during ditch construction. Common lining materials for irrigation ditches included in the tool are:

- Non-Reinforced Concreted Lined
- Reinforced Concreted Lined
- Synthetic Lining
- Closed Conduit (PVC)
- Closed Conduit (DIP)

If the user is unsure of the ditch lining type to be used in the proposed project, they may consult publications by local universities, or contact the local ditch authority for guidance. The user should keep in mind that lining types may affect not only cost but may also have environmental or flow effects. Users should consult with professionals in the field of irrigation ditch construction before making a final selection of ditch lining.

The process of designing and constructing an irrigation ditch or canal can be complex, particularity in Colorado where topography and subsurface soil conditions can vary within short distances. To simplify design for the user, only the necessary ditch capacity, which can be interpreted as an estimate of water required for their irrigation needs, is input into the tool. In order to allow for ditch capacity to represent ditch geometry, several assumptions were made and are discussed in Section A.8.3. These assumptions should be reviewed carefully and considered by the user before engaging in ditch design.

A.8.2.4 DITCH LENGTH

The final component of the Ditches and Diversions Module is Ditch Length. For new ditches this is interpreted as the length of the ditch to be constructed, usually from the diversion structure within the supply stream to the final delivery or storage point. This length will be used as a multiplier in the Costing Module and therefore should only reflect the length of the ditch being lined for ditch rehabilitation projects.

A.9: STREAMS AND HABITAT MODULE

The Streams and Habitat Module generates planning-level restoration costs based on the restoration activities employed, while keeping in mind that Colorado is home to both headwaters and major rivers that serve a myriad of communities and interests.

A.9.1 MODULE ORGANIZATION

The Streams and Habitat Module contains one section which focuses on characterization of the stream and the complexity of restoration activities, which are organized into four levels. Figure A-24 shows the inputs for this component.

Stream and Habitat Inputs		
Stream Width Range	20 to 50	ft
Stream Environment	Rural	
Length of Restoration	1,000	lf
Level of Restoration	Level 3	

Figure A-24 Streams and Habitat Module Organization

There is no specified order in which the user should complete the module components. The Reset Restoration Inputs button removes all user inputs from the module, should the user wish to start over.

A.9.2 MODULE INPUTS, OUTPUTS AND SOURCE DATA

The inputs required by the Streams and Habitat Module are focused first on an understanding of the stream to be restored. While the level of restoration is also important, cost for restoration activities can vary greatly depending on the stream environment. A summary of module inputs is provided in Table A-18.

Table A-18 Stream and Habitat Inputs

Input	Units	Description
Stream Width Range	ft	Approximate width of stream segment where project takes place
Stream Environment	-	Location of project: urban or rural
Length of Restoration	lf	Linear feet of stream being improved due to project
Level of Restoration	-	Qualification of project based on tiered grouping of typical stream and habitat project components

ft = feet lf = linear feet

It is assumed that the user can quantify the basic design components of the proposed stream and habitat project. These inputs are directly referenced in the Costing Module and therefore the module inputs and outputs are the same.

A.9.2.1 STREAM AND HABITAT INPUTS

Colorado hydrology is characterized by not only the headwaters and mainstems of large rivers such as the Colorado, Arkansas and Rio Grande, but by small mountain streams and meandering channels through the plains. An understanding of the stream environment can have significant effects on the type and extent of restoration, and therefore cost. The characterization of streams is a complex process, however for the purposes of this tool, streams are defined by three variables: width, environment and length of restoration.

Stream size is represented by stream width range. Streams are categorized into four width ranges described in Table A-19. Ranges were selected as opposed to direct input of a stream width because the width of a stream may vary significantly over the length of restoration activities. It is understood that multiple stream width ranges may represent a stream over the length of restoration; the user should select the width range that is most representative of the stream over the restoration area. It should also be noted that the stream width range accounts for width of the stream from top of bank to top of bank. If riparian activities outside of the banks are to be included in restoration, they should not be accounted for in stream width.

Table A-19 Stream Width Ranges

Typical Stream Type	Stream Width Range (ft)
Headwaters or Local Stream	5 to 20
Headwaters or Small Tributary	20 to 50
Large Tributary	50 to 100
Large River Trunk	>100

Stream length is used as a multiplier in the Costing Module and therefore should only reflect the length of the stream affected by the restoration activities. For example, if the project involves two sites that are 100 feet in length along one mile of a stream, the length input into the tool should be 200 feet, not one mile. To determine the approximate length and width range of restoration, the user should conduct site surveys or use aerial imagery tools such as Google Earth or Geographic Information Systems (GIS).

Stream restoration activities and costs also vary based on stream environment. The user specifies if the area of stream restoration will take place in a rural or urban environment. For the purposes of this tool, Urban environments are considered those where the stream restoration takes part within an incorporated area and commercial or residential development has occurred adjacent to the riparian buffer. Rural environments should be reserved for those restoration activities in areas with minimal development or human influence on the natural habitat. For instance, a few homes along an isolated river may not constitute an Urban area. The user should conduct site assessments either through site visits or aerial imagery analysis to determine the best characterization of the stream environment.

To create a simplified means of costing, restoration activities were binned into compounding levels. The tool provides a reference table, shown on **Figure A-25**, to help the user determine the appropriate level of restoration for their project.

Reference Table		
Level of Restoration	**General Description**	**Typical Components**
Level 1	*Riparian restoration*	*Grading; revegetation*
Level 2	*Level 1 + bank stabilization*	*Riprap; root wads; log jams*
Level 3	*Level 2 + in-channel structures*	*Riffles; rock vanes; boulder weirs*
Level 4	*Level 3 + channel realignment*	*Channel realignment*

Figure A-25 Stream and Habitat Level of Restoration Reference Table

The levels of restoration are compounding, meaning that if Level 4 is chosen, it is assumed that all Level 3, 2, and 1 activities are also included in restoration. Level 1 restoration is intended to only address riparian habitat improvements and assumes no in-channel work or work within the stream banks. Activities associated with riparian habitat improvements may involve regrading or contour reconnection in riparian buffer, soil compaction, vegetation restoration, landscaping and adaptive management practices.

Level 2 restoration includes work along stream banks, which may include regrading of eroded banks and erosion prevention activities such as hard armoring (rip rap or structural bank protection) or bioengineered bank stabilization which incorporates natural components such as root wads, log jams, soil wraps or geo-grid fabrics, brush mattresses and timber pilings.

Level 3 restoration includes in-channel structures typically utilized to facilitate mixing, improve water quality, improve in-stream habitats, and control erosion. In-channel structures may include pool-and-riffle habitat construction, gabion baskets, rock vanes (cross vanes, single vanes and J-hooks) and boulder or log weirs.

Level 4 restoration involves channel realignment and significant earthwork and is most typically employed during the construction of stream crossings for roadways. In stream and habitat restoration, channel realignment may be used to reverse the effects of channelization and reestablish natural flow regimes to a stream.

If the user has not determined the appropriate level of restoration for the proposed project, resources are provided on the CWCB website on watershed protection and restoration, stream management plans, and species protection.

A.10: USER-SPECIFIED PROJECTS

The purpose of the User-Specified Project Module is two-fold. First, the module provides users with projects that do not align with the pre-installed modules to submit costs for their projects; and, second, the module allows users with pre-defined cost estimates that may be more detailed than the intent of this tool to submit project costs. While the tool will not aid these users with cost-estimating, project costs may still be presented in a uniform manner with the Cost Summary Sheet.

A.10.1 MODULE ORGANIZATION

The User-Specified Projects Module is organized for direct user input of the project description and cost information. **Figure A-26** shows the User-Specified Projects Module organization.

User-Specified Project Input		
Project Description		
Total Project Yield		*ac-ft/yr*
User Cost Input		*Total Capital Cost of Project Construction*
User Cost Input		*Annual Project Operations & Maintenance Costs*

Figure A-26 User-Specified Projects Module Organization

A.10.2 MODULE INPUTS, OUTPUTS AND SOURCE DATA

In the User-Specified Project Input component, the user must provide significant elements of the project as no specific inputs are defined by the tool. Therefore, these inputs are used directly in the Costing Module and therefore the module inputs and outputs are the same. The inputs required by the tool are provided in **Table A-20**. The user should note that in fields where the user specifies a cost, such as in this module, it must be entered in the year dollars desired and selected in the Global Inputs for the project construction start time period. These costs are not converted from 2017 dollars to the selected year.

Table A-20 User-Specified Module Inputs

Input	Units	Description
Project Description	-	Project description should include any significant project parameters (size, capacity) and required infatuation (pipes, pumps, dams, among others) and activities (earthwork, special construction methods, among others)
User Cost Input	$	Total cost for only construction of project (in year dollars selected by user)
User Cost Input	$	Anticipated annual operations and maintenance costs (in year dollars selected by user)

$ = dollars

If the user is submitting a project that aligns with one of the provided modules, but has more detailed cost estimates, the user should include the same information in the project description. For example, users with a detailed cost estimate for a treatment plant should include the treatment type, average daily flow, peaking factor and design capacity of the plant, just as they would if using the Treatment Module. Data collected through the User-Specified Module will be analyzed for updates and improvements to costing data for future iterations of this tool.

Similarly, if a user is submitting a project through the User-Specified Project Module because the project does not align with a pre-defined module, the user should outline the significant project elements that most affect costs. This information will be analyzed and used to include additional modules, as needed, in future tool iterations.

A.11: COSTING MODULE AND COST SUMMARY SHEET

A.11.1 COSTING MODULE

As mentioned throughout this guide, outputs from the eight project modules are summarized and applied to project-specific cost curves in the Costing Module. An example of project information displayed in the Costing Module is provided on Figure A-27. The user should note that in fields where the user specifies a cost, such as in this module, it must be entered in the year dollars desired and selected in the Global Inputs for the project construction start time period. These costs are not converted from 2017 dollars to the selected year.

Treatment Project

Treatment Project Capital Costs				
Treatment Type	*Capacity (MGD)*	*Capital Cost*	*External Cost Est.*	*Cost*
-	-	-		-

Treatment Project Annual O&M Costs				
Treatment Type	*Capacity (MGD)*	*Annual Cost*	*External Cost Est.*	*Cost*
-	-	-		-
Total Treatment Capital Project Cost				**$0**

Reservoir Project

Reservoir Project Costs			
Reservoir Project Type	*New Capacity (ac-ft)*	*External Cost Est.*	*Cost*
-	-		-

Reservoir Rehabilitation Project Costs			
Reservoir Rehab Project	*User-specified Cost*	*External Cost Est.*	*Cost*
-	-		-
Total Reservoir Project Cost			**$0**

Water Rights Project

Water Rights Project Costs	
External Cost Estimate	-
Total Water Rights Project Cost	**$0**

Ditches and Diversions Project

Ditch Project Costs					
Type of Ditch Project	*Type of Ditch*	*Maximum Discharge (cfs)*	*Length (lf)*	*External Cost Est.*	*Cost*
-	-		-		-

Diversion Project Costs			
Type of Diversion	*Maximum Discharge (cfs)*		
-			
Total Ditches & Diversions Project Cost			**$0**

Streams and Habitat Project

Streams and Habitat Project Costs						
Stream Width (ft)	*Environment*	*Level of Restoration*	*Unit Cost*	*Quantity (lf)*	*External Cost Est.*	*Cost*
-	-	*Level 1*	-	-		-
-	-	*Level 2*	-	-		-
-	-	*Level 3*	-	-		-
-	-	*Level 4*	-	-		-
Total Streams and Habitat Project Cost						**$0**

Figure A-27 Example of Costing Module Project Outputs and Costs

The user should review the project information within the relevant module sections for accuracy of data and an initial check of unit costs and direct capital costs. In general, the Costing Module does not require any inputs by the user. However, should the user have an external cost estimate for some project modules, an alternate cost estimate may be entered in the External Cost Estimate Cell, shown on Figure A-28. The user should note that in fields where the user specifies a cost this inflation rate will **not be applied** and costs are assumed to be in the year construction will take place.

Treatment Project Capital Costs			
Capacity (MGD)	***Capital Cost***	***External Cost Est.***	***Cost***
2.2	*$14,928,678*		*$14,928,678*
Treatment Project Annual O&M Costs			
Capacity (MGD)	***Annual Cost***	***External Cost Est.***	***Cost***
2.2	*$702,742*	*800,000*	*$800,000*
Total Treatment Capital Project Cost			**$15,728,678**

Figure A-28 External Cost Entry Example

The user should note that when an external cost estimate is entered in the Costing Module, that value supersedes the unit cost estimate generated by the tool. If the user wishes to compare costs, the tool-generated costs are preserved in the cells to the left, which report the unit costs for that module. Should the user decide to revert to the tool-generated costs, the external cost estimate value must be deleted; entering a value of zero will result in a cost of zero dollars for that module.

The final section of the Costing Module also encourages user-input where applicable. If line item costs are not included in the existing tool modules, the user may add these costs in the Additional External Costs section (Figure A-29). These costs are added to capital costs and reported as Additional Project Costs in the Cost Summary Sheet.

Additional External Costs			
Additional Line Item	***Related Module***	***Line Item Description***	*Item Cost*
Fencing	*Pipelines*		*$50*
Seeding	*Streams & Habitats*		*$50*
Total Additional Project Costs			**$100**

Figure A-29 Additional External Costs Example

A.11.2 COST SUMMARY SHEET

The Cost Summary Sheet summarizes all project capital, development and annual costs for the proposed project. After reviewing data on the Cost Summary Sheet to verify accuracy, the user should select Create Cost Summary. This alters the Cost Summary Sheet to display only relevant data with associated costs. For example, if only the Pipelines and Well Fields Modules were utilized, only line items associated with their construction will be displayed on the sheet. The sheet can then be exported to a PDF for submission with a CWCB grant application. An example of a completed Cost Summary Sheet is shown in Figure A-30.

Pipeline and Treatment Project
ARK-2018-001
Arkansas Basin
Cost Analysis Computed by John Doe
11/27/2018

Capital Construction Costs

Total Pipelines Project Cost	*$21,672,000*
Total Treatment Capital Project Cost	*$41,438,000*
Construction Project Costs Subtotal (Non-Reservoir)	***$63,110,000***

Project Development Costs

Land Acquisition	*$50,000*

Non-Reservoir Project Development Costs

Engineering Services	*$12,622,000*
Surveying	*$631,000*
Legal Service	*$6,311,000*
Financing and Bond Assistance	*$631,000*
Environmental and Cultural Studies	*$631,000*
Permitting	*$631,000*
Interest During Construction	*$2,524,000*
Power Connection Costs - Pump Stations	*$136,000*
Project Development Costs Subtotal (Non-Reservoir)	***$24,117,000***
Total Project Cost (Non-Reservoir)	***$87,227,000***

Reservoir Project Development Costs

Total Project Cost	***$87,227,000***
Normalized Project Cost (per ac-ft per year)	*$8,723*

Annual Costs

Debt Service (Non-Reservoirs) Period	*$7,299,000*
Operations & Maintenance (Pipelines Project)	*$474,000*
Operations & Mainteance (Treatment)	*$1,285,000*
Power Costs	*$1,646,000*
Total Annual Costs	***$10,704,000***

Figure A-30 Water Cost Estimating Tool Cost Summary Sheet Export Example

Analysis and Technical Update to the Colorado Water Plan

Technical Memorandum

Prepared for:

Colorado Water Conservation Board

Project Title:

Colorado Water Project Cost Estimating Tool
Appendix B: Cost Curves Development

Date: May 21, 2019

Prepared by: Lauren Starosta, Eli Gruber, and Devin Schultze, CDM Smith
Reviewed by: Sue Morea and Becky Dunavant, CDM Smith

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Appendix B: Colorado Water Project Cost Estimating Tool Unit Costs and Cost Curves Development

Cost curves were derived from various sources of data for each of the project modules as discussed in the following sections. Where data was not available in terms of year 2017 dollars, the values were converted from the year available to 2017 using **Equation B.1**.

Equation B.1. $F = \mathrm{P}(1+i)^n$

Where F = future cost or year 2017 cost

P = present cost or available cost from a given year

i = inflation rate

n = difference in years from year of available data to 2017

SWSI selected an inflation rate of 3.5% based on the rolling average of historical prices.

Not included are curves for water rights or user-specified projects as those modules rely on user input only.

B.1 PIPELINES MODULE APPLICATION OF COST DATA

Cost curves for the Pipelines Module are included for pipelines, pump stations, and storage tanks. Cost for pipelines are in dollars per linear foot (LF) for a given diameter in inches. For pipelines, costs curves from a previous CWCB costing tool, the Texas Unified Costing Model (UCM) and Denver Water were all converted to 2017 dollars and compared. All compared similarly; therefore, the Denver Water source was used as it was most applicable to Colorado projects.

The selected curves considered costs for undeveloped or rural areas and developed or urban areas. The Pipelines Module refers to the construction environment as Urban or Rural. An Urban environment is already developed, and construction is more difficult resulting in a higher cost compared to Rural where construction is assumed to cost less. The cost curves are shown in **Figure B-1**Error! Reference source not found..

Pump station and storage tank cost curves are based on the curves in the Texas UCM for intake and booster pump stations and ground storage tanks (with roofs). Then the curves were escalated from 2013 to 2017 dollars. The pump station cost curves are shown in **Figure B-2** and are based on pump station power in horsepower. The storage tank cost curve shown in **Figure B-3** is based on storage volume in million gallons.

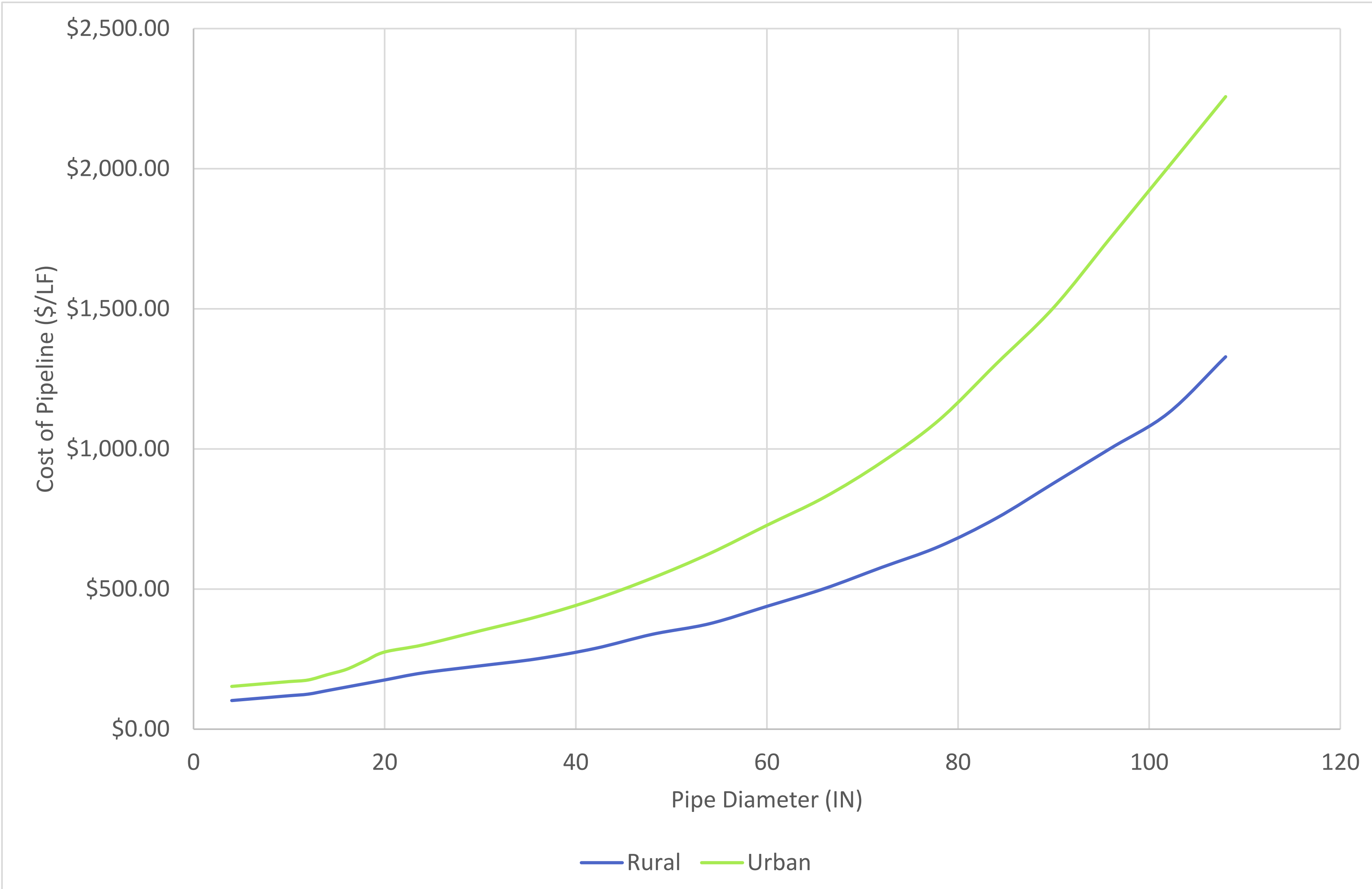

Figure B-1 Pipelines Cost Curve

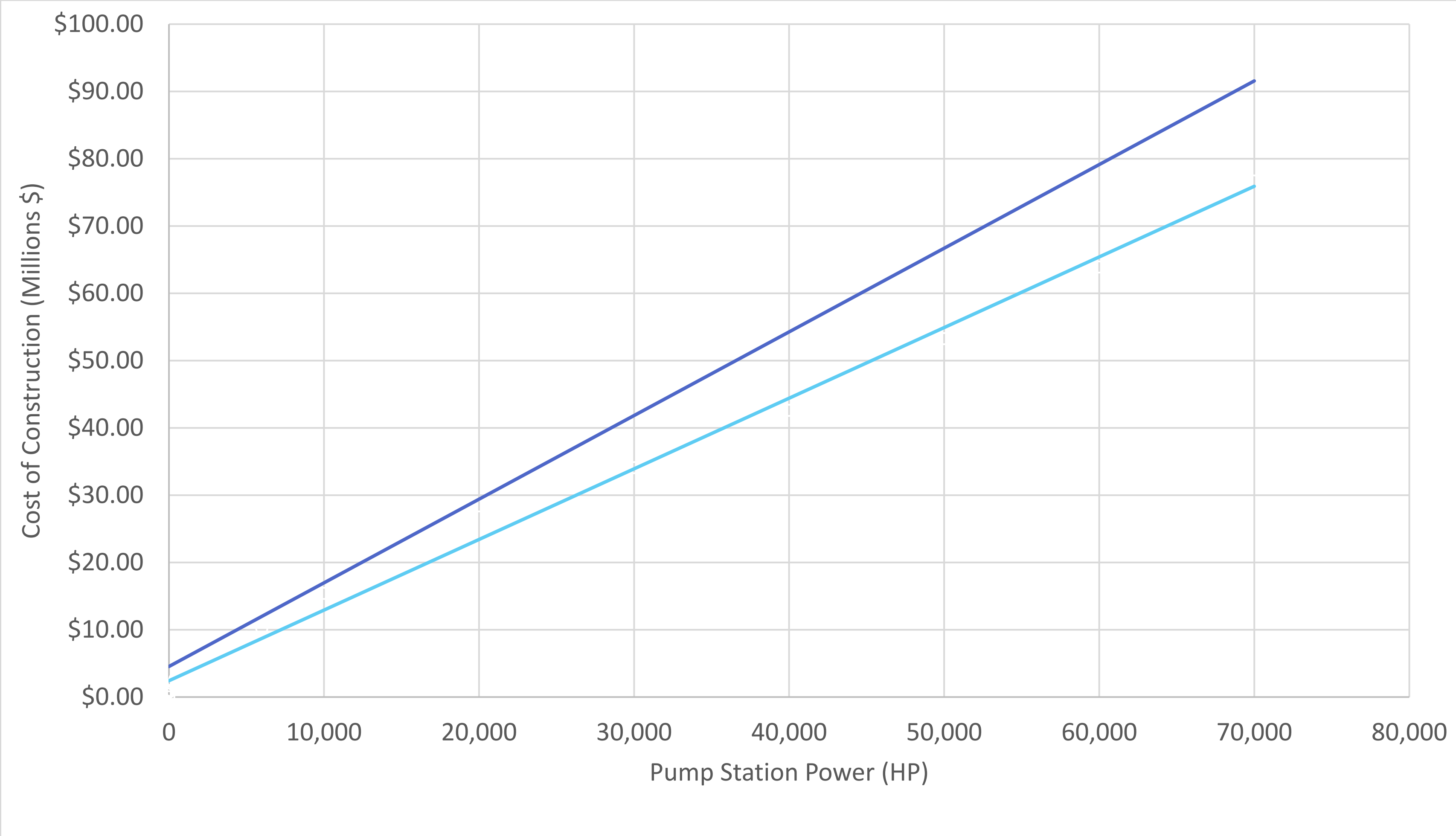

Figure B-2 Pump Station Cost Curves

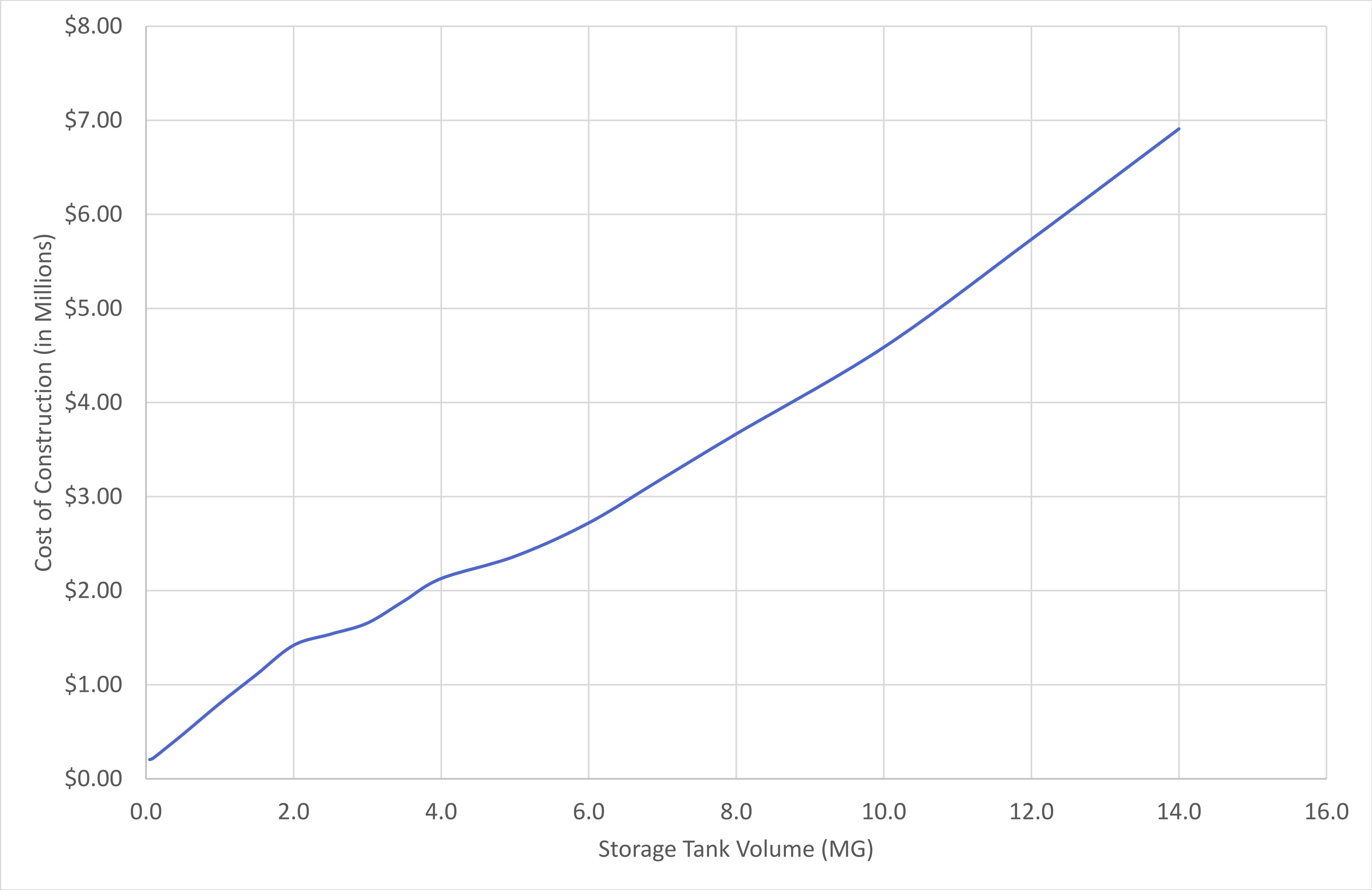

Figure B-3 Booster Pump Station Storage Tank Cost Curve

B.2 WELL FIELDS MODULE APPLICATION OF COST DATA

Cost curves for varying well capacities from 150 gpm to 1800 gpm were developed for each of the three well types: public supply, aquifer storage and recovery and irrigation. To derive the capital cost for well construction, the well capacity and depth are applied to the curve for the specific well type to return a capital cost for construction of individual wells. The cost curves are shown in Figure B-4Error! Reference source not found., Figure B-5 and Figure B-6Error! Reference source not found.. The cost for each well is summed in the Costing Module to return the cost for construction of the entire well field. The cost curves represent only the cost for construction of a well, and do not include pumping or piping costs from the well to the transmission line or to the delivery point. The cost of water conveyance through the transmission line is accounted for in the Costing Module by referencing the pipelines and booster pump station cost curves.

The cost curves for the Well Fields Module were developed based on the cost curves from the Texas UCM. The cost curves from the Texas UCM were adjusted to represent 2017 dollars. Project costs from recent well field construction projects throughout the southwest were included in the development of the cost curves to verify the Texas UCM-based curves and adjust data to be more representative of the region and time period.

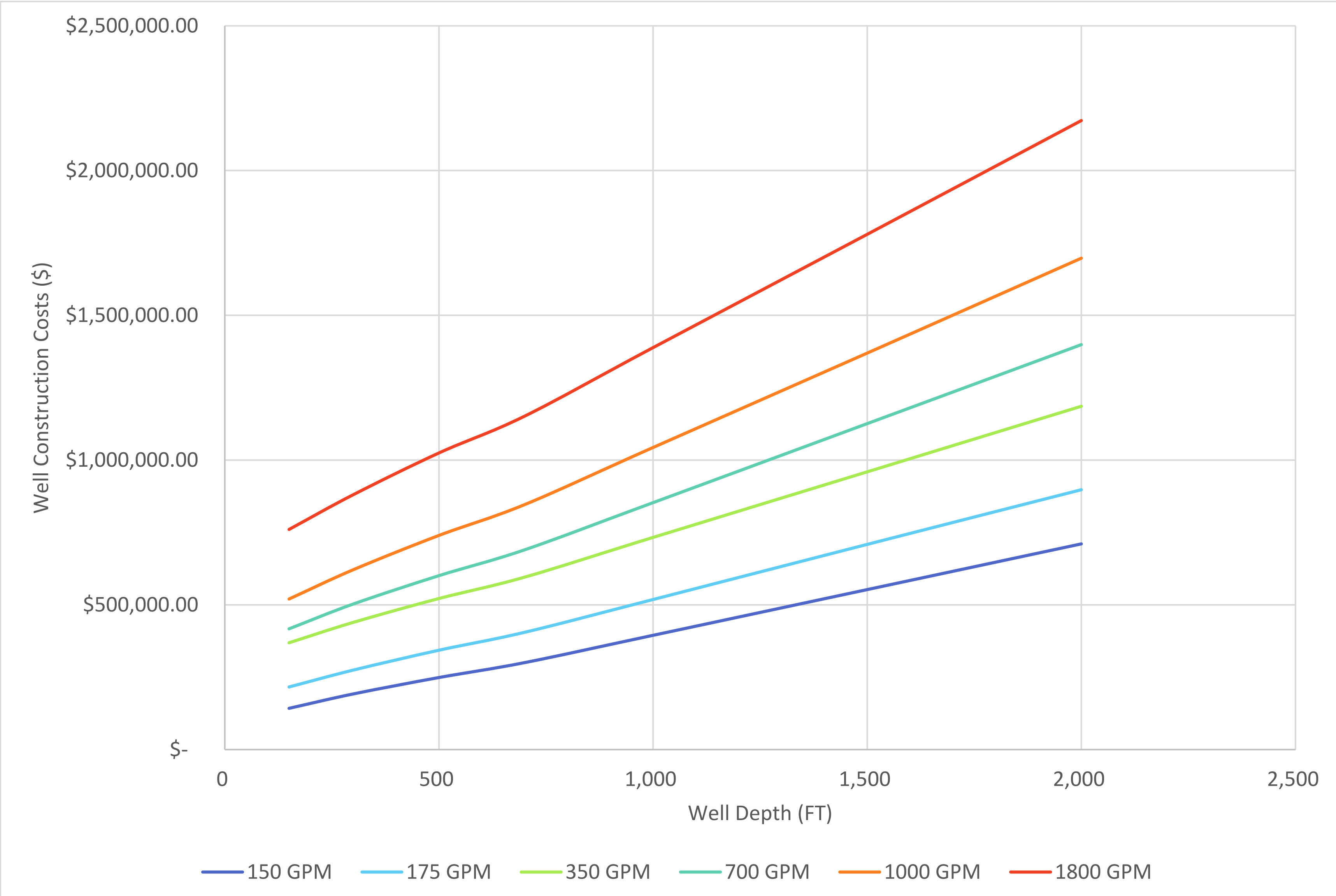

Figure B-4 Public Supply Well Cost Curves

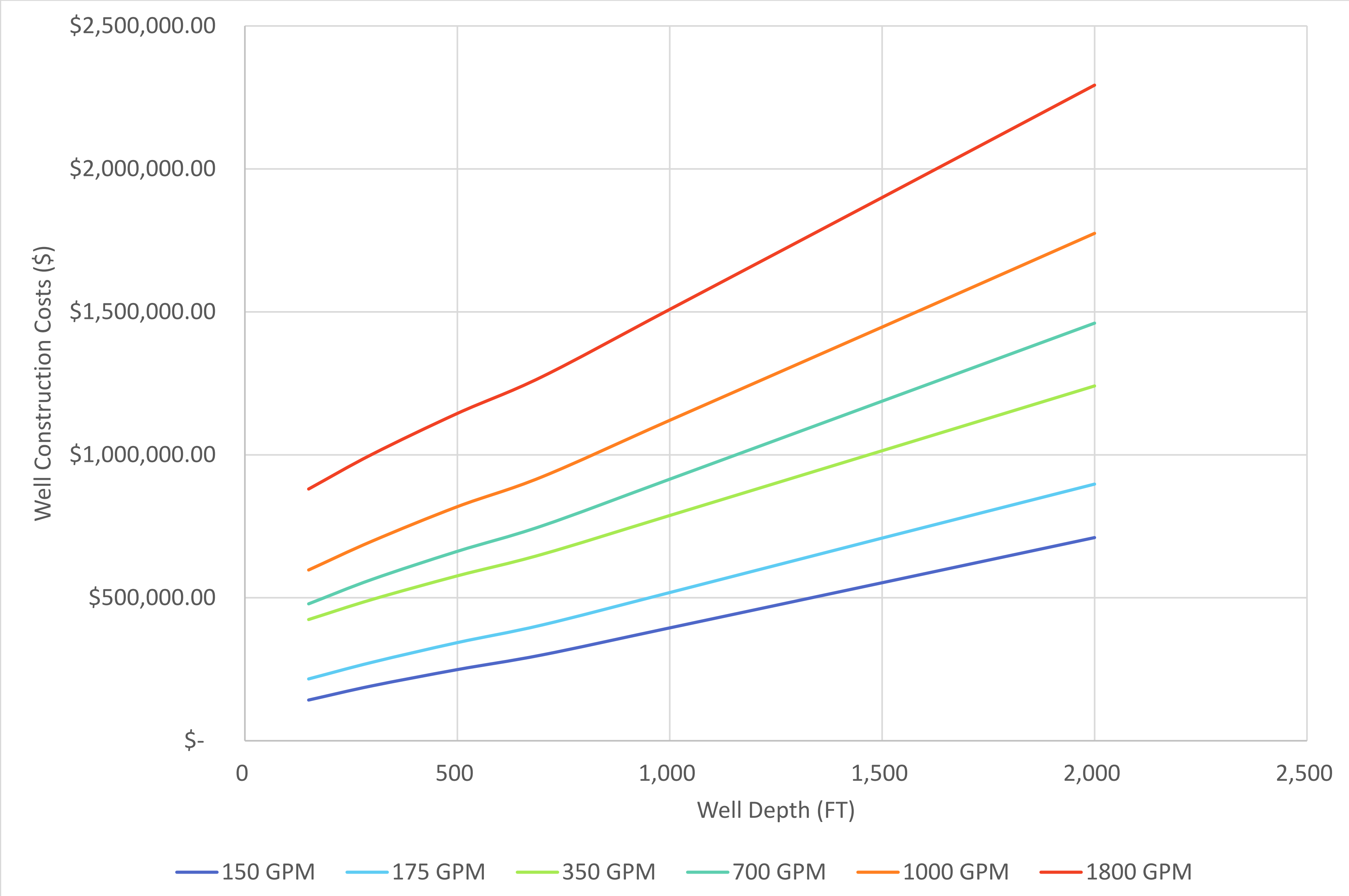

Figure B-5 Aquifer Storage and Recovery Well Cost Curves

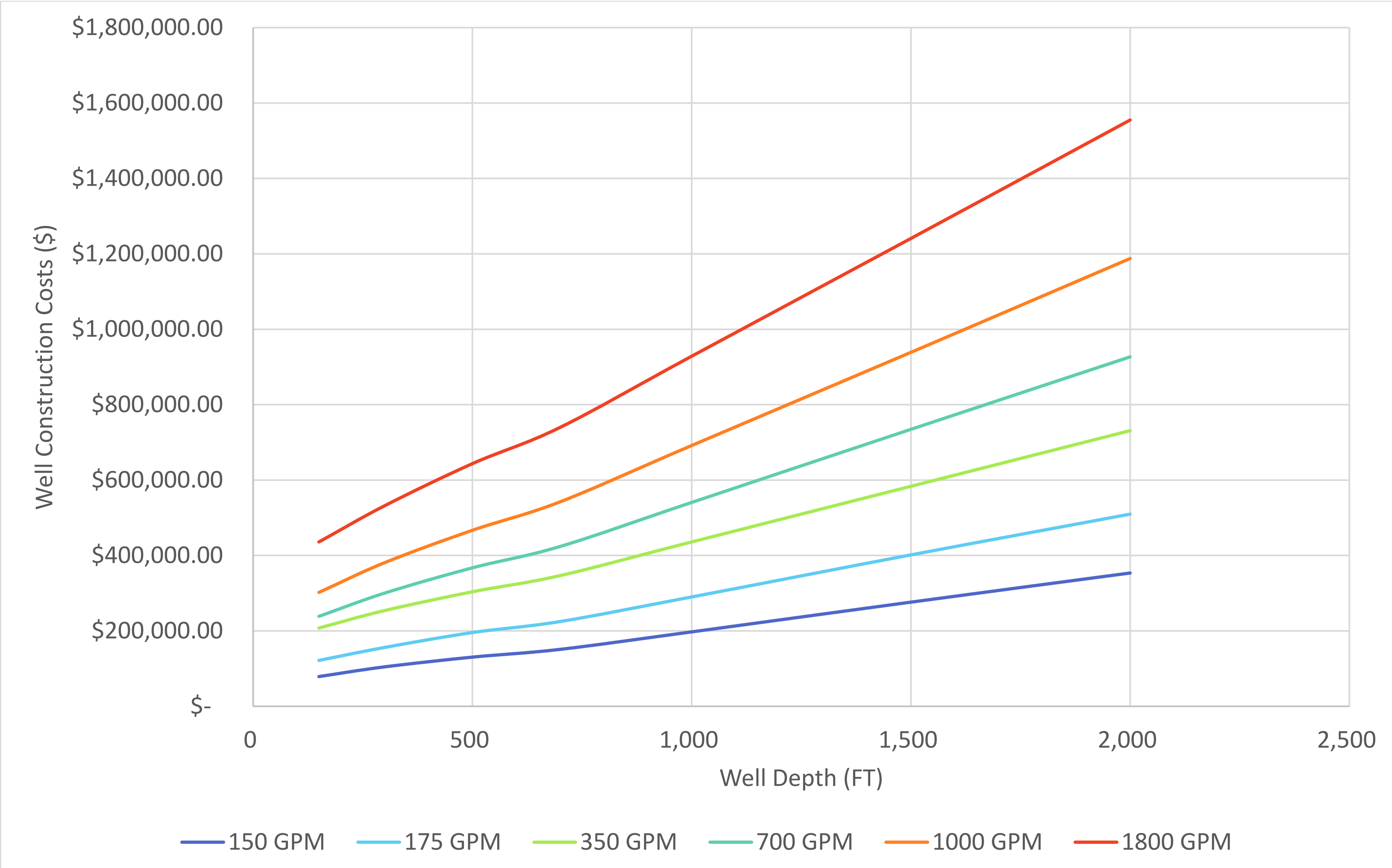

Figure B-6 Irrigation Well Cost Curves

B.3 RESERVOIR MODULE APPLICATION OF COST DATA

To convert reservoir storage into costs, cost curves were developed for new reservoirs and reservoir expansions. Cost data from recent projects were provided by the Colorado School of Mines (Burrow, 2014) and the South Platte Storage Study Final Report (Stantec & Leonard Rice, 2015) was used to develop the curves. A linear trend was fit to the data provided for new reservoirs based on storage volume and the resulting cost curve is shown in

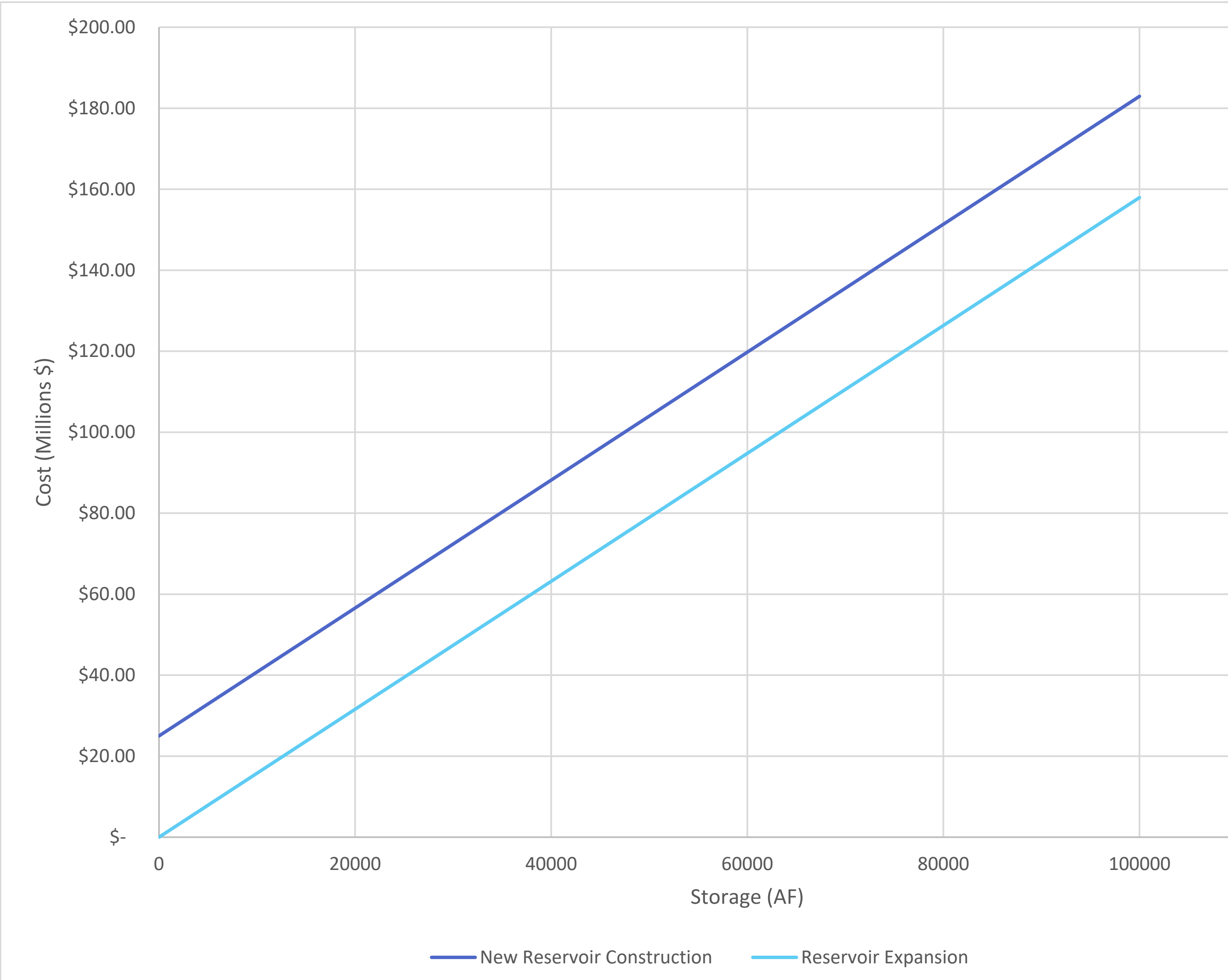

Figure B-7Error! Reference source not found.. Costs of reservoirs greater than 100,000 acre-feet is highly variable; therefore, the Cost Estimating Tool scope was limited to reservoirs up to 100,000 acre-feet. The cost curve developed assumes a minimum cost of $25 million for any new reservoir construction. Due to the limited data available for reservoir expansions, the average cost per acre-foot of storage for new reservoirs was used to develop the cost curve shown but with no minimum cost.

The cost of reservoir rehabilitation (dam, spillway, outlet piping, etc. improvements) is highly variable, depending on the geometry and mechanics of the outlet works. Cost data detailed enough to provide cost curves representing reservoir rehabilitation for varying geometries and outlet works was not available. For this reason, the reservoir rehabilitation cost data is a direct input by the user. However, recognizing that while cost data provided in the Basin Implementation Plans and other sources was not detailed enough to develop a cost curve, the data may still be useful to help users estimate costs.

During review of the April 2015 BIPs, Projects and Methods, and IPPs were documented and categorized. The list of projects provided in Error! Reference source not found. represent projects that were (1) c ategorized as Reservoir Rehabilitation or Dam Improvements and (2) provided some level of rehabilitation cost estimate. Therefore, this list does not include all projects listed in the BIPs that may include reservoir rehabilitation. The user should take note that these projects may have limited detail on rehabilitation specifics and a professional engineer in the field of reservoir outlet works should be consulted for final project cost estimation.

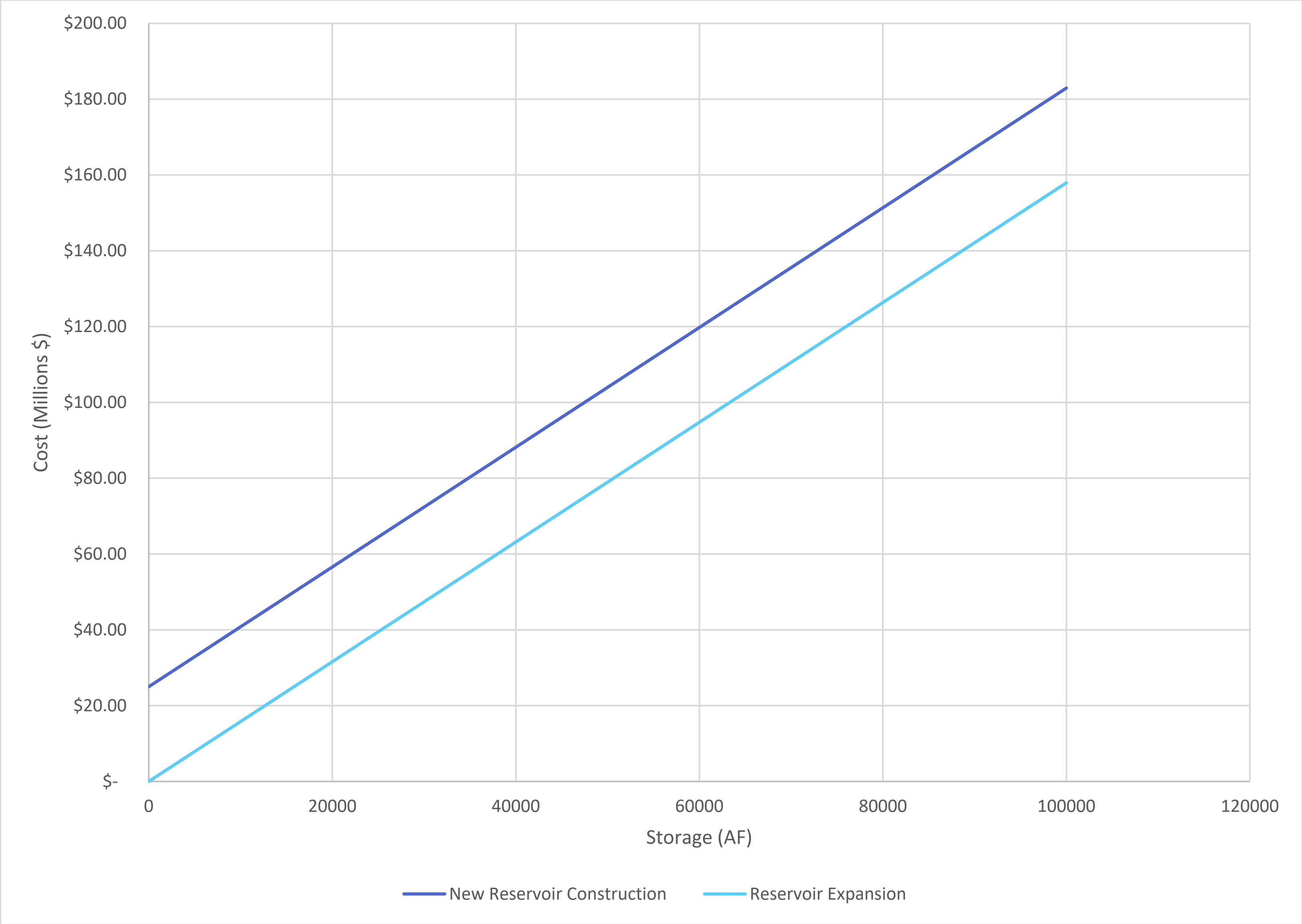

Figure B-7 New Reservoir Construction and Reservoir Expansion Cost Curves

Table B-1 Estimated Reservoir Rehabilitation Costs from 2015 Basin Implementation Plans

Basin	Project Name	BIP Project Description	Estimated BIP Cost	Notes
Gunnison	Paonia Reservoir Sediment Removal and Outlet Modification Project (Part 2)	Paonia Reservoir was designed to store 21,000 AF of water which is used for irrigation, flat-water recreation, fishing, augmentation, and improved late season flows to the North Fork of the Gunnison. Over the last fifty years, the reservoir has lost 24% of its total capacity due to sedimentation build up. The goal of this project is to investigate long-term sediment management options with the intent of minimizing future losses and possibly restoring current capacity losses.	$ 8,000,000	
Gunnison	West Reservoir #1 Outlet Pipe Replacement	West Reservoir is currently under a no-fill restriction from the State Engineers Office because of concerns about a deteriorating outlet pipe. The owners propose to replace the existing pipe and restore the reservoir to use, thus helping preserve a pre-1922 water right.	$ 426,317	
Gunnison	Lake San Cristobal Controlled Outlet Structure (Part 1)	Hinsdale County and the Upper Gunnison River Water Conservancy District (UGRWCD) explored the feasibility of constructing a new permanent control structure at the outlet of Lake San Cristobal. The new structure allows for more controlled releases to regulate the lake level and prevent failure of the structure during flood events. The additional stored water resulting from the project will be used primarily as augmentation water within the Lake Fork of the Gunnison River other beneficial uses include agriculture, recreation and releases for instream flows.	$ 40,000 *	
Gunnison	Lake San Cristobal Outlet Structure Modification (Part 2)	No detailed rehabilitation activities	$ 120,960 *	
Gunnison	Engineering for Lake San Cristobal Outlet Modification (Part 3)	No detailed rehabilitation activities	$ 75,265 *	
Gunnison	Juniata Reservoir Spillway Modification	No detailed rehabilitation activities	$ 97,000 *	
Gunnison	Hanson Reservoir Outlet Rehabilitation	No detailed rehabilitation activities	$ 50,000 *	
Gunnison	Lake San Cristobal Outlet Structure (Part 4)	No detailed rehabilitation activities	$ 150,000 *	
Gunnison	Hartland Dam Improvements	No detailed rehabilitation activities	$ 200,000 *	
Gunnison	Lining Outlet Pipe for Grand Mesa Reservoir #6	No detailed rehabilitation activities	$ 19,840 *	
Gunnison	Relief Ditch Diversion Dam Design	No detailed rehabilitation activities	$ 800,000 *	
Gunnison	Tunnel Reconstruction Project	No detailed rehabilitation activities	$ 730,110 *	
Gunnison	Dam Outlet Structure Repair	No detailed rehabilitation activities	$ 31,372 *	

Basin	Project Name	BIP Project Description	Estimated BIP Cost	Notes
Rio Grande	Mountain Home Reservoir Dam Repair	Rehabilitation of the Mountain Home Reservoir dam outlet works will improve dam safety and reliable water level management of the reservoir. The State is now requiring TIC to repair or upgrade the gates and to restore full operating capability at Mountain Home Reservoir. The Project will also provide improved water storage management and reduced storage loss (which currently amounts to 1,350 to 2,250 AF annually). Finally, improved outlet works will provide protection of the CPW conservation pool and enhancement of environmental, recreational, and wildlife habitat assets.	$ 500,000	Prelim Design: $20,000 Final Design: $20,000 Construction: $350,000 Admin, etc.: $100,00 Contingency: $10,000

Projects listed are not inclusive of all Reservoir Rehabilitation projects provided in the 2015 BIPs, but only represent those projects with an estimated cost for Reservoir Rehabilitation.

*Estimated cost reflects only WSRA requested funds. It is unknown if this cost represents the actual total cost of the rehabilitation, or only the funding amount requested from WSRA.

B.4 WATER TREATMENT FACILITY MODULE APPLICATION OF COST DATA

To derive the capital cost for treatment facility construction, the calculated design capacity is applied to the cost curve for the selected treatment type. The cost curves for the Treatment Module were developed using the Cost Estimating Manual for Water Treatment (McGivney & Kawamura, 2008). The cost curves from the manual were adjusted to represent 2017 dollars and adjusted geographically based on Colorado-based water treatment projects, as data were available.

Different cost curves were developed for each of the eight conventional treatment types. The curves were developed based on treatment plants serving small or rural populations, assuming large municipal areas would develop more detailed engineering designs and cost estimate. However, while the curve is only developed for plants 20 mgd or smaller, if a larger plant capacity is input by the user, the tool will extrapolate a cost based on the curves shown in Figure B-8 and Figure B-9. A check for geographic sensitivity of treatment costs was performed, the curves were compared against average cost of construction for the eight treatment types provided by subject matter experts. It was determined that the national-scale cost estimates from the Cost Estimating Manual for Water Treatment were acceptable median estimates for Colorado-based projects. The cost curves for estimating water treatment capital construction costs are shown in Figure B-8.

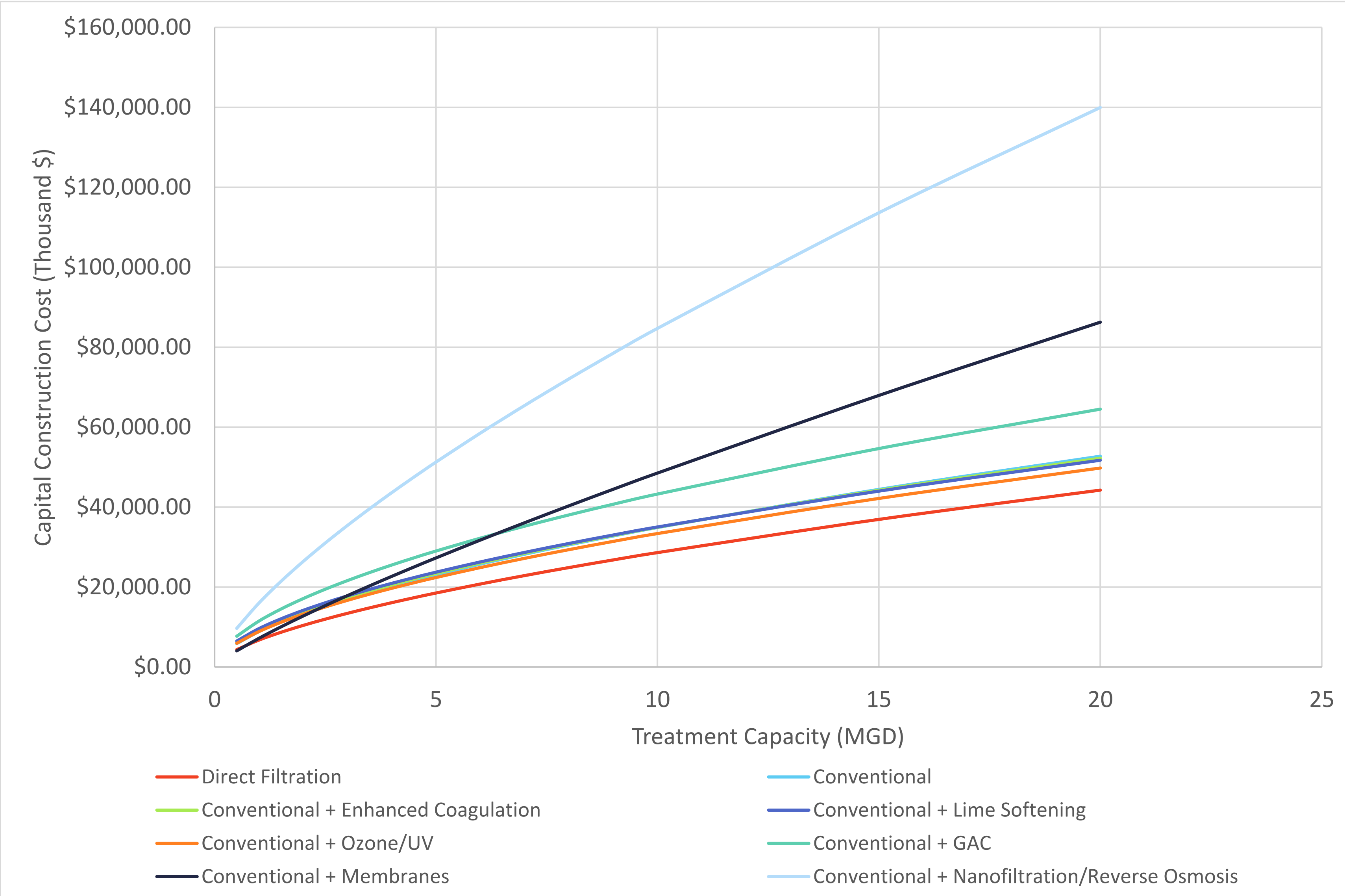

Figure B-8 Water Treatment Technology Capital Construction Cost Curves

A challenge in developing cost curves for treatment is the variability in plant processes. The treatment types were chosen to represent common treatment processes; however, in real-life applications processes may be added or removed to meet community needs. Therefore, where appropriate, adjustments were made to the Cost Estimating Manual curves for the treatment types using available costing data. For treatment types where costing data was lacking, values were interpolated between known cost curves. For example, the Cost Estimating Manual does not have a cost curve for conventional plus enhanced coagulation treatment, but costs are expected to fall between conventional and conventional plus lime softening; therefore, costs were interpolated between the two known treatment types. The estimated costs for these curves are similar and provided in Figure B-9 for clarity.

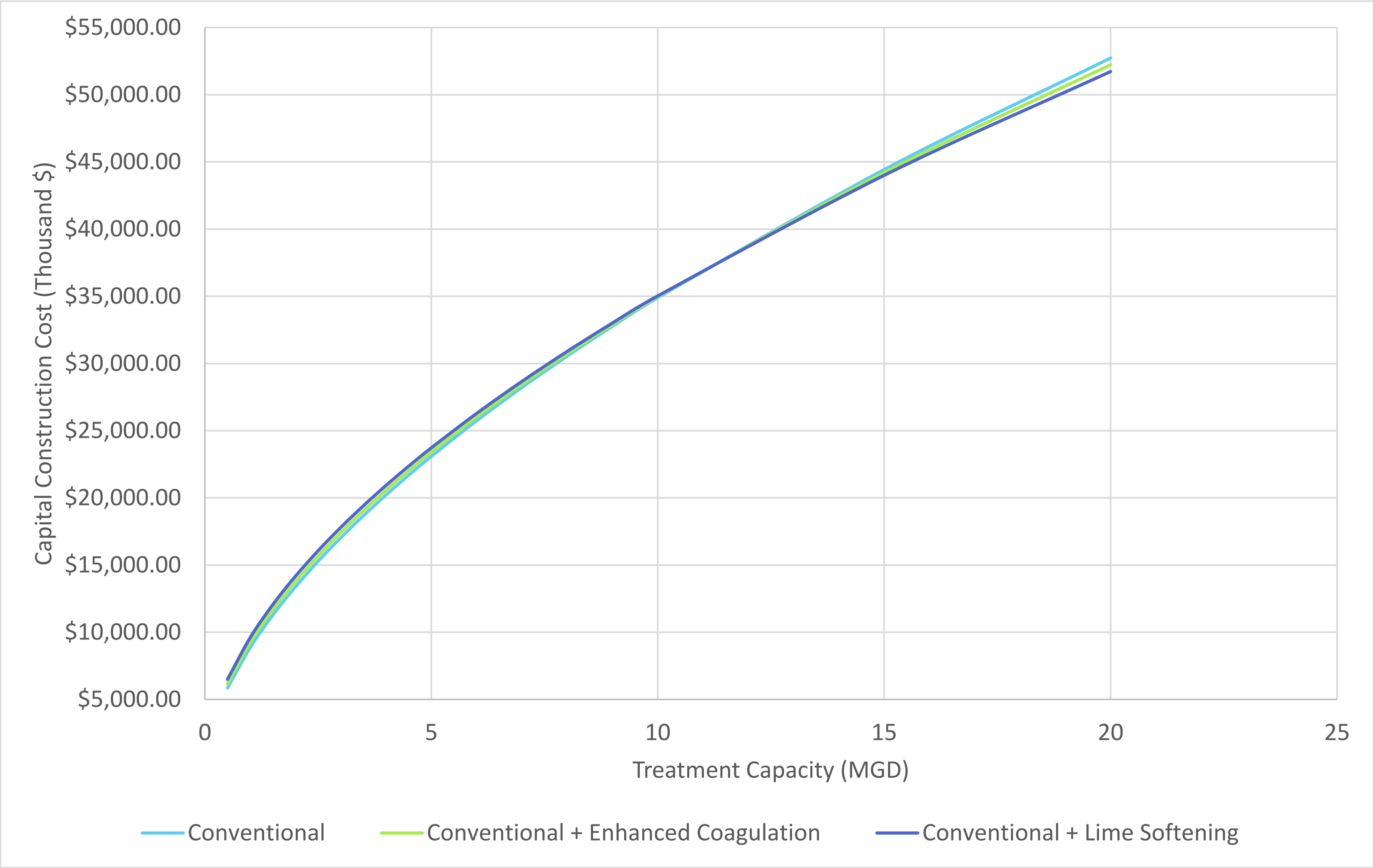

Figure B-9 Interpolated Cost Curves for Conventional plus Enhanced Coagulation Treatment

The manual combines costs of ozone and granular activated carbon (GAC) treatment; because the Cost Estimating Tool separates these two processes the individual line item costs used to develop the manual cost curves were evaluated to determine what percent each process contributed to the total construction cost. For ozone treatment, the percent of the construction cost attributed to GAC was calculated and uniformly subtracted from the ozone + GAC costs leaving only what was associated with ozone treatment. The same process was followed for GAC. While it is understood this method does not account for economies of scale, relative to other treatment types, the curves represent expected costs. This process was repeated for O&M costs.

Another adjustment from the Cost Estimating Manual was the combination of the Nano/Ultra Filtration and Reverse Osmosis cost curves, where the manual provides separate. The two cost curves were plotted together and the +50% and -30% confidence intervals also plotted. The median curve between the +50% and - 30% curves was calculated and used to represent costs for the three treatment types. Although it is recognized this method may over or underestimate some costs, it is appropriate for planning level capital and O&M costs. Figure B-10Error! Reference source not found. shows the plotting of these curves together with the selected cost curve for Nano/Ultra Filtration and Reverse Osmosis.

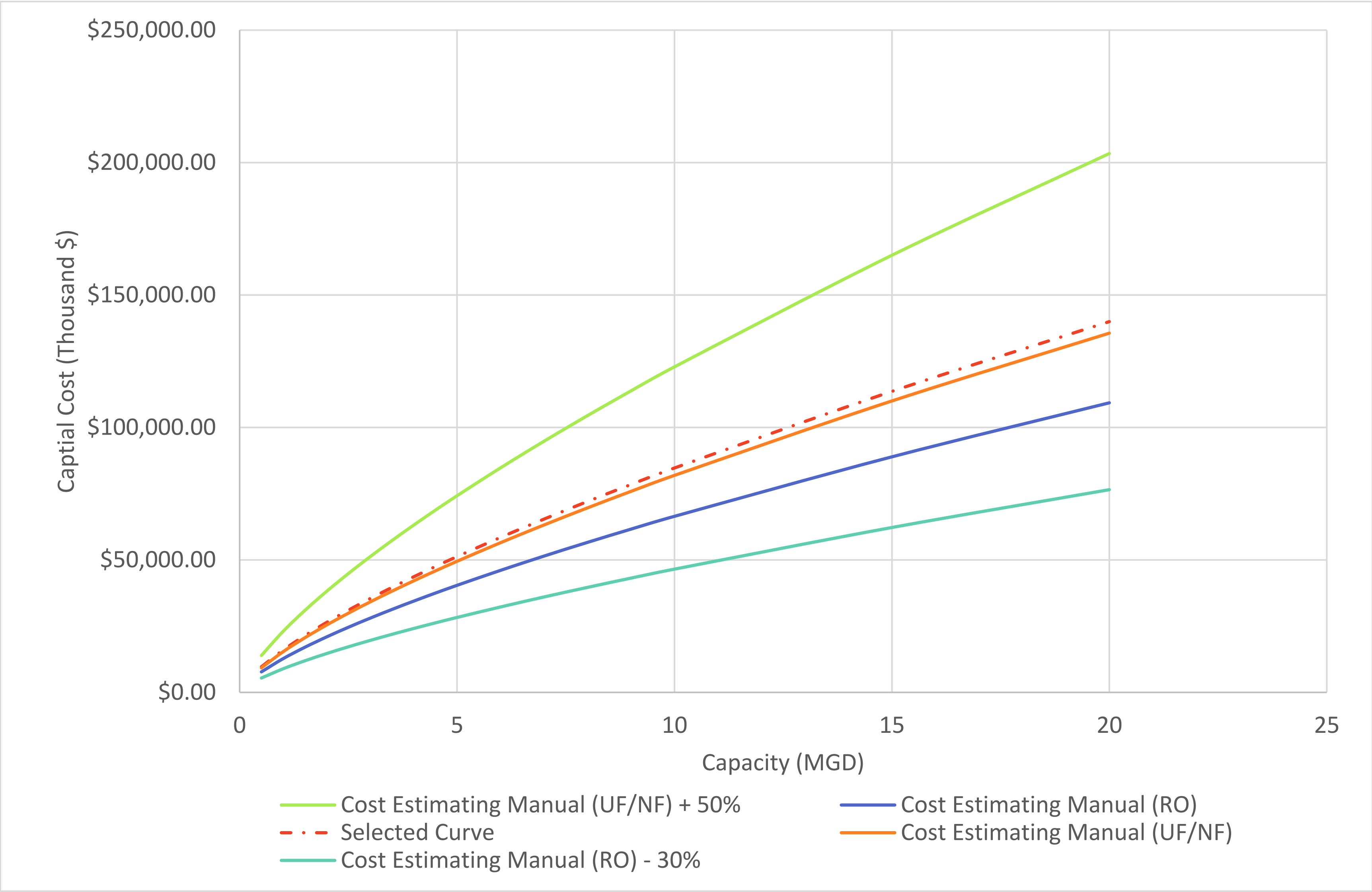

Figure B-10 Analysis of Ultra/Nano Filtration and Reverse Osmosis Capital Construction Cost Curves

Water treatment facilities typically require continual monitoring and staffing; therefore, the cost for operations and maintenance is a significant portion of the cost to be considered. To address this, separate cost curves for annual operations and maintenance costs were developed for the Treatment Module. It should be noted that these curves also consider energy demands for facility operation. These energy costs are not derived from peak day capacity, but rather the average daily production because O&M energy use must be assessed over the year.

Treatment O&M costs were also derived for treatment facility capacities from 0.5 to 20 MGD from cost curves provided in Cost Estimating Manual for Water Treatment Facilities (McGivney & Kawamura, 2008). The ENR CCI Index is not intended to provide geographic adjustments; therefore, the Cost Estimating Manual curves were checked against a recent benchmarking study of water treatment O&M costs performed for four plants located throughout the western United States and historic EPA cost curves. These costs were plotted as $1000/MGD to provide O&M cost curves for each treatment type. The final cost curves for operations and maintenance of the various treatment technologies are provided in Figure B-11.

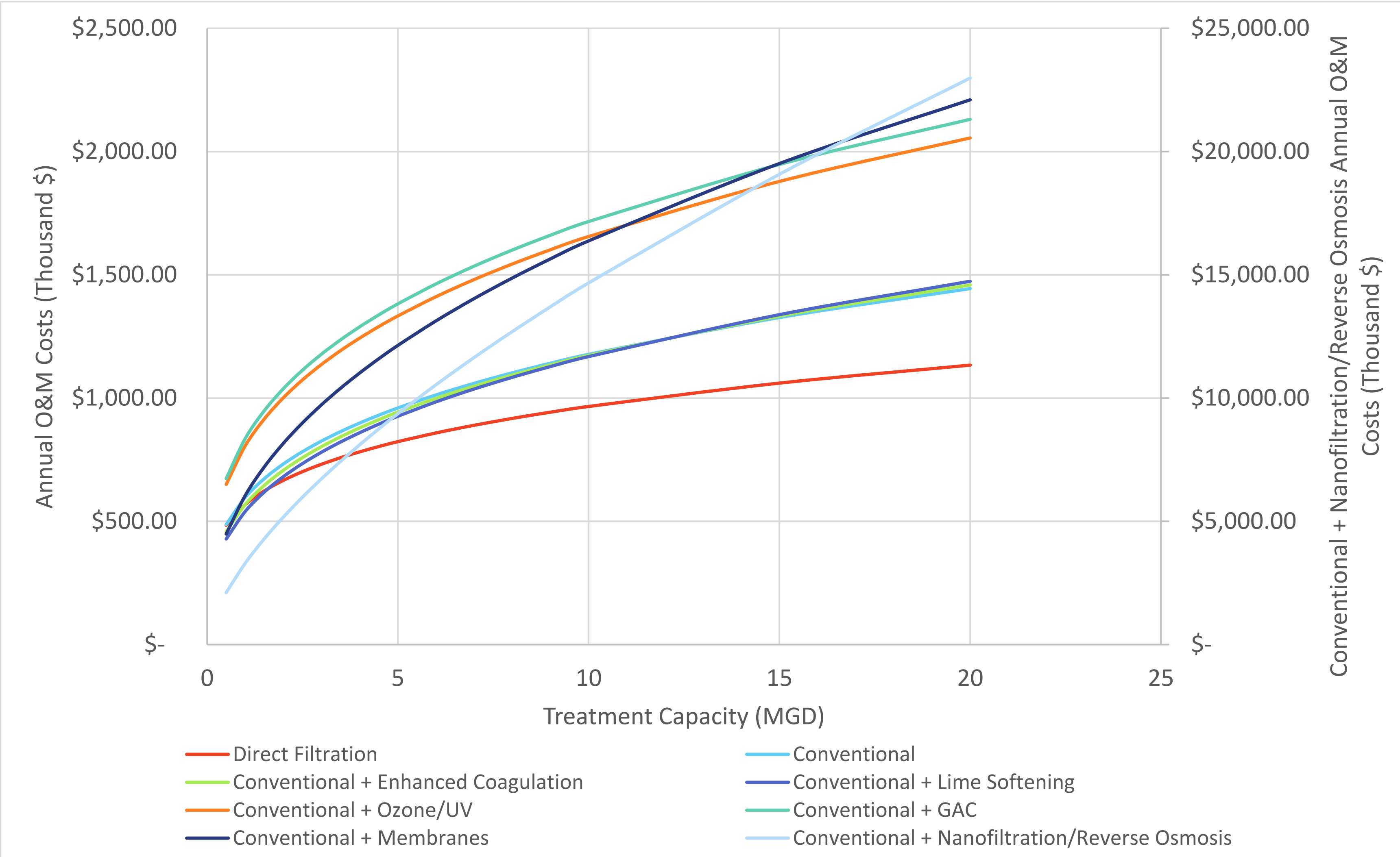

Figure B-11 Water Treatment Technology Annual O&M Cost Curves
*Note: Conventional + Nanofiltration/Reverse Osmosis Annual O&M Costs are plotted on a secondary axis

B.5 DITCH AND DIVERSION MODULE APPLICATION OF COST DATA

To convert Ditch and Diversion Module parameters into costs, curves were developed for new ditch construction and ditch rehabilitation. Project costs depend significantly on the type of ditch lining installed; therefore, a curve was also developed for each ditch lining type based on cost of lining per linear foot installed. The cost curves for new ditch construction and ditch rehabilitation are provided in **Figure B-12**Error! Reference source not found. and **Figure B-13**Error! Reference source not found., respectively.

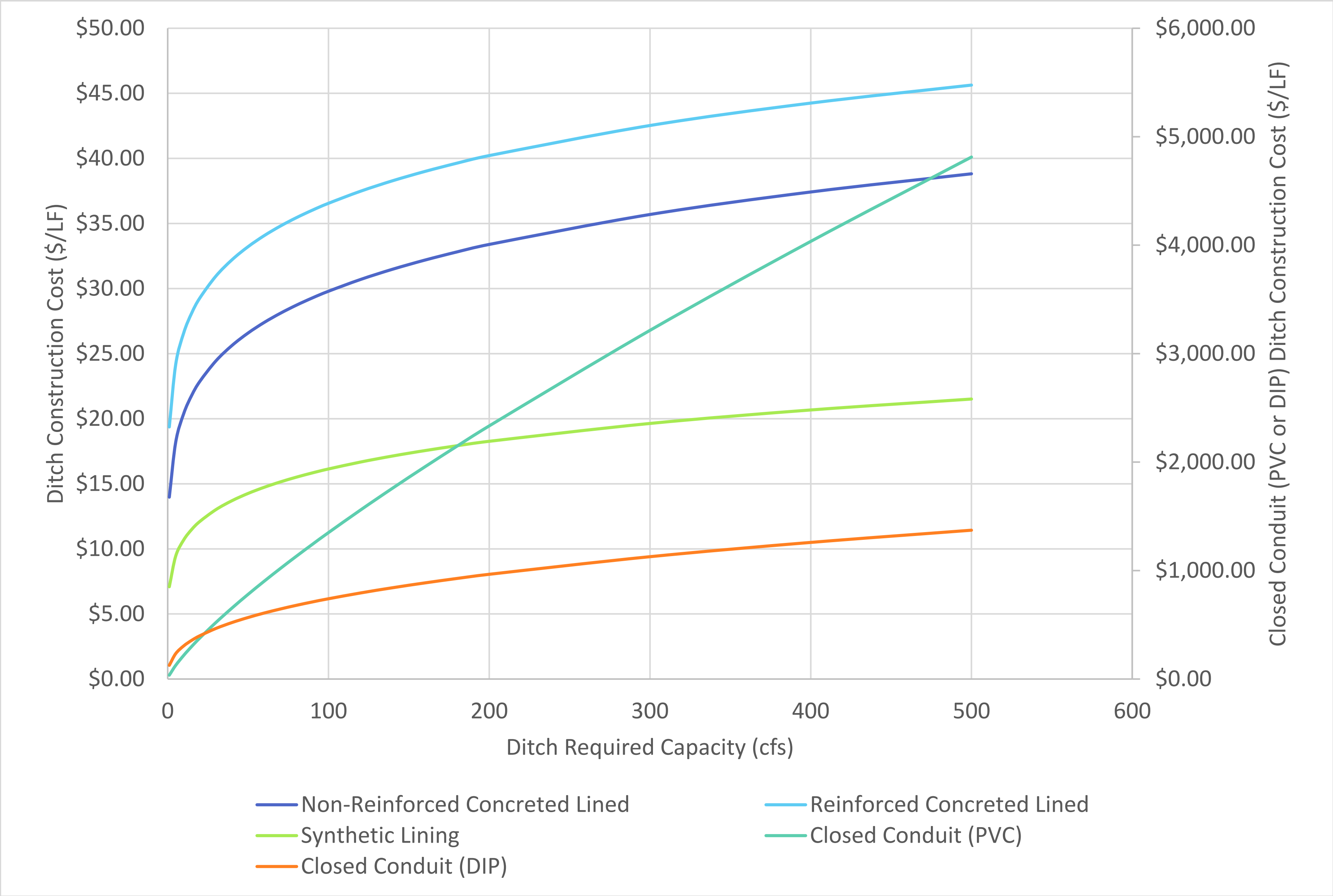

Figure B-12 New Ditch Construction Cost Curves

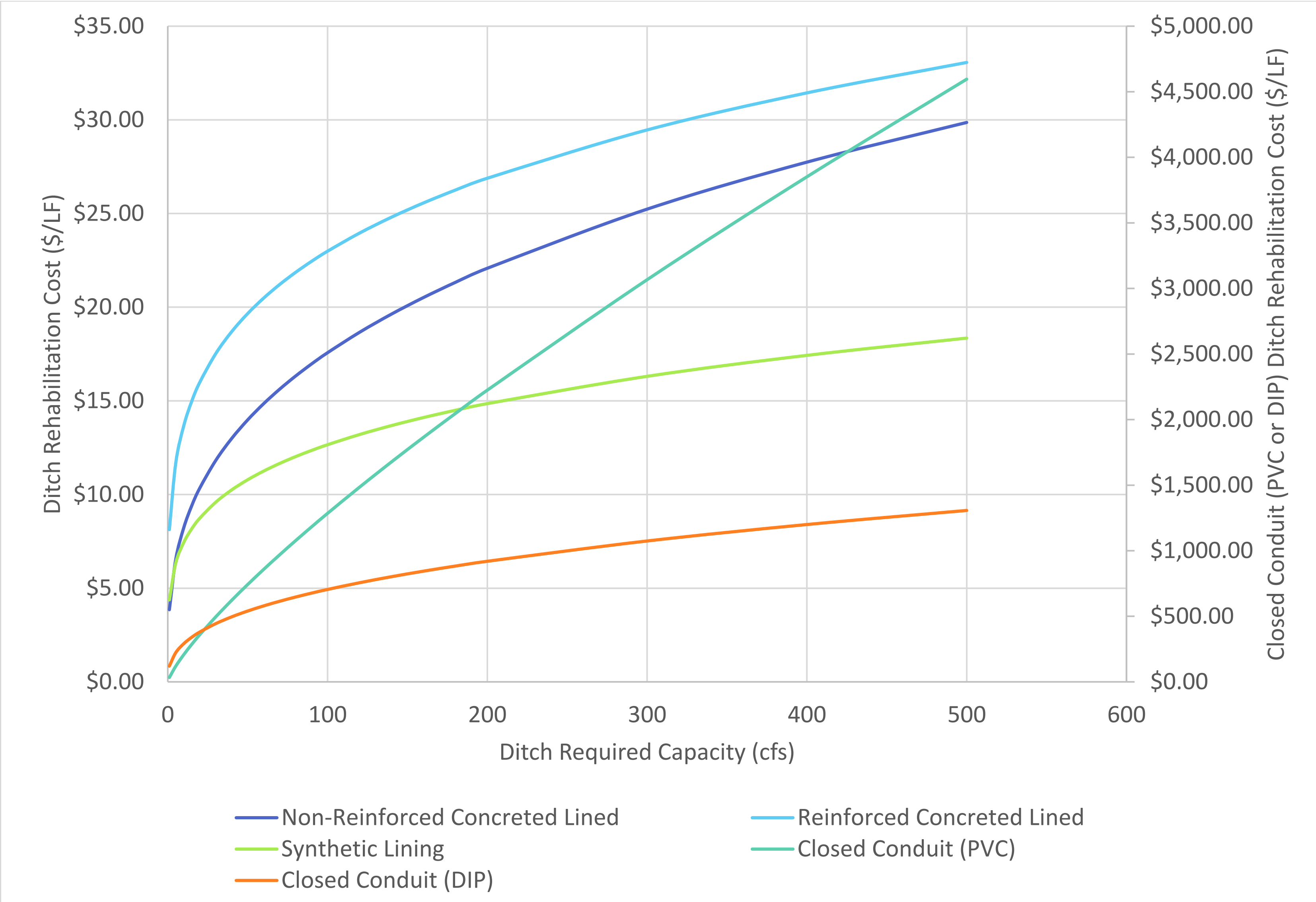

Figure B-13 Ditch Rehabilitation *Cost* Curves

The cost curves for new ditches and ditch rehabilitation were derived from costing information for ditch construction provided by the NRCS. The tool developed by the NRCS provides cost estimates for ditch construction utilizing cost data for materials within the Colorado/Utah/Idaho region. Construction costs in the tool account for earthwork, labor and associated costs for new ditch construction. The most common type of ditch rehabilitation is installation of a new ditch lining, therefore ditch rehabilitation utilizes the NRCS tool estimates for ditch lining costs, but removes the costs associated with earthwork for new ditch construction. These data were adjusted to represent 2017 dollars. The tool was utilized to develop cost curves of ditch capacity (discharge) versus cost per linear foot of lining. In order to develop cost curves in this manner, several assumptions were made regarding ditch geometry (refer to Water Cost Estimating Tool Technical Memorandum, Section Error! Reference source not found.). These assumptions were a pplied to the NRCS tool so that only the ditch capacity and length variables altered project costs to obtain the cost curves shown in Figure B-12 and Figure B-13. This process was repeated for each lining type. (NRCS, 2011)

The NRCS tool does not include costs for appurtenant construction such as a diversion structure. Costs for installation and construction of a diversion structure vary depending on stream size, environment and ditch capacity. Data on several diversion structure projects completed throughout the state were provided by Colorado DNR and included in a cost analysis. However, the projects varied widely in the level of detail specific to diversion structure design, construction and capacity. For instance, a project may have included a diversion structure as part of a larger stream restoration or ditch construction project, but the cost of just the diversion structure could not be ascertained, or any details about the diversion geometry, type or capacity. The projects were refined to those with a project cost where the diversion structure was the main component of the project. For those projects where a diversion capacity was not provided, the capacity of the diversion was estimated as the peak monthly diversion discharge recorded in the Diversion Records on the Colorado Decision Support (CDSS) website.

The cost curve resulting from this analysis is provided in Figure B-14. This curve is used in the tool to estimate the Recommended Cost of Diversion Structure Cost Curve; however, because this curve was developed based on limited data and several assumptions, the user should use discretion before entering the recommended cost in the Selected Diversion Structure Cost field. To help the user determine if the recommended cost is reasonable for their project, a reference table (

Table B-2) of the data points used to develop Figure B-14 is provided including a description of activities included in the project cost. The user should review these project descriptions and compare to the recommended cost and adjust the Selected Cost as is reasonable.

