APPENDIX B

Other Technical Reports

Thornton Water Project

Douglas Road Dual Water Pipeline Construction Sequence and Schedule

PREPARED FOR:	City of Thornton
COPY TO:	File
PREPARED BY:	CH2M HILL
DATE:	October 29, 2018

General

This technical memorandum (TM) presents a proposed construction sequence and schedule to construct dual water pipelines within Douglas Road from Shields Street to Turnberry Drive in Larimer County. One water pipeline is for the Thornton Water Project (TWP) for the City of Thornton (Thornton) and the other is the Northern Tier Pipeline for the Northern Integrated Supply Project for Northern Water (Northern). The TWP Water Pipeline is proposed to enter the Douglas Road right-of way near Bayshore Drive and the Northern Tier Pipeline is proposed to enter the Douglas Road right-of-way at Shields Street, as depicted in **Figure 1**.

Thornton and Northern coordinated separation requirements for the proposed water pipelines as presented in a TM titled *Pipeline Separation Requirements,* dated October 23, 2018 (attached). The pipeline separation TM summarizes evaluation of construction within common and separate trenches and concluded that the water pipelines would be separated by 25-feet and constructed in separate trenches, with staggered construction headings.

Conclusion/Recommendation

Using the proposed separation requirements, the TWP and NISP Northern Tier water pipelines can be concurrently constructed within Douglas Road, but it will require almost four (4) years to construct using sequential road closures between access locations plus numerous utility relocations/replacements. Both Thornton and Northern conclude that while technically possible, it is not practical to concurrently construct both water pipelines in Douglas Road and recommend that placement of both water pipelines in Douglas Road be avoided.

Construction Sequence

The major construction sequences for construction of the dual water pipelines are:

- Relocation/Replacement of existing utilities within Douglas Road to create a wide enough corridor to accommodate the two construction headings;
- Sequential construction of the dual water pipelines, including surface restoration, between existing roadway accesses (driveways, private drives, and other intersecting roadways) through rolling road closures

Thornton WATER PROJECT

CITY OF THORNTON
COLORADO
12450 WASHINGTON ST
THORNTON, CO 80241-2405

10/26/2018

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1 inch = 1,650 feet

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TWP Alignment
NISP Alignment
River/Stream/Canal/Ditch
Parcel Boundary

Figure 1
Douglas Road Alignment
Thornton Water Project

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Utility Relocations

There are a number of utilities within Douglas Road, including two (2) East Larimer County Water District water lines, gas, electric, and telephone lines. In general, there is a corridor available within Douglas Road for construction of one additional, water pipeline. Thornton, in its supplemental information submitted to Larimer County, demonstrated that its Thornton Water Project Water Pipeline could be constructed within this corridor following relocation of a portion of the gas line in Douglas Road. Concurrent construction of NISP's Northern Tier Pipeline within Douglas Road will require additional utility relocations/replacement.

To create a construction corridor wide enough to accommodate the TWP and NISP Northern Tier water pipelines requires relocation of more gas line and most of one or the other of the ELCO water lines. ELCO has long-term plans to construct a new water line in Douglas Road to replace their existing lines. This new line is proposed to be from 16-inch to 20-inch. For the purposes of this memorandum, it is assumed that the location of the dry utilities (gas, electric and telephone) will need to be consolidated to one side of the right-of-way and the proposed ELCO line constructed on the other side of the right-of-way. These utility relocations would need to occur before construction of the TWP and NISP water pipelines and existing utilities would need to stay in service while the replacement utilities are constructed. Once replacement utilities are constructed services would be switched from the old to the new. The replacement utilities and service reconnection will need to be phased and constructed in a sequential manner, mostly outside of paved areas. It is estimated that construction of these replacement utilities will take between 12 to 18 months.

Dual Water Pipeline Construction Sequence

General

As summarized in the Pipeline Separation Requirements TM, road closures between access points are required to construct the two (2) water pipelines. Segments of Douglas Road will be closed to through traffic between road closure barricades at each end of the road closure until that portion of the dual water pipeline is constructed and the surface is restored. Road closures between existing roadway accesses are proposed to allow uninterrupted access to properties outside the closed segment of road; however, properties west of a closure will only be able to use Douglas Road to travel west, properties east of a closure will only be able to use Douglas Road to travel east, and through traffic will be prohibited. Road closed to through traffic, local access only signs will be posted at the intersections with major north/south roadways and these intersections will have flaggers to allow local traffic to enter. For example, if a road closure segment was in place between Shields Street and Highway 1, then road closed to through traffic, local access only signs will be located at Douglas Road at Shields Street and Highway 1. Local traffic will be allowed to travel the non-closed portion of Douglas Road from Shields Street to access their property that is west of the closed segment and local traffic will be able to access their property that is east of the closed segment from Highway 1. Similar configurations will exist for road closures between Highway 1 and LCR 13 and LCR 13 and Turnberry Road.

Well in advance of construction, property owners and residents within the area will be provided the sequence of road closures with proposed dates that a roadway segment will be closed. Broader communications will be made to a larger audience via media and web applications to communicate closure schedules with suggested alternative routes to avoid the segment of Douglas Road that is closed. Signage in advance of closures will be placed at intersections of Douglas Road with Shields Street, Highway 1, LCR 13 and Turnberry Road.

Accesses

Douglas Road has a number of access points as presented in Table 1. Based on the field survey of Douglas Road and review of aerial imaging via GoogleEarth, the accesses have been grouped into common types. The types, their description and proposed construction impacts are as follow:

Single driveway access for one vehicle: This access is a typical driveway connection for a single property and allows a single vehicle to access the subject property in one direction, either turning onto Douglas Road or turning off of Douglas Road (two-way traffic is not possible). Width varies with some driveways wider than others. The driveway typically widens as it connects to Douglas Road. Access to properties with a single driveway access during dual water pipeline construction will be made by construction of a temporary driveway access during a road closure leading to that property. This will allow the single driveway access to be closed when that access is in the next road closure segment and property will be accessed through the temporary driveway access. Following construction, the temporary access will be removed and land disturbance restored and the permanent access will be re-established at pre-construction or better condition. Project participants will pay affected property owners for temporary construction easements to construct and remove the temporary accesses.

Some properties have more than one driveway and one driveway will be closed with the other open during construction of the water pipelines to allow continuous access.

Private Drive access for two-way traffic: This access is a connection to Douglas Road that allows two-way traffic, i.e., a single vehicle turning off of Douglas Road and a single vehicle turning onto Douglas Road. There are three subgroups for these private drives:

1. those that only connect to Douglas Road at one location that still allow access, if lanes are alternatively closed during construction of water pipelines across alternating halves of the access and flaggers are used to control one-way traffic through the access until two-way traffic is restored;
2. those that connect to Douglas Road at more than one location that still allow access, if accesses are alternately closed during construction; and
3. those that connect to another roadway that still allow access to the roadway network, if the Douglas Road access is closed during construction.

Width of these private drive connections to Douglas Road varies, but two vehicles can pass each other through the access.

Construction Sections/Closure Segments

Table 1 presents a summary of the proposed closure segments between accesses organized by the three (3) sections of Douglas Road between major, north-south through roads (Shields Street, Highway 1, LCR 13 and Turnberry Road).

As indicated in Table 1, there are 47 separate closure segments ranging in length from 60 feet to 760 feet with an average of 283 feet. The large number of closures results from the large number of driveways accessing Douglas Road.

Table 1. Construction Sections/Closure Segments

Section	Segment Number	Name	Length (Feet)
Shields to highway 1	1	Bayshore Drive (East) to Kintzley Driveway (West)	760
	2	Kintzley Driveway to Swan Lane (Middle)/Nance Driveway (West)	465
	3	Swan Lane (Middle)/Nance Driveway to The Point Townhomes (Middle)/Messick and Didier Driveway (West)	500
	4	The Point Townhomes (Middle)/Messick and Didier Driveway to Antler LLC Driveway (West)	175
	5	Antler LLC Driveway to East Access to Terry Cove Mobile Home Park (West)	400
	6	East Access to Terry Cove Mobile Home Park to Carns Driveway (West)	345
	7	Carns Driveway to S Bar G Lane (Middle)	185
	8	S Bar G Lane (Middle) to Harbor Way (Middle)	190
	9	Harbor Way (Middle) to Vigil Driveway (West)	120
	10	Vigil Driveway to O'Connell Driveway (West)	175
	11	O'Connell Driveway to Valerius/Ekblad East Driveway (West)	150
	12	Valerius/Ekblad East Driveway to Kidd East Driveway (West)	160
	13	Kidd East Driveway to La Mesa Drive (Middle)	80
	14	La Mesa Drive (Middle) to Schmer Driveway (West)	225
	15	Schmer Driveway to Highway 1 (West)	205
	16	Highway 1 Crossing	100
Highway 1 to LCR 13	17	Highway 1 (East) to east McCulloch Driveway (West)	165
	18	East McCulloch Driveway (West) to West Sheaman Driveway (West)	420
	19	West Sheaman Driveway (West) to Clyde St (West)	190
	20	Clyde St (West) to Camille Driveway (West)	590
	21	Camille Driveway (West) to Kenyon Drive (West)	685
	22	Kenyon Dr (West) to Corliss Driveway (West)	190
	23	Corliss Driveway (West) to Goldgor Driveway (West)	330
	24	Goldgor Driveway (West) to MacMillan and Butler Driveways (West)	185
	25	MacMillan and Butler Driveways (West) to Rickard Driveway (West)	260
	26	Rickard Driveway (West) to McAlpine Driveway (West)	380

Table 1. Construction Sections/Closure Segments

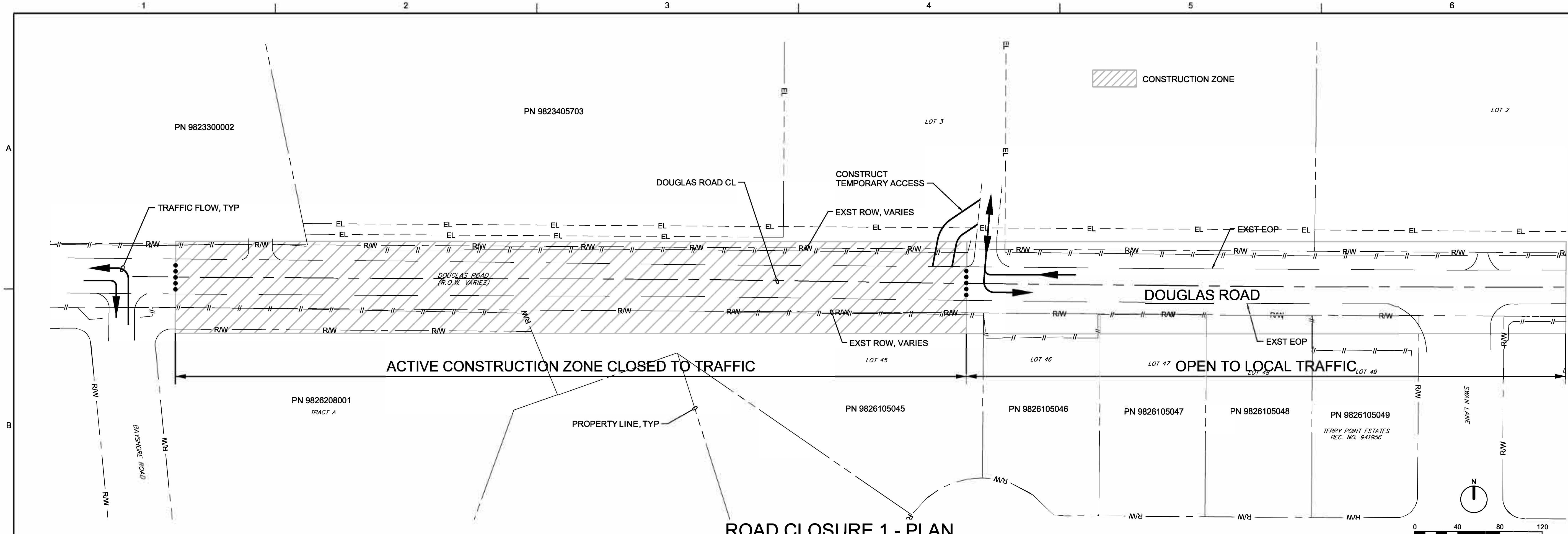
Section	Segment Number	Name	Length (Feet)
	27	Fear Driveway (West) to Wittreich Driveway (West)	80
	28	Wittreich Driveway (West) to Keaton Driveway (West)	150
	29	Keaton Driveway (West) to LCR 13 (West)	550
	30	LCR 13 Crossing	100
	31	LCR 13 (East) to Jewett Driveway (West)	460
	32	Jewett Driveway (West) to Kesel Driveway (West)	150
	33	Kesel Driveway (West) to Hearthfire Way (Middle)	510
	34	Hearthfire Way (Middle) to Schirber East Driveway (West)	200
	35	Schirber East Driveway (West) to Jan Driveway (West)	130
	36	Jan Driveway (West) to Kontz Driveway (West)	400
	37	Kontz Driveway (West) to Juanita Lane (West)	110
	38	Juanita Lane Crossing	60
LCR 13 to Turnberry	39	Juanita Lane (East) to Davies East Driveway (West)	260
	40	Davies East Driveway (West) to Crystal Cove Well Access (West)	130
	41	Crystal Cove Well Access (West) to Chavez Access (Middle)	110
	42	Chavez Access (Middle) to Davies Driveway (West)	660
	43	Davies Driveway (West) to Rau Driveway (West)	120
	44	Rau Driveway (West) to Twilight Lane (West)	440
	45	Twilight Lane (West) to Crystal Cove Driveway (West)	390
	46	Crystal Cove Driveway (West) to 1950 E Douglas Driveway (West)	70
	47	1950 E Douglas Driveway (West) to Turnberry Rd (West)	610

Representative Construction Sequence

A representative construction sequence for the rolling road closure concept is depicted in **Figure 2** for the first two (2) closure segments starting just east of Bayshore Drive and extending to Swan Lane. A narrative of the proposed construction sequence for this area is as follows:

Closure 1--Bayshore Drive (East) to Kintzley Driveway (West)

The roadway between the east side of Bayshore Drive and the west side of the Kintzley driveway will be closed and the dual water pipeline constructed via two separate, staggered trench headings. Residents living In Terry Acres will have continuous access via Douglas Road to the west of the closure. Residents of the Kintzley property will have continuous access through their driveway to Douglas Road to the east of the closure. Approximately 760 feet of dual pipe will be constructed and



ROAD CLOSURE 1 - PLAN

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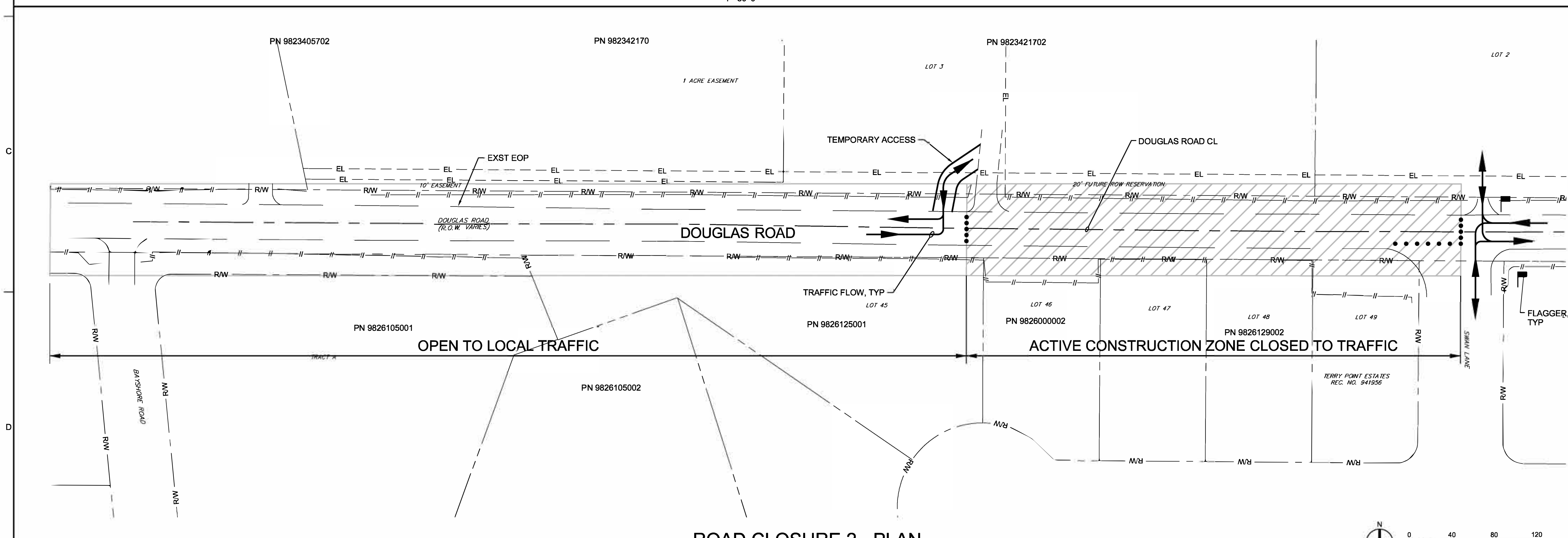

ROAD CLOSURE 2 - PLAN

1"=50'-0"

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DSGN		DR	CHK	APVD

THORNTON WATER PROJECT
CITY OF THORNTON
THORNTON, CO

EXAMPLE ROLLING ROAD CLOSURE

VERIFY SCALE

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west of the existing Kintzley driveway for their use when the road closure moves east to the next segment of construction.

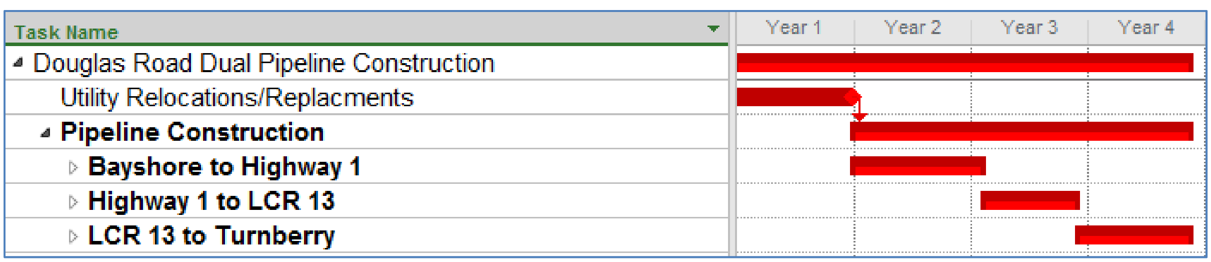
Closure 2--Kintzley Driveway to Swan Lane (Middle)/Nance Driveway (West)

The roadway between Kintzley driveway and the middle of Swan Lane on the south and the west side of the Nance driveway on the north will be closed and the dual water pipeline constructed. Residents of the Kintzley property will use the temporary driveway constructed in the previous construction segment to have continuous access to Douglas Road to the west of the closure. Residents of Terry Point will have one-way access to Douglas Road to the east of the closure via the northbound lane of Swan Lane, which will have flaggers regulating access to and from Swan Lane. Residents of the Nance property will have continuous access to Douglas Road to the east via their existing driveway. Approximately 465 feet of dual pipe will be constructed and the area restored following water pipeline construction. A temporary driveway access will be constructed just west of the existing Nance driveway for their use when the road closure moves east to the next segment of construction.

Construction Schedule

Using the representative construction sequence and applying it sequentially from west to east, a construction schedule was prepared and is presented in **Figure 3**. The dual water pipeline construction is estimated to take almost four (4) years to construct, including utility relocations/replacements before water pipeline construction begins. Each of the sections of Douglas Road between major north-south through roads will each take approximately one (1) year to construct.

Figure 3. Estimated Construction Schedule.



Appendix 1—Technical Memorandum Pipeline Separation Requirements, dated October 23, 2018

Thornton Water Project Pipeline Separation Requirements

PREPARED FOR:	City of Thornton
COPY TO:	File
PREPARED BY:	CH2M HILL
DATE:	October 23, 2018

General

This technical memorandum (TM) summarizes separation requirements for construction of the Thornton Water Project (TWP) by the City of Thornton and the Northern Integrated Supply Project (NISP) Northern Tier Pipeline by Northern Water (Northern) in Larimer County, north of Fort Collins. Both the TWP and NISP have proposed water pipelines within an area approximately bordered on the north by Highway 1 and on the south by Douglas Road. The preferred location for the TWP water pipeline as presented in Thornton's 1041 permit application is in Douglas Road. The 1041 permit application also included other reasonable alternative locations, including Larimer County Road 56 (LCR 56). The preferred location for the NISP North Pipeline as presented in its NEPA FEIS is along LCR 56, but also includes an alternative location in Douglas Road.

Larimer County, in an effort to minimize impacts from both projects, has requested separation requirements between the water pipelines should they both be approved to be located in the same corridor, either Douglas Road right-of-way or LCR 56 (right-of-way or adjacent to right-of way). The TWP pipeline is planned to be a 48-inch welded steel pipe (WSP), and the NISP water pipeline is planned to be a 54-inch WSP.

Recommendation

After consultation with Northern and evaluating considerations for considering placing the pipes in a common trench or in separate trenches, the recommended configuration is for the pipes to be in constructed in separate trenches with a 25-foot center-to-center separation as depicted in **Figure 1**, regardless of corridor location.

