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Utility Master Plan

Project No. 17-467

Volume II – Raw Water Supply Master Plan

The City of Thornton

Project Number: 60560104

March 2020

Utility Master Plan

Project No. 17-467

Raw Water Supply Master Plan

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March 2020

Quality information

Prepared by	Checked by	Verified by	Approved by
Curt Thompson	Marcela Duran	Nathan Walker	Nathan Walker

Revision History

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Raw Water Master Plan

List of Chapters

Utility Master Plan

Project No. 17-467

Raw Water Supply Master Plan

The City of Thornton

Project number: 60560104

AECOM

January 14, 2020

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Raw Water Master Plan

List of Chapters

Raw Water Master Plan

Executive Summary

Executive Summary Table of Contents

Tables

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List of Acronyms

%	percent
2009 Plan	City of Thornton 2009 Water and Wastewater Systems Master Plan
AACE	Association for the Advancement of Cost Engineering
ADD	average daily demand
ADWQ	average dry weather flow
AFY	acre-feet per year
AWWA	American Water Works Association
BC	Burlington Canal
Cache la Poudre River	Poudre River
CIP	Capital Improvement Program
DOC	dissolved organic carbon
EGL	East Gravel Lakes
EGL4	East Gravel Lake #4
ENR	Engineering News-Record
FF	fire flow
fps	feet per second
ft	feet
gpm	gallons per minute
hr	hour(s)
ID	identification
in	inch
Integrated MP	Integrated Master Plan
KPI	key performance index(ices)
MDD	maximum day demand
MG	million gallons
mgd	million gallons per day
mi	mile(s)
MIB	2-methylisoborneol
MinDD	minimum daily demand
MinM	minimum month
MWRD	Metro Wastewater Reclamation District
N/A	not applicable
NWTP	Northern Water Treatment Plant
O&M	operation and maintenance
OP	ortho-phosphorous
PDWQ	Peak Dry Weather Flow
PHD	peak hour demand
PRV	pressure reducing valves
PS	pump station
psi	pounds per square inch
RW	raw water
RWGLS	Raw Water Gravel Lakes System
RWSMP	Raw Water Supply Master Plan
Thornton	city of Thornton
TM	technical memorandum
TWP	Thornton Water Project
TWTP	Thornton Water Treatment Plant
UMP	Utility Master Plan
WBWTP	Wes Brown Water Treatment Plant
WGL	West Gravel Lakes
WGL1	West Gravel Lake #1
WGL2	West Gravel Lake #2
WQ	water quality
WT MP	Water Treatment Master Plan
WTP	water treatment plant
W/WW	water and wastewater
W/WW IMP	Water/Wastewater Infrastructure Master Plan

1. Introduction

The city of Thornton (Thornton)'s water systems provide service to over 166,000 customers within the city as well as outside its limits, including Western Hills, Welby, unincorporated Adams County, and Federal Heights (wastewater service only) communities. Thornton must cost effectively serve its customer base and plan for future growth while simultaneously meeting high standards of service. At buildout (anticipated to occur by 2065), the systems are expected to serve a population of 268,843.

This Raw Water Supply Master Plan (RWSMP) demonstrates the need for capital investment and summarizes the expected capital planning. The recommendations contained in this document were developed with the goal of providing a buildout raw water supply system that is capable of satisfying the performance criteria and the demands of the planned future residents and businesses.

Raw Water Supply System

Thornton's existing sources of raw water supply consist of Standley Lake and the Raw Water Gravel Lakes System (RWGLS), including supply from Lower Clear Creek and diversions from the Burlington Canal. A summary of the annual supplies is presented in Table 1. The RWGLS consists of a series of gravel lakes along the South Platte River (Figure 1) plus the raw water conveyance facilities that deliver raw water to the existing Thornton Water Treatment Plant (TWTP) and the Wes Brown Water Treatment Plant (WBWTP). A list of the gravel lakes is presented in Table 2.

Table 1: Thornton's Annual Raw Water Supply

Raw Water Source	Annual Supply (acre-ft per year)
Burlington Canal	18,170
Lower Clear Creek	4,655
Standley Lake	10,000

Table 2: Thornton's Raw Water Gravel Lakes System

System	Lake
West Gravel Lakes (WGLs)	West Gravel Lake #1 (WGL1)
	West Gravel Lake #2 (WGL2)
	West Gravel Lake #3 (WGL3)
East Gravel Lakes (EGLs)	South Tani Reservoir (ST)
	East Gravel Lake #4 (EGL4)
	South Dahlia Reservoir (South Dahlia)
	North Dahlia Reservoir (North Dahlia)
	East Sprat-Platte Reservoir (East Sprat)
	West Sprat-Platte Reservoir (West Sprat)
	Cooley West Reservoir Complex (Cooley West)

The Thornton Water Project (TWP) is currently underway to develop a new raw water source from the Cache la Poudre River (Poudre River). The TWP will provide an additional average annual water supply of 14,000 acre-feet per year (AFY) of high-quality water to Thornton.

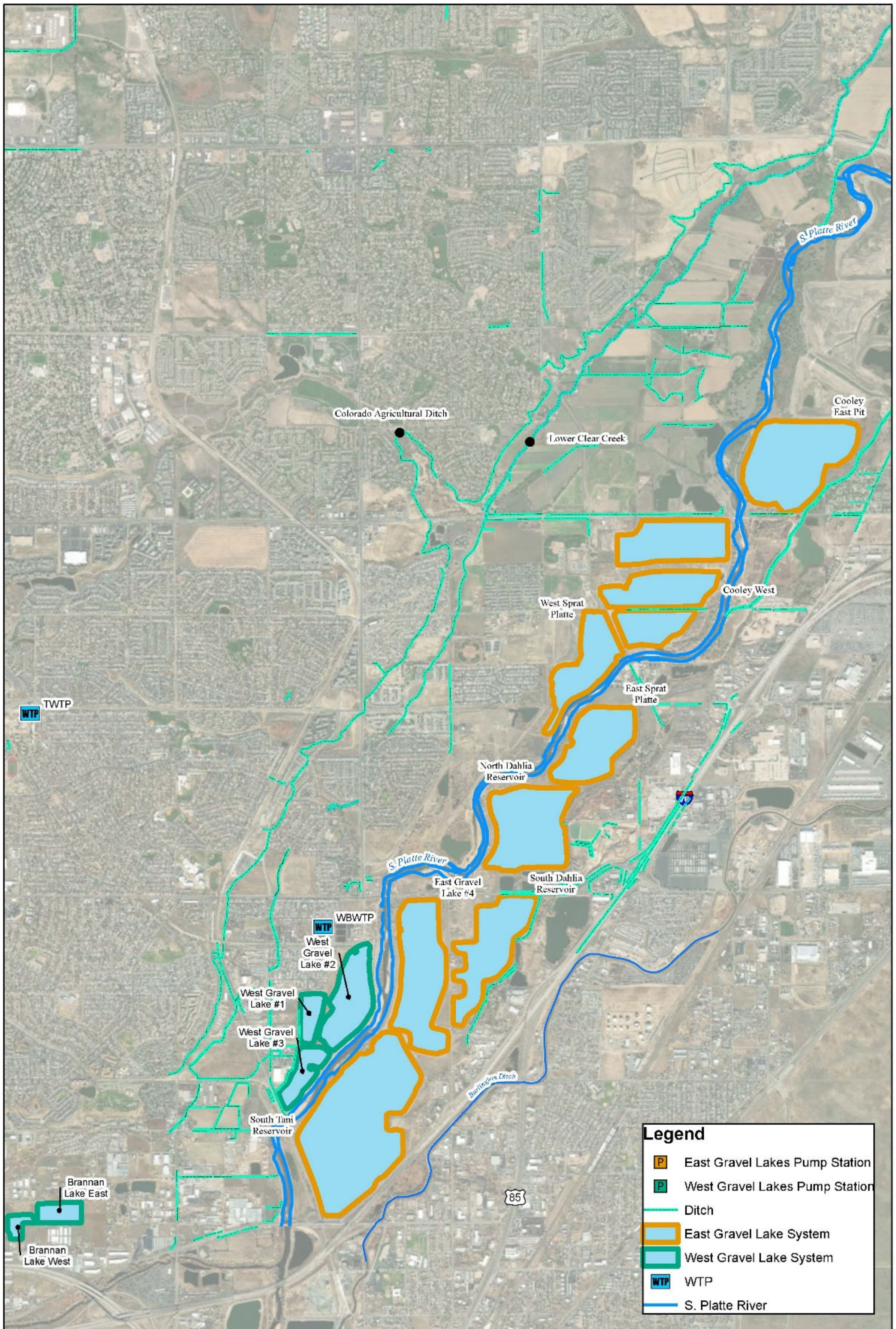

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Figure 1
Gravel Lakes Raw Water Storage System

1/7/2020
1 inch = 2,500 feet

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Utility Master Plan

Thornton's Utility Master Plan (UMP) includes planning analyses across the water transmission and distribution system, wastewater collection system, water treatment facilities, and raw water supply system. These planning evaluations and subsequent Capital Improvement Programs (CIP) identified for each system were based on a consistent planning basis and growth projections.

A master plan was developed for each of the disciplines, addressing the impact of three future alternatives. Results from individual master plans were combined into the Integrated Master Plan (Integrated MP) that establishes the preferred alternative and related CIP, phasing, prioritization, and budgets for the Utility Master Plan (UMP).

RWSMP Purpose

This RWSMP presents the performance criteria used to determine if new infrastructure is required, evaluation of the data sources and regulatory conditions for the raw water supply facilities, key findings from evaluation of the existing system, and the required upgrades to the raw water supply system to meet water supply requirements to support projected population growth and estimated demands for buildout conditions.

The proposed Raw Water Capital Improvement Program (RW CIP) is based on improvements identified as a result of data review and technical evaluations, including input from Thornton's staff. This document describes the results of these analyses and provides strategies and recommendations, including cost opinions for the proposed new infrastructure.

For the raw water supply system, improvements were developed for three future alternatives: a new Northern Water Treatment Plant (NWTP); expansion of the existing Thornton Water Treatment Plant (TWTP); and expansion of the Wes Brown Water Treatment Plant (WBWTP). A base condition of improvements to the RWGLS has been included in all alternatives. This base condition includes recommendations for modifications to existing infrastructure to improve the operations and sustainability of the existing system.

The RWSMP identified the improvements required for each of these alternatives; however, the selection of the preferred alternative was performed during the Integrated MP, which considered not only the improvements recommended in this report but also water treatment, water transmission, and distribution improvements.

RWSMP Report Organization

This report is organized into eight chapters, as described in Table 3. Each chapter was developed as an independent Technical Memorandum (TM) that includes detailed technical information and supporting documents, which led to CIP development. The TMs were then compiled into this report.

Table 3: Raw Water Master Plan Report Organization

Chapter	Description
1. Initial Data Review	Initial data review activities performed for the raw water supply.
2. System Performance Criteria	Performance criteria that were used in evaluating Thornton's RWGLS.
3. Gravel Lakes Water Quality Evaluation	Review of water quality data collected for the Gravel Lakes, identification of data gaps, and recommendation for improvements to the current data collection activities.
4. Existing Raw Water System Evaluation	Development of a water balance model of the Gravel Lakes system and use of the model to evaluate alternative operating scenarios for the Gravel Lakes.
5. Raw Water Future Alternatives Evaluation	Identification and evaluation of alternatives for improving the gravel lake operations to improve the raw water quality within the Gravel Lakes. Includes capital cost estimates associated with the improvement alternatives.
6. Gravel Lakes Management Plan	Water quality monitoring improvements recommended for the Gravel Lakes, and operating recommendations for various water quality scenarios.
7. Thornton Water Project (TWP) Pipeline Corridor Evaluation – Quebec Street	Evaluation of the Quebec Street Corridor, from 168th Avenue to 120th Avenue, as a suitable location for the new TWP Pipeline. Includes comparison of the Quebec Street Corridor with other north-south corridors.
8. TWP Pipeline Corridor Evaluation – 120th Avenue to Water Treatment Plants (WTPs)	Evaluation of alternative pipeline corridors for installation of the new TWP Pipeline from the intersection of Quebec Street and 120th Avenue to the existing water treatment plants (WTPs).

The individual chapters noted above were developed and finalized separately during the development of the RWSMP. Each chapter is a standalone document; therefore, any differences or discrepancies between the documents caused by the evolution of the studies is intended to be resolved in the Integrated MP.

2. Initial Data Review

Chapter 1 describes the initial review of data provided by Thornton to serve as the basis for raw water supply system analyses. The data review included historical water quality data for the raw water supplies and for the raw water within the Gravel Lakes, raw water daily flow volumes delivered to the water treatment facilities, operating records and the as-built construction drawings for the RWGLS, the Thornton 2009 Water and Wastewater Master Plan (2009 Plan), and discussions with Thornton regarding existing raw water system operations and issues that are not otherwise identified in the data set or 2009 Plan. The data review served as a basis for the evaluation tasks in **Chapter 3**.

3. System Performance Criteria

Chapter 2 discusses the performance criteria used in the RWSMP to evaluate the existing raw water system and future alternatives. Thornton's raw water supply infrastructure encompasses multiple components that have historically provided sufficient raw water volumes to the water treatment facilities. The performance criteria for the raw water system have been divided into three tiers, recognizing differences in the levels of system performance that may be required based on regulatory standards versus performance goals. The three tiers are summarized as follows:

- Tier 1: Criteria that must be met by the system at all time (regulatory requirements or commitment to citizens);
- Tier 2: Criteria that represent best practice and should be met by the raw water supply facilities, but may not be required at all times; and
- Tier 3: Criteria that are desired and should be met if practicable, but are not required.

4. Gravel Lakes Water Quality Evaluation

Chapter 3 summarizes the evaluations of the water quality aspects of Thornton's RWGLS. The water quality evaluations were focused on summer algae blooms and taste and odor events that affect water quality and drinking water treatment aesthetics and can affect customer satisfaction and confidence in water treatment and water supply. To evaluate the RWGLS water quality, the data for surface water elevations for each gravel lake and water quality data were reviewed and analyzed. Water quality conditions were summarized, and the annual mean values were compared to the water quality performance criteria established in **Chapter 2.** See Chapter 3, Appendix A for Water Quality Summary Metrics.

All of the annual mean values met the Tier 1 criteria. Dissolved organic carbon (DOC) was the only analyte that did not consistently meet the Tier 2 criteria. Despite East Gravel Lake #4 (EGL4) and West Gravel Lake #2 (WGL2) routinely meeting the ortho-phosphorous (OP) and nitrate criteria, each lake consistently experiences late season algae blooms that generally cause taste and odor events. Because the annual mean values generally met the water quality criteria, individual measurements were also compared to the criteria. The measured water quality conditions at mid-layer depths in EGL4 and WGL2 routinely met their respective Tier 1 water quality criteria with only a few seasonally extreme values exceeding the criteria. Turbidity levels routinely met Tier 2 water quality criteria in both EGL4 and WGL2, while total hardness, nitrate, and DOC levels often exceeded Tier 2 water quality criteria.