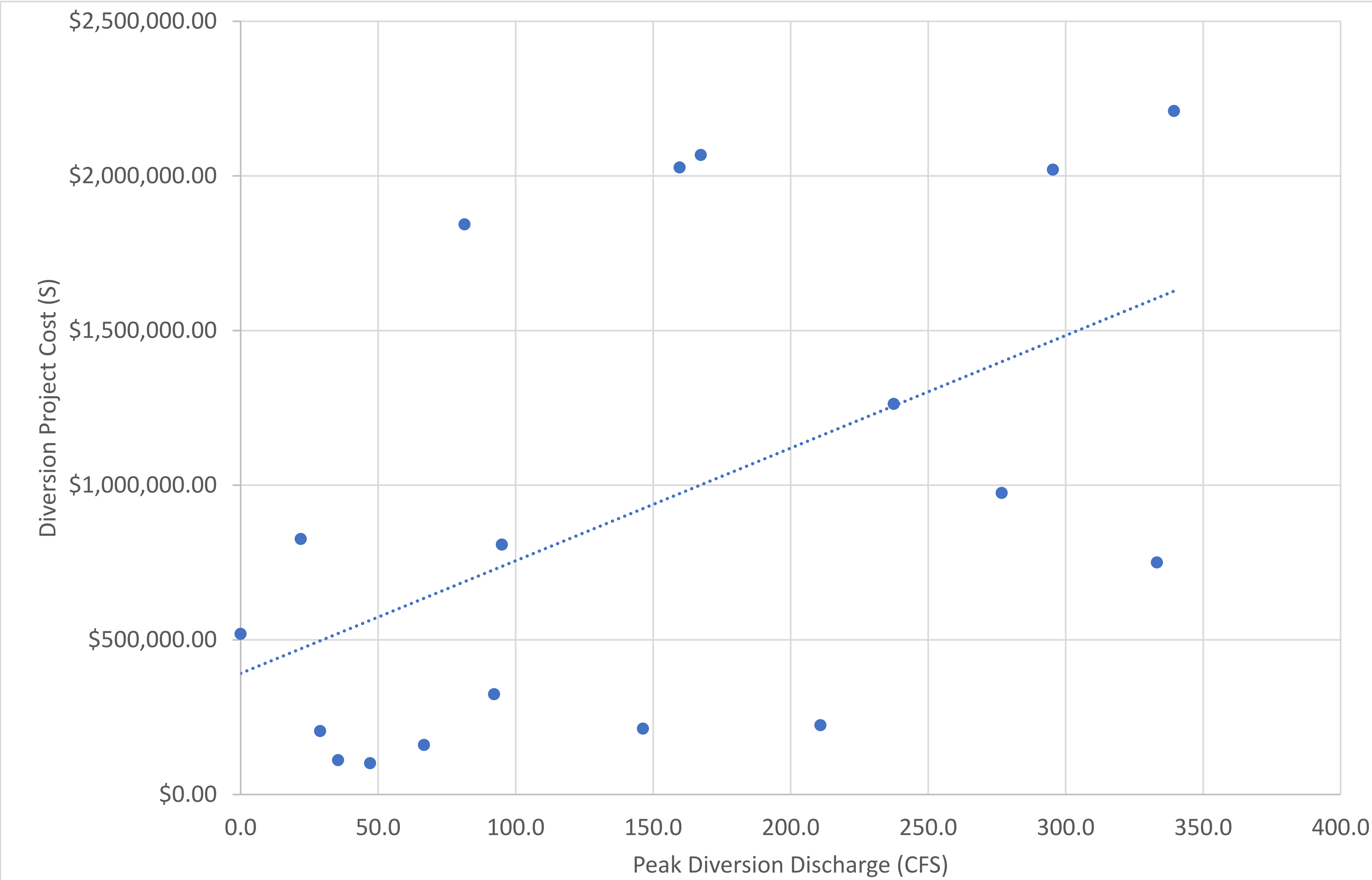

Figure B-14 Recommended Cost of Diversion Structure Cost Curve

Table B-2 Diversion Structure Costs from Various CO DNR Projects

Project ID	Project Stream	Project County	Diversion Structure Type	Maximum Diversion Capacity (CFS)	Approximate Diversion Structure Cost	Description of Project Costs
1	Saint Vrain	Boulder	Grouted Boulder Dam	92.2	$324,210	--
2	Arkansas	Chaffee	Earthen Dike	29.0	$205,000	--
3	South Platte	--	Adjustable-Height Check Dam	295.4	$2,020,000	Demolition of existing structures and reconstruction of headworks; Channel stabilization
4	--	--	--	0.0	$519,140	Diversion dam and headgate repair, Parshall flume, ditch embankment rebuild
5	South Platte	Logan/ Sedgwick	Parshall Flume	210.9	$224,000	Bypass of residual flows, dewatering, excavation, constructing new weir, riprap, removal of old structure
6	Conejos River	--	Automated Headgate	146.3	$213,000	Remove and replace diversion and headgate structures
7	Little Thompson	Larimer	--	95.0	$808,000	Headgate rehabilitation, siphon construction, flood clean up
8	Conejos River	--	Automated Headgate	47.1	$101,000	Diversion dam, headgate, sluice gates, 5 flumes, 5 stilling wells, telemetry
9	South Platte	Logan	--	167.4	$2,067,470	Replacement of river diversion structure, replacement of ditch headgate structure, installation of hydraulic bladders and controls
10	South Platte	Adams	--	159.7	$2,027,070	Construction and installation of gantry crane grate cleaning system, rehabilitate trash rack, replace diversion gates and operators
11	Saint Vrain	Boulder	--	333.2	$750,000	Diversion dam and trash rack construction
12	Rio Grande	South Fork/ Alamosa	Radial Gates with Automation	21.9	$826,000	88 ft diversion dam with fish and boat passage; 2 radial gates with automation; 1,054 LF of 36" HDPE pipe
13	Saint Vrain	Boulder	--	237.5	$1,262,500	Diversion structure, sluice and flume gates, headgates, and fish ladder
14	Rio Grande	Rio Grande	--	276.8	$975,000	120 LF grouted boulder diversion dam, trash rack structure, 4 slide headgates and structure, 1 radial sluice gate, structure and channel, headgate automation
15	Saint Vrain	Boulder	--	81.4	$1,843,250	Diversion dam with fish ladder, headgates, conveyance ditch, river turnout structure
16	Clear Creek	Adams/ Jefferson	Slide Gate	339.4	$2,209,597	Diversion dam and headgate rehabilitation including SCADA installation, rehabilitation of two siphon structures, and replacement of a storm drain pipe

Project ID	Project Stream	Project County	Diversion Structure Type	Maximum Diversion Capacity (CFS)	Approximate Diversion Structure Cost	Description of Project Costs
17	Little Thompson	Boulder/ Larimer	--	66.7	$160,000	Removing debris from the dam and diversion structure; forming and pouring new wing wall; rechanneling river
18	Clear Creek	Denver	--	35.5	$110,781	Repair Fisher Ditch headgate, install sand-out gate and pipeline, replace 650 LF of damaged CMP with RCP

B.6 STREAM AND HABITAT MODULE APPLICATION OF COST DATA

To convert Stream and Habitat Module parameters into costs, cost curves were developed for rural and urban environments. The curves represent cost per width class and dollars per linear foot of restoration length. The user inputs for environment type and level of restoration determine which curve is referenced. The width class selected is then referenced to the appropriate curve and a unit cost per linear foot of restoration length is returned. Similar to the Ditches and Diversions Module, the cost per linear foot is multiplied by the user-supplied restoration length to return a total project cost. The cost curves for rural and urban streams and habitat projects are provided in Figure B-15 and Figure B-16, respectively.

These curves were developed from actual steam and habitat restoration projects previously submitted to CWCB and other publicly available stream restoration projects throughout Colorado. Each project was reviewed for levels of restoration involved, length, and average stream width then costs for each level of restoration were converted into an average cost per linear foot.

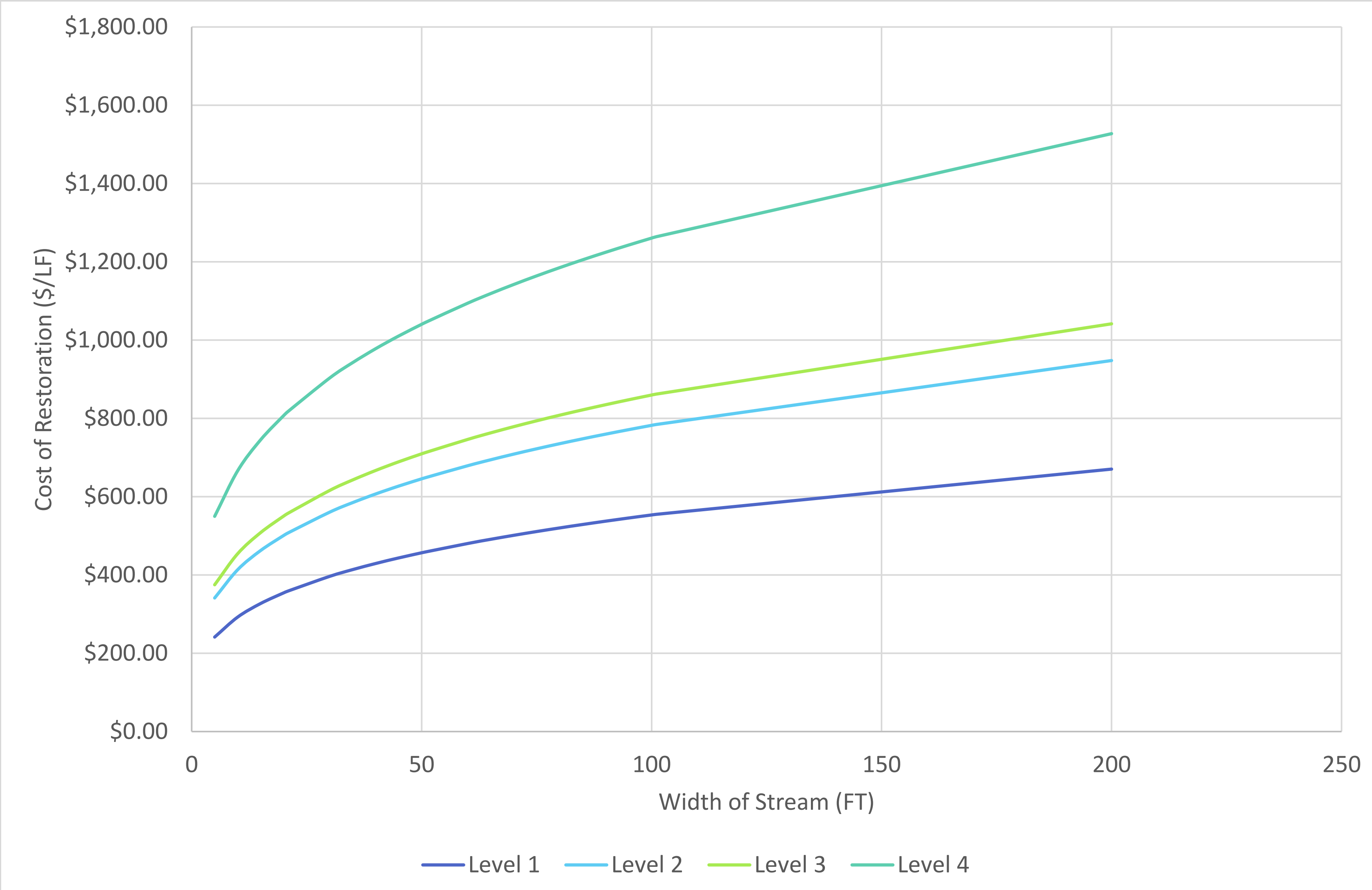

Figure B-15 Rural Streams and Habitat Project Cost Curves

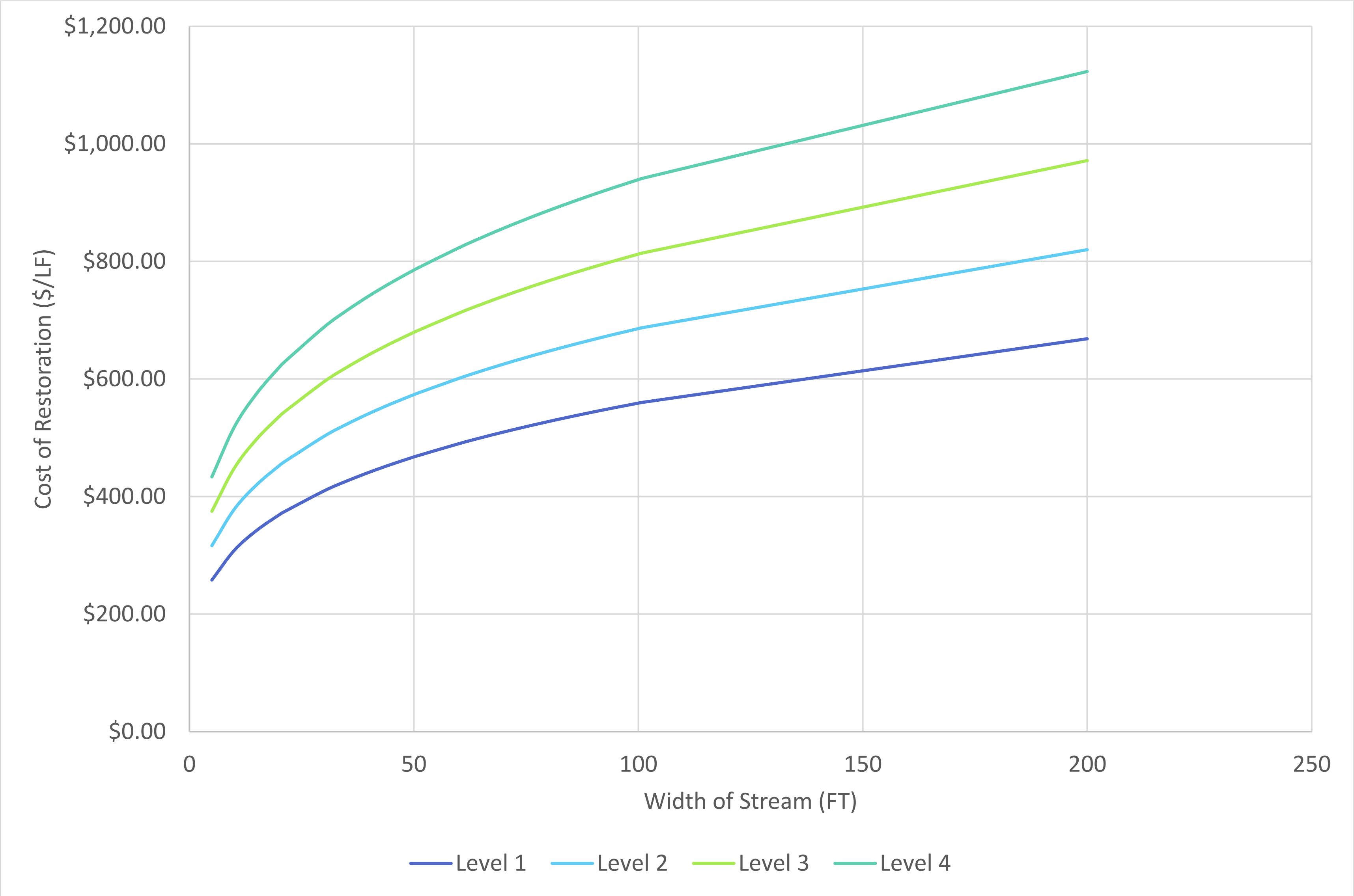

Figure B-16 Urban Stream and Habitat Project Cost Curves

Analysis showed that project costs increased with each level of restoration, as expected. Although cost per width class generally increased as stream size increased, due to limited data in each stream width class for the four levels of restoration, costs varied. Therefore, average total project cost for each width class, regardless of level of restoration, was calculated for rural and urban projects (see **Table B-3**Error! Reference source not found. and

Table B-4, respectively).

Table B-3 Average Total Cost and Percent Difference for Rural Stream and Habitat Projects

Width	Average Rural Total Project Cost	Percent Difference in Average Total Project Cost
5 to 20	$ 821,734.63	
21 to 50	$ 1,608,993.98	65%
51 to 100	$ 1,702,273.09	6%
>100	$ 2,162,828.69	24%

Table B-4 Average Total Cost and Percent Difference for Urban Stream and Habitat Projects

Width	Average Rural Total Project Cost	Percent Difference in Average Total Project Cost
5 to 20	$ 907,645.60	
21 to 50	$ 1,663,713.50	59%
51 to 100	$ 1,781,901.83	7%
>100	$ 2,189,815.16	21%

As Table B-3 Average Total Cost and Percent Difference for Rural Stream and Habitat Projects**Table B-3Error! Reference source not found.** and

Table B-4**Error! Reference source not found.** show, during analysis of restoration cost data, it was found that costs for restoring streams within the 20- to 50-foot width class and the 50- to 100-foot width class were similar, likely due to a lack of data for projects between 50 and 100 feet in width. Due to this finding, the cost curves for the two classes were combined, therefore costs for streams between 20 and 100 feet in width will be the same, however the classes were preserved for future data collection.

The percent differences between the width classes were then applied to the cost-per linear foot estimates for each level of restoration to provide cost per linear foot, level of restoration and width class. The user specifies a level of restoration and stream width, which dictates which curve the tool selects. When multiplied by total length of restoration, cost total cost for restoration for the specified level or restoration and stream width is returned.

Analysis and Technical Update to the Colorado Water Plan

Technical Memorandum

Prepared for:

Colorado Water Conservation Board

Subject:

Colorado Environmental Flow Tool Documentation

Date: August 16, 2019

Prepared by: Becky Dunavant and Tim Cox (CDM Smith), John Sanderson and Meg White (The Nature Conservancy)

Reviewed by: Sue Morea (CDM Smith) and John Sanderson (The Nature Conservancy)

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Section 1: Introduction

The Colorado Environmental Flow Tool (Flow Tool) was designed to serve as a resource to help Basin Roundtables (BRTs) refine, categorize, and prioritize their portfolio of environmental and recreational (E&R) projects and methods through an improved understanding of flow needs and potential flow impairments, both existing and projected. The Flow Tool uses hydrologic data from Colorado's Decision Support System (CDSS), additional modeled hydrologic data for various planning scenarios, and established flow-ecology relationships to assess risks to flows and E&R attribute categories at pre-selected gages across the state. The Flow Tool is a high-level tool that is intended to provide guidance during Stream Management Plan development and Basin Implementation Plan (BIP) development. Note that in the past, the term "nonconsumptive" has also been used in the place of "E&R". For the purposes of this memorandum, these two terms should be viewed as interchangeable.

1.1 BACKGROUND AND PREVIOUS TOOLS

In 2005, the Colorado legislature established the Water for the 21st Century Act. This act established the Interbasin Compact Process that provided a forum for broad-based water discussions in the state. It created two new structures: (1) the Interbasin Compact Committee (IBCC), and (2) the BRTs. As part of the Interbasin Compact Process, the BRTs were required to complete basinwide needs assessments, including an assessment of nonconsumptive water needs. The nonconsumptive needs assessment (NCNA) process included mapping E&R attributes to create a statewide technical platform and developing tools to identify and quantify nonconsumptive water needs. The Flow Tool builds on the groundwork completed to support the NCNAs by the BRTs and other stakeholders.

1.1.1 NCNA FOCUS AREA MAPPING

During the Statewide Water Supply Initiative (SWSI) 2010 update, the BRTs utilized E&R mapping tools as a common technical platform to identify nonconsumptive focus areas within their basins. Each BRT used one of three methods to develop a summary map that highlighted E&R focus areas within their basin:

- Method 1: E&R focus areas in each basin were aggregated to the watershed level (USGS 12-digit Hydrological Unit Code [HUC]).
- Method 2: E&R focus areas in each basin were aggregated to the stream level using USGS information for stream segments provided by the National Hydrography Dataset (NHD).
- Method 3: Stream reaches were selected that represented most of the E&R activity within the basin. These stream reaches were selected based on a review of all available data layers and feedback from stakeholders and public outreach efforts.

The output of this process included a map for each basin showing NCNA focus areas. As shown in **Figure 1-1**, the various approaches resulted in different spatial units and scales.

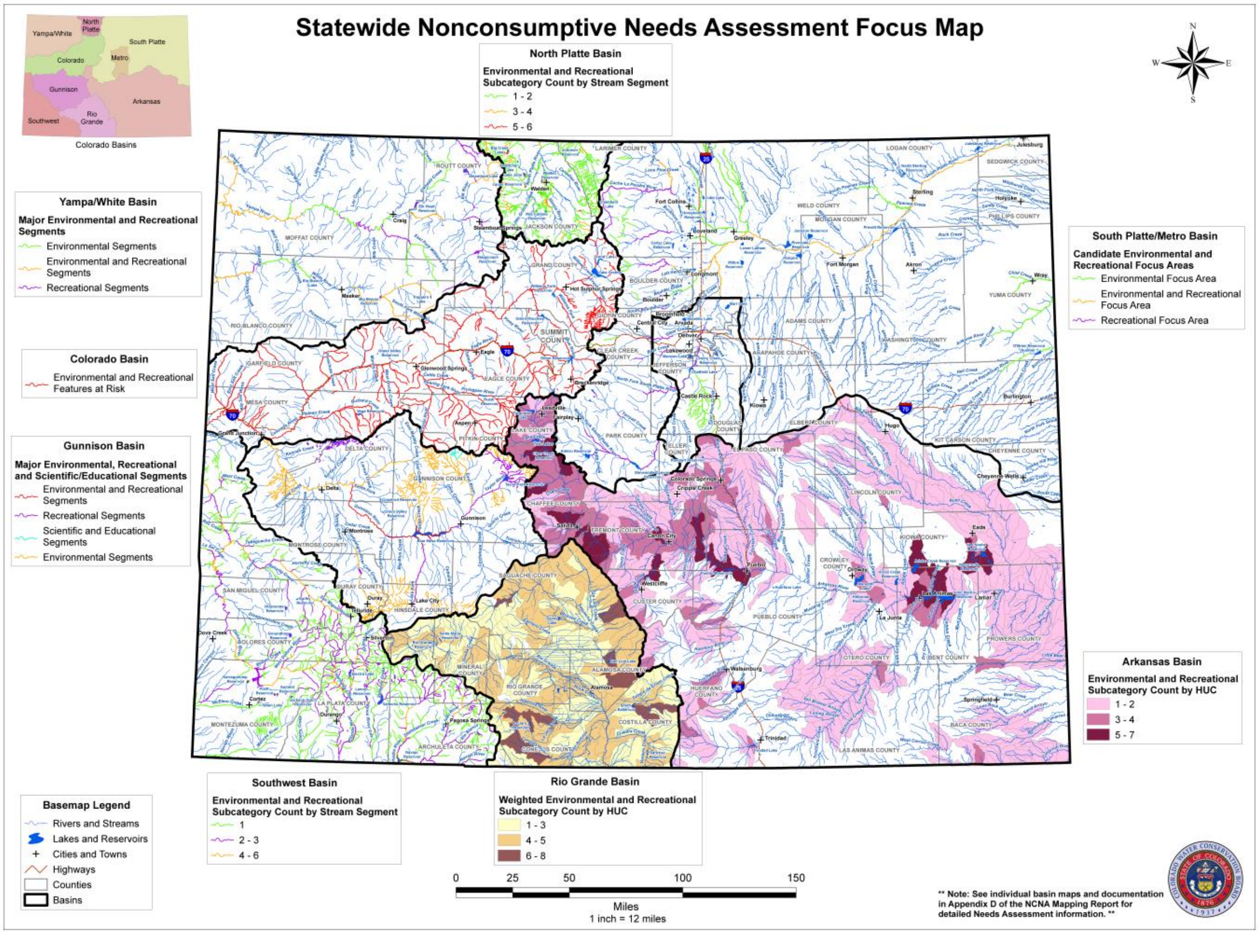

Figure 1-1. Statewide Nonconsumptive Needs Assessment Focus Area Map

1.1.2 NONCONSUMPTIVE PROJECTS AND METHODS

The BRTs also identified projects and methods required to meet the nonconsumptive needs identified as part of the NCNA focus area development process described above. The output of the Nonconsumptive Projects and Methods efforts included four maps that provided information on the location of projects and methods, the status of these projects and methods, and NCNA focus areas that had identified projects and methods completed or in progress.

1.1.3 NCNA DATABASE

From this exercise, the NCNA database (NCNAdb) was developed to help manage the nonconsumptive data received from the BRTs. The NCNAdb contained key information related to nonconsumptive attributes, projects, and associated protections. The content of the database was developed by a stakeholder-driven process that included members of the nine BRTs and statewide technical committees. Note that the database, now referred to as the E&Rdb, has also been updated, and will continue to be a tool as the BRTs work on their BIPs.

1.1.4 WATERSHED FLOW EVALUATION TOOL

CWCB also funded the development and testing of a tool known as the Watershed Flow Evaluation Tool (WFET). To date, the WFET has been applied in the Colorado and Yampa/White Basins. The WFET offers an approach to conducting a watershed-scale, science-based assessment of flow-related ecological risk throughout a basin, particularly when site-specific studies are sparse. The WFET assesses the risk that shifts in flow regimes pose to specific attributes, such as coldwater fish, warmwater fish, and riparian plant communities. The WFET was developed to identify areas that needed further site-specific studies, to support basin-wide assessments of project location and potential impacts, and to support strategic decision making about the system-wide operations of water systems to provide better ecological outcomes. The WFET was intended for additional studies on a watershed-scale. The Flow Tool described in this report provides analysis and results statewide at preselected gages.

1.1.5 HISTORICAL STREAMFLOW ANALYSIS TOOL

The Historical Streamflow Analysis Tool (HSAT) was developed and made available for use in the first round of BIPs and emphasized the evaluation of hydrologic variability at gage locations across Colorado. The user interface included a simple dropdown menu and the output included automatically generated tables and plots. Many of the basic flow summaries included in the HSAT were carried forward into the Flow Tool.

1.2 INTENDED USE OF THE FLOW TOOL

The Flow Tool is built on a legacy of stakeholder involvement and was created through a methodology that was developed collaboratively with a Technical Advisory Group and builds on the previous NCNA efforts described above. The Flow Tool, as developed for this Technical Update, can be used to assess the risk that stream-based ecological resources may change as a result of climate change, human uses, and/or the diversion of water. The Flow Tool is intended to be a high-level planning tool that:

- Uses the foundations of the HSAT and WFET to scale to a statewide platform;
- Post-processes CDSS projections to provide summaries of changes in monthly flow regime at pre-selected locations under different planning horizons;
- Identifies potential risks to E&R attribute categories through flow-ecology calculation projections;
- Serves as a complementary tool to the CDSS to refine, categorize, and prioritize projects; and
- Provides guidance during Stream Management Plan development and BIP development.

1.3 LIMITATIONS OF THE FLOW TOOL

While the Flow Tool is intended to inform and provide data for use in planning E&R projects and methods, it should be noted that it is NOT prescriptive. The Flow Tool does not:

- Designate any gap values. The Flow Tool does not identify flow deficiencies or gaps associated with the flow needs of E&R attributes. The Flow Tool analyzes where projected changes in monthly streamflow may increase risks to ecological resources based on reference conditions.
- Provide the basis for any regulatory actions. Because the Flow Tool does not require site-specific ecological data to identify the potential risk of ecological change and calculates risk using a monthly timestep, it should not serve as the basis for reach specific flow prescriptions in administrative or judicial processes.
- Identify areas where ecological change may be associated with factors other than streamflow. The Flow Tool does not explicitly evaluate or consider these additional factors that influence E&R attributes, although some of these factors are implicitly considered in the flow-ecology relationships.
- Provide results as detailed or as accurate as a site-specific analysis.

1.4 REPORT OVERVIEW

The remainder of this technical memorandum includes the following:

- ***Section 2: Tool Construction*** provides information on the software platform and inputs used to build the Flow Tool;
- ***Section 3: Results*** summarizes and discusses the Flow Tool outputs for each basin along with general statewide observations; and
- ***Section 4: Future Tool Enhancements*** discusses potential future updates to the Flow Tool.

Section 2: Tool Construction

The Flow Tool was constructed in Microsoft Excel by combining components of the HSAT and the WFET. The Flow Tool relies on modeled hydrologic data from the CDSS for "historical" and "future" flow regimes and established flow-ecology relationships to summarize flow statistics and potential risks to E&R attribute categories under each planning scenario. Detailed instructions for the use of the Flow Tool can be found in Appendix A: User Guide.

2.1 SOFTWARE PLATFORM AND INTERFACE

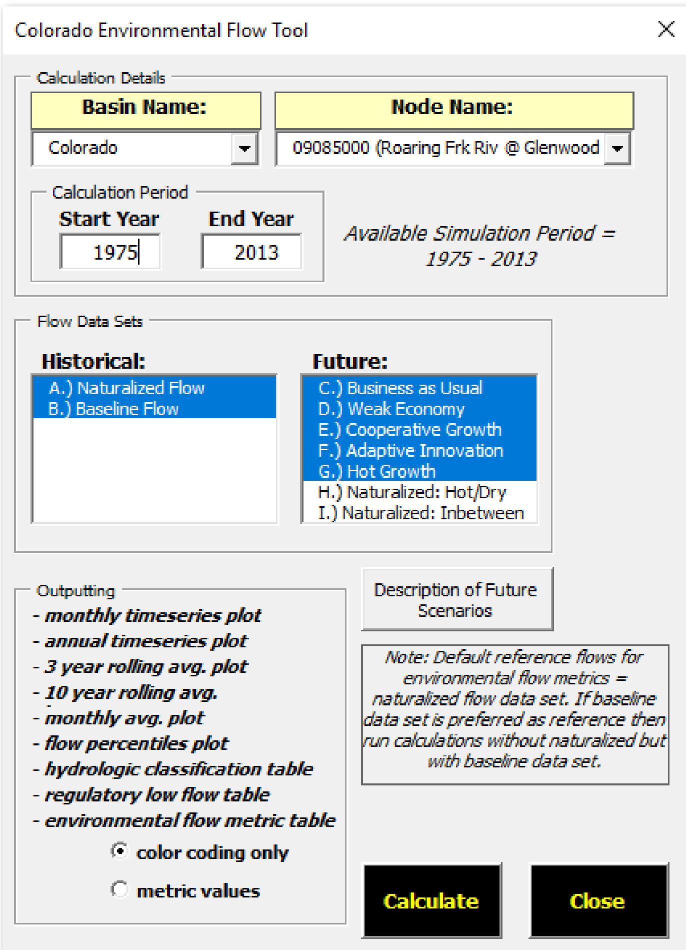

Figure 2-1. Flow Tool User Input Form

The Flow Tool was developed in Microsoft Excel using Visual Basic for Applications (VBA) programming. The Excel platform provides a familiar, and portable, working space for the tool user, as well as offers standard spreadsheet pre- and post-processing capabilities. User inputs specific to the application of the tool are provided via a user-friendly input form (Figure 2-1). The actual hydrologic and environmental flow metrics are calculated with underlying Visual Basic code. The tool graphical and tabular outputs are also generated with VBA code.

2.2 NODE SELECTION

The Flow Tool analyzes and produces data for 54 pre-selected Flow Tool nodes (**Figure 2-2**). The gages included in the Flow Tool were selected for inclusion based on a number of factors. Gages were reviewed collaboratively with key staff from The Nature Conservancy (TNC), the Colorado Water Conservation Board (CWCB), and Wilson Water Group (WWG) to determine available attribute data (where key E&R attributes were located and concentrated within a basin), consider spatial coverage across basins, and assess data availability. Some sites that were initially selected were eliminated due to data gaps, an insufficient period of record, and/or poor data quality. Additional detail for each Flow Tool node (gage name and number, HUC, E&R attribute categories present within the HUC, period of record) are available in **Appendix B.**

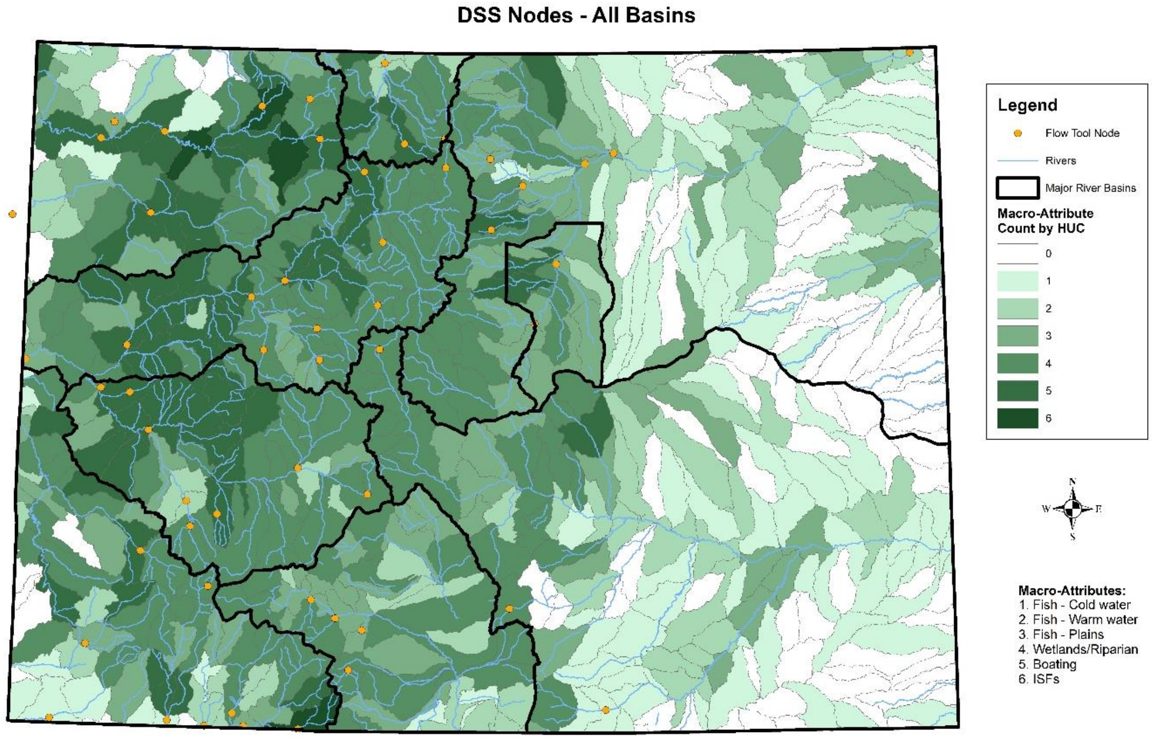

Figure 2-2. Flow Tool Nodes

2.3 DATA INPUTS

2.3.1 HYDROLOGIC DATA

The Flow Tool relies on hydrologic data from the CDSS and modeled data provided by WWG for each of the planning scenarios. Detailed analyses associated with the modeling efforts can be found in *Volume 2 of the Technical Update*. "Historical" hydrologic data loaded into the Flow Tool includes:

- Naturalized flows which represent "unimpaired" flows at the selected node, as modelled, without the impacts of water use, discharges, diversions, or storage. In other words, it is an estimate of "natural" river flows without anthropogenic impacts.
- Baseline flows that were developed (modelled) by pairing estimates of current water use and impairment with historical variable hydrology. In other words, it represents current activity in the basin, superimposed on an extended variable hydrologic profile.

While the naturalized flow data set is the default "historical" reference within the Flow Tool, the baseline data are also available and can be referenced for comparison to "future" data sets.

"Future" hydrologic data sets were provided by WWG for the following planning scenarios:

- Business as Usual;
- Weak Economy;
- Cooperative Growth;
- Adaptive Innovation; and
- Hot Growth

Figure 2-3 provides additional detail for each of the planning scenarios for which hydrologic data sets were modeled.

Drivers	A Business as Usual	B Weak Economy	C Cooperative Growth	D Adaptive Innovation	E Hot Growth
A. Economy/ Population					
B. Urban Land use	No change	No change	Higher density	Higher density	Lower density
C. Climate Status/ Water Supply	Same as 20th century observed	Same as 20th century observed	Between hot and dry and 20th century observed	Hot and dry	Hot and dry
D. Energy Water Needs	Low (no oil shale)	Moderate (no oil shale)	Low (no oil shale)	Low (no oil shale)	High (oil shale)
E. Agricultural Conditions	Total ag water demands slightly higher • Decrease in irrigated acres due to urbanization • Ag exports and demands lower • Ag is less able to compete with urban areas for water	Total ag water demands decrease • Decrease in irrigated acres due to urbanization • Ag exports and demands constant • Ag is less able to compete with urban areas for water	Total ag water demands slightly higher • Slight decrease in irrigated acres due to urbanization • Ag exports down and local demands up • Ag is better able to compete with urban areas for water • Increased ET due to climate change	Total ag water demands slightly higher • Slight decrease in irrigated acres due to urbanization • Ag exports down and local demands up • Ag is better able to compete with urban areas for water • Increased ET due to climate change	Total ag water demands higher • Significant decrease in irrigated acres due to urbanization • Ag exports and demands high • Ag is better able to compete with urban areas for water • Increased ET due to climate change
F. Availability of New Water Efficiency Technology	• M&I Moderate • Ag: Efficiencies are increased	• M&I Moderate • Ag: Efficiencies are increased	• M&I High • Ag: Efficiencies are increased	• M&I High • Ag: Much higher efficiencies are implimented	• M&I Moderate • Ag: Efficiencies are increased
G. Social/ Environmental Values	No change	No change	• Increased awareness • Increased willingness to protect environment and stream recreation	• Increased awareness • Increased willingness to protect environment and stream recreation	• Full use of resources • Low willingness to protect environment and stream recreation
H. Regulatory Constraints	Regulation / Deregulation No change	Regulation / Deregulation No change	Regulation / Deregulation Increased	Regulation / Deregulation Increased but expedited	Regulation / Deregulation Reduced
I. M&I Water Demands	Lowest of the five scenarios	Middle of the five scenarios	Second lowest of the five scenarios	Second highest of the five scenairos	Highest of the five scnarios

Figure 2-3. Technical Update Planning Scenarios

Hydrologic data sets for each planning scenario were developed based on projected changes in supplies and demands and application of climate change factors. Table 2-1 provides information on the climate factor applied to each planning scenario.

Table 2-1. Climate Adjustments by Planning Scenario

Planning Scenario	Baseline	A: Business as Usual	B: Weak Economy	C: Cooperative Growth	D: Adaptive Innovation	E: Hot Growth
Climate Factor	Historical	Historical	Historical	In-Between	Hot and Dry	Hot and Dry

Note that the Rio Grande and Arkansas Basins do not currently have surface water supply models in the CDSS. As such, the nodes currently included in the tool for these basins are high enough in the basins to be "unimpaired". In other words, they are free of any anthropogenic water use impacts, either current or future. Therefore, the future scenario modeled flow changes reflect those associated with climate change only and, in fact, exactly match the corresponding climate change scenario output.

2.3.2 FLOW ECOLOGY RELATIONSHIPS

The flow tool estimates the response of E&R attributes in rivers under various hydrologic scenarios. The flow-ecology relationships in the Flow Tool were first developed as part of the WFET and were patterned after similar relationships that have been developed across the globe (Poff and Zimmerman, 2009) to inform water management. Flow-ecology quantifies the relationship between specific flow statistics (e.g., average magnitude of peak flow, the ratio of flow in August and September to mean annual flow) and the risk status (low to very high) for environmental attribute under the flow scenario being analyzed. Data-derived relationships have been developed for riparian/wetland plants (cottonwoods), coldwater fish (trout), warmwater fish (bluehead sucker, flannelmouth sucker, and roundtail chub), and Plains fish. Other metrics were developed with basic, well-established relationships between hydrology and stream ecology. Lastly, relationships for recreational boating were developed with stakeholders during WFET development.

Flow-ecology relationships, relevant equations, descriptions of risk classes, and references that informed the relationship are described in Appendix C. Development of the flow-ecology relationships, including statistical analyses are described in the WFET reports for the Colorado and Yampa/White/Green basins. Flow-ecology relationships vary across the state and were applied only where a relevant species or ecosystem would be expected to occur, e.g., risk for cottonwood-dominated riparian areas was estimated only for nodes mapped below 9,500 feet, and risk for Plains fishes was applied only below 5,500 feet and east of the Continental Divide.

2.4 TOOL OUTPUTS

The flow tool provides the following outputs:

- Monthly and annual timeseries plots;
- 3 and 10-year rolling average timeseries plots;
- Plot of monthly means;
- Monthly flow percentile plots;
- A tabular summary of annual hydrologic classifications;
- A tabular summary of statistical low flows; and
- A tabular summary of the calculated environmental flow metrics.

2.4.1 FLOW STATISTICS

Flow statistics are calculated and presented in graphical form (and are available in tabular form) on separate tabs within the Flow Tool. Monthly and annual timeseries plots are intended to provide concise summaries and comparisons of the underlying flow data sets and their associated temporal variability. The rolling average plots are provided to remove some of the year-to-year variability "noise" and help identify and compare larger timescale patterns and trends. Monthly mean plots highlight differences (and projected changes) in hydrologic seasonality, while the percentile plots highlight the modelled range of variability in the data sets and particularly the frequency of flow extremes.

2.4.2 HYDROLOGIC CLASSIFICATION

Within a designated tab in the Flow Tool, each water year included in the specified calculation period is assigned to one of five hydrologic classes: drought, dry, average, wet, or flood. Classifications are based on the total annual flow (AFY) in the given water year, compared to category threshold values. Classification thresholds are based on the selected reference flow data set (naturalized or baseline) for the given stream node and calculated according to the flow percentile values summarized in **Table 2-2**. For example, the annual flow threshold for classifying as a drought year is defined as the 5th percentile naturalized flow (exceeded 95% of the time in the naturalized record); while flood years are classified according to the 94th percentile naturalized flow (exceeded 6% of the time in the naturalized record).

Table 2-2. Hydrologic Classification Thresholds

Annual Flow Percentile (upper limit)	Hydrologic Category
5th	Drought
24th	Dry
75th	Average
94th	Wet
100th	Flood

2.4.3 STATISTICAL LOW FLOWS

Statistical low flows of a monthly duration are calculated in the tool for reference to common water quality metrics. Monthly low flows are calculated for recurrence intervals of: 2, 5, 10, 25, 50, and 100 years. Calculations are performed generally following the USEPA's DFLOW (Rossman, 1990) methodology, assuming a Log Pearson Type 3 distribution to the underlying data. These values are calculated for reference only, particularly with respect to relative changes in low flow rates under the simulated scenarios. The calculated values themselves are not intended to be used for regulatory purposes.

2.4.4 ENVIRONMENTAL FLOWS TABLE

The Environmental Flows table is generated using the flow-ecology relationships described in **Section 2.3.2** and **Appendix C**. Numeric output is presented as percent departure from reference flows. Reference flows can be specified as either the naturalized flow data set (default) or the baseline flow data set. See **Appendix A** for further details on this option. The table is also color coded based on risk category (from "low risk" to "very high risk") (**Table 2-3**). Risk categories were developed by numerous academics, agency staff, and consultants during development of the WFET according to percent departure threshold values (compared to reference condition). Risk category thresholds differ for each metric.

Table 2-3. Environmental Flow Risk Categories

Color Key:

(dark green)	= low ecological risk
(light green)	= moderate ecological risk
(yellow)	= less moderate ecological risk (cold water baseflow only)
(orange)	= high ecological risk
(red)	= very high ecological risk

2.4.5 IMPAIRMENT ANOMALIES CHART

Also included in the tool output is a chart of "impairment anomalies". Two metrics are calculated for this plot: (1) annual average flow anomaly and (2) the standard deviation of monthly flow anomalies. The former is calculated as the percent difference between annual average scenario flow and annual average reference flow (Naturalized or Baseline) and is intended to reflect the change in long-term physical flow availability. The latter is calculated as the standard deviation of the percent changes in monthly mean flow rates, compared to reference, and is intended to reflect changes in the *timing* (rather than magnitude) of flow rates. The relative positioning of each scenario plotted by these metrics provides useful information with respect to the drivers of impairment. Large negative percent changes in annual average flow indicate a depletion impairment (consumptive use and/or climate change); while high standard deviations of monthly anomalies indicate a timing impairment (storage, water transfers, or return flows). The plotting area is divided into four quadrants reflecting four possible combinations of impairment: (1) no impairment, (2) timing impairment only, (3) timing and depletion impairment, and (4) depletion impairment only. Quadrant threshold values have been predefined, based on a coarse review of the datasets, as 10% for annual average anomalies and 20% for the standard deviation of monthly anomalies.

Section 3: Results

Flow Tool outputs for all 54 nodes across each of the nine basins were reviewed and considered for the discussion below. Flow statistics under "future" planning scenarios were compared to the timing and magnitude of "historical" peak and low flows. Risk categories identified through analysis of the environmental flow metrics were also reviewed and have informed the summaries presented for each basin.

Future risks to E&R attributes vary across the state depending on location and planning scenario. The risk to E&R attributes is influenced by basin-specific hydrology, water uses, and geographic location within basins. As a result, it is difficult to precisely characterize risks on a statewide basis (basin-specific observations are included in the summaries for individual basins below). However, several general observations can be made:

- Climate change and its impact on streamflow will be a primary driver of risk to E&R attributes.
- Projected future streamflow hydrographs, in most locations across the state, show earlier peaks and potentially drier conditions in the late summer months under scenarios with climate change.
- Under climate change scenarios, runoff and peak flows may occur earlier, resulting in possible mis-matches between peak flow timing and species' needs.
- Drier conditions in late summer months could increase risk to coldwater and warmwater fish due to higher water temperatures and reduced habitat. The degree of increased risk is related to the percent departure from reference conditions.
- In many mountainous regions without significant influence of infrastructure, peak flow and low flows are projected to be sufficient to sustain low to moderate risk for riparian plants and fish, but risks are projected to increase in scenarios with climate change.
- In mountainous regions with infrastructure, risks to E&R attributes vary. Streams that are already depleted may see increased risks in scenarios with climate change. However, some streams may be sustained by reservoir releases, which will help moderate risks for some E&R attributes in scenarios with climate change.
- Instream flow rights (ISFs) and recreational in-channel diversion water rights (RICDs) may be met less often in climate-impacted scenarios.

3.1 ARKANSAS BASIN

The Arkansas Basin is somewhat unique in that a surface water allocation model is not currently available. Hydrologic data sets in the Flow Tool include only naturalized flows and naturalized flows as impacted by climate change. A total of three nodes were selected for the Flow Tool within the Arkansas Basin (**Figure 3-1**):

- Arkansas River near Leadville, Colorado (07081200)
- Huerfano River at Manzanares Crossing, near Redwing, Colorado (07111000)
- Purgatoire River at Madrid, Colorado (07124200)

These sites were selected due to the location within the basin above major supply and demand drivers where impacts would likely be associated only with climate change factors. Management drivers impact river flows on the eastern plains. Because a water allocation model that incorporates management is not available, no data-based insights into flow change and risk to E&R attributes could be developed within this tool. The Flow Tool results for the Arkansas Basin include only Naturalized flows and Naturalized flows as impacted by climate change factors (In-Between and Hot and Dry climate factors). These data do not represent changes in flow due to irrigation, transmountain imports, and/or storage.

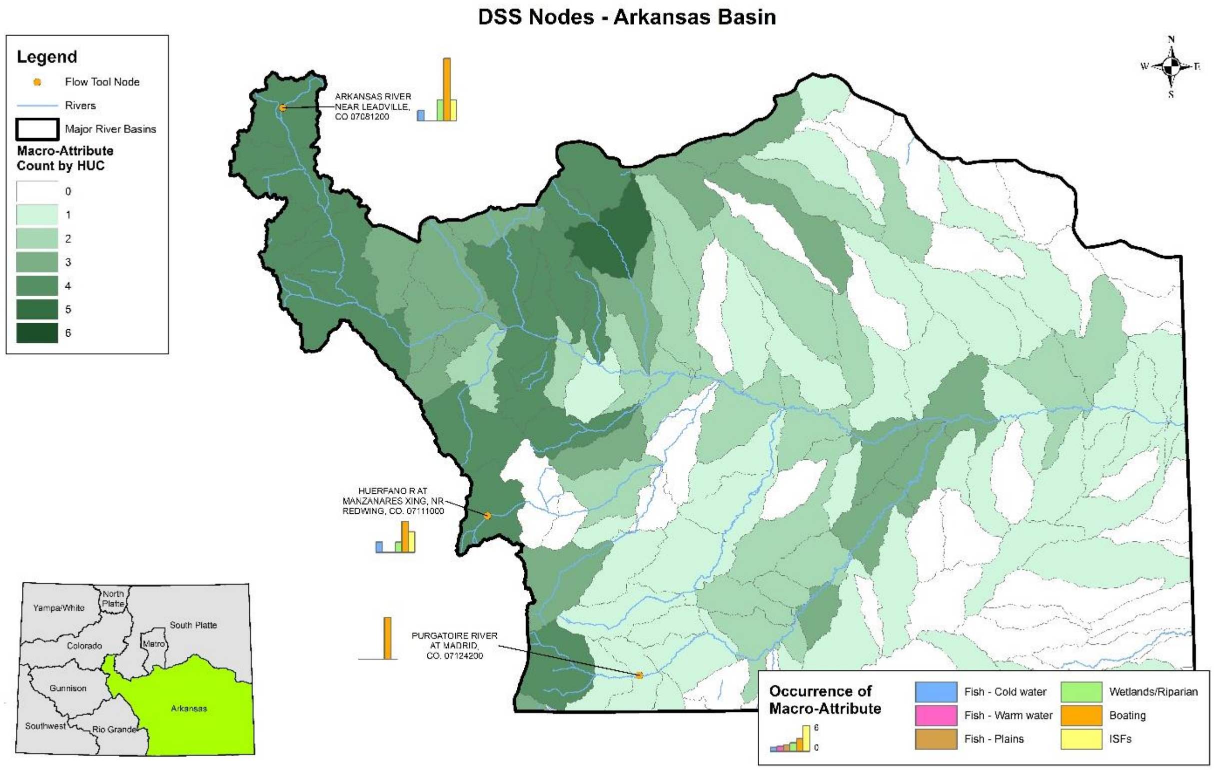

Figure 3-1. Arkansas Basin Nodes

At high elevation locations (e.g., near Leadville), peak flow magnitude does not change substantially. However, the timing of peak flow shifts to earlier in the year, with April and May flow magnitudes rising and June flows decreasing under the In-Between and Hot and Dry climate change scenarios. At montane and foothills locations (elevation range from approximately 5,500 feet to 8500 feet), peak flow magnitude drops under the In-Between and Hot and Dry climate change scenarios. Across all locations, mid- and late-summer streamflow is projected to decrease due to climate change.

At high elevations, peak-flow related risk for riparian/wetland plants and fish habitat remains low or moderate under future climate change scenarios. At lower elevations, the decline in peak flow magnitude increases the risk status for riparian/wetland plants and fish habitat. The reduction in peak flow may also adversely affect recreational boating. Metrics for coldwater fish (trout) indicate that even with climate induced changes to mid- and late-summer flows, flows are sufficient to keep risk low or moderate, although, risk may be higher in July and/or during dry years.

For the Arkansas Basin, because future flows under the five scenarios were not modeled, projected changes to flow at the selected nodes and the associated changes in risk to E&R attributes are entirely attributable to projected changes in climate. These climate-induced changes are similar to the general pattern seen in many parts of Colorado: earlier peak flow and reduced mid- and late-summer flows, with reduced peak flow magnitudes in some locations.

3.2 COLORADO BASIN

A total of eleven nodes were selected for the Flow Tool within the Colorado Basin (Figure 3-2):

- Colorado River below Baker Gulch near Grand Lake, Colorado (09010500)
- Muddy Creek near Kremmling, Colorado (09041000)

- Blue River below Green Mountain Reservoir, Colorado (09057500)
- Eagle River at Red Cliff, Colorado (09063000)
- Colorado River near Dotsero, Colorado (09070500)
- Roaring Fork River near Aspen, Colorado (09073400)
- Fryingpan River near Ruedi, Colorado (09080400)
- Crystal River above Avalanche Creek, near Redstone, Colorado (09081600)
- Roaring Fork River at Glenwood Springs, Colorado (09085000)
- Colorado River near Cameo, Colorado (09095500)
- Colorado River near Colorado-Utah State Line (09163500)

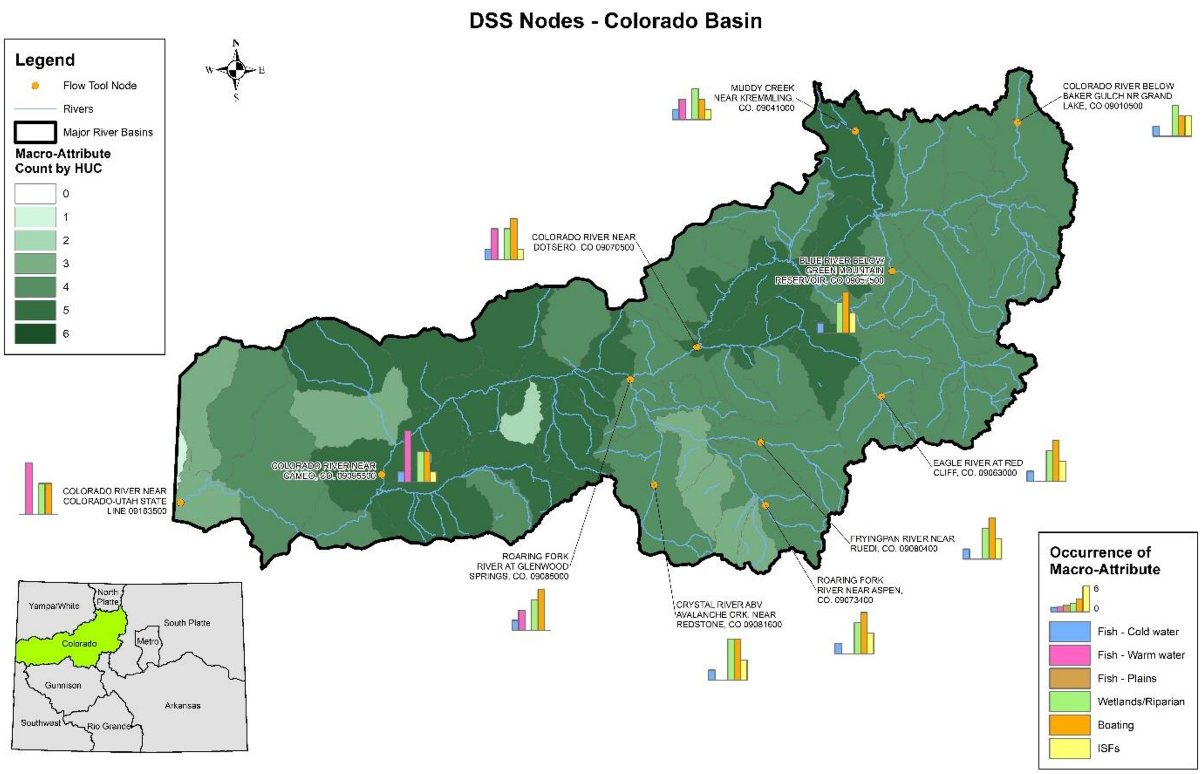

Figure 3-2. Colorado Basin Nodes

In the Colorado Basin, pattern of flow (both peak flows and low flows) are variable across the basin depending on several factors including elevation, storage, and transbasin diversions. The Colorado River usefully illustrates patterns that are present in numerous locations across the basin. Annual flow in headwaters (e.g., Colorado River below Baker's Gulch) under Baseline (Existing) conditions is currently below Natural conditions; this departure increases under climate change scenarios. Moving downstream through Dotsero, Cameo, and to the State Line, annual flow under Baseline conditions rebounds slightly closer to Naturalized conditions. Under climate change scenarios (Cooperative Growth, Adaptive Innovation, and Hot Growth), annual depletions increase from headwaters to the State Line.

Similar to the alterations in annual flows, peak flow magnitudes on the Colorado River under Baseline conditions are below Natural conditions from the headwaters through Dotsero and are closer to Natural conditions at lower elevations (Cameo and State Line). Under climate change scenarios (Collaborative Growth, Adaptive Innovation, and Hot Growth), peak flow magnitudes on the Colorado River decrease further below Natural conditions. Decreases in peak flows (from Naturalized to Baseline) are more pronounced at locations below large reservoirs (e.g., Blue River below Green Mountain Reservoir, Fryingpan River below Reudi Reservoir. This dampening of peak flows is projected to worsen under climate driven scenarios. In some locations (notably, Crystal River above Avalanche Creek), peak flow magnitude is projected to increase under some scenarios. Under the scenarios with climate change factors applied, snowmelt and timing of peak flow shifts earlier in the year. In many areas from headwaters to lower elevations, June flows decrease well below Naturalized conditions, while April and May flows remain similar to Baseline or increase slightly.

Under Baseline conditions, mid- and late-summer flows in headwaters subject to transmountain diversions currently depleted compared to Naturalized conditions. The gap between Baseline and Naturalized conditions lessens farther downstream. Under climate change scenarios, mid- and late-summer flows in headwaters drop well below Naturalized; farther downstream, this drop is less pronounced. In many locations, mid- and late-summer flows under climate change scenarios are projected to be well below Naturalized. The Fryingpan below Reudi Reservoir is an exception to the large decreases in mid- and late-summer flows, because releases are made steadily from the reservoir.

Decreased peak flows that are prevalent across the basin under Baseline conditions create risk for riparian/wetland plants and fish habitat. This risk increases under climate change scenarios. Decreases in mid- and late-summer flows create risk for fish from loss of habitat and, in trout regions, increased water temperatures. Downstream from major reservoirs (e.g., Fryingpan, Green Mountain), diminished peak flows create increase risk for riparian/wetland vegetation and fish habitat if sediment is not flushed, while consistent mid- and late-summer flows keep risk to fish low to moderate.

ISFs throughout the basin and RICDs are likely to be regularly unmet if June-August flows decrease as projected under climate change scenarios.

In critical habitat for endangered species, reduced flows in mid- and late-summer will make it more difficult to meet flow recommendations. For example, projected August flows under climate change scenarios on the Colorado River at Cameo suggest that flow recommendations for endangered fish will not be met during August in approximately one-third of years.

Under Baseline (Existing), Business as Usual, and Weak Economy scenarios, current flow issues related to E&R attributes arise from timing/water delivery issues. Under climate change scenarios, the shift in the timing of peak flow, reductions in total runoff, and increasing demands for consumptive uses contribute to reductions in mid- and late-summer flows. Several water management programs implemented in the context of the Upper Colorado Endangered Fish Program (e.g., Coordinated Reservoir Operations Program) have demonstrated that flow timing and magnitude, and stream temperature can be improved through water management that explicitly considers the needs of E&R attributes.

3.3 GUNNISON BASIN

A total of eight CDSS nodes were selected for the Environmental Flow Tool within the Gunnison Basin (Figure 3-3):

- Gunnison River near Gunnison, Colorado (09114500)
- Tomichi Creek at Sargents, Colorado (09115500)
- Cimarron River near Cimarron, Colorado (09126000)
- Uncompahgre River near Ridgway, Colorado (09146200)
- Uncompahgre River at Colona, Colorado (09147500)
- Uncompahgre River at Delta, Colorado (09149500)

- Kannah Creek near Whitewater, Colorado (09152000)
- Gunnison River near Grand Junction, Colorado (90152500)

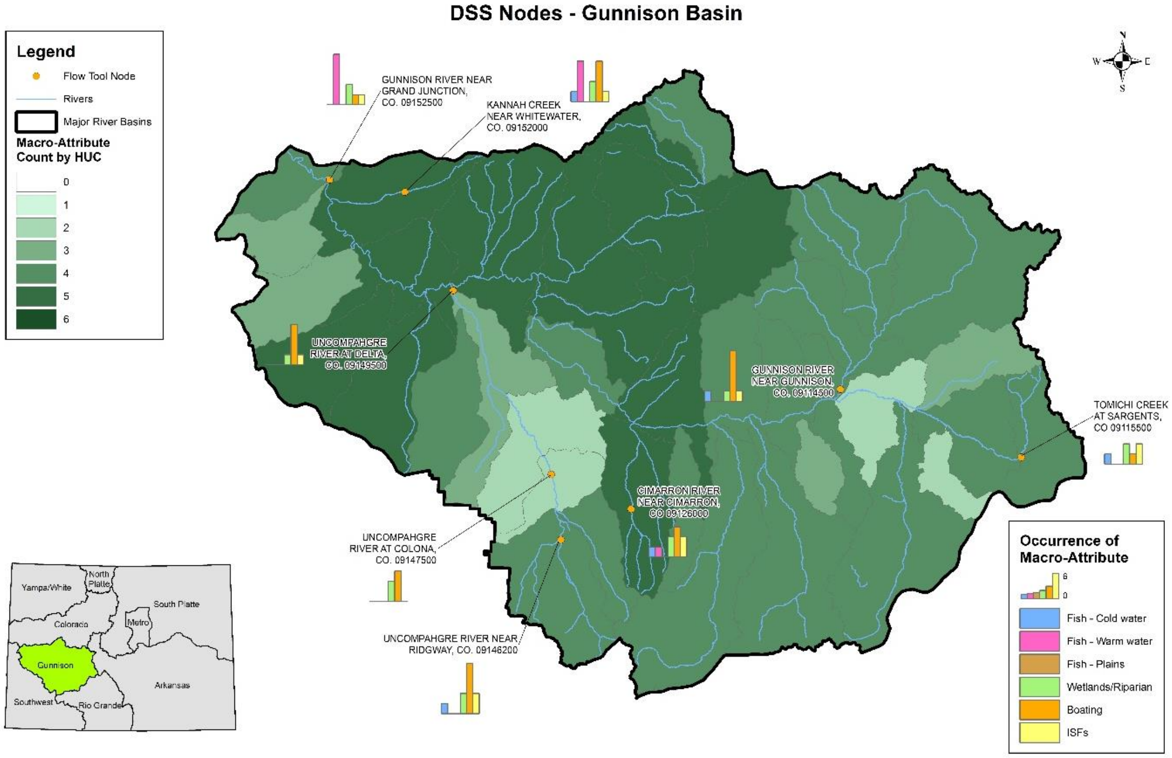

Figure 3-3. Gunnison Basin Nodes

In the Gunnison Basin, pattern of flow varies as a function of elevation, major diversions, and location relative to reservoir storage. At higher elevations (e.g., Gunnison River at Gunnison), mean annual flow under Baseline conditions is close to Naturalized conditions; under climate change scenarios (Cooperative Growth, Adaptive Innovation, Hot Growth), the gap between Natural and Baseline increases to about 20%. At locations lower in the basin (e.g., Gunnison River near Grand Junction), Baseline annual flows are further depleted; under climate change scenarios, depletions continue to grow.

In some locations (e.g., Gunnison River at Gunnison), peak flow magnitude under Baseline conditions is below Naturalized conditions, but under climate change scenarios, peak flow magnitudes increase. As a general rule, however, peak flows change little from Baseline under Business as Usual and Weak Economy scenarios, but decrease more substantially under climate change scenarios. Below major reservoirs on the Uncompahgre and Gunnison mainstems, peak flow under Baseline conditions can be half of the Naturalized condition. Peak flows continue to decrease further from Naturalized under climate change scenarios. Under all climate change scenarios in all locations, runoff and peak flows occur earlier, with June flows decreasing and April and May flows increasing. This change in peak flow timing may cause mis-matches between flow dynamics and the flows needed to support species.

At higher locations in the Gunnison Basin, mid- and late-summer flows under Baseline conditions are 0-20% depleted from Naturalized conditions; under climate change scenarios, these flows drop further below Naturalized. At lower elevations on mainstem rivers (e.g., Uncompahgre at Delta; Gunnison River near Grand Junction), mid- and late-summer flows under Baseline conditions are 30-50% below Naturalized; under climate change scenarios, these flows are also projected to fall further below Naturalized.

Ecological risk (riparian/wetland plants and fish habitat) related to projected changes in peak flow magnitude is generally low to moderate at higher elevations; under climate change scenarios this risk increases at most locations. At locations at lower elevations and on mainstems, peak flows are already reduced in general and reductions increase under climate change scenarios. Even though mid- and late-summer flows decline under climate change scenarios, flow-related risk to coldwater fish (trout) remains moderate. However, the metric used to assess risk for fish does not include the month of July because historically, July flows are sufficient. Under Cooperative Growth, Adaptive Innovation, and Hot Growth scenarios, July flows are predicted to drop, increasing risk for fish by reducing habitat and increasing stream temperatures. In at least one location (Cimmaron River), winter flows become low, also putting fish at risk.

In several locations, ISFs may be met less often, and at least one RICD (in Gunnison), may be met less often. In critical habitats for endangered species, lower mean annual flows and reduced flows in mid- and late-summer will make it more difficult to meet flow recommendations.

Under Baseline (Existing), Business as Usual, and Weak Economy scenarios, current flow issues related to E&R attributes arise from in-basin diversions and storage of peak flows in reservoirs. Under climate change scenarios, the shift in the timing of peak flow, reductions in total runoff, and increasing consumptive demands contribute to reductions in mid- and late-summer flows. Several water management programs implemented in the context of the Upper Colorado Endangered Fish Program, including on the Gunnison River below the Apsinall Unit, have demonstrated that flow timing and magnitude can be planned in a way that better meets the needs of E&R attributes.

3.4 NORTH PLATTE BASIN

A total of three CDSS nodes were selected for the Flow Tool within the North Platte Basin (**Figure 3-4**):

- Michigan River near Cameron Pass, Colorado (06614800)
- Illinois Creek near Rand, Colorado (06617500)
- North Platte River near Northgate, Colorado (06620000)

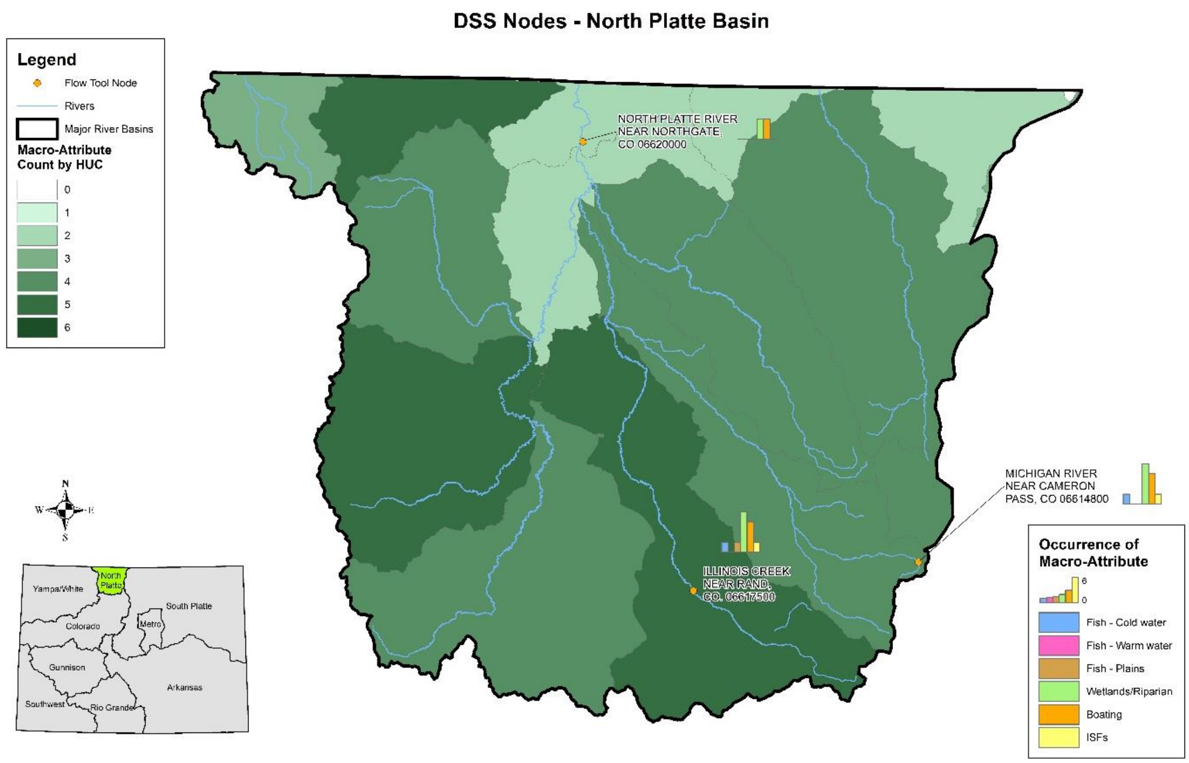

Figure 3-4. North Platte Basin Nodes

Mean annual flows in North Platte Basin under Baseline conditions are 20-35% below Naturalized conditions. Unlike all other basins analyzed, mean annual flow changes little under all scenarios, including climate change scenarios.

Although there is little change in mean annual flow in future scenarios compared to Baseline (Existing), peak flows do change. Peak flow magnitude under Baseline conditions are approximately 15% below Naturalized conditions at higher elevations and decrease further below Naturalized conditions where the North Platte leaves Colorado near North Gate. Under Business as Usual and Weak Growth scenarios, peak flow changes little. Under climate change scenarios, peak flow magnitude may increase slightly. The timing of peak flows also changes; shifting earlier in the year (April and May flows increase, offsetting June flow decreases).

Under Baseline conditions, mid- and late-summer flows in North Park are 30-60% below Naturalized conditions, depending on locations. This condition may not be as ideal for trout as many other locations in Colorado at similar elevation. Under climate change scenarios, mid- and late-summer flows are likely to decline further.

Baseline peak flow magnitudes create some risk for maintaining riparian/wetland plants and fish habitat, but this risk may lessen under climate change scenarios as peak flow magnitude increases. However, earlier and larger peak flows lead to lower mid- and late-summer flows, and these lower flows increase risk for trout under Cooperative Growth, Adaptive Innovation, and Hot Growth scenarios. Also, the change in peak flow timing under climate change scenarios may lead to mis-matches between peak flows and species' needs.

Under Baseline (Existing), Business as Usual, and Weak Economy scenarios, current flow risks related to E&R attributes arise primarily from transbasin diversions and irrigation demands. Under climate change scenarios, both the shift in the timing of peak flow and increased irrigation demands contribute to reductions in mid- and late-summer flows.

3.5 RIO GRANDE BASIN

The Rio Grande Basin is somewhat unique in that a surface water allocation model is not currently available. Hydrologic data sets in the Flow Tool include only naturalized flows and naturalized flows as impacted by climate drivers. A total of four nodes, all in the mountains and foothills west of the San Luis Valley, were selected for the Environmental Flow Tool within the Rio Grande Basin (**Figure 3-5**):

- Rio Grande at Wagon Wheel Gap, Colorado (08217500)
- South Fork Rio Grande at South Fork, Colorado (08219500)
- Pinos Creek near Del Norte, Colorado (08220500)
- Conejos River below Platoro Reservoir, Colorado (08245000)

These sites were selected due to the location within the basin above major supply and demand drivers where impacts would likely be associated with only climate change factors. Management drivers impact river flows in areas downstream of mountainous areas in the Rio Grande and Conejos Basins. Because a water allocation model that incorporates management is not available, the Flow Tool results for the Rio Grande Basin include only Naturalized conditions and Naturalized conditions as impacted by climate drivers (In-between and Hot and Dry climate change scenarios) to illustrate a representative change in flow due to climate. These data do not represent changes in flow due to irrigation, transmountain imports, and/or storage.

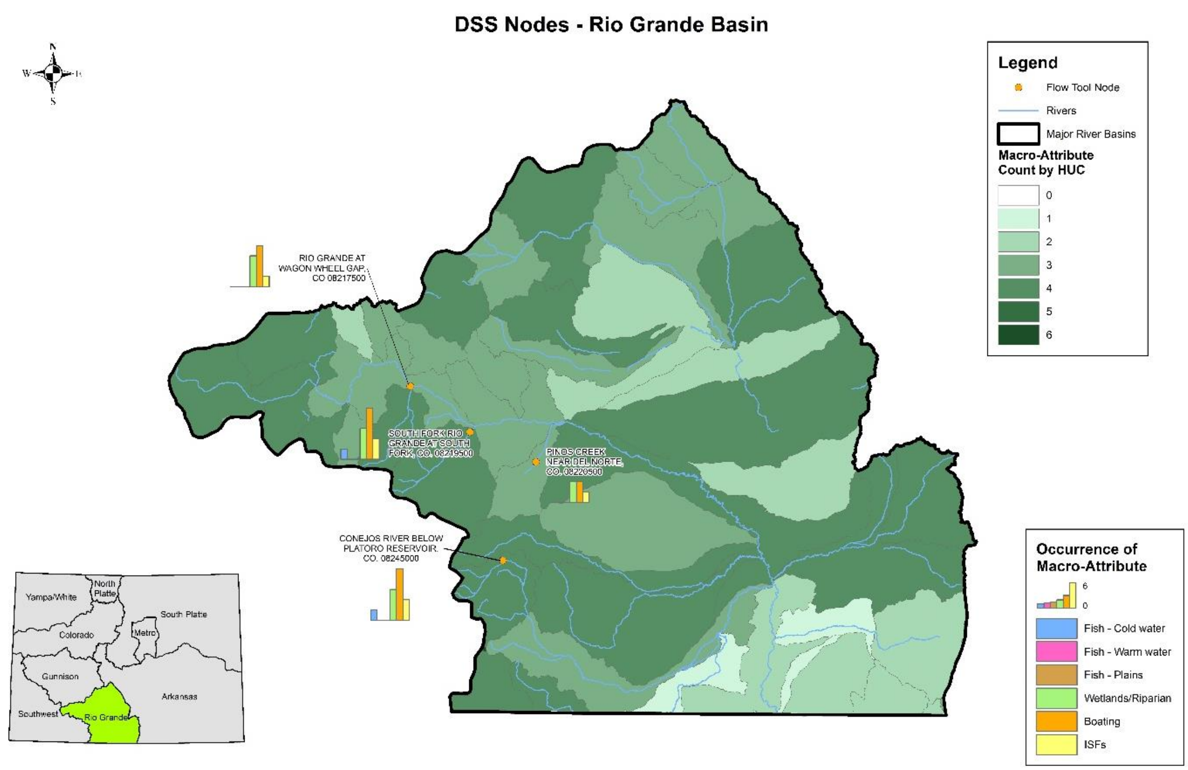

Figure 3-5. Rio Grande Basin Nodes

For the selected locations, overall peak flow magnitude does not change substantially under climate change scenarios. However, the timing of peak flow shifts to earlier in the year, with April and May flow magnitudes rising and June flows decreasing under the In-Between and Hot and Dry climate change scenarios. Mid- and late-summer flow is reduced in all locations under the In-Between and Hot and Dry climate change scenarios, with July streamflow decreasing by roughly half on the Rio Grande and tributaries and even more on the Conejos River.

Peak flow related risk for riparian/wetland and fish habitat remains low or moderate in most cases, although there are some indications that risk could increase in smaller streams. Risk to trout due to decreasing mid- and late-summer streamflow may remain moderate in most years, but could be higher in July and/or during dry years.

Because future flows under the five scenarios have not been modeled in the Rio Grande Basin, projected changes to flow and associated changes in risk to E&R attributes within the Flow Tool are attributable only to projected changes in climate. These climate-induced changes are similar to the general pattern seen in many parts of Colorado: earlier peak flow and reduced mid- and late-summer flows.

3.6 SOUTH PLATTE BASIN

A total of eight nodes were selected for the Flow Tool within the South Platte Basin (**Figure 3-6**):

- South Platte River at South Platte (06707500)
- South Platte River at Denver (06714000)
- St Vrain Creek at Lyons, Colorado (06724000)
- Middle Boulder Creek at Nederland, Colorado (06725500)
- Big Thompson River at Estes Park, Colorado (06733000)
- Big Thompson River at Mouth, near La Salle, Colorado (06744000)
- South Platte River near Kersey, Colorado (06754000)
- South Platte River at Julesburg, Colorado (06764000)

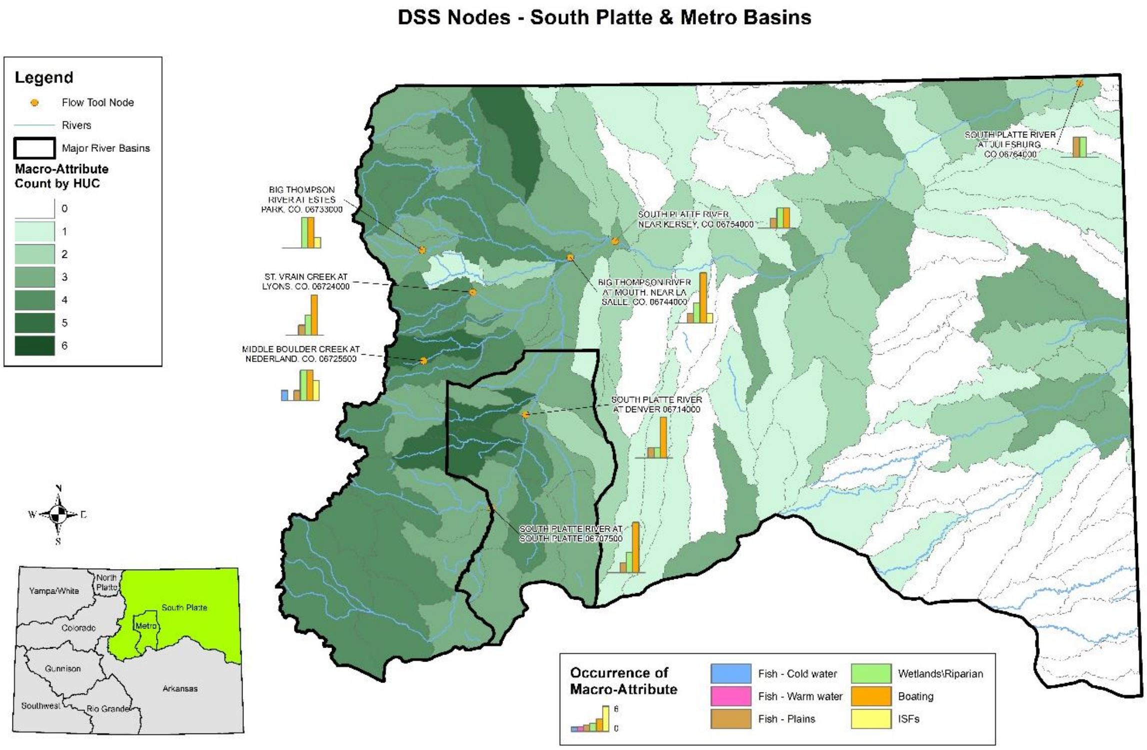

Figure 3-6. South Platte Basin Nodes

Patterns of peak flows are highly variable across locations in the basin. Baseline flow patterns diverge the most from Naturalized conditions in the Foothills and on the Plains. The magnitude of flows on the South Platte in Denver in May and June (historically the months of peak runoff) under Baseline (Existing) conditions are reduced from Naturalized conditions; the divergence from Naturalized conditions increases as the South Platte flows through Julesberg. In these locations, peak flow magnitude under the various future scenarios increases, stays the same, or decreases further, again depending on location. In the mountains (e.g., South Platte River at South Platte, Middle Boulder Creek at Nederland), Baseline peak flow magnitudes are only minimally below Naturalized peak flow magnitude. Changes to peak flow magnitude in these mountain locations also vary depending on location, with minimal changes to peak flow magnitude in some locations and larger declines elsewhere. Mountain locations demonstrate a pattern under the climate change scenarios where the timing of peak flows shifts earlier in the year, from June to May. The change in timing for peak flows may result in mismatches between peak flow timing and species' needs.

Mid- and late-summer flows are also highly variable across locations in the basin. On the Plains, Baseline low flows vary in range below Naturalized conditions. Under future scenarios, this range shifts to further departed from Naturalized conditions, with climate change scenarios (Cooperative Growth, Adaptive Innovation, and Hot and Dry scenarios) causing the greatest decline in flows. In the mountains, climate change scenarios cause a decline in low flows (e.g., Middle Boulder Creek at Nederland), while in other areas (e.g., South Platte River at South Platte) declines are less pronounced due to transbasin imports and releases of stored water.

In the Foothills and on the Plains, especially east of Interstate 25, decreased peak flow magnitudes under Baseline conditions and all future scenarios put many aspects of ecosystem function (e.g., over-bank flooding to support riparian plants, sediment transport to maintain fish habitat) at risk. Projected changes to mid- and late-summer flows also create risk for plains fishes. In the mountains, peak flow and low flows generally create low to moderate risk for riparian plants and fish, although these risks increase under climate change scenarios.

There are numerous ISF reaches in the mountains and foothills, and several RICDs in the South Platte Basin. The location of modeled flow points does not allow specific insight into what future scenarios imply for these nodes, but the general pattern of diminished flows, especially diminished flows under climate change scenarios, suggests that the flow targets for ISFs and RICDs may be met less often.

Increasing risk to E&R attributes arise from several sources. Changes in flow timing through water management (e.g., storage of peak flows) can reduce ecosystem functions that are dependent on high flows (e.g., sediment transport) and can reduce boating opportunities. Changes in timing under climate change scenarios (early peak flow) can also increase risk for ecosystems and species. Under all scenarios in most locations, ecological and recreational risk is also increased by depletions from increasing human water consumption and decreasing supply under a changing climate. Water management (e.g., reservoir releases) has the potential to mitigate negative impacts.

3.7 SOUTHWEST BASIN

A total of nine nodes were selected for the Flow Tool within the Southwest Basin (**Figure 3-7**):

- Dolores River at Dolores, Colorado (09166500)
- San Miguel River near Placerville, Colorado (09172500)
- Navajo River at Edith, Colorado (09346000)
- San Juan River near Carracas, Colorado (09346400)
- Piedra River near Arboles, Colorado (09349800)
- Los Pinos River at La Boca, Colorado (09354500)
- Animas River at Howardsville, Colorado (09357500)
- Animas River near Cedar Hill, New Mexico (09363500)
- Mancos River near Towaoc, Colorado (09371000)

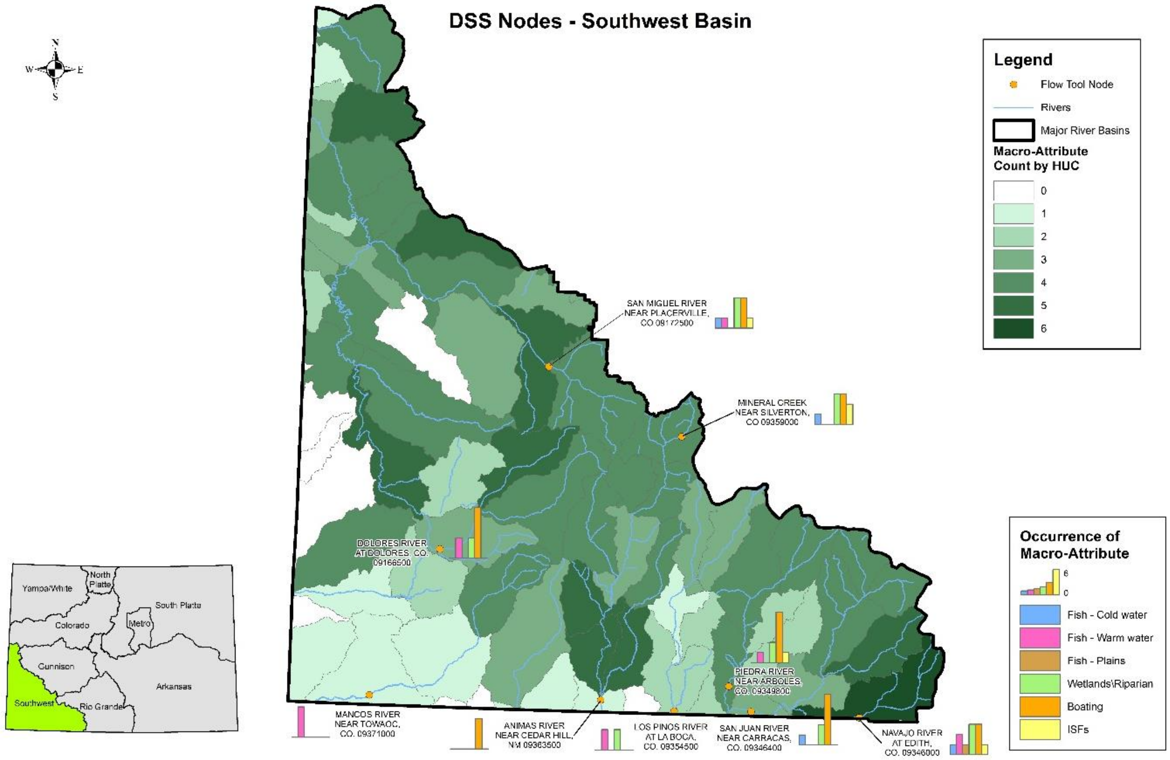

Figure 3-7. Southwest Basin Nodes

In locations where Baseline conditions are minimally depleted from Naturalized conditions (e.g., the San Miguel River), peak flow magnitude under Business as Usual and Weak Economy scenarios are projected to decline only slightly below Baseline. Under climate change scenarios, declines in peak flow magnitude are further below Baseline. At all locations, the timing of peak flow moves earlier in the year for all climate change scenarios (Cooperative Growth, Adaptive Innovation, and Hot and Dry scenarios). Under these climate change scenarios, June flows decrease the most (e.g., Dolores River at Dolores). Under these same scenarios, April flow increases, but the increase in April flow magnitude does not offset the decline in June flow magnitude. In all locations, mid- and late-summer flows are reduced under Cooperative Growth, Adaptive Innovation, and Hot Growth scenarios, increasing risks for coldwater and warmwater fish.

In locations where Naturalized and Baseline conditions are similar, peak flow-related risk to riparian/wetland plants and fish remain low to moderate under Business as Usual, Weak Economy, and Cooperative Growth scenarios. Under Adaptive Innovation and Hot Growth scenarios, this risk increases. In locations where peak flows under Baseline are already substantially less than Naturalized conditions, peak flow-related risk to riparian/wetland plants and fish is already high and increases under climate change scenarios. Under all climate change scenarios, runoff and peak flows occur earlier, and possible mis-matches between peak flow timing and species' needs may occur.

In locations where Naturalized and Baseline conditions are similar, risk to coldwater fish (mainly trout) increases under the various planning scenarios because of declines in mid- and late-summer flow. However, the risk remains moderate in most years. In locations that experience low summer flows, risk to fish increases. Note that the Flow Tool risk assessment using coldwater and warmwater fish metrics does not include July because historically July flows are sufficient. In some locations, July flows are significantly reduced under climate change scenarios, e.g., July flows under the Hot Growth scenario on the Piedra River near Arboles. The projected reduction will likely result in reduced habitat and increased stream temperatures.

ISFs throughout the Southwest and the RICD on the Animas River may not be met in many years under Cooperative Growth, Adaptive Innovation, and Hot and Dry scenarios. For example, flows on the San Miguel River near Placerville are projected to fall short of the 93 cubic feet per second (cfs) summer ISF regularly during mid- and late-summer. In August, this ISF is projected to be unmet during 1 out of 3 years under the Cooperative Growth scenario and during 2 out of 3 years under the Adaptive Innovation and Hot Growth scenarios. On the Animas River, the 25 cfs RICD near Howardsville is projected to not be met in numerous years during late summer (August) through October, and again in January and February (when the minimum flow is 13 cfs) under the three climate change scenarios.

Under Baseline (Existing), Business as Usual, and Weak Economy scenarios, current flow issues related to E&R attributes arise primarily because of depletions that increase moving downstream. In some locations, transbasin diversions reduce and change the timing of flow in the basin of origin while augmenting flows in the receiving basin. Under climate change scenarios, the shift in the timing of peak flow, reductions in total runoff, and increasing consumptive demands contribute to reductions in mid- and late-summer flows.