Analysis of Alternatives

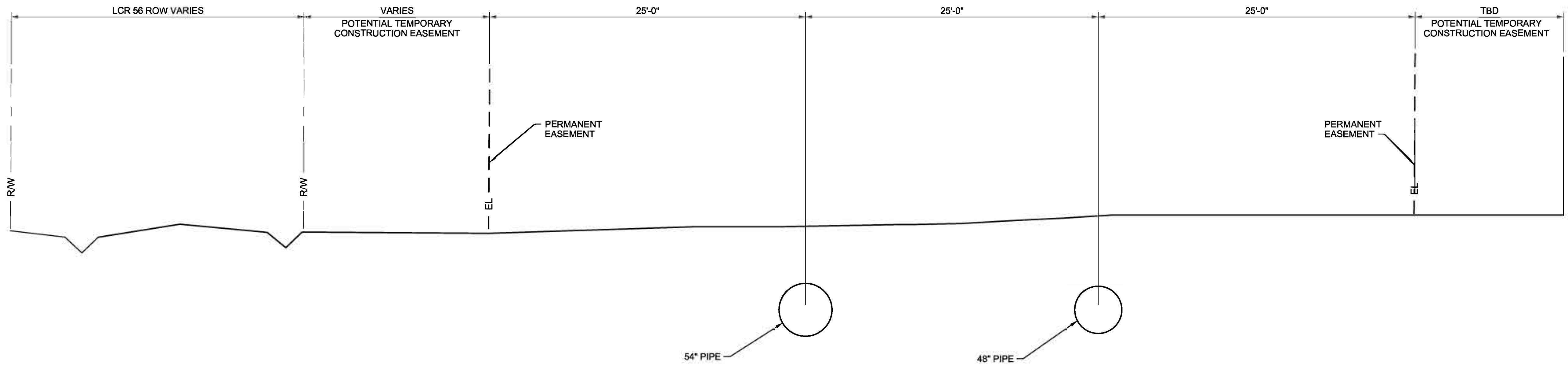
The determination of the dual pipe configuration and separation between the TWP and NISP water pipelines is based on evaluating and considering the following alternatives:

- Pipes in a Common Trench
- Pipes in Separate Trenches

Common Trench

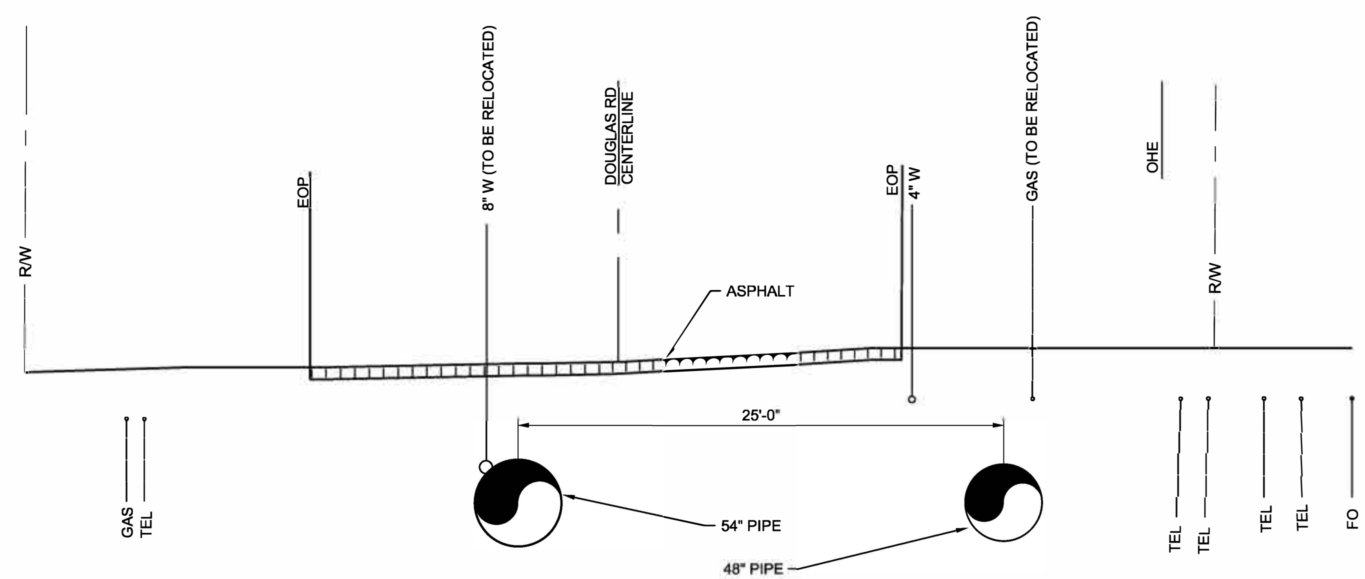
Minimum Separation

In this alternative, a single trench is excavated to a width sufficient to accommodate installation and maintenance of both water pipelines at the same time. Consideration must be given to support of the pipes, space for installation and welding, and future excavation for repairs or maintenance. For



TYPICAL SECTION BOTH PIPES OUTSIDE OF ROW

1"=5'-0"



TYPICAL SECTION BOTH PIPES INSIDE ROW

1"=5'-0"

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THORNTON WATER PROJECT
CITY OF THORNTON
THORNTON, CO

FIGURE 1
RECOMMENDED SEPARATION CROSS SECTIONS

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most soils and bedding conditions, the pipes can be installed in close proximity, so the controlling separation factor is the space between the water pipelines to allow for safe installation and for access to the water pipeline for repair in the future. Through discussions, Thornton and Northern concluded that the minimum clear space between parallel water pipelines is 7 feet to allow for excavation between the water pipelines if one of the water pipelines needs to be excavated for repair. Based on this separation, the total trench width, assuming use of shoring is approximately 21 feet.

Construction

Excavation of a single common trench (see **Figure 2**), 21 feet in width and 9.5 feet deep (assuming 4 feet of cover and 1 foot of bedding material under the pipes) produces about 200 cubic feet (7.4 cubic yards) of soil per foot of trench. Assuming the excavated material can hold a 1:1 slope, and is placed 2 feet from the trench, an additional 30 feet in width is required for stockpile of excavated material, for a combined width of 51 feet. For construction in Douglas Road with a right-of-way of 60 feet in most areas, this leaves 9 feet of ROW remaining, which is insufficient for maintenance of traffic, including construction vehicles around the trench excavation; however, the stringing of pipe along this side of the trench is possible. Road closures between accesses along Douglas Road will be required and excavated material will need to be hauled to and from a stockpile area to provide space for construction vehicles around the trench. Similar road closure for construction within LCR 56 would be required, but most of the land adjacent to LCR 56 is undeveloped and temporary construction easements could be obtained to stockpile excavated material, string pipe and provide access for construction vehicles around the active trenching/pipe installation area. For construction outside of LCR 56 right of way, a single common trench is not recommended as most lands adjacent to LCR 56 are undeveloped, large lots and Thornton and Northern would purchase permanent and temporary construction easements from those property owners. The use of a common trench requires that both water pipelines be constructed at the same time, which is not required by the County when outside of County rights-of-way.

Separate Trenches

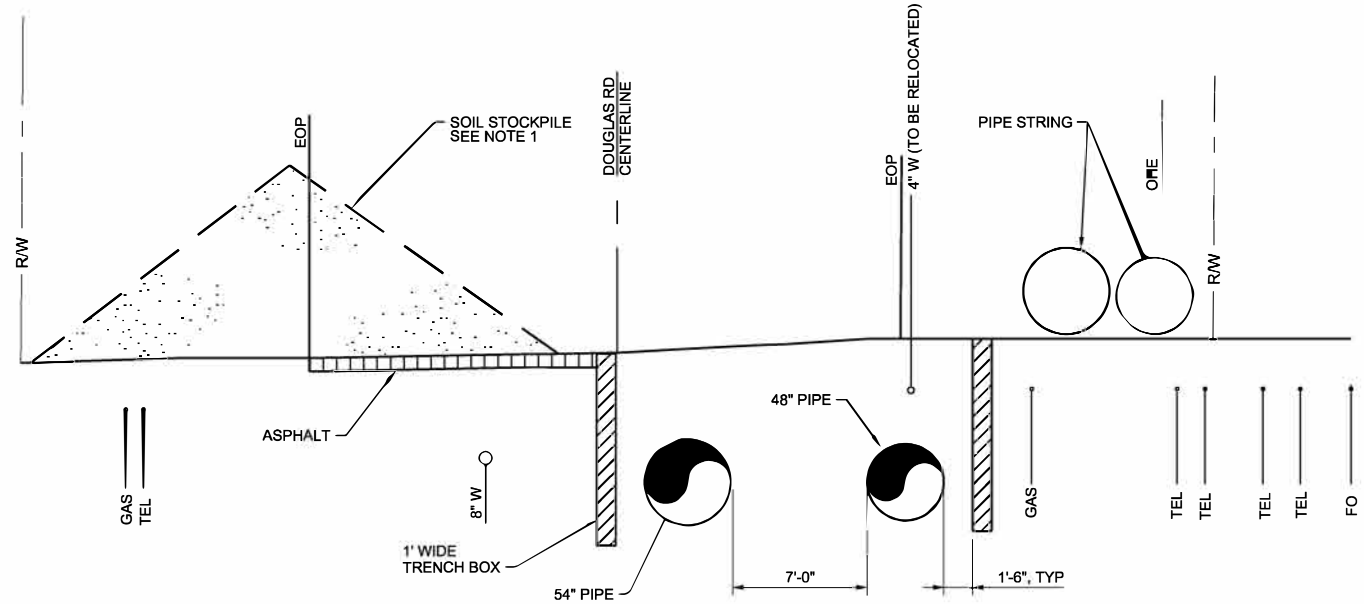
Minimum Separation

In this alternative, each pipe is installed in its own trench. Construction of both water pipelines could occur at the same time, but would require that the headings for each water pipeline be staggered, one ahead of the other. Alternatively, one water pipeline could be constructed first and the other constructed at a different time. For separate trenches, the trenches must be spaced to maintain an undisturbed soil wall between the trenches that provides the required side support for flexible pipe such as WSP. The general rule of thumb for undisturbed soil width is approximately 4 times the larger pipe diameter, or 18 feet. Through discussions, Thornton and Northern concluded that a minimum center-to-center spacing of 25 feet would provide a reasonable prism of undisturbed soil between the parallel pipe trenches after allowances for individual trench widths and possible trench shoring. Based on this separation, the minimum single trench width within a roadway (assuming use of shoring), is approximately 9 to 9.5 feet for 48-inch and 54-inch water pipelines, respectively. Outside of roadway areas, (assuming a reasonable excavation depth of approximately 10 feet) shoring would not be used and trench slopes would be laid back in accordance with standard, safe trenching practices.

Construction

Construction of a trench for a single pipe, 9 feet in width and 9.5 feet in depth produces about 86 cubic feet (3.2 cubic yards) of soil per foot of trench, if shoring is utilized. Assuming the excavated material can hold a 1:1 slope, and is placed 2 feet from the trench, an additional width of 21 feet for

NOTE:
1. SPACE BETWEEN ROW AND TRENCH INSUFFICIENT FOR SOIL STOCKPILE AND CONSTRUCTION VEHICLE INGRESS/EGRESS. SOIL TO BE HAULED TO/FROM STOCKPILE AREA.



DOUGLAS ROAD CROSS SECTION EAST OF EAGLE LAKE SOUTH LOOKING WEST - COMMON TRENCH

1"=5'-0"

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THORNTON WATER PROJECT
CITY OF THORNTON
THORNTON, CO

FIGURE 2
DOUGLAS ROAD
COMMON TRENCH

VERIFY SCALE
BAR IS ONE INCH ON ORIGINAL DRAWING.
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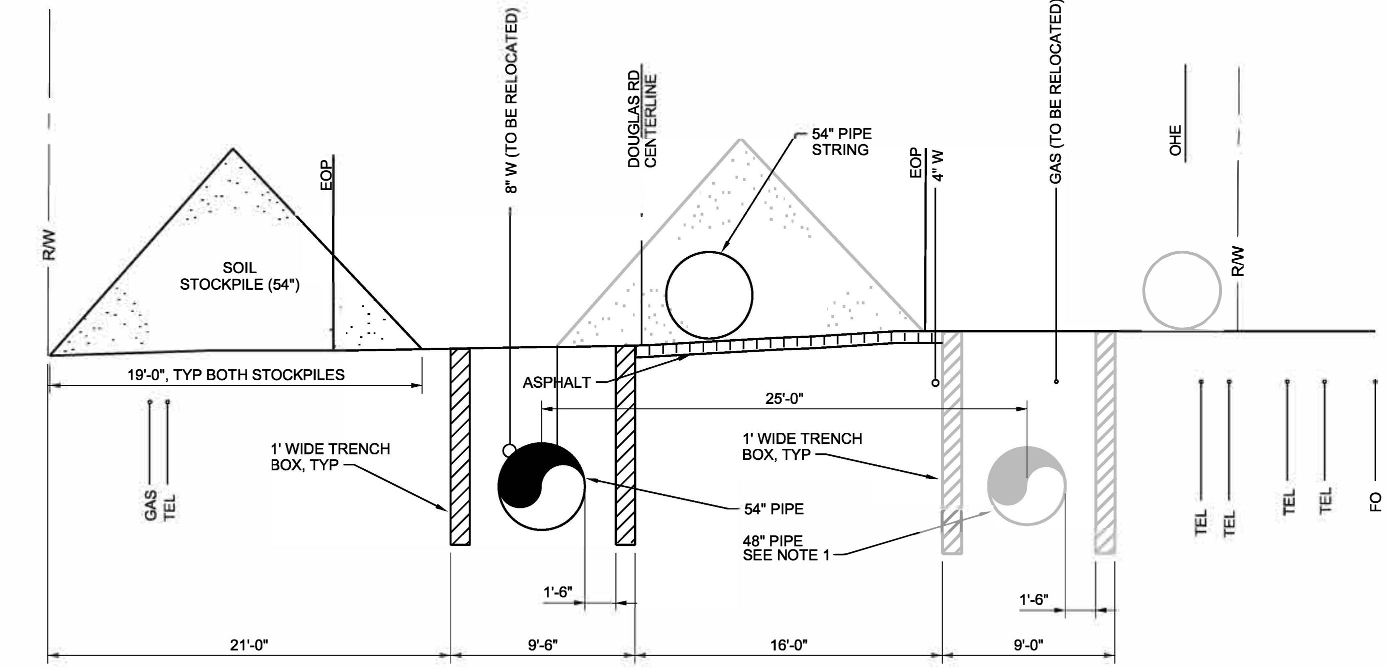
soil stockpile is required, for a combined width of 30 feet. For construction in Douglas Road (see **Figure 3**) where the minimum right-of-way is 60 feet, this leaves 30 feet of ROW remaining, which is sufficient, using a single lane closure for maintenance of traffic, including construction vehicles around the trench excavation and stringing of pipe along the trench. However, if both water pipelines are constructed at the same time, but staggered, insufficient right-of way width is available for maintenance of traffic through the construction zone. Road closures between accesses along Douglas Road will be required; however, because the water pipelines are staggered and the leading water pipeline is installed and backfilled before the following water pipeline is constructed, sufficient width is available for excavated material to be stockpiled adjacent to respective trenches and space is also available for construction vehicle access around the trench excavation and the stringing of pipe adjacent to the trench. The same would apply for construction in LCR 56 right-of-way. For construction outside of LCR 56 right-of-way most lands adjacent to LCR 56 are undeveloped, large lots and Thornton and Northern could purchase permanent and temporary construction easements from those property owners for construction of their respective water pipelines. Separate trenches would also allow differing periods of construction.

NOTE:
1. CONSTRUCTION OF 48" PIPE LAGS BEHIND TO PROVIDE SUFFICIENT CONSTRUCTION AREA.



CROSS SECTION EAST OF EAGLE LAKE LOOKING WEST - SEPARATE TRENCHES

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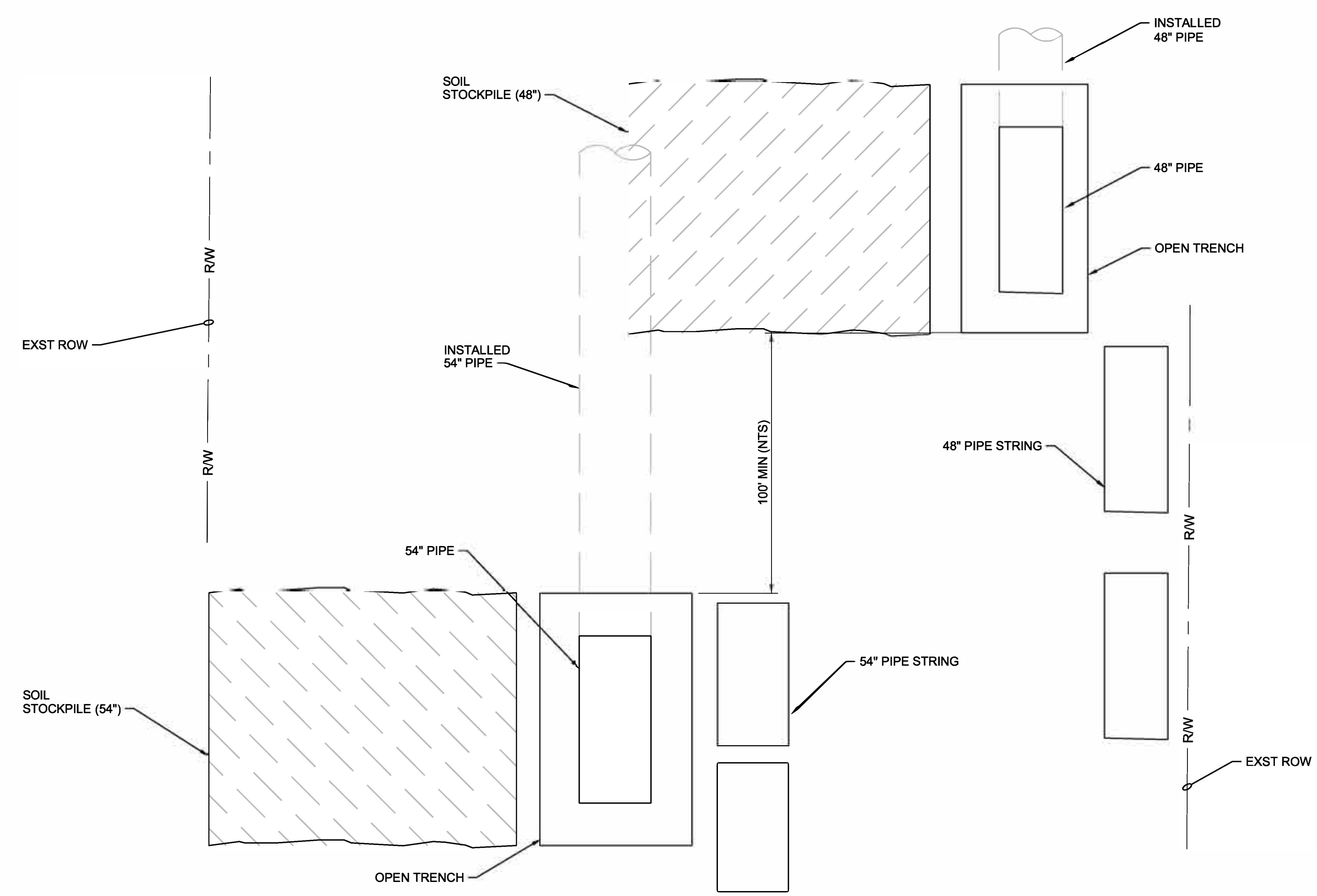

PLAN EAST OF EAGLE LAKE - SEPARATE TRENCHES

1"=5'-0"

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THORNTON WATER PROJECT
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THORNTON, CO

FIGURE 3
DOUGLAS ROAD
SEPARATE TRENCH

VERIFY SCALE
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Thornton Water Project
Modified Poudre River Alternative

PREPARED FOR: City of Thornton

COPY TO: File

PREPARED BY: CH2M HILL

DATE: November 12, 2018

General

This technical memorandum (TM) presents a general description of the infrastructure requirements for a modification to a citizen alternative for Thornton to obtain its source drinking water from WSSC Reservoir 4. The citizen alternative includes a pipeline from WSSC Reservoir 4 generally along Shields Street to the Cache la Poudre River, and withdrawal of that water downstream at Windsor, CO. This TM presents modifications to reduce water quality concerns associated with the citizen-proposed alternative. The alternative that results from these modifications is conceptually similar to the configuration of the Northern Integrated Supply Project (NISP) proposed by Northern Water (Northern). NISP includes two pipelines across Larimer County: 1) A northern tier pipeline directly from Glade Reservoir that delivers most of their source drinking water to NISP participants and 2) A Poudre River Diversion Pipeline that recovers any water discharged to the river from Glade Reservoir.

Modifications

The citizen alternative is modified to:

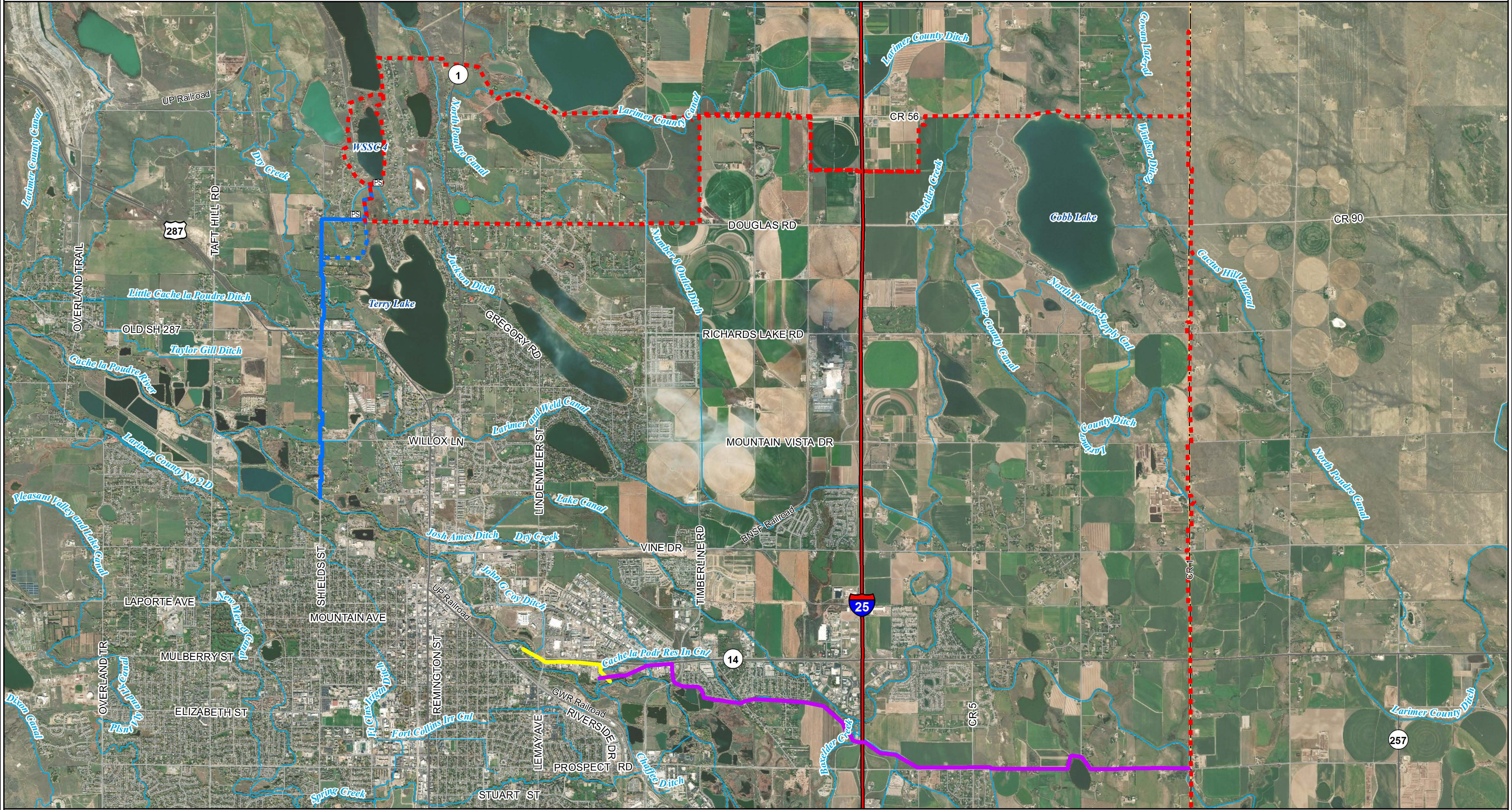
1. Keep the Shields Street pipeline concept, but only a portion of Thornton's drinking water will be delivered to the River and withdrawn downstream. Note: The citizen alternative uses a gravity pipeline from the reservoir that goes through the Terry Acres subdivision before heading west to Shields. An alternative configuration to avoid the Terry Acres pipeline would be to provide low-head pumps to convey water in a pipeline that follows Douglas Road to Shields. That pump station could be incorporated into the WSSC Reservoir 4 Pump Station (see modification 4 below).
2. To reduce the impact to the water quality of that drinking water placed into the river, the downstream withdrawal point is moved from Windsor to just upstream of the existing outfall from the Mulberry Water Reclamation Facility (WRF) or a relocated outfall as proposed by Northern Water for NISP.
3. Include a Poudre Diversion pump station and pipeline from the diversion point to a connection with the TWP Pipeline along County Line Road that follows and is parallel to a similar pipeline proposed by Northern Water for NISP.
4. Include all elements of the proposed TWP that takes drinking water from WSSC Reservoir 4, including a pump station at WSSC Reservoir 4, a pipeline from that pump station either along Douglas Road or LCR 56 to a tank near LCR 56 and County Line Road, a pipeline from the County Line Road tank along County Line Road south to a connection with the Poudre Diversion Pipeline and then the rest of the pipeline to Thornton.

Description

The attached figure presents the modified Poudre River Alternative. During appropriate river conditions of flow and quality, some source drinking water will be released from WSSC #4 to the Shields Street Pipeline (either gravity as proposed in the citizen alternative, or modified with a low-head pump station) where it will be conveyed and discharged to the river. Water released to the river would flow down the river and be diverted to the Timnath Inlet Canal where it would be pumped in a pipeline parallel to the proposed NISP Poudre Diversion Pipeline to a connection with the County Line Road Pipeline that goes south to Thornton. The remainder of Thornton's source drinking water would be delivered via either the Douglas Road Pipeline or LCR 56 Pipeline by a pump station at WSSC 4. This supply would be pumped to a tank near County Line Road and LCR 56 and that tank would feed the County Line Road Pipeline to Thornton.