Recommendations for improved water quality monitoring were designed to gain a better understanding of the limnological conditions in the open water zones of the lakes, including increased high frequency data collection efforts to provide sufficient understanding of changing water quality conditions. Detailed water quality monitoring improvements are described in **Chapter 3**.

In addition to the recommended immediate monitoring improvements, there are future water quality concerns that should be considered. The state and federal regulatory nexus that guides drinking water and wastewater compliance currently has two key water quality limitations that will directly or indirectly affect the WTPs when new regulations are fully implemented. These water quality limitations are nutrient management and corrosion control. External influences on Thornton's raw water supplies, including possible impacts of climate change or over-appropriation of upstream watercourses, could affect the performance of the raw water supplies. These future considerations should be taken into account in Thornton's raw water supply planning.

5. Existing Raw Water System Evaluation

Evaluation of the existing raw water system indicates that there are opportunities to improve operations of the Gravel Lakes with the goal of improving the quality of the water delivered to the WTPs. The primary goal of the improved operations is to reduce the taste and odor issues related to the nutrient loadings within the raw water. The findings and recommendations detailed in the Gravel Lakes Water Quality Evaluation TM were used to identify four options for modifications to the Gravel Lakes operations that could result in improved water quality.

Chapter 4 describes the analyses and evaluations performed to develop recommendations for modifications to existing RWGLS operations. Each of the four options for modifications was evaluated using a GoldSim® computer simulation based water balance model for Thornton's RWGLS. Reduction of raw water nutrient levels within the lake water column, particularly phosphorus, was identified as the primary method for reducing taste and odor issues. Each of the four options that were modeled were compared to a model of the existing conditions. All options would require new infrastructure or modifications to existing infrastructure. The conclusions and recommendations are presented in **Chapter 4**.

The capital costs and life cycle costs for implementing the proposed improvements are a critical component of the decision-making process for modifying the RWGLS operations. Cost estimates for capital requirements and life cycle costs for the improvements are addressed in **Chapter 6** of this RWSMP.

6. Raw Water Future Alternatives Evaluation

Chapter 5 identifies and evaluates the three future alternatives as they relate to the raw water system. The goal of the improvements identified for each alternative is to maintain and improve the raw water quality and to increase the raw water delivery capacity to satisfy buildout water demand requirements. The proposed improvements to the RWGLS presented in the three future alternatives are intended to address the raw water quality issues and to increase the raw water supply to satisfy buildout water demand. The three alternatives are summarized as follows:

- Alternative 1 – Construct a new NWTP located in north Thornton to meet future additional system demands.
- Alternative 2 – Expand the TWTP to meet future system demands.
- Alternative 3 – Expand the WBWTP to meet future system demands.

Table 4 summarizes the raw water supply requirements for the three alternatives during maximum day demand (MDD) events. The increased total raw water supply required for Alternative 3 is due to the higher raw water reject rate for the WBWTP.

Table 4: Summary of Future Alternative Raw Water Supply Requirements

Facility	WBWTP (mgd)	TWTP (mgd)	NWTP (mgd)	Total (mgd)
Alternative 1	60.3	21.2	22.8	**104.3**
Alternative 2	60.3	44.0	-	**104.3**
Alternative 3	83.9	21.2	-	**105.1**

Note: mgd = million gallons per day

The alternatives evaluation involved identification of the proposed infrastructure improvements needed to satisfy the performance criteria and evaluation of each alternative considering key performance indices (KPIs) or performance parameters. This evaluation included estimating the costs to implement the identified improvements. The comparative costs then allowed for a cost benefit evaluation of each improvement. The alternative benefits were evaluated against the performance criteria established in **Chapter 2**.

While the alternative evaluation was focused on meeting the required production and Tier 1 criteria, there are other factors related to system reliability and redundancy for conveyance, pumping, and power supplies that may influence the interpretation of satisfying the criteria. These factors were addressed in the Capital Improvement Program and the respective capital and operating costs were included in the final evaluation of the alternatives.

Capital Improvement Program

Existing CIP projects are presented in Table 5. This table summarizes costs associated with improvements to existing RWGLS infrastructure as identified in **Chapter 4**.

Table 5: Existing Improvements CIP Projects

Recommended Improvement	Budgetary Cost
Existing System CIPs: Improvements to RWGLS	
EGL4 pipe interconnect (McKay Pump Station [McKay PS] to WBWTP)	$8,530,000
WGL2 to EGL4 w/PS (include river crossing)	$6,840,000
Study – Precipitant addition to Burlington Canal (BC) diversions	$70,000
Study – Feasibility of floating solar panel installation on Gravel Lakes	$70,000
Mobile pump stations (PSs) back-up power	$11,940,000
New EGL4 profiling systems – buoy-mounted water quality (WQ) profiling system and temperature data monitoring (EGL4, WGL2, and South Cooley Lake)	$480,000
$Total	$27,930,000
Operation & Maintenance (O&M) Costs Associated with Existing CIPs	
One additional employee to perform all additional monitoring	$81,000
Geosmin, MIB lake sampling – Microcystin testing for 9 samples	$32,400
Additional pumping for existing system CIPs from current operations	$64,240
$Total/Year	$177,640

*MIB = 2-methylisoborneol

Project costs for identified future improvements were developed for raw water infrastructure. The values in Table 6 summarize the cost for each alternative. A detailed list of the improvements in each category is provided in **Chapter 5**. Improvements associated with the TWP are limited to those located within Thornton's city limits. Costs of improvements north of the city limits are not included.

Table 6: Raw Water CIP Cost Summary

Type	Alternative 1	Alternative 2	Alternative 3
Tier 1	$102,470,000	$92,310,000	$92,310,000
Tier 2	$12,110,000	$12,110,000	$28,580,000
Tier 3	$145,540,000	$135,380,000	$135,380,000
Total	**$260,120,000**	**$239,800,000**	**$256,270,000**
20-Year Net O&M	$3,552,800	$3,552,800	$3,552,800

7. Gravel Lakes Management Plan

Chapter 6 describes recommendations for future management of the RWGLS. The recommendations include two parts, raw water quality monitoring improvements to develop a more comprehensive understanding of the water quality dynamics within the lakes are presented in the Water Quality Monitoring Program, and development of a methodology for utilizing the raw water quality data to facilitate informed decision making for operating and maintaining the RWGLS is presented in the RWGLS Operations Plan (Operations Plan).

The recommended water quality monitoring improvements will provide the critical data needed to allow improved RWGLS operations that could result in reduced or eliminated taste and odor events and generally improved raw water quality for deliveries to the WTPs. In addition to the monitoring improvements it is also recommended that future studies be performed to better understand the water quality dynamics of the RWGLS.

The Operations Plan addresses the varying water quality conditions in the RWGLS. The focus of the Operations Plan is to improve the quality of the raw water prior to the raw water deliveries to the WTPs, with the intent of anticipating water quality scenarios that would result in reduced quality water deliveries to the WTPs (i.e., trigger events). The Operations Plan defines modifications to the RWGLS operations that could reduce or eliminate the impacts of a trigger event. The single option recommended for immediate implementation is to operate the RWGLS in series from West Gravel Lake #1 (WGL1) to the McKay PS.

8. Thornton Water Project Pipeline Corridor Evaluation – Quebec Street

Chapter 7 describes an evaluation of a possible pipeline corridor for a segment of the TWP pipeline that would extend in a north-south direction between 160th Avenue and 120th Avenue. The evaluation focused on the Quebec Street corridor from 160th Avenue to 120th Avenue, and it included comparison of the Quebec Street corridor with alternative north-south corridors such as Holly Street and Colorado Boulevard. The objective of the corridor evaluation was to provide Thornton with the background and understanding of the need and priority for reserving a pipeline location within the Quebec Street right-of-way.

The evaluation included field reconnaissance, review of existing utility mapping, and reference to the Thornton 2009 Transportation Master Plan for information regarding the Quebec Street right-of-way width. The field reconnaissance indicated that the northern portion of the Quebec Street corridor is actively being developed. The evaluation concluded that the Quebec Street corridor from 160th Avenue to 120th Avenue is a preferable pipeline corridor when compared to alternative north-south corridors within Colorado Boulevard or Holly Street. Development of properties adjacent to Quebec Street is proceeding rapidly, and the availability of potential pipeline easement width is decreasing proportionally to the amount of development.

9. Thornton Water Project Pipeline Corridor Evaluation – 120th Avenue to WTPs

Chapter 8 describes an evaluation of possible pipeline corridors for the TWP Pipeline. The study area extends from the intersection of 120th Avenue and Quebec Street to the WBWTP, with an additional pipeline connection to the TWTP. The potential pipeline corridors are comprised of primarily urban development with relatively dense residential and commercial land uses.

The study area includes more than forty miles of potential pipeline corridor segments within existing recreation trails, parks and hiking paths, utility corridors, railroad right-of-way, and major and arterial roadways. Figure 2 shows the study area with identified segments of trails, roadways, and utility corridors that could be used to develop potential pipeline corridors. The evaluation combined the identified segments to develop four possible full-length corridors that connect the intersection of 120th Avenue and Quebec Street to the existing water treatment facilities. Figure 3 shows the McKay Road-Existing Pipeline corridor. The comparative evaluation indicates that the McKay Road-Existing Pipeline corridor is the preferred option by a large margin. The McKay Road-Existing Pipeline Corridor has several significant advantages, discussed in detail in **Chapter 8**.

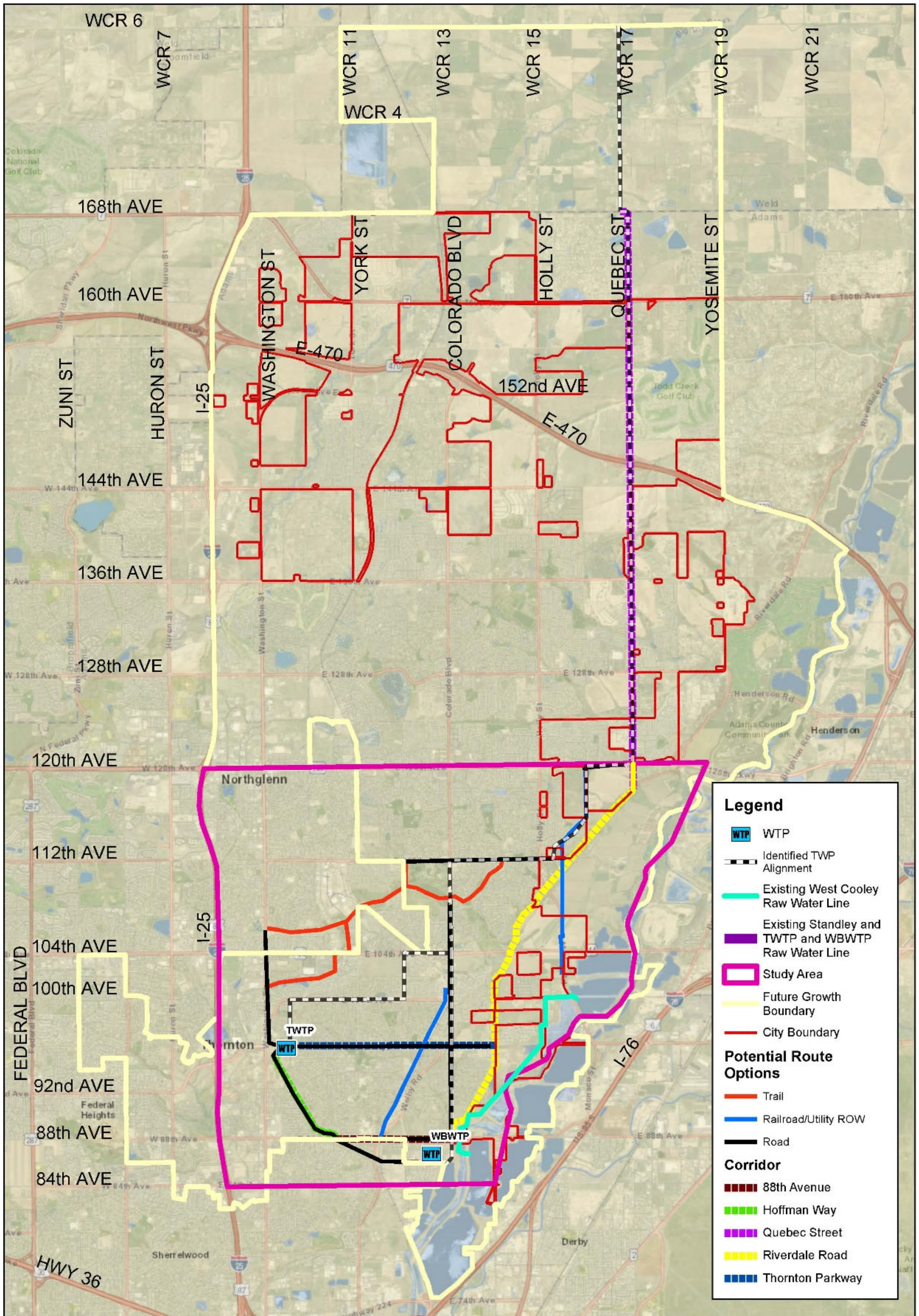

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Figure 2 -TWP Alignment Review
120th Ave to Water Treatment Plants