3.8 YAMPA/WHITE BASIN

A total of eight nodes were selected for the Flow Tool within the Yampa/White Basin (**Figure 3-8**):

- Yampa River at Steamboat Springs, Colorado (09239500)
- Elk River at Clark, Colorado (09241000)
- Elkhead Creek near Elkhead, Colorado (09245000)
- Yampa River near Maybell, Colorado (09251000)
- Little Snake River near Lily, Colorado (09260000)
- Yampa River at Deerlodge Park, Colorado (09260050)
- White River below Meeker, Colorado (09304800)
- White River near Watson, Utah (09306500)

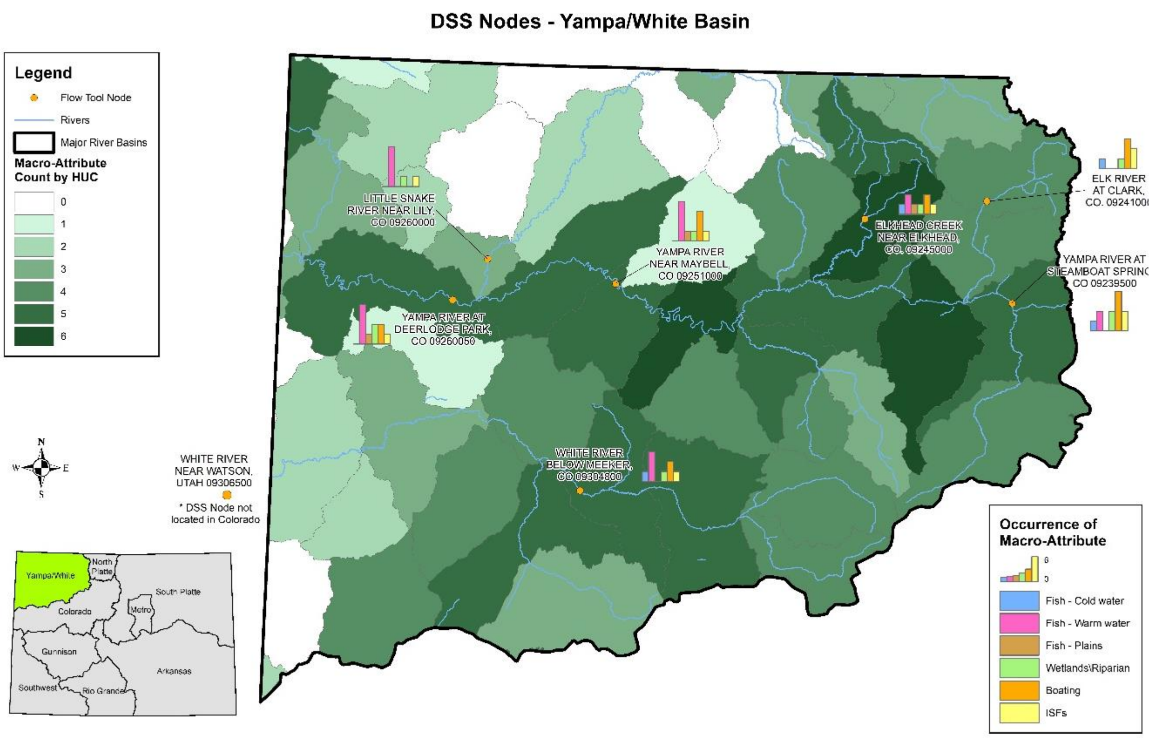

Figure 3-8. Yampa/White Basin Nodes

On the Yampa and White Rivers, peak flow magnitudes under Baseline (Existing) conditions are only slightly reduced (10%) from Naturalized conditions. A similar status holds for the Business as Usual and Weak Economy scenarios. Under the Hot and Dry scenario, total peak flows decline approximately 10%. At all locations, the timing of peak flow moves earlier in the year under all climate change scenarios (Cooperative Growth, Adaptive Innovation, and Hot and Dry scenarios). Under the climate change scenarios, June flow decreases approximately 30% at higher elevations (e.g., Elk River at Clark) and continues to decrease more at lower elevations (e.g., Yampa River at Deerlodge Park); under these same scenarios, April flows increase at a similar rate. May flows increase or decrease depending on location and scenario.

Under Baseline (Existing) conditions, mid- and late-summer flows are minimally depleted at higher elevations under Naturalized conditions, are reduced further through mid-elevations (e.g., Steamboat Springs), and continue to decline through low-elevations (e.g., White River below Meeker and Yampa River at Deerlodge Park). Under all climate change scenarios, in most locations, mid- and late-summer flows show a wide departure from Naturalized conditions.

Despite declines in peak flow magnitude, flow-related risk to riparian/wetland plants remains low to moderate across the basin. However, flow-related risk to warmwater fish increases, with the most risk occurring under the Hot and Dry scenario. The change in timing for peak flows may result in mismatches between peak flow timing and species' needs.

Projected reductions in mid- and late-summer flows result in increased risks for trout at high and mid-elevations, and for warmwater fish at low elevations. Increased risk is caused by reduction in habitat under reduced flows. For trout, increased stream temperatures under low-flow conditions also increases risks, as has been the case in some recent years in Steamboat Springs. Additionally, the projected reductions in flows in mid- and late-summer result in flows that are below the recommendations for endangered fish. For comparison, flows in August and September of 2018 were among the lowest flows on record and resulted in the first ever call on the Yampa River. September flows are projected to be similarly low in nearly one-quarter of all years under Cooperative Growth and nearly one-third of all years under Adaptive Innovation and Hot and Dry scenarios. These low flows lead to a loss of habitat for endangered fish and favor reproduction and survival of non-native fish that prey upon endangered fish.

ISFs and RICDs are at risk of being met less often in mid- to late-summer under all future scenarios that include climate change (Cooperative Growth, Adaptive Innovation, and Hot and Dry). An example of an ISF at risk is the 65 csf ISF on the Elk River. This ISF is met in July in every year under the Baseline scenario. However, under the Cooperative Growth Scenario, average July flow drops below 65 cfs in approximately one-third of years, and is unmet in approximately half of the modeled years under the Adaptive Innovation and Hot and Dry Scenarios. In August, the Elk River ISF is unmet in nearly every year under all climate change scenarios.

The total amount of boating flows during runoff may not change significantly if peak flow magnitude does not decline substantially, but the timing of boating opportunities will shift to earlier in the year under all climate change scenarios. An example of a RICD at risk is for the whitewater park in Steamboat Springs. The August RICD decreed flow of 95 cfs is often not met under Baseline conditions. Under Adaptive Innovation and Hot and Dry scenarios, the August RICD decree is almost never met.

Under Baseline (Existing), Business as Usual, and Weak Economy scenarios, current flow risk related to E&R attributes arises primarily because of depletions that increase moving downstream. Under climate change scenarios, both the shift in the timing of peak flow and reductions in total runoff contribute to reductions in mid- and late-summer flows.

Section 4: Future Tool Enhancements

The Flow Tool provides all of the information described in the previous sections, it currently lacks the ability to directly perform exploratory "what if" scenarios, with respect to flow modification or management scenarios. Any such scenarios currently require water allocation simulations, as a pre-processing step, using the CDSS models. However, potential future enhancements could include the programming of simple water allocation algorithms, on a coarse scale, into the Flow Tool. For example, generic storage, with simple routing and operating rules, could be added to the Flow Tool as an optional module. The user could use such functionality to investigate the impact of additional upstream storage on node flow regimes and environmental flow metrics. More specifically, such an enhancement would allow for simple investigations of flow storage and management alternatives to reduce risks to macroattribute categories. In addition to storage, coarse-scale flow and demand management options could be added to the Flow Tool, including (but limited to): conservation, reuse, agricultural water transfers, and trans-basin imports. Again, such enhancements would allow the Flow Tool to be used as a stand-alone predictive model for investigating, at a coarse scale, potential future flow modification scenarios. These potential enhancements are left for future consideration.

References

Poff, N. L., and J. K. H. Zimmerman. “Ecological Responses to Altered Flow Regimes: A Literature Review to Inform the Science and Management of Environmental Flows.” *Freshwater Biology* 55, no. 1 (January 2009): 194–205. https://doi.org/10.1111/j.1365-2427.2009.02272.x.

Rossman, 1990 Rossman, L. “DFLOW USER'S MANUAL.” U.S. Environmental Protection Agency, Washington, D.C., EPA/600/8-90/051 (NTIS PB90225616), 1990.

Appendix A: User Guide

Analysis and Technical Update to the Colorado Water Plan

Technical Memorandum

Prepared for:

Colorado Water Conservation Board

Subject:

Appendix A: Colorado Environmental Flow Tool: User's Guide

Date: May 31, 2019

Prepared by: Tim Cox (CDM Smith) and John Sanderson (The Nature Conservancy)
Reviewed by: Sue Morea and Becky Dunavant (CDM Smith)

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Section A1: User's Guide

A1.1 OVERVIEW

The Colorado Environmental Flow Tool (Flow Tool) was developed to provide:

a) Concise summaries of Colorado Decision Support System (CDSS) flow projections across the State; and

b) Calculations of ecologically relevant flow metrics for any combination of selected key stream node locations and flow projection scenarios.

Modelled flow summaries are available for multiple pre-selected stream nodes in each of the nine (9) major river basins in Colorado and for up to five (5) future flow scenarios. Additionally, summaries of naturalized flow are also available, for baseline (historical) conditions and for two different future climate change scenarios. Calculation periods vary by river basin but are generally on the order of 35 years. Underlying CDSS flow data are included on a monthly timestep.

The Flow Tool was designed to serve as a resource to help Basin Roundtables refine, categorize, and prioritize their current portfolio of environmental and recreational (E&R) projects and methods through an improved understanding of flow needs and flow impairments, both existing and projected. The environmental flow metrics in the tool were developed in collaboration with The Nature Conservancy (TNC) and are based on the best available ecological science and literature. The flow metrics span a range of ecological and recreational considerations, including cold and warm water fish, wetlands plants, general ecosystem health, and boating.

The Flow Tool is easy to use and designed for a wide range of potential end users. Note, however, that adding new stream nodes, or new modelled flow scenarios, to the tool is not currently an option available to the user and would require additional programming by the tool developers.

A1.2 SOFTWARE PLATFORM AND INTERFACE

The Flow Tool has been developed in Microsoft Excel using Visual Basic for Applications (VBA) programming. The Excel platform provides a familiar, and portable, working space for the tool user, as well as offering standard spreadsheet pre- and post-processing capabilities. User inputs specific to the application of the tool are provided via a user-friendly input form (Figure A1). The actual hydrologic and environmental flow metrics are calculated with underlying Visual Basic code. The tool graphical and tabular outputs are also generated with VBA code.

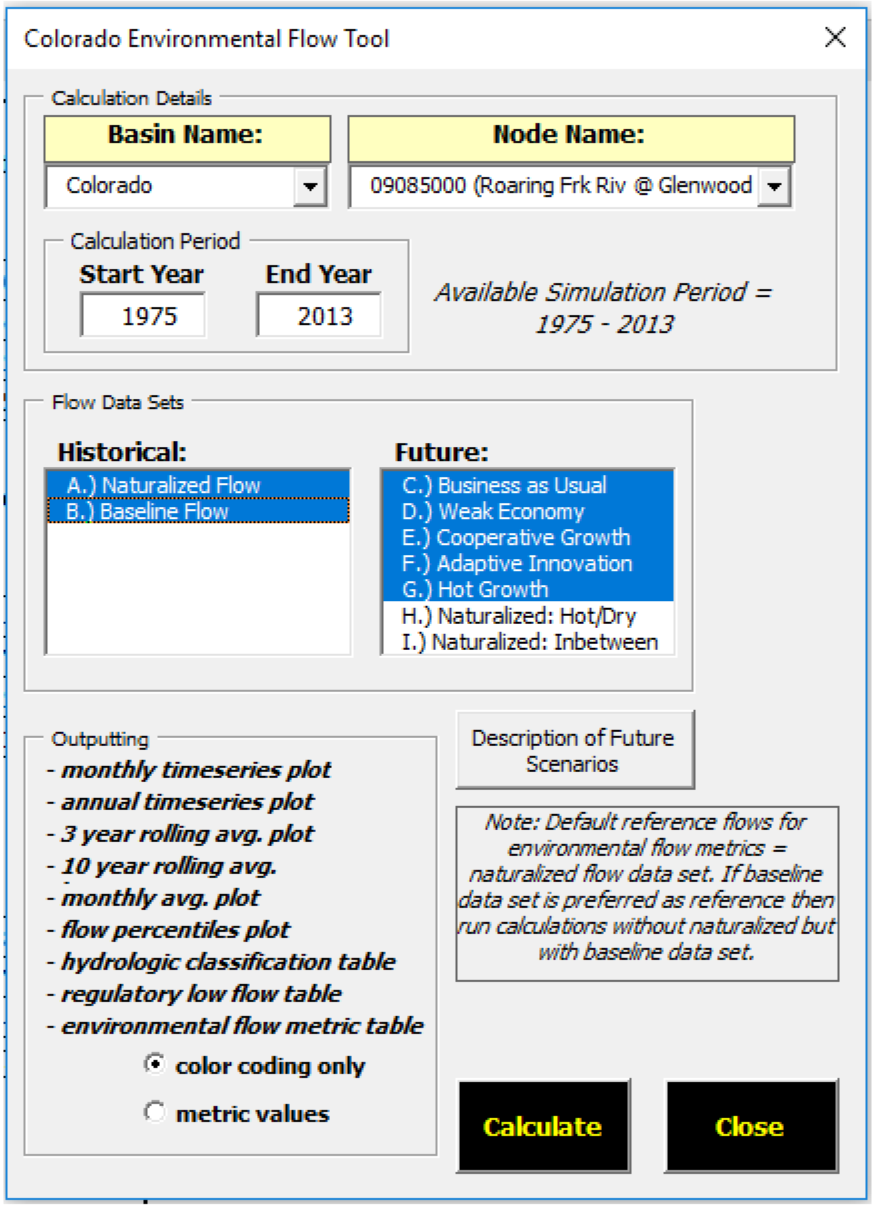

Figure A1. Flow Tool User Input Form

A1.3 USER INPUTS AND FLOW DATABASE

For each set of calculations, the user selects a river basin and stream node combination from predefined dropdown menus (Figure A1). The user must also define the calculation period (start and end year), within the available simulation period. The available simulation period varies by basin. *Note that specifying start or end years outside of the available simulation period will result in a runtime error.*

Any number of the available flow data sets can be included in the tool calculations, selected by highlighting from two list boxes. The "Historical" list box includes a naturalized and a baseline data set. The naturalized data set represents "unimpaired" flows at the selected node, as modelled, without the impacts of water use, discharges, diversions, transfers, or storage. In other words, it is an estimate of "natural" river flows without anthropogenic impacts. The baseline data set was developed (modelled) by pairing estimates of current water use and impairment with historical variable hydrology. In other words, it represents current activity in the basin superimposed on an extended variable hydrologic profile. Note that either the naturalized or the baseline data set can be used as the reference flow data for the environmental flow metric and hydrologic classification calculations. The naturalized flow data set is the default reference. However, the user can specify the baseline data set to be the reference by selecting the baseline data set from the list and de-selecting the naturalized data set.

The "Future" list box includes five different future growth and water use projections (Scenarios C – G) combined with varying levels of assumed climate change. These five scenarios have been described elsewhere, but short summaries of each are available within the tool, via the "Description of Future Scenarios" button. Also included as optional data sets are two sets of naturalized flow projections simulated under different climate change assumptions. The associated climate change projection scenarios have also been described elsewhere. These data sets are included in this tool to provide useful references that effectively isolate the impacts of climate change, and associated altered hydrologic conditions, on the node flow regimes.

Calculated environmental flow metrics can be provided in the output tables (described below) as color-coded categories only or as both numeric values and color categories. This is a user option provided on the input form (Figure A1). For users less familiar with TNC environmental flow equations (Section A1.4.3), the color-coding only option is recommended.

The modelled flow database is included in the tool with a series of basin-specific worksheet tabs. Each flow scenario data set is included as separate columns in the respective basin worksheets. Separate sets of worksheets are included for the impaired vs. naturalized data sets. The data in these worksheets can be modified by the user if, for example, the modeled scenarios are updated in the CDSS. In such a case, the new flow data must be copied and pasted into the corresponding worksheet in the same format as in the tool currently. Data date ranges cannot be changed by the user in these sheets. The worksheets should not be modified by the user in any other way as they provide the data, in a predefined format, that underpin all tool calculations. As noted above, the addition of new nodes or flow scenarios to the tool are not currently options for the user.

A1.4 TOOL CALCULATIONS AND OUTPUTS

The flow tool provides the following outputs, each on separate worksheet tabs:

- Monthly and annual timeseries plots;
- 3 and 10-year rolling average timeseries plots;
- Plot of monthly means;
- Monthly flow percentile plots;
- A tabular summary of annual hydrologic classifications;
- A tabular summary of statistical low flows; and
- A tabular summary of the calculated environmental flow metrics.

Monthly and annual timeseries plots are intended to provide concise summaries, and comparisons, of the underlying flow data sets and their associated temporal variability. The rolling average plots are provided to remove some of the year-to-year variability "noise" and help identify, and compare, larger timescale patterns and trends. Monthly mean plots highlight differences (and projected changes) in hydrologic seasonality, while the percentile plots highlight the modelled range of variability in the data sets and, particularly, the frequency of flow extremes. The hydrologic classification table (Section A1.4.1) provides information on the frequency of dry, average, and wet years in the simulated record under different simulated water impairment conditions. The table of calculated low flow metrics (Section A1.4.2) provides low flow statistics that are particularly relevant to water quality considerations. And, lastly, the table of environmental flow metrics (Section A1.4.3) highlights the degree of ecologically-relevant flow changes associated with each modelled scenario. Color coding is provided to indicate levels of risk associated with the calculated metric values.

In addition to the summary output tables and graphs described above, the raw output underpinning the summaries are also provided in separate worksheet tabs ("X Output").

A1.4.1 HYDROLOGIC CLASSIFICATION

As part of the set of tool calculations, each water year included in the specified calculation period is assigned to one of five hydrologic classes: drought, dry, average, wet, or flood. Classifications are based on the total annual flow (AFY) in the given water year, compared to category threshold values. Classification thresholds are based on the selected reference flow data set (naturalized or baseline) for the given stream node, calculated according to the flow percentile values summarized in **Table A1**. For example, the annual flow threshold for classifying as a drought year is defined as the 5th percentile naturalized flow (exceeded 95% of the time in the naturalized record); while flood years are classified according to the 94th percentile naturalized flow (exceeded 6% of the time in the naturalized record).

Table A1. Hydrologic Classification Thresholds

Annual Flow Percentile (upper limit)	Hydrologic Category
5th	Drought
24th	Dry
75th	Average
94th	Wet
100th	Flood

A1.4.2 STATISTICAL LOW FLOWS

Statistical low flows, of a monthly duration, are calculated in the tool for reference to common water quality metrics. Monthly low flows are calculated for recurrence intervals of: 2, 5, 10, 25, 50, and 100 years. Calculations are performed generally following the USEPA's DFLOW (Rossman, 1990) methodology, assuming a Log Pearson Type 3 distribution to the underlying data. These values are calculated for reference only, particularly with respect to relative changes in low flow rates under the simulated scenarios. The calculated values themselves are not intended to be used for regulatory purposes.

A1.4.3 ENVIRONMENTAL FLOW CALCULATIONS

TNC environmental flow metrics, as included in the Flow Tool, are defined in **Appendix C**. Numeric output are generally presented as percent departure from reference flows. Reference flows can be specified as either the naturalized flow data set (default) or the baseline flow data set. The output table is also color coded based on risk category (from "low risk" to "very high risk") (**Table A2**). Risk categories are pre-defined by TNC experts according to percent departure threshold values (compared to reference condition). Risk category thresholds differ for each metric.

Table A2. Environmental Flow Risk Categories

Color Key:

Dark green	= low ecological risk
Light green	= moderate ecological risk
Yellow	= less moderate ecological risk (cold water baseflow only)
Orange	= high ecological risk
Red	= very high ecological risk

A1.4.4 IMPAIRMENT ANOMALIES CHART

Also included in the tool output is a chart of "impairment anomalies". Two metrics are calculated for this plot: annual average flow anomaly and the standard deviation of monthly flow anomalies. The former is calculated as the percent difference between annual average scenario flow and annual average reference flow (naturalized or baseline). It is intended to reflect the change in long-term physical flow availability. The latter is calculated as the standard deviation of the percent changes in monthly mean flow rates, compared to reference. This metric is intended to reflect changes in the *timing* (rather than magnitude) of flow rates. The relative positioning of each scenario plotted according to these calculated metrics provides useful information with respect to the drivers of impairment. Large negative percent changes in annual average flow indicate a depletion impairment (consumptive use and/or climate change); while high standard deviations of monthly anomalies indicate a timing impairment (storage, water transfers, or return flows). The plotting area is divided into four quadrants reflecting four possible combinations of impairment: "no impairment", "timing impairment only", "timing and depletion impairment", and "depletion impairment only". Quadrant boundary values have been predefined, based on a coarse review of the data sets, as 10% for annual average anomalies and 20% for the standard deviation of monthly anomalies.

References

Rossman, L A. DFLOW USER'S MANUAL. U.S. Environmental Protection Agency, Washington, DC, EPA/600/8-90/051 (NTIS 90-225616), 1990.

Appendix B: Flow Tool Nodes

age Numb	Station Name	Status	Period Of Record		HUC10	HUC Name	Basin	MacroAttribute							Latitude	Longitude	Elevation (ft)	Datum
			Start	End				Fish_Coldwater	Fish_Warmwater	Fish_Plain	Wetlands/	Boating	ISFs	Num of Categories				
07081200	ARKANSAS RIVER NEAR LEADVILLE, CO	Active	1967	2018	1102000102	Headwaters Arkansas River	Arkansas	1	0	0	2	6	2	4	39.24899982	-106.3481121	9665	NGVD 29
07111000	HUERFANO R AT MANZANARES XING, NR REDWING, CO.	Active	1923	2018	1102000601	Headwaters Huerfano River	Arkansas	1	0	0	1	3	2	4	37.72770544	-105.3538732	8206.415714	NAVD 88
07124200	PURGATOIRE RIVER AT MADRID, CO.	Active	1972	2018	1102001003	Trinidad Lake-Purgatoire River	Arkansas	0	0	0	0	4	0	1	37.12946461	-104.6399893	6261.61	NGVD 29
09041000	MUDDY CREEK NEAR KREMMLING, CO.	Historic	1937	1999	1401000107	Muddy Creek	Colorado	1	2	0	3	2	1	5	40.29359493	-106.4836477	7856	NGVD 29
09010500	COLORADO RIVER BELOW BAKER GULCH NR GRAND LAKE, CO	Active	1953	2018	1401000103	Headwaters Colorado River	Colorado	1	0	0	3	2	2	4	40.32581748	-105.8566794	8750	NGVD 29
09080400	FRYINGPAN RIVER NEAR RUEDI, CO.	Active	1964	2018	1401000405	Fryingpan River	Colorado	1	0	0	3	4	2	4	39.36554009	-106.8255959	7473.25	NGVD 29
09081600	CRYSTAL RIVER ABV AVALANCHE CRK, NEAR REDSTONE, CO	Active	1955	2018	1401000407	Cyrstal River	Colorado	1	0	0	4	4	2	4	39.23263837	-107.2275011	6905	NGVD 29
09063000	EAGLE RIVER AT RED CLIFF, CO.	Active	1910	2018	1401000302	Upper Eagle River	Colorado	1	0	0	3	4	2	4	39.50831845	-106.3666958	8653.8	NGVD 29
09057500	BLUE RIVER BELOW GREEN MOUNTAIN RESERVOIR, CO	Active	1937	2018	1401000206	Lower Blue River	Colorado	1	0	0	3	4	2	4	39.88026343	-106.3339189	7682.66	NGVD 29
09073400	ROARING FORK RIVER NEAR ASPEN, CO.	Active	1964	2018	1401000401	Upper Roaring Fork River	Colorado	1	0	0	3	4	2	4	39.17998786	-106.8019841	8014.01	NGVD 29
09095500	COLORADO RIVER NEAR CAMEO, CO.	Active	1933	2018	1401000514	Jerry Creek-Colorado River	Colorado	1	5	0	3	3	1	5	39.23914511	-108.2661958	4813.73	NGVD 29
09070500	COLORADO RIVER NEAR DOTSERO, CO	Active	1940	2018	1401000115	Big Alkali Creek-Colorado River	Colorado	1	3	0	3	4	1	5	39.64460942	-107.0780124	6130	NGVD 29
09163500	COLORADO RIVER NEAR COLORADO-UTAH STATE LINE	Active	1951	2018	1401000519	McDonald Creek-Colorado River	Colorado	0	5	0	3	3	0	3	39.13275927	-109.0270552	4325	NGVD 29
09085000	ROARING FORK RIVER AT GLENWOOD SPRINGS, CO.	Active	1906	2018	1401000410	Outlet Roaring Fork River	Colorado	1	2	0	3	4	0	4	39.54359252	-107.3294988	5720.73	NGVD 29
09152000	KANNAH CREEK NEAR WHITEWATER, CO.	Historic	1917	1982	1402000507	Kannah Creek-Gunnison River	Gunnison	1	4	0	2	4	1	5	38.96164843	-108.2303587	6084.498803	NAVD 88
09152500	GUNNISON RIVER NEAR GRAND JUNCTION, CO.	Active	1896	2018	1402000508	Outlet Gunnison River	Gunnison	0	5	0	2	1	1	4	38.98331587	-108.4506451	4631.37	NGVD 29
09146200	UNCOMPAHGRE RIVER NEAR RIDGWAY, CO.	Active	1958	2018	1402000602	Upper Uncompahgre River	Gunnison	1	0	0	2	5	2	4	38.18387868	-107.7458922	6877.58	NGVD 29
09115500	TOMICHI CREEK AT SARGENTS, CO	Active	1916	2018	1402000301	Headwaters Tomichi Creek	Gunnison	1	0	0	2	1	2	4	38.39502721	-106.4226255	8416	NGVD 29
09126000	CIMARRON RIVER NEAR CIMARRON, CO	Active	1954	2018	1402000209	Cimarron River	Gunnison	1	1	0	2	3	2	5	38.25819317	-107.5461112	8641.48	NGVD 29
09114500	GUNNISON RIVER NEAR GUNNISON, CO.	Active	1910	2018	1402000202	South Beaver Creek-Gunnison River	Gunnison	1	0	0	1	5	1	4	38.54193584	-106.9497667	7655	NGVD 29
09149500	UNCOMPAHGRE RIVER AT DELTA, CO.	Active	1938	2018	1402000606	Lower Uncompahgre River	Gunnison	0	0	0	1	4	1	3	38.74194352	-108.0804178	4926.49	NGVD 29
09147500	UNCOMPAHGRE RIVER AT COLONA, CO.	Active	1912	2018	1402000603	Middle Uncompahgre River	Gunnison	0	0	0	2	3	0	2	38.33143299	-107.7792199	6320	NGVD 29
06617500	ILLINOIS CREEK NEAR RAND, CO.	Active	1931	2018	1018000104	Illinois River	North Platte	1	0	1	4	3	1	5	40.46282797	-106.1766898	8550.93	NGVD 29
06614800	MICHIGAN RIVER NEAR CAMERON PASS, CO	Active	1973	2018	1018000105	Michigan River	North Platte	1	0	0	4	3	1	4	40.49609395	-105.8650121	10390	NGVD 29
06620000	NORTH PLATTE RIVER NEAR NORTHGATE, CO	Active	1904	2018	1018000201	Douglas Creek-North Platte River	North Platte	0	0	0	2	2	0	2	40.93663819	-106.3391949	7810.39	NGVD 29
08245000	CONEJOS RIVER BELOW PLATORO RESERVOIR, CO.	Active	1952	2018	1301000501	Headwaters Conejos River	Rio Grande	1	0	0	3	5	2	4	37.35491208	-106.544228	9868.357416	NAVD 88
08219500	SOUTH FORK RIO GRANDE AT SOUTH FORK, CO.	Active	1910	2018	1301000111	South Fork Rio Grande	Rio Grande	1	0	0	3	5	2	4	37.65955327	-106.6491069	8224.966558	NAVD 88
08220500	PINOS CREEK NEAR DEL NORTE, CO.	Active	1919	2018	1301000201	Pinos Creek	Rio Grande	0	0	0	2	2	1	3	37.59096643	-106.4498324	8487.342445	NAVD 88
08217500	RIO GRANDE AT WAGON WHEEL GAP, CO	Active	1951	2018	1301000110	Shallow Creek-Rio Grande	Rio Grande	0	0	0	3	4	1	3	37.7664133	-106.8306458	8430	NGVD 29
06744000	BIG THOMPSON RIVER AT MOUTH, NEAR LA SALLE, CO.	Active	1914	2018	1019000606	Outlet Big Thompson River	South Platte	0	0	1	2	5	1	4	40.35064927	-104.7836473	4689.01882	NAVD 88
06725500	MIDDLE BOULDER CREEK AT NEDERLAND, CO.	Active	1907	2018	1019000504	Headwaters Boulder Creek	South Platte	1	0	1	3	3	2	5	39.96165477	-105.5044409	8182.677684	NAVD 88
06733000	BIG THOMPSON RIVER AT ESTES PARK, CO.	Active	1946	2018	1019000602	Headwaters Big Thompson River	South Platte	0	0	0	3	3	1	3	40.37831687	-105.513887	7492.5	NGVD 29
06724000	ST. VRAIN CREEK AT LYONS, CO.	Active	1895	2018	1019000507	Boulder Creek-Saint Vrain Creek	South Platte	0	0	1	2	4	0	3	40.22069988	-105.2634822	5309.949029	NAVD 88
06754000	SOUTH PLATTE RIVER NEAR KERSEY, CO	Active	1901	2018	1019000306	Little Dry Creek-South Platte River	South Platte	0	0	1	2	2	0	3	40.41250082	-104.5631794	4578.02	NGVD 29
06714000	SOUTH PLATTE RIVER AT DENVER	Active	1895	2018	1019000303	Cherry Creek-South Platte River	South Platte	0	0	1	1	4	0	3	39.75944924	-105.0039926	5157.64	NGVD 29
06707500	SOUTH PLATTE RIVER AT SOUTH PLATTE	Active	1896	2018	1019000207	Chatfield Lake-South Platte River	South Platte	0	0	1	2	5	0	3	39.40886382	-105.1698698	6090.537038	NAVD 88
06764000	SOUTH PLATTE RIVER AT JULESBURG, CO	Historic	1902	2017	1019001801	Hartley Draw-South Platte River	South Platte	0	0	2	2	0	0	2	40.97499465	-102.2518551	3449.8	NGVD 29
09346000	NAVAJO RIVER AT EDITH, CO.	Historic	1912	1996	1408010106	Navajo River	Southwest	1	2	1	3	3	1	6	37.00278742	-106.9075374	7033	NGVD 29
09172500	SAN MIGUEL RIVER NEAR PLACERVILLE, CO	Active	1910	2018	1403000303	Beaver Creek-San Miguel River	Southwest	1	1	0	3	3	1	5	38.03070183	-108.1102916	7100	NGVD 29
09357500	ANIMAS RIVER AT HOWARDSVILLE, CO	Active	1935	2018	1408010401	Headwaters Animas River	Southwest	1	0	0	3	3	2	4	37.832915	-107.5995623	9628.987458	NAVD 88
09349800	PIEDRA RIVER NEAR ARBOLES, CO.	Active	1962	2018	1408010205	Lower Piedra River	Southwest	0	1	0	2	5	1	4	37.08833574	-107.3978239	6147.52	NGVD 29
09346400	SAN JUAN RIVER NEAR CARRACAS, CO.	Active	1961	2018	1408010108	San Juan River-Navajo Reservoir	Southwest	1	0	0	2	5	0	3	37.01362025	-107.3122644	6090	NGVD 29
09354500	LOS PINOS RIVER AT LA BOCA, CO.	Active	1951	2018	1408010115	Lower Los Pinos River	Southwest	0	2	0	2	0	0	2	37.00944831	-107.5995033	6143.58	NGVD 29
09166500	DOLORES RIVER AT DOLORES, CO.	Active	1895	2018	1403000203	McPhee Reservoir-Dolores River	Southwest	0	2	0	2	5	0	3	37.47248898	-108.4975905	6940	NGVD 29
09371000	MANCOS RIVER NEAR TOWAOC, CO.	Active	1921	2018	1408010703	Lower Mancos River	Southwest	0	3	0	0	0	0	1	37.02749206	-108.7414822	5055.98	NGVD 29
09363500	ANIMAS RIVER NEAR CEDAR HILL, NM	Active	1933	2018	1408010410	City of Farmington-Animas River	Southwest	0	0	0	0	3	0	1	37.0365686	-107.8753333	5960	NGVD 29
09239500	YAMPA RIVER AT STEAMBOAT SPRINGS, CO	Active	1904	2018	1405000104	Oak Creek-Yampa River	Yampa/White	1	2	0	2	4	2	5	40.4829852	-106.8324312	6695.47	NGVD 29
09241000	ELK RIVER AT CLARK, CO.	Historic	1910	2003	1405000102	Headwaters Elk River	Yampa/White	1	0	0	1	3	2	4	40.71747221	-106.9158841	7267.75	NGVD 29
09304800	WHITE RIVER BELOW MEEKER, CO	Active	1961	2018	1405000504	Strawberry Creek-White River	Yampa/White	1	3	0	1	2	1	5	40.02258198	-108.1199471	5900	NGVD 29
09260050	YAMPA RIVER AT DEERLODGE PARK, CO	Active	1982	2018	1405000206	Hells Canyon-Yampa River	Yampa/White	0	4	1	2	2	1	5	40.45163395	-108.5251015	5600	NGVD 29
09245000	ELKHEAD CREEK NEAR ELKHEAD, CO.	Historic	1953	1996	1405000106	Elkhead Creek	Yampa/White	1	2	1	1	2	1	6	40.66969321	-107.2850596	6845	NGVD 29
09251000	YAMPA RIVER NEAR MAYBELL, CO	Active	1916	2018	1405000204	Deception Creek-Yampa River	Yampa/White	0	4	1	1	3	1	5	40.50274637	-108.0334154	5900.23	NGVD 29
09260000	LITTLE SNAKE RIVER NEAR LILY, CO	Active	1921	2018	1405000311	Outlet Little Snake River	Yampa/White	0	4	0	1	0	1	3	40.54901612	-108.4243227	5685	NGVD 29
09306500	WHITE RIVER NEAR WATSON, UTAH	Historic	1923	2018	1405000707	Asphalt Wash-White River	Yampa/White	0	0	0	0	0	0	0	39.97885572	-109.1787275	4946.78	NGVD 29

Appendix C: Flow Ecology Matrix

Appendix C: Flow Ecology Metrics

Macrocategory	Flow Need	Targets	Indicator species	How does the flow need relate to the target?	Calculation(s):	Risk Classes
Native coldwater fishes	base flows	Trout (*Greenback Cutthroat Trout, Colorado River Cutthroat Trout, Rio Grande Cutthroat Trout*)	Colorado River Cutthroat	Later summer flows are a critical "pinch point" for trout.* "Headwaters" & "transitional" zones**	$\frac{(Mean\ August\ Qscenario\ +\ Mean\ September\ Qscenario) \div}{Mean\ annual\ Qbaseline} * 100$ Q=flow (cubic feet per second [cfs])	• <10 percent: Red node color. Low flows are inadequate to support trout (very high flow-ecology risk) • 10 to 15 percent: Orange node color. Low flows have potential to make trout viability sporadic (high flow-ecology risk) • 16 to 25 percent: Yellow node color. Low flows may severely limit trout stock every few years (moderate flow-ecology risk) • 26 to 55 percent: Blue node color. Low flows may occasionally limit trout numbers (minimal flow-ecology risk) • >55 percent: Green node color. Low flows may very seldom limit trout (low flow-ecology risk)
Notes	*"Mean Annual $Q_{natural}$" is the average monthly flow, i.e., sum of all monthly flows for the year divided by 12.* *For "current" should be each of the managed and future natural scenarios; Use "historical_natural" for "natural"* **without flow modifications* ***will need to be adjusted for Front Range (or may not apply)*					
References	Tennant, 1976; Binns and Eiserman, 1979; Coleman and Fausch, 2007; Wilding and Poff, 2008; Sanderson et al., 2012a; Sanderson et al., 2012b					

Wetlands/ plant communities/ riparian	Peak/flood flows	Cottonwood recruitment (significant riparian wetland communities, rare aquatic-dependent plants, rare plant communities, national wetlands inventory, etc)	Cottonwood	Peak/flood flows are essential for cottonwood recruitment.	Calculate % alteration of peak flow: (Qscenario – Qnatural)/Qnatural	• Flow alteration of 30 to 100 percent was assigned a red node color representing very high flow-ecology risk • Flow alteration of 18 to 30 percent was assigned an orange node color representing high flow-ecology risk • Flow alteration of 7 to 18 percent was assigned a yellow node color representing moderate flow-ecology risk • Flow alteration of 0 to 7 percent was assigned a green node color representing low flow-ecology risk
Notes	Use only top 30% of years based on total Mean Annual Flow. Apply only below 9500 ft elevatoin. "Q" in above equation is average flow in Apr+May+June. (for peak flows) Thresholds for risk classes are based on probability of recruitment (see Sanderson et al. 2012, p.2-11. (Appendix I, Riparian Vegetation Methods) *Will vary based as:* • *If flow alteration is >0% (i.e. flow augmentation) then cottonwood abundance = 100%* • *If flow alteration is ≤0% then %abundance = 1.038 x %flow alteration + 1.005.*					
References	Merritt and Cooper, 2000; Merritt and Poff, 2010; Sanderson et al., 2012a					

Appendix C: Flow Ecology Metrics

Macrocategory	Flow Need	Targets	Indicator species	How does the flow need relate to the target?	Calculation(s):	Risk Classes
Warmwater fishes	Peak flows and base flows	Warmwater fishes (Bonytail chub, Colorado Pikeminnow, Humpback chub, razorback sucker, bluehead sucker, flannelmouth sucker, roundtail chub, etc.)	Razorback sucker	Minimum flows are essential for warmwater fish. Apply to nodes in West Slope transitional and West Slope warm water.	Calculate max sucker biomass under both natural and other scenarios as: • % max biomass = 0.125*Qsept^0.3021 Percent reduction in biomass is calculated as: • Reduction in biomass = (baseline - scenario)/baseline*100	• 50 to 100 percent reduction in potential biomass – nodes were assigned a red color (very high flow-ecology risk) • 25 to 50 percent reduction in potential biomass – nodes were assigned an orange color (high flow-ecology risk) • 10 to 25 percent reduction in potential biomass – nodes were assigned a yellow color (moderate flow-ecology risk) • <10 percent reduction in potential biomass – nodes were assigned a green color (low flow-ecology risk)
Notes	*Modified Sanderson et al. 2012; '30-day minimum flow' is a running mean calculated over the summer-autumn flow period (July 1 to November 30) for each year, then averaged over the study period. Biomass is estimated for natural conditions and current flow conditions.* Apply only below 7000' elevation in West Slope and in Rio Grande.					
References	Bestgen et al., 2017; Sanderson et al., 2012a, 2012b; Anderson and Stewart, 2007; Anderson, 2010; Wilding and Poff, 2008; Bezzerides and Bestgen, 2002					

Trout & Warmwater fish peak flows	Peak flows	River ecosystems (hydrology)		Peak flow is essential for mobilizing fine sediment to maintain spawning beds. Apply at all nodes.	Calculate % alteration of peak flow (Qaltered – Qbaseline)/Qbaseline. Use top 50% of years, based on total Mean annual flow (note that this differs from "cottonwood recruitement" metric. "Q" is average flow in Apr+May+Jun.	
Notes	*Greater degree of alteration = greater risk.* *Will be especially important in showing the shift in the transition zone between warm and cold water*					
References	Reiser et al., 1990 (comprehensive discussion of the need for flushing flows)					

Mean annual flow (general hydrologic metric)		River function/ structure (ecosystem health/ hydrology)		Total flow constrains overall ability to meet flow needs.	Calculate % departure between all scenarios and natural. Total flow for the water year, Oct 1-Sept 30.	
Notes	*Basic hydrologic need to support stream ecology.*					

Appendix C: Flow Ecology Metrics

Macrocategory	Flow Need	Targets	Indicator species	How does the flow need relate to the target?	Calculation(s):	Risk Classes
Winter flow (general hydrologic metric)		River function/ structure (ecosystem health/ hydrology)		Excessively low winter flow can limit over-wintering of species.	Calculate mean flows as avg (Dec, Jan, Feb). Calculate % departure between each scenario vs. historic natural.	
Notes	*Basic hydrologic need to support stream ecology.*					

Late-summer flows (general hydrologic metric)		River function/ structure (ecosystem health/ hydrology)		Excessively low late summer flows can hinder both trout and native fish, and can enhance non-native fish	Calculate mean flows as avg (Aug, Sep). Calculate % departure between each scenarios vs. historic natural.	
Notes	*Basic hydrologic need to support stream ecology.*					

Fishing (river)	Base flows, lower flows	Stocked/sports fishing		Can be calculated on regulated systems	Calculate % departure between all scenarios and natural. Total flow for the water year, Oct 1-Sept 30.	
Notes	*Similar to cold water fishes, but emphasis in on regulated systems and the low flows for meeting fish needs for recreation.*					
References	Tennant, 1976; Binns and Eiserman, 1979; Coleman and Fausch, 2007; Wilding and Poff, 2008; Sanderson et al., 2012a; Sanderson et al., 2012b					

Boating (river)	Peak and high flows	Whitewater kayaking and rafting	RICDs		*use RICDS for this layer, similar to ISFs – and point users to the hydrologic metrics to further inform recreation scenario planning	
Notes	*Boatable days needs to be a daily time-step. SWSI is monthly. Best practice is to simply use this tool to determine if RICDs will be met*					
References	Fey and Stafford, 2012.; Sanderson et al., 2012a					

ISFs	Base flows/ minimum flow reqs.	Ecosystem and fish/aquatic needs	ISFs		Will simply be an overlay of ISF needs.	
Notes						

Appendix C: Flow Ecology Metrics

Macrocategory	Flow Need	Targets	Indicator species	How does the flow need relate to the target?	Calculation(s):	Risk Classes
Plains fishes	base flows, especially late summer	Plains fishes (darters, minnows, sunfish)		late-summer baseflow metric	Calculate mean flows as avg (Aug, Sep). Calculate % departure between each scenarios vs. natural.	• Mean July/August flow departure from baseline < 10% = low risk. • Mean July/August flow departure from baseline < 25% = moderate risk. • Mean July/August flow departure from baseline 25-50% = high risk. • Mean July/August flow departure from baseline > 50% = very high risk.
Notes	*Based on conversations with CSU and other academics. Applied only below 5500 ft east of the continental divide.*					
References	Bestgen et al., 2017.					

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Analysis and Technical Update to the Colorado Water Plan

Technical Memorandum

Prepared for:

Colorado Water Conservation Board

Project Title:

Identified Projects and Processes Dataset Development

Date: September 18, 2019

Prepared by: Open Water Foundation & Wilson Water Group

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Executive Summary

The State's planning efforts, including SWSI 2010 and Basin Implementation Plans, have led to the initial development and subsequent revision of "Identified Projects and Processes" (IPP) datasets for each Basin Roundtable. These datasets reflect potential projects and processes identified by stakeholders in each basin that may be developed in the future. Due to the complexity of studies, variation by basin and number of entities involved, IPP data across basins are inconsistent in content and format. The Technical Update is reviewing and formatting IPP data to ensure that useful data products can be created and analyses can be performed consistently.

The following goals were identified in developing a consistent method for representing and using IPP datasets:

- Review existing IPP datasets from each Basin Roundtable
- Develop standard data fields that capture key IPP parameters
- Convert Basin Roundtable IPP datasets to standard format
- Create basic data visualizations (i.e. web-enabled maps and graphics) to display IPP data

IPP DATASET CONTENT STANDARDS

After a review of each Basin Roundtable's IPP dataset, the principal recommendation for developing a standard IPP dataset for the Technical Update effort was for the datasets to exist in a flat Excel file format and implement standard dataset fields. The term "flat" means that each line (row) of data contains one record corresponding to an IPP, with columns representing data fields. Excel is a common tool and the flat format can be maintained relatively easily by many users. Additionally, Excel can be integrated with multiple software tools and geospatial programs. Standard IPP dataset fields and formatting standards are listed below.

Table 1. Standard IPP dataset fields.

Field Name	Description	Section for Detailed Discussion
Project_ID	Unique project identifier in the format of Basin-Year-Number (e.g. ARK-2015-0001) that also allows for cross-reference between datasets and use by software tools.	4.1
Project_Name	Project name only.	4.1
Project_Description	Narrative content that explains the project in greater detail.	4.2
Project_Keywords	Indicator of one or more types such as storage, ATM.	4.2
Status	Implementation phase of the project; standard terms such as Completed, Planned, Implementation Ongoing.	4.3
Lead_Proponent	Main entity proposing/leading IPP project.	4.4
Lead_Contact	Name/organization of main entity that can be contacted regarding the project and their affiliation.	4.4
Municipal_Ind_Need	% of project dedicated to municipal/industrial need.	4.5
Agricultural_Need	% of project dedicated to agricultural need.	4.5

Field Name	Description	Section for Detailed Discussion
Envr_Rec_Need	% of project dedicated to environmental/recreational need.	4.5
Admin_Need	% of project dedicated to administrative need.	4.5
Latitude	Latitude of the project's general point location in decimal degrees.	4.6
Longitude	Longitude of the project's general point location in decimal degrees.	4.6
Lat_Long_Flag	Indication of how Latitude and Longitude were determined.	4.6
County	County where project is located.	4.6
Water_District	Water District where project is located.	4.6
Estimated_Yield	Estimated amount of water the project yields (average annual volume) or amount of water kept in a stream (average flow rate), based on high-level modeling.	4.7
Yield_Units	Unit of measure for capacity; including acre-feet (AF) or cubic-feet-per-second (cfs).	4.7
Estimated_Capacity	Maximum amount of water the project stores, diverts, conveys, etc. For E&R projects, this could be linear miles of stream or area of watershed affected.	4.7
Capacity_Units	Unit of measure for capacity; including acre-feet (AF) or cubic-feet-per-second (cfs), stream length (miles), or area (acres).	4.7
Estimated_Cost	Total cost to implement the project including capital and operations and maintenance (O&M).	4.8

IPP DATASET PRODUCTS

Ultimately, two primary data products were developed through this effort: a consistent standard table reflecting the statewide IPP dataset and mapping products displaying the IPP datasets. As noted above, the original IPP datasets were inconsistent across each basin and many of the basins did not provide information that could be represented using the standard fields in Table 1. The consultant team relied on the meaning of the individual basin's IPP fields and engineering judgement to convert original IPP datasets over to the standard IPP format. As reflected in Table 2, several basins did not have data for all standard fields and those fields were left blank in the standard IPP dataset deliverable. Translation of the original data to normalized form was automated using table and spatial data processing commands of the CDSS TSTool software, to allow the process to be adjusted and repeated.

Table 2. Standard IPP data fields and presence of fields in final basin IPP datasets.

Data Field/Column	Arkansas	Colorado	Gunnison	North Platte	Rio Grande	South Platte / Metro	Southwest	Yampa / White
Project_ID	X	X	X	X	X	X	X	X
Project_Name	X	X	X	X	X	X	X	X
Project_Description	X		X	X			X	X
Project_Keywords								
Status	X	X	X				X	
Lead_Proponent	X	X	X		X	X	X	X
Lead_Contact	X		X	X		X	X	
Municipal_Ind_Need	X	X	X	X	X	X	X	X
Agricultural_Need	X	X	X	X	X		X	X
Envr_Rec_Need	X	X	X	X	X		X	X
Admin_Need					X			
Latitude	X	X	X	X	X	X	X	X
Longitude	X	X	X	X	X	X	X	X
County	X	X	X	X	X	X	X	X
Lat_Long_Flag								
Water_District	X	X	X	X	X	X	X	X
Estimated_Yield	X	X	X			X		
Yield_Units	X	X	X			X		
Estimated_Capacity	X					X		
Capacity_Units	X					X		
Estimated_Cost	X	X	X		X	X		

Section 1: Introduction

The State's planning efforts, including SWSI 2010 and Basin Implementation Plans, have led to the initial development and subsequent revision of "Identified Projects and Processes" (IPP) datasets for each Basin Roundtable. These datasets reflect potential projects and processes identified by stakeholders in each basin that may be developed in the future. IPP datasets for consumptive projects are typically lists of structural projects defined with varying levels of detail and may or may not include spatial data. IPP datasets for non-consumptive (i.e. environment and recreation or E&R) projects typically include a spatial component because those projects often involve stream reaches. These datasets have been updated and referenced during current and previous SWSI efforts, Basin Implementation Plans (BIPs), Colorado Water Plan (CWP) and other studies. This memorandum focuses on consumptive IPP projects, although ongoing coordination between Technical Update contractors can consider how best to integrate updated E&R data with IPP data in the future.

Due to the complexity of studies, variation by basin and number of entities involved, IPP data across basins are inconsistent in content and format. The Technical Update is reviewing and formatting IPP data to ensure that useful data products can be created and analyses can be performed consistently. In particular, it is desirable to establish consistency in data and stewardship of data, as well as to confirm the most current IPP datasets. Improvements in data format, content and handling can benefit later phases of the Technical Update, BIP updates and other State planning efforts.

The following goals were identified in developing a consistent method for representing and using IPP datasets:

- Review existing IPP datasets from each Basin Roundtable
- Develop standard data fields that capture key IPP parameters
- Convert Basin Roundtable IPP datasets to standard format
- Create basic data visualizations (i.e. web-enabled maps and graphics) to display IPP data

Additional recommendations regarding the maintenance of the IPP datasets during future Basin Implementation Plan updates; linking IPP datasets to other analyses/data products; and integrating IPP data into the larger Technical Update modeling efforts were discussed with CWCB during this effort. These recommendations, outlined in Appendix D, may be implemented in future Technical Update planning efforts, however were not implemented during this task.

Section 2: Review of Existing IPP Datasets

Each Basin Roundtable has created one or more electronic files of IPP data with various data formats and levels of detail. The current version of the files in each basin has most recently been updated by Basin Roundtable members or consultants working for the Roundtables. A request was made to each Basin Roundtable to provide the following data and information:

- Excel workbooks, spatial dataset (geodatabase, shapefile, etc.) and other electronic files. Machine-readable files were requested since derived files, such as PDFs and Word documents, are not conducive to software processing.
- Any supporting documentation describing the IPP data that is relevant and is not otherwise included in the data files, in particular “metadata” explaining the data files.
- Information about where the original data files are maintained and are available, for example Dropbox or Roundtable website.
- Short summary of the process used to create and edit the IPP dataset. For example:
    - indicate key stakeholders at the Roundtable and consultant level (e.g., Consultant X at firm Y, Roundtable members A, B, C)
    - process used to create/update/maintain the IPP dataset (e.g., Consultant X updated the Excel file based on input from Roundtable)
    - frequency that the dataset is updated and whether an edit history is known (e.g., BIP added new projects using X process, BIP used only projects from SWSI 2010)

All Basin Roundtables' IPP datasets exist in Excel format and some also have spatial data in Esri (ArcGIS) shapefile format. Table 3 shows the dataset files received from each basin.

Table 3. IPP dataset files received from each Basin Roundtable.

Basin	IPP Dataset Filename	Date Received	Dataset Available on Website?
Arkansas	2015 04 09 Arkansas River Basin Project Database GB update 6_13_15.xls	2017-09-12	Yes, but availability has changed over time
Colorado	Basinwide_Full_IPP_List_05_27_14.xlsx, Eagle_Region_Full_IPP_List.xlsx, Grand_Valley_Region_Full_IPP_List.xlsx, GrandCo_Full_IPP_List.xlsx, Interbasin_Reliance_Full_IPP_List_05_27_14.xlsx, MiddleCo_Region_Full_IPP_List.xlsx, Roaring_Fork_Region_Full_IPP_List.xlsx, State_Bridge_Region_Full_IPP_List.xlsx, SummitCo_Region_Full_IPP.xlsx	2017-09-26	No
Gunnison	GBIP_Simplified_Project_List_4-17-15.xlsx; GBIP_IPP_GIS.zip	2017-09-24	No
North Platte	NPBIP_IPPLists.xlsx; NPBIP_IPP_GIS.zip	2017-09-21	No
Rio Grande	Updated Tables 8-10_Project Sheet Summaries_09-11-2017.xlsx	2017-09-11	No
South Platte / Metro	Gap Analysis SPMetro HDR Phase 2.xlsx	2017-09-12	Yes, but in PDF format and incomplete
Southwest	SWBRT Draft IPP List Clean copy.xlsx; IPPs.zip	2017-09-22	Yes, but in PDF format
Yampa / White	BIP_IPPs.xlsx, IPP_Point.shp, IPP_Reach.shp	2017-10-03	No

Section 3: IPP Dataset Format

The consultant team recommended the IPP datasets exist in a flat Excel file format. The term "flat" means that each line (row) of data contains one record corresponding to an IPP, with columns representing data fields. This recommendation is made for the following reasons:

- Excel table/worksheet can be easily reviewed, filtered, edited and processed into other forms
- Excel provides:
  - commenting ability
  - color-coding and other formatting
  - support in various software
- A table representation can be represented in various forms, including:
  - Excel
  - comma-separated-value (CSV)
  - database table

    - spatial data layer attribute table
    - web page table
- Allows public distribution in machine-readable electronic format, such as:
    - Excel file on a Roundtable website
    - dataset as part of a GitHub repository with version control (or other cloud platform that provides version tracking)
    - dataset on the Colorado Information Marketplace (CIM, data.colorado.gov)
    - CDSS Map Viewer
    - online electronic documents on CWCB website
    - distribution as email attachment
    - sharing on Google Drive, Dropbox, etc.
- Excel file format facilitates versioning the IPP list, as follows:
    - a worksheet (tab) can be added to the IPP dataset workbook to indicate "Date", "Who" and "Comment" for tracking edits to the file
    - the filename can include a date as YYYYMMDD or similar to clearly indicate versions of the IPP dataset
    - versioning software such as GitHub can be used, which removes the need to add timestamp to filename and allows milestone versions to be "tagged" for retrieval

It is recognized that some IPPs could benefit from a more complex data representation, in particular when one-to-many relationships exist or there is a need to represent spatial data. For example, an IPP may involve multiple stream reaches or have multiple beneficial uses. In this case, the data can be represented by creating additional worksheets within the main dataset file that split one-to-many data into one-to-one data without making the main dataset too convoluted or difficult to understand and interpret. Using a spatial data format requires access to and skill with geographic information system (GIS) software, which may be a barrier for many.

The historical evidence is that it has been difficult to acquire basic consistent IPP data. Therefore, the approach was taken to focus on the flat Excel table representation of IPP data while allowing the option of more complex formats should they be appropriate. Future management of the IPP dataset, or integration into modeling platforms, may require a more complex data format. For this effort however, the flat Excel format is sufficient to handle the basic IPP information requested by the CWCB.

Section 4: Standard IPP Dataset Fields

This section discusses the standard IPP dataset fields used in the development of the IPP dataset. Many of the basin IPP datasets already contain some of these fields and examples from each basin are provided where appropriate. Required fields are necessary to retain basic dataset integrity and support identification and communication. Optional fields are described in the context of how they will be used, but it is recognized that optional data may be difficult to obtain, or perhaps is only available after an IPP has reached a certain phase. Some of the fields impose a new data requirement on IPP data beyond what has been asked historically. For example, each IPP needs to include a spatial coordinate that can be used to create a map representing all IPPs. This is a fundamental data element that allows basic visualization of the number and spatial distribution of IPPs. The following data fields (Table 4) are discussed in subsequent sections.

Note that an initial set of potential IPP dataset fields were provided to CWCB for review, a portion of which were intended to capture specific project components necessary for future modeling of the IPP (e.g. project diversion location, project delivery point). As many of the IPP datasets provided by the Basin Roundtables did not contain this information and the fields would be difficult to make consistent, these data fields were not incorporated into the final dataset fields.

Table 4. IPP dataset fields.

Dataset Field	Description and Use	Section for Detailed Discussion
Project_ID	Unique project identifier in the format of Basin-Year-Number (e.g. ARK-2015-0001) that also allows for cross-reference between datasets and use by software tools.	4.1
Project_Name	Project name only.	4.1
Project_Description	Narrative content that explains the project in greater detail.	4.2
Project_Keywords	Indicator of one or more types such as storage, ATM.	4.2
Status	Implementation phase of the project; standard terms such as Completed, Planned, Implementation Ongoing.	4.3
Lead_Proponent	Main entity proposing/leading IPP project.	4.4
Lead_Contact	Name/organization of main entity that can be contacted regarding the project and their affiliation.	4.4
Municipal_Ind_Need	% of project dedicated to municipal/industrial need.	4.5
Agricultural_Need	% of project dedicated to agricultural need.	4.5
Envr_Rec_Need	% of project dedicated to environmental/recreational need.	4.5
Admin_Need	% of project dedicated to administrative need.	4.5
Latitude	Latitude of the project’s general point location in decimal degrees.	4.6
Longitude	Longitude of the project’s general point location in decimal degrees.	4.6
Lat_Long_Flag	Indication of how Latitude and Longitude were determined.	4.6
County	County where project is located.	4.6
Water_District	Water District where project is located.	4.6
Estimated_Yield	Estimated amount of water the project yields (average annual volume) or amount of water kept in a stream (average flow rate), based on high-level modeling.	4.7
Yield_Units	Unit of measure for estimated yield; including acre-feet (AF) or cubic-feet-per-second (cfs).	4.7
Estimated_Capacity	Maximum amount of water the project stores, diverts, conveys, etc. For E&R projects, this could be linear miles of stream or area of watershed affected.	4.7
Capacity_Units	Unit of measure for capacity; including acre-feet (AF) or cubic-feet-per-second (cfs), stream length (miles), or area (acres).	4.7
Estimated_Cost	Total cost to implement the project including capital and operations and maintenance (O&M).	4.8

4.1: PROJECT IDENTIFIERS

The use of a project identifier allows each IPP project to be uniquely identified and linked to other datasets as appropriate. Unique identifiers also minimize confusion during communication and tracking and make it easier to keep track of total number of projects in a basin. It is critical that project identifiers are added to source data because not doing so risks renumbering of projects as data are processed. A standard naming convention does not currently exist for IPP projects across basins; Table 5 shows the different formats used for each basin, if present.

Table 5. Current naming conventions for project IDs used in basin IPP datasets.

Basin	Example Naming Convention for IPP Project ID	Comment
Arkansas	ARK-2015-0001	Clear; would need to describe the significance of the year such as year when first articulated as a project.
Colorado	No ID	
Gunnison	1	Sequential, but may just be the Excel row number
North Platte	1	Sequential, but may just be the Excel row number
Rio Grande	1	Sequential, but may just be the Excel row number
South Platte / Metro	ClearCreek_UIPP_FIB	Appears to reflect county/ municipality and SWSI 2010 IPP type.
Southwest	1-SJ, 1-DM (Numbered by sub-basin)	Southwest Basin is a collection of other basins so “SJ” indicates San Juan. If this is required, perhaps use “SW-SJ” at the front.
Yampa / White	1	Sequential, but may just be the Excel row number

Other examples of project identifiers include E&R projects in the South Platte BIP, which used identifiers that varied depending on the source of the basin (e.g. CWCB instream flow case number). If a third party identifier is used, then it is helpful to know the organization or scope of that identifier, such as “CWCB-theidentifier”, or track in separate columns.

The following summarizes the methodology used to develop the fields used to help identify projects.

1. “Project_ID” is a required field:
   a. Assign a unique identifier to each IPP as they are added to the IPP dataset.
   b. The format of the identifier is set to a Basin-Year-Number, for example “ARK-2015-0001”:
      i. The basin abbreviation is ARK, CO, GUN, MET, NP, RG, SP, SW, YW.
      ii. The year is the 4-digit year when the IPP was added to the IPP list or originally identified in the BIP.
      iii. The project number is sequential and accommodates up to 9999 projects.

2. "**Project_Name**" is a required field:
   a. Name should be a short descriptive name, based on existing data.

4.2: PROJECT DESCRIPTION

The project description includes additional information to describe the project, such as a narrative that is longer than the name. There may be large variability in this data from one basin to another. The following summarizes the methodology used to develop the fields used to help describe and search for projects.

1. "**Project_Description**" is a required field:
   a. Short description of the project.
   b. As descriptions are revised in the future, consider common descriptors such as "storage", "transbasin diversion", "agricultural transfer", etc. to allow for filtering of datasets.
2. **"Project_Keywords"** is a required field:
   a. Include keywords used to indicate whether the project includes storage, ATM, etc. Keywords need to be relevant to CWCB and Basin Roundtable uses of the data. Although required in the dataset, the keywords were not populated during data review because of the wide variety of terminology that was previously used. "Project_Keywords" is a placeholder for future use.
   b. Consider future incorporation of type of document/file that describes the project (e.g., a planning document, URL).

4.3: PROJECT STATUS

An IPP project's status is an indication of how far along the project implementation may be (e.g. concept phase, planned and detailed with a start year for the project). This data field is present in some of the basin IPP datasets but standard terminology needs to be developed to maintain consistency across datasets. Table 6 shows the terminology used in each basin, if available.

Table 6. Project status information provided in basin IPP datasets.

Basin	Example Naming Conventions for Status	Comment
Arkansas	Concept, Planned, Implementation Ongoing, Completed, Obsolete	Consistent use of categories
Colorado	Conceptual idea, Under Study, Study in Progress, Beginning stages of design/permitting, Water court application filed, Diligence filed, Money not yet allocated, Needs to be brought into compliance, In development, In Progress, Status pending, Off-line, Deferred, Ongoing, Issued, In use, Underway, Trial Run completed, Feasibility Studies Completed, Completed, Decreed, Existing	Inconsistent use of categories; should be simplified
Gunnison	None	Status indicated by worksheet name ("Planned Projects", "Completed_Ongoing"); need to add within datasheet for each IPP

Basin	Example Naming Conventions for Status	Comment
North Platte	None	
Rio Grande	None	
South Platte / Metro	None	
Southwest	Investigating, Ongoing, Not Complete, Construction Completed	
Yampa / White	None	

The Arkansas River Basin provided a concise set of project status descriptors, therefore these were adopted for the standard IPP dataset. Note that IPPs listed as "Completed" or "Obsolete" may need to be removed from IPP datasets in the future, however "Completed" or "Obsolete" projects will remain in the standard IPP dataset for tracking purposes. The following summarizes the dataset fields used to help describe project status.

1. "**Status**" is a required field:
    a. Apply a standard set of terminology to include: Concept, Planned, Implementation Ongoing, Completed, Obsolete.
    b. For basins with a more robust list of status terminology, use judgment to convert them over to the standard terminology. For example, the term "Existing" would be converted over to "Completed".

4.4: PROJECT PROPONENTS AND CONTACT

Documenting and tracking project proponents and contacts over the life of a project is critical, particularly as questions arise regarding the project. Experience working with IPP data, however, has shown that it can be difficult to track who brought forth a project and who can answer questions about a project and its status. The people behind a project will vary depending on its phase and various processes that are occurring, and will inevitably change over time. The goal of the following project contact data fields is to capture the current proponent and contact and provide a standard field to revise the information as the contact information changes.

1. "**Lead_Proponent**" is a required field:
    a. Indicate the main entity that is the proponent or sponsor of the project.
    b. Many projects have multiple proponents; this field captures the lead or prime entity.
    c. Use of standard organization names would facilitate data management.
    d. Other contact information, such as phone or email address, was excluded because the contact will generally be someone that is known to the Roundtable and because this would require greater upkeep of the dataset.
2. "**Lead_Contact**" is a required field:
    a. Indicate a name of a person and their affiliated organization that can be contacted to provide information about the project.
    b. Use of standard organization names would facilitate data management.
    c. Other contact information, such as phone or email address, was excluded because the contact will generally be someone that is known to the Roundtable and because this would require greater upkeep of the dataset.

4.5: PROJECT NEED BASED ON CWP NEEDS

Project need refers to the general categories of needs as described in the CWP: Municipal & Industrial, Agricultural, and Environmental & Recreational. As some IPPs are processes (as opposed to projects), there is also an Administrative Need category. These are projects developed in conjunction with the Division of Water Resources or other state agencies that deal more with administration or operations as opposed to a specific project. Categorizing an IPP based on project type allows for a simple way to filter IPPs and can also be useful in mapping applications as a way to symbolize dataTable 7 indicates which basins have this data.

Table 7. Project need information provided in basin IPP datasets.

Basin	Example Naming Convention for Project Need	Comment
Arkansas	Municipal & Industrial; Agricultural; Environmental; Recreational	Each need is in its own column; an IPP that meets the need is indicated with an “X”
Colorado	Munic.; Irrig.; Dom; instream flows; nonconsumptive; recreational; consumptive; etc.	Needs are not separated into multiple columns. Format should be standardized; need is not clearly indicated but can be inferred from other data columns
Gunnison	M&I; AG; NC;	Needs are not separated into multiple columns. Format should be standardized
North Platte	None	Contains “CU Projects” and “NCNA_ER Projects” worksheets but each IPP is not clearly labeled as such
Rio Grande	Ag; M&I; Env/Rec	Each need is in its own column; an IPP that meets the need is indicated with an “X”
South Platte / Metro	None	Only M&I IPPs have been provided; uses categories such as Agricultural Transfer or Grow into Existing Supply
Southwest	NC; C; B (Both); “Need Addressed” column may contain Agriculture, Municipal, Aquatic habitat, Fisheries, etc.	Needs are not separated into multiple columns. Format should be standardized
Yampa / White	None	Contains “Consumptive” and “Nonconsumptive” worksheets but each IPP is not clearly labeled as such

Many IPPs will meet a variety of needs (termed multi-use projects), therefore it is necessary to develop the field in such a way that documents the multiple needs and, as requested by CWCB, provides an estimate of the project dedicated to meet that need. For example, a project could be constructed to provide primarily municipal supplies, but also have a small component to meet agricultural or E&R needs. As such, the amount of each type of need met by the IPP is defined as a percentage, totaling up to 100 percent across the four need types. Based on the information provided in the original IPP datasets and the needs defined by the Colorado Water Plan, the following data fields were developed:

1. Project need types is a required field and is formatted as follows:

a. Project need fields include:
    i. "Municipal_Ind_Need"
    ii. "Agricultural_Need"
    iii. "Envr_Rec_Need"
    iv. "Admin_Need"
b. Project need fields will be filled in with the percentage of the IPP that meets this need type; the sum of need fields for each IPP must sum to 100%.
c. The need percentages will be auto-generated based on the number and type of needs met by each IPP in the original IPP datasets. These values will need to be revised by Basin Roundtable members.

4.6: SPATIAL DATA

Ideally, each IPP project provided by the Basin Roundtables has a general location, such as latitude and longitude coordinates of the project. Coordinate data is particularly useful in any mapping application. If this information was not provided or cannot be determined, more general location information can be used, such as county, water district or hydrologic unit code (HUC). However, what may seem like an easing-off of data requirements (county rather than coordinates) often results in more work later and limits usefulness of the data for spatial purposes. Therefore, a general location field is set as a required field in the standard IPP dataset. Table 8 shows the level of spatial data provided in each basin IPP dataset.

Table 8. Spatial data provided in basin IPP datasets.

Basin	Level of Spatial Data Provided	Comment
Arkansas	Latitude/Longitude coordinates, HUC, Water District, County	Coordinates are in the Excel file; no spatial files provided
Colorado	None; datasets split by "region"	
Gunnison	Points representing both consumptive and nonconsumptive IPPs; Water District	Data are in shapefiles and can be converted to Lat/Long
North Platte	Points and lines representing both consumptive and nonconsumptive IPPs	Data are in shapefiles and can be converted to Lat/Long
Rio Grande	Points representing IPPs	Data are in a .kmz file and Lat/Long can be extracted
South Platte / Metro	County	A map of IPPs summarized by county was included in the BIP but no shapefile exists
Southwest	Points and lines representing both consumptive and nonconsumptive IPPs; County	Data are in shapefiles and can be converted to Lat/Long
Yampa / White	Points and lines representing both consumptive and nonconsumptive IPPs	Data are in shapefiles and can be converted to Lat/Long

If a municipal/industrial or agricultural (i.e., consumptive) IPP did not have location information provided, the location was estimated for this effort. Refer to Appendix B for more information on how locations were estimated for mapping products. Additionally, the IPPs were also assigned to a county and water district to aid in future aggregation of results by the CWCB.

1. "**Latitude**" is a required field for the general point location for the IPP, generally corresponding to the water source, centroid of project components, or regional centroid (such as for county-level project):
    a. Units should be decimal degrees.
    b. Use a flag column if necessary to indicate how location was determined.
2. "**Longitude**" is a required field for the general point location for the IPP, generally corresponding to the water source, centroid of project components, or regional centroid (such as for county-level project):
    a. Units should be decimal degrees.
    b. Use a flag column if necessary to indicate how location was determined.
3. "**Lat_Long_Flag**" is a required field:
    a. Indicates the method by which spatial coordinates were determined.
    b. See **Appendix B** for details on methodology and values used.
4. "**County**" is a required field:
    a. Reflects county name.
    b. Assigned using a spatial analysis based on the Latitude/Longitude.
5. "**Water District**" is a required field:
    a. Reflects standard DWR Water District number.
    b. Assigned using a spatial analysis based on the Latitude/Longitude.

4.7: PROJECT YIELD

If available, documenting the estimated average annual yield of an IPP project is very helpful in basin-wide planning efforts. A project's yield is uncertain given potential competition for the same water, hydrologic variability, and potential climate change impacts; however, a high-level yield estimate is useful to understand the amount of water the project may be able to supply and can be used to estimate a project's unit cost of water. An initial yield estimate may be omitted but should be provided once sufficient evaluation has occurred, including, for example, modeling in support of a BIP. Most municipal/industrial IPPs list yield in acre-feet; some projects, however, have yield estimates in other units. As such, it is necessary to have another field to distinguish yield units and to ensure that the yield field only contains numeric data (e.g., the "Yield" column's values should be something like "200" and not "200 AF"). This field is somewhat contingent upon the project's status: IPPs that are only in the concept phase are less likely to have information on yield. Table 9 provides naming conventions for yield and the percent of IPPs that contain yield data by basin.

Table 9. Yield information provided in basin IPP datasets.

Basin	Example Naming Convention for Yield	Percent of IPPs with Yield Data	Comment
Arkansas	36960	7	Consistent format used
Colorado	1,680 AF	17	Format should be standardized
Gunnison	146; 1,000-2,000 per yr.; 200-300	13	Format should be standardized
North Platte	None	0	
Rio Grande	None	0	

Basin	Example Naming Convention for Yield	Percent of IPPs with Yield Data	Comment
South Platte / Metro	2081	70	Consistent format used
Southwest	None	0	
Yampa / White	None	0	

Currently, yield is focused on consumptive IPPs. Environmental and recreational IPPs tend to consider "yield" in terms of cubic feet per second (cfs) remaining in stream and this amount can vary seasonally. The Environment and Recreation Methodology Development memo, part of the Technical Update, recommends that additional data fields related to flow should be added to the Environment and Recreation Database (E&Rdb), a database that houses E&R projects. These fields will detail if the project is flow-based or has a flow component and if flows have been identified and/or quantified. The memo states that the fields will be populated where possible as part of the Technical Update but that it is likely that the majority of the information will be added in the next round of BIPs.

It should be noted that yield is different than a project's capacity, particularly for storage projects. As one of the stated goals of the Colorado Water Plan is to increase storage by 400,000 acre-feet by 2050, capacity is also an important piece of information to capture. Similar to the fields designed to document project yield, a field is included to capture a project's capacity and the units associated with that capacity value. This may be particularly useful in the future for E&R projects that may impact an area or stream length, but do not necessarily have a water yield. As such, the capacity fields can be used to document these impact areas.

1. "**Estimated_Yield**" is a required field to indicate average annual yield, in particular for consumptive uses:
    a. Values should consist only of numbers and not contain ranges of numbers.
    b. Yield values should be based on the water supply analyses and not just reflect the full capacity of a project.
2. "**Yield_Units**" is a required field:
    a. Reflects a standard unit of measure, including acre-feet (AF), cubic feet per second (CFS), million gallons (MG), million gallons per day (MGD).
3. "**Estimated_Capacity**" is a required field to indicate the maximum capacity of a project, or maximum impact area for E&R projects:
    a. Values should consist only of numbers and not contain ranges of numbers.
    b. Ideally based on high-level design or impact studies.
4. "**Capacity_Units**" is a required field:
    a. Reflects a standard unit of measure, including acre-feet (AF), cubic feet per second (CFS), million gallons (MG), million gallons per day (MGD), area (acreage), stream length (miles).

4.8: PROJECT COST

The cost of the IPP project should be estimated based on capital cost plus the cost of operation and maintenance (O&M). As with yield, this field is contingent upon the project's status in that IPPs that are only in the concept phase do not tend to have a cost estimate. Cost coupled with yield provides an indication of unit cost of water supply.

Table 10 provides the naming conventions for cost and the percent of IPPs that contain cost data by basin.

Table 10. Cost information provided in basin IPP datasets.

Basin	Example Convention for Cost	Percent of IPPs with Cost Data	Comment
Arkansas	$6.0M; $300K; 14500000	4	Format should be standardized
Colorado	$5000/AF; $200M	2	Format should be standardized
Gunnison	50,000,000; 125,000-205,000	28	Format should be standardized
North Platte	None	0	
Rio Grande	$19,500	50	Consistent format used
South Platte / Metro	261000000; $122,479,600	22	Format should be standardized
Southwest	None	0	
Yampa / White	None	0	

As part of the Technical Update, the Finance Methodologies Technical Memorandum describes the development of a Water Finance Tool that will allow planners of IPP projects to estimate the cost of a project using a uniform methodology so that all projects can be compared on an "apples to apples" basis. This tool has several modules for estimating a project's costs based on the type of project, including modules for reservoir construction, pipeline construction, stream restoration and irrigation ditch improvements, among others. It is anticipated that IPP project costs will be estimated or re-evaluated once the Water Finance Tool is available for use. However, the tool may only be applied to a subset of IPPs, in particular those that are well-defined. It is recommended that further coordination occur related to how the Water Finance Tool and the IPP database will integrate. The following summarizes the field used to capture IPP cost information.

1. "Estimated_Cost" is a required field:
    a. Reflect the total cost of the project, including the capital cost and O&M in total dollars. Do not convert total cost to millions or thousands.
    b. Values should consist only of numbers and not contain ranges of numbers.
    c. This field may not be able to be populated until the Water Finance Tool is released, or the tool may create parallel data that needs to be joined to the IPP list during data processing.
    d. In the future, definition for cost needs to be determined, such as normalized to a specific year, year of a study, etc.

Section 5: Uses of the IPP Dataset

The availability of the required data fields will support several uses of IPP datasets; the following summarizes the uses of this data as scoped under this effort. It is anticipated the standard IPP dataset will be used to develop information for future Colorado Water Plan updates and serve as one of the foundational pieces of data for the Data Dissemination task.

5.1: FILTERED LISTS

It will be possible to create filtered, customized datasets and provide as maps, Excel files, and other formats for use in analysis and visualizations. For example, the IPP dataset can be filtered by basin, project need, status, etc. Filtered datasets can be created as new derived datasets, or the full dataset can be made available and filtering can occur using tools, such as a website or desktop software tools. IPPs with limited data can be filtered out to remove “noise” or can be the focus of evaluation to understand the extent of incomplete data.

5.2: MAPS

The addition of general location coordinate data for each IPP allows for all IPPs to be easily located on maps. Then, a user interested in a particular basin or region can quickly determine the IPPs in that area and find more information. Another advantage of mapping IPPs is that IPPs can be symbolized in different ways. For example, IPPs could be color-coded based on project need (municipal, environmental, etc.), status, or whether the project includes an ATM component. The following standard set of maps (Figures 1 through 9) were developed for this effort as examples of map products; however the standard IPP dataset can support many other mapping products. In the examples “multi-purpose” uses the “Municipal_Ind_Need”, “Agricultural_Need”, “Envr_Rec_Need”, and “Admin_Need” dataset fields to categorize projects.