Thornton Water Project

DRAFT Privileged Deliberative Process Work Product



CITY OF THORNTON
COLORADO
12450 WASHINGTON ST
THORNTON, CO 80241-2405

10/19/2018

0 2,250 4,500 Feet
1 inch = 4,500 feet

- Shields Street Conceptual Alignment
- Alternative Shields Street Conceptual Alignment (No Pump Station)
- Southern Pipeline Alignment
- Relocated Mulberry WRF Outfall by NISP
- Primary Delivery Pipeline
- Pump Station
- Railroad
- County Boundary
- River/Stream/Canal/Ditch

Modified Poudre River Option
Conceptual Alignment Overview
Thornton Water Project

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Water Quality Ramifications of Locating Thornton's Water Intake at a Downstream Location

Revision 0

November 14, 2018

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Contents

Summary

Diversion of Thornton's drinking water supply from the Cache La Poudre (Poudre) River below the current diversion point at the Larimer County Canal (LCC) will result in several adverse raw water quality issues associated with ensuring drinking water quality, including increased public health risk associated with the water supply, decreased water supply reliability, increased community impacts, and increased cost for drinking water treatment.

It should be noted that the ability to manage water through the ditch system further protects the Thornton water supply from run-of-the-river events such as floods, wildfires, or chemical spills. This is in addition to considerations such as the water quality in the river from below the LCC diversion to Shields Street (the downstream end of the stream segment classified as suitable for use as a drinking water source) being impacted by septage and surface runoff from urban and agricultural activities. Potential water quality impacts include increased occurrence of bacterial contamination (including human pathogens), as well as pesticides, herbicides, and nutrients. Such source water contamination increases as the river progresses to a location above the Mulberry Water Reclamation Facility (WRF). Downstream of the Mulberry WRF, Drake Wastewater Treatment Plant (WWTP), and Boxelder WWTPs, there is increased occurrence and concentrations of pathogens, nutrients, minerals, and chemicals that are listed in the primary drinking water standards, as well as contaminants of emerging concern (CECs). CECs include contaminants such as pharmaceuticals and personal care product that have public health implications, with some exhibiting endocrine disrupter characteristics.

All of these quality concerns significantly increase costs of treatment to mitigate public health risks and perceptions. In addition, aesthetics, such as taste, odor, and color, change as water quality deteriorates. Finally, water professionals (scientists and engineers) have long recognized the need to select the highest water quality source for drinking water as a priority for protection of public health. This has led to the State of Colorado's designation of source waters suitable as drinking water sources, such as the Poudre at the LCC. The increase in health risk resulting from lower raw water quality, deterioration in aesthetics, recognized scientific preference for a high-quality source, decreased water supply reliability, and increased cost to treat, all support diverting water at the LCC. Anticipated future drinking water regulations further support selection of the LCC as the diversion point for Thornton's drinking water supply.

Introduction

Figure 1 provides a reference map for the Poudre River basin locations discussed in this report, specifically:

- The LCC (the existing diversion for Thornton's water rights)
- The Poudre River reach between the LCC and Shields Street (the downstream terminus of the stream segment classified for Water Supply uses)
- The river reach from Shields Street to the Mulberry WRF
- The river reach below the Mulberry WRF, Drake WWTP, and Boxelder WWTP down to the suggested Windsor diversion

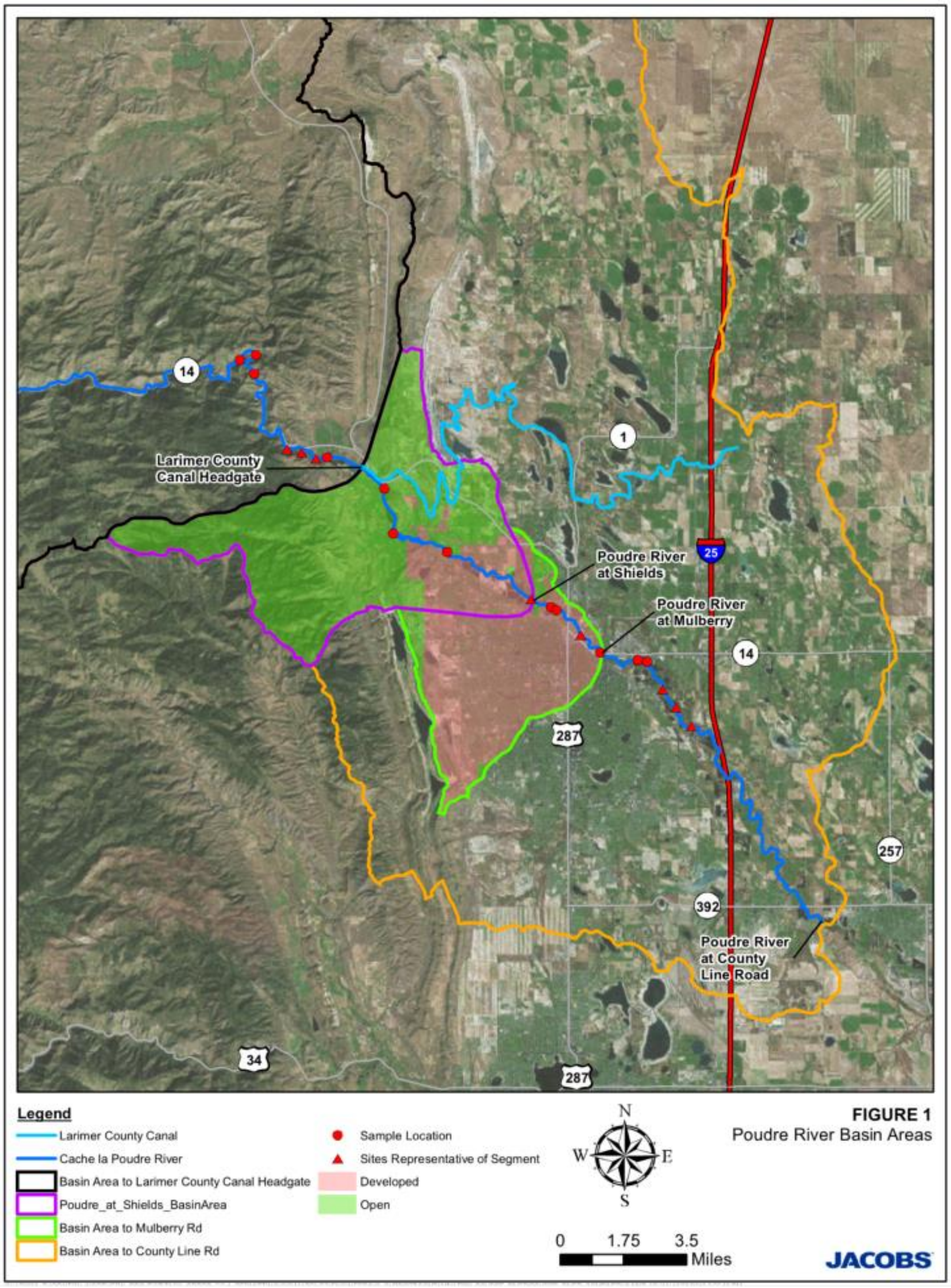

Figure 1. Poudre River Basin Areas

Water Quality Changes in the Poudre River

The following sections describe the changes and deterioration in water quality that occur as the Poudre River progresses from the LCC through agricultural and urban areas, past WWTPs, and through changing geologic formations. The discussion concentrates on the suitability of the water quality at various locations as a drinking water supply for Thornton.

Historic Selection of Drinking Water Sources

Scientists and engineers have long recognized that the source water quality for drinking water supplies is an important factor in preventing disease and promoting public health. For example, the following 1968 quote from three leading experts in drinking water quality and treatment has been referenced by water industry experts for 40 years, and its implementation continues to be an essential priority for drinking water professionals:

> "Supplies should be drawn from the best available source. …"[i]

Considered one of the leader's in early public health protection and drinking water, Allen Hazen also identified the need for high-quality source water in 1900:

> "The main point is that disease-germs shall not be present in our drinking water. If they can be kept out in the first place at reasonable expense, this is the thing to do. Innocence is better than repentance."[ii]

This essential and well-substantiated component of public health protection has been carried through to today and is manifested in the current Colorado Department of Public Health and Environment (CDPHE) source water quality designations. The current diversion point for Thornton's water rights at the LCC is designated suitable as a "Water Supply" for drinking water by the CDPHE. The Poudre River downstream of Shields Street is not so designated for a number of reasons, which are highlighted below.

Poudre River at the Larimer County Canal

As a CDPHE-designated suitable "Water Supply", the risk of pathogenic, anthropogenic, and geologic contamination in the Poudre River water is at its lowest at the LCC when compared to all other downstream locations. As such, the following sections provide a comparison of the water quality associated with Thornton's water rights to elevated public health concerns and aesthetic changes that occur at suggested diversion locations downstream of the LCC. Of major importance is the recognized scientific preference for a high-quality drinking water source. Increased health risk, deterioration in aesthetics, and increased cost all support diverting water at the LCC. This was one of the primary reasons the City of Thornton selected the LCC many years ago, and the reason Thornton negotiated an agreement with the Water Supply and Storage Company (WSSC) to continue diverting at this location.

The "Preliminary Assessment of Alternative Diversion Location for Thornton Water Rights Using Poudre River Water Quality Data"[iii] report indicates that water quality deteriorates as it passes through the WSSC system. The limited data and conclusions in the report provide a description of the canal water quality but do not characterize future WSSC Reservoir #3 water quality. The water quality data, supplied for the report by the City of Thornton, is from the canal. Water quality data representing future WSSC Reservoir #4 operations is not available until operation of the proposed facility begins. Future reservoir water quality will result from the mixing and storage of high diversion flows in the spring and summer. The resultant water quality constituent concentrations in the reservoir will be a flow weighted average, including diversions throughout the irrigation season. While it cannot be exactly predicted without a detailed understanding of the operations of the LCC system, the resultant reservoir constituent water quality can be expected to trend closer to the average of the Poudre River quality. One of the primary benefits of this mixing is a consistent water quality. Water treatment operations are significantly enhanced by limiting variability in constituents such as alkalinity, TDS, and total organic carbon (TOC).

The ditch system can be operated so that it protects the Thornton water supply from potential contamination events such as wildfires, floods, or spills in the watershed. During these periods, the diversion from the LCC to Reservoir #3 can be closed. Additionally, as mentioned above, the reservoirs will serve as a pool to mix variable water qualities that may occur over time, thus providing a predictable water supply for drinking water treatment. The ditch system is expected to operate in a manner that will deliver water quality to Thornton that closely mimics that measured at the LCC diversion.

The use of hardness, sulfate, alkalinity, E. coli, TDS, and conductivity measures to characterize a water supply does not allow for full comparison with respect to drinking water supplies. A broader spectrum of data and scientific studies that impact drinking water and public health are described in the sections below.

Poudre River Above Mulberry Water Reclamation Facility

A diversion downstream of the LCC and above the Mulberry WRF would result in source water that includes contamination from urban and agricultural runoff. This contamination has been documented and substantiated by water quality and public health professionals throughout the U.S. and globally. The U.S. Environmental Protection Agency (USEPA) summarizes the expected water contamination as follows:

> "Urbanization increases the variety and amount of pollutants carried into streams, rivers, and lakes. The pollutants include:
>
> - Sediment
> - Oil, grease, and toxic chemicals from motor vehicles
> - Pesticides and nutrients from lawns and gardens
> - Viruses, bacteria, and nutrients from pet waste and failing septic systems
> - Road salts
> - Heavy metals from roof shingles, motor vehicles, and other sources"[iv]

Source waters that are impacted by runoff from agricultural and developed areas have been linked to numerous disease outbreaks, as documented in the public health literature:

> "Fifty-one percent of waterborne disease outbreaks were preceded by precipitation events above the 90th percentile (P = .002), and 68% by events above the 80th percentile (P = .001). Outbreaks due to surface water contamination showed the strongest association with extreme precipitation during the month of the outbreak; a 2-month lag applied to groundwater contamination events."[v]

> "Drinking water outbreaks have been linked to runoff; more than half of the documented waterborne disease outbreaks since 1948 have followed extreme rainfalls. Spring rains and snowmelt preceded the Milwaukee Cryptosporidium outbreak and may have played a role in transport of the oocysts. Urban and suburban streets, parking lots, and lawns generate large loads of bacteria in stormwater, 18–20 and urban runoff is responsible for an estimated 47% of the pathogen contamination of Long Island Sound."[vi]

In addition to the citing of pathogen outbreaks, there is definitive documentation of pesticide and other human-induced contamination of source waters that pose public health concerns, such as the following:

> "The results of this study confirm that a large number of pesticides can be detected in water from streams draining developed areas, and show the importance of storm data in assessing the transport and fate of pesticides in urbanized watersheds."[vii]

> "Surface urban waters in the areas of this study frequently contain numerous different pesticide combinations at any given time. Many of these pesticides are at concentrations that are of concern, especially due to their frequent occurrence and the unknown effect of multi-pesticide combinations. The watersheds selected in this study had no reported agriculture pesticide use, thus pesticides detected were solely from urban applications."[viii]

Along with surface water runoff, septic systems also can introduce pathogen and anthropogenic contaminants that increase public health risks. Considerable research has been done on the identification of these contaminants, which has

"…lead to the documented presence of many various targeted compounds in water resource around the world including in sources of public drinking water. These detections have been associated with a variety of human and animal sources such as hospitals, septic tanks, wastewater effluents from treatment plants and livestock activities."[ix]

The following provide further substantiation of increased public health risk from septic system contamination of source waters:

"The results revealed that (1) during baseflow conditions, septic watersheds contained elevated stream discharge and E. coli concentrations and exports as compared to sewer watersheds; (2) warmer months had elevated E. coli watershed exports compared to colder months in both septic and sewer watersheds; and (3) storms significantly increased watershed E. coli exports in both septic and sewer watersheds. … These findings in conjunction with previous studies suggest that septic systems may play a pivotal role in the delivery of FIB *[Fecal Indicator Bacteria]* to receiving waters, particularly during baseflow conditions."[x]

"….. the results indicate that CECs entering surface waters from septic systems may approach levels of ecotoxicological concern."[xi]

Some bacterial data specific to the potential pathogen contamination in the Poudre River have been collected and are presented in Figures 2 and 3[xii] for 85th percentile and maximum concentrations, respectively. As shown in both figures, concentrations of E. coli increase significantly downstream of Shields Street. Both the 85th percentile and maximum E. coli measured values indicate significant increases in E. coli, which also indicates the presence of other pathogens.

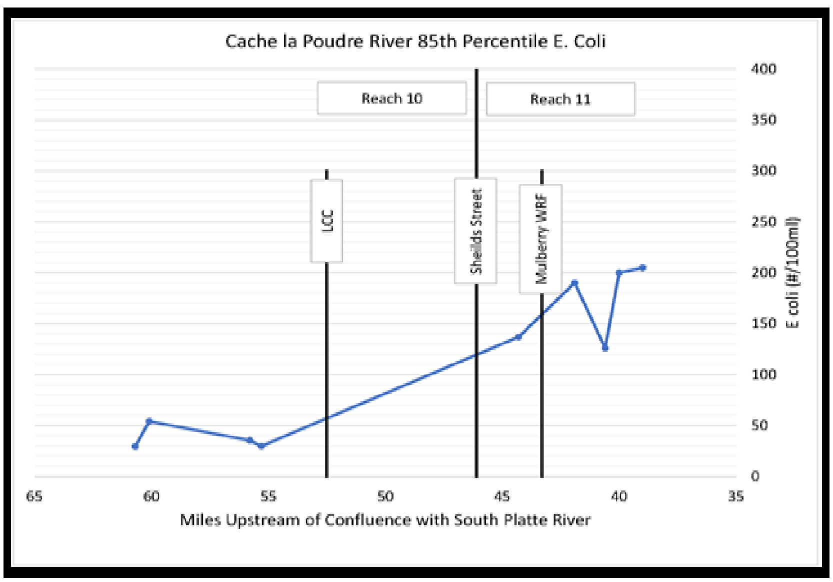

Figure 2. Concentrations of E. Coli in the Cache La Poudre River – 85th Percentile

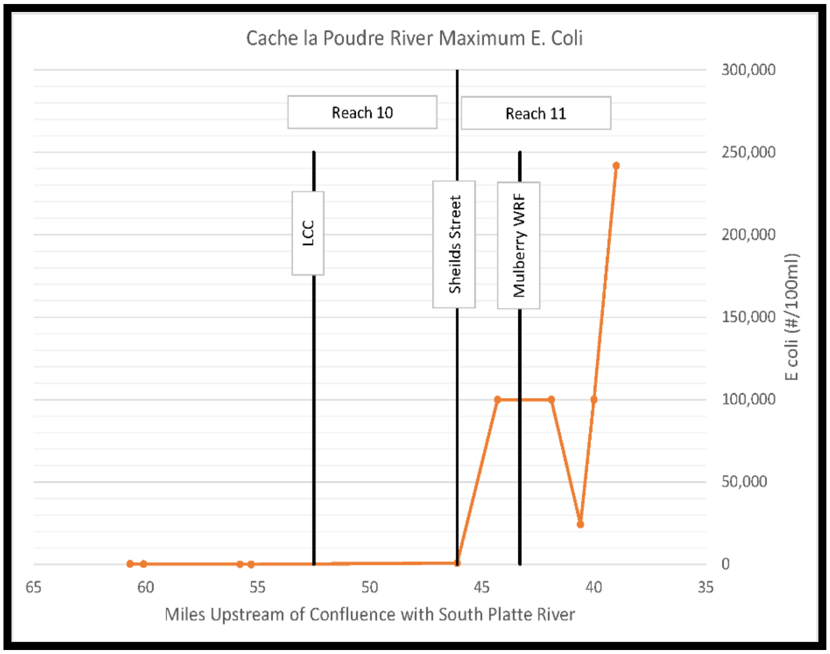

Figure 3. Concentrations of E. Coli in the Cache La Poudre River – Maximum

Poudre River Below the Treatment Plants

A diversion below the Mulberry WRF or Drake or Boxelder WWTPs would be expected to have a significant negative impact on water quality, not only from urban and agricultural runoff, but also from the WWTP effluents. Increased health risks to a public water supply caused by treated wastewater effluent are well documented. For example:

> "Raw and treated wastewater represents a significant source of emerging pathogens that has the potential to adversely affect downstream drinking water supplies. Discharges of emerging pathogens from wastewater treatment plants as far as 160 km upstream and cumulative amounts of wastewater discharge ranging from 2 to 20 ML/d have the potential to reach a water supply intake in a viable state at significant concentrations that could exceed regulatory limits, increase endemic risk from drinking water, and/or require additional drinking water treatment."[xiii]

> "Numerous studies have shown that a variety of manufactured and natural organic compounds such as pharmaceuticals, steroids, surfactants, flame retardants, fragrances, plasticizers and other chemicals often associated with wastewaters have been detected in the vicinity of municipal wastewater discharges and livestock agricultural facilities …. This source-water reconnaissance study provides new baseline knowledge on a wide range of OWCs in a variety of ground- and surface-water sources of drinking water across the United States."[ix]

As documented in the literature, and based on measured concentrations of E. coli in the Poudre River, there is increased risk of pathogens in the river water downstream of the treatment plants, and therefore increased risk to public health. In addition, there are anthropogenic contaminants resulting from runoff and from the plants' effluents. These contaminants include nutrients, minerals, and chemicals that are listed in the primary drinking water standards, as well as CECs, which are subcomponents of the bulk measurement of TOC. CECs include contaminants such as pharmaceuticals and personal care products that have public health implications, with some exhibiting endocrine disrupter characteristics. The health effects of CECs are not fully understood at this time and are being studied closely. TOC also includes precursors for disinfection byproduct (DBP) formation, which is discussed further below. Even waters with similar TOC concentrations can have very different CEC and DBP precursor concentrations. In addition, aesthetics such as taste, odor, and color change as water quality deteriorates. All of these changes in water quality increase the risk to public health and require increased treatment operations and costs to remediate the public health implications.

River Segment 12

In addition to the water quality impacts of runoff and effluent, there is a significant impact caused by the change in geologic conditions in river Segment 12, which begins near the crossing of I-25. In Segment 12, there are net inflows from local groundwater gradients, which mobilize constituents in the area's geology and results in increasing TDS, selenium, and sulfate concentrations[xii] in the Poudre River. While these increased concentrations are not related to anthropogenic effects, the mineral deterioration in water quality further decreases the desirability of this water as a drinking water source. This would result in a significant increase in treatment requirements to address the minerals of concern, e.g., reverse osmosis (RO) membrane treatment and zero liquid discharge treatment facilities for the RO concentrate.

Summary of Water Quality Impacts on Drinking Source Water Quality

Water quality in the Poudre River progressively deteriorates as the river passes through rural, suburban, and urbanized areas as a result of surface water runoff, WWTP effluent, and changing geologic formations. Water quality in the river from the existing LCC diversion to the suggested Shields Street location will be impacted by a combination of surface runoff and septage, which includes increased occurrence of bacterial contamination (including human pathogens), pesticides, herbicides, and nutrients. Such source water deterioration will continue, and increase, as the river progresses to the suggested diversion location above Mulberry WRF.[xii] Below the Mulberry WRF, Drake WWTP, and Boxelder WWTP, the occurrence and concentrations of regulated and potentially future regulated pathogens, nutrients, minerals, and chemicals that are listed in the primary drinking water standards will increase, as will CECs and DBP precursors. Mineral changes due to geologic conditions occur below the Drake WWTP. In addition, aesthetics such as taste, odor, and color change as water quality deteriorates, further reducing the desirability of extracting source waters below the existing LCC diversion point.

Source Water Reliability

Diversion at the LCC, and use of the existing ditch and reservoir system, provides Thornton extensive flexibility for source water protection. During periods of poor water quality, which could be due to flooding, wildfire runoff, spills in the watershed, or other events, the City can forego share water deliveries to the reservoirs, allowing the poor water quality to flow past. The storage in the reservoirs would be used to continue delivery to Thornton's treatment plants. Furthermore, the ditch system and associated reservoirs will allow for mixing of variable water qualities over time, buffering sudden changes that may impact water treatment approaches.

One alternative being investigated is to allow the water to remain in the LCC system and allow it to travel further to the east. While the ditch and reservoir system provides Thornton the ability to improve the water quality consistency, water degrades if it is allowed to remain in the ditch along its length. Table 1 presents water quality data over the length of the LCC ditch system.

As shown, the data for TDS and other constituents increase measurably east of the reservoirs. Geologic features as well as inflows into the ditch potentially influence water quality. Without reservoirs for storage or sufficient base flows in the ditch, this would erode the benefits of managing the water offstream from the Poudre River. To access existing storage while still using the ditch system to convey water to the east, Thornton would need to pump water back to the ditch for conveyance, which requires a pump station and a pipeline, along with associated community impacts. Finally, winter operations may become impractical because water in the ditch could freeze during periods of cold temperatures.

Table 1. Measured Water Quality in the Larimer County Canal

Parameter (ppm, unless specified)	Larimer County Canal at Poudre (May-Sep)		Larimer County Canal at Reservoir 3 (May-Sep)		Larimer County Canal at CR 56 (May-Sep)		Larimer County Canal up Black Hollow (May-Sep)		Larimer County Canal at Hwy 85 (May-Sep)	
	Range	Average	Range	Average	Range	Average	Range	Average	Range	Average
Conductivity, uS/cm	45 - 118	87	70 - 441	211	146 - 594	375	193 - 836	373	208 - 852	394
pH, STD	7.61 - 8.50	8.03	7.94 - 8.59	8.37	7.49 - 8.42	8.04	7.55 - 9.07	8.42	7.37 - 9.48	8.41
Dissolved Oxygen	8.4 - 10.0	9.2	4.1 - 10.2	8.2	7.5 - 9.4	8.5	4.9 - 11.6	8	5.8 - 11.6	8.1
Turbidity, NTU	0.2 - 14.1	4.5	4.4 - 16.4	9.7	14.6 - 45.2	23.8	6.0 - 39.8	24.4	7.8 - 145.9	50.1
Alkalinity	19 - 40	30	25 - 57	40	37 - 59	50	95 - 107	101	95 - 106	101
Total Hardness	32 - 68	50	34 - 188	92	70 - 202	145	232 - 286	259	232 - 278	255
TDS	52	52	53 - 278	157	149 - 389	254	143 - 562	265	113 - 566	267

Water Treatment Impacts and Costs

To manage increased risk introduced by treating lower water quality, there are significant cost impacts to Thornton's currently planned approach for treating up to 40 million gallons per day. Additionally, there are significant community and environmental impacts, which can be quantified by truck traffic and greenhouse gas production. Furthermore, if the water supply cannot leverage the existing storage available in the ditch system, treatment capacity would have to increase to nearly 60 million gallons per day (mgd) to use the entire resource on an as-delivered basis.