1 inch = 5,000 feet

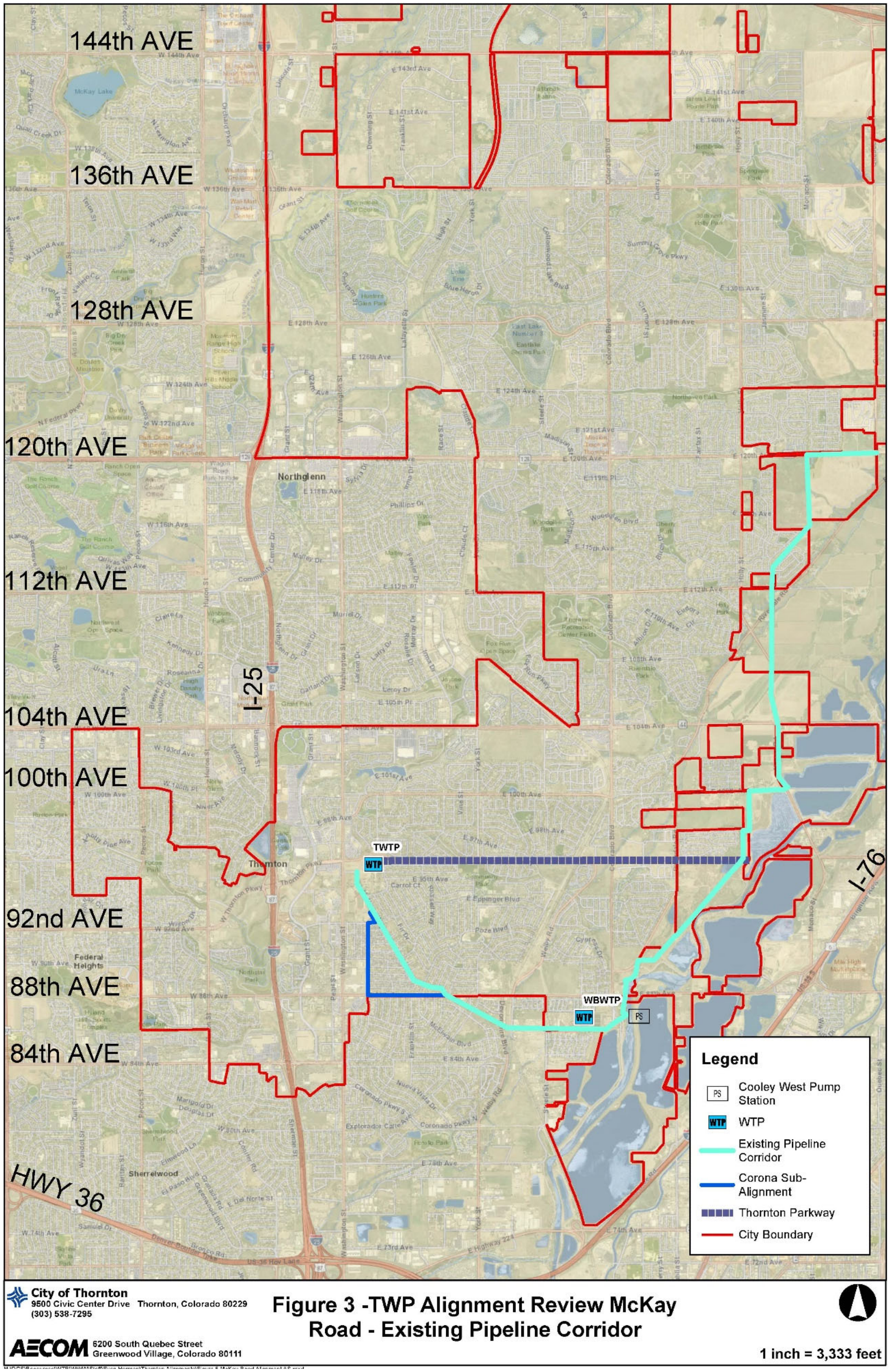

Figure 3 -TWP Alignment Review McKay Road - Existing Pipeline Corridor

Initial Data Review

Chapter 1

Utility Master Plan

Project No. 17-467

Raw Water Supply Master Plan

Initial Data Review

The City of Thornton

Project number: 60560104

AECOM

May 16, 2018

FINAL

Quality information

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Table of Contents

List of Acronyms

AFY – Acre-Feet per Year

CIP – Cast in Place

EGL – East Gravel Lake

EI&C – Electrical, Instrumentation and Controls

EPS – Extended Period Simulation

MGD – Million Gallons per Day

MWRD – Metro Wastewater Reclamation District

TM – Technical Memorandum

TWTP – Thornton Water Treatment Plant

New TTP – New Thornton Treatment Plant

PRV – Pressure Reducing Valves

RTD – Regional Transportation District

WBWTP - Wes Brown Water Treatment Plant

WGL – West Gravel Lake

WTP – Water Treatment Plant

TKN – Total Kjeldahl Nitrogen

GAC – Granulated Activated Carbon

1. Introduction

This technical memorandum (TM) describes the initial data collected for the raw water supply system being performed by AECOM for the Utility Master Plan project for the city of Thornton (Thornton). The data provided by Thornton on December 14, 2017 and in subsequent weeks provides an understanding of the system records to date, and will serve as the basis for subsequent system analyses. The initial data collected included the 2009 Water and Wastewater Master Plan (2009 Plan) and relevant historical raw water data. Sections 2 and 3 of this TM document discussions between AECOM and Thornton on the raw water supply system including current challenges and limitations associated with the system. These data will be used as a basis for the Raw Water Supply System Master Plan.

A data collection summary specific to the Water Treatment Master Plan and Water and Wastewater Infrastructure Master Plan will be provided in separate TM's.

2. Raw Water Infrastructure and Operations

A site visit of the raw water infrastructure including the gravel lakes and pump stations was conducted on December 18th, 2017. The site visit also included discussion of raw water quality details noted in a conference call on February 1st. The following system components below were discussed including associated considerations, challenges, limitations, and planned improvements. This data included relevant system data from the water treatment facilities records, and is summarized in Appendix A.

Standley Lake

Standley Lake water is currently used to supply the Thornton Water Treatment Plant (TWTP). This water is considered premium or high quality due to its lack of taste and odor issues but its annual yield is 11,832 acre-feet. During a multi-year drought, the Thornton Water Treatment Staff and Water Resources Staff agreed to set a minimum storage of 6,000 acre-feet. Standley Lake also supplies water to multiple other water providers. Additional detailed information regarding availability of Thornton's firm yield from Standley Lake will be developed in other portions of the Raw Water Supply Master Plan, as necessary.

South Tani Reservoir and East Gravel Lake 4

A surface diversion from the Burlington Canal supplies water to South Tani Reservoir during irrigation season which typically occurs from April to the end of August. A potassium permanganate feed system and a small ozone treatment system are installed at the diversion. According to Thornton Water Resources, the chemical feed system is out of date and may be in need of replacement. Water is conveyed underground from South Tani Reservoir to East Gravel Lake (EGL) 4 where the water is then pumped to the Wes Brown Water Treatment Plant (WBWTP). The WBWTP is operated as a peaking plant and does not operate for a few months during the winter, typically from November to March. As a result, the water surface elevations of the two reservoirs/lakes decline during the peak use season from July to November and when surface diversions from the Burlington Canal are shut down from November 1 through March 31.

EGL1, 2 and 3 were modified by removal of the interstitial embankments and deepening of the lake circa 2003 resulting in a single reservoir known as South Tani Reservoir. No comparative study has been completed on the water quality in South Tani Reservoir compared to the previous EGL1, 2 and 3 conditions. However the increased depth and volume of South Tani Reservoir are expected to have resulted in improved water quality.

EGL 1, 2, and 3 were initially developed as private gravel mining operations that were subsequently purchased by Thornton. The gravel mines were converted to offstream reservoirs (i.e. separate from the South Platte River and its alluvial groundwater) through the construction of a bentonite slurry trench wall, keyed into bedrock, constructed around the boundaries of each gravel pit. EGL4 was developed separately from EGL 1, 2, and 3 and was developed using a clay lining to separate it from the South Platte River and its alluvial groundwater. EGL 4 may have historically experienced poor water quality due to the clay lining.

The water quality of the lakes is relatively stable through the winter, and significantly improves in the spring from the diversion of snow melt runoff. Thornton conducts water exchanges, typically on WGL2, to replace the water sitting in the lake and improve the water quality. Generally, water exchanges occur when stream flow and water quality conditions allow. In summer the quality of the water being pumped from EGL4 to the WBWTP is often problematic from a treatment and aesthetic standpoint. As a result treated water from the WBWTP encounters taste and odors issues. To help address this problem, Thornton is planning to perform a detailed mass balance on the EGL4 for nutrients and track the anoxic zone in 2018. In the colder months the WBWTP encounters temperature issues since the membrane efficiency in the treatment process is dependent on temperature.

Metro Wastewater Reclamation District (MWRD) historically discharged treated wastewater effluent to the Burlington Canal upstream of the Thornton surface diversion. During discharge events, Thornton typically did not divert any water from the canal. In 2013 the Sandy Creek flood damaged MWRD's pumping infrastructure, which has not yet been rebuilt, resulting in elimination of the effluent discharge upstream of Thornton's diversion. Nitrate and phosphorous concentrations in the Burlington Canal have decreased for the past five years, probably due to fact that MWRD is no longer discharging in the canal and effluent concentration decreases from the Centennial and Littleton-Englewood wastewater treatment plants that discharges to the South Platte.

Additional detailed information regarding availability of Thornton's firm yield from South Tani Reservoir and EGL4 will be developed in other portions of the Raw Water Supply Master Plan, as necessary.

West Gravel Lakes

Water from lower Clear Creek is diverted and conveyed to West Gravel Lake 1 (WGL1) during irrigation season, typically from April to the end of October. Potassium permanganate is added to the lower Clear Creek diversions as an aid in taste, odor, and ozone control. Similarly to the South Tani Reservoir and EGL4 chemical equipment, the WGL potassium permanganate system is out of date and will need replacement. The water then flows through WGL3 and WGL2 where it is pumped to the WBWTP. Most of the storage volume in WGL3 is bypassed due to short-circuiting between the intake and outlet due to the locations of the connections with WGL1 and EGL2. An interconnection exists between WGL2 and WGL1 but is not currently used. WGL2 and WGL3 are open for public recreational use including fishing from the shore.

The WGL water supply has less taste and odor issues than the water supply from EGL4, but has been shown to have a higher contribution to membrane fouling of the treatment process at the WBWTP. The WGLs receive decant from the WBWTP lagoons, and it has been speculated that the decant may be a contributing factor to the membrane fouling issues.

Additional detailed information regarding availability of Thornton's firm yield from the WGLs will be developed in other portions of the Raw Water Supply Master Plan, as necessary.

Other Lakes

Multiple other lakes provide raw water storage but are not currently used for the water treatment supply, including South and North Dahlia, East and West Sprat Platte, and the Cooley West Complex which includes a South (Arvada Cell), Middle, and North Cell. Since 2013, only South Tani Reservoir and EGL4 have been used for active water supply. All the lakes are connected by buried pipes, and water flows by gravity from EGL4 to the Cooley West Complex. Multiple dead zones resulting from flow short-circuits exist throughout this system of lakes.

Cooley West Complex and West Sprate Platte can also receive water from the Lower Clear Creek ditch. In addition, Cooley West North Cell receives surface flows from the Ford seep.

The Pump Station was used from December 2016 through March 2017 to de-water 2,800 acre-feet from the reservoir by pumping to EGL4, then gravity fed through South Dahlia, to North Dahlia, and to the South Platte. Some of the water was impounded at EGL 4 and North and South Dahlia. In the spring of 2018 the pump station at the West

Cooley South Cell will restart operations and will send water back to EGL4. The lakes may need to be flushed before the start of operations, and Thornton has not yet developed an operations plan.

The Cooley West Complex, comprised of Cooley West South (Arvada cell), Middle and North, were all damaged by the 2013 and 2015 floods and need significant repairs before being placed back into operation. The Cooley East (Hazeltine) is a new reservoir being constructed northeast of the Cooley West Complex North cell and should be operational in 2020.

The two Brannan Lakes and associated pump station are currently not used for raw water supply to the water treatment plants.

Groundwater Wells

Thornton has sixteen groundwater wells that produce water that is sent to the reservoirs. Six alluvial wells discharge to South Dahlia, Well 28 discharges to South Tani Reservoir, four alluvial wells discharge to East Sprat, and 5 wells discharge to the Cooley West Complex. The 5 wells that discharge to the Cooley West Complex were damaged during the 2013 flood and are currently offline. Additional detailed information regarding availability of Thornton's firm yield from these wells will be developed in other portions of the Raw Water Supply Master Plan, as necessary.

Chemical Use

Alum has never been used in the reservoirs/lakes. There is not a set schedule for algaecide (copper sulfate) application as reservoir/lake conditions can vary in response to many factors. Algaecide is generally applied monthly and sometimes bi-monthly in EGL4, South Tani Reservoir, and the WGLs during the warmer months of May through October. Typically, no algaecide is applied to the reservoirs/lakes in the coldest winter months. Hydrogen peroxide was also tried in the summer of 2017, but no improvements in resulting water quality were identified.

SolarBees®[1]

SolarBees were first used by Thornton in 2003 following a recommendation of the 2003 EGL Management Study. The first units were used on EGL4. Over the years more SolarBees have been added to other reservoirs/lakes that provide water supply to the water treatment plants including South Tani Reservoir and WGL2. Thornton is following the vendor recommendation on the number and location of units installed. Use of these units did not prevent algae blooms and did not improve the water quality enough to solve the current treatment and aesthetic issues associated with poor water quality from EGL4 and the WGLs.

3. Thornton Water Project

Review of the Thornton Water Project occurred in a meeting on January 22nd, 2018 at the City of Thornton. The background information reviewed included the Thornton Water Project Hydraulic and Economic Analysis, Revision Date July 11, 2017, prepared by CH2MHill, and the maps of the City of Thornton Water System Improvements, Scenario 1 through Scenario 5, also prepared by CH2MHill. The purpose of the review was to discuss the project status and to understand how the Thornton Water Project will be integrated into the Utility Master Plan.

The Thornton Water Project is being planned to provide an annual water supply of 14,000 acre-feet per year (AFY). The water rights can be diverted only during the agricultural season, which varies from year to year. A small amount of storage is expected to be provided near the diversion to provide a water supply buffer between the rate of water diverted and the rate of water delivered to Thornton. The peak delivery capacity of the Thornton Water Project is expected to be 40 million gallons per day (MGD) as a minimum, possibly more. A booster pump station will convey Thornton Water Project water to Thornton and is planned to have phased capacity upgrades in 3 MGD increments.

Scenarios previously identified during planning of the Thornton Water Project were developed without consideration of Thornton's commitment to delivering blended water from each of Thornton's major water supplies to all of the water

[1] SolarBee® is a solar-powered water circulator used in freshwater lakes.

system customers. The planning scenarios of the Thornton Water Project are equivalent to the alternatives to be evaluated in the Utility Master Plan as follows:

- Planning scenario 1 is equivalent to Alternative 2 of the Utility Master Plan. Alternative 2 intends for the new water supplied by the Thornton Water Project to be delivered as untreated to the Wes Brown Water Treatment Plant. This scenario also includes expansion of the Wes Brown Water Treatment Plant sooner than the year 2035.
- Planning scenario 3 is equivalent to Alternative 1 of the Utility Master Plan. Alternative 1 intends for the new water supplied by the Thornton Water Project to be delivered to and treated by a new Northern Water Treatment Plant. Additionally, the new Thornton Water Project pipeline would be designed for bi-directional flow.
- Planning scenario 4a is equivalent to Alternative 3 of the Utility Master Plan. Alternative 3 intends for the new water supplied by the Thornton Water Project to be delivered as untreated to the Thornton Water Treatment Plant.

There is concern about rapid development occurring within the general area of the planned improvements for the Thornton Water Project. Significant development along Quebec Street is occurring at this time, and is expected to move west. Procurement of easements and establishment of final pipeline alignments must proceed in the near term, or the pipeline construction costs could increase significantly.

Alignments for the Thornton Water Project pipelines will be confirmed during development of the Utility Master Plan alternatives including identification of possible impacts that may affect pipeline routing or sizing in order to support the Thornton Water Project progress in pursuing the completion of these planned pipeline improvements.