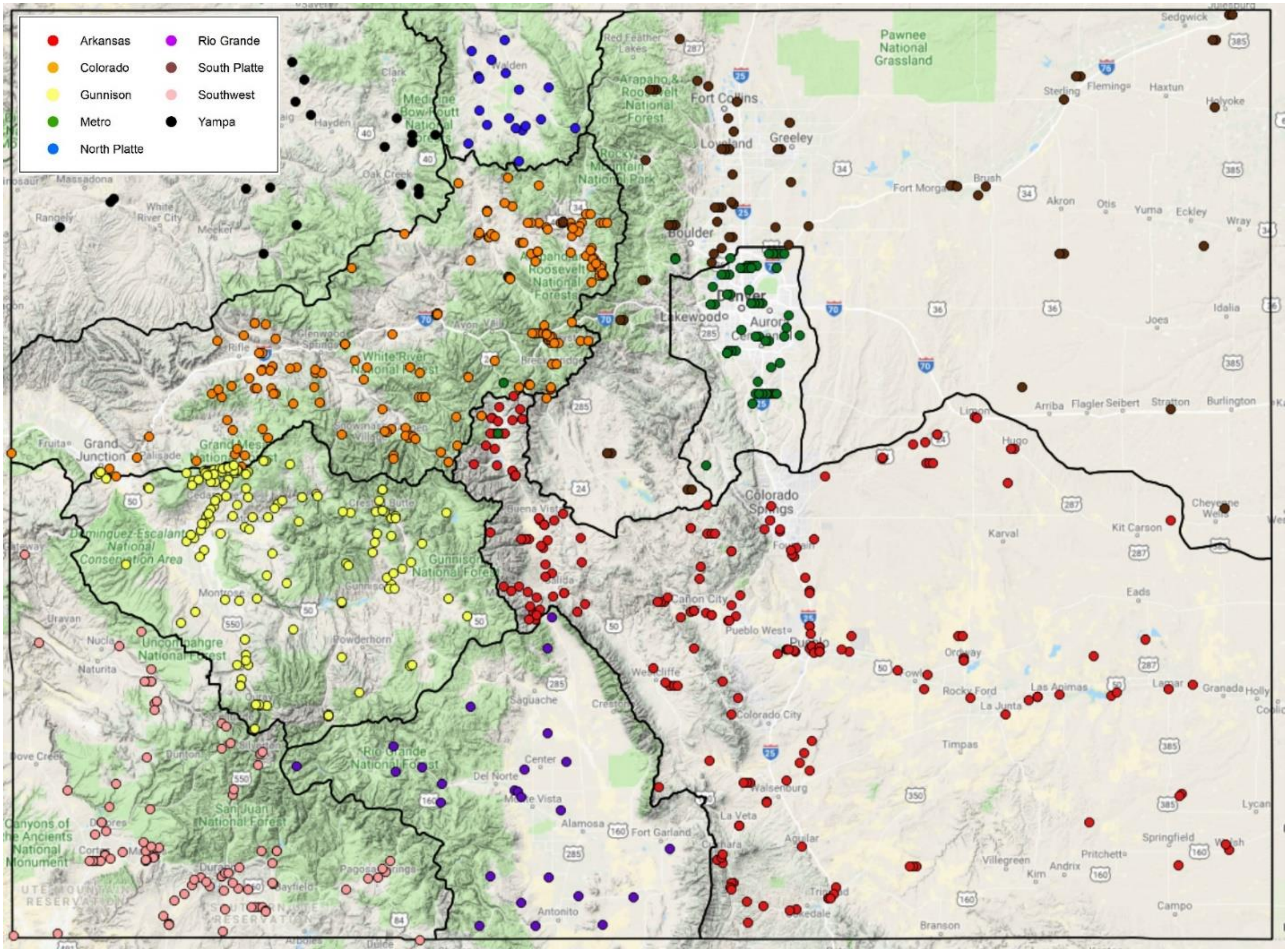


Figure 1 Statewide map of IPPs shown with basin boundaries

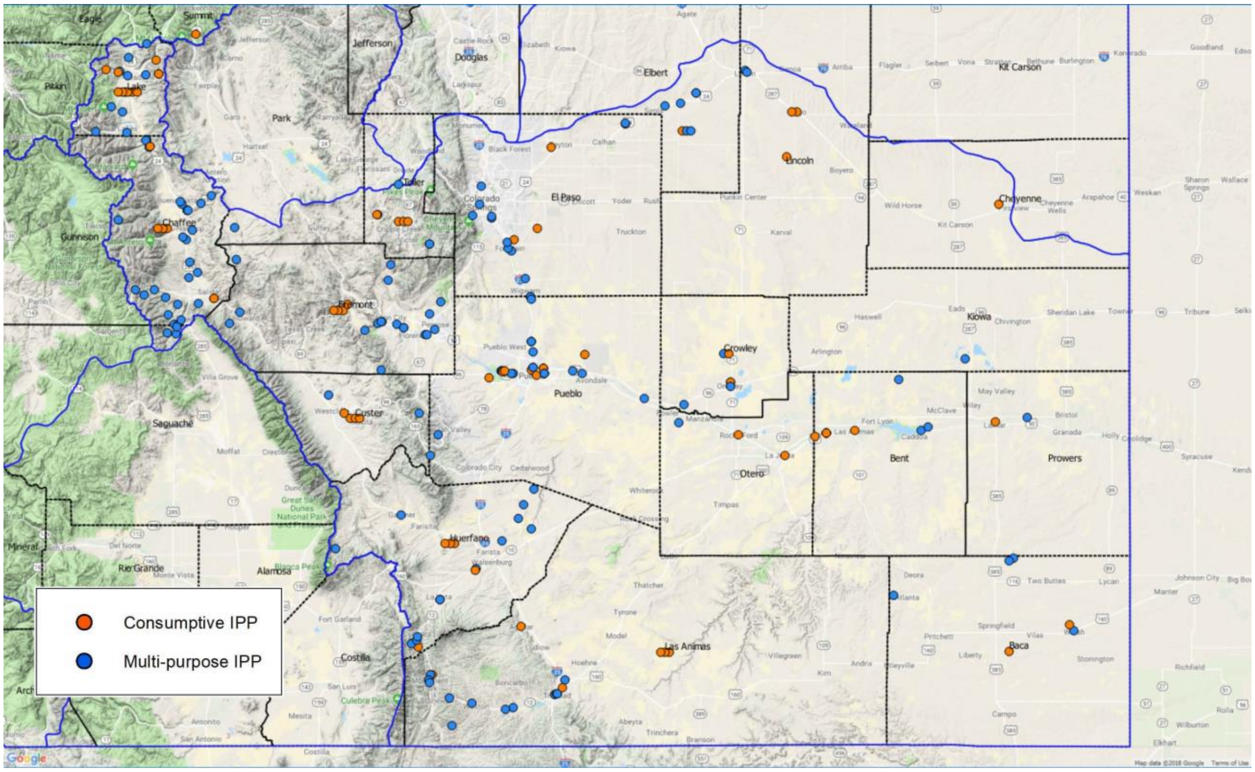


Figure 2 Arkansas Basin Consumption and Multi-Purposes/Multi-Use BIP IPPs

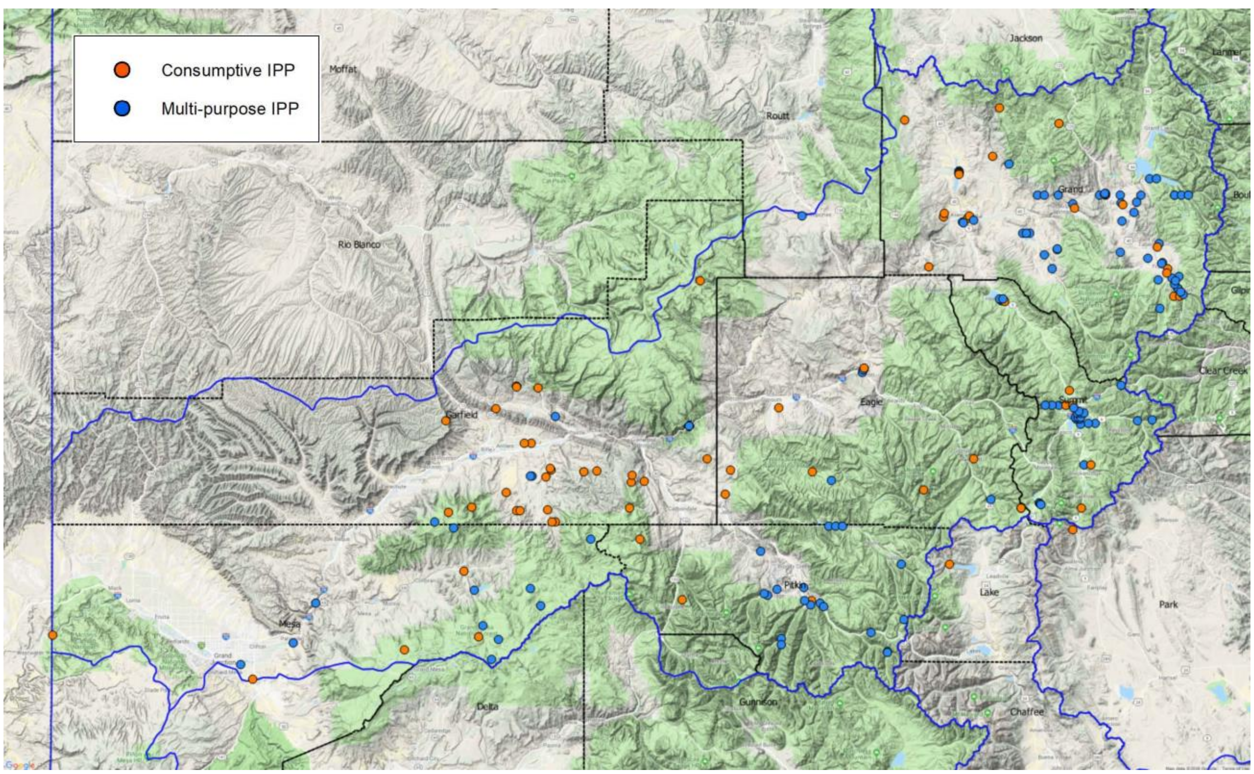


Figure 3. Colorado Basin Consumptive and Multi-Purpose/Multi-Use BIP IPPs

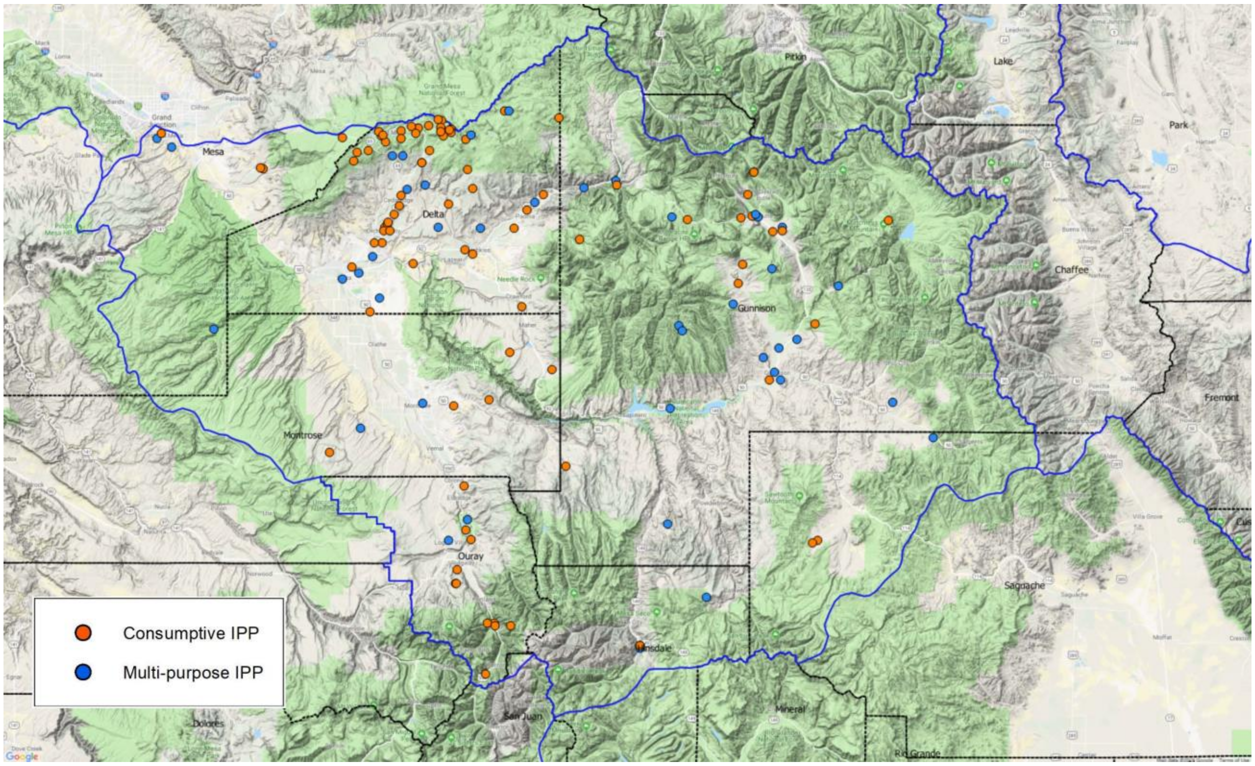


Figure 4. Gunnison Basin Consumptive and Multi-Purpose/Multi-Use BIP IPPs

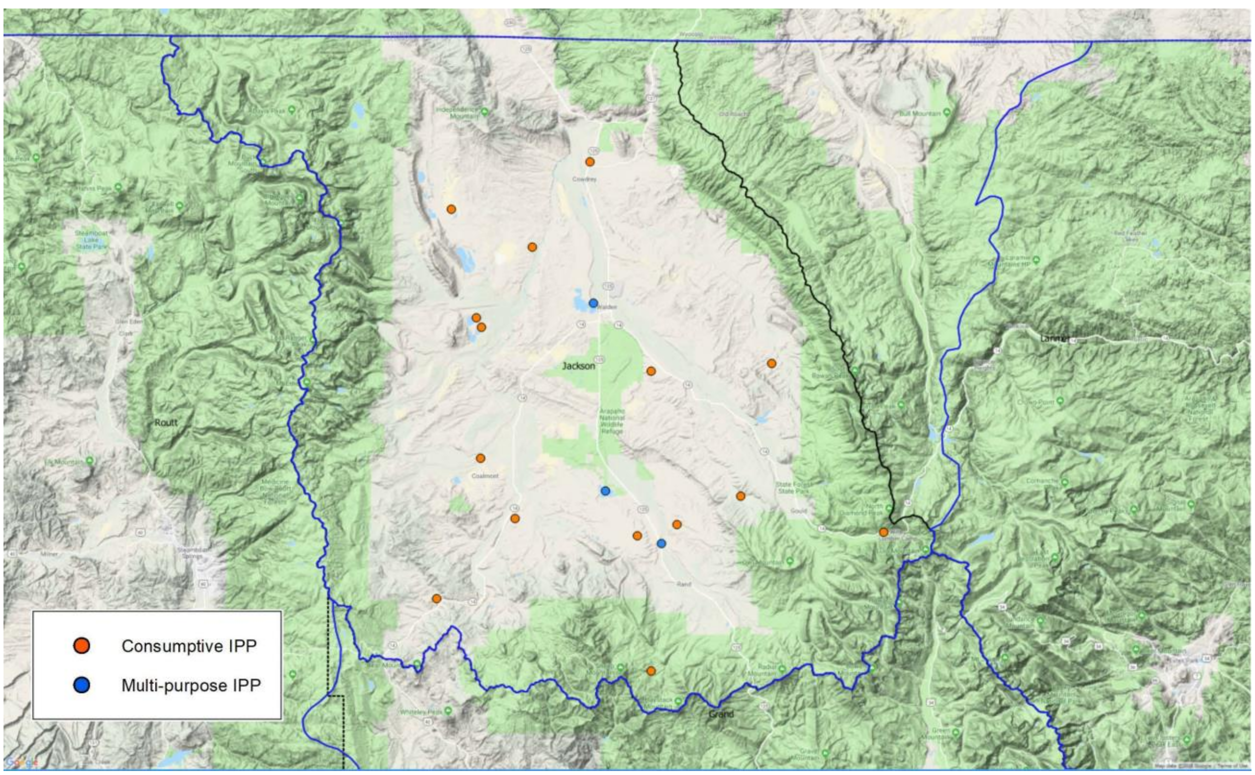


Figure 5. North Platte Basin Consumptive and Multi-Purpose/Multi-Use BIP IPPs

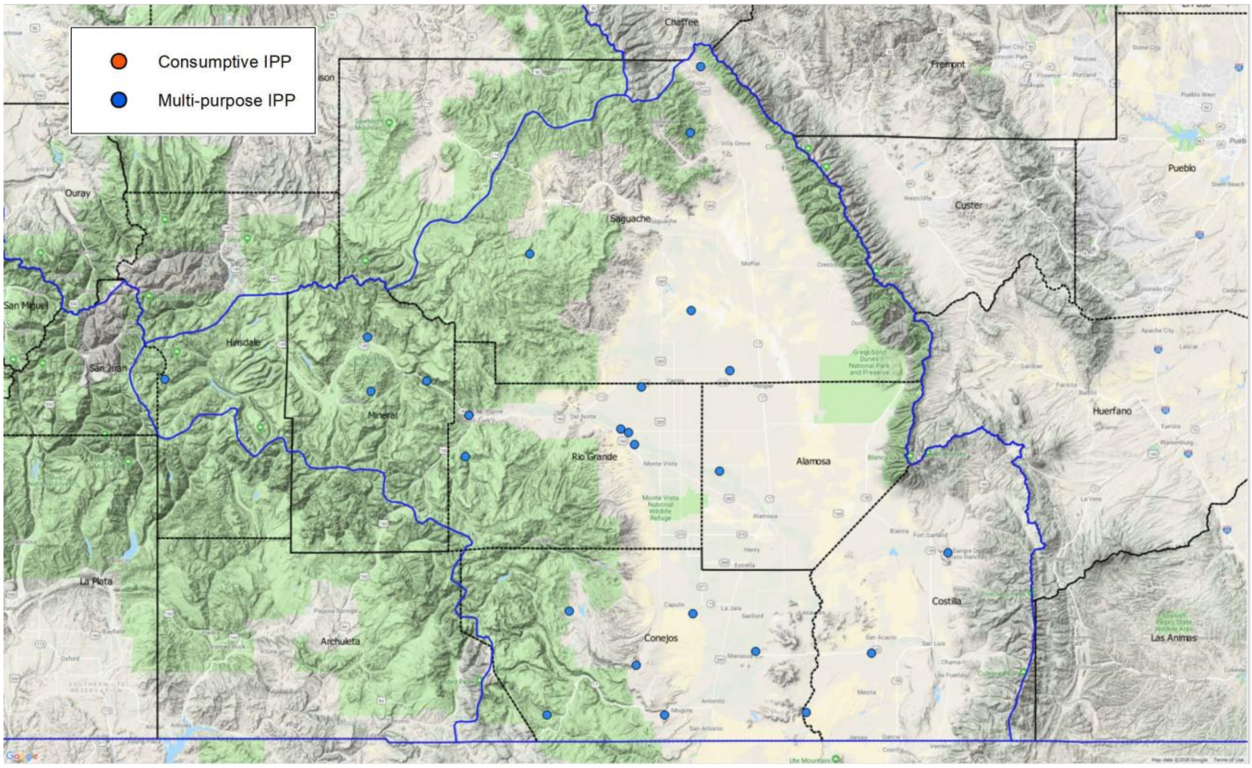


Figure 6. Rio Grande Basin Consumptive and Multi-Purpose/Multi-Use BIP IPPs

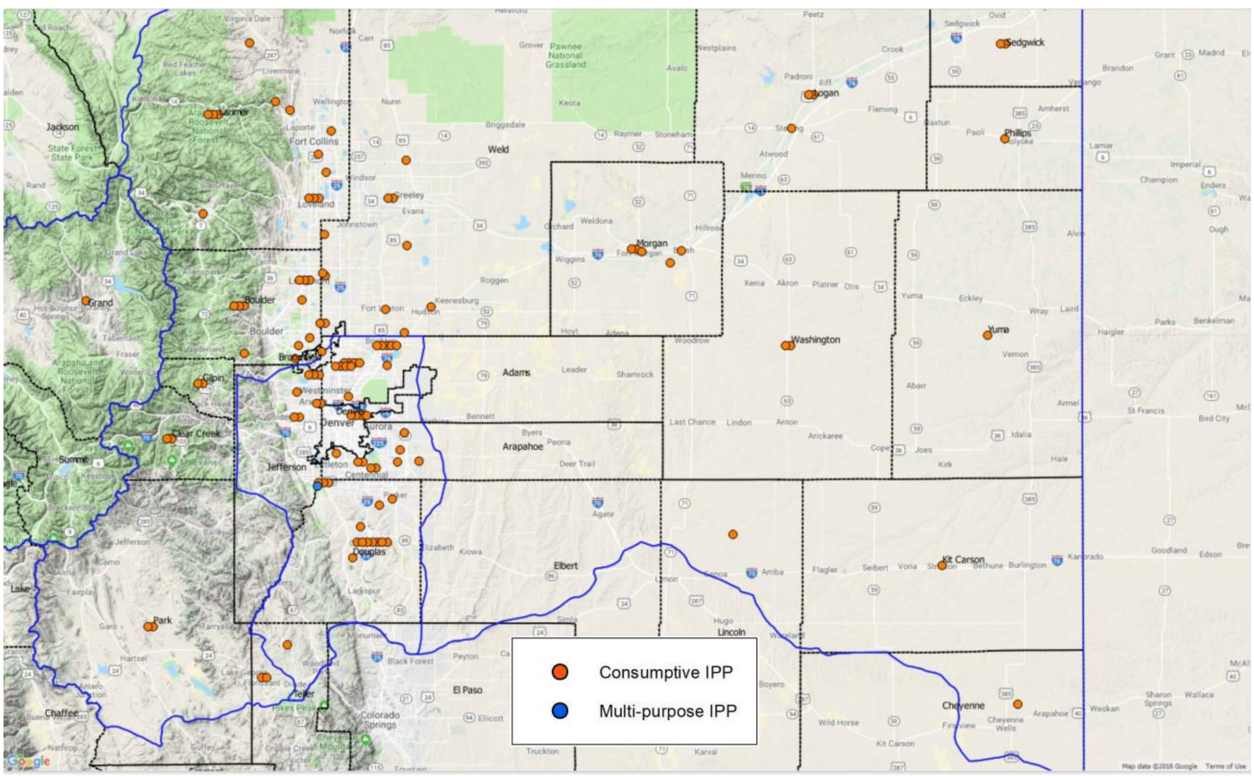


Figure 7. South Platte/Metro Basin Consumptive and Multi-Purpose/Multi-Use BIP IPPs

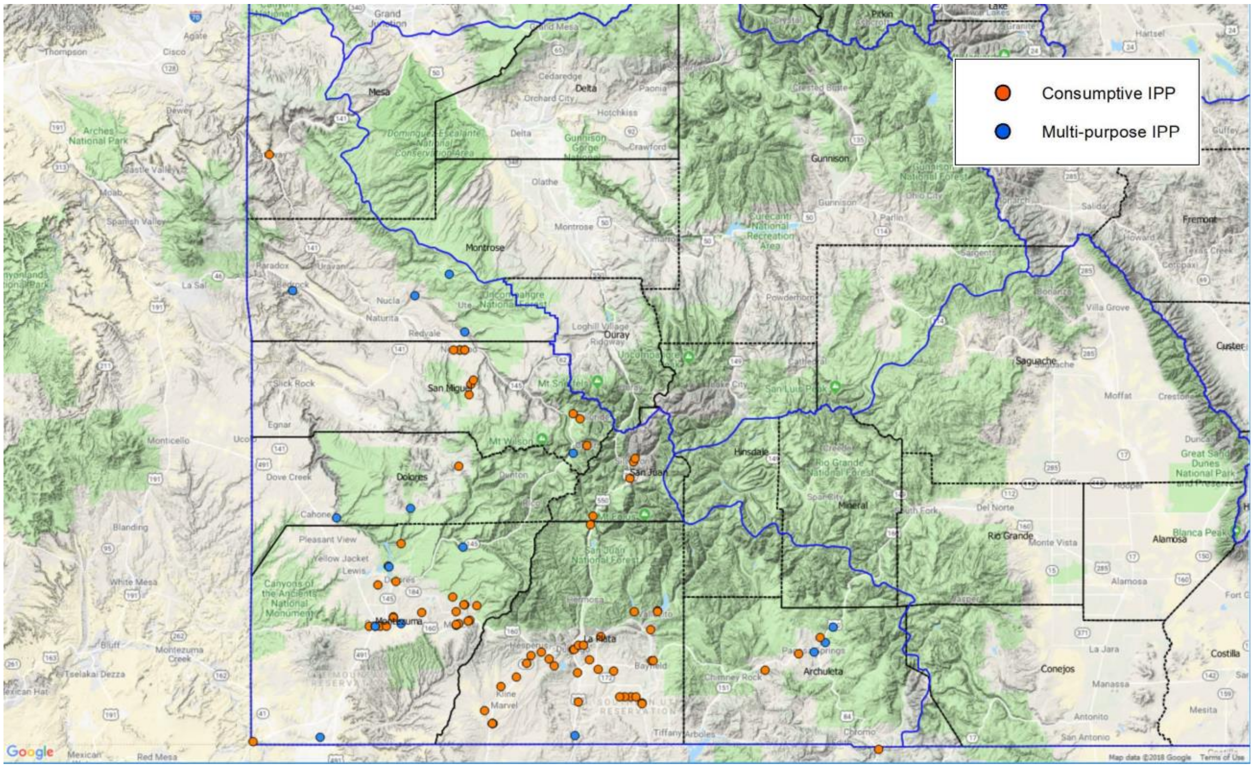


Figure 8. Southwest Basin Consumptive and Multi-Purpose/Multi-Use BIP IPPs

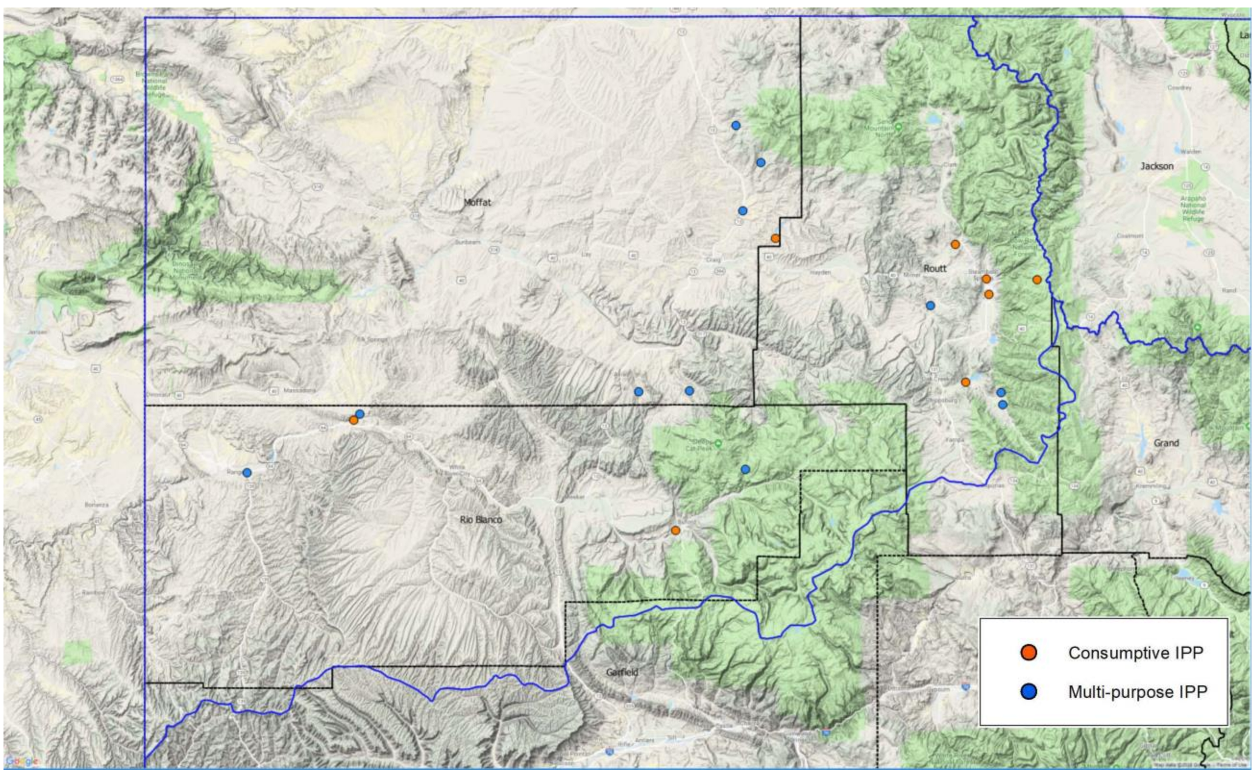


Figure 9. Yampa/White/Green Basin Consumptive and Multi-Purpose/Multi-Use BIP IPPs

Section 6: Summary of IPP Dataset Development

The standard data fields included within the standard IPP dataset are shown in Table 11. The presence of these data fields within each current basin IPP dataset is indicated, although existing column names from the Basin Roundtable IPP dataset do not correspond exactly with standard names. The exact names do not need to be matched; however the meaning of the data field should be equivalent. Software was used to rename the fields during processing.

Table 11. Standard IPP data fields and presence of fields in current basin IPP datasets.

Data Field/Column	Arkansas	Colorado	Gunnison	North Platte	Rio Grande	South Platte / Metro	Southwest	Yampa / White
Project_ID	X		X	X	X	X	X	X
Project_Name	X	X	X	X	X	X	X	X
Project_Description	X		X	X			X	X
Project_Keywords								
Status	X	X	X				X	
Lead_Proponent	X	X	X		X	X	X	X
Lead_Contact	X		X	X		X	X	
Municipal_Ind_Need	X	X	X		X		X	
Agricultural_Need	X	X	X		X		X	
Envr_Rec_Need	X	X	X	X	X		X	X
Admin_Need					X			
Latitude	X		X	X	X		X	X
Longitude	X		X	X	X		X	X
Lat_Long_Flag								
County	X						X	
Water_District	X		X					
Estimated_Yield	X	X	X			X		
Yield_Units	X	X	X			X		
Estimated_Capacity	X					X		
Capacity_Units	X					X		
Estimated_Cost	X	X	X		X	X		

6.1: BASIN-SPECIFIC DEVELOPMENT

Excel and spatial data layer files for each basin's IPPs were reviewed to understand existing data and to identify how to update the data while minimizing Basin Roundtable effort. The following sections summarize the methods used to transition the existing IPP datasets to the recommended form.

The goal was to perform the data processing as a series of steps that are transparent and repeatable (automated). In this way, it would be apparent to the Basin Roundtables how the original datasets were converted to the standardized form. The CDSS TSTool software was used to automate processing. The TSTool software is able to read and write Excel files and represents processing steps in text "command files". While the hope had been that the data could be transformed in a straightforward process using simple commands, the reality was that a substantial portion of the data needed to be cleaned with specific "search and replace" commands. While these steps were undertaken in a repeatable way, some of the data cleaning would have gone more smoothly with software enhancements or if the original data had been checked for consistency during original data entry. A lesson from the exercise is that data will not be made software-friendly until the data are used by software to perform a task.

Future updates should seek to retain existing data and improve ability to maintain and use data for Technical Updates, BIPs and the Colorado Water Plan.

The data processing tasks performed on each basin's original data in order to create a consistent dataset are summarized below. The notes correspond to data processing commands in TSTool command files for each basin (e.g., "analysis/Arkansas-IPP-DataProcessing.TSTool"), which may be updated over time as data processing is refined. Notes are also listed in the output IPP Excel files (e.g., "data/Arkansas-IPPs.xlsx") in the "Crosswalk" worksheet.

ARKANSAS BASIN

The following changes were made to the Arkansas Basin IPP dataset:

- Used whole numbers to estimate cost of an IPP, rather than using "M" to represent millions of dollars or "K" to represent thousands of dollars. Removed dollar signs where present. All values are now numeric and without any text.
- Needs that were listed under the categories Water Quality, Watershed Health and Instream Flow were added to the Envr_Rec_Need field.
- A Yield_Units field was created and filled with AF for those projects that have values in the Estimated_Yield field.
- A Capacity_Units field was created and filled with AF for those projects that have values in the Estimated_Capacity field.
- An Admin_Need field was added and set as 0% for all projects.
- The following field was added but left blank since no data were available: Project_Keywords.

COLORADO BASIN

The following changes were made to the Colorado Basin IPP dataset:

- Created a unique identifier for each project, in the format of Basin-Year-Number.
- A Project_Description field was created but was left blank. Creating a separate description from the Project_Name field was not attempted.

- Edited the Estimated_Cost field to remove dollar signs in front of values and replaced “M” with the appropriate number of zeroes to represent values in millions of dollars. Two projects used a cost per acre-feet description; the total cost was calculated based on the Estimated_Yield. All values are now numeric and without any text.
- A Municipal_Ind_Need field was created and populated according to the following rules:
    - If the beneficiary was listed as domestic or municipal (any variation with the phrase “munic”).
    - If the Water Storage field was marked with an X.
    - If the Raise Awareness of Obstacles Facing Water Providers field was marked with an X.
    - If the Ensure Safe Drinking Water field was marked with an X.
    - If the Natural Impacts to Water Supply field was marked with an X.
    - If the Project_Name field contained any of the following words: reservoir, sanitation, water conservation plan, growth planning, storage, Windy Gap, water system or intake facility.
    - The Basin Roundtable should review this designation.
- An Agricultural_Need field was created and populated according to the following rules:
    - If the beneficiary was listed as agricultural or irrigation (any variation with the phrase “agric” or “irrig”).
    - If the Reduce Agricultural Water Shortages field was marked with an X.
    - If the Land Use Policy to Reduce ATMs field was marked with an X.
    - If the Agricultural Production Incentives field was marked with an X.
    - If the Agricultural Community Education field was marked with an X.
    - If the Agricultural Efficiency Preservation Conservation field was marked with an X.
    - If the Project_Name field contained any of the following words: ditch, canal, lateral, reservoir, agric, crop or irrigation.
    - The Basin Roundtable should review this designation.
- An Envr_Rec_Need field was created and populated according to the following rules:
    - If the beneficiary was listed as nonconsumptive, rec, wildlife, Environmental or Recreational.
    - If the Ensure Safe Drinking Water field was marked with an X.
    - If the At Risk Reaches field was marked with an X.
    - If the Protect Rivers Lakes Streams Riparian field was marked with an X.
    - If the Preserve Recreational Flows field was marked with an X.
    - If the Protect Improve Water Quality field was marked with an X.
    - If the Project_Name field contained any of the following words: habitat, restoration, reclamation, fish, stream management plan, watershed plan, wild and scenic, whitewater, TMDL or salin (as in salinity).
    - The Basin Roundtable should review this designation.
- Consolidated the number of categories used to describe project status. The following rules were used:
    - A status of Ongoing was assigned to projects that described the status as “On-going”, “ongoing”, “Ongoing”, “In Progress”, “Underway” or “Investigation/Bulkhead Design Implementation Ongoing”.
    - A status of Concept was assigned to projects that described the status as "Ongoing Study", "Conceptual", "Conceptual idea", "Concept idea", "Conceptual, Conditional Water Right", "Feasibility Studies Completed", "Feasibility Studies Completed. Diligence approved in 2013.", "Study in Progress", "Conceptual design completed", "Beginning

stages of design/permitting", "Have ACOE Permit", "Under Study", "Needs to be brought into compliance" or "Proposed".
    - A status of Completed was assigned to projects that described the status as "Existing", "Completed/Ongoing", "5th year in operation", "In use" or "Plan in draft - 2004".
    - A status of Planned was assigned to projects that described the status as "Status pending", "Pumpback is pending", "In development.", "Trial Run completed", "Issued", "Decreed", "Decree issued in 10CW43", "May be constructed in fall of 2014", "Diligence filed", "Money not yet allocated", "Off-line" or "Water court application filed".
    - A status of Obsolete was assigned to projects that described the status as “Deferred”.
    - Statuses that were listed only as years were changed to blank values.
    - The Basin Roundtable should review these designations.
- Edited the Estimated_Yield field to remove units (i.e., AF) from the numbers. Created a new Yield_Units field to hold the unit type. If the Estimated_Yield was a range of values, then the value was set to the average.
- Other edits to the Estimated_Yield field were as follows: four projects listed yield in acres, which appeared to reflect acres of land, not acre-feet of water. These values were deleted. One project listed yield as a percentage, which appeared to reflect water conservation savings; this value was deleted. One project listed yield as feet of stream restored; this value was deleted. One project listed three separate yields for different entities; these were summed.
- An Admin_Need field was added and set as 0% for all projects.
- County and Water_District fields were added and populated by intersecting projects with Latitude and Longitude data with Colorado county and water district spatial data layers using geoprocessing software. For those projects without Latitude and Longitude data, these fields are blank.
- The following fields were added but left blank since no data were available: Project_Keywords, Lead_Contact, Estimated_Capacity, Capacity_Units.

GUNNISON BASIN

The following changes were made to the Gunnison Basin IPP dataset:

- Created a unique identifier for each project, in the format of Basin-Year-Number.
- Used the worksheet names (“Planned Projects”, “Completed_Ongoing”) to create a Status field. Data in the “Planned Projects” worksheet were given a status of Planned. Projects in the “Completed_Ongoing” worksheet were listed as Completed if the Funding Year column contained a year. If the Funding Year column was blank then the status was listed as Ongoing. Projects in the “NC Protections & Monitoring” worksheet are considered ongoing projects (BIP, p. 110), so the status was listed as Ongoing.
- Project need types (municipal, agricultural, etc.) were split into Municipal_Ind_Need, Agricultural_Need and Envr_Rec_Need fields. For projects listed in the “NC Protections & Monitoring” worksheet, the need is listed as 100% Envr_Rec_Need.
- The Estimated_Yield field was edited to remove “NA”, “TBD”, “per year”, “Project dependent” or ranges of values. For ranges, the minimum value listed was used instead. A Yield_Units field was created and with the exception of one project, all projects with Estimated_Yield data were listed as AF. The remaining project’s units were set to cfs based on the original data.
- The Estimated_Cost field was edited to remove “TBD” or ranges of values. For ranges, the maximum value listed was used instead.

- The Water_District field was edited so that a value of "All" was changed into a series of numbers (28, 40, 41, 42, 59, 60, 61, 62, 63, 68, 73).
- An Admin_Need field was added and set as 0% for all projects.
- A County field was added and populated by intersecting projects with Latitude and Longitude data with a Colorado county spatial data layer using geoprocessing software. For those projects without Latitude and Longitude data, this field is blank.
- The following fields were added but left blank since no data were available: Project_Keywords, Estimated_Capacity, Capacity_Units.

NORTH PLATTE BASIN

The following changes were made to the North Platte Basin IPP dataset:

- Created a unique identifier for each project, in the format of Basin-Year-Number.
- Added a Lead_Contact field for consumptive use projects; the field remains blank.
- An Admin_Need field was added and set as 0% for all projects.
- County and Water_District fields were added and populated by intersecting projects with Latitude and Longitude data with Colorado county and water district spatial data layers using geoprocessing software. For those projects without Latitude and Longitude data, these fields are blank.
- Used the worksheet names ("CU Projects", "NCNA_ER Projects") to create Municipal_Ind_Need, Agricultural_Need and Envr_Rec_Need data fields. Since the consumptive use projects were reservoir-related, it was assumed that the projects could be considered both agricultural and municipal/industrial and thus the percentages were set to 50% for both needs. In the original datasheet, three projects contained asterisks which indicated that the projects could also be considered non-consumptive. For these projects, the need percentages were changed to 33% for each need. The Basin Roundtable should review these designations.
- The following fields were added but left blank since no data were available: Project_Keywords, Status, Lead_Proponent, Estimated_Yield, Yield_Units, Estimated_Capacity, Capacity_Units, Estimated_Cost.

RIO GRANDE BASIN

The following changes were made to the Rio Grande Basin IPP dataset:

- Created a unique identifier for each project, in the format of Basin-Year-Number.
- County and Water_District fields were added and populated by intersecting projects with Latitude and Longitude data with Colorado county and water district spatial data layers using geoprocessing software. For those projects without Latitude and Longitude data, these fields are blank.
- The following fields were added but left blank since no data were available: Project_Description, Project_Keywords, Status, Lead_Contact, Estimated_Yield, Yield_Units, Estimated_Capacity, Capacity_Units.

SOUTH PLATTE / METRO BASINS

The following changes were made to the South Platte / Metro Basin IPP dataset:

- Created a unique identifier for each project, in the format of Basin-Year-Number.
- Created a Project_Description field. For most projects, the description is simply a copy of the Project_Name. However, some projects have a more detailed description due to OWF's previous work on the South Platte Data Platform, in which OWF was tasked with providing more detail to IPPs, such as determining general locations. The Basin Roundtable should review and update this field.
- A Municipal_Ind_Need field was created. All projects were assumed to be municipal/industrial in nature and thus the percentage was set to 100. While some of the projects may also have an agricultural need, OWF did not attempt to make this determination. The Basin Roundtable should review this designation.
- An Agricultural_Need field was created and set as 0% for all projects.
- An Envr_Rec_Need field was created and set as 0% for all projects.
- An Admin_Need field was added and set as 0% for all projects.
- County and Water_District fields were added and populated by intersecting projects with Latitude and Longitude data with Colorado county and water district spatial data layers using geoprocessing software. For those projects without Latitude and Longitude data, these fields are blank.
- A Yield_Units field was created and was set to AF for all projects that had Estimated_Yield values.
- A Capacity_Units field was created and was set to AF for all projects that had Estimated_Capacity values.
- The following fields were added but left blank since no data were available: Project_Keywords, Status.

SOUTHWEST BASIN

The following changes were made to the Southwest Basin IPP dataset:

- Created a unique identifier for each project, in the format of Basin-Year-Number. Because the original data contained IDs with a sub-basin identification, OWF conserved that portion of the ID. Therefore, the format of the Project ID is BasinSubbasin-Year-Number, as in SWDM-2015-0001, which indicates the Dolores and McElmo sub-basin. All sub-basins were given a two-letter abbreviation: MB = multi-basin, SJ = San Juan, PD = Piedra, PN = Pine, AN = Animas, LP = LaPlata, MA = Mancos, DM = Dolores & McElmo, SM = San Miguel.
- Split the Description field so that the Project_Name field could be filled in. This was done by taking the first sentence of the description and using that for the name. The Project_Description field is the original Description field.
- The original field Lead contact & Source of Info. was changed to Lead_Contact. OWF did not attempt to edit the contents of the field, thus the lead contact listed may actually only be the source of the information about the project. The Basin Roundtable should review this field.
- Used the NC/C/B (Nonconsumptive, Consumptive, Both) field to create the Municipal_Ind_Need, Agricultural_Need and Envr_Rec_Need fields. The original Need Addressed field also was used to fill in the new needs fields, as well as the Project_Description field. The following rules were used:
    - If the Need Addressed field contained the words "municipal" or "industrial" or the Project_Description field contained the words "hydropower", "water supply", "reservoir", "water right" or "metro district" then the project was considered to fulfill the Municipal_Ind_Need field.

    - If the Need Addressed field contained the word “agriculture” or the Project_Description field contained the words “agriculture”, “irrigation” or “reservoir” then the project was considered to fulfill the Agricultural_Need field.
    - If the NC/C/B field for a project was listed as NC or B or the Project_Description field contained the words “augmentation” or “RICD” then the project was considered to fulfill the Envr_Rec_Need field.
- Standardized the terminology used for project status. "Not Complete" and “Not completed” were replaced with "Planned". "Ongoing" was replaced with "Implementation Ongoing". “Construction Completed” was replaced with “Completed”. “Investigating” was replaced with “Concept”.
- The County field was edited so that a value of "All" was changed to list all of the counties in the basin, separated by commas.
- A Water_District field was added and populated by intersecting projects with Latitude and Longitude data with a water district spatial data layer using geoprocessing software. For those projects without Latitude and Longitude data, this field is blank.
- The following fields were added but left blank since no data were available: Project_Keywords, Estimated_Yield, Yield_Units, Estimated_Capacity, Capacity_Units, Estimated_Cost.

YAMPA / WHITE BASIN

The following changes were made to the Yampa/White Basin IPP dataset:

- Created a unique identifier for each project, in the format of Basin-Year-Number.
- Added a Project_Description field for consumptive use projects; the field remains blank.
- An Envr_Rec_Need field was added and those projects listed as Nonconsumptive were added to the Envr_Rec_Need field as 100%.
- Municipal_Ind_Need and Agricultural_Need fields were added; those projects listed as Consumptive were added to the fields as 50% for each need. Most of the consumptive use projects were related to reservoirs, so it was assumed that the need could be considered both agricultural and municipal/industrial. The Basin Roundtable should review these designations.
- An Admin_Need field was added and set as 0% for all projects.
- County and Water_District fields were added and populated by intersecting projects with Latitude and Longitude data with Colorado county and water district spatial data layers using geoprocessing software. For those projects without Latitude and Longitude data, these fields are blank.
- The following fields were added but left blank since no data were available: Project_Keywords, Status, Lead_Contact, Estimated_Yield, Yield_Units, Estimated_Capacity, Capacity_Units, Estimated_Cost.

Appendix A: Current Basin IPP Dataset Formats

This appendix provides images of the Excel workbook for of each basin's IPP dataset to illustrate existing data fields in the "flat" representation of IPP data. These examples were created from the Excel files that were provided at the start of the IPP data review summarized in Section 2.

	A	B	C	D	E	F	G	H
1	ID	Arkansas Basin Project ID	Project Title	Need or Challenge	Project Description	Project Status	Project Proponent	Associated Waterbody
2	1	ARK-2015-0001	CSWD Cucharas River Bank Intake Structure	Municipal Water Supply Gap CSWD.	Appropriate water right, conduct permitting and construct facilities for Cucharas River bank intake.	Planned	CSWD	Cucharas River
3	2	ARK-2015-0002	Cucharas Mountain Resort Storage	Water storage for summer recreation and winter snow making at Cucharas Mountain Resort (CSWD).	Transfer water right, permitting, and construct facilities.	Planned	CMR, CSWD	Cucharas River
4	3	ARK-2015-0003	South Baker Creek Reservoir	Municipal water storage shortage Cucharas SWD.	Acquisition, construction, permitting, and adjudication of South Baker Creek Reservoir.	Planned	CSWD	Cucharas River, South Baker Creek
5	4	ARK-2015-0004	Huerfano River Futile Call Administration Model and Gages	Timely futile call administration on Huerfano and Cucharas Rivers.	Transit or futile call model development as requested by DEO and HCWCD.	Planned	DEO, HCWCD	Huerfano River, Cucharas River

	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ
1	Alamosa	Baca	Bent	Chaffee	Cheyenne	Costilla	Crowley	Custer	Douglas	Eagle	El Paso	Elbert	Fremont	Gunnison	Huerfano	Kiowa	Kit Carson	Lake	Las Animas	Lincoln	Otero	Park	Pitkin	Prowers	Pueblo	Saguache	Summit	Teller
2															X													
3															X													
4															X													

	AK	AL	AM	AN	AO	AP	AQ	AR	AS	AT
1	County(s)	Validated Project (Not an Obsolete or Completed Project)	Solution	Plan of Action	MASTER NEEDS LIST	Needs Identified in BIP	Meets Min. IPP Requirements	Proponent	Intends to Meet Needs by 2050	2015 BIP IPP LIST (Yes/No)
2	Huerfano	Yes	Initiate water right application, permit, design, and construct facilities.	Authorization of activities to implement by public body.	Yes	Yes		Yes		No
3	Huerfano	Yes	Initiate water right application, permit, design, and construct facilities.	Authorization of activities to implement by public body.	Yes	Yes		Yes		No
4	Huerfano	Yes	Initiate project description.	Authorization of activities to implement by public body.	Yes	Yes		Yes		No

	AU	AV	AW	AX	AY	AZ	BA	BB	BC	BD	BE	BF	BG
1	Project Classification (List from Review Steps)	FUTURE TASK NOT FOR BIP	Municipal & Industrial	Agricultural	Storage	Environmental	Recreational	Water Quality	Watershed Health	Conservation / Efficiency	Instream Flow (ISF)	Multi-Benefit (to Populates)	Project Type
2	Master Needs List		X										Municipal & Industrial
3	Master Needs List		X		X	X	X					X	Municipal & Industrial; Storage; Environmental; Recreational; Multi-Benefit
4	Master Needs List		X		X	X	X			X		X	Municipal & Industrial; Storage; Environmental; Recreational; Conservation/Efficiency; Multi-Benefit

Figure A1. Screenshots of Arkansas Basin IPP dataset (2015 04 19 Arkansas River Basin Project Database GB update 6_13_15.xls, “All Input List” worksheet).

	BH	BI	BJ	BK	BL	BM	BN	BO	BP	BQ
1	Project Location: Latitude (##.######)	Project Location: Longitude (###.######)	Subregion	Water Conservancy District	Arkansas Basin HUC	CO Division of Water Resources District No.	Input Provided By (List or Name)	Applicant	Original Project ID (From Input Information)	Project Contact
2	37.332049	-105.096323		Huerfano County Water Conservancy District	110200060401	16	S. White H-P Projects			CSWCD; Art Pi
3	37.345076	-105.126966		Huerfano County Water Conservancy District	110200060401	16	S. White H-P Projects			CSWCD; Art Pi
4	37.355602	-105.105012		Huerfano County Water Conservancy District	110200060401	16	S. White H-P Projects			CSWCD; Art Pi

	BR	BS	BT	BU	BV	BW	BX	BY	BZ	CA	CB
1	Contact ID	Contact Organization	Contact Phone	Contact Email	Project Website	Partners	Partners Contact	Estimated Cost	Basin Funds Requested	Statewide Funds Requested	Total Funds Requested
2	erce					CSWD		$6.0M			
3	erce					CSWD		$4.0M			
4	erce					CSWD		$9.5M			

	CC	CD	CE	CF	CG	CH	CI	CJ	CK
1	Estimated Completion Date	BRT Sponsor	CWCB Approved	Location Description	Project Category	Project Type	Basin Goals Met	Multi Basin	Attributes Identified by BRT
2	Est 2022	Sandy White					M1, M2		
3	Est 2025	Sandy White					S1, S3, M2		
4	Est 2018	Sandy White					S1, S3, M1, M2, NC1, NC2, NC3, NC5, NC6, NC7		

	CL	CM	CN	CO	CP	CQ	CR	CS	CT	CU	CV	CW	CX
1	Benefit	Project Protections	Constraints and Challenges	SWSI 2010 Type	Annual Firm Yield	New Active Storage	COMID	Segment ID	Project Location ID	BNDSS IPP Category	BNDSS IPP Type	Project Note or Comment	Other
2			HB1041?; 404? USFS-SUP? DEO/SEO										
3			HB1041?; 404? USFS-SUP? DEO/SEO										
4			HB1041?; 404? USFS-SUP? DEO/SEO										

Figure A1 continued.

	A	B	C
1	**Projects, Policies and Process**	**Beneficiary**	**Project Sponsor**
2			
3	ERMOU Project The ERMOU Joint Use Water Project (ERMOU Project) derives from the 1998 Eagle River MOU among East and West Slope water users for development of a joint use water project in the Eagle River basin that minimizes environmental impact, is cost effective, technically feasible, can be permitted by local, state and federal authorities, and provides 20,000 acre feet per year (AFY) average annual yield for East Slope use, 10,000 AFY firm dry year yield for West Slope use, and 3,000 AF of reservoir capacity for Climax Molybdenum Co. The ERMOU Project is proposed as a cooperative alternative to construction of the Homestake II Project in the Holy Cross Wilderness. The ERMOU Project will utilize conditional water rights held by the ERMOU Parties and a yet-to-be determined combination of gravity diversion, storage, pumping, and/or groundwater infrastructure to develop the contemplated project yield. ERMOU Parties include: Cities of Aurora and Colorado Springs; Eagle Park Reservoir Company (consisting of the Colorado River Water Conservation District, Eagle River	ERMOU Parties	ERMOU Parties
4	Red Cliff Project (Iron Mountain)		CRWCD
5	Fryingpan Project		

	D	E	F	G	H	I	J	K
1	**Data Sources**	**Region (of Project)**	**Proposed (AF, CFS, other)**	**Existing (AF, CFS, other)**	**Cost**	**Progress**	**Basin Importance**	**Nonconsumptive Benefits**
2						**EAGLE REGION**		
3	ERMOU Parties	(Upper) Eagle Region	20,000 AFY average annual yield for Cities, 10,000 AFY firm dry year yield for the Reservoir Co., 3,000 AF storage space for Climax	2500	$5000/AF	Ongoing	High	
4	ERMOU Project	Eagle Region	60,000 AF					
5	ERMOU Project	Eagle Region						

Figure A2. Screenshots of Colorado Basin IPP dataset (Eagle_Region_Full_IPP_List.xlsx).

	L
1	**Comments (Opportunities and/or Constraints)**
2	
3	Progress on the ERMOU Project has been continuous since 1998, with development and use of the Eagle Park Reservoir as a phase component of the Project, investigation of specific project configurations described in the ERMOU, investigation of alternative project configurations, and acquisition and adjudication of water rights to be used for the ERMOU Project. Currently, the Project Sponsors are continuing investigations to evaluate the "Whitney Creek" alternative, consisting of a surface diversion from the Eagle River in the area of Camp Hale with a dual purpose storage reservoir / pumping forebay on Homestake Creek to store West Slope yield, and regulate and feed East Slope yield up to Homestake Reservoir. The Project Sponsors hope to conduct field reservoir siting studies for this possible Project component during the summer of 2014. They will continue to examine additional project variations and components that will be needed to develop the full yield contemplated for the ERMOU Project.
4	
5	

	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC
1	I.A - Increase Raw Water Storage	I.B - Improve water court process	I.C - Develop land use policy improvements	I.D - Protect mainstem water rights	I.E - Define potential natural impacts to water suppl	I.F - Raise awareness of obstacles facing water providers	I.G - Ensure adequate safe drinking water	II.A - Reduce agricultural water shortages	II.B - Develop land use policy to reduce agricultural water to municipal (ATM) transfers	II.C - Identify agricultural production incentives	II.D - Reduce the potential for transmountain diversions (TMDs)	II.E - Increase agriculture community education on water issues	II.F - Improve agricultural efficiency, preservation, and conservation	III.A - Identify reaches that are at risk or will be in t future	III.B - Protect rivers, streams, lakes and riparian ar	III.C - Protect and improve water quality	III.D - Preserve recreational flows
2																	
3	x						x										
4	x							x									
5	x																

Figure A2 continued.

Gunnison Basin Implementation Plan - Proposed Project List (4/17/15)

Note: Relative rank within each tier does not indicate a higher priority. Legend provided below table

Ref #	Tier	Project	Project Sponsor	Water District	Sponsor Type	Use Type	Project Type	Geographic Extent	Basin Goals	Included in SWSI 2010?
1	1	Gunnison Basin Roundtable 2015 Education Action Plan Activities	Gunnison Basin Roundtable	All	SE	AG, M&I, NC	NS	MD	1, 2, 7, 9	N
2	1	Regional Conservation Partnership Program (RCPP)	CRWCD, TU, TNC, UVWUA, NFWCD, CWCD, BPWCD	40, 41	P	AG, NC	S, NS	MD	1, 2, 3, 5, 6, 7, 8	N
3	1	Inventory of Irrigation Infrastructure Improvement Needs - District 28	Upper Gunnison River Water Conservancy District	28	SE	AG, NC	NS	SD	1, 3, 5, 7, 8	N
4	1	Cole Reservoirs #4 and #5	Bill Martin	40	SE	AG	S	SD	1, 3, 8	N

Project Readiness (Feasible by 2025?)	Point of Contact: Name	Point of Contact: Email	Point of Contact: Phone Number	Purpose	Water Gained or Saved (AF)	Estimated Completion Date	Estimated Budget
Yes	George Sibley	george@gard-sibley.org		Creation and implementation of the 2015 GBRT Education Action Plan (EAP) to include such items as: active education or stewardship programs for high school students, a Basin Water Leaders program at universities in the Basin for college students to develop and deliver education programs for public K-12 schools, printed materials about "comfortable and intelligent desert living", sub-basin-specific half-day programs and printed materials for decision makers, etc.	NA	Ongoing	TBD
Yes	Cary Denison			Modernize and improve off and on farm water transmission and application infrastructure in Lower Gunnison to accurately meet ag water demands while improving flow and water quality.	TBD	Ongoing	50,000,000
Yes	Frank Kugel	fkugel@ugrwcd.org	970-641-6065	Systematically examine and prioritize projects to restore, maintain, or modernize significant agricultural water supply infrastructure. Inventory will target proposed projects to maximize impact on meeting agricultural shortages, preserving existing uses, and in some cases meeting other purposes such as stream connectivity and flow.	NA	2018	100,000
Yes	Bill Martin	NA	970-255-7406	This project involves the repair or replacement of the main headgate diversion from Surface Creek and cleaning of the associated inlet ditch. It would preserve and restore the use of an important pre-Compact water	146	2015	50,000

Figure A3. Screenshots of Gunnison Basin IPP dataset (GBIP_Simplified_Project_List_4-17-15.xlsx, "Planned Projects", "NC Protections & Monitoring" and "Completed_Ongoing" worksheets).

Ref #	Project	Project Sponsor	Water District	Sponsor Type	Use Type	Project Type	Geographic Extent	Basin Goal	Included in SWSI 2010?	Project Readiness (Feasible by 2020?)	Point of Contact : Name	Point of Contact : Email	Point of Contact : Phone Number	Purpose
1	HCCA Project		40		NC		SD		Y			Jeff, DK, Tom.		
2	North Fork River Improvement Association - NFRIA		40		NC		MD	5	Y					
3	Fish Screen & Ladder at Redlands Power Canal	RWAPA (formerly USBR & FWS)	42	P	NC	S		5	N					Fish ladder and screen allow for endangered fish migration while preventing migration by nonnative fish.
4	Redlands Water and Power Canal	Redlands Power and Water Company	42	SE	NC	NS		5	N					
5	NPS WQ, Curecanti NRA (Aspinall Reservoirs) Sites		59		NC	NS			N					NPS effort to protect aquatic life and recreational Colorado WQ standards in Curecanti NRA and Black Canyon of the Gunnison NP.
6	ONRW Designation -- Streams Draining West Elks (heading in and flowing within Gunnison County only) to Curecanti NRA		59		NC	NS		5	N					NPS effort to protect quality and aquatic life of Curecanti NRA.
7	Roaring Judy	CPW	59	SE	NC	NS		5	N					Protect autumn minimum discharge needs for upstream migration of kokanee salmon.

Funding Year	Project	Description	Amount Funded	Funding Source
2007	Lake San Cristobal Controlled Outlet Structure (Part 1)	Hinsdale County and the Upper Gunnison River Water Conservancy District (UGRWCD) explored the feasibility of constructing a new permanent control structure at the outlet of Lake San Cristobal. The new structure allows for more controlled releases to regulate the lake level and prevent failure of the structure during flood events. The additional stored water resulting from the project will be used primarily as augmentation water within the Lake Fork of the Gunnison River. Other beneficial uses may include agriculture, recreation, and releases for instream flows.	40,000	WSRA
2007	Off-System Raw Water Storage Project 7 Water Authority/Uncompahgre Valley Water Users Association (Part 1)	The proposed new reservoir would be located on BLM and/or private land in the vicinity of Fairview Reservoir would have a capacity sufficient to supply P7 customers with domestic water for up to one full year. A detailed evaluation and comparative analysis of the potential sites was performed to identify the best reservoir location.	56,700	WSRA
2007	Orchard City Water Reservoir Project (Task 1-3)	This project involves the design of an approximately 500 acre foot off-channel reservoir to serve the municipal/domestic needs of	60,000	WSRA
2007	Orchard City Water Reservoir Project (Remaining Tasks)		480,000	WSRA
2007	Overland Reservoir Dam Expansion/Restoration (Part 1)		68,000	WSRA

Figure A3 continued.

No.	Project	Project Description	GIS Shapefile
1	**MacFarlane Reservoir ****	Outlet work and toe drain improvements to existing reservoir (WDID 4703614)	CUProjects_Point
2	**Evapotranspiration Project**	Continued support of climate station operation and lysimeter data collection to develop high altitude ET	N/A
3	**Walden Reservoir**	Dredge reservoir bottom to increase capacity for new use (WDID 4703627)	CUProjects_Point
4	**Basinwide Augmentation Plan**	Develop basinwide plan to augment various uses, potentially including augmenting depletions from livestock, industrial or municipal development in the basin	N/A
5	**Hanson and Wattenberg Ditch Acreage**	Irrigable acreage (1,612 acres) potentially served by rehabilitated Hanson and Wattenberg Ditch or new North	CUProjects_Poly
6	**Proposed Streamgage Installation**	Identify and potentially install new streamflow gages at key locations	N/A
7	**Storage Protocol**	Protocol for storage under the Equitable Apport. Decree	N/A
8	**Irrigation Season Protocol**	Protocol to define irrigation season in the basin	N/A
9	**Irrigated Acreage Assessment Protocol**	Protocol for delineating irrigation acreage under the Equitable Apport. Decree	N/A
10	**Proposed Willow Creek Reservoir**	New reservoir near Willow Creek crossing of Highway 125, potentially filled from Willow Creek or Illinois River	CUProjects_Point
11	**Dam Ditch Headgate Improvement ****	Redesign/replace existing headgate to increase capacity, ease maintenance issues and improve fish connectivity (WDID 4700582)	N/A

No.	Project or Segment	Project or method	Primary focus	To benefit:	Contact	GIS Shapefile
1	Bear Draw	Relocate trail out of wetland	Wetlands	Fishery, wetlands, amphibians	USFS	ERProjects_Point
2	BLM Water quality/quantity: Various reaches in North Platte Basin	Monitor water quality/quantity	Water quality/quantity	Fishery, wildlife, livestock, water quality	BLM	N/A
3	Boettcher Lake Rehabilitation	Rehabilitate/replace irrigation infrastructure	Improve/increase irrigated meadows	Waterfowl habitat	DU, Private Owner	ERProjects_Point
4	Boreal Toad Studies - Twisty Park/County Wide	Boreal Toad Studies	Species of concern	Amphibians	CPW	N/A
5	Brown Creek Fence	Improve water quality and riparian habitat from improved grazing management through fencing	Water quality, riparian habitat	Fishery, wetlands, amphibians	USFS	ERProjects_Point
6	Brownlee SWA- North Platte River	Brownlee SWA river channel/riparian corridor habitat/water quality improvements	Improve fishery habitat, water quality, erosion control	Fishery, riparian plant community	CPW	ERProjects_Point
7	Camp Creek	Remove fill & culverts from wetland	Wetlands, water quality, aquatic passage, stream function	Fishery, wetlands, amphibians	USFS	ERProjects_Poly
8	Camp Creek	Replace double culverts	Stream function, aquatic passage	Fishery	USFS	ERProjects_Poly

Figure A4. Screenshots of North Platte Basin IPP dataset (NPBIP_IPPLists.xlsx, "CU Projects" and "NCNA_ER Projects" worksheets).

ID	Project	Sponsor	Cost: Total	2014	2015	2016	2017
1	Boatable Days Flow Evaluation	Trout Unlimited	$19,500		$11,167	$4,167	$4,167
2	Conejos River System Confluence Management	Conejos Water Conservancy District	$582,000	$193,000	$355,000	$34,000	
3	Consolidated Ditch Diversion and Headgate Rehabilitation Project	Colorado Rio Grande Restoration Foundation, NRCS, Private	$1,500,000	$43,450	$173,850	$1,258,850	$23,850
4	Doppler Radar Weather Forecasting Project	RWEACT, CWCB, USFS, NWS	$393,750	$78,750	$78,750	$78,750	$78,750
5	Economic Impact Statement Analysis of the Effects of Reduced Groundwater Irrigation on the Ro Grande Basin	San Luis Valley Council of Governments	$80,364		$38,932	$41,432	
6	Groundwater Management Subdistricts	Rio Grande Water Conservation District	$66,000,000		$4,125,000	$4,125,000	$4,125,000
7	Hydrologic Recharge Feasibility Study for Rio Grande Basin Augmentation	San Luis Valley Irrigation Well Owners, Inc.	$180,000	$80,000	$100,000		
8	Increasing Water Holding Capacity of Soil for Agricultural Sustainability	Rio Grande Watershed Conservation and Education Initiative	$5,403,164	$905,861	$1,801,055	$1,801,055	$895,194

	Project or Method	Needs Met: Ag	M&I	Env & Rec	Water Admin	Basin Goals Met: 1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Boatable Days Flow Evaluation			x	x	✓	✓				✓	✓			✓	✓	✓	✓	✓
2	Conejos River System Confluence Management Project	x		x		✓	✓		✓	✓	✓				✓	✓	✓		✓
3	Consolidated Ditch Diversion and Headgate Rehabilitation Project	x		x	x	✓	✓		✓	✓	✓			✓	✓	✓	✓		✓
4	Closed Basin River / Creek and Wetland Water Table Study	x		x	x	✓	✓	✓	✓		✓				✓	✓	✓	✓	✓
5	Doppler Radar Weather Forecasting Project	x	x	x	x	✓	✓				✓	✓			✓	✓	✓	✓	✓

	Project or Method Types	Needs Met: Ag	M&I	Env/Rec	Water Admin	Basin Goals Met: 1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Acquisition of Replacement Supplies for M&I Pumping Depletions	X	X	X	X		✓	✓	✓	✓	✓	✓			✓		✓		
2	Adaptive Management to Mitigate Climate Change Impacts	X	X	X	X	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
3	Alternative Agriculture Methods and Improved Irrigation Efficiency to Reduce Consumptive Use	X		X	X	✓	✓	✓	✓	✓		✓	✓		✓				
4	Alternative Cropping Education and Promotion Program	X		X			✓	✓	✓	✓		✓	✓						
5	Basin-wide Water Public Education Program	X	X	X	X	✓	✓	✓			✓		✓		✓	✓	✓	✓	✓

Figure A5. Screenshots of Rio Grande Basin IPP dataset (Updated Tables 8-10_Project Sheet Summaries_09-11-2017.xlsx, “Budget”, “Specific Project Needs Met” and “General Projects” worksheets).

	BNDSS IPP ID	BNDSS IPP Category	Basin	Project
9	Morgan_UIPP_FIB	UIPP	South Platte	Morgan County Unspecified IPP Firming In-Basin
10	Morgan_UIPP_GIES	UIPP	South Platte	Morgan County Unspecified IPP Grow Into Existing Supply
11	ClearCreek_UIPP_FIB	UIPP	South Platte	Clear Creek County Unspecified IPP Firming In-Basin
12	ClearCreek_UIPP_GIES	UIPP	South Platte	Clear Creek County Unspecified IPP Grow Into Existing
13	FtMorganCBT&AugPlan	IPP	South Platte	Fort Morgan CBT & Augmentaion Plan
14	WindyGap	IPP	South Platte	Windy Gap Firming

	SWSI 2010 Type	BNDSS IPP Type	BNDSS Yield [Ac Ft]	BNDSS Sponsor ID	Providers
9	FIB	MDIB	2081		
10	GIES	GIES	2081		
11	FIB	MDIB	899		
12	GIES	GIES	899		
13	FIB	MDIB		FtMorgan	Fort Morgan, City of
14	FTB	TS	30000	NCWCD	Northern Colorado Water Conservancy District, Erie, Lafayette, Longmont, Louisville, Broomfield, Loveland, Greeley, Fort Lupton, Superior, Central Weld County Water District, Evans, Little Thompson Water District

	Estimated Cost	Estimated Completion Date	Storage			Data Sheet Priorities - by Yield-BNDSS & Proportion of Basin Yield	Point of Contact	Email Address
9						3	Allyn Wind	wind@kci.net
10						3	Allyn Wind	wind@kci.net
11						3	Bert Weaver	bweaver@co.clear-creek.co.us
12						3	Bert Weaver	bweaver@co.clear-creek.co.us
13							Brad Curtis	bcurtis@cityoffortmorgan.com
14	261000000		90000			1	Brian Werner	bwerner@ncwcd.org

	Comments	Date IPP Data Sheet Sent via Email	Alternate Contact Data Sheet Sent via Email		IPP Data Sheet Complete?	Condensed IPP data sheet sent via email	Condensed IPP Survey Received	Change in Yield (AFY)	Change in Estimated Year of Completion	Comment on Returned Survey
9		x		0		x				
10		x		0		x				
11		x		0		x				
12		x		0		x				
13		x		0		x				
14		x		1	x				2020	

Figure A6. Screenshots of South Platte / Metro Basin IPP dataset Gap Analysis (SPMetro HDR Phase 2.xlsx, "BNDSS IPP List" worksheet).

PROPOSED IPPs

ID	Date	Sub Basin	NC/C/B	Description	County	Status	Remaining Steps
1-A	Jul-13	Animas	C	Animas-LA Plata Project. Utilization of Animas-LA Plata Project water supplies for multiple purposes by Southern Ute Indian Tribe, Ute Mountain Ute Indian Tribe, Animas-LA Plata Water Conservancy District, City of Durango, LA Plata West Water Authority, Lake Durango Water Authority, Colorado Water Conservation Board, LA Plata Archuleta Water District, and others that may be entitled to ALP water. The utilization could include treatment and conveyance (pumps and pipelines) of raw or treated water.	La Plata, Archuleta, Montezuma	Not Complete	
2-A	Jul-13	Animas	NC	Lake Nighthorse Recreation. Provide boating, fishing, and swimming opportunities.	La Plata	Not Complete	
3-A	Oct-13	Animas	C	La Plata Archuleta Water District. Design and construction of a treatment plant for ALP water possibly in coordination with City of Durango. Transmission and distribution pipelines to convey treated water from the treatment plant to customers.	La Plata	Not Complete	Investigate potential partnerships, acquire land, design and construct
4-A	SWSI 2010	Animas (Florida)	C	Florida Water Conservancy District. Need for industrial, municipal, domestic, commercial, wildlife, wetlands, exchange, augmentation, hydropower, irrigation, and fire protection water within the Florida River basin. The District has initiated institutional changes by entering into a water service contract with the BOR to use decreed 114 AF water right for augmentation purposes and has obtained a 2,500 AF water right to address the aforementioned uses. Utilization of the 2,500 AF will require another water service contract with the BOR, voluntary water turn in by users, and irrigation system efficiency improvements by the Florida Mesa Ditch Companies that would firm up agricultural delivery and provide additional water supply for those other uses in Lemon Reservoir through the reduction of losses in the delivery system.	La Plata	Not Complete	Finalize water service contract with BOR and Complete additional irrigation system improvements

	IPP Contact Information					
Need Addressed	Sponsors	Lead contact & Source of Info.	Project vs. Process	Project ready for implementation NOW?	Does the need exist today?	Already received some WSRA funding?
Municipal water supply	Southern Ute Indian Tribe, Ute Mountain Ute Indian Tribe, Animas-LA Plata Water Conservancy District, City of Durango, LA Plata West Water Authority, Lake Durango Water Authority, Colorado Water Conservation Board, LA Plata Archuleta Water District, and others that may be entitled to ALP water		Both	Yes	Yes	Yes
Recreation	Animas La Plata Water Conservancy District, Bureau of Reclamation, La Plata county, City of Durango		Project	Yes	Yes	Yes
Municipal water supply	La Plata Archuleta Water District	Lead and Source: Ed Tolen	Project	No	Yes	Yes
Municipal, Industrial & Agricultural water supplies	Florida Water Conservancy District	Lead & Source: Florida Water Conservancy District	Project	Yes	Yes	Yes

Figure A7. Screenshot of Southwest Basin IPP dataset (SWBRT Draft IPP List Clean copy.xlsx, “Animas” worksheet).

ID	Name	Location	Additional Details	Proponents	GIS File
1	Upper Yampa backwater modifications	Initial projects located within Chuck Lewis SWA and within Steamboat Springs on the south end of city limits. However, multiple sites throughout the Upper Yampa River corridor could benefit from alterations of backwater habitats. Benefits to the Upper Colorado Endangered Fish Recovery Program by implementing one element of the program's non-native fish control strategy. Also benefits other environmental attributes of the riverine ecosystem. All other elements of the nonnative fish control strategy are part of keeping the Yampa River Basin PBO in place below.	Stakeholders would develop multi-faceted projects implementing habitat modifications/restoration activities to alleviate unnatural backwater habitats to minimize non-native species recruitment and improve ecological functions of the riverine system. Multiple recreational benefits would be realized as well.		IPP_Point
2	Loudy Simpson access and recreational river enhancements	Yampa River at Loudy Simpson Park in Craig, Colorado.	Provide improved access to river and restoration/rebuild of riffle for non-consumptive needs specific to increasing recreational opportunities and float boating in the Yampa River at the park.	Possibly Moffat County Tourism Association	IPP_Point
3	Upper Elkhead Creek Stream Restoration	Stream restoration will occur on approximately 16 miles of Elkhead Creek and its tributaries from the southern end of California Park upstream to the headwaters.	Indirect benefits to consumptive uses include a reduction in sediment entering Elkhead Reservoir.	Forest Service	IPP_Reach

Map ID	Name of Project	Location
1	Elkhead Reservoir Enlargement Project	Yampa: Elkhead Creek
2	Fish Creek Direct Flow and Storage	Yampa: Fish Creek in Buffalo Pass Area
3	Lake Avery Enlargement	White: Expansion to Big Beaver Reservoir (Lake Avery)
4	Little Bear 1 Reservoir	Yampa: Fortification Creek Basin
5	Milk Creek Reservoir	Yampa: Milk Creek

In BIP model?	Propoents	GIS File	Description
No	Colorado River Water Conservation District	IPP_Point	pg 113
No	Mt Werner Water / City of Steamboat Springs	IPP_Point	pg 113
Yes	Yellow Jacket Water Conservancy District	IPP_Point	pg 157
Yes		IPP_Point	pg 153
Yes	Juniper Creek WCD	IPP_Point	pg 155

Figure A8. Screenshots of Yampa / White Basin IPP dataset (BIP_IPPs.xlsx, “NonConsumptive” and “Consumptive” worksheets).

Appendix B: Identified Projects and Processes Maps

This appendix provides an explanation of data availability and how locations were determined for IPPs that lacked location data.

DATA AVAILABILITY

As discussed in the main document, availability of coordinate data for IPPs varied by basin. The following describes the level of coordinate data provided to OWF by basin:

- **Arkansas Basin** – latitude and longitude coordinates were provided in the Excel file of IPPs for many, but not all, IPPs. Coordinate data were available for both consumptive and E&R projects.
- **Colorado Basin** – no coordinate data were provided; IPPs were categorized by "region" within the basin.
- **Gunnison Basin** – shapefiles of point data for both consumptive and E&R projects were provided, but not all projects were included in the shapefiles.
- **North Platte Basin** – shapefiles of point and line data for both consumptive and E&R projects were provided for most, but not all, projects.
- **Rio Grande Basin** – a .kmz file of points representing IPPs for both consumptive and E&R projects was provided, but not all projects were included.
- **South Platte and Metro Basins** – no coordinate data were provided; county designation was included in the Excel file.
- **Southwest Basin** – shapefiles of point and line data for both consumptive and E&R projects were provided, but not all projects were included in the shapefiles.
- **Yampa-White Basin** – shapefiles of point and line data for both consumptive and E&R projects were provided, and all consumptive projects were included in the shapefiles.

For basins such as the North Platte, Southwest and Yampa-White that contained both point and line data, points tended to be associated with consumptive projects, whereas lines tended to be associated with E&R projects. At this time, OWF has not attempted to convert line data into point data. If an E&R project contained a point location, then that project is included in the map. Therefore, while maps focused on consumptive IPPs, it should be understood that some E&R IPPs were also included.

LATITUDE/LONGITUDE FLAG DESCRIPTIONS

In order to document and keep track of the methods used to determine coordinate locations for IPPs, OWF created a "Lat_Long_Flag" column in the IPP dataset. The flag consists of a 1- or 2-character designation; the first character is a letter and the second character is a number. The designations are as follows:

- G = coordinates are good; provided by the consultant in either an Excel datasheet or GIS shapefiles
- g = coordinates are based on an estimation technique:
    - g1 = coordinates based on centroid of county boundary
    - g2 = coordinates based on centroid of municipal boundary
    - g3 = coordinates based on centroid of water district boundary
    - g4 = coordinates based on location of reservoir
    - g5 = other; based on a location described in the IPP name, such as a school or the Shoshone Plant
    - g6 = coordinates based on centroid of county boundary, then offset by 0.02 (or 0.04, 0.06, etc.) degrees longitude to allow for visibility on map
    - g7 = coordinates based on centroid of municipal boundary, then offset by 0.02 (or 0.04, 0.06, etc.) degrees longitude to allow for visibility on map

  - g8 = coordinates based on centroid of water district boundary, then offset by 0.02 (or 0.04, 0.06, etc.) degrees longitude to allow for visibility on map
  - g9 = coordinates based on general location on stream
  - g10 = coordinates based on address of water provider, ditch company, etc.
  - g11 = coordinates based on primary diversion structure of transbasin diversion project
  - g12 = coordinates based on ditch's diversion structure
  - g13 = coordinates based on ditch's diversion structure, then offset to allow for visibility on map
  - g14 = coordinates based on IPP-Projects layer from Colorado Mesa University's Colorado Headwaters Map (applies to Colorado Basin only)
- M = coordinates missing in original source and therefore values cannot be provided:
  - M1 = coordinates not determined because general location cannot be determined from IPP name or description
  - M2 = coordinates not determined because IPP is an E&R IPP

IPPs designated with a g6, g7, g8 or g13 flag were necessary in order to allow IPPs to be shown on the map that represented the same basic location. An effort was made to standardize how much the locations were offset, such as by 0.02 degrees longitude. An example is the numerous IPPs that were generally located within Grand County. However, IPPs associated with a reservoir did not use this offsetting technique and instead were manually located to make sure they were placed within the reservoir's boundary.

For most basins, coordinate data could not be determined for several IPPs because the name or description of the IPP was too generic, such as "Improvements to Ditch and Canal Diversion Structures". In these instances, the Lat_Long_Flag designation is M1 and the IPP could not be included in the map. Therefore, it should be understood that the IPP map does not contain the entire list of consumptive IPPs.

Appendix C: Statewide IPP Locations Estimates

This is an electronic Excel workbook file that include an exhaustive list of IPPs across the state. The appendix is organized by basin and includes flag “Lat_Long_Flag” indicating how the location (latitude/longitude) was determined. See Appendix B for additional detail.

File name: *Statewide-IPPs-locations.xlsx*

Appendix D: Future IPP Management Recommendations

This appendix provides recommendations regarding the maintenance of the IPP datasets during future Basin Implementation Plan updates; linking IPP datasets to other analyses/data products; and integrating IPP data into the larger Technical Update modeling efforts that were discussed with CWCB during this effort. These recommendations are made at a higher level than the details presented elsewhere in this documentation. Some of the recommendations have been implemented during the IPP Dataset review.

D.1 RECOMMENDATIONS FOR IPP DATASET MANAGEMENT

D.2 RECOMMENDATIONS FOR INCORPORATING WATER SOURCE AND DESTINATION INFORMATION

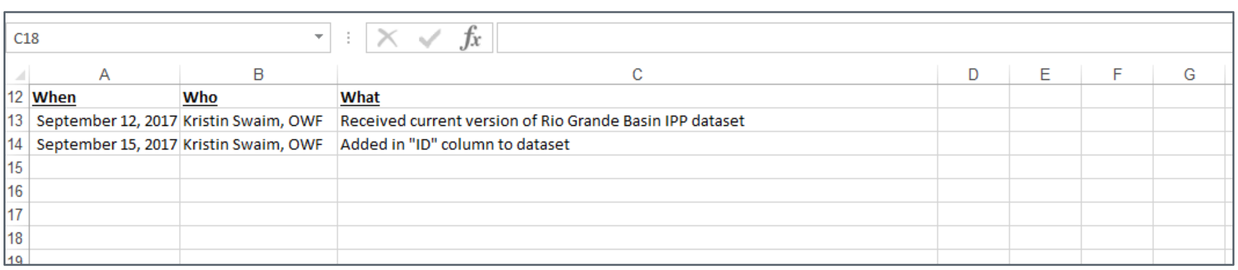
D.3 RECOMMENDATIONS FOR ESTABLISHING AN IMPROVED IPP DATASET MAINTAINENCE WORKFLOW

D.4 RECOMMENDATIONS TO LINK IPP DATASET TO OTHER DATASETS

D.1 RECOMMENDATIONS FOR IPP DATASET MANAGEMENT

As the consultant team was developing the standard IPP dataset, basic data management and maintenance procedures were documented to ease future use of the dataset. The following summarizes those recommendations:

1. Each Basin Roundtable should maintain an Excel workbook file containing IPPs.
2. The name of the electronic file should reflect the date of modification. Alternatively, use version-tracking software such as GitHub that allows versions of the data file to be retrieved.
3. A worksheet in the file named “ChangeLog” or “Changes” should be added indicating the date, person and notes about the change. Note that “History” is a reserved word in Excel and cannot be used for the worksheet name. An example is shown in Figure D1.
4. A worksheet in the file named “Notes” or “ReadMe” should be added with general information, such as explanation of workbook organization.
5. A worksheet in the file named “Definitions” should be added that defines data fields. It should include descriptions of how data should be formatted and/or directions for how to fill in a particular field. An example is shown in Figure D2.
6. The main IPP list should be represented in a flat table form with columns corresponding to data fields that are discussed in subsequent sections of this document. The worksheet should be named “IPPs” or similar (to be determined with CWCB review input).
7. Additional worksheets in the workbook can be added as appropriate, using the IPP identifier to cross-connect. However, additional sheets should not dilute the core data that should be included in the main IPP list. Examples of additional worksheets are:
    a. Definitions of terms used in the dataset list (such as project type)
    b. One-to-many data in the core dataset that include shared relationship to other worksheet(s)
    c. History of changes
    d. Optional data that will clutter up the main list but may be useful, such as more detailed contact information or information used by the Roundtable to conduct its business



C18

	A	B	C	D	E	F	G
12	When	Who	What				
13	September 12, 2017	Kristin Swaim, OWF	Received current version of Rio Grande Basin IPP dataset				
14	September 15, 2017	Kristin Swaim, OWF	Added in "ID" column to dataset				
15							
16							
17							
18							

Figure D1. Example of a “ChangeLog” tab within the IPP workbook to indicate data edits.

	A	B	C
1	**Data Field**	**Description**	**Allowed Values**
2	IPP_ID	Unique identifier for the project	Format is Basin-Year-Number
3	IPP_Description	Short description of the project	
4	Basin	IBCC basin location of the project	
5	Capacity	Annual amount of water anticipated from the project, in acre-feet or cfs	
6	Estimated_Cost	Total cost of the project	
7	Latitude	Latitude location of the project	Format in decimal degrees
8	Longitude	Longitude location of the project	Format in decimal degrees
9			

Figure D2. Example of a "Definitions" tab within the IPP workbook to describe data fields.

D.2 RECOMMENDATIONS FOR INCORPORATING WATER SOURCE AND DESTINATION INFORMATION

An IPP's water source(s) (river name, groundwater basin name, etc.) provides spatial context and a connection to water planning and administration. It is recommended to use the GNIS (Geographic Names Information System) name and identification number where possible for surface water-based IPPs. The GNIS ID was developed by the USGS and is the federal government's official repository of domestic geographic feature names. The State of Colorado uses the GNIS ID in its Source Water Route Framework (SWRF) spatial data layer, so the addition of these data fields will allow for linking to other state datasets. An alternate location ID for groundwater-based IPPs will need to be developed.

Connected to an IPP's water source is the destination of the water. Does the project deliver water to a municipality, does it divert water to a system of ditches, or does the water stay in the stream? Unlike water source, the destination can be more descriptive in nature. For example, the destination may be "City of Denver" or "Eagle River". If the destination is a stream, then the official GNIS name can be used.

It should be noted that not all water bodies are in the SWRF. Potential options are to create a new ID or to use the nearest water source that does have a GNIS ID. OWF is currently not making any recommendations regarding this issue.

Table D1 shows the level of water source information provided in each basin IPP dataset. None of the basins have information about water destination at this time.

Table D1. Water source information provided in basin IPP datasets.

Basin	Example Naming Convention for Water Source	Comment
Arkansas	Cucharas River	"Associated Waterbody" field can serve as GNIS Name
Colorado	None	
Gunnison	None	
North Platte	Illinois River	A "Water Source" field exists for some IPPs within shapefiles but is not contained in the Excel datasheet
Rio Grande	None	
South Platte / Metro	None	
Southwest	00902295; Mancos River	"GNIS_ID" and "GNIS_NAME" fields exists for some IPPs within shapefiles but are not contained in the Excel datasheet
Yampa / White	00169868; North Fork Elkhead Creek	"GNIS_ID" and "GNIS_Name" fields exists for some IPPs within shapefiles but are not contained in the Excel datasheet

Recommendations:

1. "**WaterSource_GNIS_Name**" should be a required field:
    a. GNIS Name can be found using Division of Water Resources' Map Viewer.
    b. The primary water source should be included. If the project has multiple water sources, a second worksheet can be populated that shows the additional sources.
2. "**WaterSource_GNIS_ID**" should be a required field:
    a. GNIS ID can be found using Map Viewer and Source Water Route Framework layer.
    b. The primary water source should be included. If the project has multiple water sources, a second worksheet can be populated that shows the additional sources.
3. "**WaterSource_Aquifer_ID**" and "**WaterSource_Aquifer_Name**" should be a required field for groundwater IPPs but requires additional evaluation. GNIS ID is not available for aquifers. An alternative identifier could be determined from HydroBase well permit or other data, in which case the field name should reflect the identifier type. The list of groundwater sources that are used need to be available in a published form to facilitate use. Additional evaluation is required.
4. "**WaterDestination**" should be a required field:
    a. Values can be descriptive in nature (e.g., "City of X" or "X River") to provide minimal context; no standard conventions are currently recommended but could be adopted based on more detailed review of IPP data.
    b. GNIS identifiers and names could be used for water features. However, the destination may be complex to describe, with multiple infrastructure and natural feature components. The destination value may often be assumed to be the same as the "WaterSource_GNIS_Name" field, particularly for E&R projects.

D.3 RECOMMENDATIONS FOR ESTABLISHING AN IMPROVED IPP DATASET MAINTAINENCE WORKFLOW

It is important to establish an improved workflow to facilitate maintenance and access to IPP datasets, which includes identifying how to publish IPP datasets on the web to facilitate coordination and Technical Update publication. It is understood that a considerable amount of time, effort and resources have already been put toward the development of IPP lists. Rather than suggesting that each basin revamp its dataset, it is recommended that each basin add in the missing data fields but keep existing data field names as-is if that is the recommendation of the Basin Roundtable. The Notes tab can then be used to define how data fields correspond to the standardized IPP data fields. For example, the Colorado Basin may choose to continue using the data field name “Progress” to indicate the phase of an IPP. The Notes tab could then explain that these fields are interchangeable and could be indicated with a description, such as, “Progress = Status”. If the recommendations for IPP datasets are acceptable to Roundtables and the CWCB, then more substantial changes can occur to align all of the Roundtable datasets.

It will be necessary to do some additional processing of the datasets so they are in a standard (normalized) format that can be used to create statewide data products and visualizations. One option is to use TSTool software, which is able to read and write Excel files, and represents processing steps in text “command files”. Other tools could also be used and it is recommended that the workflow should consist of transparent text instructions. This will allow for data processing to be done in a series of steps that are transparent and repeatable. Data manipulation tools may need to be implemented or enhanced to perform transformations, for example to rename fields, populate fields based on keywords, remove formatting such as dollar signs, and other manipulations.

A comprehensive, standardized, statewide IPP dataset containing consistent data fields should then be published on the web using Map Viewer, CIM, static websites (see an example at: http://data.openwaterfoundation.org/cdss-data-spatial-bybasin/index.html) or other options. Another option that OWF has direct experience with is GitHub, which is a version control system that provides a data management system for files. In GitHub, data are stored in repositories that are cloud-hosted. GitHub is somewhat similar to Google Drive and Dropbox. Repository hosting is free for public repositories but private repositories require payment. Regardless of the approach taken, it should be consistent with the technical capabilities of each Roundtable such as considering whether a Roundtable has its own website. Greater CWCB support of Roundtables may be appropriate, such as utilizing the State’s Google Cloud Platform (GCP) to provide data-hosting website for each basin. OWF has been working with the State to utilize the GCP for a project and it would be possible, for example, to use GCP to provide data and web hosting for each Roundtable.

The workflow for IPP dataset processing might be similar to the following (Figure D3 and discussion below):

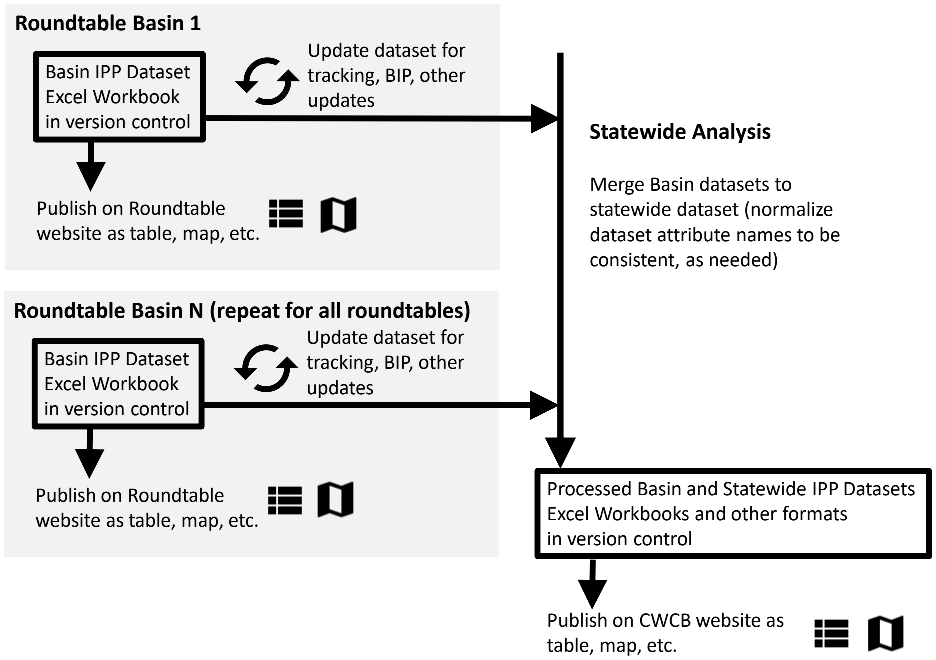


Figure D3. IPP Dataset Handling Workflow.

1. Original basin IPP datasets are published on each Basin Roundtable's website (or the CWCB's website or the Colorado Water Plan website) in a machine-readable format such as an Excel workbook.
2. Edits to the dataset are made and noted in the "ChangeLog" tab of the workbook. The edited dataset is then republished to the website, either replacing the original dataset or added as new file (perhaps with a timestamp) to indicate an updated version of the dataset. Keeping an archive of old versions is helpful given that such versions are referenced in specific versions of studies and analyses. OWF has been evaluating using platforms such as GitHub that track changes to electronic files and such a system could be used to track versions of the IPP dataset. Ideally, the chosen platform allows collaboration with a "gatekeeper" on edits and tracks changes and versions.
3. The dataset is processed with TSTool (or other software) to create a standardized dataset that is compatible with other basin IPP datasets. It would be possible to have a link to the TSTool command file that details how the data are processed so that the processing is transparent. The software that is used must support reading datasets from Excel worksheets, performing data manipulation such as filtering and cleaning data and outputting formats such as merged datasets and formats suitable for creating maps and tables for web publishing.
4. The standardized dataset (containing IPPs for all 9 basins) is then published to each Basin Roundtable's website, CWCB website, Colorado Water Plan website, GitHub repository and/or the Colorado Information Marketplace website in a machine-readable format to allow for statewide analysis and visualization.
5. Visualizations such as maps that use dataset attributes can be created using the statewide dataset. Links to example visualizations that utilize the IPP dataset will be provided via one of the above-mentioned websites.

6. The above input datasets and processed products can be used by Roundtables, consultants, CWCB staff, CWCB Board and IBCC members as appropriate.

D.4 RECOMMENDATIONS TO LINK IPP DATASET TO OTHER DATASETS

The IPP dataset has the potential to be linked to other datasets, for example:

- StateMod – the Project ID can be used as the node identifier in StateMod modeling (12-character limit).
- Source Water Route Framework (SWRF) – the SWRF contains a shapefile of points representing confluences of tributaries to streams with an attribute table that provides the GNIS ID and name of the tributary and also the GNIS ID and name of the stream to which the tributary joins. Using this information, it would be possible to determine all of the IPPs associated with an entire watershed, not just a single river. This information could assist with stream management planning.
- CWCB Grant programs - WSRF and Water Plan Grant applications could be updated to contain a question that asks if there is a Project ID for the project.

Appendix E: Dataset Electronic Files

The Open Water Foundation has created a private GitHub repository for electronic files related to this memorandum. Note that a GitHub log-in is required to access the information; contact Open Water Foundation to obtain a log-in or to request the information outside of the GitHub platform.

https://github.com/OpenWaterFoundation/swsi-data-ipps

The README file for the repository explains files that are included in repository including original data files, TSTool command files, processed output, and documents.

Analysis and Technical Update to the Colorado Water Plan

Technical Memorandum

Prepared for:

Colorado Water Conservation Board

Project Title:

Colorado Environmental and Recreational Database Documentation

Date: July 18, 2019

Prepared by: David Knight, Allison Wagner and Paniz Miesen, CDM Smith
Reviewed by: Sue Morea and Becky Dunavant, CDM Smith

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List of Acronyms

BRTs	basin roundtables
CDOW	Colorado Department of Wildlife
CDNR	Colorado Department of Natural Resources
COMID	common ID
CPW	Colorado Parks and Wildlife
CWCB	Colorado Water Conservation Board
Db	database
E&R	Environmental Recreational
E&Rdb	Environmental and Recreational Database
EnRec	Environment and Recreation
GIS	geographic information system
GNIS	Geographic Names Information System
HUC	Hydrological Unit Code
IPP	Identified Projects and Processes
NCNA	Nonconsumptive Needs Assessment
NCNAdb	Noncomsumptive Needs Assessment Database
NHD	National Hydrography Dataset
SRGAP	Southwest Regional Gap Analysis Project
SWRF	Source Water Route Framework
SWSI	Statewide Water Supply Initiative
USGS	United States Geological Survey
WSRA	Water Supply Reserve Account

Section 1: Introduction

A database was developed in 2010, known as the "Nonconsumptive Needs Assessment (NCNA) Database (db)" to help manage the nonconsumptive data received by basin roundtables (BRTs) and other stakeholders. The database included information related to nonconsumptive attributes, projects, and protections. A component of reviewing Environmental and Recreational (E&R) data for the Technical Update has been enhancing the NCNAdb. The enhanced NCNAdb is now referred to as the E&Rdb. The E&Rdb includes an enhanced technical foundation, a more engaging and meaningful user interface, and has been updated for better integration into the Colorado Water Planning process.

1.1 BACKGROUND

During the Statewide Water Supply Initiative (SWSI) 2010 process, the BRTs utilized mapping tools as a common technical platform to identify nonconsumptive needs focus areas within their basins. The BRTs initially reviewed a set of geographic information system (GIS) data layers developed by the NCNA Technical Roundtable. The term "data layer" refers to geographic data that represents a specific type of feature or attribute (e.g., wetlands or species habitat) and can also be referred to as a shapefile. After reviewing the data layers, the BRTs then suggested and contributed additional data layers as deemed appropriate for each basin.

Each basin used one of three methods to develop a summary map that highlighted NCNA focus areas:

- Method 1: NCNA focus areas in each basin were aggregated to the watershed level (US Geological Survey (USGS) 12-digit Hydrological Unit Code [HUC]).
- Method 2: NCNA focus areas in each basin were aggregated to the stream level using USGS information for stream segments provided by the National Hydrography Dataset (NHD).
- Method 3: Stream reaches were selected that represented most of the E&R activity within the basin. These stream reaches were selected based on a review of all available data layers and feedback from stakeholders and public outreach efforts.

During the SWSI 2010 process, the BRTs also identified projects and methods required to meet nonconsumptive needs. In 2010, the Colorado Water Conservation Board (CWCB) developed a survey to collect information on existing or planned nonconsumptive projects, methods and studies. CWCB ultimately facilitated 58 meetings to gather additional data from stakeholders. CWCB also collected data from agencies and projects such as Colorado Department of Natural Resources (DNR), Colorado Division of Wildlife (CDOW) and the Southwest Regional Gap Analysis Project (SRGAP).

The collected information was spatially digitized using the USGS NHD 12-digit stream segment dataset. A unique project ID and segment ID were given to all projects identified in surveys and interviews within the NCNAdb. Water Supply Reserve Account (WSRA) grant projects were also digitized in a similar fashion. A more detailed discussion on the NCNAdb is provided below.

The output of the Nonconsumptive Projects and Methods process included four maps that provided information on the location of projects and methods, the status of these projects and methods, and NCNA focus areas that had identified projects and methods completed or in progress.

The NCNAdb was developed beginning in 2010 to assist in the internal management of nonconsumptive data received from the BRTs. The NCNAdb contained key information related to nonconsumptive attributes, projects, and associated protections (direct or indirect). The content of the database was developed by a stakeholder-driven process that included members of the nine BRTs and statewide technical committees.