Capital and Operations and Maintenance Costs

The estimated capital costs for a base treatment facility, assuming the existing diversion will be approximately $176 million. Annual operations and maintenance (O&M) costs will be approximately $8.8 million per year. If the plant capacity was required to be increased to 60 mgd, capital cost would increase by approximately $48.0 million and O&M costs would increase approximately $2.3 million per year.

If the diversion was moved to upstream of the Mulberry WRF, aligning with the Shields Street Alternative, additional treatment would be required for increased TOC and pathogens. At minimum, this would lead to the addition of membrane filtration. Capital costs would increase by $85 million. O&M costs would increase by $5.5 million per year for 40 mgd of treatment.

If the diversion was moved downstream of the Mulberry WRF, additional treatment would be required for the further increase in TOC, CECs, and nutrients (such as nitrogen). The additional treatment, which would include membrane filtration and granular activated carbon (GAC) adsorption, would result in a capital cost increase of $138 million and an increase of $8.7 million per year in O&M for 40 mgd of treatment.

Finally, if the diversion was moved into Segment 12, aligning with the Windsor Alternative, treatment would have to be added to address not only the items mentioned above, but also further increases in pathogens, CECs, nutrients as well as increased TDS. This would result in a capital cost increase, over the base case, of $600 million and an O&M increase of $44 million for 40 mgd of treatment capacity. Much of this increase is due not only to RO treatment, but also for zero liquid discharge treatment of the brine waste stream from RO.

Community and Environmental Impacts

As discussed previously, diverting Poudre River water downstream of the LCC would result in measurable negative water quality impacts. Increased drinking water treatment associated with the deteriorated raw water supply would result in:

- Increased truck traffic, local to the water treatment plant, due to more chemical deliveries and solids hauling
- Increased solids production, filling regional landfills
- Increased power usage, taking power off the regional grid
- Greater greenhouse gas (GHG) footprint

The base treatment facility, which assumes use of the existing diversion, will create truck traffic of approximately 1,570 vehicles per year. This GHG footprint results in approximately 13,200 tons of CO_2 equivalents (CO_2e) per year, equivalent to the GHG footprint of approximately 700 households.

For a diversion located upstream of Mulberry WRF, the truck traffic would increase by 30 loads per year, and the GHG footprint would increase by 29,500 tons of CO_2e per year, equivalent to 1,450 households.

If the diversion was located downstream of Mulberry WRF, truck traffic would increase by 60 loads per year, and the GHG footprint would increase by 31,500 tons of CO2e per year, equivalent to 1,500 households.

Finally, if the diversion was placed in Segment 12 of the Poudre River, truck traffic would increase by 6,000 per year, and the GHG footprint would increase by more than 200,000 tons of CO2e per year, equivalent to an increase in over 10,000 households.

Conclusions

Selection of Source Water

The water quality at the existing LCC diversion is superior to all downstream locations, and the LCC should be maintained as the source water diversion point for the Thornton water supply. Selection of the LCC diversion location is supported by the following CDPHE designations:

- Current diversion at the LCC is from CDPHE Reach 10 of the Poudre River, which has a “Water Supply” classification and is therefore considered suitable for use as a source of drinking water supply. This location has the highest water quality when compared to downstream locations.
- Any diversion between Shields Street and Boxelder Creek would be from CDPHE Reach 11, and any diversion downstream of Boxelder Creek to County Line Road would be from CDPHE Reach 12. Neither of these Poudre River reaches has a “Water Supply” classification.

Water quality deteriorates as the river progresses downstream and passes through agricultural, suburban, and urbanized areas and across geologic formations. This deterioration is the primary reason CDPHE does not designate these areas with a “Water Supply” classification. The water quality deterioration is summarized as follows:

- Water diversion just upstream of the Mulberry WRF, such as the Shields Street Alternative, would include increased pathogen, nutrient, and chemical contamination (e.g., pesticides, pharmaceuticals, endocrine disruptors, and CECs), increasing public health risk and requiring additional treatment needs and costs beyond the current diversion. Treatment capital and O&M costs for these alternatives would increase by as much as $85 million and $5.5 million, respectively, and would incorporate membrane filtration treatment in the process.
- Water diversion downstream of any of the treatment plants would result in a full range of pathogen and chemical constituents that create additional risk to public health, as well as additional treatment beyond that for locations above Mulberry WRF. Treatment capital and O&M costs would increase by as much as $175 million and $10 million, respectively, and would include implementation of membrane filtration and GAC adsorption.
- Water quality deteriorates as it travels along the LCC system to the east without the benefit of the storage reservoirs. Costs and community impacts would be expected to be similar to those for diversions downstream of the treatment plants, and could be as high as for a diversion in Segment 12 (i.e., the Windsor Diversion).
- A water diversion below the Drake WWTP, such as the Windsor Diversion Alternative, would include the water quality deterioration from the WWTP effluents, as well as geologic-induced changes in minerals, resulting in significant increases in treatment costs and environmental impacts. Treatment capital costs would increase by as much as $600 million and O&M costs would increase by an estimated $44 million. Treatment would include membrane filtration, RO, and complete mechanical dewatering of the brine waste streams (zero liquid discharge).

Future Considerations

Not only are there documented and predictable impacts to the source water quality and drinking water treatment approach if the current diversion is moved downstream of the LCC, there will continue to be impacts from more restrictive drinking water quality regulations into the future. The USEPA follows a process of publishing a Contaminant Candidate List (CCL) every 5 years. The CCL is a list of constituents found in water that are not currently regulated but may be considered for future regulation based on the frequency of being found in water supplies and potential health effects. The most recent two CCLs, CCL3[xiv] and CCL4[xv], include multiple DBPs under consideration for regulation. DBPs are formed when certain organic compounds (as a subset of TOC) are exposed to oxidants like chlorine or ozone, which is common in drinking water treatment for disinfection of pathogens. As such, it can be surmised that future regulations may include additional DBPs and/or lower maximum contaminant levels compared to current requirements. These changes are driven by the impact of urban and agricultural runoff, and especially the impact from WWTP effluent, on water quality, as well as increased understanding of potential human health impacts. Continued use of the LCC diversion will lower the risk of significant impacts on the water treatment facility and cost of treatment, not only initially but into the future. There is no doubt that drinking water sources extracted downstream of developed areas, agriculture, urban areas, and especially treated wastewater discharges will increase the need for treatment and the potential for public health risks.

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[xiv] https://www.epa.gov/ccl/contaminant-candidate-list-3-ccl-3

[xv] https://www.epa.gov/ccl/contaminant-candidate-list-4-ccl-4-0

Thornton Water Project

Assessment of Proposed Microtunneled Intakes

PREPARED FOR:	City of Thornton
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DATE:	October 31, 2018

Introduction and Understanding

The City of Thornton, CO is considering potential intake tunnels (lake or wet taps) at Reservoirs 3 and 4 located north of Fort Collins Colorado as shown in **Figure 1**. The purpose of this technical memorandum is to evaluate information provided on potential intake tunnel locations, diameters, lengths and depths with consideration of geotechnical data provided and available geology information to assess the feasibility, risks and potential costs for the proposed intake tunnels. The feasibility of the proposed intake tunnels includes a comparison to experience from similar intake tunnels in North America.

The proposed intake tunnels are anticipated to have inside diameters ranging from 48-inch to 60-inches to convey adequate flow. The proposed intake tunnel locations for four schemes are shown in **Figure 2**. It shows proposed intake tunnel lengths ranging from 1,980 feet to 6,420 feet. Proposed intake tunnel lengths and estimated depths are listed in **Table 1**. The depths are ballpark estimates for discussion only and must be determined by an engineering study.

Table 1 – Proposed Intake Tunnel (Wet Tap) Lengths and Depths for Four Schemes

Intake Scheme	Intake Tunnel Drives	Proposed Tunnel Length, ft	Est'd Shaft Depth, ft	Est'd Intake Depth, ft	Comments
West 1	W1	1,980	60	50	One intake: Reservoir 4
North 1	N1a N1b	2,100 3,900	60 60	50 50	Two intakes: Reservoir 3 and 4
North 2	N2	3,900	60	50	One intake: Reservoir 4
North 3	N3	6,420	80	50	One intake: Reservoir 4, tunnel below Reservoirs 3 and 4

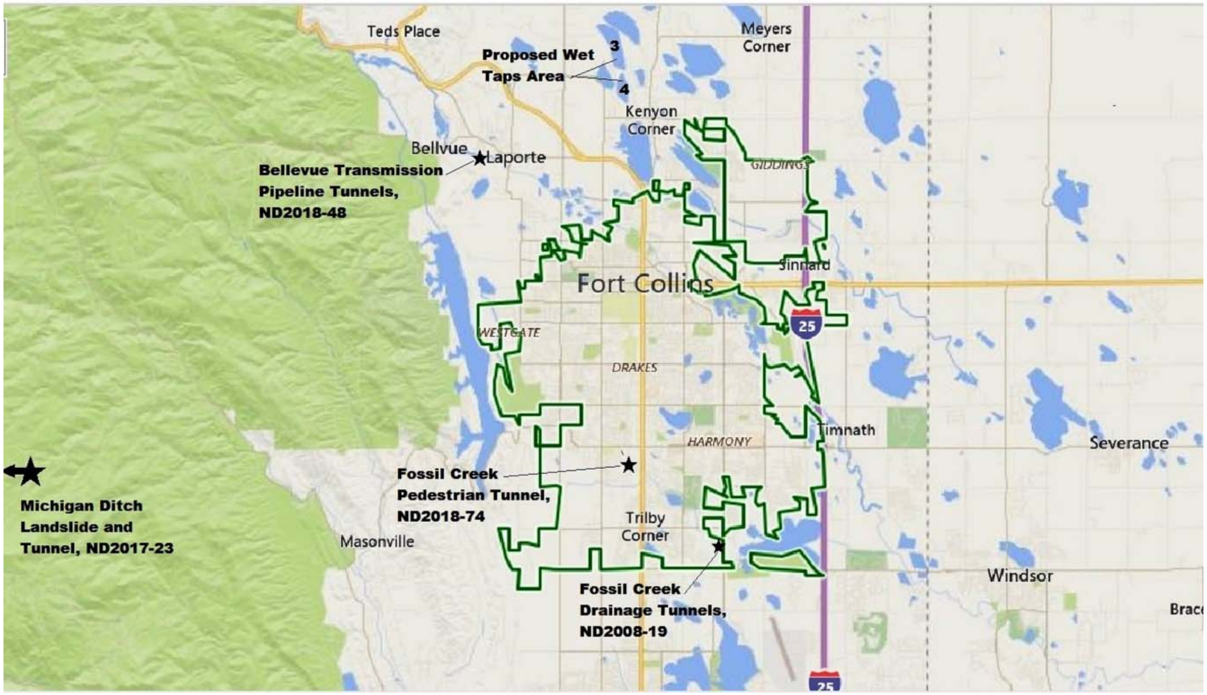


FIGURE 1
Proposed wet taps site and other Fort Collins area tunnel site locations

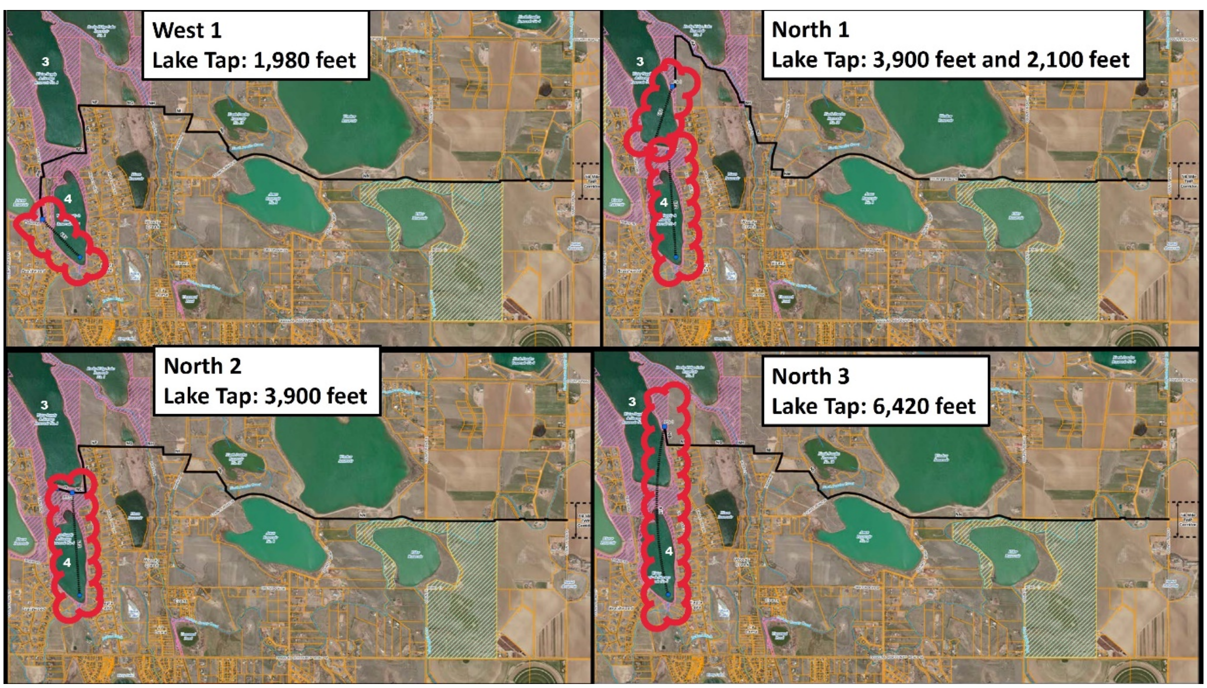


FIGURE 2
Proposed wet taps alignments at Reservoirs 3 and 4

A conceptual profile for intake scheme North 3 is shown in **Figure 3**. It assumes an 80 ft deep launch shaft along the east bank of Reservoir 3 (see **Figure 2**) and an intake bench at about 50 ft below lake level near the dam for Reservoir 3. An engineering study of land topography, lake bathometry, hydraulics and ground conditions for each scheme is needed to determine more accurate depths.

Similar profiles could be created for the other intake tunnels, but may not be of value without reliable land topography, lake bathometry, hydraulics and ground conditions information.

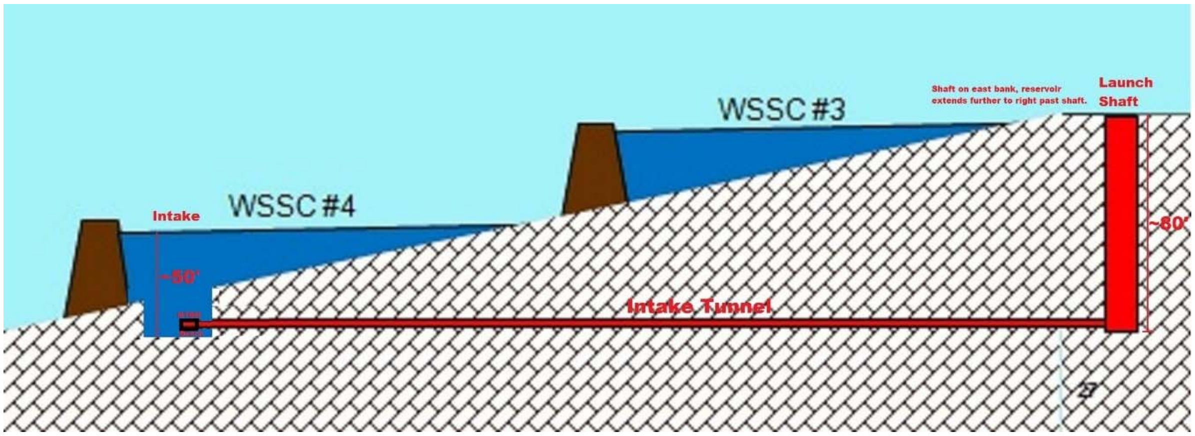


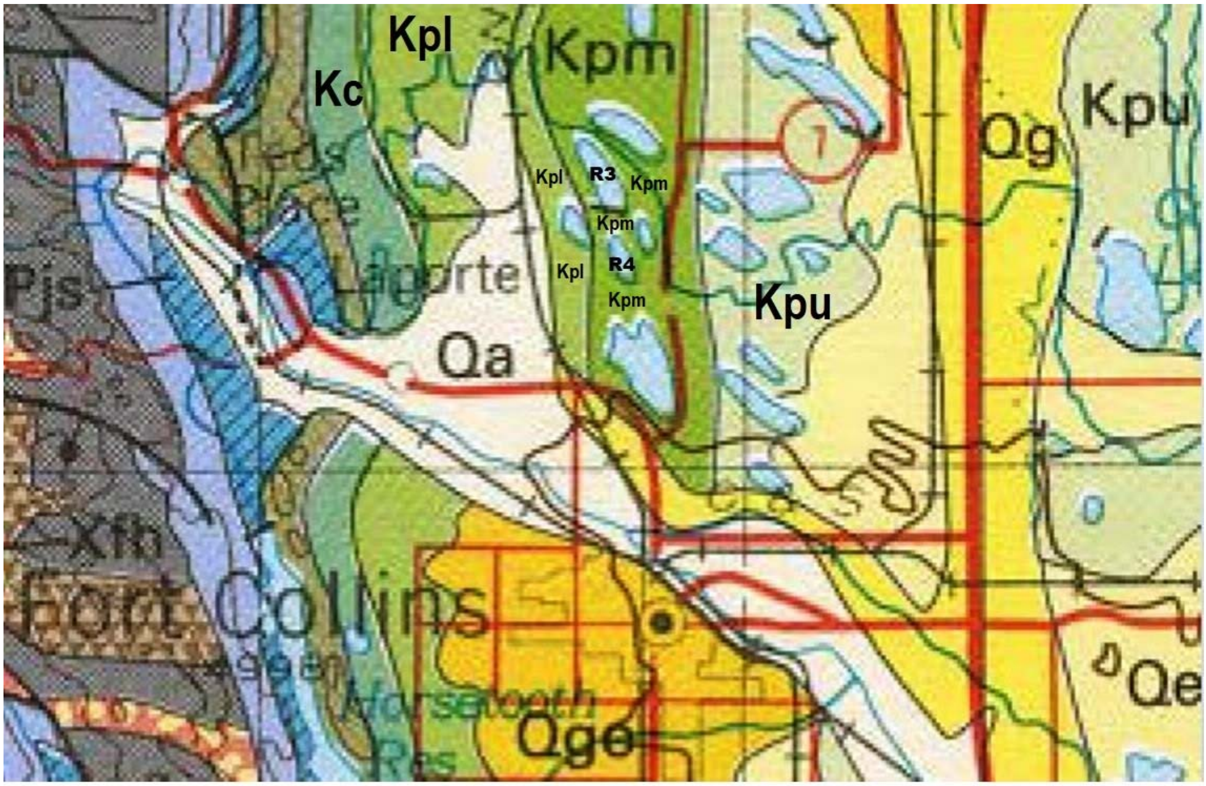
FIGURE 3
Conceptual profile with estimated depths for Scheme North 3

Geologic Setting, Geology and Local Tunnel Experience

Geologic Desk Study Data

The geologic setting for the proposed intake tunnels is within the Fort Collins-Wellington Anticline outcrop area of the Pierre Shale formation east of the Rocky Mountains along the west side of the Colorado Piedmont. The Pierre Shale is an Upper Cretaceous geologic formation of sedimentary rock situated between the Niobrara formation (below) and Fox Hills formation (above). It is of marine origin and was deposited in the Western Interior Seaway. The Pierre Formation is a series of shale deposits with embedded sandstone members. The argillaceous or shale units are described as a dark-gray shale, fossiliferous, with veins and seams of gypsum, and concretions of iron oxide. The Pierre shale of northeastern Colorado is divisible into: a Lower Pierre Shale unit (Kpl), a Middle Pierre Shale sandy unit (Kpm), and an Upper Pierre Shale unit (Kpu). The Pierre Shale is known to be potentially gassy and may produce toxic or hazardous gases such as methane and hydrogen sulfide and may also have some natural oil deposits. The gas and oil, if encountered, would increase tunneling risks and may increase the cost of tunnel muck disposal.

Figure 4 is a local geologic map that shows that Reservoir's 3 and 4 (and the proposed intake tunnels) are located within an area where the bedrock is indicated as the Middle Pierre Shale sandy unit (Kpm). The Kpm bedrock may primarily consist of the Terry Sandstone or Hygiene Sandstone members (see more below). The bedrock just to the west of the reservoirs is indicated as Kpl and it would underlie the Kpm unit. The Kpl member is described on the local USGS quadrangle geologic map as including "three lower members of the [Pierre Shale} formation: Mitten Black Shale Member, Sharon Springs Member, and Gammon Ferruginous Member. These members are mostly dark-olive-gray shale and sandy shale containing limestone and ironstone concretions. Bentonite beds are common in lower part."



From: 2015, Sue Kenney, A Special Place [Geology overview of Fort Collins area], 153 slides

Hunt Notes: R3 and R4 are Reservoirs 3 and 4; Kc = Carlile Shale; Kpl = Pierre Shale, lower unit; Kpl = Pierre Shale, middle unit; Kpu = Pierre Shale, upper unit; Qa = alluvium

FIGURE 4
Proposed intake tunnel alignments on USGS geologic map

Reservoirs 3 and 4 (R3 and R4) are located along the southern part of western side of the Fort Collins-Wellington Anticline (and oil field) as shown in **Figure 5**. It indicates that interpreted geologic units 4, Terry Sandstone Member (younger) and 5, Hygiene Sandstone Member (older) are located in the vicinity of Reservoirs 3 and 4.

The Terry Sandstone is subdivided into two facies. The higher permeability 'reservoir' facies consists of high-energy, cross-bedded, fine to medium-grained sandstone from an indurated marine sandbar while the lower permeability 'non-reservoir' facies is lower-energy, extensively bioturbated, very fine to fine-grained sandstone interpreted as originating on the flanks or margins of the sandbar. The Terry Sandstone is known to have thinly interbedded mudstones.

The Hygiene Sandstone has been recognized as the oldest of five sandstones members that may be present within the Pierre shale. It has been described as massive, cross-bedded sandstone and shaly sandstone with variable coarseness of grain and potential high permeability.