4. Summary

AECOM has reviewed the initial data provided by Thornton primarily including reservoir water surface elevations, system maps, pump station data, water quality data, water quality sampling plans, previous studies and regulatory documents. Design pipeline plans for Thornton Water Project have not been received and will be requested as needed during the Raw Water Supply Master Plan. These data have provided an adequate understanding of the existing raw water system and baseline information that will be used as the starting point for development of the Raw Water Supply Master Plan. Some data gaps including water quality sampling data, water supply delivery rates, and availability of water supply firm yield were identified during the data review process. These additional data will be coordinated with Thornton during the raw water supply system and alternatives evaluation portions of the Utility Master Plan.

Appendix A - Data Review Summary Tables

This document outlines the initial data received from the City of Thornton on December 14, 2017.

Raw Water Data

Table A.1: Raw Water Data Overview

Document Title	Type of Document	Details
ReservoirsLakeLevels	Excel	Daily lakes elevations from 2012 to 2017 (South Tani, East Gravel Lake 4, South Dahlia, North Dahlia, East Sprat Platte, West Gravel Lake 1, West Gravel Lake 2, West Gravel Lake 3, Brannan West, Brannan East, Cooley West Complex – South, Middle, and North Cells, Cell, and Rogers).
Thornton_Storage	Excel	Monthly water stored in lakes from 2008 to 2017 (Standley, East Gravel Lakes, West Gravel Lakes, Brannan Lakes, and Cooley West Complex).
Standley_Lake	Excel	Monthly Standley lake elevations and outflow from 2008 to 2017.
ReservoirStageCapTables	Excel	Lakes storage capacities at various fill levels (South Tani, East Gravel Lake 4, South Dahlia, North Dahlia, East Sprat Platte, West Gravel Lake 1, West Gravel Lake 2, West Gravel Lake 3, Brannan West, Brannan East, Cooley West Complex – South, Middle, and North Cells, Cell, Rogers, and Hammer).
Phase 1 Well Cleaning Report FULL.stmp.ltr	PDF	Deere & Ault report presenting well cleaning observations, video analysis and hydraulic pump evaluation (for wells PW-505, PW-506, PW-507, PW-508, PW-509, and PW-510), dated October 2012.
WellPumpingData-Thornton	Excel	Daily flow pumped at East Gravel Lakes Wells (2009-2017), Well 28 (2007-2017), and Cooley West Complex Wells (2007-2009).
Rogers Pump Station11x17-stamped asbuilt	PDF	As-Built drawings for Rogers Pump Station, dated June 2016. The document includes civil, mechanical and EI&C drawings.
Thornton-Reservoir-Model-V2012	Excel	Operational Model of the Southern Gravel Lakes System, version 2012, created by RJH Consultants, Inc.
DemandSource2008-2017	Excel	Daily flow pumped from the West Gravel Lakes and the East Gravel Lakes from 2008 to 2017.
Pump Station Power Data	Excel	Three spreadsheet presenting the power consumption and energy cost for Hammer, McKay, and Rogers Pump Stations from 2014 to 2017.
Raw Water Maps	PDF	Five maps and aerial photos of the Southern Gravel Lakes System.
042214 NPV_Scenarios1-5_ver1.pd0f	PDF	Cost analysis of the various scenarios for the Water Thornton Project evaluated by the CH2M HILL in April 2014. The economic evaluation includes information for Scenario 1, 2, 3, 4A, 4B, 4C, 5A and 5B.
042314 Draft_System_Improvements_20140422	PDF	Map of phased system improvements for the Thornton Water Project evaluated by the CH2M HILL in April 2014. Maps are provided for Scenario 1, 2, 3, 4A, 4B, 4C, 5A and 5B.
TWP Tech Memo Hydraulic Economic Analysis CH2MHILL 20170711 (2)	PDF	CH2M HILL report evaluating hydraulics and financials of 8 scenarios for the Thornton Water Project, dated July 2017. Recommendation is to use a 48-inch diameter transmission line from the Water Supply and Storage Company (WSSC) Reservoir #4 to Thornton Water Treatment Plant (TWTP) with a recommended flow rate of 40 MGD.
COT Raw Water Reservoirs- June 2016	PDF	Map of the Southern Gravel Lakes System, dated June 2016. The map includes lakes capacities, elevations and connections infrastructure, future improvements needed and some operation recommendations.
Thornton Reservoir Model - January 31, 2005	Excel	Operational Model of the Southern Gravel Lakes System, version 2005, created by RJH Consultants, Inc.

Water Quality Data

Table 2. Raw Water Quality Overview

Document Title	Type of Document	Details
BC@SP20122017	Excel	Water quality results for the South Platte at the start of the Burlington Ditch from 2012 to 2017.
EGL4 Sediment - Aug 2017	PDF	Water quality results for iron, manganese, Total phosphorus and TKN for the EGL Sediment, sampled in September 2017.
EGL20122017	Excel	Water quality results for EGL #4 at Pump Station (bottom, middle, top) from2012 to 2017).
LCC@CC20122017	Excel	Water quality results for Lower Clear Creak at WGL#1 diversion from 2012 to 2017.
LRCC@RES20122017	Excel	Water quality results for sampling location LRCC@RES3 from 2016 to 2017.
TTPRAW20122017	Excel	Water quality results for the raw water at the Thornton Treatment Plant from 2012 to 2017.
WGL20122017	Excel	Water quality results for WGL #2 at pump Station (bottom, middle, top) from2012 to 2017).
7 13 17 memo on water quality options during drought	Word	City of Thornton document discussing the water quality issues during drought conditions, dated July 2017. The memo provides three options: equip the WBTP with ozone and GAC contactor, or treat 20 MGD of gravel lakes to the new TTP, or supplying 10 MGD of Stanley lake to WBTP for blending.
2017 Lakes Management lessons learned	Word	City of Thornton document listing some chemical addition tests performed in 2017 to improve lakes water quality, as well as some recommendations for operations.
2017 State of the Waters before Brett edits.doc	Word	Draft city of Thornton document providing a summary of the water supply and water quality in Thornton as of 2017.
2003 EGL Management Study	PDF	Draft Report presenting the East Gravel Lakes Management Strategy, dated May 2003. The report includes information on the physical system, water quality data and operation and management considerations.
Water Quality Exchange Targets	Word	Water quality limits for exchange. Levels are specified at various sampling points at in Lower Clear Creek, the gravel lake system and at the influent of the two treatment plants.

Sampling Program Data

Table 3. Raw Water Sampling Program Overview

Document Title	Type of Document	Details
BC Sampling locations	Excel	Coordinates, elevations and driving directions for the following sampling locations: SP@BC, METRO@SP-E, METRO@SP-W, BC@EGL2, BC@O'BR, O'BR@BARR, BARR OUT, HC OUT, PROS OUT.
Burlington Analytes2017	Excel	Burlington Canal monitoring program analytes (monthly or quarterly), updated December 2016.
Gravel Lakes - Raw Sampling Schedule2017	Excel	Gravel lakes monitoring program analytes (weekly, monthly, quarterly or annually), updated December 2016.
Gravel Lakes - Raw Water Sampling Directions	Word	Driving directions for the following sampling locations: WGL2@PS, WGL1@3, .WGL3@2, LCC@WGL1, STANI@EGL4, EGL4@PS, South Dahlia, North Dahlia, Wells 7 and 10, East Sprat, Cooley, Ford Seep, West Sprat, SP@BC, LCC@CC.
Gravel Lakes - raw_water_sample_sites	PDF	Map of gravel lakes sampling sites, dated July 2013.
Gravel Lakes - soplat_augplan.pdf	Excel	Map of wells, dated December 2003.
lcc_sample_sites	PDF	Map of gravel lakes sampling sites, dated July 2013.
LCCSPCURE Analytes2017	Excel	Clear Creek monitoring program analytes (monthly or quarterly), updated December 2016.
North Project Analytes 2017	Excel	North Project monitoring program analytes (monthly or quarterly), updated December 2016.
Poudre Analytes 2017	Excel	Poudre monitoring program analytes (monthly or quarterly), updated December 2016.
2017Yearly Sample Schedule	Excel	Overall monitoring program analytes for 2017.

Planning and Development Data

Table A.4: Planning and Development Data Overview

Document Title	Type of Document	Details
3Q17 Population and Housing Summary	PDF	Summary of the "Third Quarter 2017 Population Estimate and Housing Inventory Report." The adjusted total population estimate for the City of Thornton at the end of Q3 (July 1, 2017 – September 30, 2017) was 136,547; and the total housing unit count was 47,498. This document also outlines projected future housing unit counts, and information on types of housing and development.
4Q16 Population and Housing Summary	PDF	Summary of the "Fourth Quarter 2016 Population Estimate and Housing Inventory Report." The adjusted total population estimate for the City of Thornton at the end of Q4 (October 1, 2016 – December 31, 2016) was 134,149; and the total housing unit count was 46,654. This document also outlines projected future housing unit counts, and information on types of housing and development.
WWMP pop proj 020217	Excel	City of Thornton's growth projections: 2017 – 137,500 projected population 2020 – 146,000 projected population 2025 – 160,000 projected population 2030 – 175,000 projected population Build Out – 242,000 projected population
Comp Plan Link	Email Message	Link to the City of Thornton Comprehensive Plan: http://www.cityofthornton.net/government/citydevelopment/planning/Pages/comprehensive-plan.aspx
Current Development Projects_ Dec 2016	PDF	PDF map showing current development projects as of December 12, 2016, distinguished by multi-family or single family unit counts. Current development types depicted include: Residential – Proposed, Residential – Approved, Residential – Active, Commercial – Proposed, Commercial – Approved, Commercial – Active, Institutional – Proposed, Institutional – Approved, Institutional – Active, Mixed – Proposed, and Mixed – Approved.
FW RTD Station Area Utility Studies	Email Message	Email correspondence indicating need to address/evaluate existing and proposed development at RTD stations within the Utilities Master Plan. This email includes information regarding the 124th Station, 104th Station and 88th Station.

Water and Wastewater Infrastructure Data

Table A.5: Water and Wastewater Data Overview

Document Title	Type of Document	Details
Sewer Model	ArcGIS ArcMap	Infrastructure sewer model containing both the .mxd and .IEDB files to be used in InfoSewer. The model contains information and data regarding controls, manholes, maps, pipes, pumps, wetwells, and meters. Scenarios include existing and future scenarios (2025 & 2065).
Water Model	ArcGIS ArcMap	InfoWater model containing .mxd, .IWDB and .out files. The model contains information and data regarding controls, demands, pipes, tanks and valves. Existing scenarios include EPSs at both max day and min day demands, as well as steady state. Future scenarios include 2025 EPS and 2065 EPS.
PRV_Map_02122017	PDF	City of Thornton map including water pressure zones, PRVs, tank locations, and other information dated March 2017.
Sewer_Basins_3_2_2017	PDF	City of Thornton map depicting the wastewater collection system including sewer lift stations, sewer meters, sewer lines, private lines, Metro mains and force mains. Wastewater Basins A-K are outlined on the map, dated March 2017.
Slip_Line_CIP	PDF	City of Thornton map depicting CIPP Sliplined Pipes. Distinctions are made between CIP Year 1981-1988, CIP Year 1993-1999, CIP Year 2000-2017, and sewer line pipes. The map is dated May 24, 2017.
Water Modeling Information	Word Document	City of Thornton document describing the controls and operations of the water distribution system model. Specifically, document discusses WTP operations, pump station controls, PRV settings and controls, and tank set points.

System Performance Criteria

Chapter 2

Utility Master Plan

Project No. 17-467

Raw Water Supply Master Plan

System Performance Criteria

The City of Thornton

Project number: 60560104

AECOM

July 16, 2018

FINAL

Quality information

Prepared by	Checked by	Verified by	Approved by
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Revision History

Revision	Revision date	Details	Authorized	Name	Position

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Table of Contents

Tables

List of Acronyms

µg/L – Microgram per Liter
ADD – Average Day Demand
AWWA – American Water Works Association
Bq/L – Becquerel per Liter
CDPHE – Colorado Department of Public Health and Environment
EGL – East Gravel Lake
MIB – 2-Methylisoborneol
mg/L – Milligram per Liter
mrem/yr – Millirem per year
ng/L – Nanogram per Liter
NTU – Nephelometric Turbidity Unit
pC/L – PicoCurie per Liter
TM – Technical Memorandum
WHO – World Health Organization
WTP – Water Treatment Plant

1. Introduction

This technical memorandum (TM) describes the performance criteria to be used in evaluating the City of Thornton's (Thornton) existing raw water supply system, along with identified additions and future improvements to the existing system. The criteria have been developed based on a thorough review of the 2009 Water and Wastewater Master Plan (2009 Plan), city standards; Colorado Department of Public Health and Environment (CDPHE) Regulation 11 Standards; American Water Works Association (AWWA) recommendations; and the World Health Organization (WHO) Guidelines for Drinking-water Quality. The criteria include resiliency considerations that improve the reliability of the water supply system.

The criteria for the system are divided into three tiers to recognize differences in the levels of system performance and to provide Thornton flexibility in selecting improvements based on increased levels of service that may result from different criteria. The three tiers can be summarized as follows:

- Tier 1: Criteria that must be met by the system
- Tier 2: Criteria that represent best practice and should be met by the system, but may not be required
- Tier 3: Criteria that are desired and should be met if practical, but are not required

Section 2 summarizes the supply system performance criteria including capacity, reliability, redundancy and resiliency considerations. Section 3 summarizes the water quality criteria for raw water influent to Thornton's water treatment plants (WTPs).

2. Raw Water Supply Infrastructure Criteria

Criteria Development

Based on a review of city, state and federal water system standards, selected criteria have been identified in Tables 1, 2, and 3 below.

Tier 1 Criteria

The focus of the Tier 1 infrastructure criteria is to identify minimum system requirements for raw water supply facilities and components that must be met by the system. Failure to meet these criteria would result in Thornton curtailing water deliveries to customers.

The Tier 1 raw water supply infrastructure performance criteria are described in Table 1.

Table 1: Tier 1 Raw Water Supply Infrastructure Performance Criteria

Performance Parameter	Criteria	Criteria Description
Total Delivery Capacity (Annual Basis)	Equal to one year of the Average Day Demand (ADD) under supply drought conditions	Essential capacity to provide water for increased demand due to a supply drought period
Operational Storage Capacity	Raw Water Operational Storage Capacity equal to 1.0 x Annual Demand	Essential capability to ensure robust supply availability
Water Rights Firm Yield	Adequate water rights and storage to meet three-year demand with restrictions	Essential to secure water rights to meet demand
Water Delivery	Comparable water quality to all customers through blending of the following supplies if necessary, or other suitable means: • Thornton Water project water to all WTPs • Gravel Lakes water to all WTPs Burlington Canal water to all WTPs	Necessary to ensure delivery of comparable water quality to all customers
Pump Stations Firm Capacity to WTPs	Equal to Maximum Daily Demand under drought conditions	Required for conveyance to WTPs
EGL Pump Station Standby Power	Ability to mobilize / activate sufficient backup power within 4 hours of loss of power in order to meet production requirements	Required to provide production associated with Water Treatment System Capacity
WGL Pump Station Standby Power	Ability to mobilize / activate sufficient backup power within 4 hours of loss of power in order to meet production requirements	Required to provide production associated with Water Treatment System Capacity
Water Supply Equipment Redundancy (Critical equipment to meet capacity requirements)	Firm installed capacity to meet production with one pump out of service	Redundancy requirement of N+1 essential for operations and maintenance

Tier 2 Criteria

The focus of the Tier 2 infrastructure criteria is to identify recommended best practices for raw water supply facilities and components that should be met by the system. Failure to meet these criteria may not result in Thornton having to curtail water deliveries to customers but may result in increases in operations labor and/or temporary facilities in order to maintain production and deliveries.