1.2 ENVIRONMENTAL AND RECREATIONAL DATABASE OVERVIEW

The E&Rdb is a Microsoft Access database formatted in Microsoft Access 2010 file format. Enhancements made to the NCNAdb to create the E&Rdb focused on three success factors: enhanced technical foundation, creating a meaningful user experience, and integration in the Colorado Water Planning process. A summary of each enhancement is provided below while additional detail can be found throughout the remainder of this technical memorandum.

1.2.1 ENHANCED TECHNICAL FOUNDATION

The previous NCNAdb utilized a spatial unit of analysis based on the USGS's NHD, specifically the common ID (COMID). This stream segment-based spatial unit was retired by USGS which required an update to the spatial unit of analysis within the enhanced database. The database now uses both the Source Water Route Framework (SWRF) and NHD (Geographic Names Information System (GNIS)) for spatial reference. The SWRF is a spatial data set developed only for the state of Colorado. Data in the database can be queried by HUC and/or stream segment.

Data processing procedures are critical to ensure accuracy, promote data quality, and create a process that can be adopted through training. A data loading procedure was developed to provide instructions and guidance for loading data into the database, be it new data or updates to existing data. The procedure streamlines the data loading process, facilitates transparency with the process, and improves the quality of data. Data loading templates have been developed in coordination with ongoing Identified Projects and Processes (IPP) database development so that E&R data are consistent and comparable for any future coordinated efforts.

1.2.2 ENGAGING MEANINGFUL USER EXPERIENCE

Enhancing the user experience included the development of user-friendly Excel-based templates for data loading. The templates have been created to streamline the data loading process and to increase data integrity through validations functions.

Spatial data from the database will be viewable through the existing CWCB Data Viewer. Data viewing through the CWCB Data Viewer benefits the BRTs and BIP process by providing an interactive visualization tool for retrieving data.

Standard Excel-based reports can now be used to retrieve data for additional analysis by database users. The focus of the standard reports is to provide the data for analysis in the next round of BIPs, not the analysis itself. The standard reports will ensure users are receiving a consistent dataset across the board as part of the BIP process and will be able to report back additional project, protection, and attribute information.

1.2.3 INTEGRATION INTO COLORADO WATER PLANNING PROCESS

Data have been updated within the E&Rdb to help inform the water planning process. The existing attributes list was consolidated to a manageable and consistent format across all basins to promote a unified language for attribute identification. The NCNAdb contained over 100 E&R attributes. The original attributes were reviewed and quality checked to identify repetitive or unreliable data sources and datasets. Closely related attributes that provided repetitive or overlapping data were consolidated into a single attribute. Additionally, previous attributes that did not have public data sources or datasets available to confirm spatial data were archived and not included in the updated attribute list. Several attributes were also renamed to better reflect the dataset and simplify database development. The final 58 attributes were grouped into "macro" categories that help increase organization of attributes and provide a foundation for the Colorado Environmental Flow Tool that was developed separately for the Technical Update.

Existing BIPs were reviewed for project information to be added to the E&Rdb. Due to inconsistent information, naming conventions, and lack of spatial reference, project data were not updated in this version of the db. Excel-based loading templates were developed in conjunction with the IPP database efforts so that future iterations of the E&Rdb can be expanded to include consistent project information to support planning for both consumptive and nonconsumptive needs.

1.3 REPORT OVERVIEW

The remainder of this technical memorandum contains the following sections:

- Section 2: Colorado Environmental and Recreational Database Updates – provides further details on the enhancements made to the NCNAdb including updates to the spatial unit, E&R attributes, and project information.
- Section 3: Intended Uses and Future Enhancements – discusses the capabilities and limitations of the E&Rdb as well as additional enhancements that could be implemented in future iterations of the E&Rdb to futher integrate into the Colorado Water Planning process.

Section 2: Colorado Environmental and Recreational Database Updates

A variety of updates were completed within the database in order to enhance the technical foundation, create an engaging and meaningful user experience, and provide for integration into the Colorado Water Planning process. Updates and data sources are discussed below.

Figure 2-1 show the key entities, or groups of data, and their relationships with each other within the E&Rdb. The E&Rdb contains seven core entities which include: Projects, Protections, Contacts, Segments, Segment Attribute Classes, Basins, and Attribute Classifications.

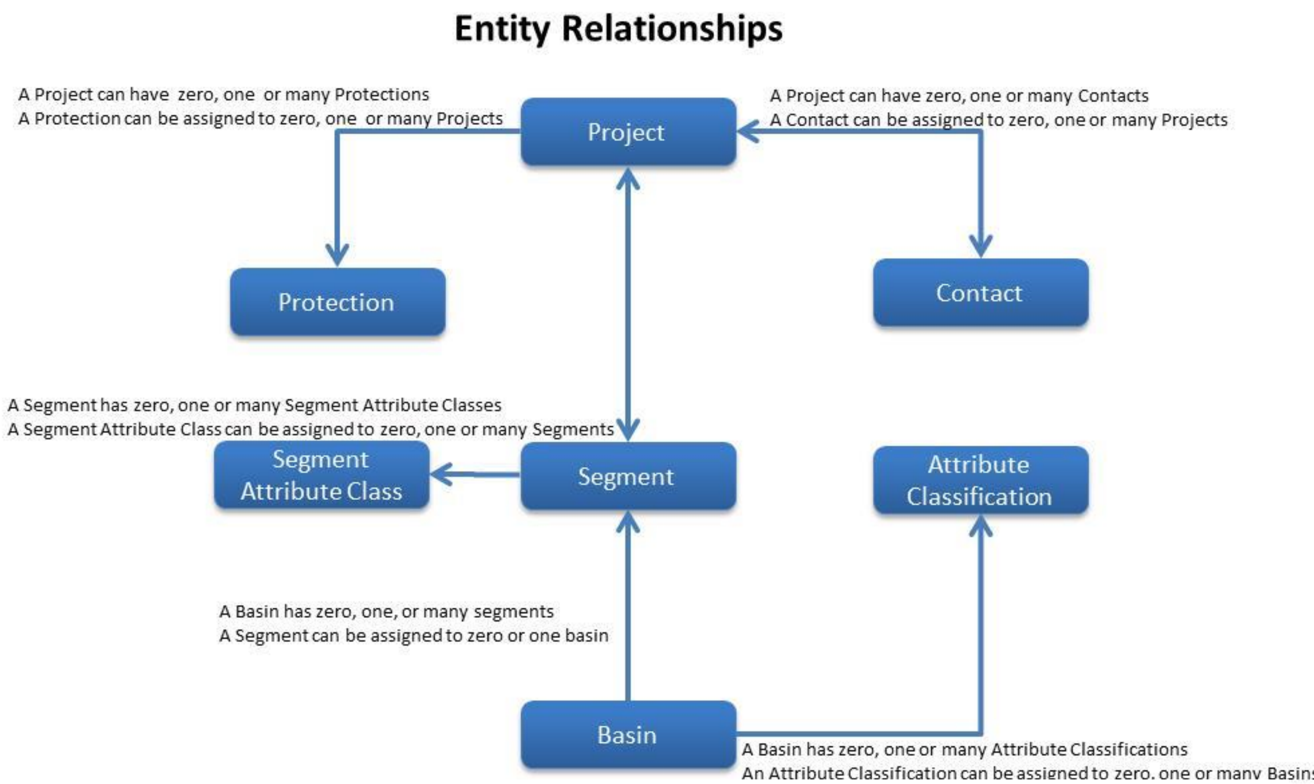

Figure 2-1: E&Rdb Relationships

2.1 SPATIAL UNIT

The previous NCNAdb utilized a spatial unit of analysis based on the USGS's NHD, specifically the COMID. This stream segment-based spatial unit was retired by USGS which required an update to the spatial unit of analysis within the enhanced database. The database now uses both the SWRF and NHD (GNIS) for spatial reference.

The SWRF is a spatial data set developed only for the state of Colorado. The SWRF extracts spatial data from the NHD if it a) has a GNIS record or b) is identified as source waters for decreed water rights in Colorado. It should be noted that while the SWRF reports all identification numbers in the GNIS ID field, not all identification numbers are official GNIS IDs. The dataset uses the USGS GNIS ID number as the unique identifier for a water feature, except those features that are decreed water rights but not GNIS recognized. These features are assigned a 5-digit identification number based on the district the feature is located (ex: the first identified stream in District 1 will have an assigned ID number 10001, the second identified stream will have the ID number 10002). The user should be aware that the SWRF water rights features may be assigned an identification number that is already in use by an official GNIS record located outside of Colorado. This dataset was utilized during the development of the South Platte BIP. Note that the SWRF does not include all tributaries covered by NHD. Because of this, the two coverages were married to create the spatial reference in the current version of the E&Rdb. With this spatial reference, the user is able to query data by stream segment and/or HUC.

2.2 E&R ATTRIBUTES

A total of 108 E&R attributes existed through the NCNA Focus Area Mapping efforts described in Section 1 (**Table B-1** of **Appendix B**). The original 108 attributes were reviewed and quality checked to identify repetitive or unreliable data sources and datasets. Closely related attributes that provided repetitive or overlapping data were consolidated into a single attribute. Additionally, previous attributes that did not have public data sources or datasets available to confirm spatial data were not included in the updated attribute list. A number of attributes were also renamed to better reflect the dataset and simplify database development. Note that original NCNA attributes are available for review in the archived NCNAdb. Refer to **Tables B-2** and **B-3** in **Appendix B** for a summary of E&R attributes that were consolidated or were not included in this update, respectively.

Once the previous attributes were consolidated and unreliable datasets were identified, the remaining E&R attributes were updated with the most recent public data sources and datasets. The final updated E&R attribute list is comprised of a total of 58 attributes as listed in **Table B-4**.

The updated E&R attributes were categorized into macro-attribute classes to facilitate map development. The E&Rdb will allow users to customize visible attribute layers by general macro-attribute class or by individual attribute. **Table B-5** identifies the individual attributes that make up each macro-attribute class.

2.3 PROJECT INFORMATION

In 2010, CWCB developed a survey to collect information on where there were existing or planned nonconsumptive projects, methods, and studies. Studies were included as they may recommend or inform the implementation of projects or methods that would provide protection or enhancement of E&R attributes. A GIS database of this information was created by digitizing the information.

In addition to identifying the spatial extent and status of the identified projects and methods, CWCB also examined what type of protection the project or method may provide to a given E&R attribute. Projects were classified as having direct or indirect protections based on a given E&R attribute. The definitions used for direct and indirect protections were as follows:

- Direct Protection – Projects and methods with components designed intentionally to protect a specific attribute. For example, ISFs provide direct protection of fish attributes. Additionally, restoration of a stream channel would provide direct protection of aquatic species.
- Indirect Protection – Projects and methods with components that were not designed to directly protect the specific attribute but may still provide protection. For example, flow protection for a fish species may also indirectly protect riparian vegetation that is located in the protected stream reach. Other examples include protective land stewardship or a wetland or bank stabilization effort that could indirectly protect aquatic species.

Project data from these efforts in 2010 has been maintained in the E&Rdb for reference.

During the last round of BIP development, BRTs were tasked with updating their completed, ongoing, and proposed projects and methods for addressing water supply needs. The intent was to include this updated information in the E&Rdb. However, upon detailed review of the BIPs, it was evident that the data needed to include updated project information lacked necessary information and were often inconsistent. Recommendations for future updates to project data within the E&Rdb are included in **Section 3**.

2.4 GEODATABASE

The E&Rdb deliverable includes supplemental geodatabases that contain the spatial data used for GIS. The spatial data were transmitted to CWCB for use in the CWCB online Data Viewer (https://gis.colorado.gov/dnrviewer/Index.html?viewer=cwcbviewer). The following 4 feature classes are available to view through the CWCB Data Viewer:

- "**Macroattributes by Segment**" (*SWRF_with_macroattributes*) and "**Macroattributes by HUC**" (WBDHU10_with_macroattributes) feature classes are stream lines and watershed boundaries respectively. Each feature has E&R attributes along with the macro-attribute categories: Fish, Wildlife, Recreation & Economy, Water Rights, and Physical Environment. These text fields are populated with a list of the macro-attributes existing within one mile of the stream segment or within the watershed boundary.
- "**Flow Tool Nodes**" (*Flow_Tool_Nodes_with_attributes*) is a point feature class containing nodes along stream segments that were selected for the Flow Tool. The basic attributes are USGS station number, name, and location data. Also included are the flow tool categories: Cold Water Fish, Warm Water Fish, Plains Fish, Boating, Wetlands/Riparian, and ISF. These fields are populated with a count of the relevant attributes that exist near that node.
- "**Legacy Project Data**" (*Project_attributes_by_reach*) is a line feature class which is a combination of the SWRF and the NHD from 2006 (as described in **Section 2.1;** see **Table 2.1** below). Feature duplicates exist where there is more than one project on a river segment to allow for each project to be recorded. For example, the South Platte River (GNIS_ID = 00201759) has 125 projects joined to it. Therefore, this feature exists a total of 125 times with different project attributes.

Table 2.1

Data Source	Number of Projects	Number of Unique River Segments	Records in Feature Class
SWRF	4,945	1,889	6,530
NHD 2006	3,614	7,171	13,491

Users can examine the attributes for a given project by querying the field [ProjectID] or [ProjectName]. See the sample query results for project 192 below (**Table 2.2**).

Table 2.2

GNIS_ID	GNIS_Name	ProjectID	ProjectName	ProjectStatus
00201748	Gunnison River	192	Recommended Minimum flows along the Gunnison and Colorado Rivers	Completed
00045730	Colorado River	192	Recommended Minimum flows along the Gunnison and Colorado Rivers	Completed

Section 3: Intended Use and Future Enhancements

The E&Rdb can be used by many stakeholders to add, view, or extract content related to non-consumptive needs. This includes projects and attributes. Attributes can be related to a project and/or a specific stream segment. The database can be utilized with the accompanying geodatabase for spatial analysis and viewing.

The current database is in a Microsoft Access format, and is designed to be used as a single user tool. Adding or modifying data should be done using the templates and providing templates to the database manager to upload.

The long-term objectives for the E&Rdb include:

1. Providing the database in an online solution. The solution would include a mapping component as well as a query tool for extracting data.
2. Expand the database content with projects and attributes provided by stakeholders.

In future iterations of the E&Rdb, the project data can be expanded to include additional information such as project dates and descriptions. It is recommended that this information be collected during the next round of BIPs. In addition, a meaningful project identifier (Project ID) should be utilized globally. The original project IDs from the data providers can be maintained while global project IDs will ensure the project IDs are uniquely identified with a meaningful ID nomenclature.

As data are collected, additional fields can be added to the tblProject that answer the following questions related to flow to help guide stakeholders in their project development and planning.

- Is the project flow-based? (Y/N)
- Does the project have a flow component? (Y/N)
- Have flow needs been identified and/or quantified? (Y/N)
- Does project success require securing flows? (Y/N)

3. Utilize the database for long-term water planning activities.

The ultimate goal for the future of the E&Rdb is to develop a comprehensive tool with the best available information on E&R projects and attributes that can be used by BRTs to inform planning and implementation of solutions to protect and enhance the E&R uses of the state's waters. The current updates and enhancements to the E&Rdb have set up a framework for reaching this goal in future iterations. Updating E&R attribute data at regular intervals, continued expansion of quality project information in the E&Rdb, and continued coordination with CWCB to work towards an online platform will ensure that the E&Rdb aligns with Colorado's water planning future.

Appendix A: Colorado Environmental and Recreational Database User's Guide

Analysis and Technical Update to the Colorado Water Plan

Technical Memorandum

Prepared for:

Colorado Water Conservation Board

Project Title:

Appendix A: Colorado Environmental and Recreational Database User's Guide

Date: July 18, 2019

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Section A1: Introduction

The Colorado Environmental and Recreational database (E&Rdb), originally named the Nonconsumptive Needs Assessment database (NCNAdb), was developed originally in 2010 by CDM Smith staff to assist in the internal management of nonconsumptive data received from Basin Roundtables (BRTs). The E&Rdb was initially used to support projects such as the Nonconsumptive Needs Assessment Focus Mapping and Noncsumptive Projects and Methods. In 2017, methodology enhancements were identified through a collaborative effort with the Colorado Water Conservation Board (CWCB). The enhancements focused on three success factors with respective methodologies that have been implemented:

Enhanced Technical Foundation

a. *Update Spatial Unit of Analysis*. The previous NCNAdb utilized a spatial unit of analysis based on the US Geological Survey (USGS) National Hydrography Dataset (NHD), specifically the common ID (COMID). This stream segment-based spatial unit was retired by USGS which required an update to the spatial unit of analysis within the enhanced database. The database now uses both the Colorado Source Water Route Framework (SWRF) and NHD (Geographic Names Information System (GNIS)) for spatial reference. The SWRF is a spatial data set developed only for the state of Colorado. Data in the database can be queried by HUC and/or stream segment.

b. *Update Data Processing Procedures*. Data processing procedures are critical to ensure accuracy, promote data quality, and create a process that can be adopted through training. A data loading procedure was developed to provide instructions and guidance for loading data into the database, be it new data or updates to existing data. The procedure streamlines the data loading process, facilitates transparency with the process, and improves the quality of data. Data loading templates have been developed in coordination with ongoing Identified Projects and Processes (IPP) database development so that E&R data are consistent and comparable for any future coordinated efforts.

Engaging Meaningful User Experience

a. *Excel Based Templates to Streamline Data Loading*. Excel-based templates for data loading were created to streamline the data loading process and to increase data integrity through validation functions.

b. *Online Mapping Tool*. Spatial data from the database will be viewable through the existing CWCB Data Viewer. Data viewing through the CWCB Data Viewer benefits the BRTs and Basin Implementation Plan (BIP) process by providing an interactive visualization tool for retrieving data.

c. *Feedback from Users*. Feedback from the BRT members and other E&Rdb users can help gauge the usefulness of the database and identify additional future needs. Feedback may be solicited in several ways, including: simple survey, continued outreach to users, and providing contact information at user end points such as the online mapping tool.
d. *Ease of Loading or Retrieving Information*. Standard Excel-based reports can be used to retrieve data to be used for analysis. The focus of the standard reports is to provide the data for analysis in the next round of BIPs, not the analysis itself. The standard reports will ensure E&Rdb users are receiving a consistent dataset across the board as part of the BIP process and will be able to report back additional project and attribute information.

Integration into Colorado Water Planning Process

a. *Improve Database Content.* The existing attributes list was consolidated to a manageable and consistent format across all basins to promote a unified language for attribute identification. The previous NCNAdb had over 100 E&R attributes. The original attributes were reviewed, and quality checked to identify repetitive or unreliable data sources and datasets. Closely related attributes that provided repetitive or overlapping data were consolidated into a single attribute. Additionally, previous attributes that did not have public data sources or datasets available to confirm spatial data were archived and not included in the updated attribute list. Several attributes were also renamed to better reflect the dataset and simplify database development. The final 58 attributes were grouped into "macro" categories that help increase organization of E&Rdb and provide a foundation for the Colorado Environmental Flow Tool.
b. *Expand Available Project Information*. Existing BIPs were reviewed for project information to be added to E&Rdb. Due to inconsistent information, naming conventions, and lack of spatial reference, project data were not updated in this version of the db. Excel-based loading templates were developed in conjunction with IPP database efforts so that future iterations of the E&Rdb can be expanded to include consistent project information to support planning for both consumptive and nonconsumptive needs.

This document details the technical specifications of the database and instructions for utilizing database features. In addition, information related to database structure and how to use the database is included.

A1.1 TECHNICAL SPECIFICATIONS

The E&Rdb is a Microsoft Access database formatted in Microsoft Access 2010 file format. The database contains several tables, queries, and modules. The database uses industry standards such as indexes, keys, referential integrity, normalization, and naming standards for tables and fields. In addition, the database contains a version table (tblApplicationVersion) which is used to identify the version of database, date of the version, and release notes related to the version.

A1.2 TABLES

There are two types of tables: reference tables and data tables. Reference tables are denoted with a 'ref' prefix and contain lookup values used within the data tables. Data tables contain the data records and their attributes. Data tables are denoted with a 'tbl' prefix.

The core data tables in the E&Rdb are described below in Table A1-1. A more in-depth data dictionary is provided as Attachment A-2 and is available within the database (tblDataDictionary).

Table A1-1. Core Data Tables

Table	Description
tblBasin	Contains Basin information
tblContact	Contact information such as name, address, phone
tblContactProject	Intermediate table relates Contacts to Projects
tblDatabaseLog	Used to document modifications to database
tblDataDictionary	Contains all tables/fields and respective attributes within the database
tblProject	Projects
tblProjectProtection	Protections assigned to projects and their attributes
tblSegment	Stream segments
tblSegmentAttributeClass	Attribute classifications for attributes along a given stream segment
tblSegmentProject	List of projects that are related stream segments, and the length of the segment
tblSegmentIDXRef	Contains cross-reference identification between COM ID and GNIS ID
tblSegmentReach	List of Reaches by COMID

Section A2: Understanding the Database Design

The first step in designing the database was to develop an understanding of the entities, or groups of data, and their relationships with each other. For the E&Rdb, there are seven core entities which include: Projects, Protections, Contacts, Segments, Segment Attribute Classes, Basins, and Attribute Classifications. The relationships between the core entities are noted in Figure A2-1 and a detailed relationship diagram is available in Attachment A-1.

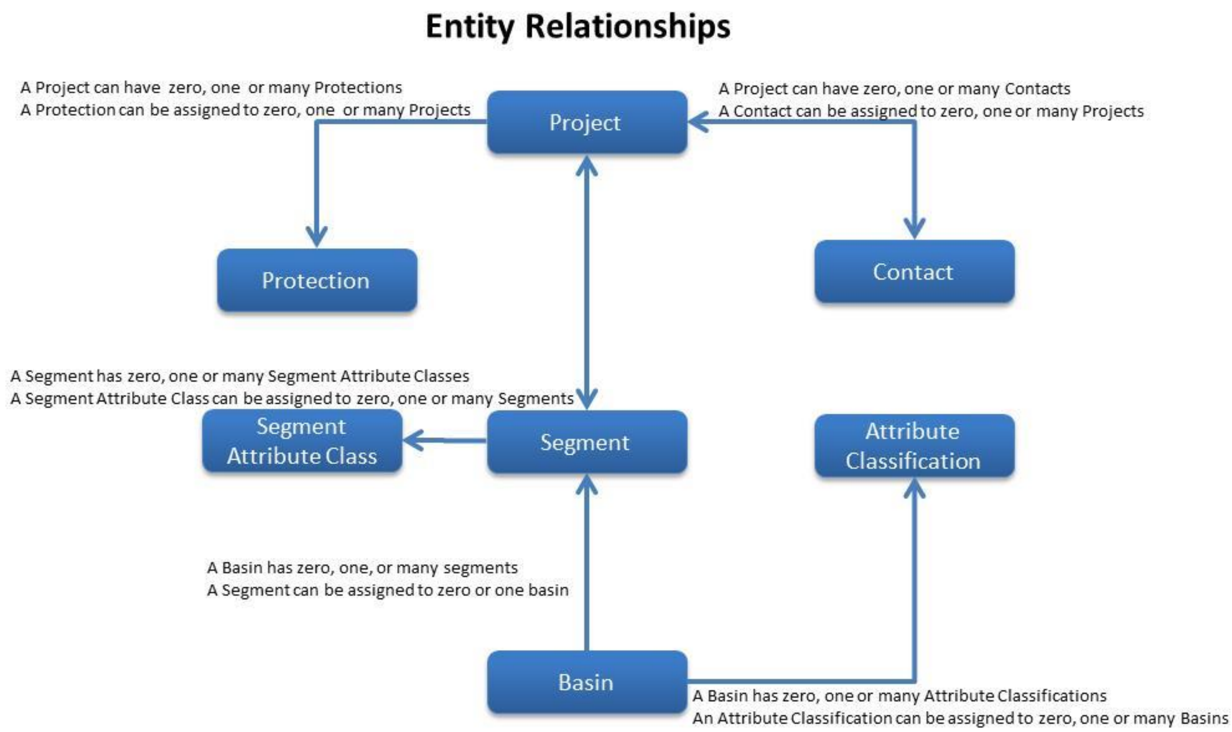


Figure A2-1. E&Rdb Entity Relationships

Once the entities and relationships were defined the database tables and relationships were designed. The database contains relational tables which are defined as two tables that share a relationship between each other. There are three types of relationships: A one-to-one (1:1), one-to-many (1:M), and a many-to-many (M:M).

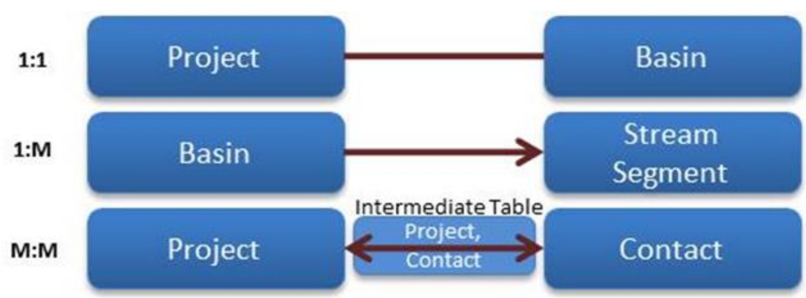


Figure A1-2. E&Rdb relationships

- **1:1 Relationship**: A one-to-one relationship is a relationship in which a record can have zero or one, and only one, related record from the other table. For example, a Project can belong in only one Basin. Note: the E&Rdb does not contain any 1:1 relationships. Rather, the core entity tables contain the related item as an attribute. So, the Project table contains a field, ProjectBasin.
- **1:M Relationship**: The 1:M relationship is the most common relationship. The relationship between the two tables has two parts. First, the parent table has a relationship to the child table (referred to as "has a"). The child table has a relationship to the parent tables (referred to as "belongs to"). Parents can have zero, one, or many children records. Conversely, children can only belong to one parent record. For example, a Basin can have one or many stream segments. And, a stream segment can only belong to one basin.
- **M:M Relationship**: Lastly, the M:M relationship is simply two 1:M relationships bound together. The two tables share the same relationship; in that, each table can have zero, one, or many records from the other table. M:M relationships are created using an intermediate table between the two tables. The intermediate table contains a unique compound key of the primary keys from each table. For example, a Project can have many contacts, and a contact can belong to many projects.

Figure A2-2. M:M Relationship Intermediate Table

The Physical Entity Relationship Diagram (ERD) below describes all the E&Rdb tables and relationships. The ERD is an effective mapping tool to help users understand how data tables are related.

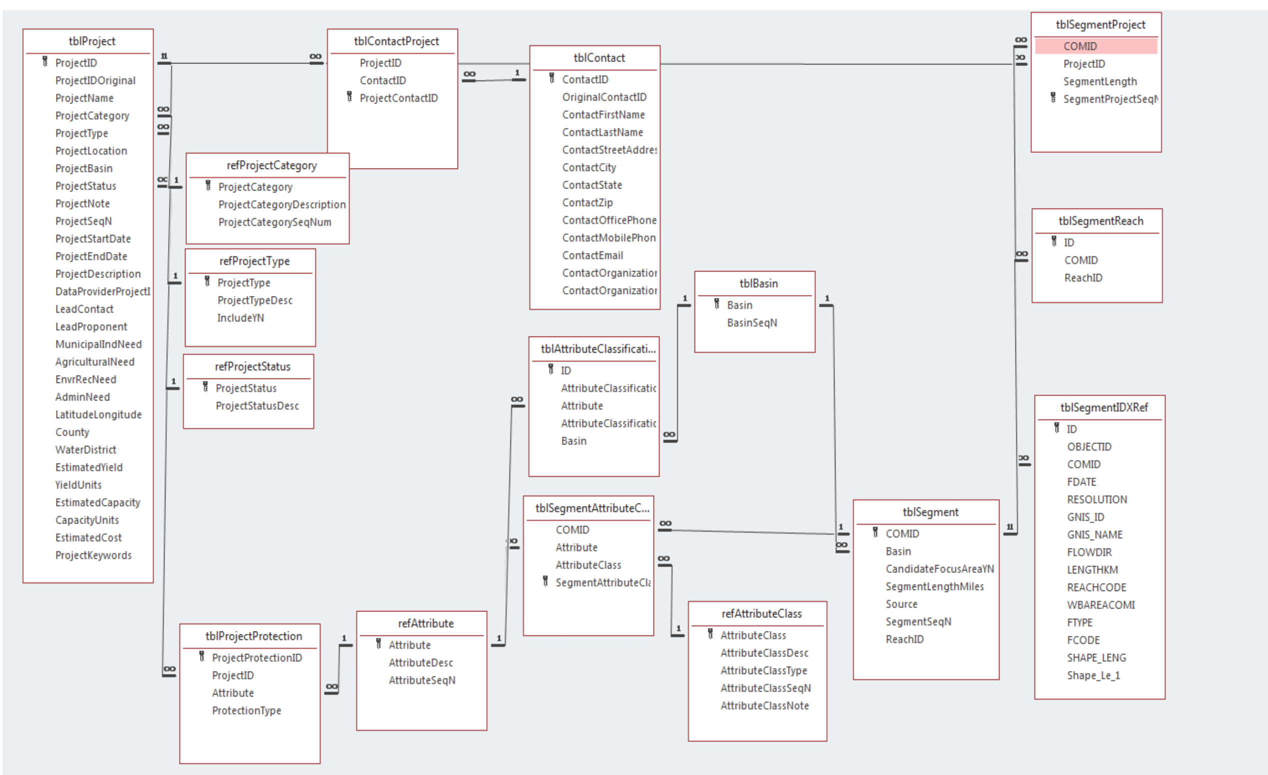


Figure A2-4. The Physical Entity Relationship Diagram

Section A3: Viewing, Editing and Reporting Tools

The database contains several tools to help browse, search and extract data. The following sections describe the process for utilizing the available tools.

A3.1 VIEW AND EDIT PROJECTS

There is a project data entry form that contains the projects and the related information.

1. From the Switchboard click Projects.
2. Select a project in the drop down.
3. There are several tabs containing groups of information about the selected project.
   a. General Info – more basic information about the project.
   b. Project Attributes – Attributes related to the selected project.
   c. Project Segments – Stream segments, by COMID, related to the selected project.
   d. Project Contacts – contacts related to the selected project.

A3.2 REPORTS

There are predefined reports that can be used to view and export data. To utilize the reports:

1. From the Switchboard click Reports.
2. Select a report from the drop down.
3. The report will be displayed in a new tab. The report utilizes a similar functionality to MS Excel with filtering, sorting and copy/paste.

A3.3 HOW TO QUERY THE DATABASE – ADVANCED USERS

Querying the database requires experience using Microsoft Access, a solid understanding of the question that is translated to a query, and familiarity with the database design to retrieve the information appropriately.

Microsoft Access provides a graphical interface for querying where users can add tables, drag fields, filter, and perform simple calculations. There are many resources available to help users become familiar with the query interface. For example, Microsoft provides a simple course (https://support.office.com/en-nz/article/Create-queries-for-a-new-database-babf5d53-66e7-405f-a6ad-c29c276ee6b0) which provides some hands-on experience.

Understanding the question that is translated to a query and familiarity with the database design are critical skills to ensure the correct data are retrieved. The example below describes two questions that seem very similar; however, they produce very different results.

- Example 1: "I'd like to see projects with their protections."
- Example 2: "I'd like to see all the projects and any protections that might be associated with the project."

In example 1, it could be implied that the user only wants projects that have related protections. The database design allows a project to have zero, one, or many protections. So, the resulting dataset will only contain projects with protections. Figure 3-1 illustrates how the join properties between the two tables that are intersecting (Inner Join).

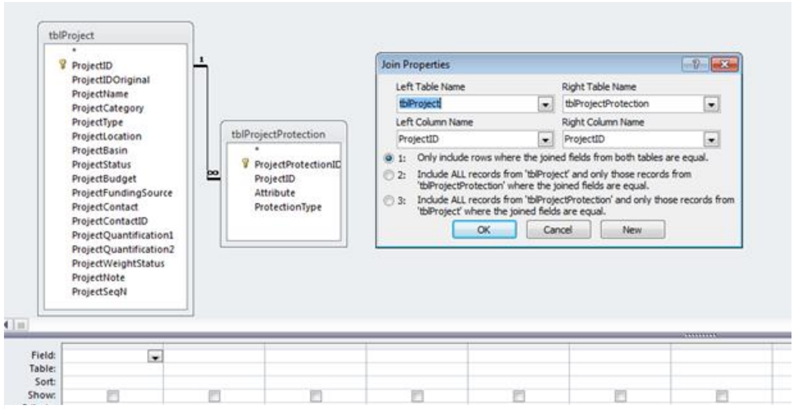


Figure A3-1. Intersecting Join Properties

Conversely, example 2 explicitly indicates the user wants all projects whether there are protections or not. The resulting dataset would include all projects and any related protections. In fact, example 2 produces over 4,400 additional projects that do not have protections. Figure 3-2 illustrates how the join properties between the two tables are inclusive (Outer Join).

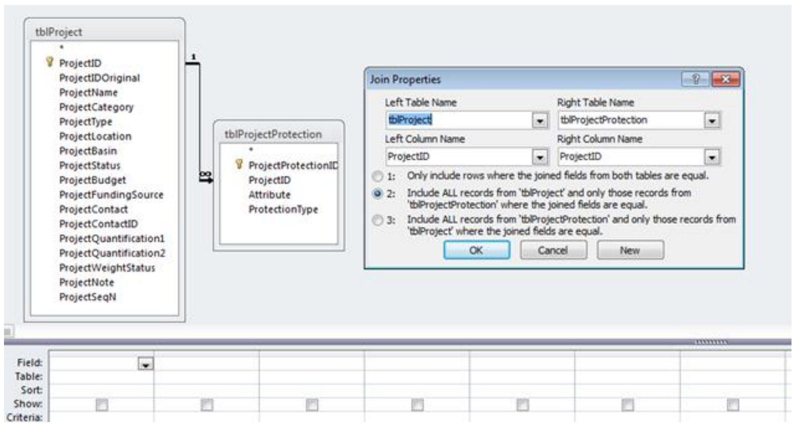


Figure A3-2. Inclusive Join Properties

A3.4 STEPS FOR QUERYING DATABASE

1. Identify question(s). This may seem simple at first glance. However, simple questions can have complex limitations, boundaries, and meaning. Understanding the data model and content can help surface these additional details.
2. Determine join properties. There are essentially three join types: inner, left outer, and right outer. The inner join is the point at which two tables intersect. The left outer join includes all the records from the left table AND records that match from the right table. The right outer join includes all records from the right table AND records that match from the left table. Figure 3-3 illustrates the different join types.

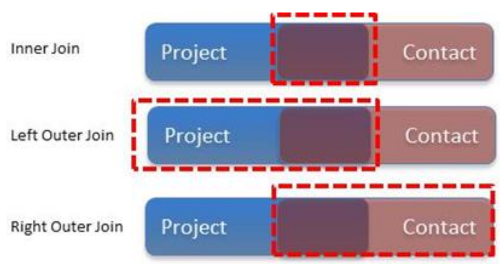


Figure A3-3. Types of Join Properties

3. Apply appropriate criteria filters (see Tips).
4. Comparison Operators. </> and <=/>= are often overlooked when translating question to query. Ensure the proper comparison is applied.

5. Logical Operators. The OR operator returns data that match any of the criteria. For example: "a" OR "b" will return data that contain either "a" or "b". The AND operator returns data where all criteria are met. For example: like "*a*" AND "*b*" will return data that contain an 'a' and a 'b'.
   a. Null values are not returned when using the NOT operator. For example, NOT Like "*a*" will not return NULL values. The criteria must explicitly filter for NULL: Not Like "*a*" OR IS NULL.
   b. Additional information on filtering can be found in Microsoft reference material (https://support.office.com/)
6. Perform quality checks. Quality checks include: performing record counts, evaluating opposing criteria (e.g., instead of LIKE "*a*", perform NOT LIKE "*a*" OR IS NULL), checking random 10% of records returned, or having a peer review the query. In addition, calculated fields and conditional statements should be reviewed thoroughly for accuracy.
7. Document and save results. The final query should be saved and the results exported for use. The filename of the export should match the query name in the database. Add a date stamp to the file name that serves as the date of query and version YYYYMMDDXXX .

Section 4: Performing Updates to Database

There are two types of updates to the database that can occur. Updates to the database structure (Data Model) include modifications to tables and fields, new tables and fields, and changes to relationships, indexes, or keys. Updates to data content (Data Definition) include adding records, removing records, or updating existing records. Best practices should be followed to ensure database changes are documented, tested, and distributed appropriately. An example database task documentation log has been provided in Attachment A-3. The document describes the tasks and their objectives, process for completing the tasks, and the quality control measures performed for each task.

A4.1 DATABASE TEMPLATE FOR ADDING OR UPDATING PROJECTS OR ATTRIBUTES

The database includes a Microsoft Excel Template that can be used to add or update projects and attributes associated with projects. It is important to follow the template instructions provided in the MS Excel Template.

Recommended Approach for database updates:

For database updates or additions, it is recommended that an advanced user provide the template to be filled out by the user. The template would be prepopulated with the existing projects and/or project attributes. This would allow users to locate the project to update and make modifications in the file.

The template contains instructions on how to fill It out. Once the template is filled out with the new projects:

1. From the Switchboard, select Import Data. This opens the Import form.
2. Select the type of import (Project or Attribute).
3. Select Add or Update from the drop down.
4. Locate the file by clicking the … button.
5. Click Import.
6. If records are being added:
   a. A message box will appear "You are about to run an append query…". Click Yes.
   b. Another message box will appear "You are about to append x row(s)". Click Yes.
7. If records are being updated:
   a. A message box will appear "You are about to run an update query…". Click Yes.
   b. Another message box will appear "You are about to update x row(s)". Click Yes.
8. In the event there are errors, another dialog box will appear with details. It is recommended to consult the database administrator for support.

A4.2 DATABASE LOG

The database includes a log table, tblDatabaseLog which can be used to document data model updates to the database. To use the database log table:

1. From the Switchboard, select Database Log.
2. Add new record.

   a. Insert a brief note in the LogNote field.
   b. The LogDOE will automatically populate with the date/time.
   c. Provide the author's name in LogAuthor.

The unique LogID can then be referenced in other documentation such as tblApplicationVersion.

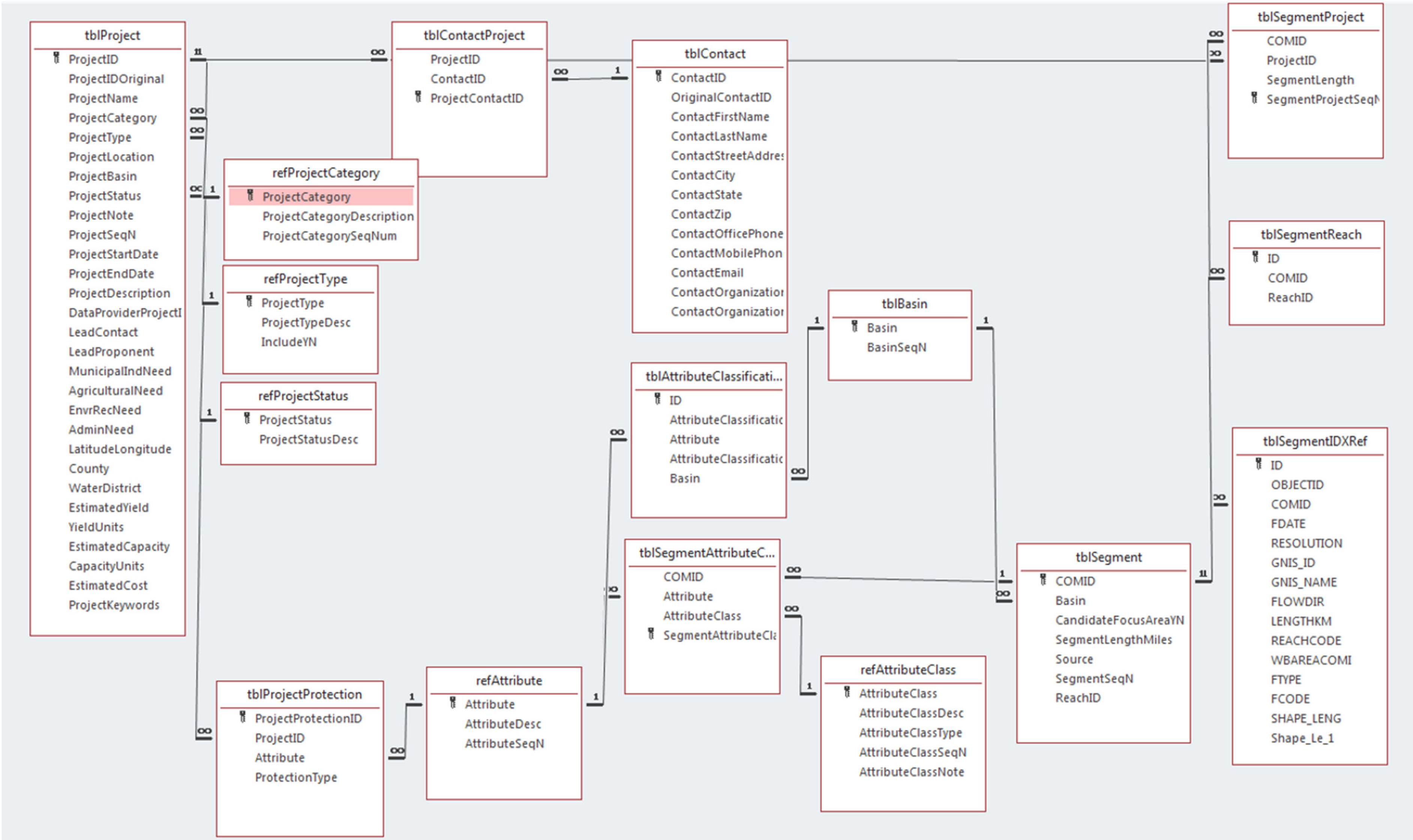
A4.3 HOW TO RE-VERSION DATABASE

A new feature within the database includes a simple versioning table, tblApplicationVersion. The purpose of the table is to provide a unique identifier for the database based on the state of its structure and content. Reports and queries that are produced from the database should reference the version number.

1. Open database.
2. Open the table, tblApplicationVersion.
3. Uncheck the ActiveYN box for the current version.
4. Add new record.
   a. The version number should be in the format of: YYYYMMDDXXX where, YYYY = 4 digit year; MM = 2 digit month; DD = 2 digit day; XXX = 3 digit incremental number starting with 001.
5. Example 1: New release on November 14, 2014 would be: 20141114001.
6. Example 2: A second release on November 14, 2014 would be: 20141114002.
   b. The version notes should include a brief summary of what modifications were performed. A more detailed summary can be referenced for large modifications.
   c. The version release date should be the date of the version.
   d. ActiveYN should be checked. Note: Only 1 version should be checked as active.

Appendix A-1: Entry Relationship Diagram

Entiry Relationship Diagram
EnRec ver 1.0.20190710001



Appendix A-2: Data Dictionary

ID	Table	Field	Description	DataType	Length	Nulls	Default	IndexList	Seed	Increment	able_or_Fie	Dictionary	cordDateEn
35	refAttribute										Table	312	11-Jul-19
36	refAttribute	Attribute	Unique attribute name	dbText	60	0		PrimaryKey			Field	313	11-Jul-19
37	refAttribute	AttributeDesc	Brief description of attribute	dbText	255	1					Field	314	11-Jul-19
38	refAttribute	AttributeSeqN	Autonumber generated by database	dbLong	4	1			1	1	Field	315	11-Jul-19
39	refAttributeClass										Table	316	11-Jul-19
40	refAttributeClass	AttributeClass	Classification used to group attributes	dbText	100	0		PrimaryKey			Field	317	11-Jul-19
41	refAttributeClass	AttributeClassDesc	Description of classification	dbText	255	1					Field	318	11-Jul-19
42	refAttributeClass	AttributeClassType	Groups classifications - attributes can be grouped in more than one classification	dbText	50	1					Field	319	11-Jul-19
43	refAttributeClass	AttributeClassSeqN	Autonumber generated by database	dbLong	4	1			1	1	Field	320	11-Jul-19
44	refAttributeClass	AttributeClassNote	Notes related to the classification	dbText	255	1					Field	321	11-Jul-19
45	refProjectCategory										Table	322	11-Jul-19
46	refProjectCategory	ProjectCategory		dbText	50	0		PrimaryKey			Field	323	11-Jul-19
47	refProjectCategory	ProjectCategoryDescription		dbText	255	1					Field	324	11-Jul-19
48	refProjectCategory	ProjectCategorySeqNum		dbLong	4	1			1	1	Field	325	11-Jul-19
49	refProjectStatus										Table	326	11-Jul-19
50	refProjectStatus	ProjectStatus	Unique project lifecycle status name	dbText	50	0		PrimaryKey			Field	327	11-Jul-19
51	refProjectStatus	ProjectStatusDesc	Describes project lifecycle status (planned, ongoing, completed)	dbText	255	1					Field	328	11-Jul-19
52	refProjectType										Table	329	11-Jul-19
53	refProjectType	ProjectType	Unique project type name	dbText	50	0		PrimaryKey			Field	330	11-Jul-19
54	refProjectType	ProjectTypeDesc	Describes project type	dbText	255	1					Field	331	11-Jul-19
55	refProjectType	IncludeYN	Yes/no field used for filtering out certain project types for statistics	dbBoolean	1	1	0				Field	332	11-Jul-19
56	Switchboard Items										Table	333	11-Jul-19
57	Switchboard Items	SwitchboardID		dbLong	4	0		PrimaryKey			Field	334	11-Jul-19
58	Switchboard Items	ItemNumber		dbInteger	2	0	0	PrimaryKey			Field	335	11-Jul-19
59	Switchboard Items	ItemText		dbText	255	1					Field	336	11-Jul-19
60	Switchboard Items	Command		dbInteger	2	1					Field	337	11-Jul-19
61	Switchboard Items	Argument		dbText	255	1					Field	338	11-Jul-19
71	tblAttributeClassificationGroup										Table	348	11-Jul-19
72	tblAttributeClassificationGroup	ID	Autonumber generated by database	dbLong	4	1		ID1			Field	349	11-Jul-19
73	tblAttributeClassificationGroup	AttributeClassificationVolume	Arbitrary value to identify a statistical grouping or volume	dbText	100	1					Field	350	11-Jul-19
74	tblAttributeClassificationGroup	Attribute	Attribute	dbText	60	1		{87A6B23C-234C-4F64-8E33-B13F2C1EB7D9}			Field	351	11-Jul-19
75	tblAttributeClassificationGroup	AttributeClassificationGroup	Groups attributes for statistics	dbText	100	1					Field	352	11-Jul-19
76	tblAttributeClassificationGroup	Basin	Basin	dbText	50	1		{37895C01-5944-45CC-8121-C6241E035671}			Field	353	11-Jul-19
77	tblBasin										Table	354	11-Jul-19
78	tblBasin	Basin		dbText	50	0		PrimaryKey			Field	355	11-Jul-19
79	tblBasin	BasinSeqN		dbLong	4	1			1	1	Field	356	11-Jul-19
80	tblContact										Table	357	11-Jul-19
81	tblContact	ContactID	Autonumber generated by database	dbLong	4	1		PrimaryKey	1	1	Field	358	11-Jul-19
82	tblContact	OriginalContactID	Contact ID from original data source	dbText	50	1		ContactID			Field	359	11-Jul-19
83	tblContact	ContactFirstName	First name of contact	dbText	50	1					Field	360	11-Jul-19
84	tblContact	ContactLastName	Last name of contact	dbText	50	1					Field	361	11-Jul-19
85	tblContact	ContactStreetAddress	Street address/PO of contact	dbText	50	1					Field	362	11-Jul-19
86	tblContact	ContactCity	Contact city	dbText	50	1					Field	363	11-Jul-19
87	tblContact	ContactState	Contact state	dbText	50	1					Field	364	11-Jul-19
88	tblContact	ContactZip	Contact zip code	dbText	50	1					Field	365	11-Jul-19
89	tblContact	ContactOfficePhone	Contact office phone	dbText	50	1					Field	366	11-Jul-19
90	tblContact	ContactMobilePhone	Contact mobile phone	dbText	50	1					Field	367	11-Jul-19
91	tblContact	ContactEmail	Contact email	dbText	50	1					Field	368	11-Jul-19
92	tblContact	ContactOrganization	Primary contact associated with contact	dbText	50	1					Field	369	11-Jul-19
93	tblContact	ContactOrganizationWebsite	Organization website	dbText	100	1					Field	370	11-Jul-19
94	tblContactProject										Table	371	11-Jul-19
95	tblContactProject	ProjectID		dbText	255	1		{8421B0CF-9A4C-4D9A-A1D1-FEF83AA85C7E}, ProjectID			Field	372	11-Jul-19
96	tblContactProject	ContactID		dbLong	4	1		{19C3291B-2EA4-49D0-8ADD-33BD4626B2CF}, ContactID			Field	373	11-Jul-19
97	tblContactProject	ProjectContactID		dbLong	4	1		PrimaryKey	1	1	Field	374	11-Jul-19
98	tblDatabaseLog										Table	375	11-Jul-19
99	tblDatabaseLog	LogNote		dbMemo	0	1					Field	376	11-Jul-19
100	tblDatabaseLog	LogDOE		dbDate	8	1	=Now()				Field	377	11-Jul-19
101	tblDatabaseLog	LogAuthor		dbText	255	1					Field	378	11-Jul-19
102	tblDatabaseLog	LogID		dbLong	4	1		LogID, PrimaryKey	1	1	Field	379	11-Jul-19
103	tblProject										Table	380	11-Jul-19
104	tblProject	ProjectID	A Unique Project ID was given to each project within this database.	dbText	50	0		PrimaryKey, ProjectID			Field	381	11-Jul-19
105	tblProject	ProjectIDOriginal	Project ID supplied in original data source	dbText	50	1					Field	382	11-Jul-19
106	tblProject	ProjectName	Name of project	dbText	200	1					Field	383	11-Jul-19

ID	Table	Field	Description	DataType	Length	Nulls	Default	IndexList	Seed	Increment	able_or_Fie	DictionaryS	cordDateEn
107	tblProject	ProjectCategory	There were 5 major project categories developed by CDM/CWCB (Instream Flow, CWCB Restoration Projects, Interviewed/Surveyed Projects, Water Supply Reserve Account Projects, Stewardship Projects, and Colorado Division of Wildlife Projects).	dbText	100	1		refProjectCategorytblProject			Field	384	11-Jul-19
108	tblProject	ProjectType	The type of the project (i.e. instream flow, restoration, habitat improvement, etc.).	dbText	50	1		{ACF272A2-BD00-4B4F-A3EA-7642862C6A8A}			Field	385	11-Jul-19
109	tblProject	ProjectLocation	A description of the project location.	dbText	150	1					Field	386	11-Jul-19
110	tblProject	ProjectBasin	Basin assigned to the project. Note: This is not used to determine the actual basin which the project sits within spatially.	dbText	20	1					Field	387	11-Jul-19
111	tblProject	ProjectStatus	The current status of a project (planned/proposed, ongoing or completed).	dbText	50	1		{78453DD5-3018-4130-A2C4-045501774630}			Field	388	11-Jul-19
112	tblProject	ProjectNote	Comments associated to any project or other miscellaneous fields.	dbText	255	1					Field	389	11-Jul-19
113	tblProject	ProjectSeqN	Autonumber generated by database	dbLong	4	1			1	1	Field	390	11-Jul-19
114	tblProject	ProjectStartDate	Project start date	dbDate	8	1					Field	391	11-Jul-19
115	tblProject	ProjectEndDate	Project end date	dbDate	8	1					Field	392	11-Jul-19
116	tblProject	ProjectDescription	Brief description of project	dbMemo	0	1					Field	393	11-Jul-19
117	tblProject	DataProviderProjectID	Project or Row ID provided by data provider	dbText	255	1		DataProviderProjectID			Field	394	11-Jul-19
118	tblProject	LeadContact	Person that can be contacted regarding the project and their affiliation. Name/Organization	dbText	255	1					Field	395	11-Jul-19
119	tblProject	LeadProponent	Indicates main entity proposing/leading project. Name/Email/Phone	dbText	255	1					Field	396	11-Jul-19
120	tblProject	MunicipalIndNeed	% of project dedicated to need	dbDecimal	16	1	0				Field	397	11-Jul-19
121	tblProject	AgriculturalNeed	% of project dedicated to need	dbDecimal	16	1	0				Field	398	11-Jul-19
122	tblProject	EnvrRecNeed	% of project dedicated to need	dbDecimal	16	1	0				Field	399	11-Jul-19
123	tblProject	AdminNeed	% of project dedicated to need	dbDecimal	16	1	0				Field	400	11-Jul-19
124	tblProject	LatitudeLongitude	Latitude and Longitude of the project's general point location in decimal degrees.	dbText	100	1					Field	401	11-Jul-19
125	tblProject	County	County where project is located	dbText	100	1					Field	402	11-Jul-19
126	tblProject	WaterDistrict	Water District where project is located	dbText	100	1					Field	403	11-Jul-19
127	tblProject	EstimatedYield	Average yield of a project that may be estimated using BIP modeing. Or how much water will be kept in a stream (average flow rate). Additional guidance will need to be provided.	dbText	200	1					Field	404	11-Jul-19
128	tblProject	YieldUnits	Unit of measure for yield; either acre-feet per year (AFY) or cubic-feet-per-second (cfs).	dbText	200	1					Field	405	11-Jul-19
129	tblProject	EstimatedCapacity	Maximum amount of water the project store, divert, convey, etc. For E&R project, this could be linear miles of stream or area of watershed effected.	dbText	200	1					Field	406	11-Jul-19
130	tblProject	CapacityUnits	Unit of measure for capacity; either acre-feet (AF), acre-feet per year (AFY), million gallons (MG), million gallons per day (MGD), cubic-feet-per-second (cfs), stream miles, area (acres).	dbText	200	1					Field	407	11-Jul-19
131	tblProject	EstimatedCost	Total cost to implement the project including capital and operations and maintenance (O&M).	dbCurrency	8	1	0				Field	408	11-Jul-19
132	tblProject	ProjectKeywords		dbText	255	1					Field	409	11-Jul-19
133	tblProjectProtection										Table	410	11-Jul-19
134	tblProjectProtection	ProjectProtectionID	Autonumber generated by database	dbLong	4	1		PrimaryKey	1	1	Field	411	11-Jul-19
135	tblProjectProtection	ProjectID	A Unique Project ID was given to each project within this database.	dbText	50	1		{0B4E96A9-2478-4B8F-88A6-417350E9EFCF}, Ukey1			Field	412	11-Jul-19
136	tblProjectProtection	Attribute	This attribute either directly or indirectly protected by the project.	dbText	60	1		{84E74A07-B3E8-494F-B7BD-226A8356B2A3}, Ukey1			Field	413	11-Jul-19
137	tblProjectProtection	ProtectionType	The protection (D-Direct, I-Indirect and DI-Both) were assigned to COMIDS based on wheither the existing/ongoing/completed project has a form of protection for the specific attribute.	dbText	2	1					Field	414	11-Jul-19
145	tblSegment										Table	422	11-Jul-19
146	tblSegment	COMID	A COMID is a unique value associated to USGS National Hydrography Dataset	dbLong	4	0		COMID, PrimaryKey			Field	423	11-Jul-19
147	tblSegment	Basin	Basin	dbText	50	1		{E850880D-F81E-449C-8E0A-11DBCF509CFB}			Field	424	11-Jul-19
148	tblSegment	CandidateFocusAreaYN	This field determines if the COMID is located within an Environmental and Recreational Stream Segment designated by the Basin Round Table.	dbBoolean	1	1	0				Field	425	11-Jul-19
149	tblSegment	SegmentLengthMiles	Length of the segment calculated in GIS.	dbDecimal	16	1					Field	426	11-Jul-19
150	tblSegment	Source	Original data source of segment	dbText	50	1					Field	427	11-Jul-19
151	tblSegment	SegmentSeqN	Autonumber generated by database	dbLong	4	1			1	1	Field	428	11-Jul-19

ID	Table	Field	Description	DataType	Length	Nulls	Default	IndexList	Seed	Increment	able_or_Fie	Dictionary$	cordDateEn
152	tblSegment	ReachID	Reach IDs were developed in NCNA Phase I to identify Basin Roundtable Attributes (please note these are only associated to a couple of basins).	dbLong	4	1		ReachID			Field	429	11-Jul-19
153	tblSegmentAttributeClass										Table	430	11-Jul-19
154	tblSegmentAttributeClass	COMID	A COMID is a unique value associated to USGS National Hydrography Dataset	dbLong	4	1		{9E8393E8-B13A-4B38-9C9A-8411A467EDED}, UKey1			Field	431	11-Jul-19
155	tblSegmentAttributeClass	Attribute	These are the Basin Roundtables environment and recreational attributes developed in Phase I NCNA	dbText	60	1		{00F38929-CF70-41E1-B1DD-153E65B8DAA7}, UKey1			Field	432	11-Jul-19
156	tblSegmentAttributeClass	AttributeClass	Attribute categories also develoepd in Phase I NCNA	dbText	100	1		{445CE058-EACA-437C-B769-7FEB4D3E0EDB}			Field	433	11-Jul-19
157	tblSegmentAttributeClass	SegmentAttributeClassSeqN	Autonumber generated by database	dbLong	4	1		PrimaryKey	1	1	Field	434	11-Jul-19
158	tblSegmentIDXRef										Table	435	11-Jul-19
159	tblSegmentIDXRef	ID		dbLong	4	1		ID			Field	436	11-Jul-19
160	tblSegmentIDXRef	OBJECTID		dbDouble	8	1		OBJECTID			Field	437	11-Jul-19
161	tblSegmentIDXRef	COMID		dbLong	4	1		{93CA24E0-83B4-43E1-B8E1-20AB41B12620}, COMID			Field	438	11-Jul-19
162	tblSegmentIDXRef	FDATE		dbDate	8	1					Field	439	11-Jul-19
163	tblSegmentIDXRef	RESOLUTION		dbText	255	1					Field	440	11-Jul-19
164	tblSegmentIDXRef	GNIS_ID		dbText	255	1		GNIS_ID			Field	441	11-Jul-19
165	tblSegmentIDXRef	GNIS_NAME		dbText	255	1					Field	442	11-Jul-19
166	tblSegmentIDXRef	FLOWDIR		dbText	255	1					Field	443	11-Jul-19
167	tblSegmentIDXRef	LENGTHKM		dbDouble	8	1					Field	444	11-Jul-19
168	tblSegmentIDXRef	REACHCODE		dbText	255	1		REACHCODE			Field	445	11-Jul-19
169	tblSegmentIDXRef	WBAREACOMI		dbDouble	8	1					Field	446	11-Jul-19
170	tblSegmentIDXRef	FTYPE		dbText	255	1					Field	447	11-Jul-19
171	tblSegmentIDXRef	FCODE		dbDouble	8	1		FCODE			Field	448	11-Jul-19
172	tblSegmentIDXRef	SHAPE_LENG		dbDouble	8	1					Field	449	11-Jul-19
173	tblSegmentIDXRef	Shape_Le_1		dbDouble	8	1					Field	450	11-Jul-19
174	tblSegmentProject										Table	451	11-Jul-19
175	tblSegmentProject	COMID	A COMID is a unique value associated to USGS National Hydrography Dataset	dbLong	4	1		{ADF251B5-E304-40C1-B8DA-E1320DBE3F53}, UKey1			Field	452	11-Jul-19
176	tblSegmentProject	ProjectID	A Unique Project ID was given to each project within this database.	dbText	50	1		{2F6CAE17-E79F-41AD-8A88-24EDA1E9ABC7}, UKey1			Field	453	11-Jul-19
177	tblSegmentProject	SegmentLength	Lengh of the segment that was calculated in GIS.	dbDecimal	16	1	0				Field	454	11-Jul-19
178	tblSegmentProject	SegmentProjectSeqN	Autonumber generated by database	dbLong	4	1		PrimaryKey	1	1	Field	455	11-Jul-19
179	tblSegmentReach										Table	456	11-Jul-19
180	tblSegmentReach	ID	Autonumber generated by database	dbLong	4	1		PrimaryKey	1	1	Field	457	11-Jul-19
181	tblSegmentReach	COMID	A COMID is a unique value associated to USGS National Hydrography Dataset	dbLong	4	1		{CC6866CF-B5C7-4F29-978F-7EA5404AFAE8}, COMID			Field	458	11-Jul-19
182	tblSegmentReach	ReachID	Reach IDs were developed in Phase I NCNA to identify Basin Roundtable Attributes (please note these are only associated to a couple of basins).	dbLong	4	1		ReachID			Field	459	11-Jul-19

Appendix A-3: Database Template for Adding or Updating

Field -->	**Project_ID**	Project_Name	Project_Description	Project_Start_Date	Project_End_Date
Data Type/Size -->	**Text(200)**	Text(200)	Text(63,999)	Date	Date
Description ---> LEAVE THIS COLUMN BLANK	Unique project identifier in the format of Basin-Year-Number (i.e., ARK-2015-00001) that also allows for cross-reference between datasets and use by software tools.	Name of project (Required)	Brief description of project	Start date of project	End date of project

Field -->	Status	Keywords	Project_Location	Project_Type	Project_Category
Data Type/Size -->	Look up	Text(200)	Text (200)	Look up	Look up
Description ---> LEAVE THIS COLUMN BLANK	See look up values	Keywords are used for searching projects.	Brief description of location	See look up values	There were 5 major project categories developed by CDM/CWCB (Instream Flow, CWCB Restoration Projects, Interviewed/Surveyed Projects, Water Supply Reserve Account Projects, Stewardship Projects, and Colorado Division of Wildlife Projects).

Field -->	Lead_Proponent	Lead_Contact	Municipal_Ind_Need	Agricultural_Need
Data Type/Size -->	Text(200)	Text(200)	Percentage	Percentage
Description ---> LEAVE THIS COLUMN BLANK	Indicates main entity proposing/leading project. Name/Email/Phone	Person that can be contacted regarding the project and their affiliation. Name/Organization	% of project dedicated to need	% of project dedicated to need

Field -->	Envr_Rec_Need	Admin_Need	Latitude_Longitude	County
Data Type/Size -->	Percentage	Percentage	Text(200)	Text(200)
Description ---> LEAVE THIS COLUMN BLANK	% of project dedicated to need	% of project dedicated to need	Latitude and Longitude of the project's general point location in decimal degrees.	County where project is located

Field -->	Water_District	Estimated_Yield	Yield_Units	Estimated_Capacity
Data Type/Size -->	Text(200)	Text(200)	Text(200)	Text(200)
Description ---> LEAVE THIS COLUMN BLANK	Water District where project is located	Average yield of a project that may be estimated using BIP modeing. Or how much water will be kept in a stream (average flow rate). Additional guidance will need to be provided.	Unit of measure for yield; either acre-feet per year (AFY) or cubic-feet-per-second (cfs).	Maximum amount of water the project store, divert, convey, etc. For E&R project, this could be linear miles of stream or area of watershed effected.

Field -->	Capacity_Units	Estimated_Cost
Data Type/Size -->	Text(200)	Currency
Description ---> LEAVE THIS COLUMN BLANK	Unit of measure for capacity; either acre-feet (AF), acre-feet per year (AFY), million gallons (MG), million gallons per day (MGD), cubic-feet-per-second (cfs), stream miles, area (acres).	Total cost to implement the project including capital and operations and maintenance (O&M).

Appendix B: Environmental and Recreational Attribute Data

Table B-1 NCNA Focus Area Mapping Attributes

Attribute	Source(s)
Active Bald Eagle Nests	NHDPlus V2, USFWS, CPW
Arkansas Darter	CNHP, CPW, USFWS
Arkansas Wilderness Areas	
Audubon Important Bird Areas	Audubon
Birding Trails	Audubon
BLM – Wilderness Study Areas	
Bluehead Sucker	CNHP, CPW, USFWS
Boreal Toad	CNHP, CPW, USFWS
Brassy Minnow	CNHP, CPW, USFWS
Colorado Outstanding Waters	CDPHE WQCD
Colorado Pikeminnow	CNHP, CPW, USFWS
Common Garter Snake	CNHP, CPW, USFWS
Common Shiner	CNHP, CPW, USFWS
CWCB Instream Flow Water Rights	
CWCB Natural Lake Level Water Rights	
Ducks Unlimited Projects	Ducks Unlimited
Eligible Wild and Scenic	
Federally Listed Critical Habitat	NHDPlus V2, USFWS
Flannelmouth Sucker	CNHP, CPW, USFWS
Flatwater Boating	
GMUG Wilderness Area Waters	
Hebron Slough Ponds	
High Recreation Lakes and Reservoirs	
High Recreation Rivers	
Humpback Chub	CNHP, CPW, USFWS
Important Reservoirs, Lakes, and Ponds	
Iowa Darter	CNHP, CPW, USFWS
Lake Chub	CNHP, CPW, USFWS
Lake Fishing	
Least Tern	CNHP, CPW, USFWS
Lesser Prairie Chicken	CNHP, CPW, USFWS
Northern Cricket Frog	CNHP, CPW, USFWS
Northern Leopard Frog	CNHP, CPW, USFWS
Northern Redbelly Dace	CNHP, CPW, USFWS
Other Fishing Streams and Lakes	
Peregrine	CNHP, CPW, USFWS
Piping Plover	CNHP, CPW, USFWS

Attribute	Source(s)
Plains Minnow	CNHP, CPW, USFWS
Preble's Meadow Jumping Mouse	CNHP, CPW, USFWS
Pueblo Fishing	
Rafting / Kayaking / Flatwater Reaches	
Rare Plants	
Razorback Sucker	CNHP, CPW, USFWS
Recreational In-Channel Diversion Structures	
Reservoir and Lake Fishing	
Rio Grande Chub	CNHP, CPW, USFWS
Rio Grande Sucker	CNHP, CPW, USFWS
River and Stream Fishing	
River Otter	CNHP, CPW, USFWS
Roundtail Chub	CNHP, CPW, USFWS
Sandhill Crane	CNHP, CPW, USFWS
Significant Plant Communities	
Stonecat	CNHP, CPW, USFWS
Suckermouth Minnow	CNHP, CPW, USFWS
Waterfowl Habitat	
Waterfowl Hunting / Viewing	
Whitewater Boating OR Rafting	
Wood Frog	CNHP, CPW, USFWS
Yellow Mud Turtle	CNHP, CPW, USFWS
Additional Wilderness Areas and Wilderness Study Areas	
Arkansas Headwaters Recreation Areas	
Arkansas State Wildlife Areas and State Fishing Units	
Bald Eagle Sites	NHDPlus V2, USFWS, CPW
Bald Eagle Winter Concentrations	NHDPlus V2, USFWS, CPW
Bonytail Chub	CNHP, CPW, USFWS
Camelback Roubideau Wilderness Study Area Waters	
Colorado River Cutthroat Trout	CNHP, CPW, USFWS
Durango Natural Studies	
Fish Hatchery	
Gold Metal Trout Lakes	
Gold Metal Trout Streams	
Greater Sandhill Crane	CNHP, CPW, USFWS
Greenback Cutthroat Trout	CNHP, CPW, USFWS
Important Wetlands	NHDPlus V2, FEMA, NLCD, Landfire, NWI
Kayaking	

Attribute	Source(s)
National Wetlands Inventory	NHDPlus V2, FEMA, NLCD, Landfire, NWI
Osprey Active Nest Site	NHDPlus V2, USFWS, CPW
Osprey Foraging Area	NHDPlus V2, USFWS, CPW
Plains Leopard Frog	CNHP, CPW, USFWS
Plains Orangethroat Darter	CNHP, CPW, USFWS
Rafting / Kayaking	
Rare Aquatic-Dependent Plants	
Rare Plant Communities	
Razorback Sucker, Humpback Chub, Colorado Pikeminnow	CNHP, CPW, USFWS
Rio Grande Cutthroat Trout	CNHP, CPW, USFWS
Riparian / Wetlands	NHDPlus V2, FEMA, NLCD, Landfire, NWI
River Otter Sightings	CNHP, CPW, USFWS
Sandhill Crane Staging / Nesting Areas	NHDPlus V2, USFWS
Significant Fishing Waters	
Significant Riparian / Wetland Communities	NHDPlus V2, FEMA, NLCD, Landfire, NWI
Significant Riparian / Wetland Plants	NHDPlus V2, FEMA, NLCD, Landfire, NWI
Signification Fishing Waters	
Southwestern Willow Flycatcher	CNHP, CPW, USFWS
Stream Fishing	
Wetlands	NHDPlus V2, FEMA, NLCD, Landfire, NWI
Whitewater Boating	
Wilderness Area Waters	
Wildlife Viewing and Waterfowl Hunting	
WQCD Outstanding Waters	CDPHE WQCD
Aquatic_Ec	
Geomorph_F	
Rec_Boatin	
RICD	
RipWet_Eco	NHDPlus V2, FEMA, NLCD, Landfire, NWI
Trout Lakes	
Trout Streams	
Water_Qual	CDPHE WQCD
Waterfowl Hunting	

Table B-2 Attribute Consolidation

Original Attributes	Consolidated Attribute	Source(s)
Colorado Outstanding Waters	Colorado Outstanding Waters	CDPHE WQCD
WQCD Outstanding Waters		
Gold Medal Trout Lakes	Gold Medal Trout Lakes	CPW
Trout Lakes		
Gold Medal Trout Streams	Gold Medal Trout Streams	CPW
Trout Streams		
Lake Fishing	CPW Fishing Atlas	CPW
Reservoir and Lake Fishing		
Other Fishing Streams and Lakes		
Pueblo Fishing		
Significant Fishing Waters		
River and Stream Fishing		
Stream Fishing		
Arkansas State Wildlife Areas and State Fishing Units		
Rec_Boatin	Recreational Boating/Kayaking/Rafting	BLM, USFS
Flatwater Boating		
Rafting / Kayaking / Flatwater Reaches		
Kayaking		
Rafting / Kayaking		
Whitewater Boating OR Rafting		
Whitewater Boating		
Arkansas Headwaters Recreation Areas		
Significant Riparian / Wetland Communities	National Wetlands Inventory	NWI
Significant Riparian / Wetland Plants		
Riparian / Wetlands		
RipWet_Eco		
National Wetlands Inventory		
Important Wetlands		
Wetlands		
Aquatic_Ec		
Rare Plants	Plant Communities	
Rare Plant Communities		
Significant Plant Communities		
Rare Aquatic-Dependent Plants		
Audubon Important Bird Areas	Important Bird Areas	Audubon
Birding Trails		
Waterfowl Habitat	CPW Fishing and Hunting	CPW
Wildlife Viewing and Waterfowl Hunting		
Waterfowl Hunting / Viewing		
Waterfowl Hunting		
Sandhill Crane	Sandhill Crane Habitat	CPW
Sandhill Crane Staging / Nesting Areas		
River Otter	River Otter Habitat	CPW
River Otter Sightings		
Additional Wilderness Areas and Wilderness Study Areas	Wilderness Areas	BLM
Wilderness Area Waters		
Arkansas Wilderness Areas		
BLM Wilderness Study Areas		

GMUG Wilderness Area Waters

Table B-3 Archived Attributes

Original Attribute	Reason for Dropping
Razorback Sucker, Humpback Chub, Colorado Pikeminnow	Separate attribute layers for Razorback Sucker, Humpback Chub, and Colorado Pikeminnow already exist
Important Reservoirs, Lakes, and Ponds	No public data sources/datasets available
Recreational In-Channel Diversion Structures	An RICD dataset already exists
Durango Natural Studies	No public data sources/datasets available
High Recreation Lakes and Reservoirs	No public data sources/datasets available; other attributes related to water recreation (ex. RICD, recreational boating/kayaking/rafting, CPW fishing atlas) provide associated information
High Recreation Rivers	No public data sources/datasets available; other attributes related to water recreation (ex. RICD, recreational boating/kayaking/rafting, CPW fishing atlas) associated related information
Brassy Minnow	No public data sources/datasets available
Colorado River Cutthroat Trout	No public data sources/datasets available; other attributes related to cutthroat trout (ex. gold medal trout lakes and streams) provide associated information
Hebron Slough Ponds	No public data sources/datasets available
High Recreation Lakes and Reservoirs	No public data sources/datasets available; other attributes related to recreational waters (ex. CPW fishing atlas, Recreational Boating/Kayaking/Rafting, and CPW fishing and hunting) provide associated information
High Recreation Rivers	No public data sources/datasets available; other attributes related to recreational waters (ex. CPW fishing atlas, Recreational Boating/Kayaking/Rafting, and CPW fishing and hunting) provide associated information
Northern Redbelly Dace	No public data sources/datasets available
Rio Grande Cutthroat Trout	No public data sources/datasets available; other attributes related to cutthroat trout (ex. gold medal trout lakes and streams) provide associated information

Table B-4 Updated Attributes

Attribute	Source(s)	Year Data Last Updated
Active Bald Eagle Nests	CPW	2017
Arkansas Darter	IUCN	2018
Important Bird Areas	Audubon	
Bluehead Sucker	IUCN	2018
Boreal Toad	CPW	2017
Colorado Outstanding Waters	CDPHE WQCD	2018
Colorado Pikeminnow	USFWS	2018
Common Garter Snake	CPW	2017
Common Shiner	IUCN	2018
CWCB Instream Flow Water Rights	CWCB	2014
CWCB Natural Lake Level Water Rights	CWCB	2014
Ducks Unlimited Projects	DU	2008
Eligible Wild and Scenic	USFS	2018
Federally Listed Critical Habitat	USFWS	2018
Flannelmouth Sucker	IUCN	2018
Recreational Boating / Kayaking / Rafting	BLM	2018
Humpback Chub	USFWS	2018
Iowa Darter	IUCN	2018
Lake Chub	IUCN	2018
CPW Fishing Atlas	CPW	2015
Least Tern	CPW	2017
Lesser Prairie Chicken	CPW	2017
Northern Cricket Frog	USGS	2013
Northern Leopard Frog	USGS	2013
Peregrine	CPW	2017
Piping Plover	CPW	2017
Plains Minnow	IUCN	2018
Preble's Meadow Jumping Mouse	CPW	2017
Plant Communities		
Razorback Sucker	USFWS	2018
Rio Grande Chub	IUCN	2018
Rio Grande Sucker	IUCN	2018
River Otter Habitat	CPW	2017
Roundtail Chub	IUCN	2018
Sandhill Crane Habitat	CPW	2017
Stonecat	IUCN	2018
Suckermouth Minnow	IUCN	2018
CPW Fishing and Hunting	CPW	2017
Wood Frog	USGS	2013
Yellow Mud Turtle	USGS	2013
Wilderness Areas	BLM	2018
Bald Eagle Sites	CPW	2017
Bald Eagle Winder Concentration	CPW	2017
Bonytail Chub	USFWS	2018
Camelback/Roubideau Wilderness Study Area	BLM	2018

Attribute	Source(s)	Year Data Last Updated
Fish Hatchery	USFWS	2018
Gold Medal Trout Lakes	CPW	2018
Gold Medal Trout Streams	CPW	2018
Greater Sandhill Crane	CPW	2017
National Wetlands Inventory	USFWS	2018
Osprey Active Nest Site	CPW	2017
Osprey Foraging Area	CPW	2017
Plains Leopard Frog	IUCN	2017
Plains Orangethroat Darter	IUCN	2018
Southwestern Willow Flycatcher	USGS	2013
Geomorphology	USGS	1992
RICD		
Water Quality	CDPHE WQCD	2016

Table B-5 Macro-Attribute Classifications

Updated E&R Attribute	Macro-Attribute Classification
Arkansas Darter	Fish
Bluehead Sucker	
Bonytail Chub	
Colorado Pikeminnow	
Common Shiner	
Flannelmouth Sucker	
Humpback Chub	
Iowa Darter	
Lake Chub	
Plains Minnow	
Plains Orangethroat Darter	
Razorback Sucker	
Rio Grand Sucker	
Rio Grande Chub	
Roundtail Chub	
Southwestern Willow Flycatcher	
Suckermouth Minnow	
Active Bald Eagle Nests	Wildlife
Bald Eagle Sites	
Boreal Toad	
Common Garter Snake	
Greater Sandhill Crane	
Important Bird Areas	
Least Tern	
Lesser Prairie Chicken	
Northern Cricket Frog	
Northern Leopard Frog	
Osprey Active Nest Site	
Osprey Foraging Area	
Peregrine	
Piping Plover	
Plains Leopard Frog	
Preble's Meadow Jumping Mouse	
River Otter Habitat	
Sandhill Crane Habitat	
Stonecat	
Woodfrog	
Yellow Mud Turtle	
CPW Fishing and Hunting	Recreation and Economy
CPW Fishing Atlas	
Fish Hatchery	
Gold Medal Trout Lakes	
Gold Medal Trout Streams	
Recreational Boating / Kayaking / Rafting	
RICD	

CWCB Instream Flow Water Rights	Water Rights
CWCB Natural Lake Level Water Rights	
Camelback/Roubideau Wilderness Study Area	Important Wilderness Areas
Ducks Unlimited Projects	
Eligible Wild and Scenic	
Federally Listed Critical Habitat	
Wilderness Areas	
Colorado Outstanding Waters	Physical Environment
Geomorphology	
National Wetlands Inventory	
Plant Communities	
Water Quality	

Analysis and Technical Update to the Colorado Water Plan

Technical Memorandum

Prepared for:

Colorado Water Conservation Board

Subject:

Potential Economic Impacts of Not Meeting Projected Gaps

Date: August 22, 2018

Prepared by: Doug Jeavons, BBC Research &Consulting
Reviewed by: Brown and Caldwell

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Section 1: Purpose and Overview

Using a scenario planning process, the Colorado Water Plan compares projected future water supply needs to projected future water supply availability. When projected needs exceed projected supplies, the difference is documented as supply versus demand gaps, or simply "gaps." Previous studies have evaluated different infrastructure, conservation, or policy projects that have potential to increase supplies or reduce demands in order to reduce the gaps. Each of those projects has varying financial costs as well as technical, environmental, and political challenges. The rough estimates of the financial costs of filling the gaps have received considerable attention. To date, however, limited information has been developed regarding the economic consequences of failing to meet the projected gaps between future water needs and future supplies.

This report provides order-of-magnitude estimates of the economic consequences of failing to meet the gaps within the state of Colorado and each of its basins. This economic impact case study is based on data developed for the medium scenario[1] for 2050 municipal and self-supplied industrial (M&SSI) gaps from the previous SWSI effort (SWSI 2010), which anticipated a statewide gap for these uses of approximately 390,000 acre-feet per year (AFY) by 2050,[2] and the projected 2050 gap in water supplies for irrigated agriculture from the previous SWSI study, which is estimated at more than 1.7 million AFY.[3]

When completed, the SWSI update will develop revised estimates of current water use, future water needs, and the remaining gaps between supplies and demands under the five specific planning scenarios identified in the 2015 Colorado Water Plan. The updated and revised gap analyses may indicate larger or smaller gaps than the example from the 2010 SWSI analysis analyzed in this case study and will likely result in different estimates of the future water supply-demand gaps under the planning scenarios. If desired, the methods, tools, and data sets developed for this economic case study could be applied to estimate the economic consequences of the revised estimates of future water supply gaps when those estimates become available.

The economic analysis conducted for this case study is based on a relatively simplified approach consistent with the goal of identifying the general magnitude of the economic consequences of failing to meet future gaps. In the simplified framework used for this analysis, water demands in Colorado meet one of two purposes: agricultural use or combined M&SSI use. Consequently, this analysis focuses on the economic implications of projected future gaps for these two use types. Further details regarding the analysis methodology are provided at the end of this technical memorandum.

There are also significant economic implications for the state of Colorado, and each of its river basins, in failing to meet non-consumptive needs for environmental and recreation purposes. Quantifying the economic implications of gaps in those needs is beyond the scope of this study.

The Colorado Water Conservation Board (CWCB) has supported, and continues to undertake, a number of other studies on related topics. The CWCB and the state's basin roundtables continue to examine Colorado's non-consumptive water needs, and have developed a non-consumptive toolbox.[4] The CWCB helped support a detailed examination of the short- and long-term impacts of the state's most recent

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[1] Other scenarios examined in the SWSI 2010 analysis projected the 2050 gap in M&SSI supplies to potentially be as low as 190,000 acre-feet per year or as high as 630,000 acre-feet per year.

[2] See Table ES-6 from SWSI 2010 Executive Summary.

[3] See Table ES-4 from SWSI 2010 Executive Summary.

[4]. http://cwcb.state.co.us/environment/non-consumptive-needs/Pages/main.aspx

drought in 2012[5] and has developed a drought toolbox to assist in planning and preparing for future droughts.[6] The CWCB directed a study of climate change in Colorado to support water resources management and adaptation[7] and collaborates with other state agencies on the Colorado Climate Plan. Currently, the CWCB is working with the Colorado Department of Local Affairs on an evaluation—known as the Future Conditions Study—of potential future impacts from fires, floods, and droughts.

Components of the case study economic analysis. Three types of economic costs are included in this case study:

- **Agricultural costs which are already being incurred.** Colorado's agricultural sector has historically been limited by the water supplies available to irrigate crops, and the 2010 SWSI analysis projected that shortages would continue into the future. Consequently, the economic impacts of agricultural water gaps described in this case study do not necessarily represent new impacts that will occur between now and 2050. Instead, the economic impacts related to agriculture in this case study represent losses relative to potential production, and economic activity, if there were sufficient water supplies to meet the full irrigation water requirements of Colorado's irrigated acres.

  Figure 2-1 depicts the estimated agriculture-related job impacts that have already been incurred due to the lack of sufficient supplies to meet full irrigation water requirements in each basin.
- **Marginal costs of a portion of projected future M&SSI gaps.** Like many other commodities in our economy, the value of water consumed for M&SSI purposes is subject to diminishing marginal returns. In the context of this analysis, managing the first acre-foot of shortage in the M&SSI sector—which might logically involve mandatory reductions in the water supply available for outdoor use—would have a smaller economic impact than managing the last acre-foot of the projected M&SSI shortage.

  The exact threshold where M&SSI gaps begin to create larger impacts on the regional economy is unknown and likely varies among different locations and different providers. This case study provides a range of economic impacts from M&SSI gaps based on alternative assumptions regarding the point at which gaps in M&SSI supplies transition from marginal impacts to larger opportunity costs.

  Marginal impacts from M&SSI gaps of up to 10 or 15 percent of 2050 demand projections from the SWSI 2010 study were analyzed in terms of reduction in the welfare of the water users due to mandatory reduction or elimination of outdoor uses, as well as in terms of the corresponding impacts on the municipal "green industry," such as nursery production, landscaping services, and car washes. The bases for the 10 and 15 percent shortage thresholds in the M&SSI sector—which define the high range and low range of projected economic impacts from M&SSI gaps, respectively—are discussed further in the methodology section of this memorandum. It is worth noting that some measures to increase municipal water use efficiency, such as utility loss reduction efforts, may be largely transparent to water consumers and could reduce impacts to consumer welfare.
- **Opportunity costs of foregone future economic development.** In this case study, M&SSI gaps beyond 10 or 15 percent of projected 2050 demands were analyzed based on the average level of economic activity currently supported by each acre-foot of M&SSI water use. This effectively assumes that larger M&SSI shortages could result in tap moratoriums or other slowdowns in overall economic development due to limitations in available water supplies. While improvements in the efficiency of M&SSI use are likely to continue in the future, such efficiency gains will actually increase the economic

[5] Estimating the Short and Long-term Economic & Social Impacts of the 2012 Drought in Colorado. James Pritchett, Chris Goemans and Ron Nelson.

[6] http://cwcb.state.co.us/technical-resources/drought-planning-toolbox/Pages/main.aspx.

[7] http://cwcbweblink.state.co.us/WebLink/ElectronicFile.aspx?docid=191995&searchid=e3c463e8-569c-4359-8ddd-ed50e755d3b7&dbid=0

productivity of each acre-foot of water used in this sector. Consequently, this component of the case study analysis may understate the economic consequences of future M&SSI gaps.

Economic Terminology in this Case Study

Backward Linkages: Economic relationships between the primary activity being evaluated (e.g.agriculture) and its employees and suppliers (feed, equipment, etc.)

Consumer Welfare: A measure of effects on the well-being of consumers. Measured in terms of the difference between the value consumers would be willing to pay for a good (e.g. water) and the price they actually have to pay. Also referred to as "consumer surplus."

Employment: Full and part-time jobs, including self-employed business owners.

Forward Linkages: Economic relationships betweenthe primary activity being evaluated and industries that purchase and use its products (e.g. feed lots, processors, etc.)

Indirect Impacts: Impacts on suppliers of the directly affected industry (see backward linkages).

Induced Impacts: Impacts on suppliers to employees of the directly affected industry and employees of the indirectly impacted industries.

Labor Compensation: Includes wages, salaries, benefits, and employment taxes paid by businesses for social security and medicare.

Output: Generally equivalent to the total annual value of sales by businesses.

Value-added. The value of business sales net of the costs of supplies and materials purchased from other businesses. The sum of value-added across the economy is equivalent to "gross domestic product" or GDP (nationally), "**gross regional product**", or "**gross state product**."

Section 2: Summary Insights from the Economic Impact Case Study

The projected economic impacts of failing to meet the gaps identified in the specific 2010 SWSI demand conditions analyzed in this case study provide a number of general insights regarding the importance of Colorado's water planning efforts.

The lack of sufficient supply to meet the full consumptive use requirements for irrigated crops in Colorado is estimated to already result in an annual loss in potential production value of more than $3 billion and about 28,000 fewer jobs directly and indirectly supported by irrigated agriculture.[8] In many basins, economic impacts on livestock production due to reduced crop and forage output are larger than the economic impacts on the crop producers. Projected gaps in 2050 irrigation water supplies indicate that these reductions in potential agricultural economic activity will continue into the future.

Figure 2-1 depicts the estimated impact that is already occurring in agriculture-related employment in each basin due to the lack of a full irrigation supply across Colorado.