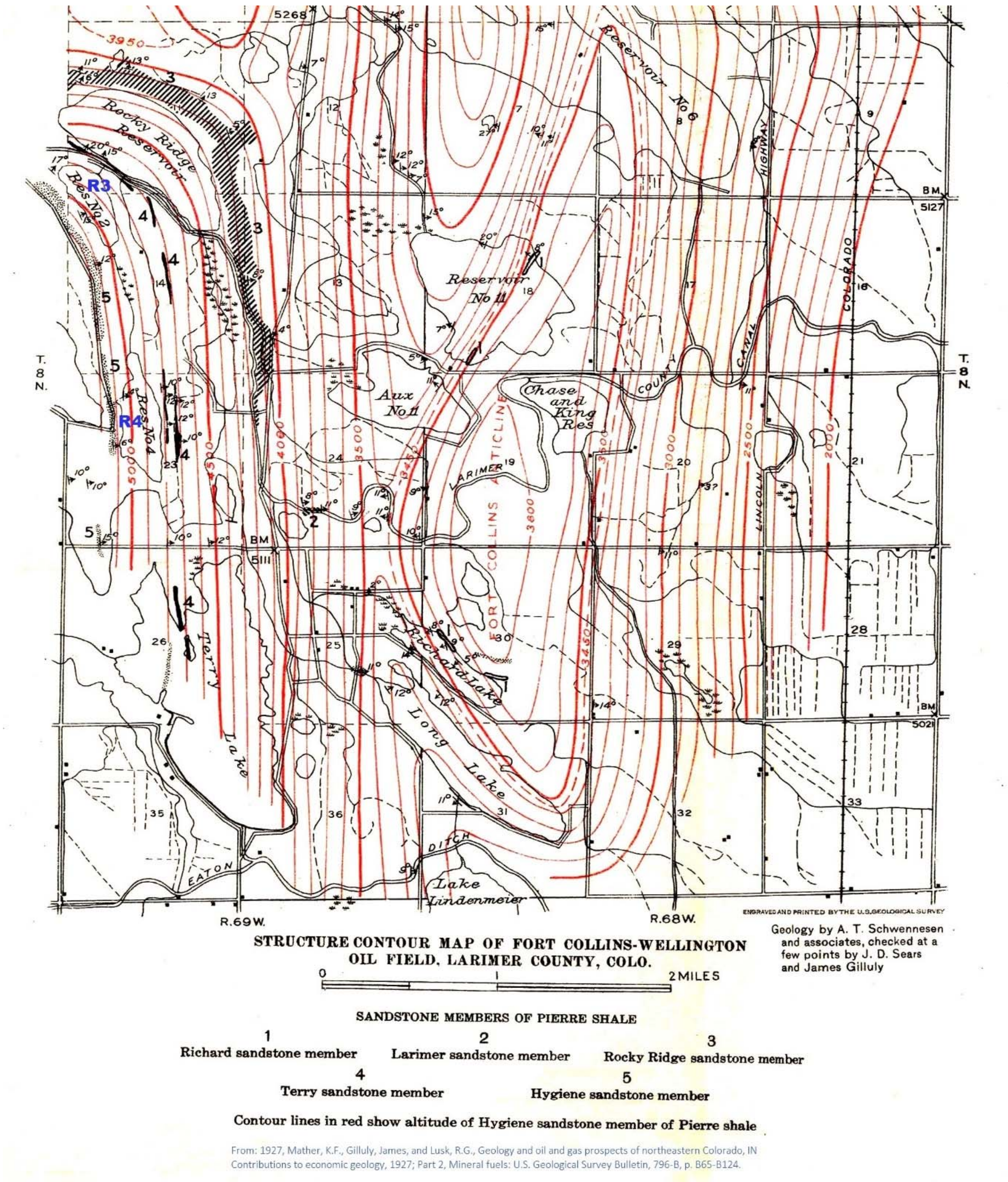


FIGURE 5

Proposed intake tunnel alignments at Reservoirs 3 and 4 along Fort Collins to Wellington Anticline

Available Subsurface Investigation Data

Two subsurface investigation reports were provided for consideration:

- A geotechnical report with borings for an Excel Gas Pipeline constructed beneath Reservoir 3 (see yellow dots in **Figure 6**) [Reference: HP Geotech, 2011].
- A location plan and boring logs for a proposed East Larimer County Water District (ELCO) water line (see blue dots in Figure 6) [Reference: Terracon, 2015].

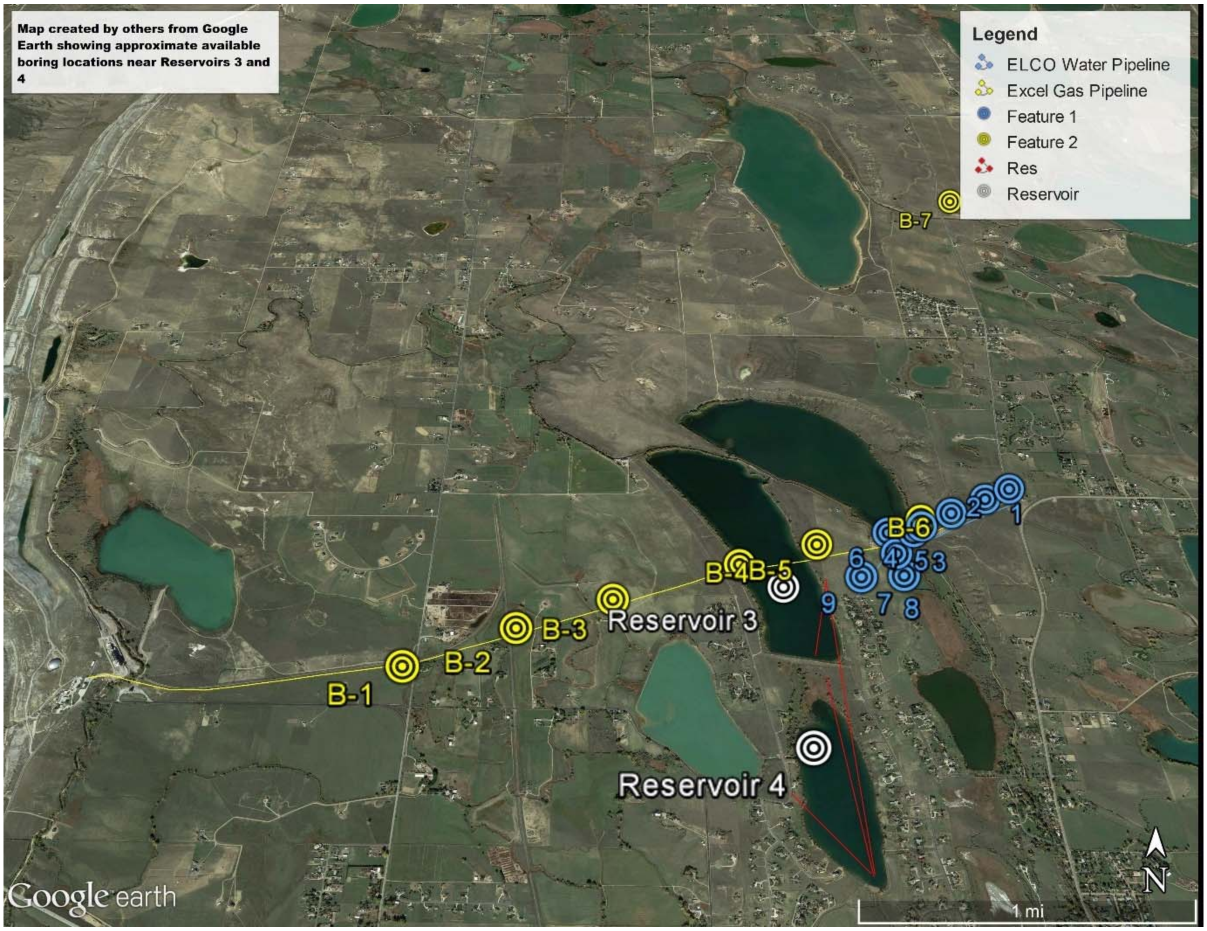


FIGURE 6
Locations of available borings near Reservoirs 3 and 4

The borings closest to the proposed intake tunnels are:

- B-4, B-5 (yellow dots) [HP Geotech, 2011]
- Boring 9 (blue dot) [Terracon, 2015]

While these borings are closest, the other boring logs were reviewed and help indicate three-dimensional geology and variations in ground conditions in the vicinity.

Boring B-5 [HP Geotech, 2011] is close to the proposed ~ 80 ft deep launch shaft for schemes North 1 and North 3. The boring log indicates:

- 0-3' Sand (SM)
- 3'-17' Sandstone
- 17'-35' Siltstone
- 35'-50' Claystone
- 50' EOB [~30' above proposed shaft depth]

Boring 9 [Terracon, 2015] is closest to the proposed ~ 80 ft deep launch shaft for schemes North 1 and North 3. The boring log indicates:

- 0-0.5' Vegetative Layer

- 0.5’-1’ Sandy Lean Clay
- 1’-14.5’ Sedimentary Bedrock - Sandstone, trace clay, fine grained, light brown rust and gray, hard to very hard
- 14.5’ EOB [~65,5’ above proposed shaft depth]

Boring B-4 [HP Geotech, 2011] is close to the proposed ~ 60 ft deep launch shaft for scheme West 1. The boring log indicates:

- 0-1’ Topsoil (SM)
- 2’-9.5’ Clay (CL)
- 9.5’-35’ Sandstone
- 35’ EOB, Practical Refusal, [~25’ above proposed shaft depth]

These borings generally indicate 1-9.5 ft of soil overlying sandstone, siltstone and claystone. The indicated geologic conditions are consistent with those implied by the geologic desk study. However, these borings are too shallow for proper shaft and tunnel design, which is a risk. In addition, none of the borings in the two reference reports were drilled, sampled and tested with methods commonly used and acceptable for tunneling. Auger drilling and driven split spoon samplers were used. This information has some value but is not suitable for design and geotechnical baseline report (GBR) preparation for tunneling. Additional tunneling focused, phased subsurface investigations would be required for tunnel design and tendering.

Tunneling focused borings should have rock coring, acoustic televiewer scanning, water pressure testing with packers; and lab testing to provide unconfined compressive strength, Brazilian tensile strength, Cerchar abrasivity data and more. The rock core should be logged to provide rock quality designation (RQD) data, core recovery and other rock character data to allow evaluation or rock quality parameters such as Geologic Strength Index (GSI), Rock Mass Rating (RMR) and/or Quality System (Q).

The reservoir area borings indicate Standard Penetration Test N-values in the rock but no unconfined compressive strength data for the rock. The N-values within the rock are of little value.

Ground Conditions and Experience from Local Tunneling Projects

The closest known tunnel project to the Reservoirs 3 and 4 site is the Bellvue Transmission Pipeline Tunnels project (see **Figure 1**). Soule et.al 2018 indicated:

> *“The subsurface investigation revealed that the Overland Tunnel would be constructed entirely through flat lying shale and claystone of the Lower Shale Member [Kpl] of the Pierre Shale (Figure 2). Representative samples of the formation were tested for various properties that affect tunnel design such as unconfined compressive strength, Brazilian tensile strength, and Cerchar Abrasivity Index (CAI). The CAI quantifies the rock abrasivity that is used to evaluate the extent of wear on tunneling equipment. The baselined values for Lower Shale Member were an unconfined compression strength of 12,000 psi, Brazilian tensile strength of 300 psi, and a CAI of 0.6. The CAI values are considered non-abrasive (Cerchar, 1973). Due to the tunnel being primarily located in shale and claystone, the stickiness potential, based on the consistency index and plastic index of the material was evaluated and baselined to exhibit 70% medium stickiness potential and 30% low stickiness potential. The stickiness potential measures the materials tendency to “gum up” equipment and stick to*

itself which can be a significant design consideration when selecting tunneling equipment."

And

"The East-West Tunnel alignment extended through several different Mesozoic aged formations (Figure 2), including the Mowry Shale, South Platte Formation (sandstone, interbedded shale and sandstone, and shale), and the Lytle Formation (sandstone). The bedrock formations encountered had compressive strengths ranging from 1,095 psi to 21,481 psi, tensile strengths varying from 92 psi to 1,195 psi, and CAI values of 0.4 to 4.2. The CAI values are considered to range from non-abrasive to highly abrasive (Cerchar, 1973)."

Based on this information, the rock unconfined compressive strengths (UCS) for the proposed intake tunnels may range from ~1.0 ksi (weak) to 22,0 ksi (moderate to hard) and the abrasivity (CAI) from low to high [actual data must be determined by a proper subsurface investigation program]. Rock with UCS over ~10 ksi and perhaps lower, will require rock disc cutters instead of soil rippers and scrapers. This means that rock microtunneling, rock TBM tunneling or rock drill-blast tunneling would likely be required.

The reservoir area borings do not provide any data on rock porosity or permeability – a very important parameter for tunneling. Soule et.al 2018 do state the following for the Overland Tunnel:

"The shale and claystone encountered had a relatively low permeability resulting in low groundwater inflows that did not exceed the inflow outlined in the GBR."

For the East-West Tunnel, Soule et.al state:

"The most notable challenges to overcome during construction was combination of significant groundwater inflows combined with an excavation through several, very-fine grained rock formations in the East-West Tunnel. The groundwater inflows into the East-West Tunnel were significantly higher than the GBR value of 1,200 gallons-per-minute. At the peak, the flow meters placed on the settling tanks measured 1,766 gallons-per-minute. These high groundwater inflows combined with fines from the excavation made separation of the water and solids a significant challenge and created an issue with meeting the Colorado Department of Public Health and Environment's (CDPHE) suspended solid discharge limit."

The high groundwater inflow for the East-West tunnel where the ground was reported to be "Mowry Shale, South Platte Formation (sandstone, interbedded shale and sandstone, and shale), and the Lytle Formation (sandstone)", is an indication that high permeability and high potential inflows may occur for the proposed intake tunnels at Reservoirs 3 and 4, where sandstone, siltstone and claystone is expected. Such high potential inflows generally preclude the use of open-face tunneling methods such as conventional drill-blast tunneling, TBM shield tunneling or small main-beam gripper TBM tunneling without substantial, expensive and slow pre-excavation grouting. Such pre-excavation grouting is normally completed from the tunnel heading and would be very difficult and impractical in small diameter tunnels intended to install 48- to 60-inch pipelines.
Another consideration is the risk of toxic or hazardous (explosive) gasses. The geologic papers reviewed indicate that the site is near a known oil-gas field and that the Pierre Shale is known to potentially contain methane gas and other hazardous or toxic gasses. These gases increase tunneling risk and may be a serious issue for open-face tunneling methods. The risk of toxic or hazardous

(explosive) gasses may be mitigated by use of slurry or slurry mix-shield microtunneling. Experience in gassy ground is that this method is effective at mitigating the gas risk.

For both the potential inflow and gas reasons, the best assumed tunneling method to handle the preliminary interpreted ground conditions at Reservoirs 3 and 4, is pressurized face rock microtunneling. This method generally utilizes a slurry shield or slurry mix-shield microtunnel boring machine (MTBM) that allows the water pressure at the face to be counterbalanced thus preventing heading inflows. Note that slurry mix-shield microtunneling differs from slurry microtunneling in that a compressed air chamber is added behind the excavation chamber and compressed air allows much tighter control of face pressures than ordinary slurry microtunneling which relies on pumping rates to control pressure. The microtunneled intake method involves jacking steel pipe such as Permalok (most common) or reinforced concrete pipe (occasionally). Additional discussion of the tunneling method is provided below.

North American Experience with Microtunneling for Intakes

As indicated in the ground conditions discussion above, pressurized face microtunneling using a slurry shield or slurry mix-shield MTBM is assumed to be the most appropriate method for the proposed intake tunnels. Other potential methods are discussed after the microtunneling discussion.

Microtunneling for Intake Tunnels

If the tunnel zone ground conditions are found to include sandstone with UCS values over ~ 10 ksi as previously discussed, the MTBM selected would likely utilize multi-kerf disc cutters such as were used to bore through sandstone to jack 60-inch ID steel Permalok pipe for the Ute Reservoir Intake – **Figure 7**. If the tunnel zone is found to be all shale or claystone with UCS less than 10 ksi, ripper and scraper cutters may be utilized such as equipped on the MTBM used to jack 72-inch ID steel Permalok pipe for the Standley Lake Colorado intake tunnels – **Figure 8**.

FIGURE 7

62.5-inch diameter Akkerman SL60 MTBM at Ute Reservoir Intake (Anderson 2014, Worthen et.al 2015)

FIGURE 8

75-inch diameter Akkerman SL74 MTBM at Standley Lake Intake (Deere et.al 2005, Goss 2006, Jacobs files)

Microtunneling with a slurry MTBM or slurry mix-shield MTBM utilizes a water and soil slurry, or water, soil and bentonite-polymer slurry to balance the water pressure and the heading. After the cutters fracture (chip) or pluck the rock, the 'muck' passes into the excavation chamber and is crushed into sand and gravel size material. The tunnel muck and slurry are then pumped through a discharge pipeline down the tunnel and up the launch shaft to a separation plant where the muck is separated from the slurry and subsequently disposed. The slurry is generally recycled back down a feed pipeline to the MTBM to repeat the cycle. Once the slurry has lost effectiveness or at the end of tunneling, it is generally pumped into tanker trucks and disposed in an environmentally acceptable landfill.

Microtunnel Reception at Intake

Microtunneling can be used in a conventional manner and jacked from a launch to a reception shaft such as done for the Table Rock lake input in South Carolina (Leiendecker 2006). Use of an intake riser and MTBM reception shaft in the lake is uncommon due to the extra shaft cost involved. More commonly, microtunneling through a cut bench within the reservoir walls or lake bottom is used. A study by the author indicated that the wet recovery method was used for 13 out of 14 microtunneled intakes in North America – The Table Rock intake was the exception.

The wet recovery method generally requires preparation of a bench or excavation within the lake bottom. For the Ute Reservoir Intake, a bench was cut with underwater excavating in the steeply sloped sandstone wall along the lake shore – **Figure 9**. For the Standley Lake Intake, a bench was dug into the lake claystone lake bottom – **Figure 10**.

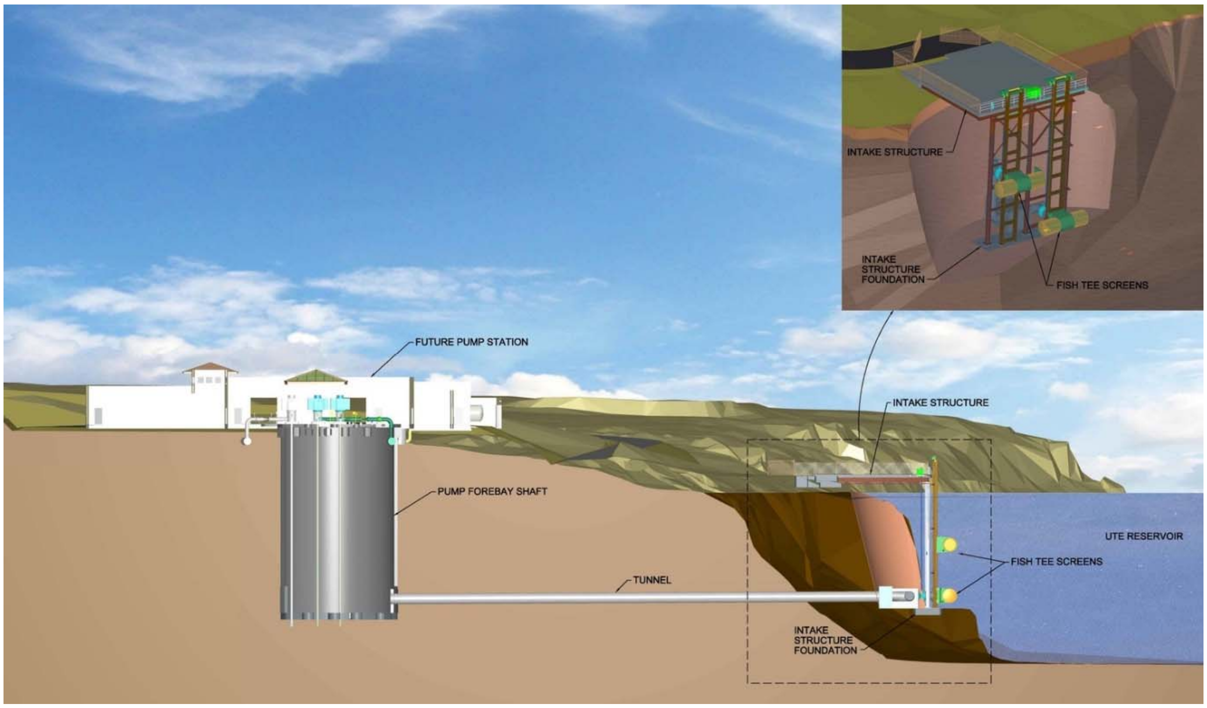


FIGURE 9

Ute Reservoir Intake pump station wet well launch shaft to MTBM wet recovery bench (Jacobs files)

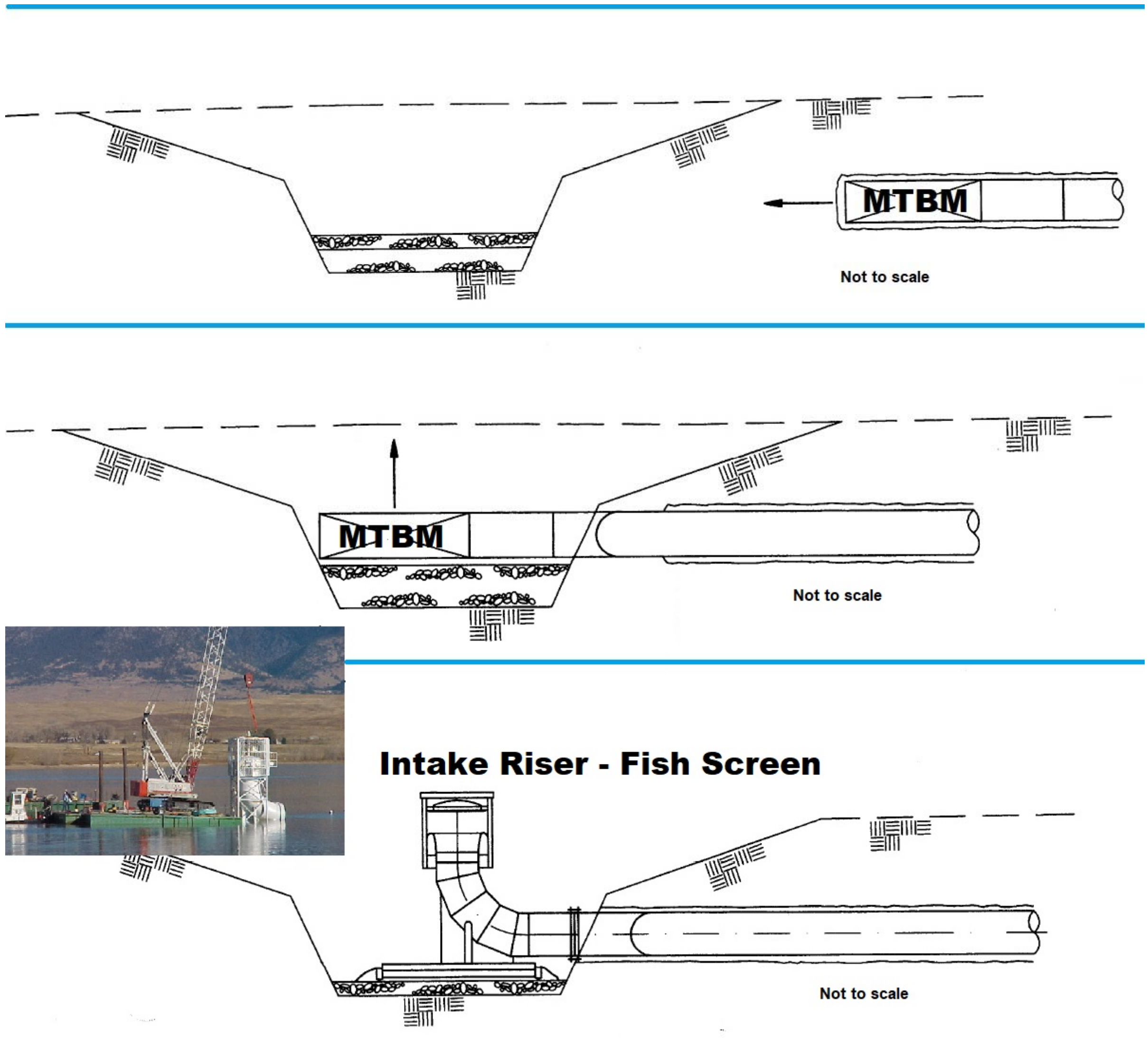


FIGURE 10
Standley Lake Intake bench cut with MTBM wet recovery then intake fish screen (Jacobs files)

Not shown but utilized for all the wet recovery intakes are water isolation bulkheads on both the MTBM shield and the lead jacked pipe. The bulkhead on the MTBM protects the internal equipment from flooding as it is removed and until it is returned to land. The bulkhead on the pipe generally has a valve that allows pipeline flooding and bulkhead removal when ready. Intake structures or fish screens are installed after the MTBM is removed.

Microtunnel Drive Length

A critical issue for microtunneling is the drive length. Drive length is affected by tunnel diameter, pipe material skin friction, ground convergence or squeezing ground risk which may increase skin friction, increases in skin friction from interface shear strength increases or convergence during stoppages, MTBM face pressure, cutter thrust forces, stresses in the jacked pipe, thrust jack capacity and other factors. In general, the practical maximum drive length is smallest for small diameter jacked pipes and increases with diameter.