The Tier 2 raw water supply infrastructure performance criteria are described in Table 2.

Table 2: Tier 2 Raw Water Supply Infrastructure Performance Criteria

Performance Parameter	Criteria	Criteria Description
System Redundancy	Delivery capacity equal to 0.5 x Annual Demand under drought supply conditions with the largest supply system down for up to 12 months	Essential capacity to provide water during a major outage assuming mandatory outdoor water use restrictions
Water Rights Firm Yield	Adequate water rights and storage to meet three-year demand without restrictions	Important to secure water rights to meet demand
Operational Storage Capacity	Raw Water Operational Storage Capacity equal to 1.5 x Annual Demand	Important capability to ensure robust supply availability
EGL Pump Station Standby Power	Dual power source available in order to meet production requirements without service interruption	Recommended to provide production associated with Water Treatment System Capacity

Tier 3 Criteria

The focus of the Tier 3 infrastructure criteria is to identify recommended system goals for raw water supply facilities and components that improve performance and ease operations. Failure to meet these criteria is not expected to result in Thornton having to curtail water deliveries to customers but may increase risk of disruption to operations and maintenance activities that temporarily increase costs.

The Tier 3 raw water supply infrastructure performance criteria are described in Table 3.

Table 3: Tier 3 Raw Water Supply Infrastructure Performance Criteria

Performance Parameter	Criteria	Criteria Description
Water Rights Firm Yield	Adequate water rights and storage to meet four-year demand without restrictions	Desired capability to ensure robust supply availability
Total Raw Water Storage Capacity	Raw Water Storage Capacity equal to 4 x Annual Demand	Desired capability to ensure robust supply availability and to develop water supply yield
EGL Pump Station Standby Power	A reliable power source meeting the requirements of the NEC for Emergency Power available for immediate use at each treatment plant.	Recommended to provide production associated with System Capacity
System Redundancy	Parallel supply pipelines to avoid downtime due to individual pipe failures	Desired to secure water rights to meet demand
Sustainability	Possible locations for mini-hydro systems should be considered	Desired to minimize the operations impacts
Sustainability	Water evaporation should be minimized	Important to minimize the operations impacts
Sustainability	Energy efficient/alternative power sourced pumps and facilities	Desired to improve environmental impact of facilities

3. Raw Water Supply Water Quality Criteria

Criteria Development

Based on a review of regulatory requirements associated with the CDPHE Regulation 11 Standards as well as recommendations associated with water treatment plants ease of operation and maintenance, selected criteria for water quality have been identified in the Water Treatment Facilities Master Plan System Performance Criteria TM and shown in Tables 4, 5, and 6 below. The quality standards apply to various portions of the raw water supply system for either raw water or water delivered to the WTPs required to meet the WTP performance criteria.

Tier 1 Criteria

The focus of Tier 1 is to identify minimum influent water quality and treatment performance criteria that must be met by the system at all times in order to meet the minimum CDPHE standards as well as for the WTPs to meet the Safe Drinking Water Act requirements. Failure to meet these criteria may result in Thornton having to issue advisory orders to customers.

The Tier 1 raw water supply water quality criteria are described in Table 4.

Table 4: Tier 1 Raw Water Supply Water Quality Criteria

Performance Parameter	Criteria	Criteria Description
Raw Water – Nitrite as Nitrogen	0 – 1.0 mg/L	CDPHE Regulation 11 – Supplier Criteria
Volatile Organic Compounds		
Raw Water - Vinyl Chloride	0 – 0.002 mg/L	CDPHE Regulation 11 – Supplier Criteria
Raw Water - Benzene	0 – 0.005 mg/L	CDPHE Regulation 11 – Supplier Criteria
Raw Water - Carbon Tetrachloride	0 – 0.005 mg/L	CDPHE Regulation 11 – Supplier Criteria
Raw Water - 1,2-Dichloroethane	0 – 0.005 mg/L	CDPHE Regulation 11 – Supplier Criteria
Raw Water - Trichloroethylene	0 – 0.005 mg/L	CDPHE Regulation 11 – Supplier Criteria
Raw Water - Para-Dichloroethylene	0 – 0.075 mg/L	CDPHE Regulation 11 – Supplier Criteria
Raw Water - 1,1-Dichloroethylene	0 – 0.007 mg/L	CDPHE Regulation 11 – Supplier Criteria
Raw Water - 1,1,1-Trichloroethane	0 – 0.2 mg/L	CDPHE Regulation 11 – Supplier Criteria
Raw Water - Cis-1,2-Dichlorobenzene	0 – 0.07 mg/L	CDPHE Regulation 11 – Supplier Criteria
Raw Water - 1,2-Dichloropropane	0 – 0.005 mg/L	CDPHE Regulation 11 – Supplier Criteria
Raw Water - Ethylbenzene	0 – 0.7 mg/L	CDPHE Regulation 11 – Supplier Criteria
Raw Water - Monochlorobenzene	0 – 0.1 mg/L	CDPHE Regulation 11 – Supplier Criteria
Raw Water - o-Dichlorobenzene	0 – 0.6 mg/L	CDPHE Regulation 11 – Supplier Criteria
Raw Water - Styrene	0 – 0.1 mg/L	CDPHE Regulation 11 – Supplier Criteria
Raw Water - Tetrachloroethylene	0 – 0.005 mg/L	CDPHE Regulation 11 – Supplier Criteria
Raw Water - Toluene	0 – 1.0 mg/L	CDPHE Regulation 11 – Supplier Criteria
Raw Water - Trans-1,2 Dichloroethylene	0 – 0.1 mg/L	CDPHE Regulation 11 – Supplier Criteria
Raw Water - Xylenes (total)	0 – 10 mg/L	CDPHE Regulation 11 – Supplier Criteria
Raw Water - Dichloromethane (methylene chloride)	0 – 0.005 mg/L	CDPHE Regulation 11 – Supplier Criteria
Raw Water - 1,2,4-Trichlorobenzene	0 – 0.07 mg/L	CDPHE Regulation 11 – Supplier Criteria
Raw Water - 1,1,2-Trichloroethane	0 – 0.005 mg/L	CDPHE Regulation 11 – Supplier Criteria
Polyromantic Hydrocarbons		
Raw Water - Alachlor	0 – 0.002 mg/L	CDPHE Regulation 11 – Supplier Criteria
Raw Water - Altrazine	0 – 0.003 mg/L	CDPHE Regulation 11 – Supplier Criteria
Raw Water - Carbofuran	0 – 0.04 mg/L	CDPHE Regulation 11 – Supplier Criteria
Raw Water - Chlordane	0 – 0.002 mg/L	CDPHE Regulation 11 – Supplier Criteria
Raw Water - Dibromochloropropane	0 – 0.0002 mg/L	CDPHE Regulation 11 – Supplier Criteria
Raw Water - 2,4-Dichlorophenoxyactic Acid	0 – 0.07 mg/L	CDPHE Regulation 11 – Supplier Criteria
Raw Water - Ethylene dibromide	0 – 0.00005 mg/L	CDPHE Regulation 11 – Supplier Criteria
Raw Water - Heptachlor	0 – 0.0004 mg/L	CDPHE Regulation 11 – Supplier Criteria
Raw Water - Heptachlor epoxide	0 – 0.0002 mg/L	CDPHE Regulation 11 – Supplier Criteria
Raw Water - Lindane	0 – 0.0002 mg/L	CDPHE Regulation 11 – Supplier Criteria
Raw Water - Methoxychlor	0 – 0.04 mg/L	CDPHE Regulation 11 – Supplier Criteria
Raw Water - Polychlorinated biphenyls	0 – 0.0005 mg/L	CDPHE Regulation 11 – Supplier Criteria
Raw Water - Pentachlorophenol	0 – 0.001 mg/L	CDPHE Regulation 11 – Supplier Criteria
Raw Water - Toxaphene	0 – 0.003 mg/L	CDPHE Regulation 11 – Supplier Criteria
Raw Water - 2,3,5-TP (Silvex)	0 – 0.05 mg/L	CDPHE Regulation 11 – Supplier Criteria
Raw Water - Benzopyrene	0 – 0.0002 mg/L	CDPHE Regulation 11 – Supplier Criteria
Raw Water - Dalapon	0 – 0.2 mg/L	CDPHE Regulation 11 – Supplier Criteria

Table 4: Tier 1 Raw Water Supply Water Quality Criteria

Performance Parameter	Criteria	Criteria Description
Raw Water - Di(2-ethylhexyl)adipate	0 – 0.4 mg/L	CDPHE Regulation 11 – Supplier Criteria
Raw Water - Di(2-ethylhexyl)phthalate	0 – 0.006 mg/L	CDPHE Regulation 11 – Supplier Criteria
Raw Water - Dinoseb	0 – 0.007 mg/L	CDPHE Regulation 11 – Supplier Criteria
Raw Water - Diquat	0 – 0.02 mg/L	CDPHE Regulation 11 – Supplier Criteria
Raw Water - Endothall	0 – 0.1 mg/L	CDPHE Regulation 11 – Supplier Criteria
Raw Water - Endrin	0 – 0.002 mg/L	CDPHE Regulation 11 – Supplier Criteria
Raw Water - Glyphosate	0 – 0.7 mg/L	CDPHE Regulation 11 – Supplier Criteria
Raw Water - Hexachlorobenzene	0 – 0.001 mg/L	CDPHE Regulation 11 – Supplier Criteria
Raw Water - Hexachlorocyclopentadiene	0 – 0.05 mg/L	CDPHE Regulation 11 – Supplier Criteria
Raw Water - Oxamyl (Vydate)	0 – 0.2 mg/L	CDPHE Regulation 11 – Supplier Criteria
Raw Water - Picloram	0 – 0.5 mg/L	CDPHE Regulation 11 – Supplier Criteria
Raw Water - Simazine	0 – 0.004 mg/L	CDPHE Regulation 11 – Supplier Criteria
Raw Water - 2,3,7,8-Tetrachlorodibenzodioxin	0 – 0.00000003 mg/L	CDPHE Regulation 11 – Supplier Criteria
Inorganics		
Raw Water - Antimony	0 – 0.006 mg/L	CDPHE Regulation 11 – Supplier Criteria
Raw Water - Arsenic	0 – 0.010 mg/L	CDPHE Regulation 11 – Supplier Criteria
Raw Water - Asbestos	0 – 7 Million Fibers/L	CDPHE Regulation 11 – Supplier Criteria
Raw Water - Barium	0 – 2 mg/L	CDPHE Regulation 11 – Supplier Criteria
Raw Water - Beryllium	0 – 0.004 mg/L	CDPHE Regulation 11 – Supplier Criteria
Raw Water - Bromate	0 – 0.010 mg/L	CDPHE Regulation 11 – Supplier Criteria
Raw Water - Cadmium	0 – 0.005 mg/L	CDPHE Regulation 11 – Supplier Criteria
Raw Water - Chlorite	0 – 1.0 mg/L	CDPHE Regulation 11 – Supplier Criteria
Raw Water - Chromium	0 – 0.1 mg/L	CDPHE Regulation 11 – Supplier Criteria
Raw Water - Cyanide (as free Cyanide)	0 – 0.2 mg/L	CDPHE Regulation 11 – Supplier Criteria
Raw Water - Fluoride	0 – 4.0 mg/L	CDPHE Regulation 11 – Supplier Criteria
Raw Water - Mercury	0 – 0.002 mg/L	CDPHE Regulation 11 – Supplier Criteria
Raw Water - Selenium	0 – 0.05 mg/L	CDPHE Regulation 11 – Supplier Criteria
Raw Water - Thallium	0 – 0.002 mg/L	CDPHE Regulation 11 – Supplier Criteria
Radionuclide		
Raw Water - Gross Alpha particle activity (including radium-226)	0 – 15 pCi/L	CDPHE Regulation 11 – Supplier Criteria
Raw Water - Combined radium-226 and radium-228	0 – 5 pCi/L	CDPHE Regulation 11 – Supplier Criteria
Raw Water - Uranium	0 – 30 µg/L	CDPHE Regulation 11 – Supplier Criteria
Raw Water - Beta particle and photo radioactivity	0 – 0.00000003 mrem/yr (Dose Equivalent) 0 – 1 Bq/L (Radioactivity)	CDPHE Regulation 11 – Supplier Criteria (Dose Equivalent) WHO Guidelines for Drinking-water Quality
Chlorine, Chloramines, and Chlorine Dioxide		
Raw Water - Chlorine	0 – 0.011 mg/L	CDPHE Regulation 11 – Supplier Criteria
Raw Water - Chloramines	0 – 0.011 mg/L	CDPHE Regulation 11 – Supplier Criteria
Biological		
Raw Water - Cryptosporidium	0 – 0.075 oocyts/L	CDPHE Regulation 11 – Supplier Criteria
Raw Water - Coliform	> 5% of the Routine/Repeat samples in a month of total coliform-positive	EPA – Total Coliform Rule

Table 4: Tier 1 Raw Water Supply Water Quality Criteria

Performance Parameter	Criteria	Criteria Description
Raw Water - Rotavirus	Presence or Absence	CDPHE Regulation 11 – Supplier Criteria
Water Quality to WTP - Turbidity	0.1 – 50 NTU	Standley Lake and EGL4 Historical Source Water Quality
Water Quality to WTP - pH	6.0 – 10	Standley Lake and EGL4 Historical Source Water Quality
Water Quality to WTP - Temperature	0.5 – 27 degrees C	Standley Lake and EGL4 Historical Source Water Quality
Water Quality to WTP - Alkalinity	35 – 250 mg/L as $CaCO_3$	Standley Lake and EGL4 Historical Source Water Quality
Water Quality to WTP - Total Organic Carbon	0.5 – 9.0 mg/L	Standley Lake and EGL4 Historical Source Water Quality
Water Quality to WTP - Dissolved Organic Carbon	0.5 – 9.0 mg/L	Standley Lake and EGL4 Historical Source Water Quality
Water Quality to WTP - Total Hardness	60 – 350 mg/L as $CaCO_3$	Standley Lake and EGL4 Historical Source Water Quality
Water Quality to WTP - Total Dissolved Solids	50 – 750 mg/L	Standley Lake and EGL4 Historical Source Water Quality
Water Quality to WTP - Iron (Dissolved)	0 – 1.5 mg/L	Standley Lake and EGL4 Historical Source Water Quality
Water Quality to WTP - Manganese (Dissolved)	0 – 1.0 mg/L	Standley Lake and EGL4 Historical Source Water Quality
Water Quality to WTP - Bromide	0 – 0.5 mg/L	Standley Lake and EGL4 Historical Source Water Quality
Water Quality to WTP - Geosmin	0 – 500 ng/L	Standley Lake and EGL4 Historical Source Water Quality
Water Quality to WTP - MIB	0 – 500 ng/L	Standley Lake and EGL4 Historical Source Water Quality
Water Quality to WTP - Ortho-Phosphate as PO4	0 – 3.0 mg/L	Standley Lake and EGL4 Historical Source Water Quality
Water Quality to WTP - Nitrate as N	0 – 3.0 mg/L	Standley Lake and EGL4 Historical Source Water Quality
Trihalomethanes (TTHM) and Haloacetic Acids (HAA5)		
Raw Water - Total Trihalomethanes	0 – 0.080 mg/L	CDPHE Regulation 11 – Supplier Criteria
Raw Water - Haloacetic Acids	0 – 0.060 mg/L	CDPHE Regulation 11 – Supplier Criteria

Tier 2 Criteria

Tier 2 criteria is established to identify minimum influent water quality and treatment performance criteria that are recommended to be met by the system at all times in order to meet industry standards. Failure to meet these criteria may negatively impact overall system performance, resulting in higher costs for Thornton and/or reduced water quality aesthetics for customers such as but not limited to taste and odor.