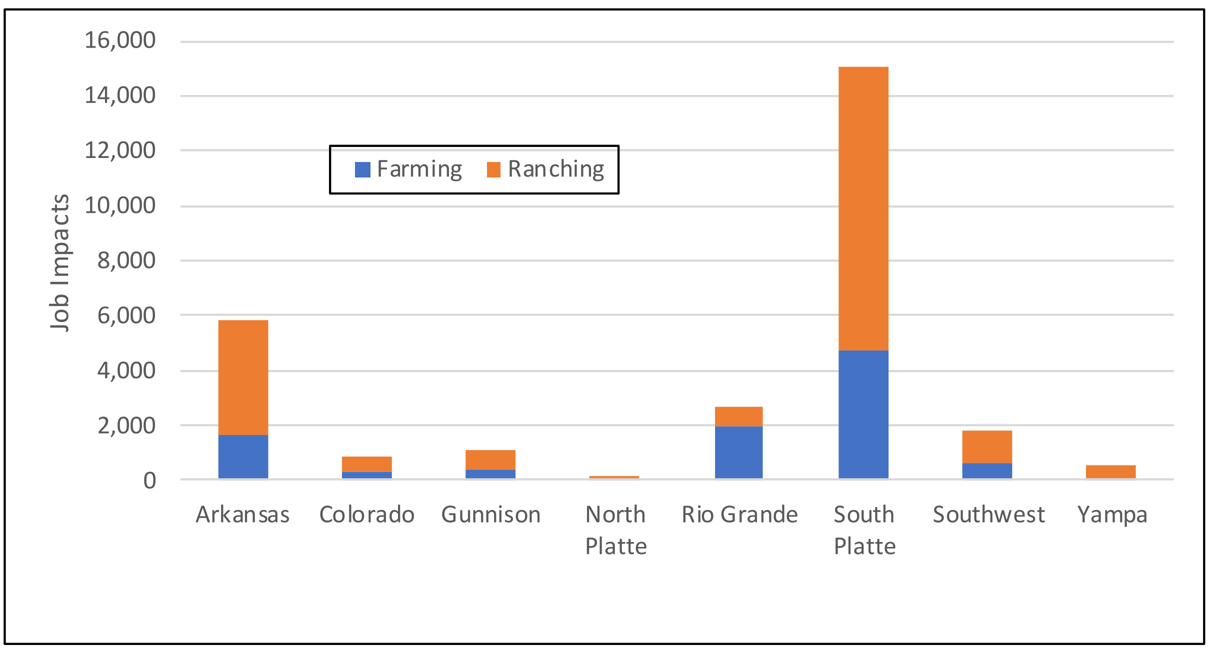

Figure 2-1. Farming and ranching job impacts already incurred due to limited irrigation supplies (Includes backward-linked support industries)

Figure 2-2 depicts the breakdown of the projected 2050 economic impacts in each basin under the low range scenario for future M&SSI economic impacts. Each bar in the figure summarizes the proportion of impacts that are already being incurred due to water supply gaps in the agricultural sector alongside incremental new impacts that are projected to occur in the future due to projected gaps in water supply

[8] Based on the estimated existing gap between available water supplies for irrigated agriculture and the full irrigation requirement for currently irrigated acres shown in Table ES-3 from SWSI 2010 Executive Summary.

for the M&SSI sector. Although the Arkansas Basin and the South Platte Basin have already incurred the largest impacts on agriculture and its supporting industries, in absolute terms, due to limited water supplies, the projected incremental new economic impacts in these basins are very large due to the scale and severity of their projected future gaps in M&SSI supplies.

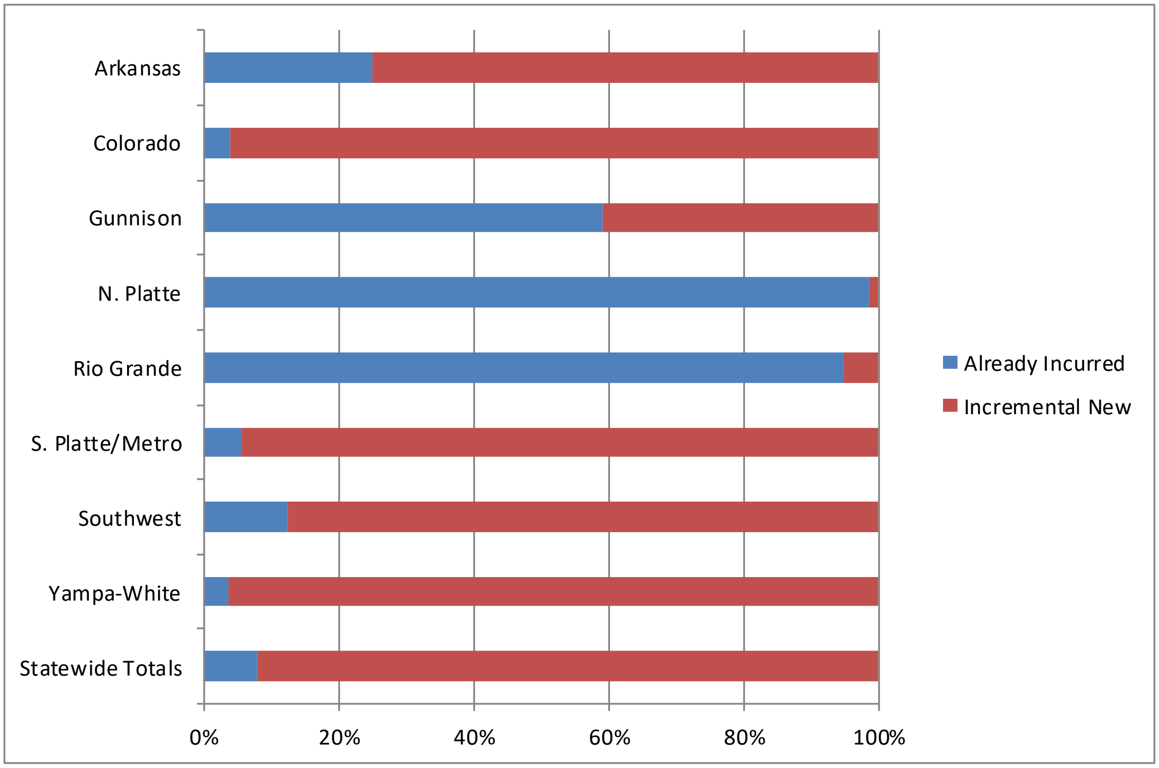

Figure 2-2. Proportions of projected 2050 economic impacts already incurred due to gaps in available agricultural water supply (Low range scenario for incremental new M&SSI impacts)

Figure 2-3 depicts the proportions of the projected 2050 economic impacts in each basin that have already been incurred under the high range scenario for incremental new M&SSI impacts.

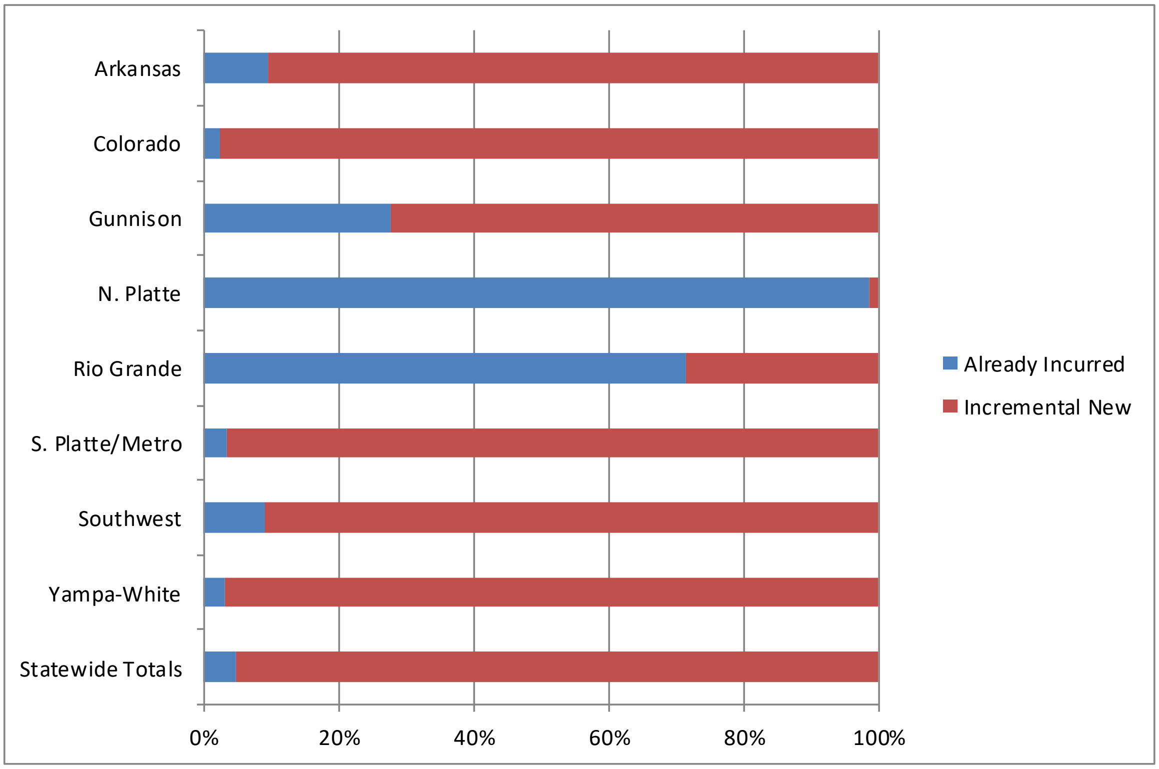

Figure 2-3. Proportions of projected 2050 economic impacts already incurred due to gaps in available agricultural water supply (High range scenario for incremental new M&SSI impacts)

Economic effects of projected M&SSI gaps depend on the severity of the projected gap in each basin. In areas with smaller M&SSI gaps relative to projected 2050 demands (less than 10 percent or 15 percent of projected demand), the primary effects would likely be a substantial reduction in consumer welfare due to greatly reduced water availability for outdoor use and severe effects on the municipal “green industry,” involving sectors such as landscape services, nurseries, and car washes.

In areas with more severe M&SSI gaps (greater than 10 percent or 15 percent of projected future M&SSI demand), much larger economic impacts are projected due to the opportunity cost of foregone future residential, commercial, and industrial development.

Overall, the economic impacts and opportunity costs of the projected gaps in agricultural and M&SSI water supplies are substantial in every basin in Colorado. From a statewide perspective, failing to meet the gaps identified in the 2010 SWSI demand condition example analyzed in this case study could lead to between 355,000 and 587,000 fewer jobs in Colorado in 2050; $53 to $90 billion fewer dollars in annual economic output; a reduction in gross state product of between $30 and $51 billion per year; $20 to $33 billion in reduced labor income; and $3 to $6 billion fewer dollars in state and local tax revenues. To put these numbers in perspective, the projected economic impacts are equivalent to approximately nine to 16 percent of current statewide economic output, gross state product, statewide employment, and statewide labor income.

While the projected economic impacts of the gaps from the SWSI 2010 scenario analyzed in this case study are largest in the combined South Platte/Metro basin, that basin is also Colorado’s largest in terms of its current population, overall economy, and agricultural economy. Relative to the scale of current basin economies, the projected economic impacts of the SWSI 2010 scenario analyzed in this case study are the most severe in the Yampa-White Basin and the Southwest Basin.

The economic values associated with agricultural water use are substantial but are generally considerably lower than the economic values associated with M&SSI use. This reality, combined with the flexibility to move water among different uses and locations under Colorado law, implies that there will be continuing economic pressure to shift water from Colorado's farms to its cities and industrial users. Given the importance that the state's residents place on maintaining agriculture in Colorado,[9] these economic pressures highlight the need for strategies to mitigate potential future impacts resulting from water transfers that would negatively affect Colorado's agricultural economy. One important component of the current SWSI update is the study of alternative transfer methods to reduce impacts to agriculture and rural communities.

[9] Public Opinions, Attitudes and Awareness Regarding Water in Colorado. Colorado Water Conservation Board. July 2013.

Section 3: Basin Impact Summaries

The following pages provide estimated economic impacts from the case study scenario in each of Colorado's basins. Employment numbers described in these summaries include both wage and salary workers and self-employed proprietors (including farm owners). Labor compensation includes wages, benefits, and proprietor income.

3.1 ARKANSAS BASIN

Current Economic and Demographic Characteristics

- Population: 1,009,000
- Total Economic Output: $75.3 billion
- Gross Regional Product: $43.3 billion
- Employment: 586,000
- Total Labor Compensation: $29.1 billion

Agricultural Characteristics

- Irrigated Cropland: 428,000 acres
- Proportion of Cropland Irrigated: 20 percent
- Estimated Direct and Secondary Agricultural Economic Contribution:[10]
  - $1.6 billion in economic output
  - 14,300 jobs
  - $136 million in labor compensation

Projected 2050 Water Supply Conditions

- Agricultural gap: 386,000 AFY (45 percent)
- M&SSI gap: 64,000 AFY (17 percent)

Projected Annual Opportunity Costs of Failing to Meet Gaps (by 2050)

- Reduced Economic Output: $2.5 to $7.5 billion
- Reduced Gross Regional Product: $1.3 to $4.2 billion
- Reduced Employment: 22,500 to 60,400 jobs
- Reduced Labor Compensation: $0.9 to $2.9 billion
- Reduced State and Local Tax Revenues: $143 to $511 million
- Reduced Consumer Welfare: $258 to $442 million[11]

[10] Includes farming, ranching, and indirect and induced effects from agriculture on other industries.

[11] Estimated reduction in consumer surplus assuming first 10 percent of M&SSI gap leads to involuntary rationing measures such as prohibitions on outdoor water use and/or substantially increased water rates designed to drive down consumption.

3.2 COLORADO BASIN

Current Economic and Demographic Characteristics

- Population: 309,000
- Total Economic Output: $29.4 billion
- Gross Regional Product: $17.0 billion
- Employment: 233,000
- Total Labor Compensation: $9.9 billion

Agricultural Characteristics

- Irrigated Cropland: 268,000 acres
- Proportion of Cropland Irrigated: 80 percent
- Estimated Direct and Secondary Agricultural Economic Contribution:[12]
    - $334 million in economic output
    - 5,100 jobs
    - $65 million in labor compensation

Projected 2050 Water Supply Conditions

- Agricultural gap: 77,000 AFY (17 percent)
- M&SSI gap: 33,000 AFY (22 percent)

Projected Annual Opportunity Costs of Failing to Meet Gaps (by 2050)

- Reduced Economic Output: $3.0 to $4.9 billion
- Reduced Gross Regional Product: $1.7 to $2.9 billion
- Reduced Employment: 25,000 to 39,000 jobs
- Reduced Labor Compensation: $1.2 to $1.9 billion
- Reduced State and Local Tax Revenues: $212 to $354 million
- Reduced Consumer Welfare: $99 to $170 million[13]

[12] Includes farming, ranching, and indirect and induced effects from agriculture on other industries.

[13] Estimated reduction in consumer surplus assuming first 10 percent of M&SSI gap leads to involuntary rationing measures such as prohibitions on outdoor water use and/or substantially increased water rates designed to drive down consumption.

3.3 GUNNISON BASIN

Current Economic and Demographic Characteristics

- Population: 103,000
- Total Economic Output: $6.3 billion
- Gross Regional Product: $3.0 billion
- Employment: 54,000
- Total Labor Compensation: $1.8 billion

Agricultural Characteristics

- Irrigated Cropland: 272,000 acres
- Proportion of Cropland Irrigated: 91 percent
- Estimated Direct and Secondary Agricultural Economic Contribution:[14]
  - $332 million in economic output
  - 4,800 jobs
  - $85 million in labor compensation

Projected 2050 Water Supply Conditions

- Agricultural gap: 116,000 AFY (20 percent)
- M&SSI gap: 5,100 AFY (13 percent)

Projected Annual Opportunity Costs of Failing to Meet Gaps (by 2050)

- Reduced Economic Output: $122 to $395 million
- Reduced Gross Regional Product: $52 to $184 million
- Reduced Employment: 1,800 to 4,000 jobs
- Reduced Labor Compensation: $41 to $118 million
- Reduced State and Local Tax Revenues: $4 to $31 million
- Reduced Consumer Welfare: $26 to $45 million[15]

[14]Includes farming, ranching, and indirect and induced effects from agriculture on other industries.

[15] Estimated reduction in consumer surplus assuming first 10 percent of M&SSI gap leads to involuntary rationing measures such as prohibitions on outdoor water use and/or substantially increased water rates designed to drive down consumption.

3.4 NORTH PLATTE BASIN

Current Economic and Demographic Characteristics

- Population: 1,400
- Total Economic Output: $115 million
- Gross Regional Product: $47 million
- Employment: 900
- Total Labor Compensation: $34 million

Agricultural Characteristics

- Irrigated Cropland: 117,000 acres
- Proportion of Cropland Irrigated: 86 percent
- Estimated Direct and Secondary Agricultural Economic Contribution:[16]
    - $27 million in economic output
    - 180 jobs
    - $8 million in labor compensation

Projected 2050 Water Supply Conditions

- Agricultural gap: 110,000 AFY (44 percent)
- M&SSI gap: 20 AFY (3 percent)

Projected Annual Opportunity Costs of Failing to Meet Gaps (by 2050)

- Reduced Economic Output: $32 million
- Reduced Gross Regional Product: $9 million
- Reduced Employment: 170 jobs
- Reduced Labor Compensation: $9 million
- Reduced State and Local Tax Revenues: $0.8 million
- Reduced Consumer Welfare: $0.5 million[17]

[16] Includes farming, ranching, and indirect and induced effects from agriculture on other industries.

[17] Estimated reduction in consumer surplus assuming first 10 percent of M&SSI gap leads to involuntary rationing measures such as prohibitions on outdoor water use and/or substantially increased water rates designed to drive down consumption.

3.5 RIO GRANDE BASIN

Current Economic and Demographic Characteristics

- Population: 46,000
- Total Economic Output: $2.9 billion
- Gross Regional Product: $1.5 billion
- Employment: 27,000
- Total Labor Compensation: $947 million

Agricultural Characteristics

- Irrigated Cropland: 622,000 acres
- Proportion of Cropland Irrigated: 93 percent
- Estimated Direct and Secondary Agricultural Economic Contribution:[18]
  - $668 million in economic output
  - 5,500 jobs
  - $202 million in labor compensation

Projected 2050 Water Supply Conditions

- Agricultural gap: 369,000 AFY (33 percent)
- M&SSI gap: 3,600 AFY (13 percent)

Projected Annual Opportunity Costs of Failing to Meet Gaps (by 2050)

- Reduced Economic Output: $298 to $396 million
- Reduced Gross Regional Product: $135 to $185 million
- Reduced Employment: 2,400 to 3,400 jobs
- Reduced Labor Compensation: $95 to $127 million
- Reduced State and Local Tax Revenues: $9 to $21 million
- Reduced Consumer Welfare: $18 to $31 million[19]

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[18] Includes farming, ranching, and indirect and induced effects from agriculture on other industries.

[19] Estimated reduction in consumer surplus assuming first 10 percent of M&SSI gap leads to involuntary rationing measures such as prohibitions on outdoor water use and/or substantially increased water rates designed to drive down consumption.

3.6 SOUTH PLATTE/METRO BASIN

Current Economic and Demographic Characteristics

- Population: 3.8 million
- Total Economic Output: $434 billion
- Gross Regional Product: $250 billion
- Employment: 2.6 million
- Total Labor Compensation: $162 billion

Agricultural Characteristics

- Irrigated Cropland: 1,381,000 acres
- Proportion of Cropland Irrigated: 33 percent
- Estimated Direct and Secondary Agricultural Economic Contribution:[20]
    - $8.5 billion in economic output
    - 50,000 jobs
    - $2.1 billion in labor compensation

Projected 2050 Water Supply Conditions

- Agricultural gap: 434,000 AFY (25 percent)
- M&SSI gap: 240,000 AFY (21 percent)

Projected Annual Opportunity Costs of Failing to Meet Gaps (by 2050)

- Reduced Economic Output: $43 to $72 billion
- Reduced Gross Regional Product: $25 to $41 billion
- Reduced Employment: 273,000 to 442,000 jobs
- Reduced Labor Compensation: $16 to $27 billion
- Reduced State and Local Tax Revenues: $2.7 to $4.7 billion
- Reduced Consumer Welfare: $0.7 to $1.3 billion[21]

[20] Includes farming, ranching, and indirect and induced effects from agriculture on other industries.

[21] Estimated reduction in consumer surplus assuming first 10 percent of M&SSI gap leads to involuntary rationing measures such as prohibitions on outdoor water use and/or substantially increased water rates designed to drive down consumption.

3.7 SOUTHWEST BASIN

Current Economic and Demographic Characteristics

- Population: 108,000
- Total Economic Output: $9.2 billion
- Gross Regional Product: $4.8 billion
- Employment: 74,000
- Total Labor Compensation: $3.0 billion

Agricultural Characteristics

- Irrigated Cropland: 259,000 acres
- Proportion of Cropland Irrigated: 71 percent
- Estimated Direct and Secondary Agricultural Economic Contribution:[22]
    - $192 million in economic output
    - 4,000 jobs
    - $29 million in labor compensation

Projected 2050 Water Supply Conditions

- Agricultural gap: 191,000 AFY (34 percent)
- M&SSI gap: 12,000 AFY (25 percent)

Projected Annual Opportunity Costs of Failing to Meet Gaps (by 2050)

- Reduced Economic Output: $1.7 to $2.4 billion
- Reduced Gross Regional Product: $0.9 to $1.2 billion
- Reduced Employment: 14,000 to 20,000 jobs
- Reduced Labor Compensation: $548 to $787 million
- Reduced State and Local Tax Revenues: $133 to $196 million
- Reduced Consumer Welfare: $32 to $55 million[23]

[22] Includes farming, ranching, and indirect and induced effects from agriculture on other industries.

[23] Estimated reduction in consumer surplus assuming first 10 percent of M&SSI gap leads to involuntary rationing measures such as prohibitions on outdoor water use and/or substantially increased water rates designed to drive down consumption.

3.8 YAMPA-WHITE BASIN

Current Economic and Demographic Characteristics

- Population: 43,000
- Total Economic Output: $5 billion
- Gross Regional Product: $2.7 billion
- Employment: 33,000
- Total Labor Compensation: $1.4 billion

Agricultural Characteristics

- Irrigated Cropland: 119,000 acres
- Proportion of Cropland Irrigated: 49 percent
- Estimated Direct and Secondary Agricultural Economic Contribution:[24]
  - $197 million in economic output
  - 2,900 jobs
  - $36 million in labor compensation

Projected 2050 Water Supply Conditions

- Agricultural gap: 39,000 AFY (19 percent)
- M&SSI gap: 37,000 AFY (42 percent)

Projected Annual Opportunity Costs of Failing to Meet Gaps (by 2050)

- Reduced Economic Output: $2.4 to $2.8 billion
- Reduced Gross Regional Product: $1.3 to $1.5 billion
- Reduced Employment: 15,000 to 18,000 jobs
- Reduced Labor Compensation: $682 to $799 million
- Reduced State and Local Tax Revenues: $162 to $191 million
- Reduced Consumer Welfare: $59 to $100 million[25]

[24] Includes farming, ranching, and indirect and induced effects from agriculture on other industries.

[25] Estimated reduction in consumer surplus assuming first 10 percent of M&SSI gap leads to involuntary rationing measures such as prohibitions on outdoor water use and/or substantially increased water rates designed to drive down consumption.

3.9 STATEWIDE SUMMARY

Current Economic and Demographic Characteristics

- Population: 5.5 million
- Total Economic Output: $563 billion
- Gross State Product: $323 billion
- Employment: 3.6 million
- Total Labor Compensation: $208 billion

Agricultural Characteristics

- Irrigated Cropland: 3.5 million acres
- Proportion of Cropland Irrigated: 40 percent
- Estimated Direct and Secondary Agricultural Economic Contribution:[26]
    - $11.8 billion in economic output
    - 87,000 jobs
    - $2.7 billion in labor compensation

Projected 2050 Water Supply Conditions

- Agricultural gap: 1.7 million AFY (30 percent)
- M&SSI gap: 390,000 AFY (21 percent)

Projected Annual Opportunity Costs of Failing to Meet Gaps (by 2050)

- Reduced Economic Output: $53 to $90 billion
- Reduced Gross State Product: $30 to $51 billion
- Reduced Employment: 355,000 to 587,000 jobs
- Reduced Labor Compensation: $20 to $33 billion
- Reduced State and Local Tax Revenues: $3.4 to $6.0 billion
- Reduced Consumer Welfare: $1.2 to $2.1 billion[27]

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[26] Includes farming, ranching, and indirect and induced effects from agriculture on other industries.

[27] Estimated reduction in consumer surplus assuming first 10 percent of M&SSI gap leads to involuntary rationing measures such as prohibitions on outdoor water use and/or substantially increased water rates designed to drive down consumption.

Section 4: Case Study Methodology

Models and data sources. The economic analysis presented in this case study was conducted using the IMPLAN regional economic modeling system. IMPLAN was originally developed by the U.S. Forest Service and is now the most commonly used regional economic modeling tool in the U.S. The case study analysis incorporated data from the following sources:

- Current and projected water use and projected future gaps for irrigated agriculture and M&SSI uses in each basin from SWSI 2010 (Section 4);
- Irrigated and non-irrigated harvested acreage by crop and county from the 2007 and 2012 Censuses of Agriculture;
- 2016 IMPLAN data files for each county in Colorado and corresponding regional economic models for each basin;
- Average statewide municipal cost of water per 10,000 gallons from the 2016 Colorado Municipal Water and Wastewater Rate Survey; and
- Approximate municipal water price elasticity of demand based on prior study team analyses for the cities of Aurora, Denver, and Greeley

Agricultural sector impacts. Figure 4-1 shows the current water supply available for irrigated crops in each basin from the SWSI 2010 report. The table also shows the projected available irrigation supply in 2050, the projected full irrigation water requirement, and the corresponding gap in irrigation supplies from the 2010 SWSI analyses.

	Current Water Demand (SWSI 2010)			Projected Demand 2050		
Basin	Supply Limited	Full Requirement	Gap	Supply Limited	Full Requirement	Gap
Arkansas	542,000	995,000	453,000	476,000	862,000	386,000
Colorado	485,000	584,000	99,000	366,000	443,000	77,000
Gunnison	505,000	633,000	128,000	457,000	573,000	116,000
North Platte	113,000	202,000	89,000	140,000	250,000	110,000
Republican	602,000	802,000	200,000	480,000	640,000	160,000
Rio Grande	855,000	1,283,000	428,000	739,000	1,108,000	369,000
South Platte	1,117,000	1,496,000	379,000	820,000	1,094,000	274,000
Southwest	382,000	580,000	198,000	367,000	558,000	191,000
Yampa-White	181,000	235,000	54,000	170,000	209,000	39,000
Total	4,782,000	6,810,000	2,028,000	4,015,000	5,737,000	1,722,000

Figure 4-1. Projected current irrigation water use and future needs, supplies, and gaps from SWSI 2010

Source: SWSI 2010 Section 4, Consumptive Needs Assessments.

To quantify the economic value of agricultural water supplies in each basin, the study team conducted the following analysis:

1. Based on 2007 and 2012 Census of Agriculture data and general estimates of the relative yields of irrigated versus non-irrigated lands by crop, we estimated the portion of the economic activity (e.g., output or sales value) in each of the six agricultural sectors in IMPLAN that are most relevant to Colorado crop production.
2. We then summed the direct economic activity from crop production attributable to irrigation across the six sectors and divided the sum by the total water use for irrigation in the basin (water

supply limited consumptive use in the SWSI 2010 analysis) to determine the direct economic value per acre-foot.

3. We used the IMPLAN model to calculate the indirect and induced economic contribution in each basin corresponding to the direct contribution from irrigated cropping. Note that IMPLAN captures only backward linkages from effects on farm suppliers and farm labor; it does not capture forward linkages on sectors that further process the production from irrigated farms.
4. The most important forward linkage related to irrigated crop production is livestock production. To calculate the effects on livestock production related to irrigated farming, we estimated the portion of the output in the two IMPLAN cropping sectors that account for most of the livestock feed that is produced from irrigated lands (Sector 2—Grain Farming and Sector 10—Hay Production) based on the same data used in step 1. We then used the portion of the feed sectors that is contributed by irrigated lands to apportion the direct economic contribution from the livestock-raising sectors.
5. We then calculated the indirect and induced economic contributions associated with the portion of livestock-raising activity attributable to irrigated farms and netted out the indirect effects on the crop production sectors (to avoid double counting). The combined direct, indirect, and induced effects from irrigation-based crop production and irrigation-related livestock production were then summed and divided by irrigated agricultural water use to estimate the total economic contribution per acre-foot of irrigation consumptive use.

The statewide relationship between projected irrigation water shortages and agriculture-related employment (including direct crop production, livestock raising based on feed from irrigated acres, supporting industries, and local governments) is illustrated in Figure 4-2. The shortage–employment relationship differs in each basin and is based on current agricultural economic activity per acre-foot of irrigation supply from the SWSI 2010 analyses, so the relationship illustrated in Figure 4-2 may not be applicable to other scenarios or locations or the revised analyses that are being developed in the SWSI update.

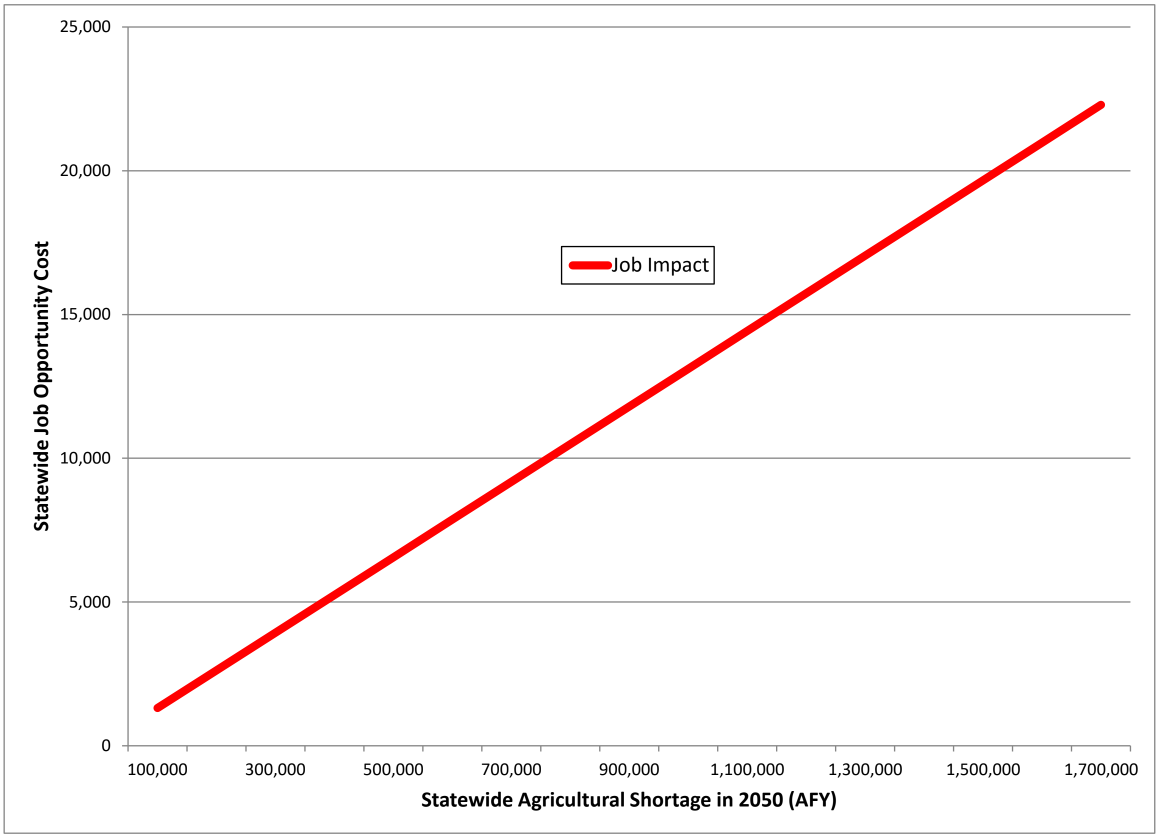

Figure 4-2. Estimated statewide relationship between irrigation water shortages and agriculture-related employment in this case study

M&SSI impacts. Considering the information available from the previous SWSI analysis and Colorado Water Plan, and the resources and time constraints for this analysis, the economic implication of municipal and self-supplied industrial gaps were evaluated on a combined basis. The M&SSI economic analysis was designed to reflect a combination of the marginal economic value of water supplies in these uses for a portion of the projected gap as well as the average economic value of those supplies for larger gaps.

Figure 4-3 shows the estimated combined demand for M&SSI water use from SWSI 2010 and projected demands and gaps for the specific scenario analyzed in this case study. For consistency with the 2016 IMPLAN economic data used in this case study analysis, we estimated 2016 M&SSI water use (demand) by interpolating between the 2008 water use estimates and 2035 water use projections from SWSI 2010.

	Estimated Demand 2016*			Projected Demand 2050			Projected Gap	
Basin	M&I	SSI	Combined	M&I	SSI	Combined	Combined	Percentage
Arkansas	219,000	60,000	279,000	320,000	67,800	387,800	64,000	17%
Colorado	76,000	5,000	81,000	140,000	9,440	149,440	33,000	22%
Gunnison	24,000	0	24,000	39,000	650	39,650	5,100	13%
Metro	473,000	64,000	537,000	642,000	67,400	709,400	130,000	18%
North Platte	1,000	0	1,000	700	0	700	20	3%
Rio Grande	19,000	0	19,000	26,000	1,500	27,500	3,600	13%
South Platte	237,000	32,000	269,000	367,000	51,320	418,320	110,000	26%
Southwest	26,000	3,000	29,000	43,000	5,310	48,310	12,000	25%
Yampa-White	14,000	36,000	50,000	30,000	58,070	88,070	37,000	42%
Total	1,088,000	202,000	1,290,000	1,607,700	261,490	1,869,190	394,720	21%

Figure 4-3. Estimated current M&SSI demands by basin
and projected demands and gaps in 2050 from SWSI 2010 scenario

*Note: *2016 demands estimated based on interpolation between reported 2008 demands and 2035 forecasts in SWSI 2010 report.*

Source: SWSI 2010 Section 4, Consumptive Needs Assessments.

Threshold where M&SSI gaps move from marginal economic effects to greater economic opportunity costs. If less water is available in the M&SSI sector than customers would like to use, the economic effects could be relatively modest or quite severe, depending on the severity of the shortfall. The approach employed in this economic impact case study is intended to recognize the difference in economic impacts between relatively modest shortfalls in the M&SSI sectors (similar to Colorado's experience during the 2002 drought) and more severe and sustained shortages of water available for M&SSI purposes.

Sizeable municipal providers in Colorado generally have established drought response plans. These plans are essentially intended to mitigate the economic impacts of relatively modest, short-term water shortages. Typically, drought response plans involve sequential stages targeting a reduction in outdoor water use, ranging from voluntary watering restrictions to complete bans on outdoor irrigation (and often bans on other water intensive activities such as car washing).

Denver Water provides an example of the potential reductions in water use from municipal drought response plans. Denver Water's Drought Response Plan indicates that their water use reduction goal under Stage 2 drought restrictions would be a 35 percent cut in overall systemwide water use. This goal is evaluated by comparing water use during the months when the restrictions are in place to average water use without the restrictions. In essence, Denver Water expects to reduce overall water use during the irrigation season by 35 percent while effects on indoor use during the rest of the year are expected to be minimal with some reduction occurring due to behavioral drought awareness response (personal communication with Mitch Horrie, July 27, 2018). About 70 percent of Denver Water's total annual use occurs during the irrigation season, from April through October. If Denver Water reduced that use by 35 percent, overall annual use would be reduced by approximately 25 percent (70 percent*35 percent = 24.5 percent).

Although the Denver Water Drought Response Plan provides a useful example of how a large urban provider intends to manage a short-term water shortage, the threshold where projected future gaps in M&SSI supplies begin to have much larger economic impacts would likely be at a lower level than a 20 or 25 percent gap. This case study evaluates the effects of projected water supply gaps more than 30 years in the future. The proportion of water used for outdoor irrigation in the Front Range is generally declining for several reasons; firstly, decreasing this type of use is a growing focus of municipal water conservation plans. Outdoor water use is also generally more responsive to price increases (more price elastic) than indoor use, and Denver Water and other Front Range providers report that an increasing number of their customers are ceasing to irrigate their lawns for what are believed to be economic reasons. Further, changes in development patterns towards more multifamily housing and smaller lots for detached single family homes will also tend to reduce outdoor use as a proportion of total demand.

Perhaps more importantly, the SWSI analysis estimated overall gaps in water supply at the basin, and statewide, levels. The aggregated M&SSI gaps mask the fact that shortages would not likely be equally distributed across all of the municipal providers in a particular basin. For example, in the scenario analyzed in this case study, the South Platte/Metro Basin is projected to have a 21 percent gap in M&SSI supply. However, that basin-wide estimate does not mean that the major established water providers—like Denver, Aurora, Fort Collins, and Greeley—would be 21 percent short of water supplies in 2050. Instead, much of this growth-related gap would likely fall on smaller and newer providers, perhaps including providers that do not even exist today, which would experience much larger shortages (in percentage terms) than the overall basin-wide average.

With these considerations in mind, this case study examines a range of potential economic impacts from the projected M&SSI gaps. The low range estimate assumes that gaps of up to 15 percent of projected 2050 demands in this sector would primarily affect 1) consumer welfare, as measured in terms of lost consumer surplus due to mandatory reductions or prohibition of outdoor uses; and 2) the "green industry" in each region, including landscaping services, nurseries, and car washes. The high range estimate assumes that more severe economic effects would begin to occur when the projected gaps in M&SSI supplies reach 10 percent of projected 2050 demands.

In economic analysis focusing on consumer welfare, the contribution of a particular good to consumer wellbeing is typically measured in terms of consumer surplus. To estimate the reduction in consumer surplus from a mandatory 10 or 15 percent decrease in municipal water use, the study team estimated a generic demand curve for municipal water supplies based on the average cost per 1,000 gallons from the 2016 Colorado Municipal Water and Wastewater Rate Survey and an estimated typical municipal water price elasticity of -0.3 based on our previous studies. Figure 4-4 illustrates the generic demand curve and the reduction in consumer surplus that would result from a mandatory 10 percent decrease in consumption due to involuntary restrictions or prohibitions on outdoor water uses or substantial penalty pricing. Based on the generic demand curve, the study team estimated the annual impact on consumer welfare of an involuntary 10 percent reduction in M&SSI water use at approximately $700 per acre-foot.

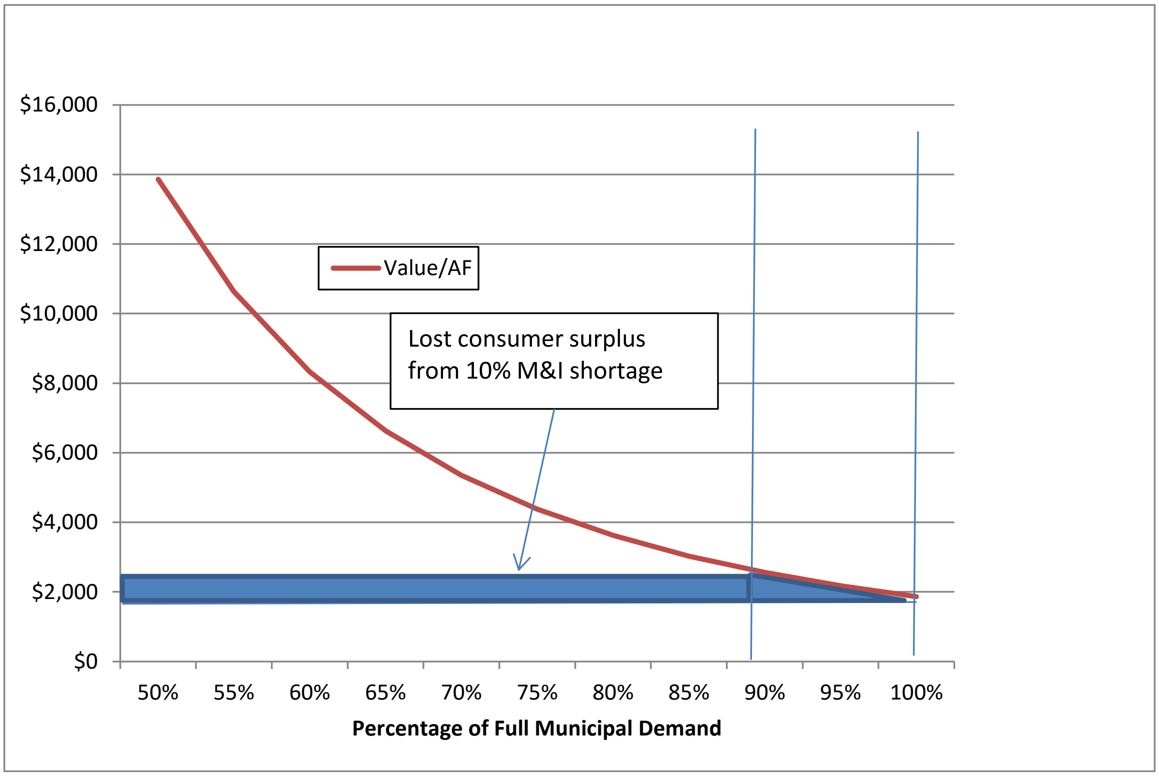

Figure 4-4. Generic municipal water supply demand curve and projected reduction in annual consumer surplus from involuntary 10 percent reduction in use

Source: 2016 Colorado Municipal Water and Wastewater Rate Survey and prior study team water demand studies for Aurora, Denver, and Greeley.

Gaps beyond 10 or 15 percent of projected M&SSI demands in 2050 were assumed to result in foregone opportunities for future residential, commercial, and industrial development. Since the combined M&SSI category in SWSI includes municipal, self-supplied industrial, and self-supplied domestic water uses, the economic effects of these larger gaps in M&SSI water supply were estimated based on total regional economic activity—net of the activity directly and indirectly supported by the agricultural sector—per acre-foot of M&SSI water use.

Based on the methodology used in this case study, the economic impacts of projected M&SSI gaps in each basin reflect a varying blend of marginal and average economic values for M&SSI water use, depending on the projected percentage gap in M&SSI supply. Figure 4-5 illustrates the estimated statewide relationship between projected M&SSI water shortages and future decreases in employment from this case study. The shortage–employment relationship differs in each basin and is based on current economic activity per acre-foot of M&SSI supply from the SWSI 2010 analyses, so the relationship illustrated in Figure 8 may not be applicable to other scenarios or locations or the revised analyses that are being developed in the SWSI update.

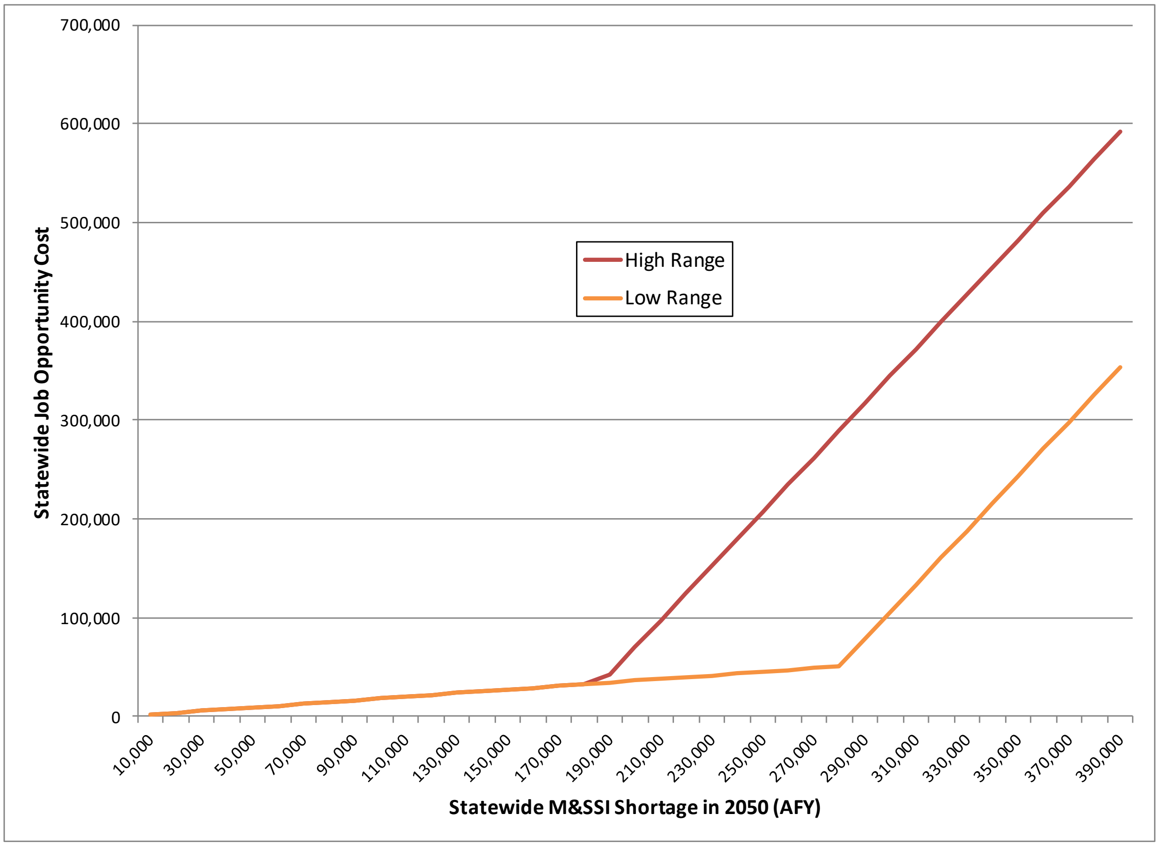

Figure 4-5. Estimated statewide relationship between M&SSI water shortages and employment in this case study

Analysis and Technical Update to the Colorado Water Plan

Technical Memorandum

Prepared for:

Colorado Water Conservation Board

Subject:

Opportunities for Increasing Storage

Date: May 10, 2019

Prepared by: Jacobs

Reviewed by: Brown and Caldwell

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Section 1: Introduction & Purpose of Water Storage

This technical memorandum (TM) investigates concepts related to increasing water storage to assist in meeting current and future water supply challenges throughout Colorado. Section 6.5.3 of the 2015 Colorado's Water Plan (CWP) sets a measurable objective of attaining 400,000 acre-feet (AF) of innovative water storage by 2050.

The introduction to the CWP states that Colorado must develop additional storage to manage and share conserved water and manage the challenges of a changing future climate. The CWP further states that tomorrow's storage projects should work to increase the capacity of existing reservoirs, address a diverse set of needs[1], and involve more partners. New storage projects will be increasingly innovative and will rely on technologies such as aquifer storage and recovery. Additionally, water managers will need to be more agile in responding to changing future conditions so that storage can be more rapidly added to Colorado's water portfolio while maintaining strong environmental health. To accomplish these goals, a permitting system that currently can produce uncertainty, significant delays, and foster mistrust among project stakeholders must be addressed.

To provide further context to these future storage goals, this case study provides a summary of existing surface water storage across the state and describes opportunities for increasing surface water storage in existing facilities, constructing new surface water storage facilities, and utilizing groundwater aquifers as storage facilities.

This TM also includes brief permitting considerations for each of these types of potential new storage opportunities. However, this TM does not include a comprehensive discussion on detailed permitting processes or attempt to predict the likelihood of success of the permit process for a specific storage project or any of the storage concepts presented herein.

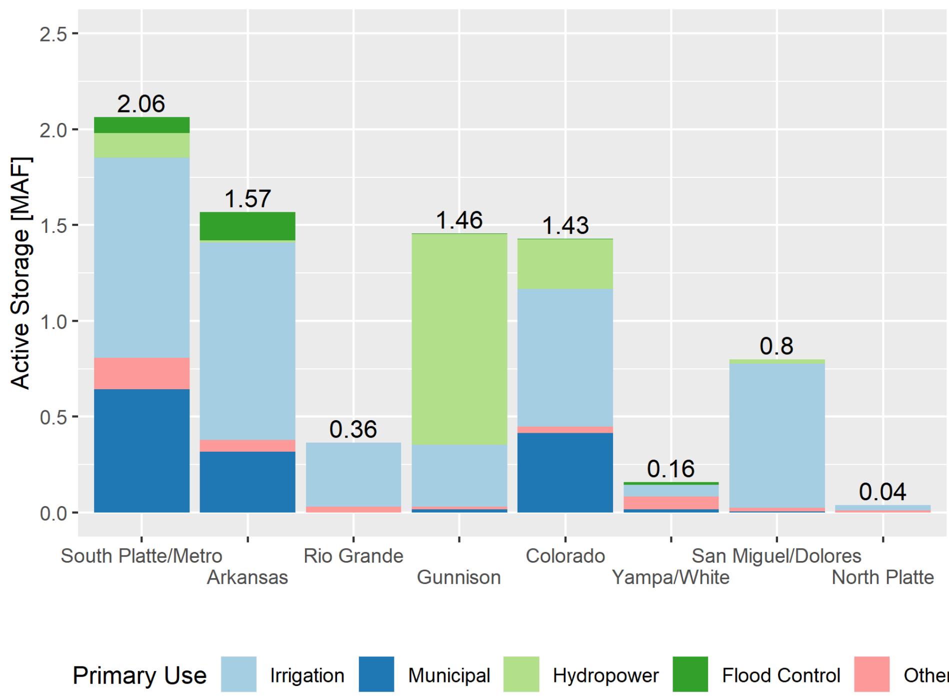
Section 2: Summary of Existing Surface Water Storage

Section 4 of the CWP provides an overview of surface water storage development in Colorado between the 1860s and 2010s. Figure 1 shows that there is currently about 7.5 million-acre-feet (MAF) of surface water storage in Colorado. Each reservoir in Colorado has a primary and often numerous secondary designated uses. Figure 1 shows how existing surface water storage is distributed across the state and how the designated primary uses vary significantly by basin.

Figure 1 is presented here to provide the reader with a frame of reference of what it may mean to contemplate varying volumes of future storage projects as outlined in the following sections of this TM.

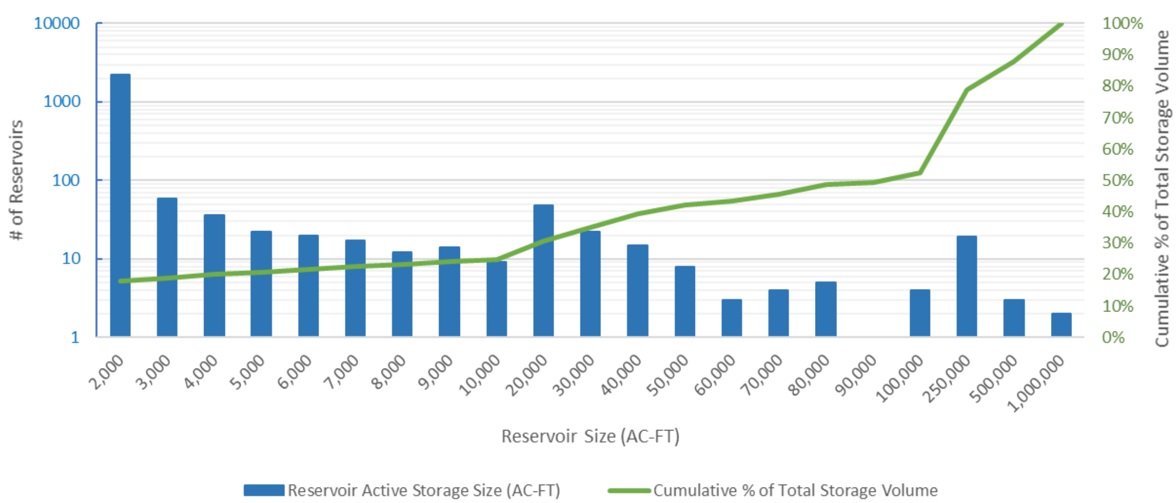
[1] Note that this TM only briefly considers multi-purpose storage and does not intend to identify or predict the likelihood for any specific project.

Figure 1: Existing Surface Water Storage in Colorado in 2018, by Basin



For some perspective on the number of existing reservoirs and their size, the vast majority (92%) of jurisdictional reservoirs in Colorado are less than 5,000 acre-feet (shown in Figure 2). Large reservoirs make up a small fraction of the total number of reservoirs in the state, with only 41 reservoirs being larger than 50,000 acre-feet. However, these reservoirs account for more than 50% of total storage volume. To accomplish the CWP's goal of 400,000 acre-feet of new storage, at least some new large reservoirs are needed.

Figure 2: DWR Jurisdictional Dam Active Storage Overview



Section 3: Opportunities to Increase Operational Storage of Existing Reservoirs

There are numerous opportunities to increase operational storage in existing reservoirs that (if made available) could increase both reliable water deliveries to municipal and agricultural water users and environmental and recreation flows during critical drought periods. Key opportunities are summarized below:

Reallocate Some Flood Storage to Active Storage: The Colorado Department of Water Resources (DWR) requires that reservoirs be designed to safely pass a designated Inflow Design Flood (IDF) which is based on the hazard classification of each dam. Current dam safety regulations dictate a range of frequency rainfall events from as low as a 1/25 percent per year event up to and including the Probable Maximum Precipitation (PMP) be utilized when determining the IDF. To provide this capability, many reservoirs throughout Colorado are designed and operated with a flood pool that is not used for storage operations. Instead, this volume is held in reserve and only used to safely capture and then immediately release flood waters in a controlled fashion. The required volume of unused storage dedicated to passing the IDF event is sometimes based on dated meteorology, hydrology, and dam engineering practices and data. In some cases, assessing the required flood storage against newer meteorological and hydrological design methodologies could allow a portion of the currently dedicated IDF volume in many reservoirs to be reallocated to active operational storage. This volume reallocation concept is referred to as the "storage delta concept" in Section 4 of the CWP.

To accurately define the potential to reallocate flood storage to active operational storage, detailed hydrological assessments would need to be performed at each individual reservoir being considered for reallocated storage. A comprehensive effort to perform these analyses in Colorado has not yet occurred; however, however many dams do have some amount of dedicated flood control volume. Even if a small amount of capacity in a select few of these reservoirs could be reallocated to active operational storage, the "storage delta concept" could provide meaningful contributions towards the CWP's goal of achieving additional storage in existing reservoirs.

Removal of Sediment: Sediment transport is a natural process that takes place in watersheds upstream of reservoirs, and it can be accelerated due to landscape changes that increase erosion potential. For example, large sediment transport events can occur over a relatively short period in watersheds that have experienced large-scale wildfires or other events that disrupt the watershed. In many cases, these sediments are transported into on-channel and off-channel reservoirs. Over time, the accumulation of sediment can displace a significant amount of the original operational storage volume of the reservoir. Reservoir sediment removal projects require significant planning to identify technically feasible methods for removing the sediments and identifying economically viable options for transporting and disposing of the removed sediments. Reservoirs that have been in operation for many decades or are downstream of wildfire areas could be good candidates for sediment removal as a means to increase operational storage volume.

It is important to note that sediment removal can be attractive because it recovers active storage in an existing structure and does not require a new reservoir permit. However, key technical considerations that may impact feasibility and cost can include removal of sediment using dredging versus pumping, identifying suitable locations for ultimate disposal of removed sediments, and the associated haul distance. Depending upon these characteristics, physically removing sediment can be technically difficult and can potentially cost more than new reservoir construction.

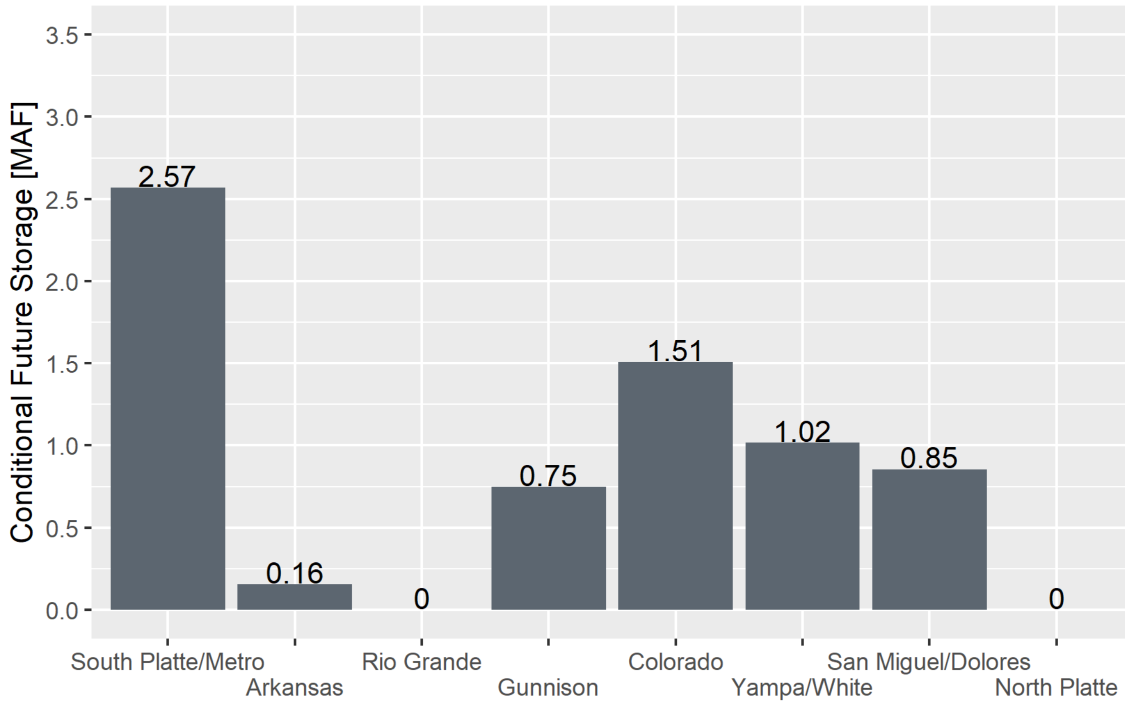
Rehabilitate Dams Currently Under Storage Restrictions: State statutes require that the State Engineer (DWR Dam Safety) inspect and evaluate regulated dams for signs of instability and set the safe storage level at those dams based on the conditions. When unsafe conditions are observed that risk is mitigated through storage restrictions that reduce the safe storage level to something less than full storage. Due to aging dams, a number of storage restrictions are ordered annually. Similarly, due to dam owner desire and based on the value of the lost storage, dams are rehabilitated and returned to full storage annually. In an average year there are about 130 dams with storage restrictions in Colorado. Some of the dams on the restricted list have issues that have not been addressed for numbers of years or even decades, and those dams remain to be utilized at less than full storage capacities. Rehabilitation of dams with long-standing storage restrictions could restore some or all of the original operational storage volume and, in some cases, rehabilitation would also safely allow enlargement of capacity at those facilities. DWR maintains an up-to-date database of all dams with reservoirs currently under storage restrictions. The database documents the deficiency that causes the restriction as well as the volume of lost storage compared to original design storage volume. It is also worth noting that many of the reservoirs under long-standing storage restrictions are owned by agricultural interests that may not have the funds to perform the rehabilitation that would return the reservoir to normal operations. However, some of the largest reservoirs that are under fill restrictions may be good candidates for a collaborative municipal and agricultural project where municipal water providers assist in funding the rehabilitation in exchange for use of a portion of the recovered storage volume.

Dam Enlargements: Increasing the height of existing dams is one option for providing additional future water storage. When compared to constructing entirely new dams, enlarging existing dams could have lower environmental impacts because changes to the natural landscape have already occurred at the existing dam location. However, detailed environmental assessments and permitting are typically still required, and the dam enlargement must be shown to be the least environmentally damaging alternative for meeting the documented storage need. In addition to permitting considerations, the existing dam must be in a location where the increased storage strategically fits into the overall operation of the regional water infrastructure and where excess water is physically and legally available for storage. Therefore, the number of dams that could be feasibly enlarged depends on many factors that require further detailed technical analyses.

Section 4: New Surface Water Storage Opportunities

In Colorado, water right holders can file for conditional water rights and conditional storage rights when there is an expected future water need or a current need with yet to be secured funding or permits. To gain one perspective of the opportunity for potential new surface water storage sites, the State's current water right database was queried for potential reservoir sites with conditional storage rights that are greater than 5,000 acre-feet. Sites smaller than 5,000 acre-feet were also queried. However, for this analysis it was assumed that the intended purpose of the smaller sites was for daily or seasonal operational storage. A cursory analysis showed that a larger number of smaller reservoirs do not accomplish the same operational objectives as a mix of larger reservoirs due to significant increases in evaporation losses and the loss of the benefits of economies of scale, which are significant for dams. The findings of the database query are shown in Figure 3.

Figure 3: Summary of Conditional Surface Water Storage Rights (Greater Than 5,000 AF), by Basin



As shown in Figure 3, there are over 6.5 million-acre-feet (MAF) of conditional storage rights that are greater than 5,000 AF on file with the State of Colorado. To gain a further understanding of the types of proposed facilities that make up the values shown in Figure 2, the top five conditional storage sites (greater than 5,000 AF) statewide and for each basin are listed in Table 1.

Table 1: Largest Conditional Storage Sites by Basin (Greater Than 5,000 AF)

Conditional Storage Name	Filed Conditional Storage Volume [AF]	Notes
Statewide		
Two Forks Reservoir	672,737	Denver Water, in conjunction with other Front Range utilities, pursued permitting of Two Forks Reservoir near Deckers. The project was vetoed by the EPA in 1990, although an alternate configuration, size, and precise location could be considered in the future, and therefore the project's conditional water rights are still active.
Animas-LaPlata Project	618,000	Conditional storage rights for unconstructed reservoirs as part of part of the Project are still active. Numerous configurations of this project have been proposed. A smaller scale configuration was completed in 2009 when Lake Nighthorse began to fill.
Weld Co. Reservoir	350,570	Proposed South Platte River reservoir near existing Riverside Reservoir.
Eagle-Colorado Reservoir	350,000	Denver Water maintains conditional storage rights for a new reservoir near Wolcott that could store water from the Eagle or Colorado Rivers.
Union Park Reservoir	320,550	Proposed reservoir near Taylor Park Reservoir. Project was canceled in mid-2000s, although conditional storage rights remain active.
South Platte/Metro Basin		
Conditional Storage Name	Filed Conditional Storage Volume [AF]	Notes
Two Forks Reservoir	672,737	Denver Water, in conjunction with other Front Range utilities, pursued permitting of Two Forks Reservoir near Deckers. The project was vetoed by the EPA in 1990, although an alternate configuration, size, and precise location could be considered and therefore the project's conditional water rights are still active.
Weld Co. Reservoir	350,570	Proposed South Platte River reservoir near existing Riverside Reservoir.
Grey Mtn. Dam (Glade)	220,000	Part of proposed Northern Integrated Supply Project.
Dowe Flats Reservoir	119,000	Proposed by St. Vrain & Left Hand Water Conservancy District, north of Hygiene.
Coffintop Reservoir	115,902	Proposed by St. Vrain & Left Hand Water Conservancy, south of Lyons.
Arkansas Basin		
Conditional Storage Name	Filed Conditional Storage Volume [AF]	Notes
Tri-State Reservoir	85,000	Proposed reservoir as part of Tri-State power generation project.
Williams Creek Reservoir	35,000	Proposed reservoir as part of Colorado Springs Utilities' Southern Delivery System.
Southeast Plant Reservoir	20,000	Proposed Arkansas River irrigation and industrial reservoir near Los Animas.
Phantom Canyon Reservoir	8,400	Proposed power generation reservoir outside Canon City.
White Creek Reservoir	7,000	Proposed M&I and irrigation reservoir outside Walsenburg.
Gunnison Basin[1]		
Conditional Storage Name	Filed Conditional Storage Volume [AF]	Notes
Union Park Reservoir	320,550	Proposed reservoir near Taylor Park Reservoir. Project was canceled in mid-2000s, although conditional storage rights remain active.
Snowshoe Dam & Reservoir	74,955	Proposed industrial (coal mining) reservoir outside Paonia, conditional storage rights remain active.
Saltado Reservoir	72,600	Proposed irrigation reservoir west of Telluride as part of San Miguel Project.
Radium Reservoir	49,600	Proposed irrigation reservoir near Nucla as part of San Miguel Project.
Gorsuch Reservoir	28,754	Proposed reservoir as part of the Grand Mesa Project located on Currant Creek, tributary to the Gunnison River.

Conditional Storage Name	Filed Conditional Storage Volume [AF]	Notes
Colorado Basin		
Conditional Storage Name	Filed Conditional Storage Volume [AF]	Notes
Eagle-Colorado Reservoir	350,000	Denver Water maintains conditional storage rights for a new reservoir near Wolcott that could store water from the Eagle or Colorado Rivers.
Azure Reservoir	178,794	Proposed irrigation and M&I reservoir west of Kremmling.
Una Reservoir	173,477	Proposed irrigation, M&I, and power generation reservoir west of Parachute.
Red Cliff Proj. Iron Mt	98,042	Proposed irrigation, M&I, and power generation reservoir on Homestake Creek near Red Cliff.
Roan Creek Reservoir	71,300	Proposed irrigation, M&I, and power generation reservoir west of Parachute.
Yampa/White Basin		
Conditional Storage Name	Filed Conditional Storage Volume [AF]	Notes
Rio Blanco Reservoir	131,034	Proposed M&I reservoir north of Glenwood Springs.
Wolf Creek Reservoir	90,000	Recently filed with DWR by Rio Blanco Water Conservancy District Project (RBWCD)-conditional storage volume estimated.
Fourteen Mile Reservoir	85,988	Proposed irrigation and M&I reservoir north of Rifle.
South Fork Reservoir	85,342	Conditional rights transferred to RBWCD for proposed Wolf Creek Reservoir, located on South Fork of the White River.
Strawberry Creek Reservoir	75,957	Proposed outside Meeker.
San Miguel/Dolores Basin		
Conditional Storage Name	Filed Conditional Storage Volume [AF]	Notes
Animas-LaPlata Project	618,000	Conditional storage rights for unconstructed reservoirs as part of part of the Project are still active. Numerous configurations of this project have been proposed. A smaller scale configuration was completed in 2009 when Lake Nighthorse began to fill.
Plateau Creek Afterbay	44,900	Proposed by Dolores WCD, irrigation and M&I storage north of Cortez.
Oneal Park Reservoir	40,700	Proposed irrigation reservoir by Southwestern Water Conservation District.
Dawson Creek Reservoir	35,635	Located on Dawson Creek in Gunnison County.
Campbell Forebay	22,800	Proposed as part of Plateau Creek Afterbay.
Rio Grande Basin		
None Identified		
North Platte Basin		
None Identified		

1. Radium Evap. Pond (86,800 conditional AF) was not included in this list. This reservoir's proposed use is for brine storage as part of the Paradox Valley Unit Salinity Control Program, and is therefore assumed to be not applicable to water supply storage.

It is worth noting that some of the storage sites shown in Table 1 have previously undergone some amount of permitting efforts and, on occasion, some of the previous permitting efforts were either abandoned or the lead permitting agency declined to issue the required permits to construct the dam. However, conditional storage rights for the sites remain active since alternate sizes and configurations to those originally proposed remain a consideration.

Additionally, 6.5 million acre-feet (MAF) of conditional storage rights (if constructed) would nearly double the existing surface water storage in Colorado and is more than fifteen times the CWP's measurable objective of 400,000 AF of additional storage by 2050. Although the 6.5 MAF of new surface water storage is not likely to occur by 2050, if only a portion of the conditional storage sites are ultimately determined to be technically and environmentally feasible, those new surface water storage facilities could become a critical component to a balanced approach to meeting the projected water resources gaps throughout Colorado.

Section 5: Aquifer Storage and Recovery Opportunities

Groundwater aquifer storage and recovery (ASR) is another method for storing water for later use[2]. Generally, there are two types of aquifer storage projects: 1) water stored in an unconfined aquifer and 2) water stored in a confined aquifer. Both types of ASR can be implemented to contribute to the Colorado's Water Plan 400,000 AF storage goal.

Unconfined ASR: Unconfined ASR projects often include diverting surface water during times when recharge water rights (generally, these water rights are relatively junior) are in priority and conveying that water to recharge pits that allow the water to naturally percolate into the alluvial aquifer system. Depending on the characteristics of the unconfined aquifer system, the recharge water can be used as credit for depletions associated with alluvial groundwater pumping. Because the entity implementing unconfined ASR does not have complete control over how the recharged water migrates through the alluvial system, it is possible that the water stored in the unconfined alluvial system can flow back into the surface water system during a time when the water is not needed, and the storage objective is therefore not always achieved. This type of ASR project may be most applicable for near-term or seasonal retiming of water availability and less applicable for equalizing water availability over a series of dry and wet years. Additionally, there has been more recent interest in developing long term recharge credits that would help provide augmentation supply during dry times, although a challenge with this method is ensuring that the timing of recharge credits aligns with the need for dry-year supplies.

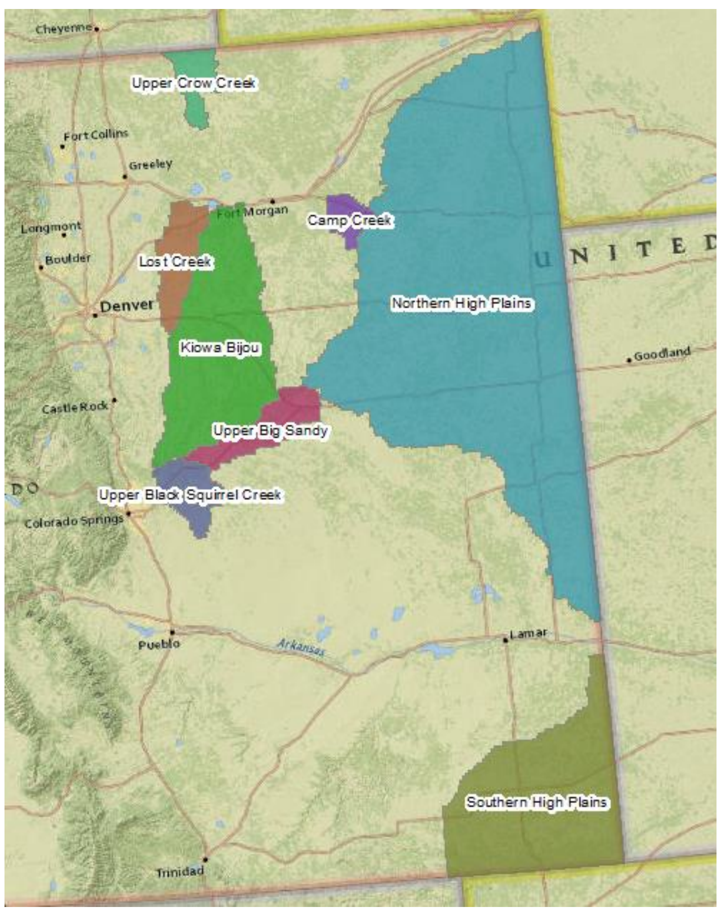
Confined ASR: Confined ASR projects often include diverting surface water during times when the surface water is not immediately needed for other uses, treating the water to drinking water standards and EPA Class V injection well standards and then injecting the water into a deep/confined aquifer system. Because the water is put into a confined system, it generally remains available for subsequent withdrawal even several years after injection occurs. However, a major disadvantage is that deep aquifer characteristics in Colorado are such that it can be difficult to achieve sustainable injection rates of over 250 gallons per minute per well. This means that if an entity desired to store 10,000 acre-feet of wet-year

[2] Note that Colorado Department of Public Health & Environment Water Quality Control Commission Regulation No. 41 establishes use classifications and water quality standards for groundwater supplies in Colorado.

spring river flows over a two-month period, approximately 150 injection wells may be needed. This is impractical from both a cost perspective and well-siting perspective. For these reasons, deep aquifer/confined ASR projects work best in conjunction with surface water storage projects, where surface water reservoirs capture peak available surface water flows and then slowly transfer that water to a deep well injection system. The water transferred to the deep aquifer can be stored for years and be available during the next major drought. As the water is transferred from the surface storage system, surface storage capacity is made available to capture the next round of high surface water flows. A well-known example in Colorado is the Centennial Water and Sanitation District capturing surface water under junior water rights, storing that water in South Platte Reservoir, and then treating and injecting that water into their Denver Basin wells at a controlled rate.

Designated Groundwater Basins: In Colorado, there is an additional type of recognized aquifer system. Called Designated Groundwater Basins, these eight basins (Figure 4) in Colorado's eastern plains are administered by the Colorado Groundwater Commission instead of through water court. Groundwater identified as being in a Designated Basin is mostly confined, although may also contain characteristics of both confined and unconfined aquifer systems, with some (but little) hydrologic connectivity to surface water systems. Careful analysis is required when contemplating use of a Designated Basin for ASR, and both advantages and disadvantages of ASR in unconfined and confined systems (described above) may be realized. Additionally, stored water in a Designated Basin may be vulnerable to other users' pumping.

Figure 4: Designated Groundwater Basins



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Section 6: Storage Opportunities Summary and Conclusions

There are several different types of potential storage options that could assist efforts to meet Colorado's projected water supply/demand gaps. Table 2 summarizes the key considerations for each type of potential storage discussed in this TM.

Table 2: Overview of Different Water Storage Opportunities

Reallocation of Some Flood Storage to Active Storage
• The volume reallocation from flood control to reservoir operations (referred to as the "storage delta concept") could be a part of achieving additional storage in existing reservoirs. • Further meteorological and hydrologic analysis could be performed on key reservoirs that have dedicated flood storage to identify the most likely opportunities for implementing the "storage delta concept in the future.
Removal of Sediment
• Further analysis should be completed on key reservoirs (i.e. reservoirs that have been in operation for a long period of time or are downstream of wildfire areas) to clarify the degree to which sediment removal could achieve additional operational storage volume.
Rehabilitation of Fill Restricted Dams
• Further analysis should be completed on key reservoirs with fill restrictions to determine the degree to which dam rehabilitation and removal of fill restrictions could achieve additional operational storage volume. • Collaborative partnerships between municipal and agricultural water users should be explored as a way to share in the cost of reservoir rehabilitation in some cases.
Dam Enlargements
• In select cases where water is physically and legally available, and the reservoir fits into existing system operations, raising the height of a dam could be a feasible option for achieving additional storage in an existing reservoir. • In a dam enlargement situation, significant permitting efforts will be required.
New Dam Sites
• Approximately 6.5 million acre-feet of conditional storage water rights that are greater than 5,000 AF are on file with DWR. Many of the largest conditional storage rights in each basin are decreed for municipal, industrial, and irrigation uses. • When considering future storage options, a larger number of smaller reservoirs do not accomplish the same operational objectives as a mix of larger reservoirs due to significant increases in evaporation losses and the loss of the benefits of economies of scale.
Aquifer Storage and Recovery (ASR)
• Unconfined/Shallow ASR projects may be best for near-term or seasonal surface water availability retiming due to potential connections to surface water systems that may limit the duration water can feasibly be stored in the unconfined system. • Confined/Deep ASR projects may be most applicable for longer-term water storage and can be used in conjunction with a surface water storage system to better enable capture of surface water peak flows and optimize the sizing of the ASR system.

Analysis and Technical Update to the Colorado Water Plan

Technical Memorandum

Prepared for:

Colorado Water Conservation Board

Subject:

Review of Successful Alternative Transfer Method Programs and Future Implementation

Date: July 16, 2019

Prepared by: Jacobs and BBC Research & Consulting

Reviewed by: Brown and Caldwell

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Section 1: Introduction & Overview of ATMs

Colorado's Water Plan (Water Plan) describes how future population growth in Colorado will translate into higher municipal, industrial and other non-agricultural water demands, placing increased pressure on existing agricultural water rights to be transferred to new uses. The Water Plan further notes that permanent reductions in irrigated agricultural lands to transfer water (commonly referred to as "buy-and-dry") results in harmful impacts to rural agricultural communities and economies. Across the state, water stakeholders want to minimize buy-and-dry in ways that respect property rights, recognize the importance of agriculture in Colorado, and support a sustainable agriculture industry - while identifying diverse and flexible options to provide water for municipal, industrial, and non-consumptive needs.

These options, referred to as Alternative Transfer Methods (ATMs), offer voluntary tools that enable both farmers and other water users to share water in a sustainable and economically beneficial manner. In addition, ATMs can support the environment, as well as recreation, industry, groundwater sustainability, and compact compliance. Colorado's Water Plan sets a goal of achieving 50,000 acre-feet of water transfers through voluntary alternative transfer methods by 2030. This case study reviews select ATM projects that have been recently implemented while highlighting key characteristics of the ATM that provide insight into how future ATMs might also be successfully structured.

1.1 MECHANICS OF ATMS

ATMs broadly encompass a variety of voluntary methods to transfer agricultural water to other uses. Each ATM includes a unique set of supply and transfer methods to move water from one user to another on a temporary contract or intermittent supply basis. Recent ATM projects have also incorporated indefinite or perpetual interruptible water supply agreements to address end-user concerns regarding long-term water availability. Altogether, ATMs typically transfer water to a new use without permanently removing irrigation water use, maintain agricultural ownership of the water right, add flexibility and resilience to water systems, and minimize economic impacts associated with traditional transfers. ATMs consist of two components: (1) agricultural water conservation methods and (2) water transfer methods.

Agricultural water conservation methods are the types of changes made by agricultural water users to reduce their water consumption such that the right to use that increment of water supply can be transferred to other uses, or to reduce demand on water systems in furtherance of groundwater sustainability and compact compliance efforts. Example agricultural supply methods for ATMs include varying degrees of crop land fallowing (such as full season, rotational, and split season fallowing), regulated deficit irrigation, or, in some limited cases, agricultural infrastructure improvements and on-farm practices that reduce evaporative loss.

Water transfer methods are the contractual terms by which water is made available through the agricultural supply methods and is transferred to new users. Example water transfer methods include water banks, interruptible water supply agreements, short term leases, and long-term leases.

1.2 ATM ATTRIBUTES & BARRIERS

ATM projects provide several general benefits when compared to permanent, buy-and-dry water transfers. For municipalities, ATMs may provide a reliable source of dry-year water supplies and can be more cost effective than permanent transfers and other traditional new supply sources. By maintaining some farm operations as part of the ATM program, rural economies that depend on agricultural activities can be sustained and agricultural users can have access to new income streams for purchasing new equipment, investing in infrastructure improvements, or other operational needs. ATMs can also be useful in preserving ecosystem services associated with working agricultural lands such as open space and wildlife habitat. Additionally, ATMs can be applied to address multiple water supply challenges including municipal and industrial needs, compact compliance, groundwater management, and non-consumptive needs. This flexibility allows implementation of ATM programs that maximize benefits to both the agricultural community and the end users of transferred water.

Barriers to implementation include both balancing the municipal and industrial user's desire for certainty and permanence of long-term supply with the supplier's desire to maintain agricultural and farming viability, and potentially high new infrastructure costs needed to implement a viable water transfer (it is worth noting that potentially high infrastructure costs are also a barrier to implementing a permanent transfer and are not necessarily unique to ATMs). Furthermore, high transaction, legal, engineering, and administration costs can discourage some parties from pursuing an ATM arrangement, particularly for temporary agreements. Additionally, socio-normative barriers exist where water managers either lack the capacity or incentives to try new approaches to water management. Water managers may not feel empowered or compelled to implement ATMs that may have broader economic, social and environmental benefits, but make their primary duties more difficult or do not align with their primary goals.

Several efforts have been made to address these challenges over recent years, including the continued financing of ATM projects through the CWCB's long-standing ATM Grant Program and development of more flexible, administrative ATM project approvals through the HB 13-1248 Fallowing-Leasing Pilot Program and Agricultural Water Protection Water Right (described further in Section 1.3).

1.3 NEW LEGAL STRUCTURES

Under Colorado water law, only the historical consumptive use (HCU) of the crops can be transferred to another water use, while the historical return flows to the river system must be replicated under the ATM operation to avoid injury to downstream water right holders who depend on these historical return flows to fulfill their water rights[1]. Traditionally, transferring a water use from a historical location of use to another location and for a different use requires approvals through the water court process. This approval process can require extensive amounts of time and substantial legal and engineering costs and, therefore, this system can be a barrier to transferring small amounts of water or transferring water on an intermittent basis.

In response to this challenge, the Agricultural Water Right Protection Act (House Bill 16-1228) was passed in May 2016. Currently, this Act only applies to Water Divisions 1 and 2. Specifically, the Act protects the agricultural use for which a water right was originally decreed while permitting renewable one-year transfers of up to 50 percent of the historical consumptive use to another water user. The law requires that the remaining water must continue to be used for agricultural production. The primary benefit is that after the water use change is approved by water court, the water can be easily used as irrigation water in some years and for the other approved use or uses in other years without the need for additional court approvals. An important and novel aspect of this law is that the new (non-agricultural) water use does not have to be explicitly defined at the time of water court approval.

[1] This is not unique to ATMs, and applies to buy and dry transfer operations as well.

Other recent Colorado legislative changes since 2010 related to ATM facilitation include:

- House Bill 13-1248: This bill authorizes the CWCB to approve pilot projects to test fallowing-leasing as an alternative to buy-and-dry. In 2015, under Senate Bill 15-198, the pilot program was expanded from municipal use to include other uses, including agricultural, environmental, industrial, or recreational uses. Each project can last up to 10 years and no more than 5 pilot projects may be located in any one of the major river basins. The legislation also led to the creation of the Lease Fallow Tool (LFT), which was developed to simplify and streamline the evaluation of historic depletions and return flows, thus reducing ATM transaction costs.
- House Bill 13-1130: Clarifies operation of interruptible water supply agreements and allows for a temporary change in location and type of use of a water right without water court approval. The original interruptible water supply agreement legislation allowed the State Engineer to approve a lease agreement that provides a changed use in 3 out of 10 years for a single period. This bill modifies the previous legislation to allow the State Engineer to approve of up to two additional 10-year periods for the agreement.
- Senate Bill 13-019: Offers protection to water rights holders when consumptive use of the water right is decreased due to participation in select conservation programs, including some ATMs. The bill provides that a determination of HCU may not consider years in which the water right, or the land appurtenant to the water, was enrolled in a government conservation program. More specifically, the bill says that HCU will not be decreased because of the following: (1) the land was enrolled in a Federal land conservation program, (2) reduced use of the water right for up to 5 out of 10 years because the water right was involved in a water conservation program, a land fallowing program, or a water banking program. This provision applies to all Water Divisions in Colorado, with the exception of Division 7.

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Section 2: Case Studies

ATMs in Colorado are predominantly used to transfer water from agriculture to municipal, industrial, or environmental uses on a temporary basis. Recent efforts have also explored using ATMs to comply with interstate water compacts. Generally, ATMs reflect the values and competing demands for water within each basin. For example, ATMs have been implemented in basins with growing population pressures (e.g., the South Platte and Arkansas Basins), environmental pressures (e.g., the Colorado, Yampa, and Gunnison Basins), or facing other water administration challenges such as groundwater sustainability and compact compliance. The following sections summarize some of the key characteristics of the following ATM projects, shown in Figure 1 and categorized by type:

- Agricultural to Municipal/Industrial
    - Little Thompson Farm
    - Catlin Canal
- Agricultural to Environmental
    - McKinley Ditch
- Compact Compliance
    - Grand Valley Water Users Association Conserved Consumptive Use Pilot Program

Figure 1: Case Study Locations

2.1 LITTLE THOMPSON FARM

Project Description	
River Basin:	South Platte
Supplier:	Larimer County Open Lands Program
Buyer:	City and County of Broomfield
General Narrative Description:	The Larimer County Open Lands Program (OLP) works with willing landowners to conserve land throughout the County using various conservation tools, including acquiring fee title to the land. Through various planning efforts, the OLP heard from citizens urging the county to prioritize the acquisition of water rights to protect prime agricultural land and provide land for emerging farmers. In 2014, the OLP was approached by the owners of the Little Thompson Farm, a 211-acre agricultural property southwest of Berthoud, Colorado to learn about opportunities for conserving the farm as a working operation. In exploring options and potential tools for financing the project, OLP began exploring the possibility of an ATM.
How/Why Parties Came Together:	In 2016, the OLP acquired the farm using public open space resources with the goals of conserving a viable, irrigated farm in perpetuity, offsetting the purchase costs through piloting a water-sharing agreement, and providing a catalyst for a viable model for future ATMs. After acquiring the farm, Larimer County secured a CWCB ATM grant to hire a consultant team to compile the water, agricultural, and legal knowledge needed to design an agreement that would work for both the farm and a municipality, while meeting the above-stated goals. The project team met with multiple water providers with the City and County of Broomfield ultimately agreeing to pursue a water-sharing agreement. The City and County of Broomfield and OLP agreement is a combination sale of 115 Colorado Big Thompson (CBT) units and an interruptible water supply agreement for 80 CBT units. The parties determined that an interruptible water supply could be an effective way to meet dry-year municipal water demands while maintaining water supplies for the farm during normal/wetter years.

Project Facts	
Type of ATM Project:	Agriculture to Municipal Transfer
Supply Method:	Temporary fallow
Transfer Agreement Type:	Interruptible Water Supply Agreement (IWSA)
Agreement Length:	Perpetuity (indefinite IWSA, first perpetual agriculture to municipal ATM in Colorado)
Frequency of Transfer:	3 out of 10 years on a rolling basis for an indefinite period
Volume/Flow Transferred:	115 C-BT units sold outright, with OLP retaining a right of first refusal to lease back these units any time Broomfield is putting them up for lease. 80 Units of Colorado-Big Thompson (C-BT) water, or roughly 60 acre-feet annually, is subject to the IWSA.
Unit Price of Water Transferred:	115 units sold for the appraised value of $26,000/unit, with Broomfield paying $25,500/unit, and CWCB ATM Grant funding $450/unit. For the IWSA, a one-time cost of $832,000 or roughly $15,000 per acre-foot. Plus, a dry-year lease payment of $225/unit each year the ATM is exercised, or roughly $320/acre-foot. The rental payment is subject to a price escalator based on the lease price for CB-T shares beginning in 2028. Broomfield is responsible for reimbursement of crop-related costs if notice to use water is given between January 31st and June 1st.
Factors Determining Price:	Several factors contributed to determine the above costs. Since the City and County of Broomfield have rights to the water every 3 out of 10 years, it agreed to pay 30% of the appraised value for each C-BT share plus 10% extra to have access to water in dry years for a total of 40% of the appraised value. Annual costs were added to the agreement to

2.1 LITTLE THOMPSON FARM

	compensate Larimer County for transaction costs to fallow the farm and the opportunity cost of lost crop production.