To reduce the risk of getting stuck and to provide more thrust to the MTBM heading without overstressing the jacked pipe, intermediate jacking stations are commonly installed within the pipe train as a precaution. Experience with long distance pipe jacking and microtunneling around the world helped produce the guideline chart shown in **Figure 11**. The chart shows four lines:

- A practical maximum without the use of intermediate jacking stations.
- A practical maximum with the use of intermediate jacking stations.
- Adams 2001 maximum achieved (with the use of intermediate jacking stations).
- Ishizuka 2003 maximum possible (with the use of intermediate jacking stations).

All the limit lines clearly show that viable drive lengths increase with pipe diameter. The costs and risks are generally much higher for long drives above the practical maximum with the use of intermediate jacking stations. For 60-inch jacked pipe, the limits are:

- ~600 ft practical limit without the use of intermediate jacking stations.
- ~1,800 ft practical limit with the use of intermediate jacking stations.
- ~3,000 ft maximum achieved (with the use of intermediate jacking stations).
- ~4,000 ft maximum possible (with the use of intermediate jacking stations).

Note that these long drive lengths are mostly <u>not</u> for microtunneled tunneled intakes. Drive data for microtunneled intakes and outfalls is shown in **Figure 12**. It shows that only 2 out of 14 plotted case history points are above the practical maximum without the use of intermediate jacking stations and none are above the practical maximum with the use of intermediate jacking stations. The figure also shows four points for global (non-North American) intakes and outfalls that are near above the practical maximum with the use of intermediate jacking stations. While theoretically, microtunneled intakes could achieve the limits and data shown in **Figure 11**, the risks of subaqueous tunneling with marginal ground cover and the wet recovery risks tend to limit drive lengths for microtunneled intakes.

The data suggests the practical drive length limit and maximum possible limit is ~600 ft and ~1,600 ft, respectively for 48-inch ID pipe and 1,000 ft and ~3,000 ft, respectively for 60-inch ID pipe. This means that all five proposed microtunnel drives for the four Reservoir 3 and 4 schemes exceed the practical limit for both 48 or 60-inch pipe, and that all proposed tunnel lengths exceed the maximum possible for 48-inch pipe. Two of the five drives are within the maximum possible limit for 60-inch pipe. In all the cases, the risk of getting stuck, pipe damage and other hazards increases for drives above the practical maximum with use of intermediate jacking stations. Exceeding that limit should only be attempted with careful, proactive risk mitigation measures in place.

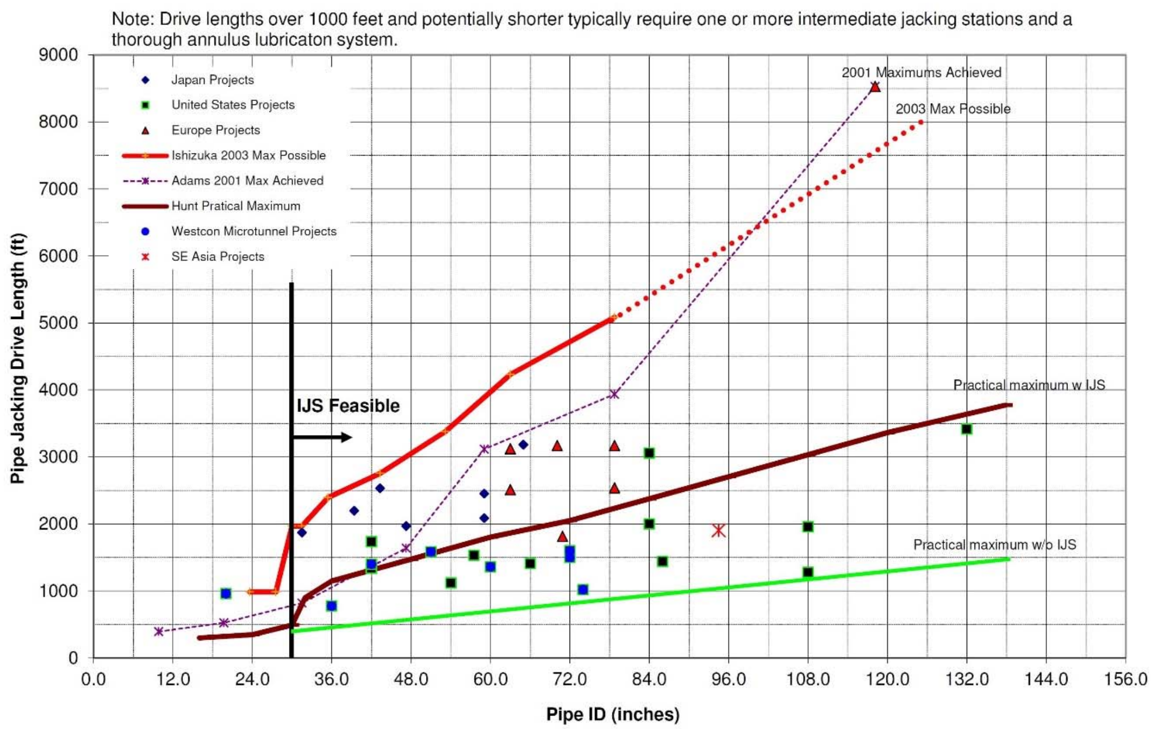


FIGURE 11

Global Long Drive Microtunnel Drive Length vs. Pipe ID

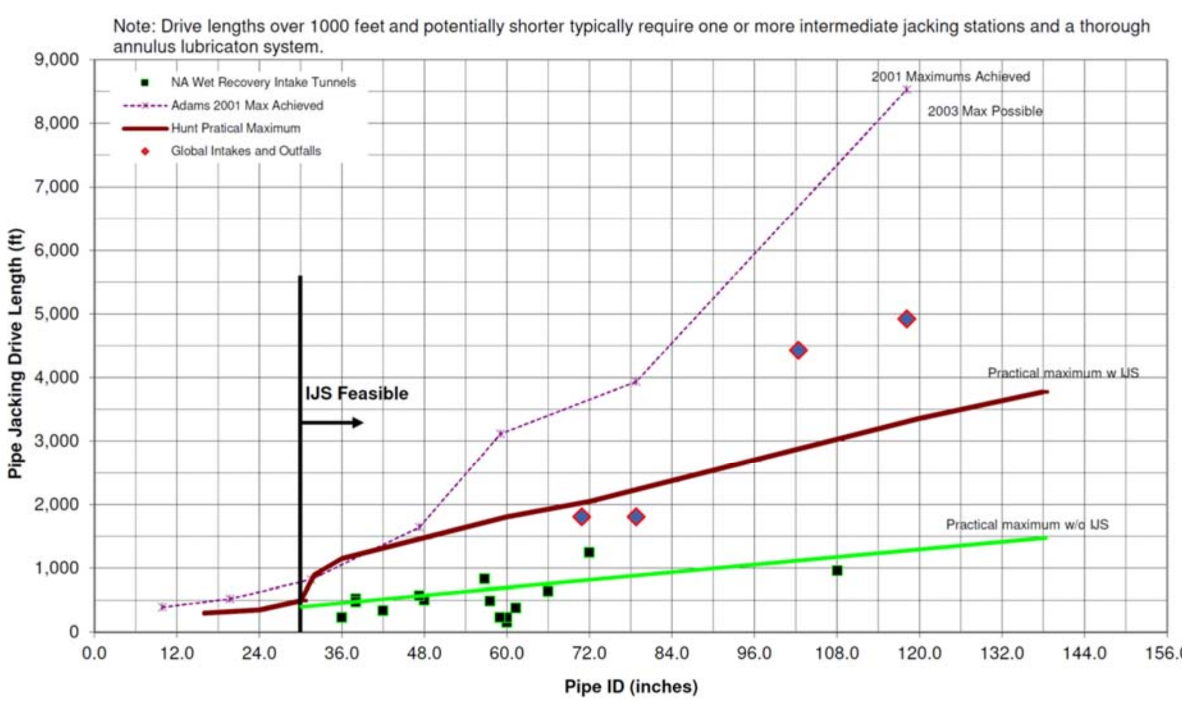


FIGURE 12

North American Microtunneled Intake and Global Intake and Outfall Drive Length vs. Pipe ID

Other Tunneling Methods for Small Diameter Intake Tunnels

Other tunneling methods could be used to drive a small diameter intake tunnel, but the cost and risk of these methods may make them impractical. Those methods and their applicability include:

- Hand mined, roadheader (rotary milling machine) or conventional drill-blast tunnels in atmospheric conditions – these methods are viable in low permeability, competent ground that is stable with common initial support such as liner plate, ribs and lagging or rock dowels and shotcrete. In wet ground zones, the method would require substantial, effective pre-excavation grouting. These open face methods not only may require grouting, but are also ineffective at isolating hazardous and toxic gases. The smallest practical size with roadheader and drill-blast tunneling is around 8 feet, so a large opening and more muck removal is required. Tunneling is generally advanced to a location for 'wet tap' plug removal by blasting after the tunnel is flooded; or it is advanced to an intake riser shaft or casing. A carrier pipe with the pipe material of choice would be subsequently placed and grouted unless the rock is hard and durable without a secondary lining such as designed for Lake Mead Intake No. 1. Hand mined tunnels are generally short with lengths less than 500 ft. Roadheader and conventional drill blast tunnels may be 5,000 feet long or more with no risk of a TBM getting stuck.
- Hand mined, roadheader (rotary milling machine) or conventional drill-blast tunnels in compressed air or with pre-excavating grouting to control water inflows. The method is the same as above with compressed air or grouting added, both of which increase risks and cost making the method impractical for tunnel zone conditions with significant groundwater inflow risk.
- Pressurized face tunneling with a precast concrete segmental lining. With this method, a slurry or earth pressure balance TBM is used to isolate groundwater inflows and a precast concrete segmental lining is installed in the tail of the shield and extruded as the TBM incrementally advances. The smallest practical inside diameter for this method is 72 inches or 6 feet, so it is not viable for the proposed intake diameters. One advantage of the method is that the tunnel length may be up 5,000 ft or more with little risk of the TBM getting stuck, although advance rate generally decreases with length.

Local Tunnel Experience

Four tunnel projects were found from a desk study for Fort Collins area tunneling experience. The approximate locations are shown in **Figure 1**. Table 2 summarizes information for the three closest projects.

The closest and most relevant tunnel project was the Bellvue Transmission Main Tunnels project as previous discussed. The Bellvue project provides useful information on ground conditions and behavior, but it involved open-face, larger diameter two pass tunneling and not one-pass pressurized face microtunneling. The open-face tunneling method worked well for the Overland Tunnel which was situated in shale and claystone - only small inflows were reported. The East-West tunnel encountered much higher permeability sandstone and shale resulting in high inflows and a GBR differing site condition. Soule et.al 2018 reported: "The groundwater inflows into the East-West Tunnel were significantly higher than the GBR value of 1,200 gallons-per-minute. At the peak, the flow meters placed on the settling tanks measured 1,766 gallons-per-minute." These high inflows appear to have impacted tunneling productivity and resulted in extra water disposal measures and costs. Impacts such as these are good reasons for specifying pressurized face tunneling for the proposed reservoir intake tunnels.

Table 2 – Fort Collins Area Tunneling Experience

Project Name	Tunnel Purpose	Dates	Inside Diam., ft	Tunnel Length, ft	Ground Conditions	Tunneling Method	Comments
Bellvue Transmission Main Tunnels	Water conveyance	2016-2017	5’ steel carrier pipe. 0.5” wall	Overland Tunnel: 567’ East-West Tunnel: 1814’	Shale and claystone, sandstone and shale	86” OD open-face TBM with ribs and lagging	Ref: ND2018.48
Fossil Creek Pedestrian Tunnel	Pedestrian underpass below rail	2016-2017	14’ steel casing pipe, 1.25” wall	70’	Embankment fill and alluvium	Mini-backhoe shield and casing pipe jacking on auger bored steel guide rails	Ref: ND2018.74
Fossil Creek Drainage Tunnels	Stormwater below railroad embankment	2006-2007?	twin 10’	2 x 200’	Embankment fill and alluvium	Jacked pipe on rails behind open face digger shield	Ref: ND2008.19

Potential Construction Issues and Risks

Anticipated or potential construction issues and risks have been mentioned in the previous discussion but are summarized in Table 3 for microtunneling 60-inch pipe for the proposed intake tunnels. Use of 48-inch pipe would have even higher risks than for the 60-inch ID pipe and therefore, one-pass microtunneling of 48-inch pipe is not considered viable for any of the proposed drives as indicated in **Figure 12**. Only drives W1 and N1A are viable for the 60-inch ID pipe.

Table 3 – Summary of Potential Risks for Proposed Microtunneling with Wet Recovery, 60-inch ID

Tunnel Drive→	**West 1, W1**	**North 1, N1a**	**North 1, N1b**	**North 2, N2**	**North 3, N3**
Length→ **Risk ↓**	(1,980 ft)	(2,100 ft)	(3,900 ft)	(3,900 ft)	(6,420 ft)
Stuck from excess skin friction, delay	High risk, but possible	High risk, but possible	Extremely high – exceeds limit	Extremely high – exceeds limit	Extremely high – exceeds limit
Pipe or joint damage from high jacking stress	Moderate risk but manageable with IJS use	Moderate risk but manageable with IJS use	High risk even with IJS use	High risk even with IJS use	High risk even with IJS use
Ground movement, shifting at MTBM approaches bench wall	Moderate risk, short delays may be tolerable	Moderate risk, short delays may be tolerable	High risk, even short delays may result in stuck drive	High risk, even short delays may result in stuck drive	High risk, even short delays may result in stuck drive
Slurry frac-out to lake	Lowest risk, ~75% or ~1485 ft of drive below lake	Lower risk, ~95% or ~1995 ft of drive below lake	High risk, ~80% or ~3120 ft of drive below lake	High risk, ~80% or ~3120 ft of drive below lake	Highest risk, ~80% or ~5136 ft of drive below lake
Slow advance rate from IJS use	Lowest risk	Low risk	High risk	High risk	Highest risk
Unexpected ground condition, fault zone, low cover, gas, oil, etc.	Lowest risk	Low risk	High risk	High risk	Highest risk

General Cost Considerations

Accurate cost estimating for intake tunnel schemes is not possible until additional tunnel focused subsurface exploration and at least preliminary design are completed. Conceptual planning levels costs can be made, but due to scope and other uncertainties, such costs are not considered reliable for budget assessment. Conceptual planning level cost estimates can be used to compare costs for various tunneling alternatives or between tunneling and trench methods.

The author's database for North American microtunneled intakes has 14 project case histories but only cost data for 8 projects. **Figure 13** shows a plot of North American microtunneled intake construction cost in 2018 dollars vs. flow capacity. This plot may be misleading since it does not allow intake length to be considered. The eight projects in the plot had lengths ranging from 180 to 1246 ft, averaging 600 ft. Thus, this figure would not be useful for estimating costs for the reservoir tunnels.

A better indication of ballpark construction cost can be made using **Figure 14** which shows North American microtunneled intake construction cost per foot of tunnel in 2018 dollars vs. tunnel inside diameter. It indicates that the trendline cost for a 60-inch ID tunnel is ~$34,000 per foot of tunnel with a scatter range from $25,000/ft to $72,000/ft. On a per inch of tunnel diameter basis, the range is from $100/ft/inch to $1200/ft/inch. The scatter is due to differences in scope, depth, ground conditions risks, etc. For comparison purposes, a general, planning unit cost for construction of trenched pipeline is approximately $15/ft/inch of diameter. Therefore, construction cost for tunneled intakes is almost 7 to 80 times greater than an equivalent length of trenched pipeline.

These unit rated costs for intake tunnels may be compared to non-intake microtunneling contract costs. **Figure 15** shows a chart with microtunnel construction costs in 2018 dollars per foot versus tunnel ID. For 60-inch ID, the low risk trend cost is ~$2,000/ft, the medium risk trend cost is ~$3,200/ft and the high-risk trend cost is ~$6,200/ft. All of these unit rate costs are much lower than the intake tunnel costs due to substantial differences in scope and risk. **Figure 15** does help indicate how ground conditions and risk influence the cost trendlines. Unit rate costs are much higher for higher risk conditions.

Ground conditions and risks should be considered when making estimates for the proposed reservoir tunnels. With current uncertainties on ground conditions and with the long lengths proposed, the risks and the estimated unit costs should be on the higher side of ranges shown.

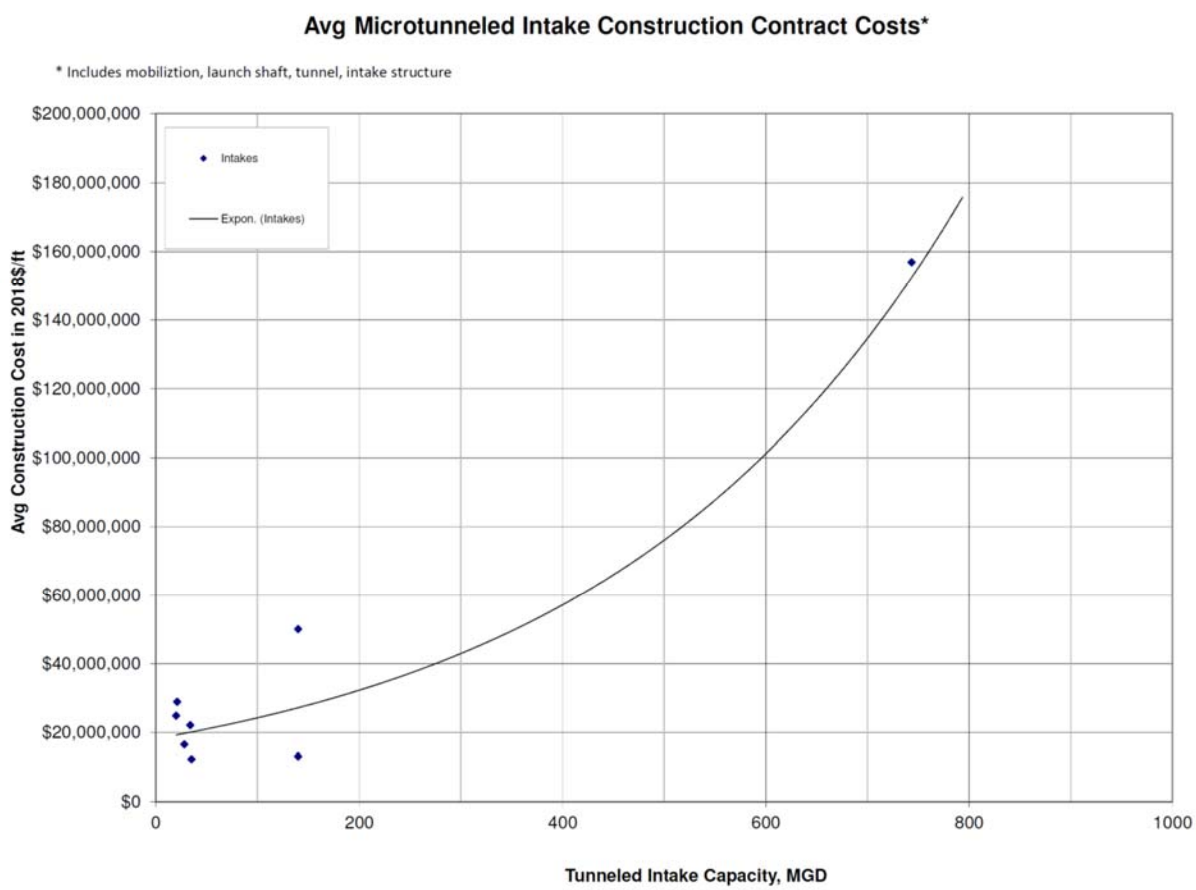


FIGURE 13
North American Microtunneled Intake Construction Cost vs. Flow Capacity

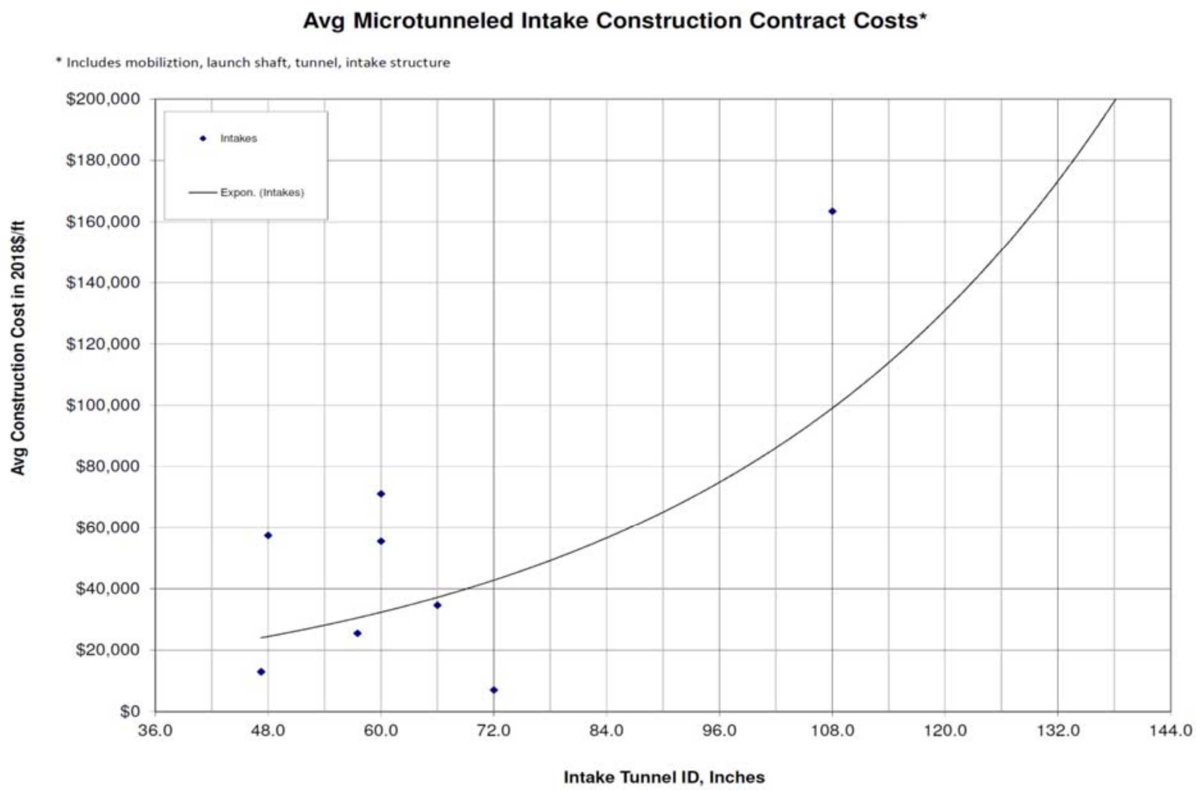


FIGURE 14
North American Microtunneled Intake Construction Cost vs. Tunnel ID

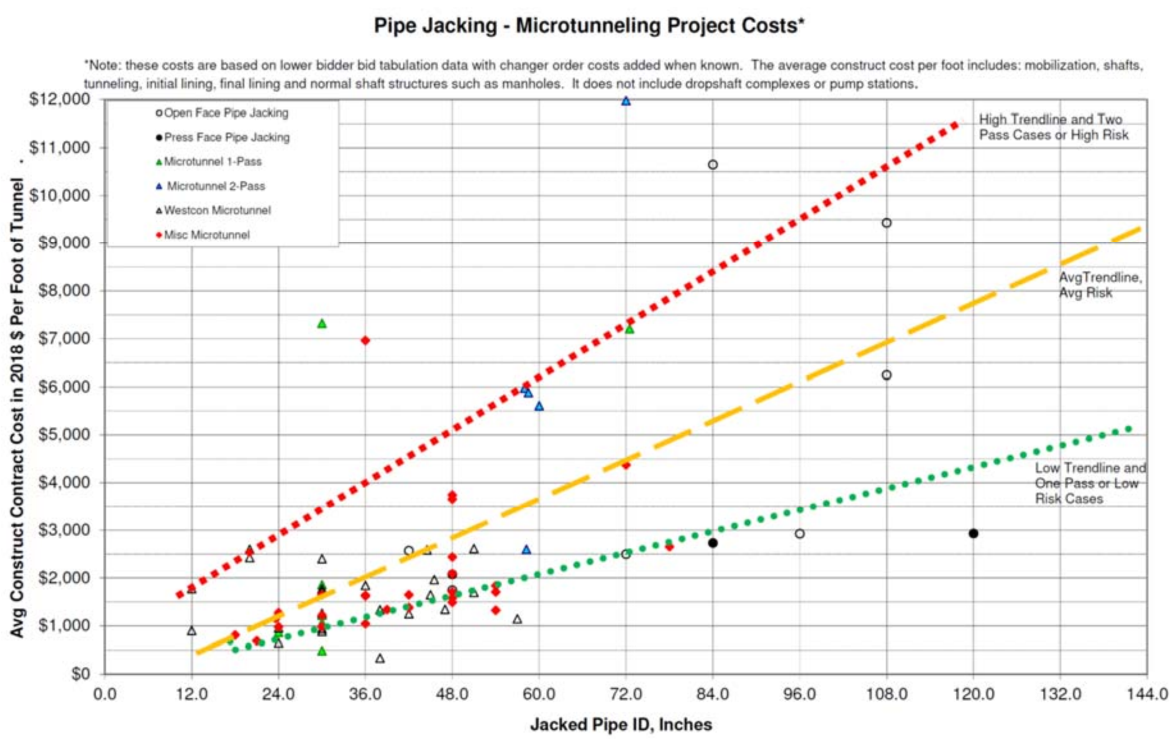


FIGURE 15
North American Microtunneled Non-Intake Construction Cost vs. Tunnel ID

Summary and Conclusions

This technical memorandum provides an assessment of the conceptually planned intake tunnels for four schemes at Reservoirs 3 and 4. A desk study review of geologic papers and available reservoir area borings indicates that the tunnels are likely situated within relatively high permeability sandstone or sandstone interbedded with siltstone and claystone. Considerable uncertainty exists on the ground conditions and a tunnel focused, phased subsurface exploration program would be required to reduce these uncertainties.