The Tier 2 raw water supply water quality criteria are described in Table 5.

Table 5: Tier 2 Raw Water Supply Water Quality Criteria

Performance Parameter	Criteria	Criteria Description
Inorganics		
Water Quality to WTP - Copper	0 – 1 mg/L	National Secondary Drinking Water Regulation
Water Quality to WTP - Fluoride	0 – 2 mg/L	National Secondary Drinking Water Regulation
Water Quality to WTP - Iron	0 – 1 mg/L	National Secondary Drinking Water Regulation
Water Quality to WTP - Manganese	0 – 0.05 mg/L	National Secondary Drinking Water Regulation
Water Quality to WTP - Nitrate as Nitrogen	0 – 1.5 mg/L	Important Contaminant for WTP operations and performance (50% of Tier 1)
Water Quality to WTP - Nitrite as Nitrogen	0 – 0.5 mg/L	Important Contaminant for WTP operations and performance (50% of Tier 1)
Water Quality to WTP - Total Hardness	60 – 175 mg/L as CaCO3	Important Contaminant for WTP operations and performance (50% of Tier 1)
Water Quality to WTP - Turbidity	0.1 – 25 NTU	Important Contaminant for WTP operations and performance (50% of Tier 1)
Water Quality to WTP - Total Organic Carbon	0.5 – 4.5 mg/L	Important Contaminant for WTP operations and performance (50% of Tier 1)
Biological		
Water Quality to WTP - Geosmin	0 – 50 ng/L	Important Contaminant for WTP operations and performance (10% of Tier 1)
Water Quality to WTP - MIB	0 – 55 ng/L	Important Contaminant for WTP operations and performance (10% of Tier 1)
Water Quality to WTP - Cylindrospermopsin	0 – 0.7 µg/L	10-day Health Advisory for infants (2015)
Water Quality to WTP - Microcystins	0 – 0.3 µg/L	10-day Health Advisory for infants (2015)
Trihalomethanes (TTHM) and Haloacetic Acids (HAA5)		
Water Quality to WTP - Total Trihalomethanes	0 – 8.0 µg/L	Important Contaminant for WTP operations and performance (10% of Tier 1)
Water Quality to WTP - Haloacetic Acids	0 – 6.0 µg/L	Important Contaminant for WTP operations and performance (10% of Tier 1)

Tier 3 Criteria

The emphasis of Tier 3 is to identify minimum influent water quality and treatment performance criteria that are recommended to be met by the system to improve performance and ease operations.

The Tier 3 raw water supply water quality criteria are described in Table 6.

Table 6: Tier 3 Raw Water Supply Water Quality Criteria

Performance Parameter	Criteria	Criteria Description
Raw Water - Cryptosporidium	0 – 10 organism/L	WHO Guidelines for Drinking-water Quality
Raw Water - Campylobacter	0 – 100 organism/L	WHO Guidelines for Drinking-water Quality
Raw Water -Rotavirus	0 – 10 organism/L	WHO Guidelines for Drinking-water Quality
Water Quality to WTP – Nitrate as Nitrogen	0 – 3.3 mg/L	Important Contaminant for WTP operations and performance (33% of Tier 1)
Water Quality to WTP – Nitrite as Nitrogen	0 – 0.33 mg/L	Important Contaminant for WTP operations and performance (33% of Tier 1)
Water Quality to WTP - Total Hardness	60 –120 mg/L as $CaCO_3$	Important Contaminant for WTP operations and performance (33% of Tier 1)
Water Quality to WTP - Turbidity	0.1 – 16 NTU	Important Contaminant for WTP operations and performance (33% of Tier 1)
Water Quality to WTP - Total Organic Carbon	0.5 – 3.0 mg/L	Important Contaminant for WTP operations and performance (33% of Tier 1)
Water Quality to WTP - Geosmin	0 – 10 ng/L	Important Contaminant for WTP operations and performance (2% of Tier 1)
Water Quality to WTP - MIB	0 – 10 ng/L	Important Contaminant for WTP operations and performance (2% of Tier 1)

Gravel Lakes Water Quality Evaluation

Chapter 3

Utility Master Plan

Project No. 17-467

Raw Water Supply Master Plan

Gravel Lakes Water Quality Evaluation

The City of Thornton

Project number: 60560104

AECOM

July 17, 2019

FINAL

Quality information

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Revision History

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List of Acronyms and Abbreviations

µg/L	Micrograms per liter
BC	Burlington Canal
CDPHE	Colorado Department of Public Health and Environment
DO	Dissolved oxygen
DOC	Dissolved organic carbon
EGL4	East Gravel Lake #4
LCC	Lower Clear Creek
mg/L	Milligrams per liter
MIB	2-methylisoborneol
OP	ortho-phosphorus
ST	South Tani Reservoir
TDS	Total dissolved solids
TIN	Total inorganic nitrogen
TN	Total Nitrogen
TOC	Total Organic Carbon
TP	Total phosphorus
TSS	Total Suspended Solids
TWTP	Thornton Water Treatment Plant
WGL1	West Gravel Lake #1
WGL2	West Gravel Lake #2
WGL3	West Gravel Lake #3
WQCC	Colorado Water Quality Control Commission
WBWTP	Wes Brown Water Treatment Plant
WTP	Water Treatment Plant

1. Introduction

This Technical Memorandum (TM) summarizes the evaluations of the water quality aspects of the city of Thornton's (Thornton) gravel lakes as part of the Raw Water Supply Master Plan for the Utility Master Plan Project (Project). This water quality evaluation is part of the existing system evaluation. The following remaining portions of the existing system evaluation will be provided under separate cover:

1. Water balance evaluation of the existing raw water system;
2. Water balance evaluation of water quality improvement options;
3. Raw water system operational plan development.

2. Background

Thornton's existing raw water system consists of a series of gravel lakes along the South Platte River (Figure 1) that were developed through conversion of gravel pits into water storage reservoirs. The conversions from gravel pits to water storage reservoirs consisted of installation of clay linings around the gravel pits. Several of the reservoirs were formed by construction of vertical slurry trench walls around the perimeter of the gravel pit. West Gravel Lakes #1, #2, and #3 (WGL1, WGL2, and WGL3), and East Gravel Lake #4 (EGL4) were formed by the installation of a clay lining along the slopes of each gravel pit.

The raw water gravel lakes system (RWGLS) experiences summer algae blooms and taste and odor events that affect water quality and drinking water treatment aesthetics, and can affect customer satisfaction and confidence in water treatment and water supply. Most tastes and odors in drinking water supply systems are organic compounds [i.e., geosmin and 2-methylisoborneol (MIB)] derived from planktonic algae (floating microscopic plants) and cyanobacteria (a group of photosynthetic bacteria, some of which are nitrogen-fixing, that live in a wide variety of moist soils and water [blue-green algae]), although soil bacteria such as actinomycetes have been linked to taste and odor events. Filamentous and colonial cyanobacteria such as sp. *Cylindrospermopsis*, sp. *Aphanizomenon* sp. *Anabaena* sp., and *Microcystis* sp. are most commonly associated with the production of geosmin and MIB, although benthic (occurring at the bottom of a body of water) forms of cyanobacteria such *Oscillatoria* sp., *Phormidium* sp. and *Lyngbya* sp. have also been linked to geosmin and MIB production. Furthermore, cyanobacteria are also responsible for a parallel water quality issue – cyanotoxins. While geosmin and MIB affect the aesthetics of drinking water, they generally do not result in a risk to human health; whereas cyanotoxins can pose a risk to human health, domestic animals, and livestock. Because cyanobacteria are implicated in taste and odor and water quality issues, controlling their growth along with other algae is important in raw water management.

A complex interaction of environmental conditions affects algae and cyanobacteria growth, and includes a range of physical, chemical, and biological interactions. Physical conditions include the shape and depth of the waterbody, water column stability, inflow and outflow rates, the horizontal and vertical mixing due to flow and wind, light availability, and water temperature; Chemical conditions include nutrient availability (nitrogen, phosphorus, iron), pH, carbonates; Biological conditions include competition with other algae, and predation from zooplankton (typically the tiny animals found near the surface in aquatic environments). Of these conditions, nutrient availability, water column mixing, and flow are the most easily targeted by raw water management strategies.

In order to control the excessive growth of algae, algaecide (copper sulfate) is generally applied monthly and sometimes bi-monthly in EGL4, South Tani Reservoir, and the WGLs during the warmer months of May through October. Typically, no algaecide is applied to the reservoirs/lakes in the coldest winter months.

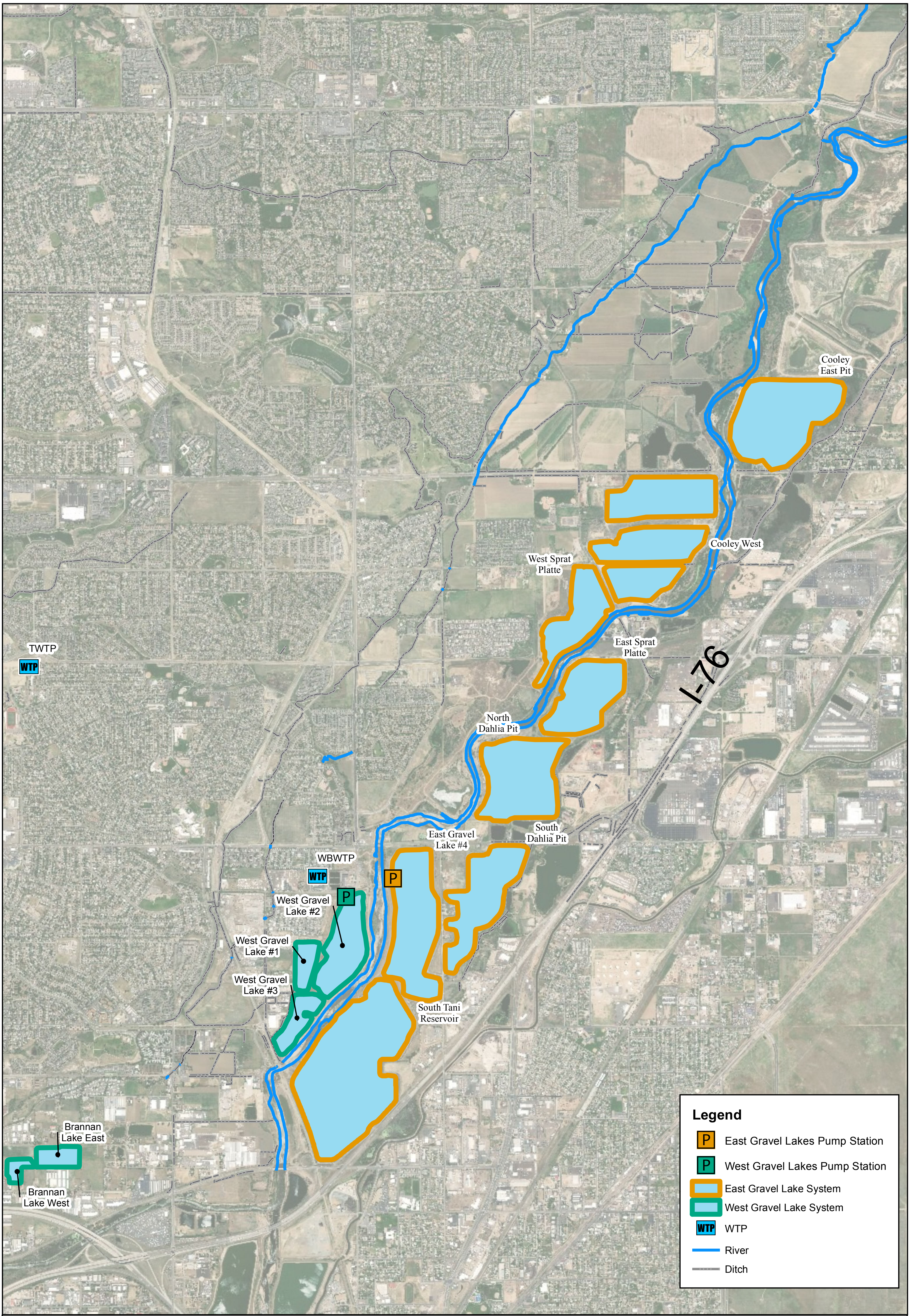

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Figure 1
City of Thornton Gravel Lakes Raw Water Storage System

1/7/2019
1 inch = 2,500 feet

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3. Existing Water Quality Conditions

Thornton's current routine raw water quality monitoring is primarily focused on the southern lakes in their gravel lakes system which include the West Gravel Lakes (WGL1, WGL2, and WGL3), South Tani Reservoir (ST), and East Gravel Lake #4 (EGL4). During the period of interest from 2012 to 2017, the West Gravel Lakes system operated independently from ST and EGL4 with little comingling of the raw water supply. Water is periodically pumped from WGL2 to South Tani but the water volumes are minimal. Records show that this addition is less than 2% of the water coming into ST for the past 10 years. The West Gravel Lakes received inflow from Lower Clear Creek (LCC) Canal and supernatant from the decant ponds of the Wes Brown Water Treatment Plant (WBWTP), while the Burlington Canal (BC) provided inflows to ST. The pipe interconnect between ST and EGL4 allowed the gravity fed water to flow into EGL4, where one of the intakes to the WBWTP is located on the northwest shoreline. Functionally, the WBWTP operated on the ST and EGL4 waterbodies and the West Gravel Lakes and their tributary inputs during the 2012 to 2017 period, while the northern portion of the gravel lake system remained isolated from the WBWTP. For the purposes of this discussion, the northern portion of the gravel lake system includes: South Dahlia, North Dahlia, East Sprat Platte, West Sprat Platte, and the South-Middle-North Cooley West Lakes.