Methods for Overcoming Typical ATM Barriers

Transaction Costs:	The transferred water came from the C-BT project. One of the unique aspects of C-BT water shares is that they do not require water court to add or change uses. CWCB ATM grant funds were used to cover a portion of the legal, engineering, and administrative costs.
Water Rights Administration and Accounting:	Prior to initiating the ATM project, Larimer County contacted Northern Water to make sure a perpetual agricultural-to-municipal interruptible water supply agreement involving C-BT was permitted in accordance with Northern Water's rules, regulations and policies. When the idea of a perpetual interruptible supply agreement was broached with Northern Water staff, they thought this was unique enough from their typical year-by-year lease arrangements that they would require more review and oversight. As a result, the team navigated an unexpected rulemaking process with Northern Water that delayed the ATM. The new rules required that all C-BT subcontracts must be approved by the Northern Water Board. Northern Water also agreed that non-irrigation use of CBT water is allowed for 3 out of 10 years. In the event of prolonged drought, this term can be extended on a case-by-case basis.
Reliability:	While the team initially thought the ATM deal would be a dry-year interruptible water supply agreement involving all or most of the 240 C-BT units, reluctance amongst municipal water providers to pay a premium of 60 to 80 percent of the total water value necessitated an alternative approach. The parties agreed to transfer 115 units of C-BT, less than half the 240 C-BT units. The financial return of selling those units enabled the County to keep 45 C-BT units out of the ATM and acquire additional Handy Shares. The 45 units plus the additional Handy shares contribute to the farm's viability by making the ATM less of an "all-or-nothing" arrangement and allowing for higher crop production in years when the ATM is utilized. The sale of the C-BT units also ultimately provided the "carrot" the water provider needed to commit the time and resources necessary to negotiate and execute this first-of-its-kind deal.
Infrastructure:	No new or additional infrastructure was required for this ATM. It is worth noting that the City and County of Broomfield currently receives C-BT water separately from this ATM and is able to utilize its existing raw water conveyance infrastructure from Carter Lake to take delivery of water supplied by the ATM.

Unique Issues Overcome

Seller Issues:	Even when an ATM appeared feasible, according to the experts, Larimer County needed to find the right water-sharing partner with compatible water portfolio needs, financial capacity, and decision-maker support for trying something new and innovative. The County pushed hard for a dry-year payment in addition to the up-front payment for the ATM to ensure the farm viability and preserve the financial health of the deal. The dry year payment adds to the farm's viability two-fold: providing a disincentive to the M&I partner using the water when the water is not truly needed and helping cover ATM-year costs/losses on the farm such as weed management and lower yields. The $225/unit ATM-year payment met the County's farm viability and financial needs while providing value to Broomfield in securing a below market rental price.
Buyer Issues:	Broomfield's current and future water demands were analyzed to make certain the C-BT units included in the ATM would have a positive impact on the City's water supply and would not hinder any type of development. The amount of water included in the ATM was a welcome and viable fit to support potential dry-year water demands in the city, especially in the period while Broomfield is developing storage and water firming capability in Chimney Hollow Reservoir.

2.1 LITTLE THOMPSON FARM

Benefits Derived from ATM

Seller Benefits:	The ATM agreement allowed Larimer County to maintain a viable 211-acre farm in perpetuity as part of its open space program and provide opportunities for young/new farmers entering the industry. This ATM would not have been financially feasible without the consideration of public benefits and underlying motivation of Larimer County to preserve agricultural lands.
Buyer Benefits:	Overall, the addition of the ATM units to Broomfield's water supply portfolio was an excellent fit. The nature of the agreement allowed Broomfield to purchase C-BT units at a fraction of the full market value. The units will help aid Broomfield in times of drought and drought recovery.

Lessons Learned

Widespread use of ATMs will likely require additional tools that facilitate the transfer of water back and forth between municipal and agricultural uses. Legislation and other measures aimed at reducing the cost and uncertainty of changing water in water court for ATM purposes, while still, of course, protecting other water rights from injury, should be considered.

It was critical to the success of this project that staff educate the decision makers continually and often and have a well thought out backup plan if the ATM could not be executed for any number of reasons. Strong political support was an important factor for the County to even attempt to implement this project given the large investment of staff time and resources and the complicated nature of negotiating a new and innovative conservation project.

The team would advise other entities that pursue this sort of arrangement to begin as locally as possible to the farm and exhaust those opportunities before moving outward. The intrinsic value of keeping viable farmland close to the community involved in the water sharing deal may also add to the value of the arrangement, particularly in municipalities, which tend to have multiple objectives such as those with an open space initiative that also have unmet water needs, or a water district with board members that also farm in the same ditches as the farm being conserved.

2.2 CATLIN CANAL (A.K.A. SUPER DITCH)

Project Description

River Basin:	Arkansas
Supplier:	Catlin Canal
Buyer:	Multiple municipalities (Town of Fowler, City of Fountain, and Security Water and Sanitation District)
General Narrative Description:	After years of permanent water transfers from agricultural producers to municipalities, irrigators in the Lower Arkansas basin came together to develop an alternative to the permanent sale of water rights to municipalities. The Super Ditch project was created in 2008 as a solution to this challenge. The Super Ditch was formed as a general working group to implement various types of ATMs in the Arkansas River Basin spanning from Pueblo Reservoir to John Martin Reservoir. The Super Ditch is comprised of shareholders from six ditches to utilize rotational fallowing to make water available for alternative uses. The overall objectives of the Super Ditch are to: • Conserve rural community values; • Increase market power through consolidation; • Increase marketability of water supplies; and • Reduce transaction costs. Under an agreement with Lower Arkansas Valley Water Conservancy District (LAVWCD) the first pilot project was developed and is formally known as the Catlin Pilot Project.
How/Why Parties Came Together:	Lower Arkansas Basin irrigators were motivated to make water available to the municipal providers in a way that reduced permanent transfers. The ATM terms were attractive to municipal water providers that were looking for a cost-effective near-term water supply, alternative water sources due to quality concerns, and augmentation supply.

Project Facts

Type of ATM Project:	Agriculture to Municipal Transfer
Supply Method:	Rotational fallow (30% of participating land fallowed each year)
Transfer Agreement Type:	Lease
Agreement Length:	10 years (the Catlin pilot program is limited to ten years by statute)
Frequency of Transfer:	Annually; fallowing is rotated to adhere to HB13-1248 requirements prohibiting the fallowing of the same land for more than three years in a ten-year period or the fallowing of more than 30% of a single irrigated farm
Volume/Flow Transferred:	Up to 500 acre-feet per year
Unit Price of Water Transferred:	500 per acre-foot of water transferred and $150 per acre of land fallowed, or approximately $982 per acre fallowed (payment varies annually due to several climatic and operational factors)
Factors Determining Price:	A steering committee helped estimate the value of the irrigation water by comparing the profitability to an irrigator of selling a water right, using the right on a fallowing-leasing basis, or continuing to use the right to irrigate. The study estimated that the price for an outright purchase would need to be in the range of $5,000 per acre-foot to make the "sell" strategy competitive with the lease strategy. The study estimated that farm returns would need to be about $500 per acre to make the continue-to-irrigate decision preferable. This latter value was used to set the water price.

2.2 CATLIN CANAL (A.K.A. SUPER DITCH)

Methods for Overcoming Typical Barriers

Transaction Costs:	The Catlin Pilot Project was the first application to be submitted and approved through the CWCB's HB13-1248 pilot program, which is designed to streamline the approval of fallowing-leasing projects outside of the typical water court change of use process, while still maintaining historic return flow conditions.
Water Right Administration and Accounting:	For the current project, historical consumptive use and return flows were quantified using the Lease Fallow Tool (LFT) per criteria and guidelines established by HB13-1248. Terms and conditions to prevent injury were developed through public meetings moderated by the SEO under the administrative processes defined in HB13-1248. The streamlined approach embodied in the LFT proved to be an efficient means to calculate water available for lease and to determine return flows owed to avoid injury to other water rights holders and to ensure compliance with the Arkansas River Compact. Just as significant, the LFT facilitated and expedited the application and approval process.
Reliability:	The Catlin Canal Pilot project is limited to ten years by statue, but has generated municipal interest in future lease arrangements. The Super Ditch and Fountain are currently in the process of seeking administrative approval for a separate interruptible water supply agreement that will provide up to 1,100 AF per year beginning in 2019. The Super Ditch is also in the process of developing a second fallowing-leasing project involving Colorado Springs Utilities.
Infrastructure:	An engineering study determined it is not financially feasible to construct a dedicated pipeline for this project. Therefore, this ATM uses a series of exchanges using existing and planned diversion & storage facilities to deliver water to municipal lessees. For the current project, measurement devices and recharge facilities were installed by the LAVWCD.

Unique Issues Overcome

Seller Issues:	The Catlin Pilot Project application was the first to go through the process established in the CWCB's Criteria and Guidelines and was also the first to conduct an analysis using the LFT that was developed by the State Engineer. As a result, the process of putting together the Catlin Pilot Project application, working through the comments of nine parties, preparing a joint conference report with proposed terms and conditions, obtaining the CWCB approval and then complying with the "conditions precedent" to project operations that were set out in that approval, involved significant commitment of time and financial resources by the LAVWCD. Because of the costs incurred in developing the first pilot project application, the Lower Ark District requested and obtained grant funding from the CWCB's ATM Grant Program in May 2015. The grant money covered certain operational expenses incurred as a part of the 2015, 2016 and through February of 2017 Catlin Pilot Project operations, including accounting and reporting.
Buyer Issues:	Some potential lessees expressed initial concern that the newly formed Super Ditch Company may not have the administrative ability to sufficiently manage the ditch company members in a way that would guarantee that water would be available under the terms of the contract. Extensive work was required to ultimately gain the required trust.

Benefits Derived from ATM

Seller Benefits:	This project allows the producer to have additional crop in their rotation with a fallowed piece of land tied to a revenue stream. The declining economy in the Arkansas Basin benefits from the producers staying in business and spending money locally. Ownership stays with the farm and the amount of land dried up on a year by year basis is determined by the producer. The project has resulted in several additional benefits such as improved water quality and enhanced soil health.
Buyer Benefits:	Lessees gain access to water supplies to address drought concerns and replace groundwater pumping, while participation in projects benefits the region's agricultural economy.

2.2 CATLIN CANAL (A.K.A. SUPER DITCH)

	Transactional costs associated with the water court process and long-term management of permanently fallowed lands are also avoided.

Lessons Learned

	The continued experience gained during Catlin Pilot Project operations is identifying ways to streamline operations and administration for this and future rotational fallowing-leasing projects. For the current project, engineering costs to quantify historical consumptive use were minimized using the streamlined processes defined under HB 13-1248. Also, use of on-farm recharge facilities to maintain return flows reduced concerns of injury to other water rights. Operations continued to increase irrigators' interest in rotational fallowing-municipal leasing and further demonstrated to municipal users that temporary transfers for municipal use can be accomplished through the successful exchange and delivery of wet water. The continued success of the Catlin Pilot Project is significant in that it reflects the first "proof of concept" in Colorado for rotational land fallowing-municipal leasing as a viable alternative to the permanent buy-and-dry of agricultural lands. After the project began, the producers have learned how to strategically fallow land years in advance to allow the project to continue. Weed management becomes difficult on a dry parcel of land and puts more ownership on the producer. In the dry years the delivery of water and exchange potential are low and new mechanisms are required to deliver the full amount of HCU. Operations of the project are very comprehensive with daily, monthly, and yearly reporting to all interested parties. Being able to plant a dry land shallow rooted crop has allowed for additional cropping patterns as well as weed and erosion control.

2.3 MCKINLEY DITCH

Project Description	
River Basin:	Gunnison
Supplier:	Colorado Water Trust
Buyer:	Colorado Water Conservation Board
General Narrative Description:	The McKinley Ditch project is a pioneering opportunity to provide streamflow and ecological benefits for the Little Cimarron River while keeping agricultural lands in production. In 2014, the Colorado Water Trust purchased the water rights associated with a 200-acre irrigated ranch in the Gunnison River Basin that had been recently acquired by the Western River Conservancy. The water rights include 1.5 shares in the McKinley Ditch, which diverts water from the Little Cimarron River, approximately 5 miles above its confluence with the Cimarron River. Agricultural use is maintained using a split-season operation, where water is used for agriculture during the first part of the irrigation season, then left instream when flows reach critically low levels later in the season. This is the first decreed environmental ATM in the state.
How/Why Parties Came Together:	The goals of the Colorado Water Conservation Board, Colorado Water Trust and the Western River Conservancy are to preserve agricultural use of land by through split-season use, pilot and agricultural/environment multi-use projects, restore flows to a 9.2 mile reach of the Little Cimarron and Cimarron Rivers, and re-water a seasonally dry 3.3 mile reach of the Little Cimarron Ditch.
Project Facts	
Type of ATM Project:	Agriculture to Environmental Transfer
Supply Method:	Split season (typically July or August) fallow
Transfer Agreement Type:	Grant of Flow Restoration Use from the Colorado Water Trust to the CWCB
Agreement Length:	Perpetuity
Frequency of Transfer:	Varies based on per-determined conditions each year
Volume/Flow Transferred:	Varies - up to 5.8 cfs
Unit Price of Water Transferred:	CWCB paid $145,640 for instream flow use of the water rights to be left in the stream.
Factors Determining Price:	The original land and water right owner lost the farm to foreclosure before it was purchased by the Western River Conservancy. The Colorado Water Trust purchased the land's 5.8 cfs of water rights from the deed holder for $500,000, with funding support from the Walton Family Foundation.
Methods for Overcoming Typical Barriers	
Transaction Costs	Change of water right to add instream flow use; decree in Case No. 14CW3108 entered October 1, 2018. CWCB grant funding and other resources were utilized to facilitate the project and reduce project costs.
Water Right Administration and Accounting	The McKinley Project was a new approach and several steps were taken to maintain historic return flow conditions and ditch operations. Ditch loss from the shares shall be left in the ditch during times of instream flow use; diversions are limited to monthly, annual, and 20-year volumetric limits; measurement and accounting requirements; dry-up provisions.
Reliability:	The McKinley Ditch ATM project is perpetual.

2.3 MCKINLEY DITCH

Infrastructure:	Several ditch modifications were necessary to facilitate the agreement, including installation of a new splitter box and data recording system. A CWCB Water Plan Grant was secured to enable final design and construction of modifications to manage the shares for the split-season operation and to measure and protect the water applied for instream flow use.
Unique Issues Overcome	
Seller Issues:	The property and water rights were in foreclosure.
Buyer Issues:	This was the first agriculture to environmental ATM agreement completed in Colorado and, therefore, significant due diligence was required to confirm all legal aspects of the project. Also, the CWCB board members had to be convinced this was a good use of public funds before authorizing the purchase of a portion of the water right.
Benefits Derived from ATM	
Seller Benefits:	N/A
Buyer Benefits:	Piloting an agriculture/environment ATM and restoring streamflows while keeping agricultural lands in production.
Lessons Learned	
	Social considerations are more challenging than legal or technical issues. More information is needed on impacts of deficit irrigation on high altitude hay operations, which this project will provide.

2.4 GRAND VALLEY WATER USERS ASSOCIATION CONSERVED CONSUMPTIVE USE PILOT PROGRAM (CCUPP)

Project Description

River Basin:	Colorado
Supplier:	Ten Members of the Grand Valley Water Users Association (GVWUA)
Buyer:	Grand Valley Water Users Association (GVWUA), Using Grant Funds
General Narrative Description:	Continued drought and worsening water supply conditions in the Upper Colorado River Basin could increase the risk of Lake Powell storage declining below critical elevations to maintain operational functionality and mandated curtailment of the exercise of water rights to maintain compact compliance. Recent efforts, including the System Conservation Pilot Program (SCPP), have explored voluntary, temporary, and compensated consumptive use reduction programs with the goal of avoiding or mitigating the risk of involuntary compact curtailment or buy-and-dry of agricultural lands and to foster a better understanding of the impacts of such a program. In a desire to proactively learn about some of the benefits and impacts of a potential large-scale fallowing program, the GVWUA implemented the Conserved Consumptive Use Pilot Project (CCUPP). Specifically, GVWUA stated the goals of the project were: 1) **Protection** of GVWUA water rights and western Colorado agriculture as a whole. 1) **Benefit** from continued beneficial use of western slope agricultural water rights and infrastructure investment. 2) **A Seat at the Table for Western Slope Agriculture** in conversations and potential negotiations related to demand management as a drought resiliency measure. The GVWUA CCUPP was part of the broader SCPP. The overall goals of the SCPP were to, among other things, help explore, learn from and determine whether a voluntary, temporary and compensated reduction in consumptive use in the Upper Basin is a feasible method to partially mitigate the decline of or raise water levels in Lake Powell and thereby serve as a useful tool for the drought contingency planning processes in the Upper Basin.
How/Why Parties Came Together:	The purpose of the pilot study was to test the mechanisms necessary for a Western Slope irrigation water provider to intentionally reduce consumptive use in a voluntary, temporary and compensated manner.

Project Facts

Type of ATM Project:	Voluntarily reducing agricultural system demand on a temporary and compensated basis; compact compliance
Sources of Conserved Water:	Full or partial season fallowing; Reduced delivery option offered but not exercised
Transfer Agreement Type:	Water bank; compact compliance
Agreement Length:	Two years
Frequency of Transfer:	Irrigation season (April to November)
Volume/Flow Transferred:	3,178 acre-feet (season total savings)
Unit Price of Water Transferred:	Payments for participation varied per program activity (from $623 to $356 per acre enrolled in program). Prices per acre foot varied depending on the program activity (e.g. full fallow, partial fallowing) selected by the participant.
Factors Determining Price:	At no point were the actions undertaken during the project intended to seek or set a price for Western Slope irrigation water under lease/fallow programs. Money was exchanged only to compensate farmers for their participation in the pilot project.

2.4 GRAND VALLEY WATER USERS ASSOCIATION CONSERVED CONSUMPTIVE USE PILOT PROGRAM (CCUPP)

Methods for Overcoming Typical Barriers

Transaction Costs	GVWUA utilized funding through the System Conservation Pilot Program, CWCB, and non-governmental partners to offset administration of the program and foregone revenue. Program activities were selected in part for ease of administration, no required instrumentation to measure water use, ability to fit into existing crop rotations, and feasibility to implement on short notice in a 1-year program. GVWUA secured a CWCB ATM Grant to help to hire a consultant team to conduct an operational assessment with the goal of determining feasibility of a demand management program within the GVWUA service area.
Water Right Administration and Accounting	The GVWUA used data from previously completed studies and CoagMet to estimate the reduction in consumptive use that would be realized under the eligible program activities that were part of the project. The non-consumptively used water remained in the GVWUA ditch system to avoid injury to other ditch users. Cooperators participating in the program were covered under SB 13-019 which provides that a determination of HCU may not consider years in which the water right was enrolled in a water conservation program, land fallowing program, and/or water banking program.
Reliability:	The GVWUA CCUPP was a temporary pilot program.
Infrastructure:	The project set aside approximately 20 percent of its budget to fund investments in necessary infrastructure.

Unique Issues Overcome

Supplier Issues:	Participants were concerned about the protection and continued beneficial use of the irrigation water. SB 05-133 and SB 13-019 provided cooperators with assurance that their participation in the CCUPP would not put them at risk of abandonment or impact future HCU determinations. Specific and enforceable land management measures were designed into the pilot project to alleviate concerns about weed and plant pest issues.
Buyer Issues:	The myriad of unknown tasks and extensive member outreach and coordination required the hiring of a dedicated consultant to manage the program. Extensive time was also required by the GVWUA legal counsel. There has been significant legal work associated with project development and there is ongoing legal due diligence associated with it. Other issues were developing a project with an unknown budget during the early stages of the project, coordinating with the Bureau of Reclamation, and building trust with program participants.

Benefits Derived from ATM

Supplier Benefits:	Cooperators benefited from the revenue they received for participating in the program, as well as the knowledge that their participation in the project was a proactive way to learn and engage in ongoing discussions about solutions to water use issues in the Upper Colorado River Basin. The CCUPP explored the feasibility of alternative approaches to involuntary compact compliance methods and program activities were selected to achieve agronomic benefits such as potential agricultural diversification and soil health.
Buyer Benefits:	Compensation for administering the program, infrastructure improvements, developing a process for administering future temporary fallowing programs.

2.4 GRAND VALLEY WATER USERS ASSOCIATION CONSERVED CONSUMPTIVE USE PILOT PROGRAM (CCUPP)

Lessons Learned	
	According to the GVWUA: “Putting together the project has been a fascinating exercise and one that consistently required nimble thinking. Conversations with stakeholders, unknown project budgets, Board of Directors reluctance, and discovering the previously unknown complications are just a few of the factors that continually changed the project emphasis." Contracting for agricultural demand management should take place at a minimum one year in advance of the first date or project implementation. The steps leading up to contracting should take place at a minimum two irrigation seasons prior to any expected water savings. It is necessary that any irrigation provider beginning or participating in a demand management project contract for the necessary outreach within their constituents or designate a full-time employee to complete the task. Any long-term and/or large-scale agricultural demand management program should consider the negative externalities within the community in a meaningful manner and take steps to mitigate these impacts. There must be an advocate or advocates to guide the administration of demand management program activities within an organization. Someone who understands the potential risks and benefits and can view of the decisions of the group with an understanding of their apprehensions while continuing to lead the conversations and actions of the organization.

Section 3: Hypothetical Agricultural to Municipal Transfer

This section provides context and considerations for a hypothetical agricultural to municipal water transfer, with a focus on general drivers for why municipal and agricultural entities would enter into a general ATM program (regardless of specific supply or transfer methods used), and infrastructure potentially needed to successfully implement an ATM.

3.1 DRIVERS OF WATER TRANSFER FREQUENCIES FOR MUNICIPAL ATMS

The following presents potential general situations where a municipal water supplier might be inclined to enter into an ATM agreement for a future water supply. The situations are listed in order of the lowest to highest frequency of ATM utilization:

Drought and Drought Recovery Supply: The municipal provider only needs water supplies in drought years and/or the year immediately following a drought as required to recover reservoir levels. Water for the ATM could be supplied by not irrigating select agricultural lands in what might be one, two or three years in a 10 or 20-year period. In most years, the water would remain on the farm lands and be used for agricultural purposes.

Normal and Drought Supply: The municipal provider needs water supplies during all conditions where the municipal provider's existing junior water rights are not sufficient to meet municipal demands. This type of ATM is accomplished by selectively rotating non-irrigated areas during all normal and drought years. Depending on the ability to forecast successive wet years, rotational fallowing might occur in all years except extended wet periods.

Wet, Normal and Drought Supply: The municipal provider needs water supplies during normal and drought years and in some wet years as required to refill reservoirs or aquifers. Due to the limited ability to predict when the municipal provider might not need the supplies, rotational fallowing of agricultural lands is likely to occur under most or all hydrologic conditions. The major difference between this ATM and traditional buy and dry is that rotational fallowing of select farm lands avoids a single piece of land or potentially a single community from having farm lands completely out of production.

Table 1 presents a graphic comparison of the above different drivers for ATM arrangements. As shown, the degree to which historically irrigated lands are no longer irrigated can vary significantly based on the type of ATM agreements implemented. ATM transfer arrangements that are used by the municipal entity primarily for drought and drought recovery supplies result in the least dry-up or fallowing of agricultural lands on average. It is worth noting that an ATM arrangement that transfers a baseload supply (dry, normal, and some wet years supplies) to a municipal entity may not significantly reduce the amount of dry acres as compared to a traditional buy and dry condition, but if the water is transferred using large scale and multi-regional rotational fallowing, the productive and temporarily fallowed agricultural lands can be rotated and a situation where a single area is not being overly burdened with loss of agricultural lands can occur.

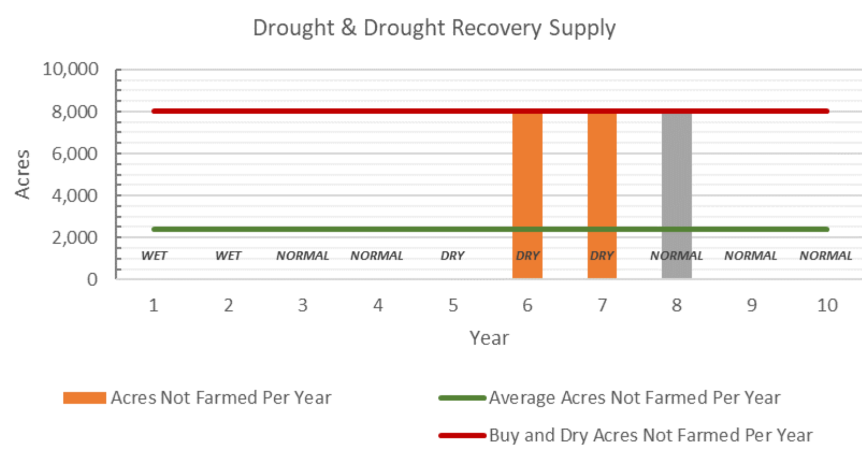
Table 1: Hypothetical Example of Frequency That Municipal Water Providers May Exercise Their Option to Transfer 10,000 AFY of ATM Water

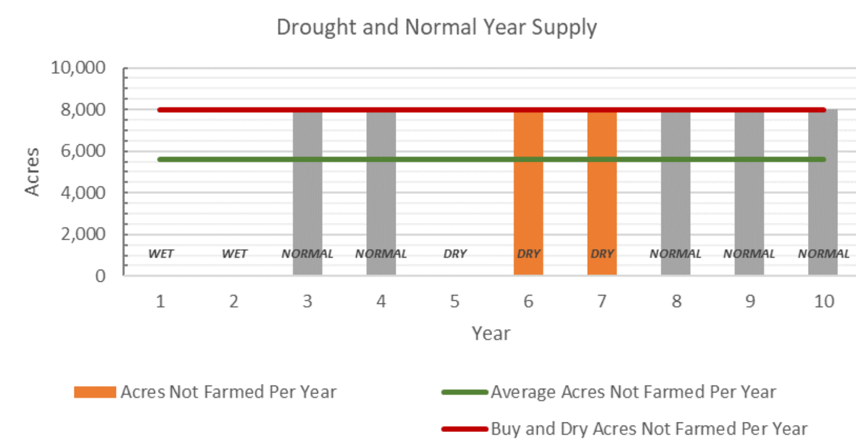
Municipal Supply Need	Dry Years *Assumes 3 in 10 Years Are Dry*		Normal Years *Assumes 5 in 10 Years Are Normal*		Wet Years *Assumes 2 in 10 Years Are Wet*		Typical 10-Year Period With ATMs		Typical 10-Year Period Permanent Buy and Dry
	Number of Dry Years ATM Options are Exercised	Average Dry Year Acres Not Farmed, Per Year	Number of Normal Years ATM Options are Exercised	Average Normal Year Acres Not Farmed, Per Year	Number of Wet Years ATM Options are Exercised	Average Wet Year Acres Not Farmed, Per Year	Years in 10 ATM Options Exercised	Average 10-year Period Acres Not Farmed, Per Year	Average Acres Not Farmed Per Year
Drought & Drought Recovery Supply	2	5,333	1	1,600	0	0	3	2,400	8,000
Drought and Normal Year Supply	2	5,333	5	8,000	0	0	7	5,600	8,000
Drought, Normal, and Some Wet Supplies	3	8,000	5	8,000	1	4,000	9	7,200	8,000

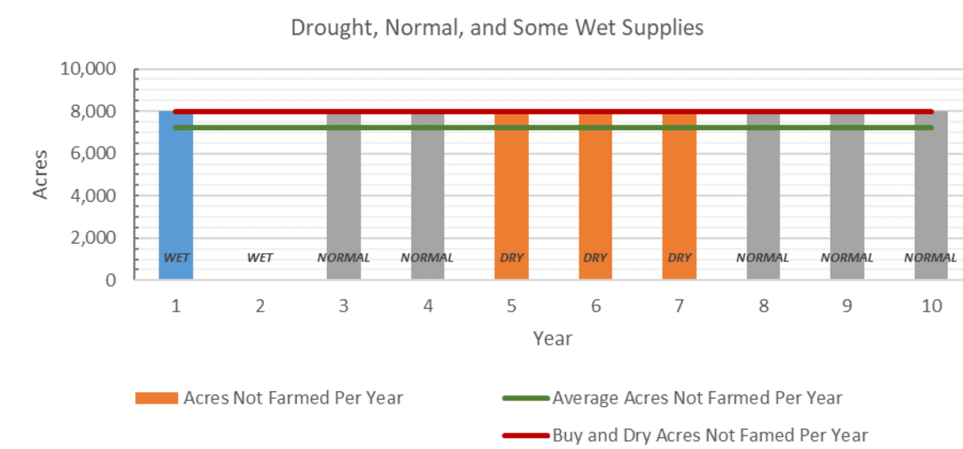
Notes:

Assumed feet per year of HCU per acre of irrigated lands: 1.25 FT

Total acres per year not irrigated to transfer 10,000 AF of Historical CU: 8,000 AC







3.2 INFRASTRUCTURE CONSIDERATIONS FOR MUNICIPAL ATMS

Depending on the configuration and specific details of a particular ATM, all, none, or combinations of the following conveyance infrastructure components may be needed:

Exchange Capability: Depending on the location of the historical diversion point of the agricultural water right and location where the municipal provider needs to take delivery of the water, it may be feasible to exchange the water along a river between the two points. Under this condition, pumps and pipes are not required to transfer the water to the municipal water provider. This condition results in minimal or no conveyance infrastructure costs.

Augmentation Stations: When water from an irrigated parcel on a ditch is transferred to a new use, the ditch headgate may reduce its diversions by the same amount as the transferred portion of its water right, or the water may still be delivered to the farm headgate and routed back to the river and measured through an augmentation station. The latter is becoming increasingly common for several reasons including lack of a ditch headgate bypass structure and to assure that the remaining irrigators on a ditch do not suffer higher ditch losses as a result of the change of use. This feature may also be mandated through the Ditch Company's bylaws.

Return Flow Obligation Storage: Under any agricultural operation, a given amount of water is applied to the fields, and some of that water is consumed due to crop evapotranspiration. Some water is not consumed by crops and is instead returned to the watershed (via groundwater or other flow) and subsequently used by a downstream water user under separate water rights. Under Colorado water law, only the HCU of the crops can be transferred to the municipal water provider under an ATM, while the historical return flows to the river must be replicated in amount and time under the ATM operation to avoid injury to downstream water right holders who may depend on these historical return flows to fulfill their water rights. To replicate the historical return flows when water is not applied to the farm lands, the portion of water that historically deep percolated may be placed in a recharge pond near the farm. Alternatively, storage may be used to hold the water during the historical diversion period and release that water to the river at the estimated time and quantity when the historical return flows would have been returned to the river under pre-ATM operations. In this case, a portion of the consumptive use water credit may be required to replace evaporative losses due to pond or reservoir storage. It may be possible that either the municipal provider or agricultural water right holder has access to sufficient existing storage in the required location to meet the storage needs, but it is also possible that new recharge facilities or storage would need to be constructed or purchased to meet the needs for return flow obligations.

Operational Storage: In addition to storage needed to meet historical return flow obligations, additional storage may be needed to facilitate the water exchange described above, or to hold the water that cannot be exchanged and allow for a steady conveyance flow rate to the municipal provider as described below. Such operational storage could also support the development of water banks which can connect buyers and sellers, allowing interested parties to conduct temporary water trades with reduced transaction costs. Water banks could also help avoid or endure a compact curtailment.

Pipelines and Pump Stations: If the water cannot be exchanged to the required delivery location needed by the municipal provider, pipelines, pump stations, and other conveyance infrastructure would be required to convey the water from the legally allowable water diversion location to the needed delivery location.

Water Treatment Systems: If the water transferred to the municipal water provider cannot meet the drinking water quality goals of the municipal provider using the municipal provider's existing water treatment facilities, additional water treatment facilities may be needed. There could be a wide range of contaminants in the transferred water that can require additional levels of water treatment. Some of the most prevalent and most difficult to manage contaminants include total dissolved solids (TDS), Phosphorus, and organic Carbon.

It is important to note that all potential infrastructure requirements described above would be needed for an ATM project or a traditional buy and dry project. The primary purpose for bringing attention to these infrastructure requirements is to make sure the reader is aware that even if the traditional barriers to ATM projects are reduced or eliminated, there could still be significant infrastructure permitting and infrastructure financing hurdles that would need to be overcome before a municipal water supplier would realize any new supplies from an ATM project. These infrastructure needs also help explain why the municipal sector continues to be interested in acquiring permanent sources of supply instead of ATMs. While not considered in detail here, ATMs addressing non-consumptive needs may require distinct infrastructure improvements such as diversion structure rehabilitation and system modernization. Public and private resources such as the CWCB's grant programs are available to offset infrastructure costs for ATM projects.

3.3 HYPOTHETICAL EXAMPLE OF LARGE-SCALE AGRICULTURE TO MUNICIPAL ATM PROJECT

This simplified example is intended to provide the reader with some context into the potential amount of irrigated lands in the South Platte Basin that might need to be enrolled in a rotational fallowing program as part of a large coordinated ATM program to meet 25 percent of the SWSI 2010 estimated medium 2050 M&SSI gap of 110,000 acre-feet per year:

- Hypothetical amount of water transferred per year = 27,500 acre-feet
- Assumed historical crop consumptive use per acre of irrigated land = 1.25 feet per year
- Amount of lands not irrigated each year = 22,000 acres
- Number of times per decade a piece of land in a rotational fallowing program is not irrigated = 2
- Total acres that might need to be enrolled in a rotational fallowing program = 110,000 acres
- Approximate total number of irrigated acres in the South Platte Basin = 825,000 acres
- Approximately percentage of total irrigated acres enrolled in rotational fallowing program = 15%

This hypothetical example shows that if 15% of the irrigated acres in the South Platte Basin were enrolled in a rotational fallowing program as part of a large-scale ATM, 25% of the previously estimated 2050 M&SSI gap could be met. Of course, larger areas would be required if a greater portion of the gap were to be met with this type of arrangement.

Section 4: Lessons Learned, Data Needs, & General Recommendations

4.1 MONITORING OF ATM IMPLEMENTATION AND EFFECTIVENESS

Section 6.4 of the CWP includes an action to further consider ways to monitor ATMs to aid evaluation of the effectiveness of varying kinds of ATM programs. Monitoring the effectiveness of ATMs would provide valuable insight into the actual benefits and challenges of these programs and could provide guidance for how to refine the terms of ATMs to best benefit all parties and meet Colorado's Water Plan goals. Table 2 includes several data items that, if collected, could provide insight into the effectiveness of ATMs as they are implemented in the future. These monitoring metrics could help give insight to the effectiveness and operation of a single ATM, or a large-scale ATM program across a geographic area to gauge regional or basin-wide trends.

Table 2: Potential ATM Monitoring Data

	Desired Data	Applicability to ATM Monitoring
Monitor ATM Structural Data	Buyer Type, Seller Type, Date of Agreement, Ag. Conservation Method Used, Transaction Method, Term of Agreement, Legal Process Utilized, Allowable Frequency of Usage, Intent of buyer's use for water - percent of water transferred successfully utilized by new use	Indicates effectiveness of infrastructure, ditch operations, and/or exchange mechanisms to move water to desired location
Monitor Frequency, Timing, Amount of Water Transferred, and Number of ATM Transactions	Amount of water transferred (in acre-feet) in drought years and drought recovery years.	When compared to other data points, this information will give an indication of the degree to which ATMs are being used by a municipal water provider as drought and drought recovery supplies instead of baseline supplies.
	Number of transactions associated with the volume of drought year and drought recovery year water transfers.	Indicates if the amount of water transferred via ATM programs is largely driven by a small number of ATM agreements (regardless of the amount of water transferred under the ATM programs) or if dry year transfers are part of a larger and more diverse marketplace.
	Amount of water transferred (in acre-feet) in normal years (non-drought years and non-wet years).	Indicates if water is being transferred to meet a municipal base supply need as opposed to or in addition to a dry year supply need.
	Number of transactions associated with the volume of non-drought year and non-wet year transfers.	Indicates if a single larger transfer is present, or a diverse ATM market for baseline transfers of water exists.
	Amount of water transferred (in acre-feet) in wet years.	Indicates degree to which ATMs are being used by municipal entities to refill storage following drought or non-wet years.
	Number of transactions associated with the volume of wet year transfers.	Indicates if a single larger transfer is present or if a diverse wet year ATM market exists.

Table 2: Potential ATM Monitoring Data

	Desired Data	Applicability to ATM Monitoring
Monitor Sustainability of Farms Under ATMs	Acres historically irrigated (prior to ATM arrangement) in dry, normal, and wet years by specific water rights used to facilitate the ATM agreement.	Provides means for comparing how ATM arrangements change historically irrigated acreage and, by extension, how consumptive use of the agricultural land changes as a result of the ATM program.
	Acres irrigated and crop types used in drought years since ATM arrangement has been active.	Gives indication of how irrigator of agricultural land under ATM program uses water differently under ATM agreements. It is possible that less acres are irrigated, or also possible that fewer crops are grown per year on the same acreage. Additionally, the irrigator may favor different crop types when in an ATM agreement.
	Acres irrigated in normal years during ATM period.	
	Acres irrigated in wet years during ATM period.	Indicates if irrigators return to pre-ATM growing practices in wet years, or if some acres are no longer farmed due to the challenges of increased variability in the water supply due to the ATM arrangement.
Monitor Locations Where ATMs are Feasible	Locations of historical diversions for ag. water rights, and locations of transferred new water use under ATM arrangement.	Indicates if certain types of water rights appear to be favorable for ATM arrangements. For example, favorable types of water rights may include Colorado-Big Thompson (C-BT) water, water rights in a watershed above or closer to metro regions, or water rights located in areas where upstream exchanges are most feasible.
Monitor ATM Economics	Financial terms of each unique ATM arrangement.	Indicates how costs of ATM transactions vary based on location, frequency, timing, amount of water transferred, and infrastructure needed to facilitate an ATM transfer. Includes legal and engineering fees, as well as infrastructure components. These costs can be compared with traditional transactions to evaluate if legislation and/or other steps to reduce transaction costs are effective.

4.2 CONCLUSIONS AND NEXT STEPS

ATMs provide an opportunity to meet increasing water demands of a growing population while maintaining the viability of Colorado agricultural communities. Next steps to be considered include:

- Develop better guidance as to what types of projects and processes further Water Plan goals related to maintaining or enhancing agricultural viability, while meeting potential new demands and addressing other water resource management issues.
- Continue funding for ATM development through CWCB's grant program and other sustainable funding mechanisms.
- Assess institutional support of ATMs and evaluate progress made on addressing the primary barriers to ATM development and implementation and broaden outreach to potential ATM participants such as government open space programs and elected officials.
- Develop additional pilot projects for the varying types of ATM programs and engage in thoughtful monitoring of their effectiveness.
- Work with basin roundtables to consider how ATMs can play a role in addressing basin needs and priorities.
- Further pursue the collection of the recommended monitoring data for ATMs as they are developed and share this information through existing platforms such as CDSS or new platforms such as an ATM data clearinghouse.

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Analysis and Technical Update to the Colorado Water Plan

Technical Memorandum

Prepared for:

Colorado Water Conservation Board

Subject:

Observations Regarding Public Perceptions on Water

Date: May 28, 2019

Prepared by: Doug Jeavons, BBC Research & Consulting
Reviewed by: Brown and Caldwell

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Insights from Public Perceptions of Water Research

1.1 INTRODUCTION AND BACKGROUND

Public acceptance of the Colorado Water Plan and support for its recommendations will be important in seeking to address Colorado's water needs over the next several decades. This memorandum provides a review of the 2012-2013 survey that BBC conducted for CWCB regarding *Public Opinions, Attitudes and Awareness Regarding Water in Colorado* (CWCB survey), and other survey research relevant to understanding social values in the context of the planning scenarios and water supply challenges that Colorado is facing in the future.

The CWCB survey was neither the first, nor the last, effort to understand public values related to water supply. A 2008 survey by researchers at Colorado State University[1] gathered information from Colorado residents on several topics related to some of the questions in the CWCB survey, as did a national survey by ITT in 2010[2], and a 2009 survey conducted on behalf of the Colorado River Water Conservation District.[3] More recent survey research for the San Diego County Water Authority[4] and across the State of Texas[5] provides further insights regarding public values in connection to water supply issues.

1.2 THE CWCB SURVEY

In late 2012, the BBC team surveyed 1,950 Colorado residents regarding water-related awareness, perceptions and concerns. Surveys were conducted with 325 residents in each of six regions across the state, with each region corresponding to one or two Colorado basins – as shown in Figure 1.

[1] *Public Perceptions, Preferences and Values for Water in the West*. Colorado State University. 2008.

[2] Value of Water: Americans on the U.S. Water Crisis. ITT. 2009.

[3] *Key findings from a Colorado River District survey of 500 registered voters conducted May 31 -June 2, 2009*. Public Opinion Strategies.

[4] *2017 Water Issues Public Opinion Poll*. San Diego Water Authority. May 2017.

[5] *Texas Statewide Water Conservation Survey*. Baselice & Associates, Inc. October 5-20, 2014.

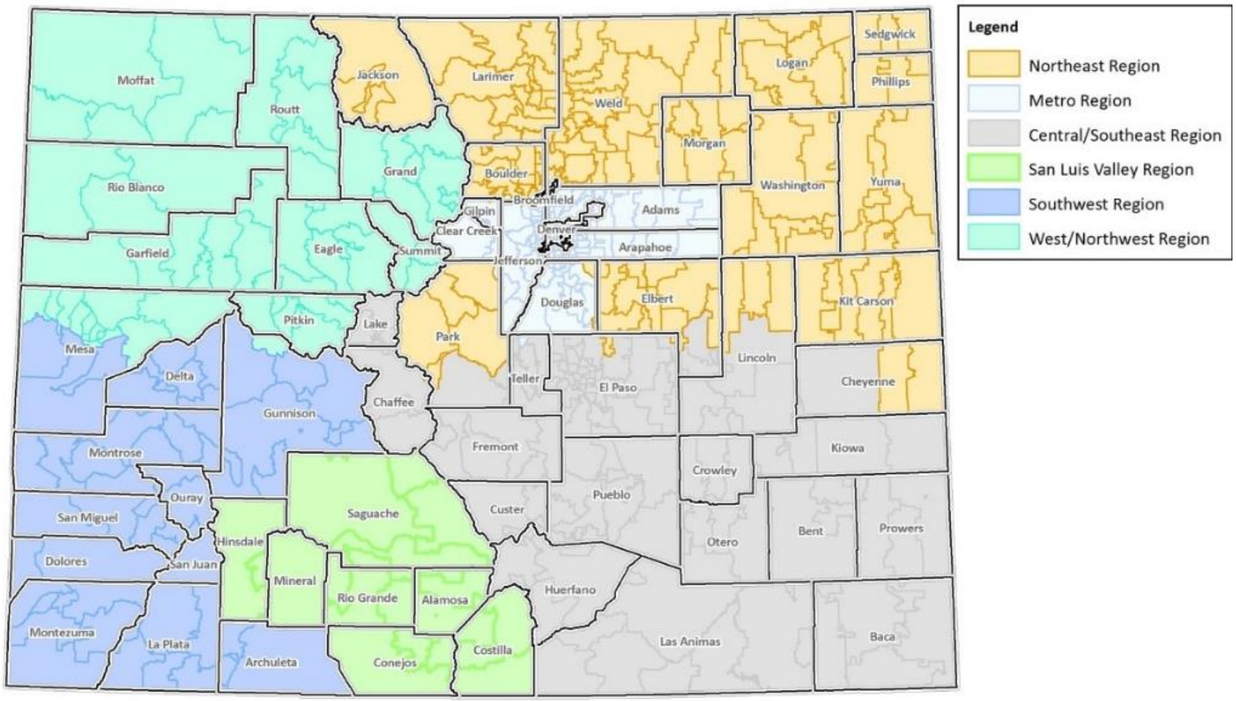


Figure 1. Map of study regions

The six regions defined for the CWCB survey approximately correspond to the Colorado Basin Roundtables as follows: Northeast Region = North Platte and South Platte Basins; Metro Region = Metro Roundtable; Central/Southeast Region = Arkansas Basin; San Luis Valley Region = Rio Grande Basin; Southwest Region = Gunnison and San Juan/Delores Basins; and West/Northwest Region = Yampa/White and Colorado Basins.

1.2.1 SURVEY TOPICS

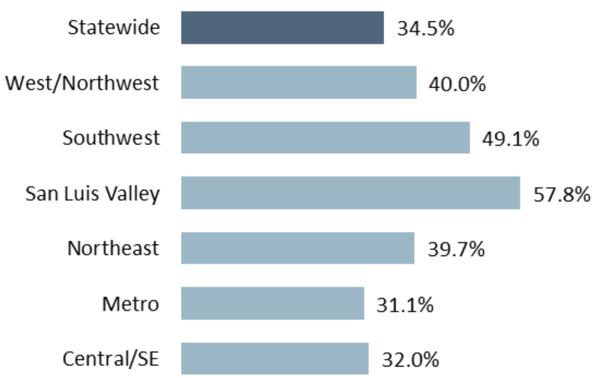
The CWCB survey gathered a variety of information from respondents on the following topics:

- Knowledge of Colorado water use and awareness of water issues;
- Perceptions regarding household water service;
- Performance of government agencies;
- Scarcity perceptions;
- Water-related concerns;
- Need for more information and most trusted sources; and
- Demographics.

Several of these topics are particularly relevant from the standpoint of the Colorado Water Plan and the alternative planning scenarios. The remainder of this memorandum focuses on public perceptions regarding those topics. Much more detail on the CWCB survey results is available from the original report.

1.3 PUBLIC KNOWLEDGE AND AWARENESS OF WATER ISSUES

As of 2012-13, public knowledge regarding basic information concerning water use in Colorado was mixed and varied somewhat by region. Overall across the state, about 35 percent of Colorado residents correctly identified farms and ranches as the largest water user in Colorado. Nearly two-thirds of Colorado residents did not recognize this basic water use fact, instead identifying households as the largest water user (32%) or industrial and commercial users (30%). As shown in Figure 2, residents in the more rural regions were generally more likely to recognize that agriculture was the largest water user, while residents in the more urban basins (the Metro region and the Central and Southeast Region which contains the Colorado Springs and Pueblo areas) were less likely to know this information.



Both the 2008 survey by CSU researchers in Colorado and a recent statewide survey in Texas found similar gaps in basic water use knowledge.

Figure 2. Public knowledge that agriculture is the largest Colorado water user

Source: CWCB survey, 2013.

Across the state, Colorado's residents were paying increasing attention to water-related issues. About 72 percent of Coloradan's indicated they were paying more attention to water issues today than in the past. As shown in Figure3, this finding was relatively consistent across the regions of the state. When asked why, the most common answer was the recent drought/dry year experience in Colorado during 2012.

Recent surveys by the San Diego County Water Authority indicate that public attention to water issues can fade following droughts as other issues compete for public attention. During the California drought in 2015, one-third of San Diego residents identified water supply as the most important issue facing county residents. After the drought, in 2017, only 6 percent identified water supply as the most important issue.

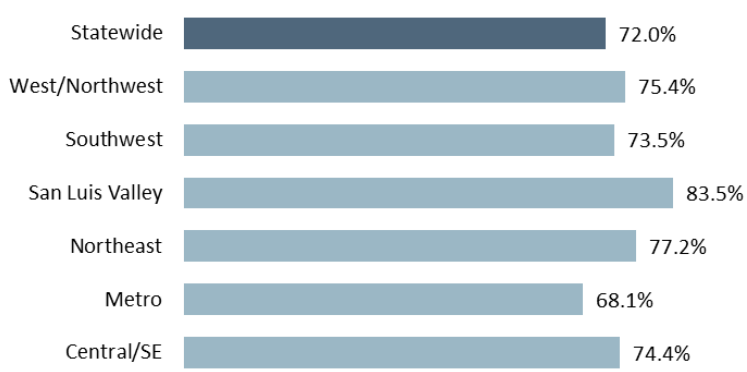


Figure 3. Residents indicate they are paying more attention to water issues and water use than in the past

Source: CWCB survey, 2013.

1.3.1 PERCEPTIONS REGARDING WATER SCARCITY

In the CWCB survey, Coloradans were asked whether they agreed or disagreed with the statement that **"Colorado has enough water to meet our current needs**." On a scale of 1 to 10 — with 10 indicating strong agreement that we have enough water for current needs, and 1 indicating strong disagreement —the mean response statewide was 4.9. Put differently, 46 percent of Coloradan's disagreed with the premise that we have enough water to meet current needs, about 29 percent agreed with the statement, and the remainder were neutral. Responses to this statement were fairly consistent across all regions of the state except in the San Luis Valley, where a larger majority (62%) disagreed that Colorado has enough water to meet current needs.

Coloradans were more consistent in their disagreement with the statement that "Colorado has enough water for the next 40 years." The mean score in regard to this statement was 3.5, with 68 percent disagreeing with the statement and only 13 percent agreeing with the premise that we have enough water to meet future needs over this period. Figure 4 compares the responses in regard to the sufficiency of supplies to meet current needs, and to meet future needs. Again, residents of the San Luis Valley felt the most strongly about the future scarcity of water in Colorado, with 81 percent disagreeing with the statement our existing water supply is sufficient to meet future needs.

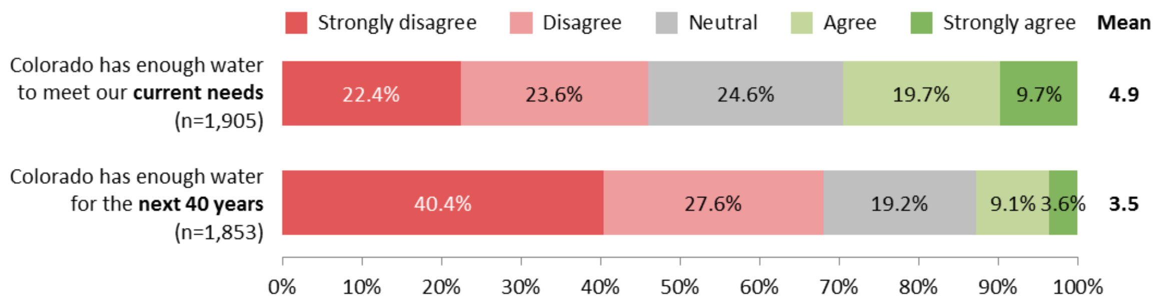


Figure 4. Agreement with statements that: 1) Colorado has enough water to meet current needs, and 2) Colorado has enough water for the next 40 years

Source: CWCB survey, 2013.

1.4 SOCIAL VALUES

The Colorado Water Plan identified future social values as one of the primary drivers in developing the five alternative planning scenarios evaluated in the SWSI update (along with future changes in M&I water demand and water supply availability). More specifically, in Chapter 6 of the Colorado Water Plan, social values are described as a measure of statewide public sentiment that may trend toward a "more green" orientation or may shift toward "greater resource utilization."

The "more green" perspective was further described as:

Favor(ing) more dense, low-impact urban development, greater reliance on water reuse and energy efficiency, greater protection of environmental and recreational resources, and preservation of local agriculture and open space.

The "greater resource utilization" perspective was further described as:

Gravitat(ing) toward full use of existing natural sources as well as the development of new sources to satisfy M&I water demands.

While Coloradans cannot be neatly categorized into either of these two alternative perspectives, and many of the states' residents likely embody some of both perspectives to varying degrees, the CWCB survey results do shed some light on the social values of Colorado residents as of 2013. The most useful questions from the CWCB survey in terms of identifying social values may have been the question posed to survey respondents regarding the "most important" water-related concern facing the state, and what they thought should be done to address their most important water-related concern.

1.4.1 MOST IMPORTANT WATER-RELATED ISSUE

Respondents to the CWCB survey were given a list of nine potential water-related concerns (read to each respondent in a different, randomized sequence) and asked to identify which concern was the most important. The options included:

- Water quality in our rivers, lakes and streams
- Amount of water available for Colorado's cities and towns
- Amount of water available for Colorado's farms and ranches
- Amount of water for recreational use such as boating, rafting and fishing
- Amount of water for fish and wildlife
- Condition of underground water pipes, dams and other water utility infrastructure
- The quality of water you receive in your home
- Amount of water used for energy development
- Effects of energy development on water quality

From a statewide perspective, the largest number of Coloradan's identified home water quality as the most important water-related issue, followed by the amount of water available for Colorado's farms and ranches, then by the amount of water available for Colorado's cities and towns – as shown in Figure 5.

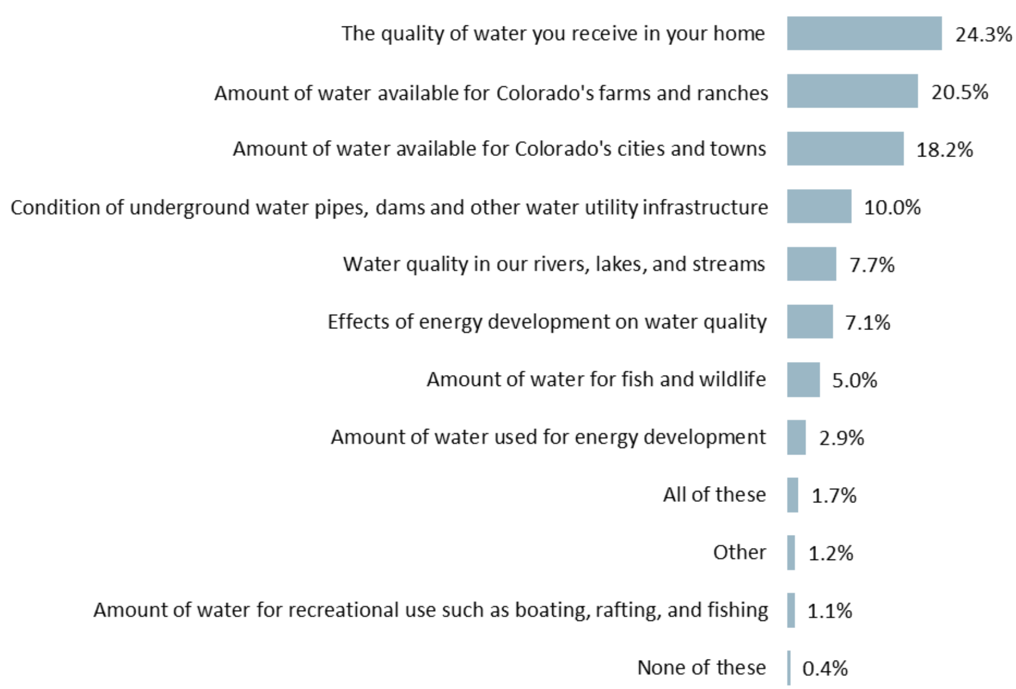


Figure 5. Most important water-related issue

Totals may not equal 100% due to rounding.

Source: CWCB survey, 2013.

To further understand these results, the study team conducted 20 brief, follow-up telephone interviews with respondents who had indicated the quality of water they receive in their home or the amount of water available for Colorado's farms and ranches were their most important concern.

The interviews with respondents who had identified the quality of water they receive in their home was their most important issue generally indicated that:

- Most of these respondents selected quality of water at home because of water's critical contribution to their family's health, and
- Most were satisfied with their current home water quality, but were concerned about potential contamination in the future, and
- Some respondents cited stories in the media regarding water contamination as a reason for their concerns.

The follow-up interviews with respondents who had identified the amount of water available for Colorado's farms and ranches were their most important concern indicated:

- These respondents were concerned about maintaining the ability of Colorado's farms and ranches to produce our food locally and about maintaining the vitality of Colorado's rural communities, and
- They were concerned about growth in Colorado's larger cities and pressure to move water from agricultural to urban uses, and
- Although some respondents indicated concerns about these situations at present, most were more concerned about the future.

Home water quality, the amount of water available for farms and ranches, and the amount of water available for cities and towns were consistently identified as the three most important water-related issues across all of Colorado's regions. However, the regions did rank these top issues in different orders. As shown in Figure 6, having enough water for Colorado's farms and ranches was identified as the most important issue in most of the less urbanized regions of the state, while having enough water for Colorado's cities and towns was more frequently identified as the most important issue in the more urbanized regions (Metro and Central/Southeast Colorado).

	Ranking Order for Top Water Issues		
Region	**Home WQ**	**Water for Farms**	**Water for Cities**
Central/SE	2	3	1
Metro	1	3	2
Northeast	2	1	3
San Luis Valley	2	1	3
Southwest	3	1	2
West/Northwest	1	2	3
Statewide	**1**	**2**	**3**

Figure 6. Rankings of most Important water-related issue by region

Source: CWCB survey, 2013.

1.4.2 ADDRESSING THE MOST IMPORTANT WATER-RELATED ISSUES

Survey participants were asked what they thought should be done to address their most important concerns. That question was open-ended (unprompted), but responses (including a few multiple responses) were coded by the surveyors. Figure 7 presents those results.

Overall, respondents most frequently indicated that their most important potential water-related issue should be addressed through conservation (19%), though the response to this question differed depending on which water-related issue respondents felt was most important (as discussed on the following page). Respondents also frequently indicated that their most important concerns should be addressed by:

- Prioritizing environmental needs (14%); or
- Developing new projects/building more dams or reservoirs (14%).

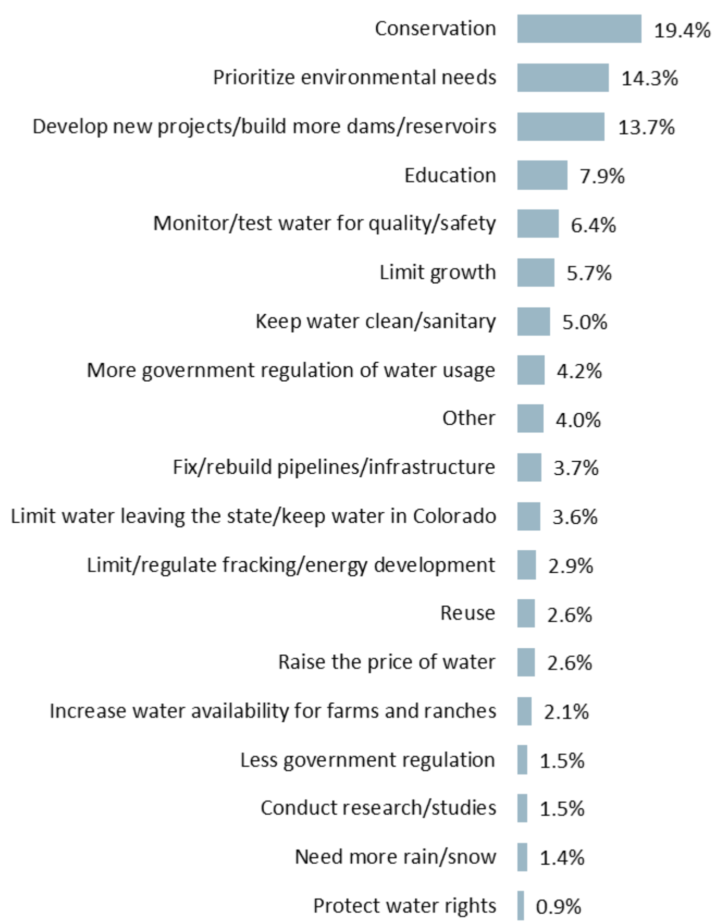


Figure 7. What should be done to address the most important water concerns?

Totals do not equal 100% because respondents could choose more than one option.

Source: CWCB survey, 2013.

How participants thought about addressing water-related issues varied depending on what they had identified as their most important water-related concerns. Figure 8 presents responses for addressing the top three most important potential water related concerns:

- Quality of water you receive in your home;
- Amount of water available for Colorado's farms and ranches; and
- Amount of water for Colorado's cities and towns.

Quality of water you receive in your home. To address the concern of quality of household water, respondents most frequently indicated that water pipelines or infrastructure should be fixed or rebuilt (19%). A number of respondents also indicated that the quality of household water should be addressed by:

- Keeping water clean/sanitary (16%); and

- Increasing government regulation of water usage (16%).

Amount of water available for Colorado's farms and ranches. Respondents most frequently indicated that concerns about water for farms and ranches should be addressed through conservation (25%).

Amount of water for Colorado's cities and towns. Respondents most frequently indicated that concerns about water for cities and towns should be addressed through conservation (29%).

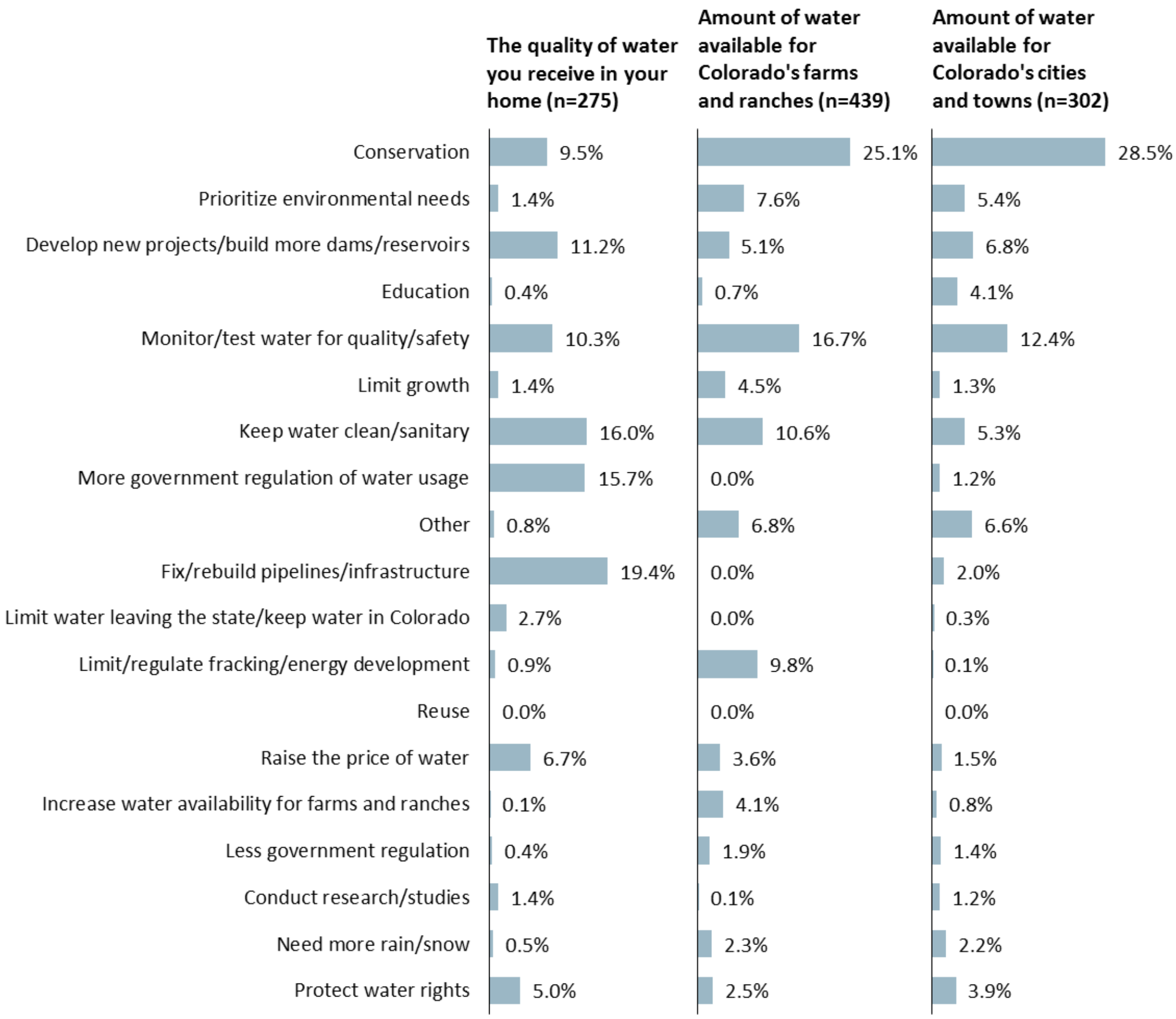


Figure 8. What should be done to address the most important water concerns?
Breakdown by top three concerns

Totals do not equal 100%, because respondents could choose more than one option.

Source: CWCB survey, 2013.

Public preferences on addressing water-related concerns by region. Figure 9 shows the percentage of respondents by region that identified each of the top three strategies for addressing their most important water-related concern. Conservation was the top priority among respondents from each region, and support for placing more emphasis on environmental needs was relatively consistent across the regions. Support for developing new projects varied by region.

Region	Percentage Choosing Each Strategy		
	Conservation	Prioritize Environmental Needs	Build New Projects
Central/SE	16%	15%	15%
Metro	20%	14%	12%
Northeast	20%	13%	17%
San Luis Valley	22%	12%	7%
Southwest	23%	19%	10%
West/Northwest	21%	15%	16%
Statewide	**19%**	**14%**	**14%**

Figure 9. Most frequently identified strategy for addressing top water-related concern by region

Source: CWCB survey, 2013.

Several other surveys have gathered public input on their preferences concerning water strategies. The *Public Perceptions, Preferences and Values for Water in the West* survey by CSU researchers found that building reservoir storage was ranked first among strategies. Various conservation and reuse options, however, were ranked second, third and fifth among the eight options provided. Taken together, conservation and reuse as a package would have ranked first. Respondents in that survey also indicated mild agreement with the proposition that "Reallocating water for the natural environment and for human use should have the same priority" (average score about 3.5, where 3.0 is neutral and 5.0 is strong agreement). A 2013 survey of 710 Colorado voters by Public Opinion Strategies found that 80 percent of Colorado voters favored emphasizing conservation over building new projects in order to meet Colorado's water needs.

1.4.3 FINANCIAL SUPPORT FOR ADDRESSING WATER-RELATED CONCERNS

Whether tackled through additional conservation, environmental flow and habitat enhancement, new water storage and supply projects or most likely a combination of these measures and others – addressing Colorado's water related concerns and issues will require financial support from its citizens. Information gathered during the CWCB survey indicates the public is willing to pay more to address water-related issues.

During the earlier stages of each survey interview, respondents were asked about the affordability of home water service. Statewide, and in each region, Coloradan's consistently rated water service as more affordable ("inexpensive" or "priced about right") than other home services including energy, telephone service, and cable or satellite television service.

During the later stages of each interview, following discussion about the most important water-related issues facing Colorado and the respondents' suggestions regarding how they should be addressed, each interviewee was asked questions to identify their willingness-to-pay to address these issues. On average, survey respondents indicated their household would be willing to pay \$5 to \$10 per month to address Colorado's water related-issues:

- 66 percent of respondents indicated that they would be willing to pay an additional \$1 per month;
- 54 percent of respondents indicated that they would be willing to pay an additional \$5 per month;

- 48 percent of respondents indicated that they would be willing to pay an additional $10 per month; and
- 34 percent indicated that they would be willing to pay an additional $25 per month.

The degree of financial support for addressing water-related issues did vary by household income level. As shown in Figure 10, higher income households (above $75,000 per year) were more supportive of larger monthly costs (e.g. up to $25 per month), while the majority of lower income households (less than $50,000 per year) were unwilling to pay more than $5 per month.

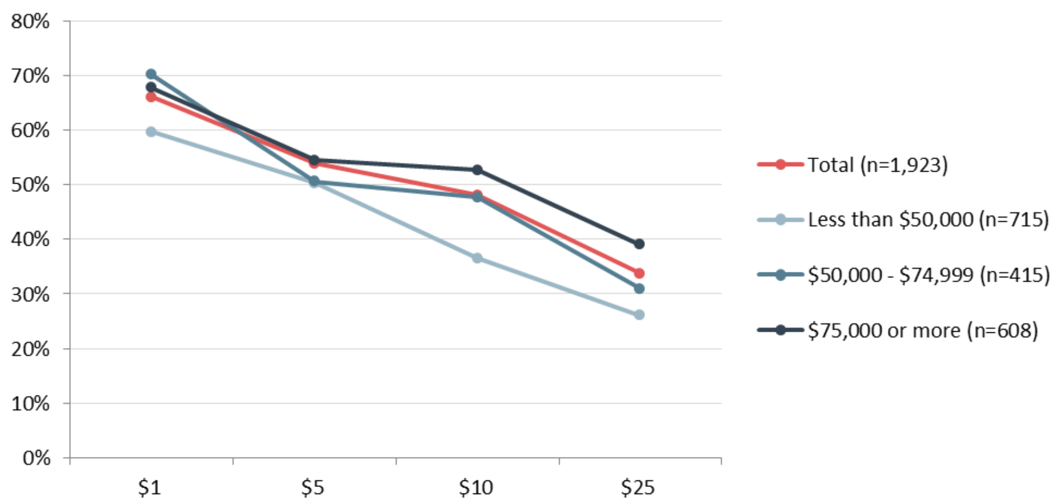


Figure 10. Willingness to pay to address water-related issues

Source: CWCB survey, 2013.

Colorado currently has a little over 2.1 million households (U.S. Census, ACS 2017 1-year estimates). If each household contributed $5 per month (in some fashion) toward resolving Colorado's water-related issues, those contributions would provide an annual funding stream of more than $125 million.

1.5 SUMMARY

- Coloradans have varied levels of knowledge regarding water use in the state. Only one in three residents recognizes that agriculture is that largest water user in Colorado. There is room for further education.
- But, in 2012-2013, a large majority of the state's residents were paying more attention to water issues, and their own water use, than they had in the past. In part, this was likely due to the very dry conditions during the summer of 2012. Repeated surveys in other locations have found that water awareness rises during droughts and diminishes after the drought recedes.
- The Colorado Water Plan identified social values as one of the key drivers in developing alternative future scenarios. More specifically the Colorado Water Plan discussed the possibility of values either trending towards a "more green" perspective or shifting toward "greater resource utilization."
- The CWCB survey provides some perspective on social values regarding water as of 2013, particularly in terms of identifying the water issues that residents felt were most important, how they thought Colorado's water issues should be addressed, and their willingness-to-pay to help resolve those issues. Social values can and do shift over time, and may also be affected by droughts, water contamination outbreaks (such as the Flint crisis which occurred after the CWCB survey was conducted), and public education and outreach efforts.
- Among eight potential water concerns, Coloradan's identified protecting home water quality, having enough water for Colorado's farms and ranches, and having enough water for Colorado's cities and towns

as the most important. These were the top three issues in each region of the state, though the ranking order of the issues varied by region.

- Coloradans most frequently described conservation as their preferred approach to addressing Colorado's water issues, followed by prioritizing environmental needs and building new water supply projects. Conservation was the most frequently recommended strategy in every region and support for prioritizing environmental needs was also quite consistent across Colorado's regions. Support for developing new water supply projects was more varied among the regions.
- Coloradans perceive home water service to be affordable compared to other home services, and are willing to pay more to address Colorado's water issues. On average, Coloradans are willing to pay between \$5 and \$10 more per month to address their water-related concerns. At \$5 per month per household, this willingness-to-pay would correspond to statewide annual financial support of about \$125 million.

1.6 POTENTIAL NEXT STEPS

The CWCB may want to undertake an updated public opinion survey prior to the next update to the Colorado Water Plan. As described in this memorandum, public awareness and opinions regarding water and water-related issues can and do change in response to climate variability, ongoing public education efforts by water providers and other entities, and external issues such as the highly publicized Flint water crisis that occurred several years ago (but after the 2012-2013 CWCB Survey). The makeup of Colorado's population is also dynamic. Census Bureau data from the American Community Survey indicate that approximately 1.2 million people moved to Colorado from other states or countries during the five-year period from 2013 and 2017. While some of those migrants may have already moved on to other locations, it seems likely that 10 to 20 percent of Colorado's current residents were not here when the 2012-2013 CWCB Survey was conducted.

If CWCB does sponsor an updated survey in the next few years, we would recommend that the new survey be conducted with a similar sampling frame to again produce statistically representative results for each basin, as well as the state as a whole. The survey instrument should include many of the same (or very similar) questions to allow comparison of results over time, although some new questions may be warranted to further examine social values in the context of the Colorado Water Plan scenarios and updated technical information.

Analysis and Technical Update to the Colorado Water Plan

Technical Memorandum

Prepared for:

Colorado Water Conservation Board

Subject:

Opportunities and Perspectives on Water Reuse

Date: May 15, 2019

Prepared by: Jacobs

Reviewed by: Brown and Caldwell

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As part of the analysis and technical update to the Colorado Water Plan (Technical Update), this technical memorandum (TM) provides an overview of different types of water reuse mechanisms and key considerations for evaluation and potential implementation of future reuse projects in Colorado. The concepts outlined in this TM build upon the ideas and recommendations from Colorado's Water Plan. Key objectives of this TM include:

- Provide guidance on how to define potential municipal reuse projects in future Basin Implementation Plan (BIP) efforts.
- Provide conceptual examples that demonstrate how to perform evaluations that quantify water supply benefits to the implementing entity and both quantify or qualify the impact of a local reuse project on the greater basin and watershed system.

Section 1: Water Reuse Overview

Colorado's Water Plan notes that various forms of water reuse will be an important component of closing future supply-demand gaps for municipalities, and the plan encourages water providers to build on the successes of the many types of reuse projects already implemented in Colorado. The following sections presents an overview of key types of municipal water reuse that may be encountered in Colorado, and further expands on descriptions of reuse provided in Section 6.3.2 of Colorado's Water Plan. Reuse mechanisms summarized in the following sections of this TM include:

- Reuse via exchange: Reuse via exchange can be described as when water right decrees stipulate if a water right holder can reuse water after the initial first use or if they are required to return unconsumed water (assumed to be treated wastewater from municipal users) to the watershed. Under the reuse via water exchange method, return flow water that can be legally reused is returned to the river or watershed and a like amount of water can be diverted from the river at a different point upstream (resulting in no water particles physically being reused) as long as the exchange does not adversely impact other water right holders. Reuse via exchange may fall outside the typical definition of "reuse" for water treatment professionals; however, it is appropriate and relevant when considered in the context of meeting a municipal supply and demand imbalance, or "gap".
- Non-potable reuse: Under the non-potable reuse method (also termed "reclaimed water"), water that can be legally reused receives additional treatment at the wastewater treatment plant and is then conveyed through a non-potable water distribution system (sometimes referred to as a "purple pipe system") to approved non-potable demands (e.g. commercial landscape areas, parks, golf courses, commercial cooling towers).
- Indirect potable reuse: Under the indirect potable reuse method, water leaving a wastewater treatment plant is further treated to potable water standards by an advanced treatment plant before or after being introduced into an environmental buffer water source and prior to delivery for potable consumption. This buffer can be a reservoir, natural stream, or aquifer storage facility to allow blending of the advanced treated water with water in the buffer. The water is either further treated via advanced water treatment, or blended with the other raw water sources and treated at the existing Water Treatment Plant before entering the potable drinking water distribution system.
- Direct potable reuse: Under the direct potable reuse method, water leaving a wastewater treatment plant is further treated to potable water standards by an advanced water treatment plant before being introduced directly into a potable water distribution system, where it is blended with other treated drinking water supplies.

- **Graywater reuse:** Graywater reuse has been implemented in other regions but is not currently fully approved in Colorado. Graywater reuse is typically implemented at an individual building or small community level. This type of reuse involves capturing drainage flows from showers, sinks (not including kitchen sinks), and clothes washers, and then sending that water through a localized water treatment and storage system to satisfy a portion of indoor flushing and outdoor irrigation demands. Like reuse via exchange, graywater reuse may not be considered a formal reuse mechanism by some, but it is appropriate to consider in the context of addressing supply/demand gaps.

Legal Eligibility of Reuse Water

In Colorado, water that is reused must first meet certain legal eligibility requirements. Water sources that can be reused typically include:

- **Water That is Not Native to the Basin**: These types of sources, such as some transbasin water and non-tributary groundwater, can be reused because downstream water right holders cannot develop a dependence on return flows or make a legal claim to water that is not native to the basin unless they are the owner of that water.
- **Historically Consumptive Water Which is Changed to Non-Consumptive Use**: Water that was historically consumptively used but has since been transferred to a non-consumptive use can be reused because downstream water right holders have not historically been dependent on any return flows for this water right.
- **Other Legally Decreed Water Sources**: Select other sources of water that have been legally decreed as reusable in Colorado water court.

Municipal Drivers for Exploring Reuse

Municipal water reuse can generally be divided into two typical situations: 1) a municipality begins to reuse water that they have historically had the legal right to reuse but have not historically reused or 2) a municipality acquires new water supplies that are legally reusable and immediately begins to reuse return flows from those supplies. A few recently implemented examples of these two situations in Colorado include:

Table 1: Recently Implemented Reuse Examples in Colorado

Examples of Reuse of Previously Unused Existing Supplies:	Example of Reuse of New Supplies:
• Aurora Water: Prairie Waters Project • Colorado Springs Utilities: Southern Delivery System • Denver Water: Non-Potable Recycled Water System	• Aurora Water: Reuse of the historically consumed portion of acquired agricultural water rights

Thus far in Colorado, implemented large-scale reuse projects have taken the form of non-potable reuse, indirect reuse, or reuse via exchange. No direct potable reuse (DPR) projects have been implemented for municipal use in Colorado to date, although several pilot-scale research installations of DPR have been developed (such as Denver Water's 1 million-gallon per day DPR demonstration project in the 1980s, and their 2018 PureWater Colorado Demonstration Project). However, the Colorado Department of Health and Environment (CDPHE)—along with support from the Colorado Water Conservation Board (CWCB) and key water providers—has been working to clarify the regulatory environment and enable future DPR projects. Therefore, DPR projects should be considered a viable option when a water provider is contemplating future water reuse alternatives.

Regulatory Considerations

Key regulatory considerations for reuse in Colorado include the following:

- Non-Potable Reuse: CDPHE Regulation 84 currently governs the uses and treatment standards for non-potable reuse water in Colorado
- Indirect-Potable Reuse: Existing Colorado Primary Drinking Water Regulations apply to the Water Treatment Plant prior to reuse water entering the potable water system. It is worth noting that reuse source water is, however, not explicitly regulated.
- Direct Potable Reuse: There are no current federal or state regulations in Colorado that specifically control implementation of direct potable reuse. However, CDPHE—along with support from the CWCB and key water providers—has been working towards developing a framework for regulating direct potable reuse in Colorado, similar to many other states.
- Graywater Reuse: CDPHE Regulation 86 currently governs the uses and treatment standards for graywater reuse water in Colorado.

Section 2: Hypothetical Examples of Different Types of Water Reuse

Different types of water reuse projects have unique effects on the overall water balance within a watershed. This section describes how some reuse projects (mostly non-potable) result in one-time water reuse and others (reuse via exchange or indirect and direct potable reuse) result in opportunities for multiple reuse cycles. Per Action Item #2 in Section 6.3.2 of Colorado's Water Plan, this section also describes how some reuse mechanisms can result in minimal future reductions in flow in the watershed downstream of the reuse project, while others can have a one-to-one reduction in downstream flow. When reductions in downstream flow occur, basin scale water planning should consider that the water supply-demand gap for one region may be reduced while the gap for a downstream region can be increased. The purpose of providing these hypothetical examples is to help illustrate the trade-offs of different reuse strategies and provide guidance on how to quantify the future benefits and potential impacts of different reuse projects.

Note that the hypothetical examples, evaluations, and concepts presented herein are generic examples that are not based on any actual implemented or planned reuse projects in Colorado.

The following sections examine a hypothetical municipality that has a current municipal and industrial (M&I) demand of 100 units of water and a future demand of 150 units of water[1]. The community is located near a river that has 900 existing units of water flowing from upstream.

In this example, the following assumptions are made:

- The municipality is assumed to fill an existing storage facility with existing water rights and release 100 units of water from storage as needed to satisfy current demands.

[1] Hypothetical flow, demand, or supply units of water presented in this TM are assumed to be annual units of water unless otherwise noted

- It is also assumed that 50% of the current M&I demands are attributed to non-consumptive uses (such as toilet, shower, and sink uses) and, therefore, 50 units of water are returned to the river as return flows from the municipality's wastewater treatment plant. This results in a river flow of 900 units of water in the river upstream of the community and 950 units of water downstream of the wastewater treatment plant return flow location. This current conditions system is shown in Figure 1, with conceptual units of flow through the system shown in red text for each major system component.

HYPOTHETICAL CURRENT CONDITIONS

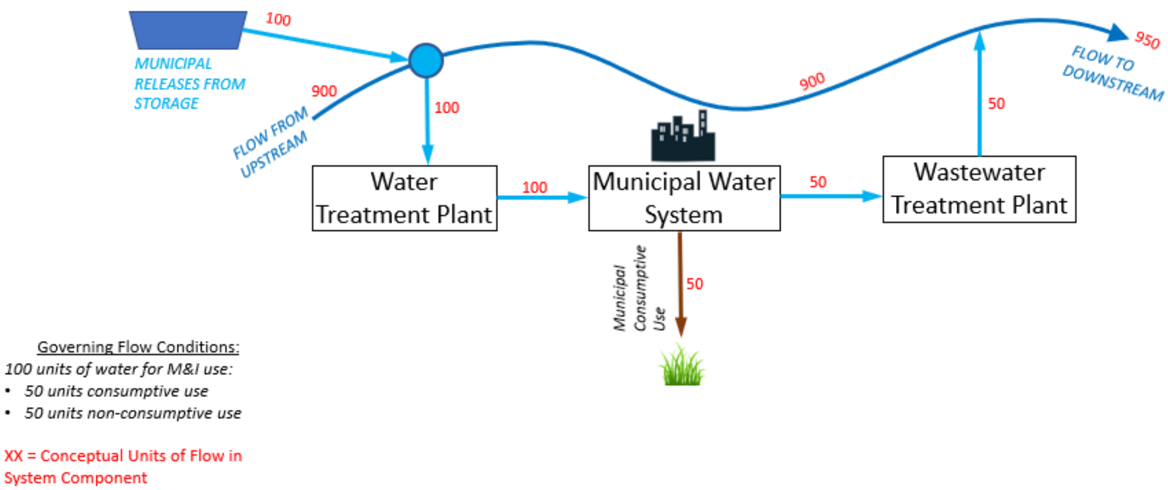

Figure 1: Hypothetical Current Conditions System

Next, it is assumed that the municipality experiences growth and M&I demands increase by 50 units of water. Under a default operational scenario with no reuse implemented, the municipality would be required to obtain 50 additional units of new water supplies to satisfy the increased demands. This scenario is shown below in Figure 2, with 50 additional units of newly acquired water supplies being released from upstream storage to satisfy the increased demands. Note that the upstream flow in the river is assumed to be unchanged from the current condition and, therefore, the new units of water are assumed to be from a transferred water right or non-tributary water right. This assumption is typical in Colorado due to the state's prior appropriation water right system.

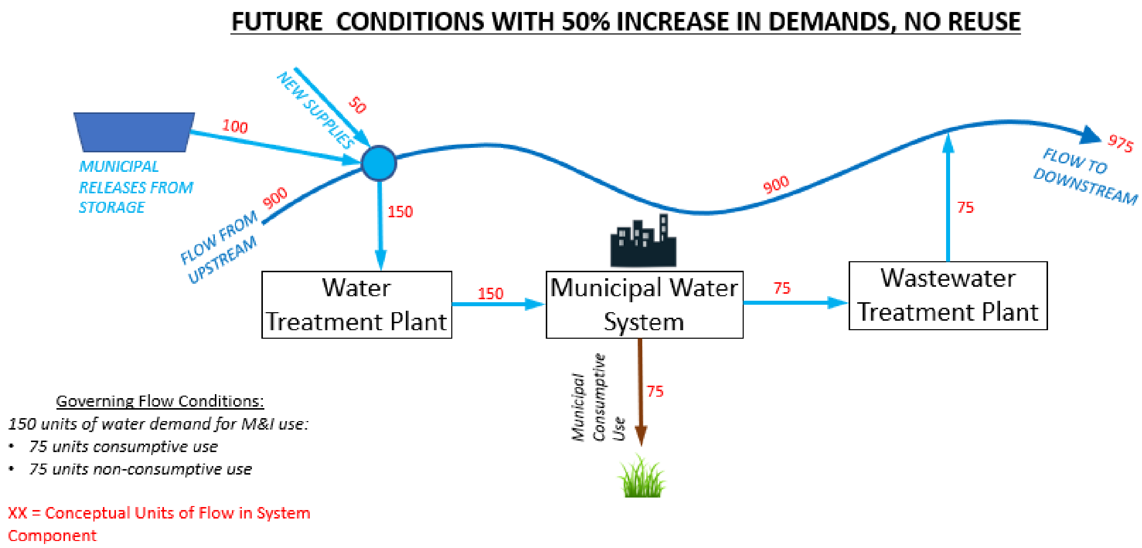

Figure 2: Hypothetical Increased Demands System

Alternatively, instead of acquiring a full 50 units of new water supplies to satisfy increased demands (which may be increasingly difficult or prohibitively expensive for some municipalities in the future), the municipality could implement a form of water reuse to meet all or part of the increased demands and potentially reduce the amount of new supplies that need to be acquired.

Following are several examples of types of reuse projects that could be used to meet the hypothetical increase in demands described above. Evaluation of each type of reuse is presented in fact-sheet style format. These fact-sheets are designed to convey the following major points for each type of reuse:

- A definition and description of how the particular type of reuse functions
- A mass-balance schematic showing how the type of reuse accommodates the hypothetical increased-demands scenario. Schematics are included for two situations:
  - where demands are met by reuse of return flows that have historically not been reused
  - where demands are met via reuse of new supplies
- A brief discussion of potential benefits, tradeoffs, and unintended consequences of the type of reuse
- Key water quality, treatment and regulatory considerations

In each of the below hypothetical mass-balances presented in the fact-sheets, annual conditions are assumed. Appendix A (at the end of this TM) provides a more extensive quantification comparison of each of the reuse mechanisms during annual conditions.

Additionally, a generic qualitative example of how graywater reuse could be considered is provided in fact-sheet format.

It is worth noting that multiple forms of reuse (such as indirect potable, direct potable, and non-potable) can potentially be combined, further altering the overall water balance considerations presented in this TM.