Based on the interpreted ground condition data and a review of local tunneling experience, particularly that for the Bellvue Transmission Pipeline tunnels, pressurized face tunneling such as with slurry shield or slurry mix-shield microtunneling will be required. Microtunneling to a reception shaft is viable, but wet recovery microtunneling would cost less and is assumed to be the preferred method. Open-face tunneling such as used for the Bellvue Transmission Pipeline tunnels is not considered viable based on the interpreted ground conditions, for tunnel alignments below the lake and considering that the open-face methods would require a reception shaft in the lake at much higher additional cost. In addition, the open-face methods would result in a much higher risk of toxic or hazardous gas impacts such as explosions. To effectively isolate groundwater and gas, pressurized face microtunneling is considered the most viable method for the proposed diameters.

The biggest risks with the proposed five tunnels for the four reservoir intake schemes are the proposed tunnel lengths. The proposed lengths range from 1,900 to 6,240 feet. These lengths are much longer than microtunneled intake experience in North America. A study of 14 North American microtunneled intake case histories show a tunnel drive length range from 153 to 1,246 ft with an average of 498 ft. The longest microtunneled intake completed in North America is less than the shortest of the five proposed intake tunnels.

An assessment of the tunnel lengths and associated risks indicates that microtunneled 48-inch ID pipe is not feasible for any of the five proposed intake tunnels. For 60-inch pipe, only drives W1 for the West 1 scheme and N2 for the North 1 scheme are viable. The risks for these two proposed tunnels are still higher than usual, but the risks for the other three tunnels are excessive.

Some general intake and microtunneling conceptual planning charts are provided and implied costs can be compared to potential trenched intakes for comparison. Cost estimates should consider the anticipated high risks and higher trend unit costs should be assumed. For 60-inch ID microtunneled pipelines, the ballpark intake cost may exceed $40,000 per foot of tunnel (**Figure 14**) depending on scope, ground conditions, final tunnel length, depth, etc.

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Thornton Water Project

Larimer County Road 56 Construction Sequence

PREPARED FOR:	City of Thornton
COPY TO:	File
PREPARED BY:	CH2M HILL
DATE:	October 29, 2018

General

This technical memorandum (TM) summarizes the proposed construction sequence for parallel installation of the Thornton Water Project (TWP) by the City of Thornton (Thornton) and the Northern Integrated Supply Project (NISP) North Pipeline by Northern Water (Northern) in Larimer County, north of Fort Collins. Both the TWP and NISP have proposed water pipelines within an area bordered on the north by Highway 1 and on the south by Douglas Road. The preferred location for the TWP water pipeline as presented in Thornton's 1041 permit application is in Douglas Road. The 1041 permit application also included other reasonable alternative locations, including Larimer County Road 56 (LCR 56). The preferred location for the NISP North Pipeline as presented in its NEPA FEIS is along LCR 56, but also includes an alternative location in Douglas Road.

Larimer County, in an effort to minimize impacts from both projects, has requested evaluation of parallel installation of TWP and NISP along LCR 56. For the LCR 56 corridor, the County prefers that the water pipelines be installed in easements adjacent to County road rights-of-way but will consider installation in the right of way if space is not available outside the right of way. The TWP water pipeline is planned to be a 48-inch welded steel pipe (WSP), and the NISP water pipeline is planned to be a 54-inch WSP.

The proposed corridor for the two water pipelines is as described in the Technical Memorandum *Thornton Water Project Larimer County Road 56 Alignment Alternative,* October 17, 2018 (attached as Appendix A).

Construction Sequence

Construction of the two water pipelines will occur with both water pipelines in easements on private property outside rights-of-way or both water pipelines within LCR 56 right-of-way. The construction process for both cases is described in further detail below.

Water Pipelines in Easements

The typical cross section for installation of both the TWP and NISP water pipelines in easements on private property is shown in Section 1 attached. Most construction will be by traditional open cut methods, with the two water lines spaced 25 feet apart center to center in permanent easement with an overall width of 75 feet. In areas where the water lines are installed in easements on private property, construction can occur at the same time with separate trench headings staggered

100 feet, or at separate times. If they are constructed at the same time, temporary construction easements will be required on one or both sides of the permanent easement (depending upon available space) to provide an overall width of 120 feet. If they are constructed at separate times, temporary construction easements will be required on one or both sides of the permanent easement (depending upon available space) to provide an overall width of 90 feet for TWP and 100 feet for NISP.

TWP cannot open cut areas designated as wetlands or waters of the US. In these areas, TWP will be installed by trenchless methods, with additional temporary easement required on a case by case basis. NISP is allowed to install by open cut methods in these areas, and will do so, acquiring additional temporary easement as required.

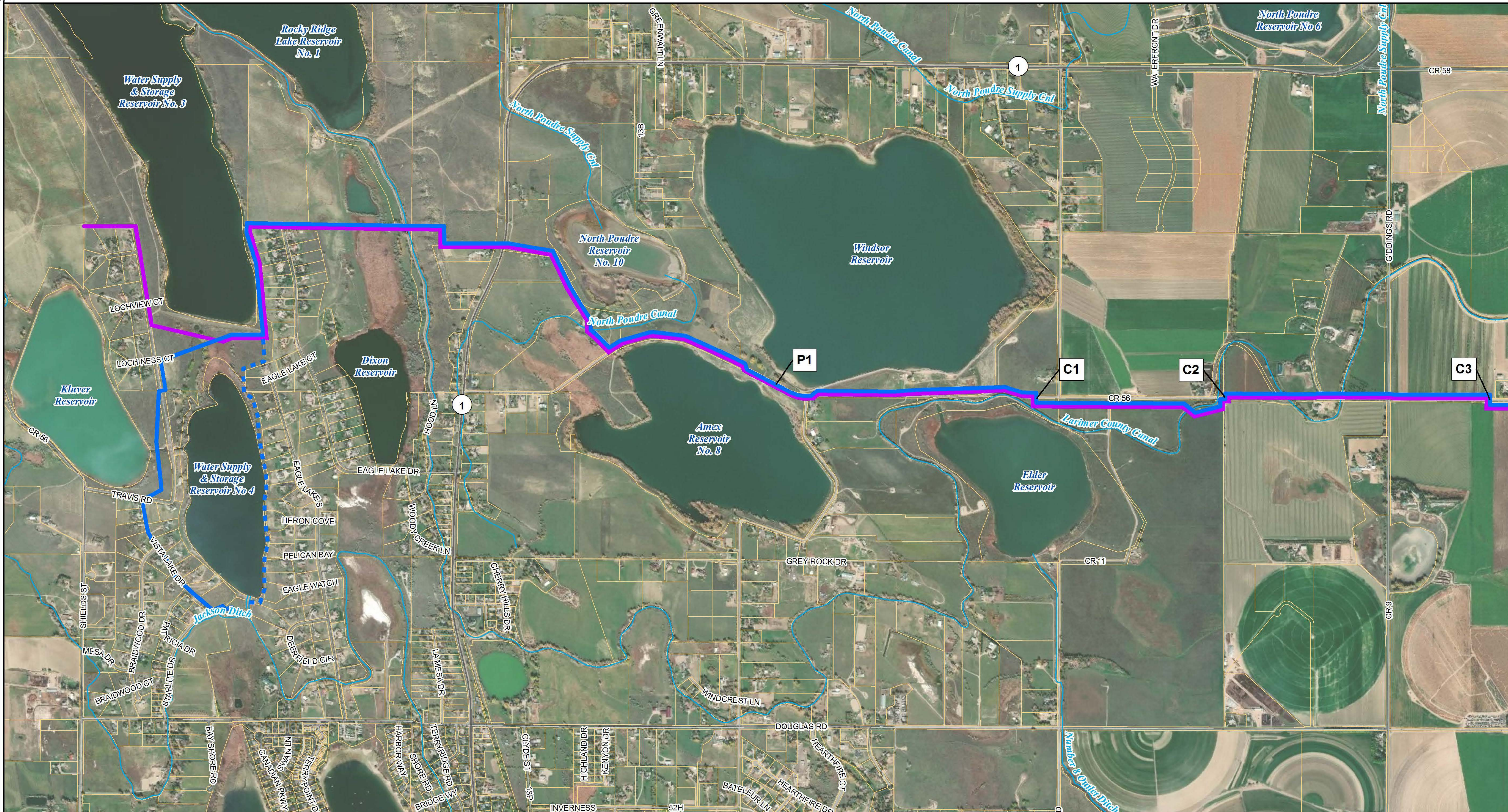
Water Pipelines in Right-of-Way

The typical cross section for installation of both the TWP and NISP water lines in the LCR 56 right of way is shown in Section 2 attached. Construction will be by traditional open cut methods, with the two water lines spaced 25 feet apart center to center. In areas where the water lines are installed in right of way, construction must occur at the same time with separate trench headings staggered 100 feet. The LCR 56 right of way varies from 50 to 60 feet in areas where the water lines are proposed within the right of way. Temporary easement may be acquired on one or both sides of the right of way (depending upon available space) to provide an overall width of 120 feet. Where space is available to acquire temporary easements, and that space is sufficient, the water pipelines may be installed with slope trench walls to eliminate the need for trench shoring. If space is not available, or at the Contractor's discretion, trench shoring will be used to limit extent of the excavations.

Construction Schedule within LCR 56 Between Highway 1 and Interstate Highway 25

As noted in Technical Memorandum *Thornton Water Project Larimer County Road 56 Alignment Alternative,* October 17, 2018, there are only four (4) locations along LCR 56 where construction is proposed within the right-of-way of LCR 56 between Highway 1 and Interstate Highway 25 as shown in **Figure 1**. One crossing P1, is within and parallel to the right-of-way and the other three (3) are crossings of the right-of-way. **Table 1** presents estimated duration of construction within these four (4) locations. Crossings will be constructed across half the ROW, then construction area switched to opposite side of ROW, so a single lane remains open during construction of the crossing.

Thornton Water Project



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10/29/2018

NISP Alignment	Railroad
TWP CR56 Conceptual Alignment	River/Stream/Canal/Ditch
TWP WSSC 4 East Conceptual Alternative	Canals and Ditches

Figure 1
CR 56 Conceptual Alignment
Thornton Water Project

Table 1. Construction Duration for Dual Water Pipeline Construction at locations within LCR 56 Between Highway 1 and Interstate Highway 25

Segment	Length (ft, if parallel)	Duration (Work Days)	Comments
P1	1,200	15-20	Road Closure-- Approximately 1,200 feet of dual water pipeline construction, including a crossing of LCR 13
C1	NA	5	Alternate single lane closures for crossings-- Crossing from the northside of LCR 56 to the southside of LCR 56
C2	NA	5	Alternate single lane closures for crossings-- Crossing from the southside of LCR 56 to the northside of LCR 56 through the intersection of LCR 56 and LCR 11/Turnberry Road
C3	NA	5	Alternate single lane closures for crossings-- Crossing from the northside of LCR 56 to the southside of LCR 56

Appendix 1—Technical Memorandum Thornton Water Project Larimer County Road 56 Alignment Alternative, October 17, 2018

TECHNICAL MEMORANDUM

Thornton Water Project
Larimer County Road 56 Alignment Alternative

PREPARED FOR: City of Thornton

COPY TO: File

PREPARED BY: CH2M HILL

DATE: October 17, 2018

General

This technical memorandum (TM) summarizes the proposed alignment for parallel installation of the Thornton Water Project (TWP) by the City of Thornton (Thornton) and the Northern Integrated Supply Project (NISP) North Pipeline by Northern Water (Northern) in Larimer County, north of Fort Collins. Both the TWP and NISP have proposed water pipelines within an area bordered on the north by Highway 1 and on the south by Douglas Road. The preferred location for the TWP water pipeline as presented in Thornton's 1041 permit application is in Douglas Road. The 1041 permit application also included other reasonable alternative locations, including Larimer County Road 56 (LCR 56). The preferred location for the NISP North Pipeline as presented in its NEPA EIS is along LCR 56, but also includes an alternative location in Douglas Road.

Larimer County, in an effort to minimize impacts from both projects, has requested evaluation of parallel installation of TWP and NISP along LCR 56. For the LCR 56 corridor, the County prefers that the water pipelines be installed in easements adjacent to County road rights-of-way, but will consider installation in the right of way if space is not available outside the right of way. The TWP water pipeline is planned to be a 48-inch welded steel pipe (WSP), and the NISP water pipeline is planned to be a 54-inch WSP.

Alignment Description

As shown in the attached figure, TWP and NISP can be in a common corridor along LCR 56 from the area between Water Supply and Storage Company (WSSC) Reservoirs 3 and 4 to approximately LCR 7.5. TWP approaches this corridor from the south, and NISP from the northwest. The TWP water pipeline originates from the outlet works of WSSC Reservoir 4, and routes around the west side of WSSC 4 and west between WSSC 3 and WSSC 4. Alternately, TWP could route east of WSSC 4 to the same point between the reservoirs. NISP routes around the north side of Kluver Reservoir and existing residential development, then south and west to the common corridor with TWP.

The common corridor for the two pipes runs north between WSSC 3 and the Eagle Lake development, then east to Highway 1 along the north end of existing residential development. From Highway 1, the corridor routes south and east in easements to the LCR 56 alignment north of Annex Reservoir No. 8. The water pipelines are located in easements adjacent to the LCR 56 right of way on the north side to a point where space is limited between Annex Reservoir No. 8 and Windsor Reservoir No. 8. In that area, the water pipelines are proposed within LCR 56 right of way for approximately 1,200 feet to a location just east of LCR 13. From this point east to approximately LCR 11, the water pipelines are in easements on the north side of LCR 56. At LCR 11, the water pipelines cross to the south side of LCR 56, on to Thornton property to LCR 9.5. At LCR 9.5, a short

Thornton Water Project

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10/19/2018

0 750 1,500 Feet
1 inch = 1,500 feet

- NISP Alignment
- TWP CR56 Conceptual Alignment
- TWP WSSC 4 East Conceptual Alternative
- Railroad
- River/Stream/Canal/Ditch
- Parcel Boundary

CR 56 Conceptual Alignment
Thornton Water Project

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TECHNICAL MEMORANDUM

Thornton Water Project Larimer County Canal Alternative Configuration and Cost

PREPARED FOR: City of Thornton

COPY TO: File

PREPARED BY: CH2M HILL

DATE: November 12, 2018

General

This technical memorandum (TM) summarizes the alignment and cost of the of the Larimer County Canal (LCC) Alternative to the Thornton Water Project (TWP). The following sections describe the proposed configuration and estimated costs of the LCC Alternative.

Configuration

The LCC Alternative is shown in **Figure 1**. This alternative includes diversion of Thornton's water at the LCC headgate, routing of the water through Water Supply and Storage Company Reservoir No. 4 (WSSC No. 4) to make use of existing storage, a pump station to take the water from the WSSC No. 4 outlet works and return it via pipeline to the LCC northwest of WSSC No. 3. Water would flow down the LCC to the Larimer/Weld County line at approximately Weld County Road (WCR) 84.5 where it would be diverted from the ditch and piped approximately 1.25 miles south to a farm owned by Thornton where a pump station would be built to convey the water to Thornton.

WSSC No. 4 Pump Station

The WSSC No. 4 pump station located at the WSSC No. 4 outlet would have a capacity of 44 million gallons per day (MGD) to pump 40 MGD to Thornton and 4 MGD to account for ditch losses, and pump water back up to the LCC with a total dynamic head (TDH) of 120 feet. The approximate cost of that pump station is $9.5 million.

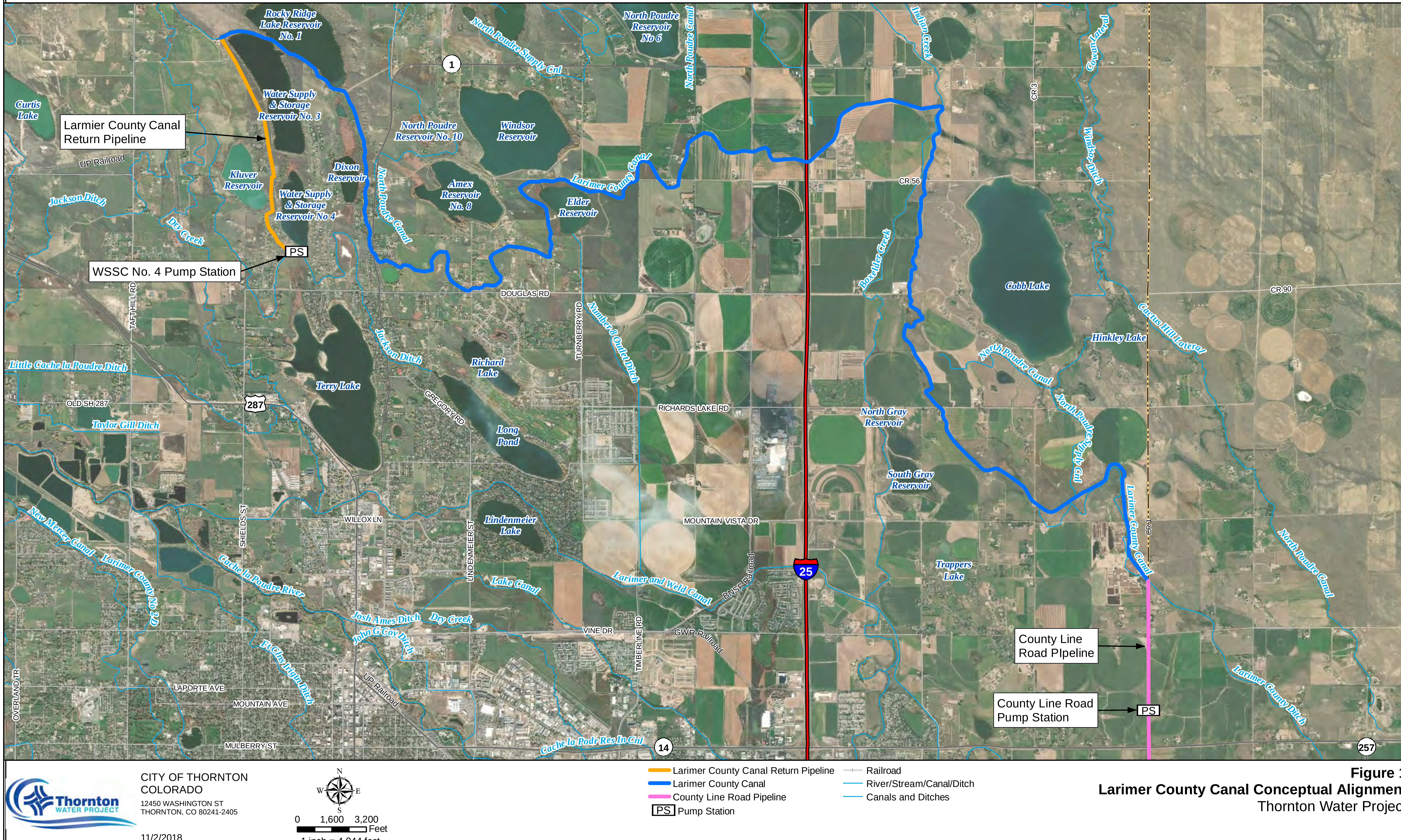
LCC Return Pipeline

The LCC Return pipeline is approximately 12,000 feet in length at 48-inches in diameter. Using a planning level cost of $15 per inch-diameter per foot for open cut installation results in a unit price of $720 per foot for 48-inch pipe. Applying this unit price results in an estimated cost for the pipeline of about $8.6 million. This is a schematic level estimate and should be assumed to have an accuracy of ±30%.

County Line Road Pipeline

The County Line Road pipeline is approximately 6,500 feet in length at 48-inches in diameter. Applying the unit price for 48-inch pipe as described above results in an estimated cost for the pipeline of about $4.7 million. This is a schematic level estimate and should be assumed to have an accuracy of ±30%.

Thornton Water Project



Thornton WATER PROJECT

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11/2/2018

Figure 1
Larimer County Canal Conceptual Alignment
Thornton Water Project

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County Line Road Pump Station

The County Line Road pump station located on a farm owned by Thornton at WCR 82 would pump up to 40 MGD at a TDH of 235 feet south to a booster pump station that would deliver water to Thornton. The approximate cost of this pump station is $10.6 million. This is a schematic level estimate and should be assumed to have an accuracy of ±30%.

The total cost of the LCC Alternative to deliver Thornton's water from WSSC #4 to the LCC, down the LCC to the Larimer/Weld County Line, and then to the TWP mainline at sufficient pressure is $33.4 million, not including additional water treatment costs to treat the poorer quality water from withdrawing water from the lower reaches of the LCC. This is a schematic level estimate and should be assumed to have an accuracy of ±30%.

TECHNICAL MEMORANDUM

Thornton Water Project Modified Poudre River Alternative Shields Street and Southern Pipelines Capacity and Cost

PREPARED FOR: City of Thornton

COPY TO: File

PREPARED BY: CH2M HILL

DATE: November 12, 2018

General

This technical memorandum (TM) summarizes the proposed capacity and estimated cost of the Shields Street and Southern Pipelines that would be included in the Modified Poudre River Alternative of the Thornton Water Project (TWP). The Modified Poudre River Alternative is described in the TM *Thornton Water Project Modified Poudre River Alternative,* November 12, 2018.

As described in the *Thornton Water Project Modified Poudre River Alternative* TM, a portion of Thornton's drinking water could be conveyed from Water Supply and Storage Company Reservoir Number 4 (WSSC No. 4) to the Poudre River at Shields Street through the Shields Street Pipeline, then diverted from the river just upstream of the outfall from Mulberry Water Reclamation Facility for delivery to Thornton through the TWP Southern Pipeline.

The following sections describe the proposed capacities and estimated costs of the Shields Street and TWP Southern Pipelines

Shields Street Pipeline

The Shields Street Pipeline is proposed to carry a portion of Thornton's drinking water, plus some of Thornton's return flow obligations that have delivery points along the alignment.