There is a pipe interconnect between EGL4 and South Dahlia, as well as interconnects between the other gravel lakes that allow gravity fed flows to fill each lake. However, prior to 2018 the McKay pump station was not actively utilized due to infrastructure and water quality issues. As a result, this water quality evaluation focuses on the southern portion of the East Gravel Lakes system.

Metro Wastewater Reclamation District (MWRD) historically has had the ability to discharge directly into the Burlington Canal upstream of Thornton's intake from the Burlington Canal into the East Gravel Lakes system. When MWRD discharged to the Burlington Canal, Thornton did not divert any water from the Burlington Canal. In 2013, the Sand Creek flood damaged the pipeline allowing the MWRD to discharge into the Burlington Canal and this piping has not yet been repaired. . Nitrate and phosphorous concentrations in the BC have decreased slightly for the past five years, probably due to the termination of the MWRD discharge in the Burlington Canal and decreases in nutrient effluent concentrations from the Centennial and Littleton-Englewood wastewater treatment plants that discharges to the South Platte River.

To explore the gravel lakes water quality, Thornton provided surface water elevations for each gravel lake and analytical data from 2012 through 2017. Older data became available to evaluate some long-term conditions in the South Platte River; although the focus was on the past six years of data. These data included measurements at LCC, WGL2, BC, ST, and EGL4. The physical monitoring locations are shown in Figure 2. At the WGL2 and EGL4 pump stations, water quality samples were collected from three levels in the water column (surface, middle, and bottom), and from the surface at the ST interconnect with EGL4. The data contained 151 analytes that included anion/cation chemistry (e.g., pH, sulfate, hardness), inorganic and organic nutrients (nitrogen and phosphorus), solids (suspended and dissolved), metals (arsenic, copper, zinc), and an extensive list of organochlorine/organic compounds found in herbicides, pesticides, and petroleum products. Because the focus was on nutrients, algae production and the factors that contribute to algae growth, 23 analytes were selected for the water quality evaluation (Table A.1). Notably, the sample collection frequency varied by location and analyte, ranging from twice a week to quarterly. Except for the physicochemical (i.e., temperature, pH, dissolved oxygen, and conductivity) water quality conditions in the surface and bottom water layers were monitored infrequently.

The frequency of data collection varied greatly for the selected list of 23 analytes and many analytes were not collected at depths that would provide important information regarding limnological conditions (relating to the scientific study of bodies of fresh water, such as lakes) that influence lake dynamics. Total inorganic nitrogen (TIN) was also calculated using the available data by adding ammonia, nitrite, and nitrate when at least both ammonia and nitrate data were available for a location. Nitrite was often left out of this calculation as the values were generally less than method detection limits. Inorganic nitrogen and ortho-phosphorus (OP) are both bioavailable (the degree and rate at which a substance such as phosphorus is absorbed into a living system) nutrient forms that are readily incorporated into algae or cyanobacteria biomass. Algae or cyanobacteria biomass is the mass of living biological organisms in a given area or ecosystem at a given time. Biomass can refer to species biomass, which is the mass of one or more species, or to community biomass, which is the mass of all species in the community. As such, the relative concentrations of these nutrients provide information regarding the potential growth of algae. Therefore, TIN and OP concentrations were used to calculate a stoichiometric mass-based ratio and compared to the commonly used ratio of 7.2 nitrogen to 1 phosphorous, which is an extension of the Redfield Ratio (molar-based) for balanced algae growth. Stoichiometric ratios that are dissimilar to the ratio indicate a nutrient imbalance, which can result in algal blooms favoring specific algae, or bacteria such as cyanobacteria. In addition, box plots were made for ortho-phosphorus, total inorganic nitrogen, and chlorophyll-a. These analytes were selected because TIN and OP are directly available for algae growth, while chlorophyll-a is a surrogate measure of algae biomass that water quality standards often target. These three metrics were evaluated based on individual measurements (e.g., daily estimate) and were summarized on a monthly mean basis to evaluate seasonal patterns.

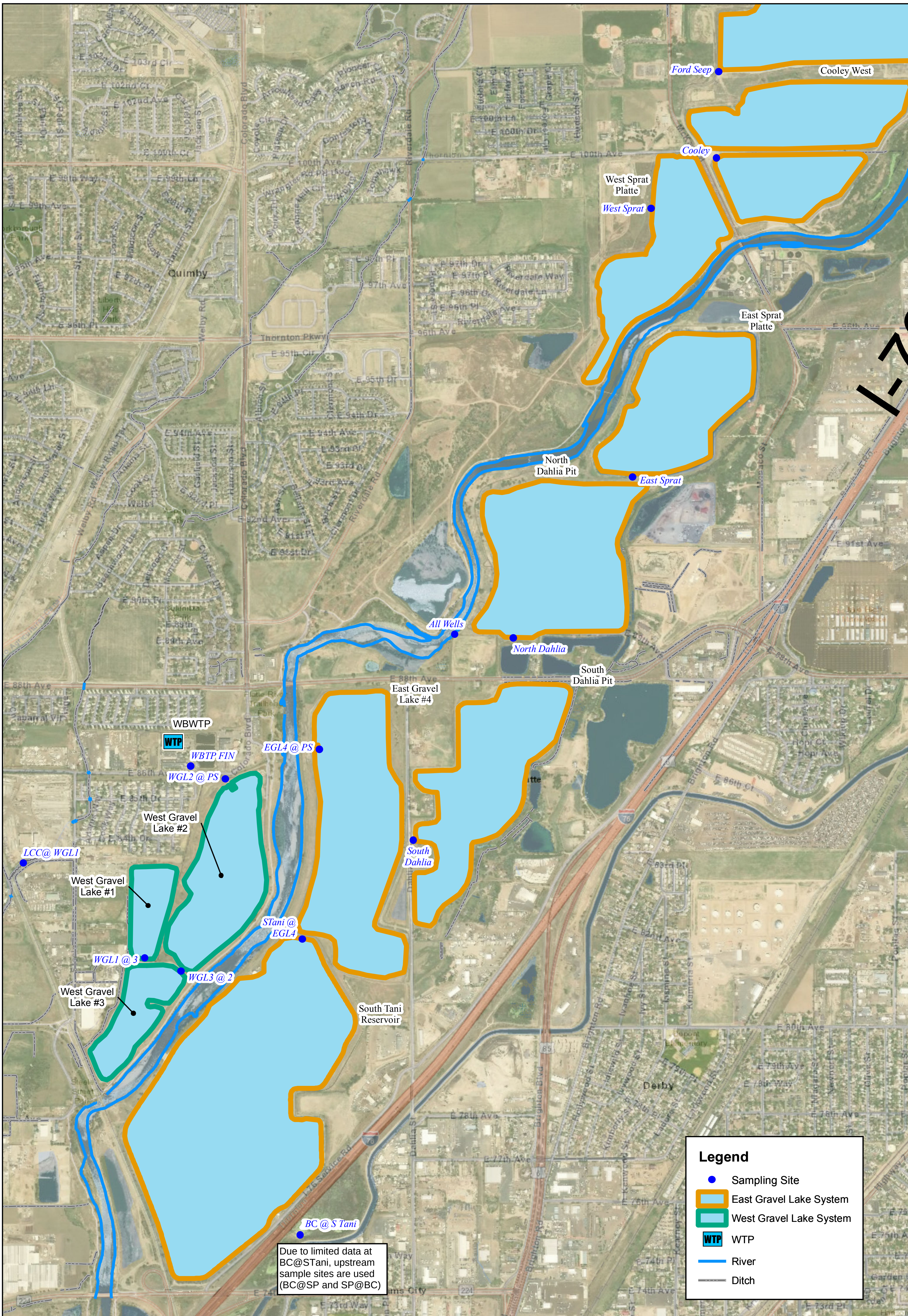

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Figure 2
City of Thornton Raw Water Monitoring Locations

1/7/2019
1 inch = 1,333 feet

C:\Users\evon.harmon\Documents\Figure 2 Raw Water Monitoring Locations.mxd

3.1 General Water Quality Assessment

Water quality conditions were summarized, and the annual mean values were compared to the water quality performance criteria established in the System Performance Criteria TM for the raw water system dated July 16, 2018. This comparison provides a general level assessment of raw water supply conditions. The performance criteria involve various parameters that are arranged as follows:

Tier 1: Criteria that must be met by the system

Tier 2: Criteria that represent best practice and should be met by the system, but may not be required

Tier 3: Criteria that are desired and should be met if practical, but are not required

All the annual mean values calculated for turbidity, pH, temperature, alkalinity, total organic carbon, dissolved organic carbon, total hardness, total dissolved solids, bromide, ortho-phosphorus, and nitrate met the Tier 1 criteria (Appendix A). Dissolved organic carbon was the only analyte that did not consistently meet the Tier 2 criteria; although, it should be noted that only 5 of the 12 Tier 1 criteria have a Tier 2 criterion value. Despite EGL4 and WGL2 routinely meeting the ortho-phosphorus and nitrate criteria, each lake consistently experiences late season algae blooms that generally cause taste and odor problems. The criterion values for ortho-phosphorus and nitrate are excessively high at 3.0 milligrams per liter (mg/L), which is an order of magnitude greater than levels that support nuisance algae growth in many other lakes.

Because the annual mean values mostly met the water quality criteria, individual measurements were also compared to the criteria. The measured water quality conditions (water temperature, pH, alkalinity, total hardness, turbidity, total dissolved solids, ortho-phosphorus, nitrate, total organic carbon, and dissolved organic carbon (DOC)), at mid-layer depths in EGL4 and WGL2 routinely attained their respective Tier 1 water quality criteria with only a few seasonally extreme values exceeding the criteria. Turbidity routinely attained Tier 2 water quality criteria in both EGL4 and WGL2, while total hardness, nitrate, and DOC often exceeded Tier 2 water quality criteria.

3.2 Assessment of Physical Conditions

The water column in EGL4 and WGL2 appear to develop stratified water layers during the summer months in all years, based on the water temperature and dissolved oxygen (DO) data collected at the surface and bottom layers. However, it was not possible to determine the strength of the stratification or whether the gravel lakes exhibited periodic wind mixing (i.e., polymixis) based on the frequency and spatial data collection efforts. Monthly mean temperature and DO differed between surface, middle, and bottom sample locations from late spring to early fall with both analytes being highest at the surface and lowest at the bottom. Temperature and DO was very similar between layers in other months. These data indicate that surface water is warming in summer months and not mixing into the water column. Without mixing, aerobic bacteria in the sediment will consume available oxygen (i.e., sediment oxygen demand) until anoxic conditions, (areas of water that are depleted of dissolved oxygen; i.e., < 2 mg/L) develop near the water/sediment boundary. At this point, a strong reducing environment is created, favoring anaerobic bacteria. Even though the aerobic decomposition can result in nutrient release, the metabolic shift from aerobic to anaerobic results in the greatest release of soluble nutrients into the water column (i.e., internal loading), which facilitates algal growth. Instantaneous DO measurements often revealed anoxic conditions during summer months in most years at EGL4 and WGL2. However, nutrient data were not collected at bottom depths to confirm whether internal loading of ammonia or ortho-phosphorus was occurring during stratified conditions. Monthly mean pH and conductivity did not differ between layers and conductivity was very consistent throughout the water column, which is not uncommon in a stratified lake. The water column in ST was likely stratified as well, but analytes (substances or materials being analyzed) were not recorded at multiple depths.

Understanding the frequency and strength of stratification is important when evaluating mechanisms that may trigger late summer algae blooms. If weakly stratified conditions are eroded by wind mixing events, then the soluble TIN and OP can become immediately available for algae growth during the summer season. Whereas, if stratification is persistent through the summer, soluble nutrients will be trapped in the hypolimnion during the summer. The hypolimnion, or under lake, is the dense, bottom layer of water in a thermally-stratified lake. It is the layer that lies below the thermocline. Typically the hypolimnion is the coldest layer of a lake in summer, and the warmest layer during winter. When fall turnover occurs, the trapped soluble nutrients are released into the photic zone, (the uppermost layer of water in a lake or ocean that is exposed to intense sunlight) and can trigger a fall season algae bloom. Characterizing the low DO conditions in the bottom waters also becomes important when considering the potential to support aquatic life use for recreational purposes. While anoxic bottom waters are a natural phenomenon in lakes and reservoirs, the areal and vertical extent of anoxia, a total depletion in the level of dissolved oxygen, can decrease useable lake habitat in shallow lakes as fish seek refuge during the warm summer months. The gravel lakes are not currently designated for recreational purposes, although limited recreational fishing occurs on some of the lakes such as the West Gravel Lake system and West Sprat Platte Lake. However, as the connectivity of greenways increases along the Colorado Front Range Trail, the recreational fishing uses may become an important part of the planning and management process for the gravel lake system.

3.3 Assessment of Spatial and Temporal Patterns

East Gravel Lake #4 tended to have poorer nutrient water quality conditions than WGL2. This is attributed to the poorer source water quality from the BC as compared to the Lower Clear Creek canal. Monthly mean temperature and DO stratification at EGL4 were more extreme than at WGL2 during summer months. The seasonally lower and more prolonged poor DO concentrations at the bottom of EGL4 likely contributed to internal loading and the observed increase in total phosphorus, ortho-phosphorus, and TIN concentrations at mid-layer depths of EGL4 and greater chlorophyll-a and algae concentrations at the surface of EGL4 than observed in WGL2 as shown in Figure 3. In addition, monthly mean hardness, total dissolved solids (TDS), ortho-phosphorus, ammonium, TIN, and sulfate concentrations at mid-layer depths of EGL4 were greater than at mid-layer depths of WGL2 for all or most months. Median ortho-phosphorus and TIN concentrations were also greater at mid-layer depths of EGL4 than at WGL2 in all or most months. Median chlorophyll-a concentrations at the lake surfaces; however, were slightly greater at WGL2 in more months than at EGL4, indicating the extreme variability in the data. Finally, monthly mean TIN:OP ratios were less than 7.2 at both lakes, although the values for EGL4 were consistently less than WGL2. The relatively low ratios are indicative of an abundance of phosphorus in each lake.

3.3.1 East Gravel Lakes

While it is important to evaluate the general magnitude of water quality concentrations of the inflow and the gravel lakes system, understanding how concentrations change as flow circulates and disperses through the system is an important aspect of managing water quality. The combination of both magnitude and the temporal/spatial changes will help guide practicable water quality management options. Therefore, the patterns in the seasonal (i.e., monthly) and spatial data (i.e., inflow to lake to WBWTP intakes) were examined more closely. Measured concentrations of turbidity, total suspended solids, total phosphorous, ortho-phosphorus, nitrate, and total inorganic nitrogen at the BC were consistently greater than concentrations observed in the mid-layer samples from ST and EGL4. In addition, concentrations of these analytes at ST were generally greater than concentrations observed at EGL4, especially for ortho-phosphorus, nitrate, and TIN. Monthly mean concentrations for turbidity, total suspended solids (TSS), total phosphorous, nitrite, nitrate, and TIN at BC were greater than at the EGL4 mid-layer for most months; while conductivity, alkalinity, hardness, ammonia, total organic carbon (TOC) and sulfate were greater during winter months. Monthly mean nitrate and TIN concentrations at ST were between estimates for BC and EGL4 mid-layer, indicating a natural decline in concentrations as flow passes through the east gravel lake system.