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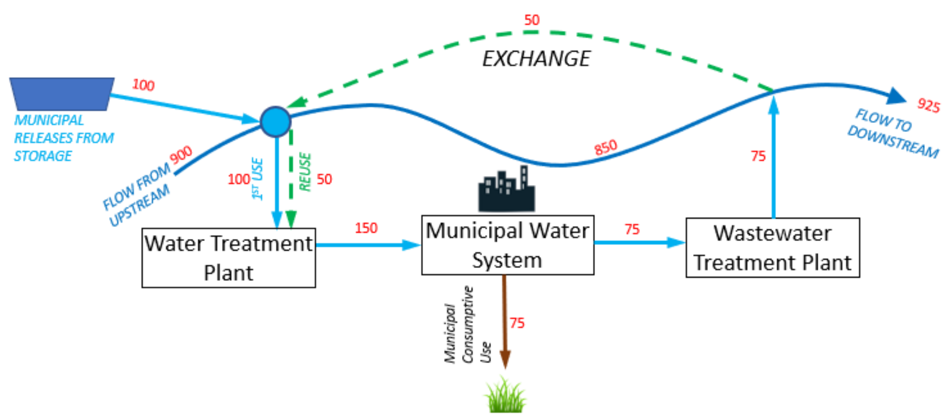
Reuse via Exchange

Reuse via Exchange can be described as when water right decrees stipulate if a water right holder can reuse water after the initial first use or if they are required to return unconsumed water (assumed to be treated wastewater from municipal users) to the watershed. Under the reuse via water exchange method, return flow water that can be legally reused is returned to the river or watershed and a like amount of water can be diverted from the river at a different point upstream (resulting in no water particles physically being reused) as long as the exchange does not adversely impact other water right holders. Reuse via exchange may fall outside the typical definition of "reuse" for water treatment professionals; however, it is appropriate and relevant when considered in the context of meeting a municipal supply and demand imbalance, or "gap".

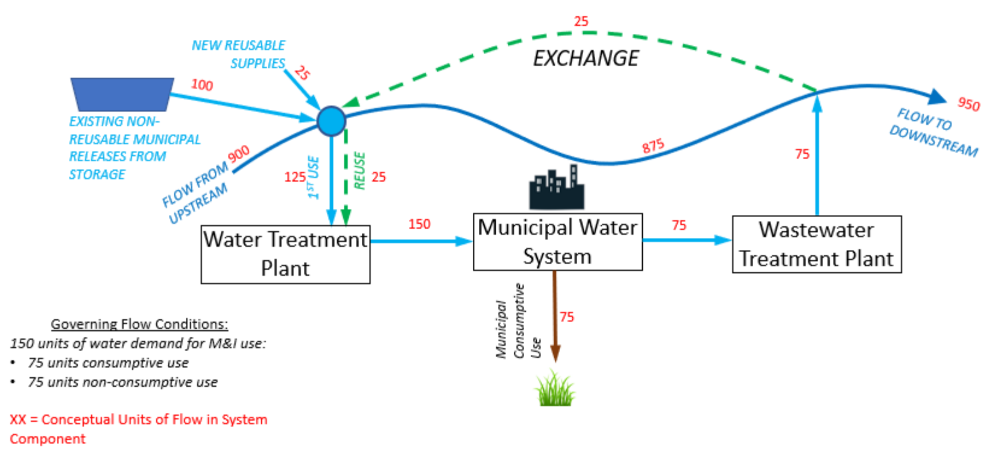
The below example examines a hypothetical municipality that has a current daily municipal and industrial (M&I) demand of 100 units of water and a future demand of 150 units of water. The community is located near a river that has 900 existing units of water flowing from upstream. The green path of water highlights the reuse cycle and the light blue path of water highlights traditional supplies, including new supplies. The brown path of water represents where water leaves the watershed entirely (i.e. consumptive use).

Reuse via Exchange

Reuse of Water Not Historically Reused



Reuse of New Supplies



Note that the hypothetical examples, evaluations, and concepts presented herein are generic examples that are not based on any actual implemented or planned reuse projects in Colorado.

Benefits:

- Reduced Salt Build-up: Water particles are not directly and physically reused, creating an open system which avoids a closed loop that can result in elevated salt/Total Dissolved Solids (TDS) concentrations over time.
- Uses Conventional Treatment: Requires conventional water and wastewater treatment only.
- Not Infrastructure Intensive: Typically does not require conveyance infrastructure.
- Less Water Diverted: Although the total amount of consumptive demands are the same in all of the hypothetical water supply scenarios (assuming all demands are met), the amount of new water supplies required to satisfy increased demands for this reuse via exchange example is lower when compared to not implementing any form of reuse.

Tradeoffs:

- Exchange Potential Needed: Requires sufficient water in river for exchange to occur without adversely impacting other water right holders.
- Increased Water Accounting: Can require more complex water accounting and water rights administration than other reuse alternatives.

Reuse via Exchange

- **Reduced Instream & Downstream Flow**: Results in less river flow through both the instream exchange reach and downstream reach when compared to current conditions.
- **Increased WTP Capacity**: The capacity of the Water Treatment Plant needs to be increased by 50 units of water in order to accommodate exchanged reuse flow.

Unintended Consequences:

- Reuse via exchange methods encourage all return flow to be returned to the watershed. Return flows are often of lower quality and higher salinity than existing flow in the river, resulting in stream water quality degradation. Other reuse methods divert the return flow water and apply it to other water demands that do not require as high of quality water, reducing undesirable constituents returned to the river.

Typical Treatment Required/Water Quality Considerations:

- Conventional wastewater treatment at return flow location.
- Conventional water treatment at diversion location.

Regulatory Considerations:

- Under this reuse scenario, water is not directly reused, and there are no current applicable reuse regulations.

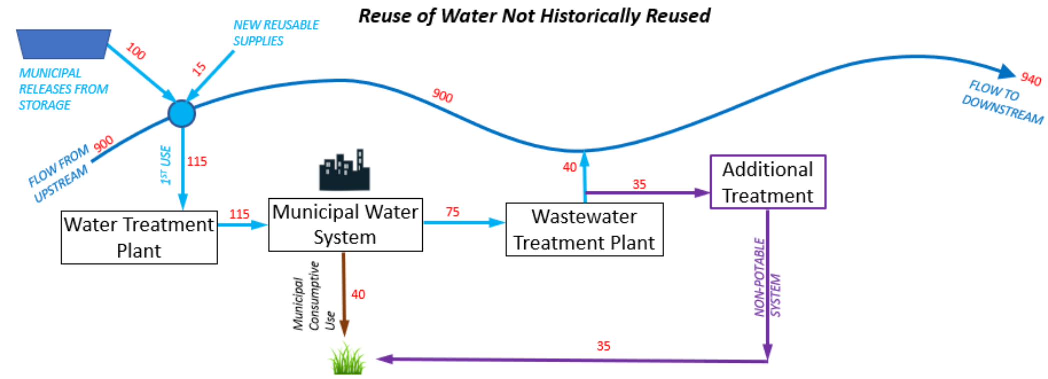
Non-Potable Reuse

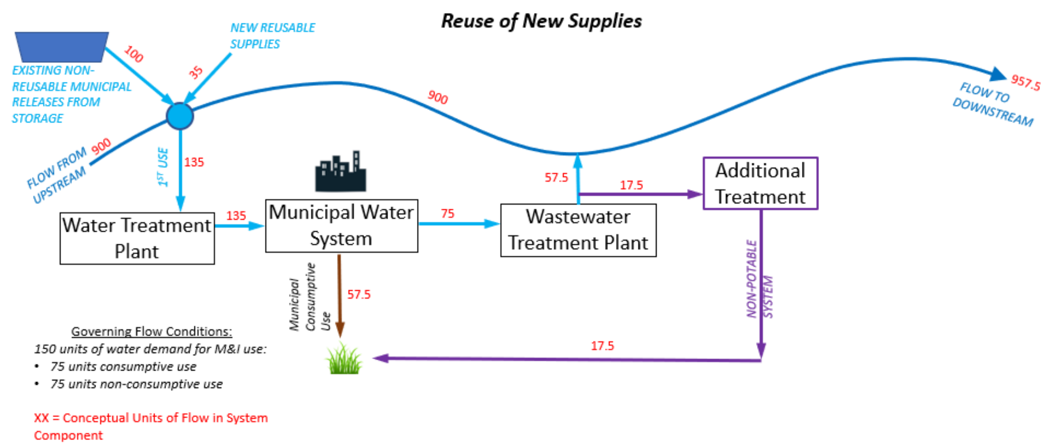
Under Non-Potable Reuse, water right decrees stipulate if a water right holder can reuse water after the initial first use or if they are required to return unconsumed water (assumed to be treated wastewater from municipal users) to the watershed. Under the non-potable reuse method (also termed “reclaimed water”), water that can be legally reused receives additional treatment at the wastewater treatment plant (to CDPHE Water Quality Control Commission Regulation 84 standards) and is then conveyed through a non-potable water distribution system (sometimes referred to as a “purple pipe system”) to approved non-potable demands (e.g. commercial landscape areas, parks, golf courses, commercial cooling towers). Recently passed legislation in 2018 and 2019 allows for non-potable water to be used on edible crops, marijuana cultivation and industrial hemp use, and indoor toilet flushing if the reclaimed water meets specified water quality standards.

The below example examines a hypothetical municipality that has a current daily municipal and industrial (M&I) demand of 100 units of water and a future demand of 150 units of water. The community is located near a river that has 900 existing units of water flowing from upstream. The

Non-Potable Reuse

purple path of water highlights the reuse cycle and the light blue path of water highlights traditional supplies, including new supplies. The brown path of water represents where water leaves the watershed entirely (i.e. consumptive use).





The above schematics show just one potential configuration where non-potable reuse water serves only consumptive uses. Non-potable reuse water could also be used to serve other non-consumptive demands such as industrial or power generation activities.

Note that the hypothetical examples, evaluations, and concepts presented herein are generic examples that are not based on any actual implemented or planned reuse projects in Colorado.

Benefits:

- Less Water Diverted: Although the total amount of consumptive demands (75 units of water) are the same in all of the hypothetical water supply scenarios (assuming all demands are met), the amount of new water supplies required to satisfy increased demands for this non-potable reuse example is lower when compared to not implementing any form of reuse.
- Lower Impacts to Instream Water Quality: In this example, lower quality and higher salinity water is not returned to the watershed because it is consumed by end uses that do not require as high of quality water (such as irrigation and some industrial uses), reducing undesirable constituents returned to the river relative to the existing condition.

Tradeoffs:

- Separate Distribution System: Requires costly parallel pipe distribution system to be operated and maintained by the water provider.

Non-Potable Reuse

- **Seasonal Operation**: Non-potable systems are built to meet demands that typically only exist during the warmest months of the year (~4 months per year), resulting in potentially limited amounts of reused water on an annual basis as compared to other water reuse mechanisms.
- **Reduced Downstream Flow**: Because the total amount of water diverted is reduced, non-potable reuse results in a flow reduction in the downstream river reach when compared to not implementing reuse.

Unintended Consequences:

- Some end users may justify high water use landscaping in lieu of xeric landscaping methods because the landscaping is irrigated with reuse water. This logic can create a false public perception that reuse water is less usable and valuable than other water supplies, which can potentially cause inefficient uses of reuse water and result in unnecessary reductions in downstream river flows.
- End use of water that is often largely consumptive, therefore limiting reuse to one use cycle.

Typical Treatment Required/Water Quality Considerations:

- Reuse water destined for non-potable demands typically requires tertiary wastewater treatment (filtration and disinfection) which is not as expensive as potable reuse options. However, the potable water treatment plant size can be reduced as reuse is meeting a portion of summer/peak season demands.

Regulatory Considerations:

- Regulation 84 governs the uses and treatment standards for non-potable reused water in Colorado.

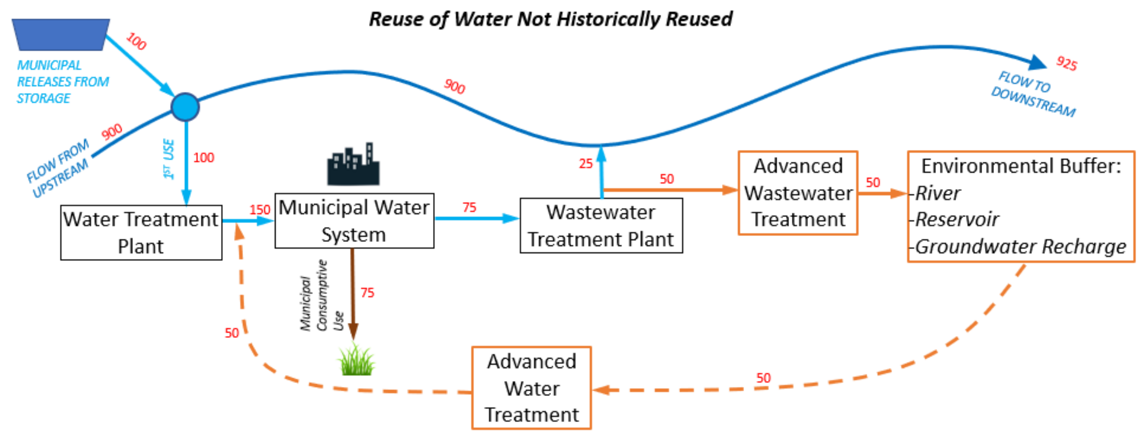
Indirect Potable Reuse

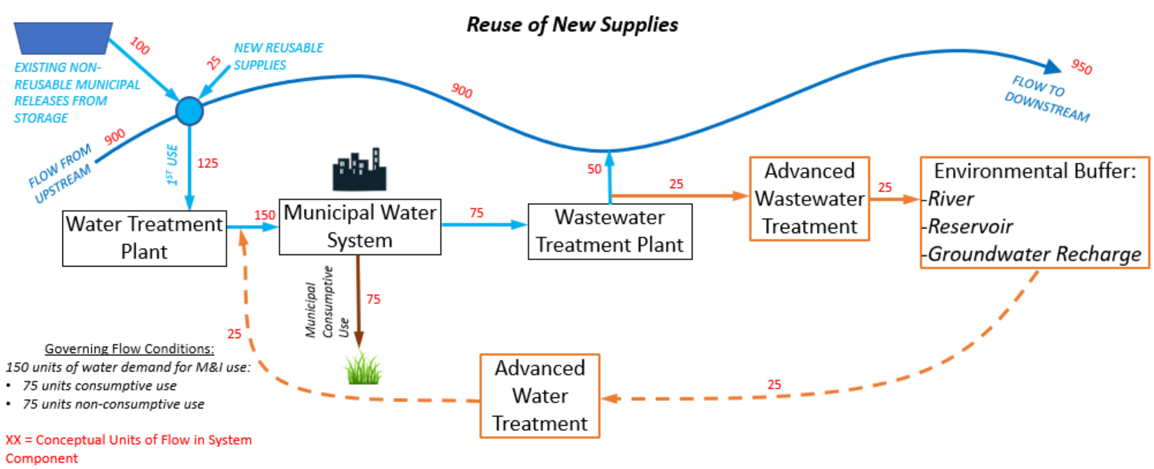
Under Indirect Potable Reuse, water right decrees detail whether a water right holder can reuse water after the initial first use or if they are required to return unconsumed water (assumed to be treated wastewater from municipal users) to the watershed. Under the indirect potable reuse method, water leaving a wastewater treatment plant is further treated to potable water standards by an advanced wastewater treatment plant before or after being introduced into an environmental buffer water source. This buffer can be a reservoir, natural stream, or aquifer storage facility to allow blending. The water can then be further treated via advanced water treatment after leaving the buffer and before entering the potable drinking water distribution system.

The below example examines a hypothetical municipality that has a current daily municipal and industrial (M&I) demand of 100 units of water and a future demand of 150 units of water. The community is located near a river that has 900 existing units of water flowing from upstream. The orange path of water highlights the reuse cycle and the light blue path of water highlights traditional

Indirect Potable Reuse

supplies, including new supplies. The brown path of water represents where water leaves the watershed entirely (i.e. consumptive use).





The above schematics represent just one example configuration of Indirect Potable Reuse. Water leaving the environmental buffer could also be blended with other raw water upstream of the water treatment plant before water treatment and introduction into the potable distribution system.

Note that the hypothetical examples, evaluations, and concepts presented herein are generic examples that are not based on any actual implemented or planned reuse projects in Colorado.

Benefits:

- No Separate Distribution System: When compared with non-potable reuse, indirect potable reuse does not require construction of two separate water distribution systems to enable use of reused water.
- Year-Round Use by All Demands: Unlike non-potable reuse, indirectly reused water can be reused by all demands, which allows year-round operation of the reuse system and multiple reuse cycles.
- Less Water Diverted: Although the total amount of consumptive demands are the same in all of the hypothetical water supply scenarios (assuming all demands are met), the amount of new water supplies required to satisfy increased demands for this indirect-potable reuse example is lower when compared to not implementing any form of reuse.

Indirect Potable Reuse

Tradeoffs:

- **Treatment & Conveyance Systems:** Expensive advanced treatment systems are required to treat reuse water to required water quality standards, and extensive conveyance systems may be required to convey the water to a location where it can be reintroduced to the distribution system.
- **Salt Buildup Over Time:** Because water particles are being directly and physically reused, multiple reuse cycles of water can cause salt/TDS buildup in the reuse system over time.
- **Reduced Downstream Flow**: Indirect potable reuse also results in a flow reduction in the downstream river reach by the amount of reuse water used when compared to the no-reuse conditions.

Unintended Consequences:

- Water stored in a reservoir environmental buffer may require chemical or other treatment to prevent algae growth that negatively impacts water quality. This may become less of a concern as future regulations reduce allowable nutrient levels in wastewater effluent.

Typical Treatment Required/Water Quality Considerations:

- Advanced wastewater treatment processes may be required, and advanced water treatment processes are required for indirect potable reuse.

Regulatory Considerations:

- There is no explicit regulation of indirect potable reuse in Colorado. Discharge to an environmental buffer is regulated by water quality requirements of the receiving water body.
- Existing Colorado Primary Drinking Water Regulations apply to the final delivered potable water from the Water Treatment Plant.

Direct Potable Reuse

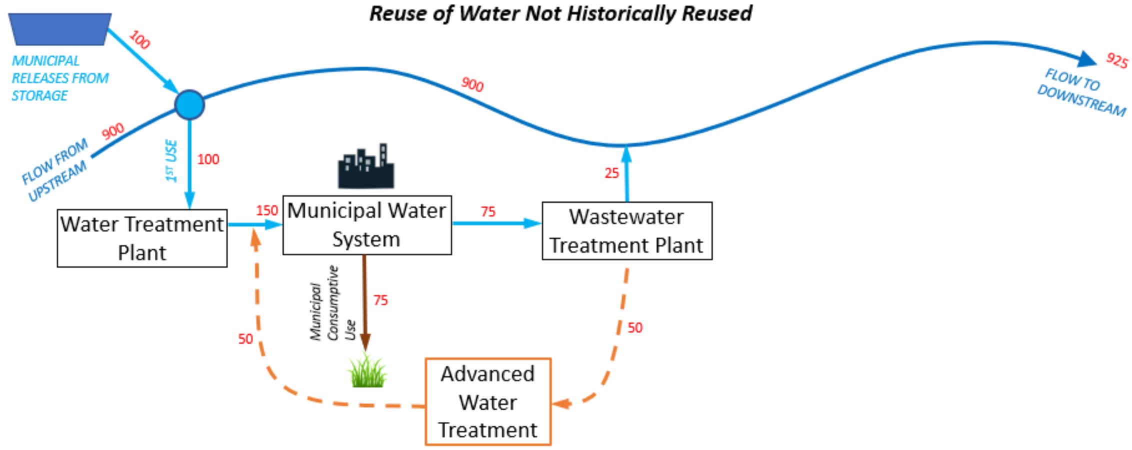
Under Direct Potable Reuse, water right decrees stipulate if a water right holder can reuse water after the initial first use or if they are required to return unconsumed water (assumed to be treated wastewater from municipal users) to the watershed. Under the direct potable reuse method, water leaving a wastewater treatment plant is further treated to potable water standards by an advanced water treatment plant before being introduced directly into a potable water distribution system, where it is blended with other treated drinking water supplies.

The below example examines a hypothetical municipality that has a current daily municipal and industrial (M&I) demand of 100 units of water and a future demand of 150 units of water. The community is located near a river that has 900 existing units of water flowing from upstream. The

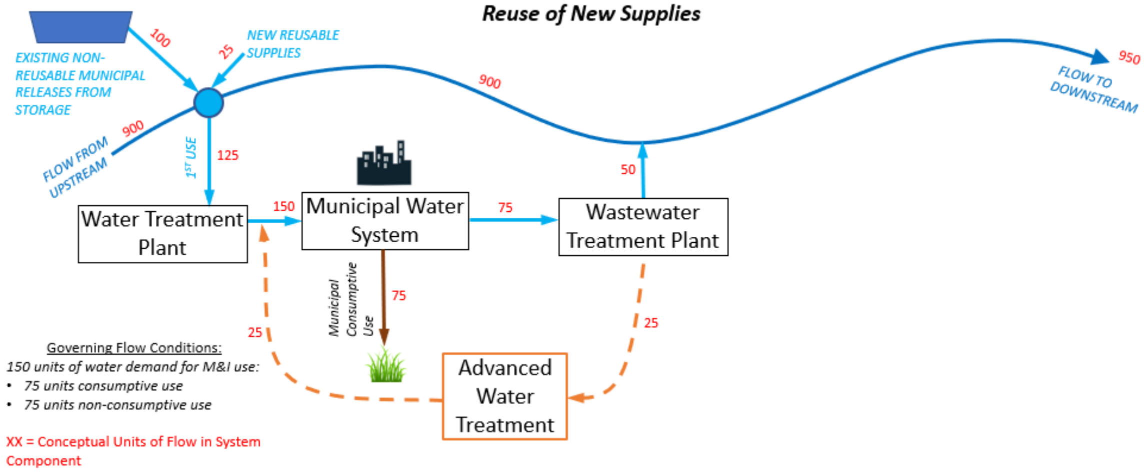
Direct Potable Reuse

orange path of water highlights the reuse cycle and the light blue path of water highlights traditional supplies, including new supplies. The brown path of water represents where water leaves the watershed entirely (i.e. consumptive use).

Reuse of Water Not Historically Reused



Reuse of New Supplies



Note: The above schematic represents just one example configuration of direct potable reuse. DPR can discharge water either upstream of the water treatment plant or directly into the distribution system.

Note that the hypothetical examples, evaluations, and concepts presented herein are generic examples that are not based on any actual implemented or planned reuse projects in Colorado.

Benefits:

- No Separate Distribution System: When compared with non-potable reuse, direct potable reuse does not require construction of two separate water distribution systems to enable use of reused water.
- Year-Round Use by All Demands: Unlike non-potable reuse, directly reused water can be reused by all demands, which allows year-round operation of the reuse system and multiple use cycles.
- Less Water Diverted: Although the total amount of consumptive demands are the same in all of the hypothetical water supply scenarios (assuming all demands are met), the amount of new

Direct Potable Reuse

water supplies required to satisfy increased demands for this direct potable reuse example is lower when compared to not implementing any form of reuse.

Tradeoffs:

- **Treatment Systems**: Expensive advanced treatment systems are required to treat reuse water to required water quality standards.
- **Additional Water Quality Monitoring**: Extensive monitoring of water quality is required since there is not a significant buffer between the treatment of wastewater and introduction of the treated water to the potable water system.
- **Public Acceptance**: Public perception issues must be overcome to enable successful long-term implementation.
- **Reduced Downstream Flow**: Direct potable reuse results in a flow reduction in the downstream river reach by the amount of reuse water used, when compared to current conditions.
- **Salt Buildup Over Time**: Because water particles are being directly and physically reused, multiple reuse cycles of water can cause salt/TDS buildup in the reuse system over time.

Unintended Consequences:

- Reverse-osmosis (RO) treatment is not required for direct potable reuse unless salinity buildup becomes a challenge, in which case it may be required to meet water quality objectives. If required, disposal of brine concentrate resulting from RO treatment may be difficult from both a technical and permitting standpoint.

Typical Treatment Required/Water Quality Considerations:

- Advanced treatment for direct potable reuse requires a multi-barrier approach to pathogens and organics. The treatment processes included in direct potable reuse schemes are typically more expensive (both capital and operating) relative to conventional drinking water treatment.
- Some states (such as California) have historically required RO to be one of the treatment processes used in potable reuse applications. Other states (such as Texas) have not mandated the use of RO for potable reuse applications. Initial discussions with CDPHE have indicated Colorado is not likely to require RO as part of Direct Potable Reuse implementation.

Regulatory Considerations:

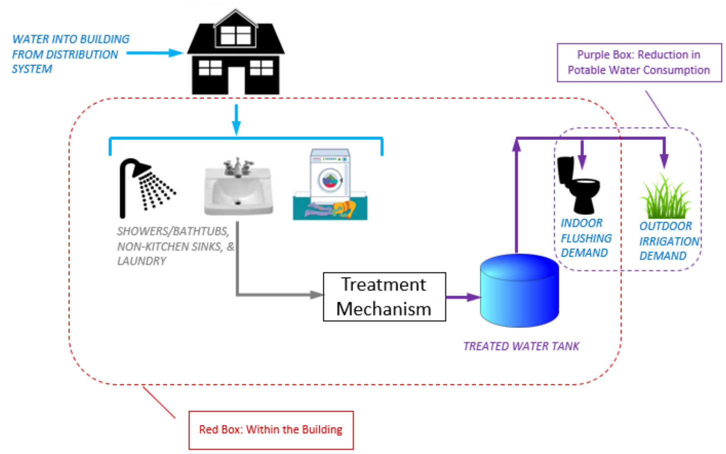
- There are no current federal or state regulations in the United States that specifically control implementation of direct potable reuse. However, CDPHE—along with support from the CWCB and key water providers—has been working towards developing a framework for regulating direct potable reuse in Colorado, similar to many other states. This will address technical and public acceptance barriers and aim towards approval and development of a direct potable reuse project in Colorado.

Graywater Reuse

Graywater Reuse has been implemented in other regions but is not currently fully approved in Colorado. Graywater reuse is typically implemented at an individual building or small community level. This type of reuse involves capturing drainage flows from showers, sinks (not including kitchen sinks), and clothes washers, and then sending that water through a localized water treatment and storage system to satisfy a portion of indoor flushing and outdoor irrigation demands.

Graywater Reuse

GRAYWATER REUSE



Benefits:

- Reduces potable water consumption by meeting some indoor flushing and outdoor irrigation demands.

Tradeoffs:

- High installation, operation, and maintenance costs for end-users.
- Customer perception of water quality.
- Compliance with future regulations.
- Cross connection of non-potable pipes and potable water pipes within the building is an increased risk.
- Requires building/home owners to maintain their own relatively sophisticated water treatment system.

Unintended Consequences:

- Potable backup supply still required if full water service is desired in times when graywater reuse system is not operational.

Typical Treatment Required/Water Quality Considerations:

- Graywater treatment systems typically include tanks that allow solids to settle to the bottom and fats and greases to float to the top. The remaining water then passes through a cartridge type filter. Chemicals that improve the treatment process may or may not be used.

Regulatory Considerations:

- Graywater reuse is not fully approved for use in Colorado as of the date of this TM.
- Regulation 86 (adopted by the Water Quality Control Commission) was developed by CDPHE in 2015 and governs the uses and treatment standards of graywater in Colorado. The regulation requires that counties and cities adopt their own ordinances for local graywater regulation.
- Additionally, a plumbing code governing graywater piping will need to be developed and adopted by the Colorado Plumping Board, although advancement of this action has not yet occurred.

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Section 3: Considerations for Future Evaluations & Implementation of Water Reuse Projects

The mass balance exercises described in the previous section highlight four key metrics that should be considered when evaluating future water reuse projects:

- Annual volume of water reused under the particular reuse mechanism
- Annual volume of new supplies required (water that is not reused and must be sourced from elsewhere to satisfy increased demands, and must be of a suitable reliability to fit within a water provider's overall water supply portfolio)
- Flow in the river between the diversion location and return flow location
- Flow in the river downstream of the return flow location

Figure 3 provides a qualitative comparison of different reuse options against each of the above four metrics for the reuse mass balances presented previously. A full numerical summary of the mass balance for each compared option can be found in Appendix A.

			Annual Volume of New Supplies [annual units of water]	Flow Between Diversion & Return Points [annual units of water]	Annual Volume of Water Reused [annual units of water]	Downstream Flow [annual units of water]
		Current Conditions	0	900	0	950
Future Conditions	No reuse	Meet New Demands With New Supplies and **Without Reuse**	--	=	=	++
Future Conditions	Assumes Existing Supplies are Reused	Meet New Demands With Reuse of **Historically Unused Return Flows via. Exchange**	=	--	++	--
Future Conditions	Assumes Existing Supplies are Reused	Meet New Demands With **Non-Potable Reuse of Historically Unused Return Flows**	-	=	+	-
Future Conditions	Assumes Existing Supplies are Reused	Meet New Demands With **Indirect-Potable Reuse of Historically Unused Return Flows**	=	=	++	--
Future Conditions	Assumes Existing Supplies are Reused	Meet New Demands With **Direct-Potable Reuse of Historically Unused Return Flows**	=	=	++	--
Future Conditions	Assumes New Supplies are Reused	Meet New Demands With New Supplies and **Exchange Reuse of New Supplies**	-	-	+	=
Future Conditions	Assumes New Supplies are Reused	Meet New Demands With New Supplies and **Non-Potable Reuse of New Supplies**	-	=	+	+
Future Conditions	Assumes New Supplies are Reused	Meet New Demands With New Supplies and **Indirect Potable Reuse of New Supplies**	-	=	+	=
Future Conditions	Assumes New Supplies are Reused	Meet New Demands With New Supplies and **Direct Potable Reuse of New Supplies**	-	=	+	=

indicates most favorable when compared to current conditions
indicates more favorable when compared to current conditions
indicates no change from current conditions
indicates less favorable when compared to current conditions
indicates least favorable when compared to current conditions

Figure 3: Qualitative Comparison of Reuse Options

Key Takeaways

Figure 3 confirms many commonly known benefits and considerations of water reuse projects, including the following:

Reuse of Existing Reusable Return Flows: If a municipality can reuse existing return flows, the amount of new supplies needed to meet future demands can be reduced. Implementing indirect, direct, or reuse via exchange methods have the largest opportunity to reduce the need for new supplies due to the ability to reuse water year-round. It is important to note that when a municipality begins to reuse return flows that have not historically been reused, this can result in a flow reduction to downstream users. Coordination between the water provider and downstream water users could help those users plan for this reduction in downstream water availability.

Reuse of New Supplies: If a municipality cannot reuse existing return flows, reuse of future, new legally reusable supplies will reduce the amount of future new supplies needed. If a municipality reuses the new supplies using indirect, direct, or reuse by exchange methods, these types of reuse can be used year-round, maximizing the benefit of reuse to the municipality and minimizing the amount of new supplies needed.

Appendix A: Example Mass Balances of Hypothetical Water Reuse Projects

		Example System, Annual Conditions							
		M&I Demands [annual units of water]	Release from Existing Storage [annual units of water]	New Supplies Required [annual units of water]	Annual Volume Reused [annual units of water]	Upstream River Flow [annual units of water]	Flow Between Diversion & Return Points [annual units of water]	Downstream River Flow [annual units of water]	Comment
	Current Conditions	100	100		-	900	900	950	-
	Meet New Demands With New Supplies and Without Reuse	150	100	50	-	900	900	975	-
Future Conditions, Assuming Existing Supplies are Reusable	**Meet New Demands With Reuse of Historically Unused Return Flows via. Exchange**	150	100	0	50	900	850	925	Reuse via exchange meets year-round demands without the need for new water supplies, but results in less river flow through both the instream exchange reach and downstream reach when compared to current conditions
	Meet New Demands With Non-Potable Reuse of Historically Unused Return Flows	150	115	15	35	900	900	940	Non-potable reuse largley meets summer consumptive use demands, resulting in lower new supplies needed when compared to meeting new demands solely with new supplies. The amount of demand met by reuse water on an annual basis is lower than other options due to the seasonality of non-potable demands.
	Meet New Demands With Indirect-Potable Reuse of Historically Unused Return Flows	150	100	0	50	900	900	925	Indirect potable reuse reduces the need for new supplies needed when compared to meeting new demands solely with new supplies, is not dependent on an exchange river reach, and indirect potable reuse water can be used to meet year-round demands. Indirect potable reuse also results in a flow reduction in downstream reach by the amount of reuse water used, when compared to current conditions.
	Meet New Demands With Direct-Potable Reuse of Historically Unused Return Flows	150	100	0	50	900	900	925	Same impacts to hydrologic system as indirect potable reuse, minus the use of an environmental buffer. This option could require treatment processes that produce waste streams that require extra consideration.
Future Conditions, Assuming Existing Supplies are not Reusable	Meet New Demands With **New Supplies** and **Exchange** Reuse of New Supplies	150	100	25	25	900	875	950	This option assumes that historical return flows are not reusable, but new supplies obtained to meet increased demands are fully reusable
	Meet New Demands With **New Supplies** and **Non-Potable Reuse** of New Supplies	150	100	35	17.5	900	900	957.5	This option assumes that historical return flows are not reusable, but new supplies obtained to meet increased demands are fully reusable. New suppies are required to meet summmer consumptive demands
	Meet New Demands With **New Supplie**s and **Indirect Potable Reuse** of New Supplies	150	100	25	25	900	900	950	This option assumes that historical return flows are not reusable, but new supplies obtained to meet increased demands are fully reusable
	Meet New Demands With **New Supplies** and **Direct Potable Reuse** of New Supplies	150	100	25	25	900	900	950	This option assumes that historical return flows are not reusable, but new supplies obtained to meet increased demands are fully reusable

Notes:

- When M&I demands are held constant, various types of reuse can result in varying reductions in reservoir releases to meet the M&I demand. The water left in storage can be used to meet demands during drought conditions, or future demands.

- Under all scenarios, the amount of water not released from storage due to reuse results in a like amount of downstream flow reductions.

Analysis and Technical Update to the Colorado Water Plan

Technical Memorandum

Prepared for:

Colorado Water Conservation Board

Subject:

Temperature Offsets and Precipitation Change Factors Implicit in the CRWAS-II Planning Scenarios

Date: June 12, 2019

Prepared by: Adam N. Wlostowski, Lynker Technologies LLC
Reviewed by: Taryn Finnessey and Megan Holcomb, CWCB

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Section 1: Executive Summary

This memorandum specifies monthly averaged temperature offsets and precipitation change factors implicit in key planning scenarios for future year 2050: “Hot and Dry” and “Between 20th Century Observed and Hot and Dry”. A temperature offset (°C) quantifies the predicted temperature change from baseline conditions (1970 – 1999) to future conditions (2050). A precipitation change factor (unitless) is the ratio of predicted future (2050) to baseline (1970 – 1999) precipitation totals. Table 1 summarizes temperature offsets and precipitation change factors for two key scenarios, spatially averaged over the entire state.

Table 1. Summary of temperature offsets and precipitation change factors, averaged across the entire state for the “Hot and Dry” and “Between 20th Century Observed and Hot and Dry” planning scenarios.

Scenario	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
Temperature Offsets °C													
Hot & Dry	1.7	1.7	2.0	2.2	2.7	2.7	2.7	2.7	2.7	2.4	2.0	1.7	2.3
Between	1.4	1.5	1.7	1.8	2.2	2.3	2.2	2.5	2.4	2.5	1.9	1.8	2.0
Precipitation Change Factors [-]													
Hot & Dry	1.13	1.05	1.01	0.91	0.85	0.97	0.94	0.95	0.96	0.98	1.06	1.07	0.99
Between	1.14	1.23	1.10	0.93	0.90	1.00	1.00	0.95	1.06	1.05	1.10	1.10	1.05

Additionally, this memorandum reviews the logic and methodology behind the development of the planning scenarios, explains the methodology used to calculated monthly average temperature offsets and precipitation change factors, and presents and discusses the analysis results. Analysis results presented in this memorandum are provided in a directory of .csv files, shared via a Google Drive link. Additionally, temperature offset results are visualized through an interactive ArcGIS Story Map.

Section 2: Background

The primary performance metric of a water supply system is the ability to meet beneficial water use demands, such as agricultural water use, ecological flows, or reservoir storage withdrawals. One metric of water supply stress is the basin-scale balance between runoff and beneficial consumptive use. High stress conditions manifest when runoff is low and consumptive use is high, whereas low stress conditions emerge when runoff is high and consumptive use is low. Under this conceptual umbrella, CRWAS-II identified seven future planning scenarios intended to explore the full range of water supply stress conditions plausible for the state of Colorado in 2050. Two of these scenarios have been used by the state as key planning scenarios, known as “Hot and Dry” and “Between 20th Century Observed and Hot and Dry”.

The foundation of the CRWAS-II scenario development process is a set of model runs conducted by the U.S. Bureau of Reclamation (USBR) simulating future hydrologic conditions for the United States (Bureau of Reclamation, 2013). Specifically, the Variable Infiltration Capacity (VIC) model (Liang, Lettenmaier, Wood, & Burges, 1994) was forced with predicted climate conditions from the Coupled Model Intercomparison Project (CMIP) Phases 3 and 5, commonly known as CMIP3 (Meehl et al., 2007) and CMIP5 (Taylor et al., 2012). In total, USBR produced 209 VIC simulations generated from 112 CMIP3 and 97 CMIP5 model predictions, providing an ensemble of future hydrologic projections.

Next, each of the USBR hydrologic model projections were summarized for the state of Colorado by calculating average runoff and consumptive irrigation requirement (CIR) anomalies between current and future 2050 conditions across each 1/8-degree grid cell of the model domain covering the state. Consumptive irrigation requirement (CIR) is the depth of water required to satisfy the gap between potential and actual evapotranspiration. When plotted on a range-normalized axis, the relationship between runoff and CIR anomalies is approximately linear and represents a gradient of water supply stress conditions (Figure 1, blue points). When runoff is high, CIR is low, and the system is minimally stressed (upper right quadrant of Figure 1). Conversely, when runoff is low, CIR is high, the system is maximally stressed (lower left quadrant of Figure 1).

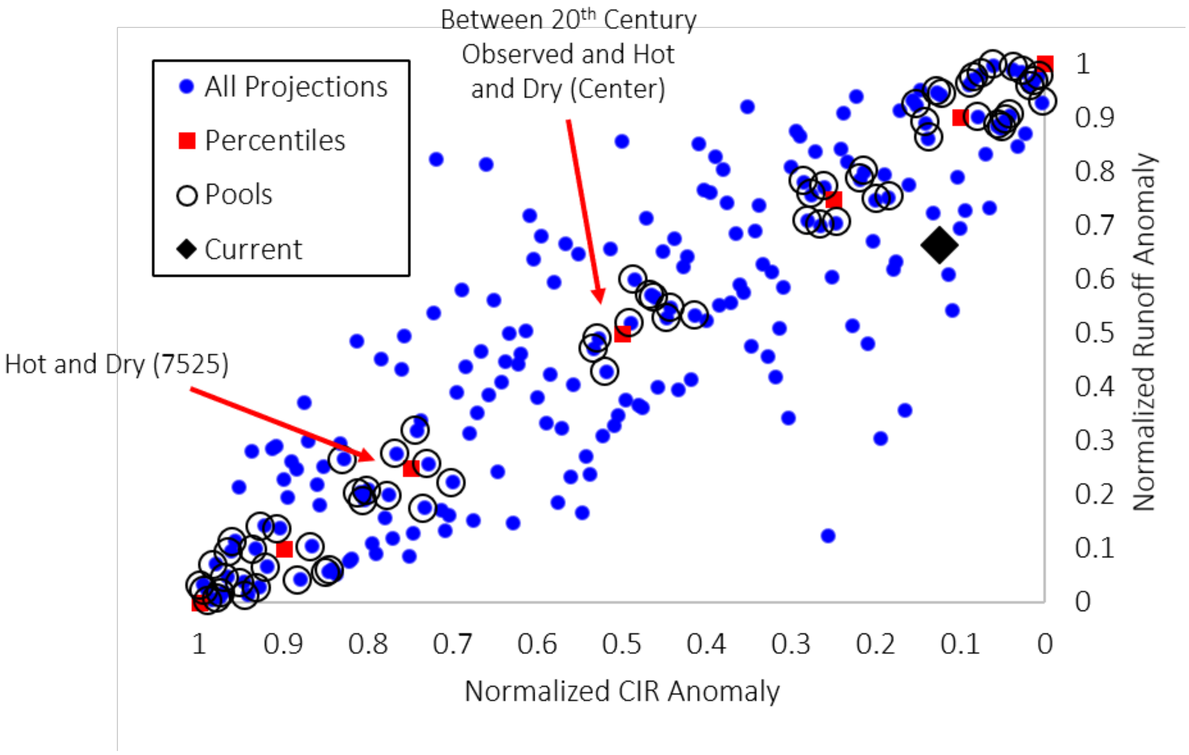

Figure 1. A linear relationship emerges between state-averaged normalized consumptive irrigation requirement (CIR) and normalized runoff anomalies in the 209 VIC projections conducted by the U.S. Bureau of Reclamation (blue points). The point cloud of VIC projections is discretized by seven characteristic points located at select CIR and runoff percentile combinations (red points). A nearest neighbor sampling method is then used create pools associated with characteristic points by identifying the 10 VIC projections nearest each point (black circles identifying blue points).

Because the relationship between runoff and CIR anomaly synthesizes water supply stress, CRWAS-II planning scenarios were defined in the runoff/CIR anomaly space (i.e. Figure 1). The runoff/CIR anomaly space was discretized by seven characteristic points, located at select runoff and CIR percentile combinations (Table 1, Figure 1 red points). A nearest neighbor clustering approach was used to identify the 10 projections nearest each characteristic point, creating seven pools of 10 projections corresponding to each characteristic point (Figure 1 black circles).

Table 2. The cloud of VIC projections in consumptive irrigation requirement (CIR) – runoff space (i.e. Figure 1) was discretized by seven characteristic points located at select runoff and CIR percentiles. This table specifies the location of those points. Additionally, each characteristic point and associated pools of VIC projections are referred to by a common designation, such as "upper right", or "lower left".

Designation	CIR Percentile	Runoff Percentile
Lower Left (ll)	100%	0%
9010	90%	10%
7525 ("Hot and Dry")	75%	25%
Center (c) ("Between 20th Century Observed and Hot and Dry")	50%	50%
2575	25%	75%
1090	10%	90%
Upper Right (ur)	0%	100%

For each projection in a pool, monthly changes in temperature and precipitation were calculated between the simulated baseline condition (1970 – 1999) and the simulated future condition (2035-2054). Monthly changes in temperature are expressed as offsets (future = baseline + offset, units °C) and monthly changes in precipitation are expressed as factors (future = baseline * factor, unitless). Monthly temperature offsets and precipitation change factors were averaged across all 10 projections in each pool, yielding a set of characteristic temperature offsets and precipitation change factors for seven scenarios.

Finally, pool-averaged monthly offsets and change factors were applied to historical daily temperature and precipitation data using a “delta” approach to create a set of seven climate-impacted forcing scenarios, colloquially referred by their designation terminology in Table 1. These scenarios were used to run a separate VIC model for the state of Colorado, and ultimately predict changes in water resources under future climate change conditions. In this technical memorandum, we report pool-averaged monthly temperature offsets and precipitation change factors at three spatial resolutions, 1) state, 2) basin, and 3) HUC10, in order to improve stakeholder understanding of how each scenario is related to specific changes in climate (in terms of temperature and precipitation). Specific emphasis is placed on two key scenarios: “Hot and Dry” and “Between 20th Century Observed and Hot and Dry”.

Section 3: Methodology

Temperature offsets and precipitation change factors for each of the seven planning scenarios, were quantified over three spatial extents of interest; 1) state, 2) basin, and 3) HUC10 (Table 2). Temperature offsets and precipitation change factors are available at every 1/8-degree grid cell of the hydrological model used in CRWAS-II. Using GIS software, we identified model grid cells located within or partially within 1) the Colorado state boundary, 2) the boundaries of 8 major drainage basins within the model domain, and 3) the boundaries all HUC10s within the model domain. Once we identified model grid cells corresponding to each spatial extent of interest, we calculated a weighed spatial average of temperature offsets and precipitation change factors for each month of the year. Spatial averages were weighted by the fraction of a spatial extent of interest accounted for by each model grid cell. Grid cells that partially reside within a spatial extent of interest were given less weight than those residing completely within the boundaries.

Table 3. Descriptions of the spatial extents of interest considered in the analysis.

Spatial Extent of Interest	Description
State	State boundaries of Colorado as defined by a TIGER/Line Shapefile obtained from the U.S. Census Bureau
Basin	8 major drainage basins: South Platte, North Platte, Arkansas, Colorado, Gunnison, San Juan/Dolores, Yampa/White, Rio Grande
HUC 10	575 Hydrologic Unit Code (HUC) 10 watersheds located both completely or partially within the state boundaries of Colorado.

Section 4: Results and Discussion

Monthly average temperature offsets and precipitation change factors over each spatial extent of interest for seven 2050 planning scenarios are provided in an attached file directory, shared via Google Drive (Appendix). At the state-wide level, annual average temperature offsets (arithmetic mean across 12 months) range from 1.6 – 3.0 °C and precipitation change factors range from 0.88 to 1.20 across all scenarios (Table 3). The weighted average precipitation change factors, weighted against mean monthly state-wide precipitation totals, range from 0.86 - 1.19. The hottest scenario is "Lower Left" and the coolest scenario is "1090". The wettest scenario is "Upper Right" and the driest scenario is "Lower Left" (by weighted mean precipitation change factor, Table 3, row 4).

Table 4. State-wide, annual average temperature offsets and precipitation change factors for each of the seven planning scenarios, year 2050. [a]Annual mean precipitation change factors are calculated as an arithmetic mean of monthly change factors. [b]Weighted mean precipitation change factors are calculated as a weighted mean of monthly change factors, where the average monthly precipitation totals across 266 NOAA precipitation gauges throughout the state (Figure 4) are used as weights.

Scenario designation	Annual Mean Temperature Offset (˚C)	Annual Mean Precipitation Change Factor [-][a]	Weighted Mean Precipitation Change Factor [-][b]
Lower Left (ll)	3.0	0.88	0.86
9010	2.8	0.94	0.92
7525 ("Hot and Dry")	**2.3**	**0.99**	**0.97**
Center (c) ("Between 20th Century Observed and Hot and Dry")	**2.0**	**1.05**	**1.02**
2575	2.1	1.08	1.08
1090	1.6	1.11	1.10
Upper Right (ur)	2.2	1.20	1.19

There is a seasonal signal in the magnitude of state-wide average temperature offsets, with most scenarios showing greater offset magnitudes in the late summer and early fall (August and September) (Figure 2). However, temperature offsets for scenarios "1090", "2575" and "upper right" exhibit contradictory annual patterns. State-wide average precipitation change factors exhibit a common seasonal variation across scenarios, with the greatest change factors in the early winter (December and January) (Figure 3). Some months will encounter an increase in precipitation (change factor >1) and others will experience a decrease in precipitation. Most of the scenarios show less spring and summer precipitation, and more winter precipitation (Figure 3).

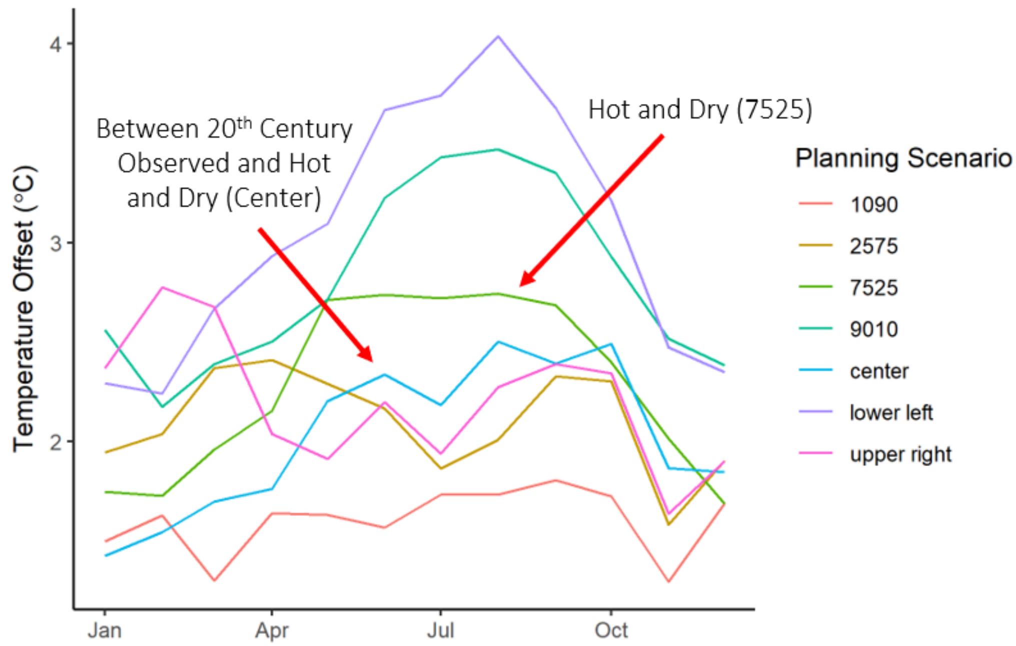

Figure 2. State-wide monthly temperature offsets for seven planning scenarios.

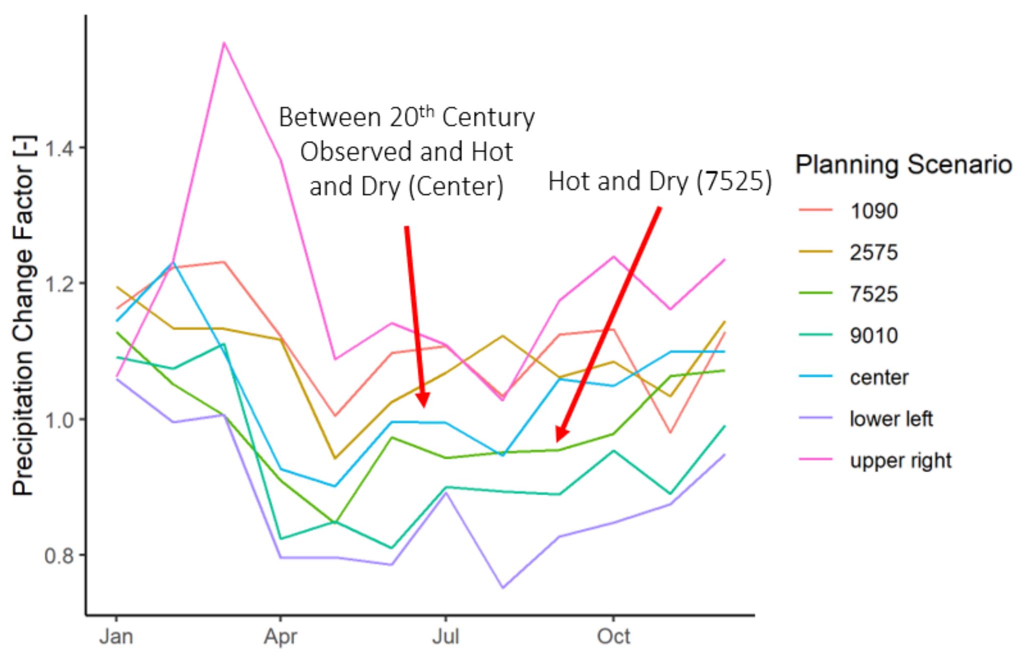

Figure 3. State-wide monthly precipitation change factors for seven planning scenarios.

When interpreting precipitation change factors, it is important to recall that future precipitation is predicted by multiplying monthly change factors by historical monthly precipitation totals. In this sense, precipitation change factors are informative for predicting the direction of change (more or less), but less intuitively describe the magnitude of future change. To understand the magnitude of future precipitation change, one must account for historical monthly precipitation trends (Figure 4). While all scenarios show the greatest change factors during the winter, winter precipitation in Colorado is relatively low, compared to spring, fall and summer (Figure 4). A weighted mean of monthly precipitation change factors, using historical monthly precipitation totals as weights, provides a more holistic summary (Table 3, row 4). Because of the non-uniform distribution of annual precipitation (i.e. some months are wetter/drier than others), caution should be applied when interpreting the arithmetic mean of precipitation change (Table 3, row 3).

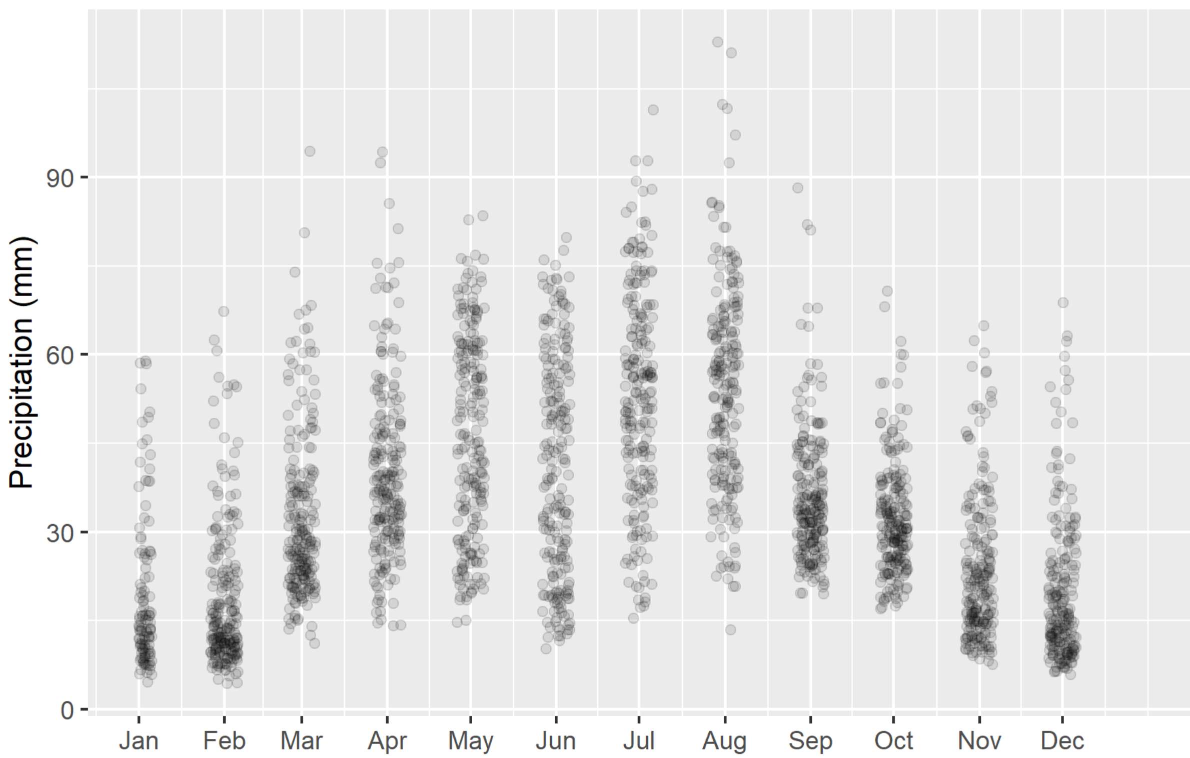

Figure 4. Monthly precipitation normal from 266 NOAA climate stations throughout the state of Colorado. It is critical to account for monthly variation in precipitation totals when interpreting precipitation change factors. Data shown in this plot were obtained from NOAA Climate Data Online (https://www.ncdc.noaa.gov/cdo-web/)

The range of state-wide annual averaged temperature offsets and precipitation change factors implicit in the seven planning scenarios spans the greater distribution of temperature offsets and precipitation change factors associated with the larger ensemble of CMIP 3 and 5 simulations used to force USBR VIC simulations (Figure 5). There is a clear relationship between precipitation change factors and temperature offsets implicit in the seven planning scenarios, where an increase in temperature offset corresponds to a decrease in precipitation change factor. This is a somewhat happenstance result because the seven planning scenarios were identified based on VIC-simulated runoff and CIR, not temperature and precipitation. However, it is intuitive that scenarios with warmer air temperatures and less precipitation would yield less streamflow and higher CIR in VIC model simulations. While the seven planning scenarios do not probe the extremes of the CMIP 3 and 5 future climate distribution, particularly the upper right (hot and wet) and lower left (cool and dry) quadrants of Figure 5, they do intentionally cover the full distribution of VIC-simulated future water supply stress (Figure 1).

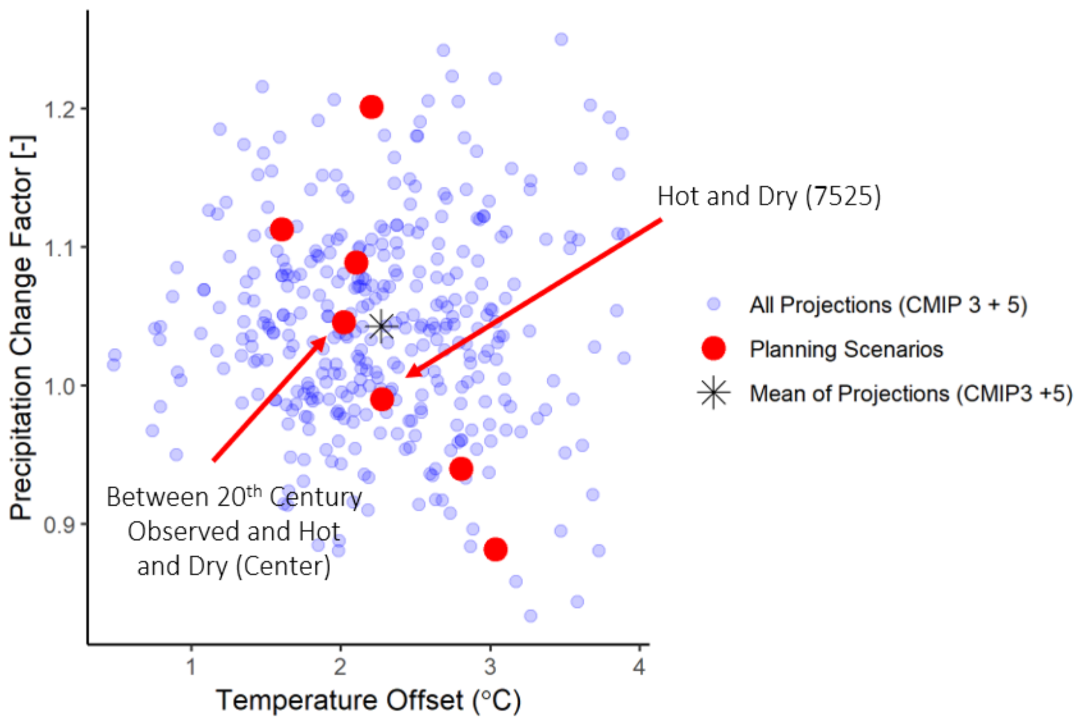

Figure 5. State-wide annual mean precipitation change factors plotted as a function of temperature offsets for all CMIP 3 and 5 model runs used to force the USBR VIC projections (blue points) and the seven planning scenarios identified by CRWAS-II.

Subtle spatial variations in temperature offset are apparent in all seven planning scenarios (Figure 6). Most notably for scenario upper right, annual average temperature offsets are greater for the western part of the state, relative to the eastern part of the state. A more complete visualization of annual-average and monthly temperature offsets at the state, basin, and HUC10 level will be made available through an ArcGIS Online Story Map at: https://arcg.is/1nyzSO.

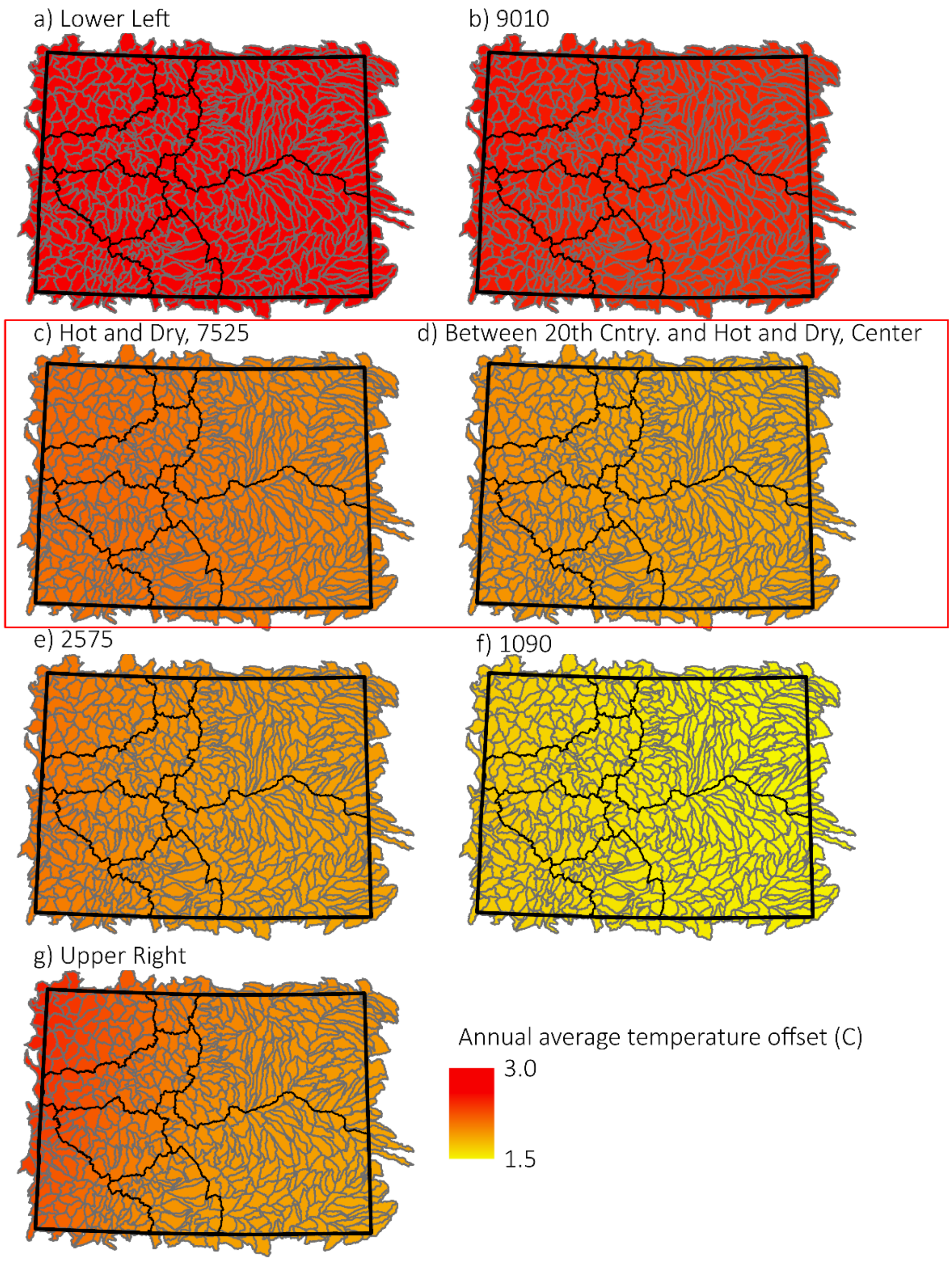

Figure 6. Annual averaged variations in temperature offset at the HUC10 level throughout the state. Each panel (a-g) represents a different planning scenario and the color scale indicates the magnitude of the temperature offset. 8 Major river basins and the state boundaries are traced with solid black lines. The "Hot and Dry" (c) and "Between 20th Century Observed and Hot and Dry" (d) scenarios are highlighted in a red box.

Section 5: Summary

- Seven CRWAS-II planning scenarios were developed to cover a distribution of potential future water supply stress conditions predicted by USBR VIC projections forced by an ensemble of CMIP3 and CMIP5 climate model outputs (Figure 1). Two of these scenarios were embraced by the state as key scenarios: “Hot and Dry” (7525) and “Between 20th Century Observed and Hot and Dry” (Center).
- State-wide, annual-average, temperature offsets implicit in the seven CRWAS-II scenarios range from 1.6 – 3.0 °C (Table 3). **The “Hot and Dry” (7525) scenario corresponds to a 2.3 °C offset, and the “Between 20th Century Observed and Hot and Dry” (Center) scenario corresponds to a 2.1 °C offset.**
- State-wide, annual-average (arithmetic mean), precipitation change factors implicit in the seven CRWAS-II scenarios range from 0.88 to 1.20 (Table 3, row 3). Weighted mean annual precipitation change factors range from 0.86 to 1.19 (Table 3, row 4). **The “Hot and Dry” (7525) scenario corresponds to a precipitation change factor of 0.99 (1% decrease in annual precipitation), and the “Between 20th Century Observed and Hot and Dry” (Center) scenario corresponds to a precipitation change factor of 1.05 (5% increase in annual precipitation).**

Table 5. Summary of temperature and precipitation changes expected for the “Hot and Dry” (7525) and “Between 20th Century and Hot and Dry” (Center) scenarios.

Scenario	Temperature Change	Precipitation Change
Hot and Dry	2.3°C	-1-3%
Between 20th Century Observed and Hot and Dry	2.1°C	+ 2-5%

- Temperature offsets and precipitation change factors for each of the seven CRWAS-II planning scenarios are provided in an attached file directory in .csv format. Results are provided for three spatial extents of interest: state, basin, and HUC10.
- Temperature offsets for each of the seven CRWAS-II planning scenarios are explorable through an ArcGIS Online Story Map, covering three spatial extents of interest: state, basin, and HUC10.

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Taylor, K. E., Stouffer, R. J., Meehl, G. A., Taylor, K. E., Stouffer, R. J., & Meehl, G. A., An Overview of CMIP5 and the Experiment Design, Bulletin of the American Meteorological Society, 93(4), 485–498. https://doi.org/10.1175/BAMS-D-11-00094.1, (2012)

Appendix A: Data Access and Visualization

Analysis result data can be accessed through the following Google Drive link:
https://drive.google.com/drive/folders/1LKcm9SLVRqEvunoY-LpQZJMycrd-Uhhw?usp=sharing

Anyone with the link above can both view and edit the information within the file directory. A brief README file explains where information is stored within the directory and provides meta data necessary to understand and use the data.

Visual exploration of temperature offset results is available through at ArcGIS Online Story Map at:
https://arcg.is/1nyzSO

Letter of Support

STATE OF COLORADO

OFFICE OF THE GOVERNOR
136 State Capitol Building
Denver, Colorado 80203
(303) 866 - 2471
(303) 866 - 2003 fax

John W. Hickenlooper
Governor

November 7, 2017

U.S. Army Corps of Engineers
Colonel John L. Hudson
Commander and District Engineer, Omaha District
1616 Capital Ave, Ste. 9000
Omaha, NE 68102

RE: Northern Integrated Supply Project, *Fish and Wildlife Mitigation and Enhancement Plan*

Dear Colonel Hudson:

Enclosed is the Fish and Wildlife Mitigation and Enhancement Plan for the Northern Integrated Supply Project, recommended by the Colorado Parks and Wildlife Commission and the Colorado Water Conservation Board as the State of Colorado position with regard to mitigation of impacts from this project to these resources.
Under Colorado law (Section 37-60-122.2, C.R.S.), an applicant for any water diversion, delivery, or storage facility, which requires an application for a permit, license, or other approval from the United States must inform the Colorado Parks and Wildlife Commission and the Colorado Water Conservation Board of its application and submit a fish and wildlife mitigation proposal. Once there is agreement on reasonable mitigation actions between the Colorado Parks and Wildlife Commission and the Colorado Water Conservation Board, that agreement becomes the state position on mitigation of impacts to fish and wildlife resources. This state position must then be communicated to each federal, state, or other governmental agency from which the project applicant must obtain a permit, license, or other approval for consideration in these decision-making processes.

This letter is to inform you that the State of Colorado has adopted the enclosed Fish and Wildlife Mitigation and Enhancement Plan for the Northern Integrated Supply Project. This mitigation plan fulfills one of two state processes that must be completed related to water supply projects. The Colorado Department of Public Health and Environment must also complete the Clean Water Act Section 401 Water Quality Certification process. I believe that this mitigation plan maintains a balance between the development of the state's water resources and the protection of the state's fish and wildlife resources. I urge its consideration in the Federal permitting process.

Sincerely,

John Hickenlooper
Governor

Enclosed: Northern Integrated Supply Project Fish and Wildlife Mitigation and Enhancement Plan

CC: John Urbanic, NISP EIS Project Manager, U.S. Army Corps of Engineers, Omaha District

Water Secure Handout

Northern Water and the NISP participants are also exploring various options to keep supplies in the ditch systems and available for these exchanges, to help ensure a **WaterSecure** future for Northern Colorado.

To avoid water permanently leaving farms in the New Cache and Larimer & Weld systems, **Northern Water and the NISP participants are exploring purchases of land and water from willing sellers** in the two systems, as well as looking at various other avenues to keep water on the farms. This will help ensure those supplies remain available for the NISP exchanges.

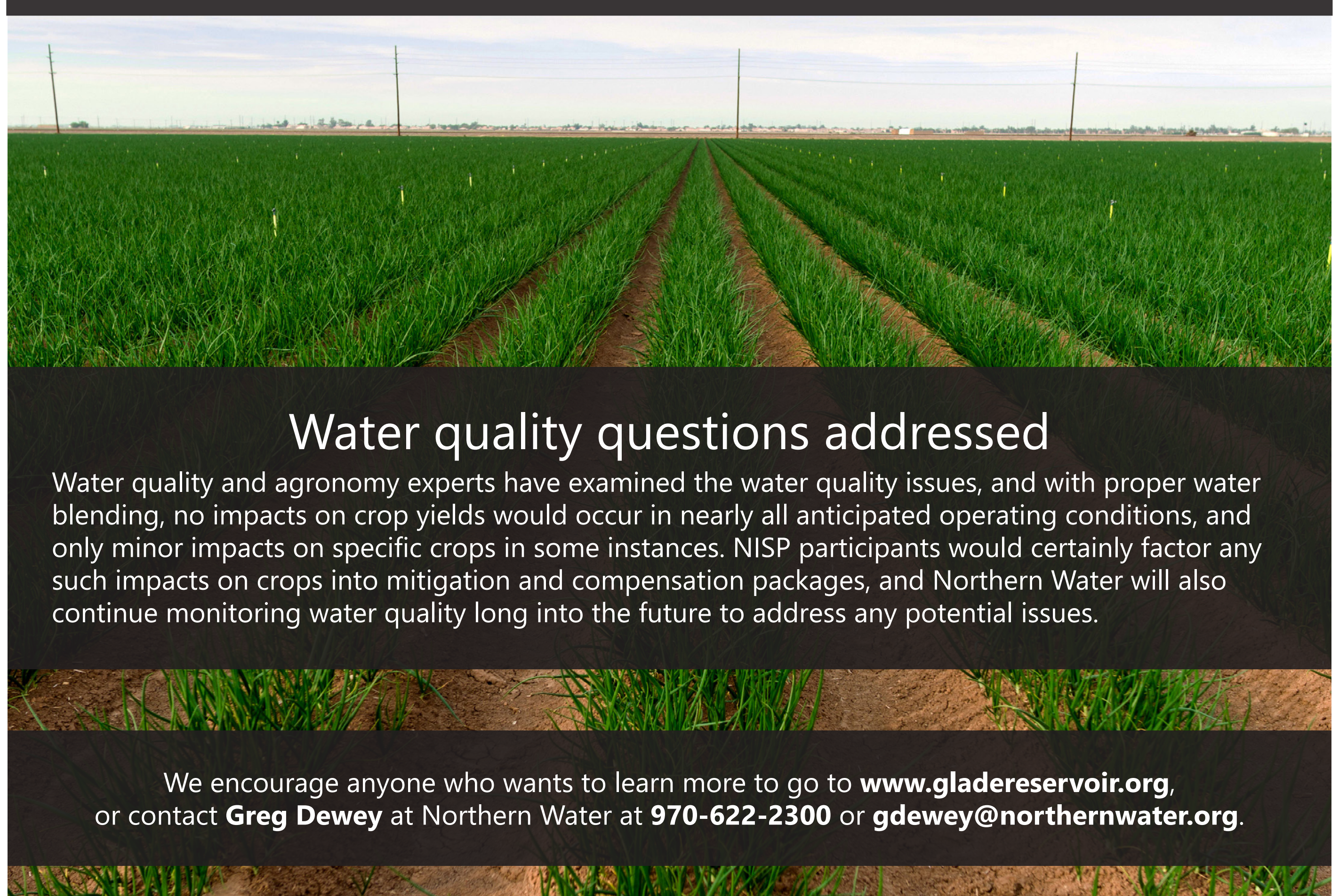
Rather than "buy-and-dry," this is an **outside-the-box, "buy-and-*supply*" approach** to address tightening supplies.

Farms in the New Cache and Larimer & Weld systems purchased by Northern Water and the NISP participants will remain in production through:

- **Limited land-use easements on the property**
- **Lease-back agreements**
- **Other arrangements that will require continued irrigation on those farms**

Furthermore, the purchase of any irrigated lands will be done with the goal to eventually **return the operations to private ownership**.

We are also exploring agreements in which New Cache and Larimer & Weld shareholders could be compensated for giving Northern Water and the NISP participants first priority in buying their land and water assets if they are planning to sell them in the future.



Water quality questions addressed

Water quality and agronomy experts have examined the water quality issues, and with proper water blending, no impacts on crop yields would occur in nearly all anticipated operating conditions, and only minor impacts on specific crops in some instances. NISP participants would certainly factor any such impacts on crops into mitigation and compensation packages, and Northern Water will also continue monitoring water quality long into the future to address any potential issues.

We encourage anyone who wants to learn more to go to **www.gladereservoir.org**, or contact **Greg Dewey** at Northern Water at **970-622-2300** or **gdewey@northernwater.org**.

NISP: Striving to develop a **WaterSecure** future for Northern Colorado's communities and farms

Northern Water
Northern Integrated Supply Project

Collaborating in a shift away from the 'buy-and-dry' approach that has stressed our agriculture communities

As part of a long-term strategy that's consistent with the goals and principles established in the Colorado Water Plan, Northern Water and the NISP participants are working to implement various measures – including a collaborative effort with the New Cache and Larimer & Weld ditch systems – that will provide supplemental water to approximately 500,000 residents in Northern Colorado while also helping preserve tens of thousands of irrigated farm acres.

Without these innovative approaches, the region is on pace to see hundreds of thousands of irrigated acres dried up by mid-century.

NISP at a glance

Once constructed, the **Northern Integrated Supply Project** will consist of:

- **Glade Reservoir** northwest of Fort Collins, which will divert water from the Poudre River
- **Galeton Reservoir** east of Ault, which will store water piped from the South Platte River
- Pipelines, pump plants and other infrastructure needed for operations

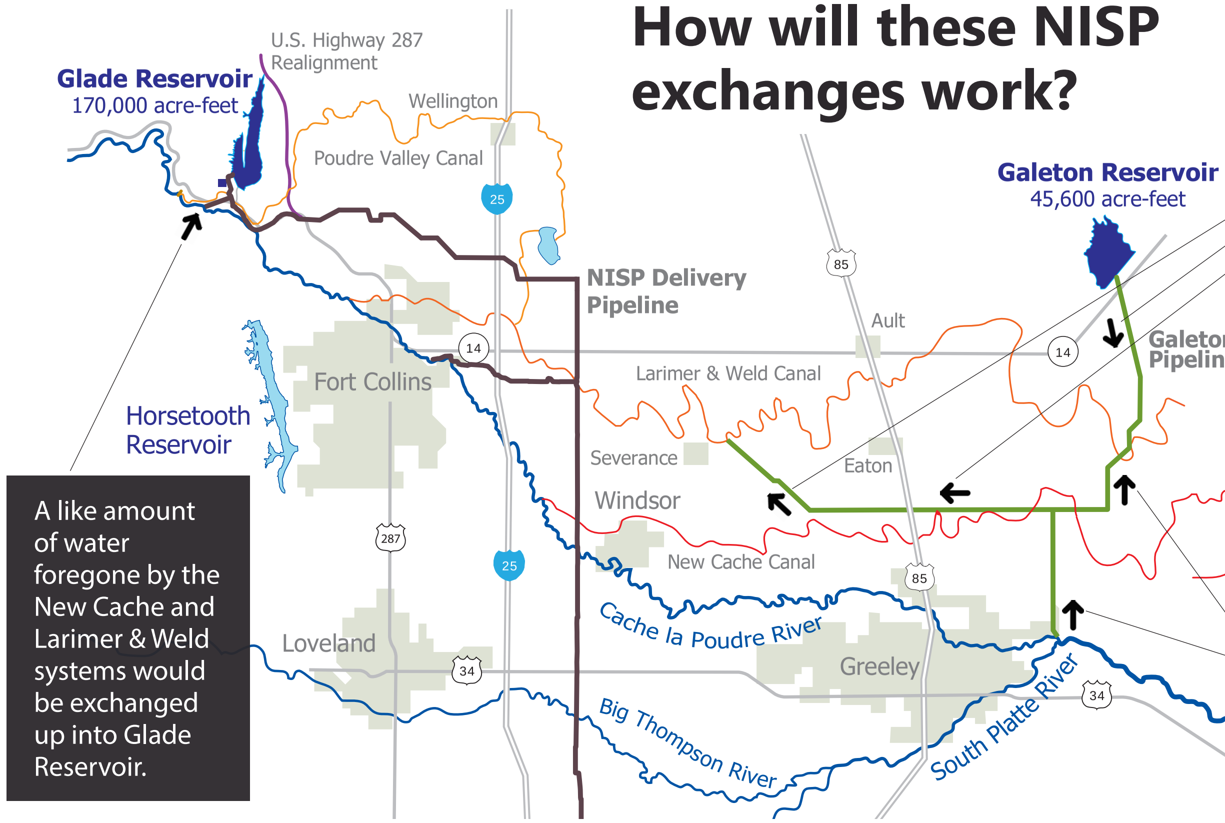
40,000 acre-feet
of additional water will be made available annually for
15 rapidly growing communities and water districts
across northern Colorado

A key component of NISP will be **water substitutions and exchanges,** in which Northern Water and the NISP participants will work with the New Cache and Larimer & Weld ditch systems. NISP will provide new water supplies to the ditch systems in order to allow Glade Reservoir to store water, by exchange, for the communities in need of those supplies.

In return, the NISP participants will provide **compensation for the two participating ditch systems, including:**

- **Monetary payments**
- **Additional water supplies from Galeton Reservoir**
- **Ditch-system improvements**

How will these NISP exchanges work?



A like amount of water foregone by the New Cache and Larimer & Weld systems would be exchanged up into Glade Reservoir.

In addition to filling Galeton Reservoir, a new pipeline system will also deliver Galeton water to the New Cache and Larimer & Weld canals, to compensate the farms in those systems.

Water will be diverted via pipeline from the South Platte River to fill Galeton Reservoir.

The NISP exchanges: A **win-win** for the farms

The NISP water exchanges are designed to be a win-win for the farms in the two ditch systems, in that:

- **Shareholders maintain control of their water, and water will continue flowing to the farms**
- Compensation from the NISP participants will **enhance the long-term viability of those ag operations**
- The ditch systems will receive additional **water later in the growing season**
- These exchanges **will not reduce the value of their water shares**
- These exchanges have been adjudicated and approved by the water court, and **will not subject the two systems' water rights to a change case**

About 25,000 acre-feet would be exchanged annually between the ditch companies and NISP participants.

This is NOT an alternative transfer method, or ATM, as they're often called. **Farms participating in the NISP exchanges will receive water each and every year**.

With this arrangement, the New Cache and Larimer & Weld shareholders **could receive more water for irrigation than they currently receive**.

NISP is expected to receive its Record of Decision from the Army Corps of Engineers in 2020, and following final design and construction, **the exchanges could be operational by about 2027**.

Furthermore, **without NISP**, the communities participating in the project will most likely be left to purchase more water from existing farms and ranches – needing to **dry up over 64,000 acres** of irrigated farmground to attain the amount of water that NISP would provide.

The approximately 90,000 irrigated acres under the New Cache and Larimer & Weld systems are estimated to provide **more than $300 million in agricultural production annually.**

All of northern Colorado will benefit from keeping more irrigated acres in production. Our agriculture industry employs thousands of local residents and feeds even more, while our farms and ranches also offer quality-of-life and environmental enhancements with open space and wildlife habitat – all of which Northern Water and the NISP participants want to preserve for future generations.

287 Relocation Memo

Montaño • Freeman • Sinor • Thompson P.C.

1120 Lincoln Street • Suite 1600
Denver, Colorado 80203-2141
303.861.1963
www.troutlaw.com

To: Larimer County Attorney and Board of County Commissioners
From: Peggy E. Montano and Anne E. Sibree for Trout Raley
Re: Highway 287 under Larimer County 1041 Regulations
Date: September 1, 2020

The plain language of the Larimer County regulations along with the statutory scheme governing those regulations make it clear that Highway 287 relocation does not require a 1041 permit.

The County's regulations designate the "[s]ite selection and construction of a new water storage reservoir" as an activity of state interest requiring a 1041 permit. § 14.4.K., Larimer County Land Use Code. A water storage reservoir includes "all appurtenant uses, structures and facilities, roads, parks, parking, trails and other uses which are developed as part of the water storage reservoir." *Id.* In construing this phrase to determine whether the relocation of Highway 287 falls within its purview, "we look to the entire statutory scheme in order to give consistent, harmonious, and sensible effect to all of its parts, and we apply words and phrases in accordance with their plain and ordinary meanings." *Oakwood Holdings, LLC v. Mtg. Inv's Ent. LLC*, 410 P.3d 1249, 1252 (Colo. 2018).

Plain meaning

Given the plain meaning of the County's regulation, Highway 287 relocation does not qualify as an "appurtenant use" or "road" of Glade Reservoir. The adjective "appurtenant" modifies both "uses" and "roads" in this phrase. *See* Antonin Scalia & Bryan A. Garner, *Reading Law: The Interpretation of Legal Texts*, 147 (2012) ("When there is a straightforward, parallel construction that involves all nouns or verbs in a series, a prepositive or postpositive modifier normally applies to the entire series."). Neither "appurtenant" nor "appurtenance" is defined in the Areas and Activities of State Interest Act (the Act), Larimer County's 1041 regulations, or in other county land use statutes. But in legal parlance, "appurtenant" means "annexed to a more important thing" and an "appurtenance" is "something that belongs or is attached to something else." *See* Black's Law Dictionary 98 (7th ed. 1999).

An "appurtenant use" under this phrase refers to the secondary or tertiary benefits derived from a reservoir's construction. This follows from the meaning of "use" as "the privilege or benefits of using" something, *see Use*, Webster's Online Dictionary, coupled with the modifier, "appurtenant." *See, e.g., Kane v. Martel*, 103 N.E.3d 765 (Ma. App. 2018) (describing beach access as an "appurtenant use" of a lot ownership in a seaside community). For example, if Glade Reservoir's primary *use* is water storage and supply, an appurtenant use might be recreational use of the reservoir.

Likewise, an "appurtenant road," is not any roadway, but only that class of roadways subordinated to, and used for the benefit of, a single-other dominant purpose. *Compare Zweygardt v. Bd of Cty. Com'rs of Elbert Cty.*, 190 P.3d 848, 850 (Colo. App. 2008) (describing a road, which "provides the only method for general ingress to and egress from" a parcel as a "road appurtenant to" that parcel) *with Petition of Palumbo*, 225 N.Y.S.2d 98 (N.Y. 1962) (holding that a public street was not an "appurtenance" to abutting real property); *see also* § 34-20-102, C.R.S. (defining a "mine" for purposes of Colorado's Mine Safety Statutes to include "[p]rivate ways and roads appurtenant to such area").

Here, Highway 287 relocation could not be fairly characterized as an "appurtenant use" of Glade Reservoir. The relocation is a one-time consequence of the reservoir's construction, not an ongoing benefit provided by it. Though Glade Reservoir will be "used" for recreation, for example, it will not be "used" to relocate Highway 287—rather the highway is an impediment to Glade's development.

Nor is Highway 287 an "appurtenant road" of Glade Reservoir. This segment of Highway 287 is a U.S. Highway, has been in existence since 1935, is maintained by the Colorado Department of Transportation, and serves as a major north-south thoroughfare between Denver and Wyoming—connecting many communities and serving many purposes. As such, Highway 287 is not subordinate to, or used for the sole-benefit of, Glade Reservoir.

To the extent there is any ambiguity in the meaning of "appurtenant use" or "appurtenant road," the last term in this same phrase supplies additional meaning. *See Young v. Brighton School Dist 27J*, 325 P.3d 571, 578 (Colo. 2014) (under the *noscitur a sociis* construction canon, "a word may be known by the company it keeps"); *see also* Scalia & Garner, *supra*, at 196. The last term includes "other uses which are developed as part of the water storage reservoir." Therefore an appurtenant use or road are those "developed" as part of Glade Reservoir's construction. Highway 287 is not being "developed" to serve Glade Reservoir; to the contrary: it has long existed and stands as an impediment to Glade's construction and therefore must be re-aligned.

As a final consideration, although the County's land use code does not define "appurtenant" or "appurtenant road" it does define "major road system" and "regional road system" as used in other sections of the code. *See* § 0.1.1, Larimer County Land Use Code. The "major road system" is all the county-maintained arterial (thruway) roads in Larimer County and the "regional road system" is all the roadways identified by participating local governments as "major inter-urban travel corridors or as major corridors that connect urban areas to the interstate highway system" as shown in Exhibit A attached to the County's regulations. *See id.* That map shows Highway 287 as part of the regional road system. Borrowing from these definitions, it would seem an "appurtenant road" would, in the least, exclude such a "regional" road as Highway 287.

Statutory scheme

The statutory scheme governing county 1041 regulations also compels the conclusion that Highway 287 relocation is not governed by the County's 1041 regulations.

The Act outlines categories of activities that a county may designate and regulate. In addition to "municipal and industrial water projects," the Act lists site selection of "arterial highways" as a separate and distinct activity of state interest. *See* § 24-65.1-203, C.R.S. Under the Act, it is entirely within the county's discretion whether to designate an activity from the statutory list.[1] *See id.* And once a county choses to so designate, the Act requires the county to explain why it has designated a certain activity one of state interest and provide public notice and a hearing finalizing the designation. *See* § 24-65.1-401 C.R.S.

Here, the County has not designated "arterial highways" an activity of state interest, and Highway 287 clearly falls within that definition. *See Arterial*, Webster's Online Dictionary ("A through street or highway").

[1] In fact, the legislative history of the Act is replete with discussions from the bill's sponsors emphasizing that a county has not obligation to designate an activity from the statutory list. This was critical to garner support for the bill from Colorado's rural counties, which feared the bill would otherwise impose burdensome demands on county resources spent on the designation and regulation processes.