Capacity

The South Poudre Diversion Pipeline (Southern Pipeline) of the Northern Colorado Water Conservancy District's (Northern) Northern Integrated Supply Project (NISP) is proposed to deliver up to 25 cfs of flow, which is approximately 25 percent of the 102 cfs of total delivery capacity. For the purpose of this analysis, Thornton assumes the same portion of their drinking water could be delivered to the river and withdrawn downstream, similar to NISP. Thornton also has certain return flow obligations owed to the Larimer and Weld Ditch and the river that could also be delivered from WSSC No. 4. The capacity of the Shields Street Pipeline from WSSC No. 4 would thus equal 25 percent of the TWP delivery capacity of 40 million gallons per day (MGD), or 10 MGD plus approximately 5 MGD of return flow obligations for a total capacity of 15 MGD (23.2 cfs). For a design capacity of 15 MGD, a 30-inch pipe is proposed to maintain appropriate hydraulics for the pipeline.

Estimated Cost

The Shields Street pipeline is approximately 16,000 feet in length. Approximately 500 feet of the alignment would be installed by trenchless methods. Using a planning level cost of $15 per inch-diameter per foot for open cut installation results in a unit price $450 per foot for 30-inch pipe. For auger boring of trenchless portions of the project, a unit price of $1,500 per foot is assumed for 30-inch carrier pipe with 42-inch steel casing. Applying these unit prices results in an estimate cost for the pipeline of about $7.7 million.

As described in the TM *Thornton Water Project Shields Street Alignment and Construction Sequence,* there are two alignments being considered. If the alignment along Douglas Road is chosen, the water will have to be pumped over a small hill. For a flow of 23.2 cfs, and total dynamic head of 50 feet, the estimated capital pump cost is approximately $1.2 million.

The total cost for the Shields Street pipeline is estimated to be in the range of $7.7 to $8.9 million, depending upon alignment chosen. This is a schematic level estimate and should be assumed to have an accuracy of ±30%.

TWP Southern Pipeline

The TWP Southern Pipeline is proposed to carry a portion of Thornton's drinking water, and parallel the NISP Southern Pipeline.

Capacity

Since the TWP Southern Pipeline will only carry Thornton's drinking water, the capacity of this pipeline is 10 MGD. For a design capacity of 10 MGD, a 24-inch pipe is proposed.

Estimated Cost

The Southern Pipeline is approximately 32,200 feet (6.1 miles) in length. The amount of trenchless construction that would be required is unknown at this time, so will be assumed to add 10% to the overall cost assuming all construction is open cut. Applying the same $15 per inch diameter per foot to 24-inch pipe results in a unit price of $360 per foot, or a cost of $11.6 million for the entire alignment. Adding 10% for trenchless installations results in a total estimated pipeline cost of $12.8 million.

Water in the Southern Pipeline will have to be pumped to the TWP Primary Delivery Pipeline. For a flow of 15.5 cfs (10 MGD), and total dynamic head of 570 feet, the estimated capital pump cost is approximately $5.0 million.

The total cost for the Southern Pipeline is estimated to be about $17.8 million. This is a schematic level estimate and should be assumed to have an accuracy of ±30%.

TECHNICAL MEMORANDUM

Thornton Water Project

Shields Street Alignment and Construction Sequence

PREPARED FOR:	City of Thornton
COPY TO:	File
PREPARED BY:	CH2M HILL
DATE:	November 12, 2018

General

This technical memorandum (TM) summarizes the proposed alignment and construction sequence for installation of the Thornton Water Project (TWP) by the City of Thornton (Thornton) in Larimer County, north of Fort Collins. Larimer County citizens have expressed a desire for Thornton to augment flows in the Cache la Poudre River (Poudre Rive) through Fort Collins as part of the TWP. Several alternatives have been proposed for flow augmentation, including diversion of Thornton's water at the Larimer County Canal (LCC) headgate, routing the water through Water Supply and Storage Company Reservoir No. 4 (WSSC No. 4) via the LCC to make use of existing storage, and returning water to the Poudre River via a water pipeline for diversion and delivery to Thornton at some point downstream. This alternative (SS/PR Alternative) is described in more detail in the document *Shields Street/Poudre River Alternative to the Thornton Pipeline Proposal,* Mick Ondris, September 19, 2018.

The alignment and construction sequence for the Shields Street portion (Shields Street water pipeline) of the Modified Poudre River Alternative are described in the following sections.

Alignment Description

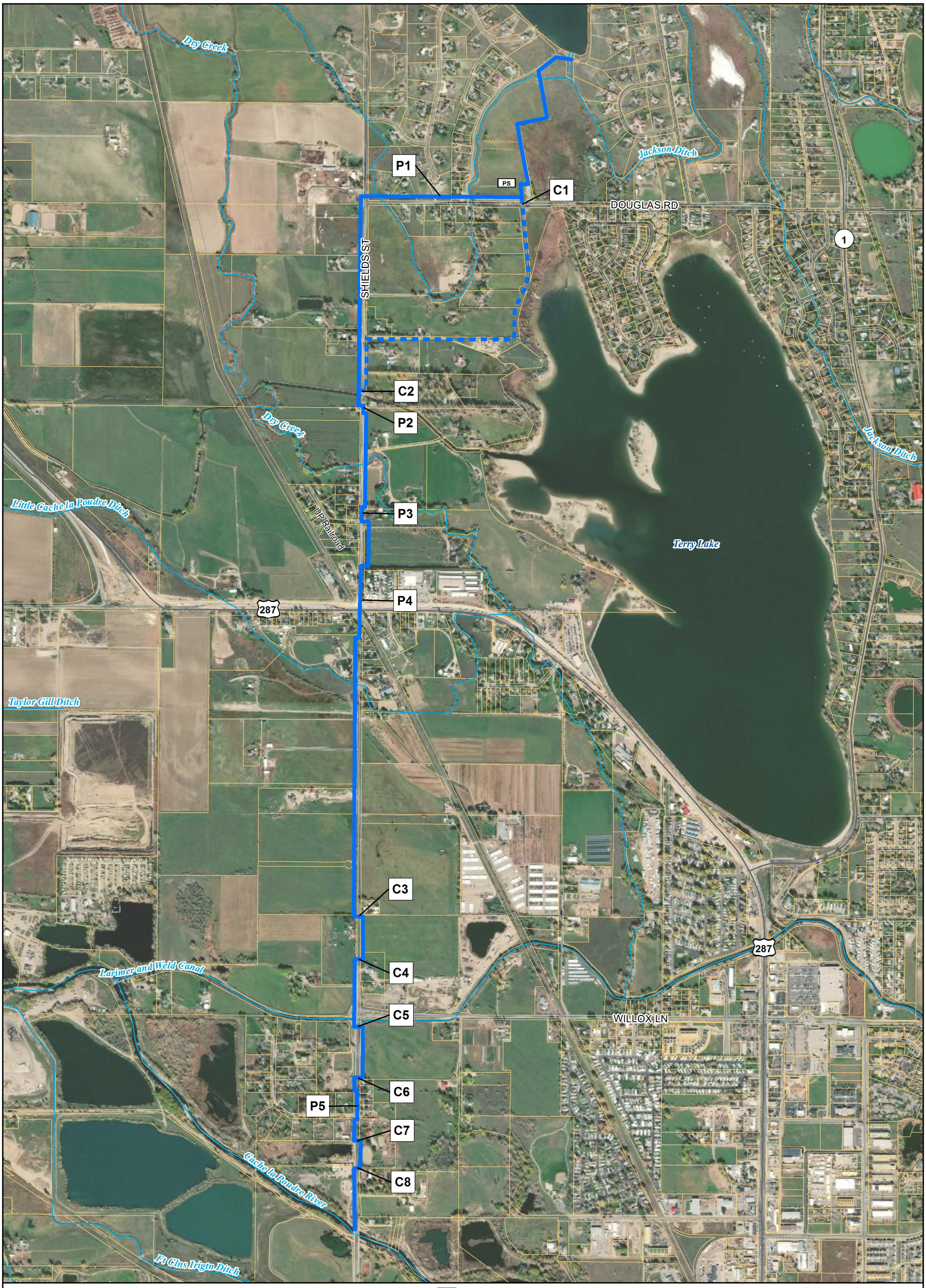
The conceptual alignment of the Shields Street water pipeline is shown on **Figure 1**. Preference is given to locating the water pipeline outside County rights-of—way to limit disruption to traffic. The water pipeline would route from the outlet works of WSSC No. 4 in an easement on private property to a location just north of the Douglas Road/Bayshore Drive intersection. From this location, there are two alternatives as described below.

Alternative 1

The first alternative includes a pump station on the north side of Douglas Road, and a water pipeline routing west along (as space allows) or in the Douglas Road right of way (ROW) to Shields Street. From the Douglas Road/Shields Street intersection, the water pipeline would route south along the west side of the Shields Street ROW to Blue Heron Lane.

Thornton Water Project

DRAFT Privileged Deliberative Process Work Product



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10/29/2018

N W E S

1 inch = 1,200 feet

0 600 1,200 Feet

PS Pump Station
Shields Street Conceptual
Alternative Shields Street Conceptual Alignment (No Pump Station)
Railroad
County Boundary
River/Stream/Canal/Ditch
Parcel Boundary

Figure 1
Shields Street Conceptual Alignment
Thornton Water Project

Sources: NHD, USGS, CDWR, Larimer County, CDOT, City of Thornton

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Alternative 2

The pump station could be eliminated if the water pipeline were routed south along Bayshore Drive, in easements on private property to the Blue Heron Lane ROW and west to Shields Street as shown on **Figure 1**.

Shields Street/Blue Heron Lane Intersection to Poudre River

From the intersection of Shields Street and Blue Heron lane, the water pipeline would route south along Shields Street, in private property easements where space allows on either side of the ROW to the Poudre River. Four segments of the water pipeline would be located in the Shields Street ROW due to existing development present on both sides of the ROW.

No survey has been performed for the proposed alignment south of the Douglas Road/Bayshore Drive intersection. Consequently, the presence of other utilities and/or encumbrances on both within rights-of-way and on private property is unknown at this time. The conceptual alignments, construction sequencing, and duration of work in rights-of-way presented herein are contingent upon verification of space available for construction.

Construction Sequence

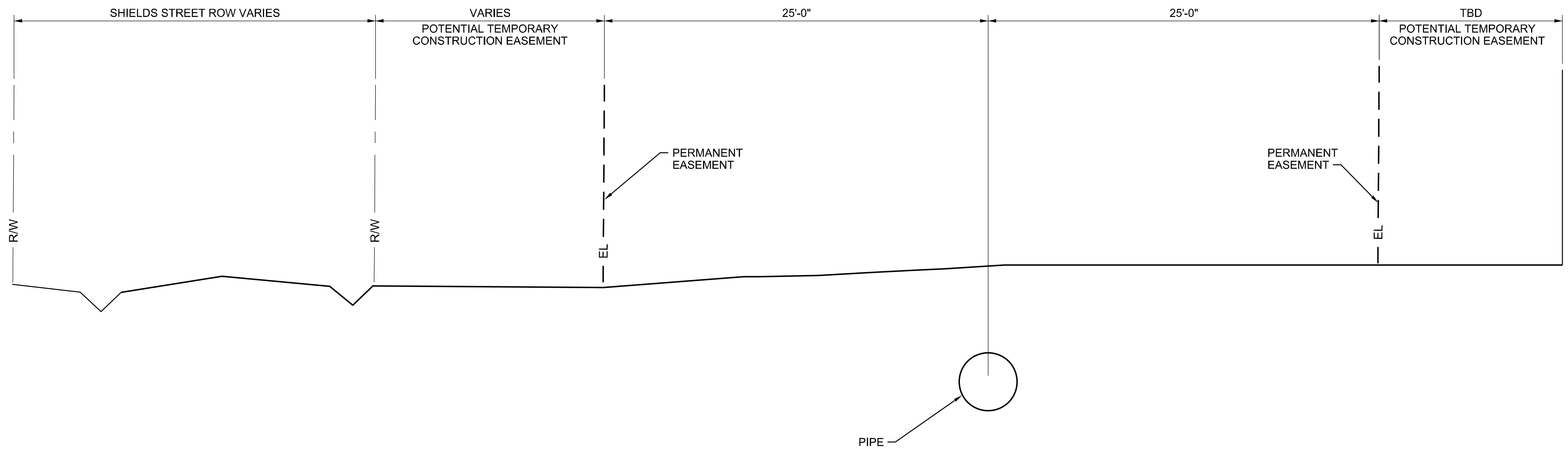
There are two potential construction sequences of the Shields Street water pipeline depending upon location in relation to right of way as described below.

Water Pipeline in Easements

The typical cross section for installation of the TWP Shields Street water pipeline outside ROW is shown in **Figure 2**. As shown, the permanent easement is 50 feet, with temporary construction easement totaling 40 feet on one or both sides of the permanent easement depending upon space available. The water pipeline would be installed by traditional open-cut methods, with the exception of ditch crossings that would be installed by trenchless methods. The trench would be sloped or bench to provide safe working conditions. Use of trench boxes or other shoring methods would be allowed subject to Contractor preference.

Water Pipeline in Right-of-Way

Construction within County ROW would include temporary easement on one or both sides of the right of way subject to available space. Rolling single-lane road closures would be required to accomplish construction and maintain access. The water pipeline would be installed by traditional open-cut methods. The trench would be sloped or benched to provide safe working conditions. Use of trench boxes or other shoring methods would be allowed subject to Contractor preference, limited available work space, or presence of other utilities.



1 TYPICAL SECTION PIPELINE OUTSIDE OF ROW

NTS

DRAFT - FOR DISCUSSION ONLY

NO.	DATE	REVISION	BY	APVD

DSGN | DR | CHK | APVD

THORNTON WATER PROJECT
CITY OF THORNTON
THORNTON, CO

FIGURE 2

VERIFY SCALE
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DATE	OCTOBER 2018
PROJ	000181
DWG	
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FILENAME: LCR-DT-005.dgn PLOT DATE: PLOT TIME:

Construction Duration in County Right-of-Way

As discussed, the water pipeline is proposed outside County ROW to the extent practical to limit traffic disruption. Traffic impacts will occur where the water pipeline crosses or is installed inside ROW. ROW crossings and parallel installations in the ROW are shown on **Figure 1**, crossings are denoted as CX and parallel installations are denoted PX. **Table 1** shows approximate duration of work within right-of-way for each segment.

Table 1: Right-of-way Work Durations

Segment	Length (ft, if parallel)	Duration (Work Days)	Alignment		Comments
			Conceptual	Alternative	
P1	2040	34	Y	N	Single lane closure subject to verification
C1	NA	5	N	Y	Alternate single lane closures for crossings
C2	NA	5	N	Y	Alternate single lane closures for crossings
P2	100	10	Y	Y	Single lane closure subject to verification
P3	200	11	Y	Y	Single lane closure subject to verification
P4	930	27	Y	Y	Trenchless crossing of Highway 14/287, full closure of Shields St 10 work days.
C3	NA	5	Y	Y	Alternate single lane closures for crossings
C4	NA	5	Y	Y	Alternate single lane closures for crossings
C5	NA	5	Y	Y	Alternate single lane closures for crossings
C6	NA	5	Y	Y	Alternate single lane closures for crossings
P5	370	13	Y	Y	Single lane closure subject to verification
C7	NA	5	Y	Y	Alternate single lane closures for crossings
C8	NA	5	Y	Y	Alternate single lane closures for crossings

Crossings will be constructed across half the ROW, then construction area switched to opposite side of ROW, so a single lane remains open during construction of the crossing. Should the Shields Street water pipeline be selected, required work space will be determined during final design, which may require full closure of some water pipeline segments. Construction of parallel segments using single lane closures will be verified at that time. Segment P4 includes crossing of Highway 14/287. It is assumed that crossing of Highway 14/287 will be by trenchless construction including launching and receiving pits of such a size that require full closure of Shields Street.

TECHNICAL MEMORANDUM

Thornton Water Project Modified Shields Street/Poudre River Alternative Capacity and Cost

PREPARED FOR: City of Thornton

COPY TO: File

PREPARED BY: CH2M HILL

DATE: November 12, 2018

General

This technical memorandum (TM) summarizes the proposed capacity and estimated cost of the modified Shields Street/Poudre River Alternative (SS/PR) of the Thornton Water Project (TWP). The SS/PR Alternative is described in more detail in the document *Shields Street/Poudre River Alternative to the Thornton Pipeline Proposal*, Mick Ondris, September 19, 2018.

As described in the Ondris document, the SS/PR alternative proposes that Thornton's water be diverted at the Larimer County Canal (LCC) headgate, routed through Water Supply and Storage Company Reservoir No. 4 (WSSC No. 4) via the LCC to make use of existing storage, and returning water to the Poudre River via a Shields Street pipeline for diversion from the river at Windsor and delivery to Thornton. As proposed in this TM, the Modified SS/PR Alternative changes the point of diversion from Windsor to a point just upstream of the relocated outfall from the Mulberry Water Reclamation Facility (WRF) through the Timnath Reservoir Inlet Canal. Water would then be conveyed via pipeline from the point of diversion east to the Larimer/Weld County line via the TWP Southern Pipeline.

The following sections describe the proposed capacities and estimated costs of the Shields Street and TWP Southern Pipelines.

Shields Street Pipeline

The Shields Street Pipeline is proposed to carry Thornton's drinking water, plus some of Thornton's return flow obligations that have delivery points along the alignment.

Capacity

Thornton has certain return flow obligations owed to the Larimer and Weld Ditch and the river that could also be delivered from WSSC No. 4. The capacity of the Shields Street Pipeline from WSSC No. 4 would thus equal the TWP delivery capacity of 40 million gallons per day (MGD) plus approximately 5 MGD of return flow obligations plus approximately 0.5 MGD of river losses between Shields and Timnath Reservoir Inlet for a total capacity of 45.5 MGD (70.4 cfs). For a design capacity of 45.5 MGD, a 48-inch pipe is proposed, which maintains appropriate hydraulics for the pipeline.

Estimated Cost

The Shields Street pipeline is approximately 16,000 feet in length. Approximately 500 feet of the alignment would be installed by trenchless methods. Using a planning level cost of $15 per inch-diameter per foot for open cut installation results in a unit price $720 per foot for 48-inch pipe. For auger boring of trenchless portions of the project, a unit price of $2,200 per foot is assumed for 48-inch carrier pipe with 60-inch steel casing. Applying these unit prices results in an estimated cost for the pipeline of about $12.3 million.

As described in the TM *Thornton Water Project Shields Street Alignment and Construction Sequence,* there are two alignments being considered. If the alignment along Douglas Road is chosen, the water will have to be pumped over a small hill. For a flow of 70.4 cfs, and total dynamic head of 50 feet, the estimated capital pump cost is approximately $3.7 million.

The total cost for the Shields Street pipeline is estimated to be in the range of $12.3 to $16.0 million, depending upon alignment chosen. This is a schematic level estimate and should be assumed to have an accuracy of ±30%.

TWP Southern Pipeline

The TWP Southern Pipeline is proposed to convey Thornton’s drinking water, and parallel the NISP Southern Pipeline from the Timnath Reservoir Inlet Canal to County Line Road.

Capacity

Since the TWP Southern Pipeline will only carry Thornton’s drinking water, the capacity of this pipeline is 40 MGD (61.9 cfs). For a design capacity of 40 MGD, a 48-inch pipe is proposed.

Estimated Cost

The Southern Pipeline is approximately 32,200 feet (6.1 miles) in length. The amount of trenchless construction that would be required is unknown at this time, so it will be assumed to add 10% to the overall cost assuming all construction is open cut. Applying the same $720 per foot to 48-inch pipe results in a cost of $23.2 million for the entire alignment. Adding 10% for trenchless installations results in a total estimated pipeline cost of $25.5 million.

Water in the Southern Pipeline will have to be pumped to the TWP Primary Delivery Pipeline. For a flow of 61.9 cfs (40 MGD), and total dynamic head of 350 feet, the estimated capital pump cost is approximately $14.0 million.

The total cost for the Southern Pipeline is estimated to be about $39.5 million, not including additional water treatment costs to treat the poorer quality water withdrawn from the Timnath Inlet Canal. This is a schematic level estimate and should be assumed to have an accuracy of ±30%.

TECHNICAL MEMORANDUM

Thornton Water Project
Shields Street/Poudre River Alternative
Capacity and Cost

PREPARED FOR:	City of Thornton
COPY TO:	File
PREPARED BY:	CH2M HILL
DATE:	November 12, 2018

General

This technical memorandum (TM) summarizes the proposed capacity and estimated cost of the Shields Street/Poudre River Alternative (SS/PR) of the Thornton Water Project (TWP). The SS/PR Alternative is described in more detail in the document *Shields Street/Poudre River Alternative to the Thornton Pipeline Proposal*, Mick Ondris, September 19, 2018.

As described in the Ondris document, the SS/PR alternative proposes that Thornton's water be diverted at the Larimer County Canal (LCC) headgate, routed through Water Supply and Storage Company Reservoir No. 4 (WSSC No. 4) via the LCC to make use of existing storage, and returning water to the Poudre River via a Shields Street pipeline for diversion from the river at Windsor and delivery to Thornton.

The following sections describe the proposed capacities and estimated costs of the Shields Street Pipeline, TWP Windsor Diversion, and TWP Windsor Pump Station.

Shields Street Pipeline

The Shields Street Pipeline is proposed to carry Thornton's drinking water, plus some of Thornton's return flow obligations that have delivery points along the alignment.

Capacity

Thornton has certain return flow obligations owed to the Larimer and Weld Ditch and the river that could also be delivered from WSSC No. 4. The capacity of the Shields Street Pipeline from WSSC No. 4 would thus equal the TWP delivery capacity of 40 million gallons per day (MGD) plus approximately 5 MGD of return flow obligations plus approximately 2.6 MGD of river losses between Shields and Windsor for a total capacity of 47.6 MGD (73.7 cfs). For a design capacity of 47.6 MGD, a 48-inch pipe is proposed. This maintains appropriate hydraulics for the pipeline.

Estimated Cost

The Shields Street pipeline is approximately 16,000 feet in length. Approximately 500 feet of the alignment would be installed by trenchless methods. Using a planning level cost of $15 per inch-diameter per foot for open cut installation results in a unit price $720 per foot for 48-inch pipe. For auger boring of trenchless portions of the project, a unit price of $2,200 per foot is assumed for 48-inch carrier pipe with 60-inch steel casing. Applying these unit prices results in an estimated cost for the pipeline of about $12.3 million.

As described in the TM *Thornton Water Project Shields Street Alignment and Construction Sequence,* there are two alignments being considered. If the alignment along Douglas Road is chosen, the water will have to be pumped over a small hill. For a flow of 73.7 cfs, and total dynamic head of 50 feet, the estimated capital pump cost is approximately $3.8 million.

The total cost for the Shields Street pipeline is estimated to be in the range of $12.3 to $16.1 million, depending upon alignment chosen. This is a schematic level estimate and should be assumed to have an accuracy of ±30%.

TWP Windsor Diversion

The TWP Windsor Diversion is proposed to divert Thornton's drinking water from the Poudre River at the Larimer/Weld County line.

Capacity

Since the TWP Windsor Diversion will only divert Thornton's drinking water, the capacity of this diversion is 40 MGD (61.9 cfs).

Estimated Cost

Cost for river diversions is very site specific. Actual diversion costs would be estimated further during design. In general, costs for river diversions will range from $30,000 to $52,000 per cfs of diverted flow. Using the upper end for planning purposes, a cost of $3.2 million is assumed for the diversion.

TWP Windsor Pump Station

The TWP Windsor Pump Station is proposed to pump Thornton's drinking water to a booster pump station located further south in Weld County.

Capacity

Since the TWP Windsor Pump Station will only pump Thornton's drinking water, the capacity of this pump station is 40 MGD (61.9 cfs).

Estimated Cost

For a flow of 61.9 cfs (40 MGD), and total dynamic head of 360 feet, the estimated capital pump cost is approximately $14.2 million.

The cost for the SS/PR Alternative is estimated to be about $29.7 to $33.3 million, not including additional water treatment costs to treat the poorer quality water withdrawn at Windsor. This is a schematic level estimate and should be assumed to have an accuracy of ±30%.