The measured and monthly mean TIN:OP ratios generally decreased as flows traveled from BC to STL to mid-layer depth at EGL4. Median ortho-phosphorus concentrations also decreased from the South Platte River at the Burlington Canal diversion to ST to at mid-layer depth at EGL4 in most months while the median TIN concentration decreased from site to site in all months as seen in Figure 3, Figure 4, Figure 5, and Figure 6. Measured temperature, conductivity, alkalinity, hardness, turbidity, TDS, total phosphorous, ortho-phosphorus, nitrite, nitrate, TOC, sulfate, and TSS showed greater variability at BC than ST and EGL4 at mid layer for all years evaluated. Finally, monthly mean chlorophyll-a and algae counts were greater for the ELG4 top-layer than at ST. These patterns indicate a general decline in analyte concentration from the source water inflow to the intake structure on EGL4, although algae biomass and individual counts appeared to increase. These general patterns were more closely examined for ortho-phosphorus, total inorganic nitrogen, and chlorophyll-a.

The ortho-phosphorus data show that monthly mean concentrations decrease as flows travel from the Burlington Canal diversion source to the mid-layer depths in EGL4 during the periods from January through March (approximately 54% reduction) and again from August through December [approximately 40% reduction, (Figure 3). The fate of ortho-phosphorus in the top layer (epilimnion) generally follows two basic pathways: 1) abiotic complexation and settling out of the water column; and 2) biotic incorporation and eventual settling out of the water column. Owing to the electrical charge of the phosphate ion (PO_4^{3-}), ortho-phosphorus forms relatively weak bonds with suspended sediment (i.e., clay) or other inorganic complexes and settles out of the water column. The biological uptake of ortho-phosphorus by bacteria or algae changes the soluble fraction to a particulate fraction that is contained in living cells. Thus, the measurement of total phosphorus provides insight to the transformation of ortho-phosphorus through the gravel lakes system. The eventual senescence (biological aging) of the plankton results in the settling out of the water column. Both pathways contribute to the phosphorus content in the sediments that can eventually be recycled via internal loading mechanisms facilitated by microbial decomposition of organic matter or chemical mediated redox pathways.

During May through July, the monthly mean ortho-phosphorus concentrations in the EGL4 mid-layer depth is typically greater than concentrations observed in ST or BC inflows (approximately 17% increase). In terms of source water supply, May and June represent the best inflow conditions from a water quality standpoint, given the snow-melt runoff characteristics of the South Platte River, which is often combined with spring wet-weather events that dilute the total and dissolved suspended solids content of inflows. This pattern in ortho-phosphorus concentrations indicates that the internal cycling of nutrients is likely occurring in EGL4 during the summer months and may also influence the relatively higher concentrations observed in September and October when fall turnover of the lake layers occurs. Gaining insight into the conditions or mechanisms that result in higher ortho-phosphorus concentrations in EGL4 during the summer will be an important aspect of managing the raw water supply.

The inorganic nitrogen data show that mean concentrations decrease every month as inflows travel from the BC to the mid-layer depth in EGL4. The smallest decreases of approximately 55% occur during May through July, with typical decreases in concentrations of approximately 80% occurring during the remaining months as shown in Figure 2. The fate of inorganic nitrogen in the top layer (epilimnion) generally follows these basic pathways: 1) microbial transformation via nitrification or denitrification; and 2) biotic incorporation and eventual settling out of the water column, which also facilitate the denitrification pathway. The nitrification process (conversion of ammonia to nitrate) is facilitated by aerobic conditions in the water column, while the denitrification process (conversion of nitrate to nitrogen gas) is facilitated by anaerobic conditions near the water/sediment boundary or within the active sediment layer. Nitrogen gas is a metabolic byproduct that is released back into the water column and eventually the atmosphere. The biological uptake of inorganic nitrogen by bacteria and algae changes the soluble fraction to a particulate fraction that is contained in living cells. The eventual senescence of the plankton results in the settling out of the water column, contributing to nitrogen content in the sediments that can eventually lead nitrogen being recycled via oxidation-reduction mechanisms facilitated by microbial decomposition of organic matter.

3.3.2 West Gravel Lakes

At the Lower Clear Creek diversion, measured concentrations of Total Suspended Solids (TSS), Total Dissolved Solids (TDS), total phosphorous, ortho-phosphorus, ammonia, nitrite, nitrate, TIN, and sulfate were generally greater than concentrations measured at the mid-layer in WGL2. Monthly mean turbidity, TSS, total phosphorous, nitrite, nitrate, and TIN concentrations were also generally greater at LCC than in WGL2 on a year-round basis, while conductivity, alkalinity, hardness, ammonia, TOC, and sulfate exhibited seasonal differences between the two waterbodies. These anion/cation-based concentrations were considerably greater in LCC during the winter months when stream flows are strongly influenced by road salts and low baseflow conditions that tend to magnify the effects of road maintenance. During the spring and early summer months, the anion/cation-based concentrations are diluted by snowmelt runoff and are less at LCC than in WGL2. The measured and monthly mean TIN:OP ratios were generally less at the WGL2 mid-layer depth than in LCC. Median OP and TIN were greater at both inflow streams than at LCC in all or most months as shown in Figure 3, Figure 4, Figure 5, and Figure 6. Finally, daily temperature, conductivity, alkalinity, hardness, turbidity, TDS, total phosphorous, ortho-phosphorus, nitrite, nitrate, TOC, sulfate, and TSS had greater variability in LCC than at the WGL2 mid-layer throughout all years. No data were available for WGL1 or WGL3; therefore, the general reduction in analyte concentrations as flow passes through the system was not evaluated. However, similar to the East Gravel Lakes and their source water, measured concentrations in WGL2 were often less than concentrations in LCC.

The dissimilarity in water quality between the gravel lakes and their source water inflows, indicate that ST, EGL4, and the West Gravel Lakes allow for settling and microbial transformation/uptake of nutrients and stabilization of water quality. Less nutrients, especially nitrate, in the lakes than compared to the inflows indicate that the nutrients are either settling or being rapidly incorporated directly from the water column by algae or autotrophic bacteria which are capable of synthesizing their own food from inorganic substances.

The Burlington Canal, along with the natural cycling of senescent algae, provides a consistent supply of organic matter to the sediment of ST and East Gravel Lake #4. This facilitates autotrophic (capable of synthesizing their own food) or heterotrophic (incapable of synthesizing their own food; must rely on other organisms, both plants and animals, for nutrition) microbial decomposition. Depending on the thermally or oxygen stratified conditions of the lakes, aerobic (with oxygen) or anaerobic (without oxygen) recycling of nutrients at the water-sediment interface can facilitate the growth of bacteria (actinomycetes) or cyanobacteria. At this interface, the actinomycetes can switch to anaerobic decomposition and continue to release taste and odor compounds in addition to facilitating internal nutrient loading from the sediment. Benthic cyanobacteria can also grow at this interface and eventually be released into the water column providing a potential source of taste and odor compounds. However, based on the information provided, there is currently no direct linkage between the taste and odor events and the organisms that may be responsible. Understanding the sources of taste and odor events, whether from external sources such as the Burlington Canal or internal sources from either benthic/pelagic cyanobacteria, diatoms (photosynthesizing algae, found in almost every aquatic environment) or soil/sediment bacteria will be an aspect of managing the raw water supply.

In comparison of the source water inflows, measured concentrations of the selected water quality analytes differed between the BC inflows and LCC inflows; although no analyte was consistently greater for one inflow compared to the other. However, when summarized monthly, the mean pH, ortho-phosphorus, nitrate, and TIN concentrations were consistently greater in the BC than in the LCC for all months, while the monthly mean alkalinity, ammonia, and TOC concentrations at BC were less than at LCC in winter months. Median TIN and OP concentrations were also generally greater in the BC than in LCC as shown in Figure 3, Figure 4, Figure 5, and Figure 6, and monthly mean TIN:OP ratios were less than 7.2 for both inflows. Furthermore, measured pH, turbidity, ortho-phosphorus, ammonia, nitrate, and TIN concentrations were more variable at BC than at LCC, which is likely a result of upstream influences from wastewater, stormwater runoff, and irrigation return flows that have a major impact on the quality of the source waters.

3.3.3 Algae Biomass

Eutrophic conditions (rich in organic and mineral nutrients and supporting an abundant plant life, which in the process of decaying depletes the oxygen supply for animal life) existed in ST, EGL4, and WGL2 from 2012 through 2017, with multiple algae blooms observed in each lake. Elevated chlorophyll-a concentrations often corresponded with higher algae counts, but the resolution of the algae count data was poor. Algae biomass routinely exceeded 20 micrograms per liter (µg/L) of chlorophyll-a, which is a threshold commonly applied to Colorado warm water lakes. Notably, algaecides are used throughout the summer months to help control the excessive growth of algae; although winter applications do not occur given the reduced off-season demand for water. These conditions certainly influence the patterns in algae biomass as measured by chlorophyll-a. Winter blooms are common in front-range eutrophic reservoirs as small bodied, low-light adapted chlorophyte algae (e.g., *Chlamydomonas* sp.) and cryptophyte algae (e.g., *Cryptomonas* sp.) grow well in the colder, nutrient-rich waters of ice-covered lakes (Kugrens and Clay 2003). The winter blooms can result in relatively higher suspended solids concentrations, mainly comprising algae, that decrease the efficiency of filtration units and water treatment (Smith and Emde 1999).

Summer blooms, that are often dominated by cyanobacteria and diatoms, can also create water treatment issues. In response to various physical or biological conditions, these algae can produce geosmin or MIB, which can be released into the water column upon algae rupture or death, causing taste and odor events (Zhang et al. 2013; Pattanaik and Lindberg 2015). In addition, dead algae will settle on lake bottom substrate where they decompose with the help of bacteria (e.g., actinomycetes), which can also produce taste and odor compounds. These compounds can be recognized by their muddy/earthy smell, which has a very low threshold for human perception in the range of 4 to 6 parts per trillion (e.g., geosmin – 4 ng/L and MIB – 6 ng/L, [Kaloudis and Hiskia 2016]).

While the measurement of geosmin and MIB provides a quick identification of a taste and odor event, often this knowledge is too late in the process to effectively manage a bloom or other conditions that may trigger the event. A key component to understanding the mechanisms behind a taste and odor event is documenting the algae assemblage using a high resolution technique, including a phycologist who can identify cyanobacteria to the species level. Pairing geosmin and MIB results with species level data will provide insight into the organisms responsible and the mechanisms that initiate the event. Because geosmin production is species specific (Jüttner and Watson 2007, Taylor et al. 2006), a routine monitoring program should focus closely on cyanobacteria enumeration and identification to the species level such that the data can be used in a more proactive treatment approach. Notably, species level taxonomic data can be cost prohibitive to pair with each chemical analysis of geosmin and MIB; therefore, it is best to collect the algae identification sample and analyze the sample when conditions warrant further examination. Repetitive patterns in the data will likely be evident year after year and surrogate or indicator measurements such as water temperature, seasonal timing, or quiescent periods will be useful to inform management strategies, such as changing intake water elevations, blending of other source waters, or being able to switch from a southern gravel lake to a northern gravel lake.

4. Future Water Quality Considerations

The state and federal regulatory nexus that guides drinking water and wastewater compliance currently has two key water quality limitations that will directly or indirectly affect the WBWTP when new regulations are fully implemented. These water quality limitations are nutrient management and corrosion control. Additionally, external conditions on Thornton's raw water supplies, including possible impacts of climate change or over-appropriation of upstream watercourses, could affect the performance of the raw water supplies. These future considerations should be taken into account in Thornton's raw water supply planning

4.1 Nutrients Management Control Regulation

The Colorado Water Quality Control Commission (WQCC) Regulation #85 – Nutrients Management Control Regulation (5 CCR 1002-85) will establish numerical effluent limitations for many domestic wastewater treatment plants and industrial wastewater dischargers and will have other requirements for smaller point source dischargers, along with voluntary programs for nonpoint sources (many diffuse sources) to address nutrients. As limits are eventually established in discharge permits, the target concentrations for TIN will become an annual median concentration of 15 mg/L-N, and the total phosphorus (TP) annual median will be 1.0 mg/L. While these values are threshold limits it is anticipated that over time the instream concentrations will be even less. These limits are expected to impact Burlington Canal as the South Platte River, which feeds the canal, is associated with a number of domestic and industrial discharges. The historic long-term (2009-2017) median TIN and TP concentrations observed for the monitoring station at the Burlington Canal are 3.4 mg/L and 1.7 mg/L, respectively. The TIN concentrations show no significant trend over time. TP concentrations have significantly decreased over time (2009 through 2015) at a rate of approximately -0.32 mg/L per year, such that TP concentrations are typically less than 2.0 mg/L. The TN:TP ratios over time indicate a surplus of phosphorus in the system despite the decreasing TP concentrations. The trend in TN:TP ratios over time is showing an improvement such that if the trend in TP reduction continues, the emphasis on watershed management would shift to nitrogen too. However, the relative concentrations for both analytes indicates a surplus of nutrients in the source waters that facilitates algae growth, indicating that reduction strategies should focus on both nutrients, although phosphorus reduction is the most feasible and achievable with raw water management strategies.

4.2 Lead and Copper Rule

The second key water quality limitation that will directly affect the WBWTP and its source waters, once implemented, is the federal guidance on the Optimal Corrosion Control Treatment under the federal Lead and Copper Rule. Utilities that provide drinking water that potentially passes through lead and galvanized pipes could be required to add chemical corrosion control such as orthophosphate to achieve the optimal reduction in lead exposure at the tap from the legacy use of lead and galvanized materials in the water system. As of March 2018, the Colorado Department of Public Health and Environment (CDPHE) designated orthophosphate as the best treatment for Denver Water to reduce lead at their customers' drinking water taps. Potentially, 1 mg/L of ortho-phosphorus (equivalent to approximately 3 mg/L orthophosphate) could be added during the treatment process. While the addition of phosphate in drinking water prevents leaching of lead and copper from pipes and fixtures, the environmental consequences on downstream receiving waters, such as Thornton's gravel lakes system, may be negative. Input of nutrients in water may create eutrophication (when a body of water becomes overly enriched with minerals and nutrients that induce excessive growth of plants and algae) of lakes and reservoirs.

The bioavailable form of phosphorus (ortho-phosphorus) comprises approximately 90% of the total phosphorus concentrations observed at BC. The addition of ortho-phosphorus to drinking water supplies will potentially increase concentrations in the receiving waters of South Platte River Basin via return flows. This condition will likely influence source water conditions for the WBWTP and provide an additional source of bioavailable phosphorus that may increase algae and cyanobacteria blooms in the gravel lakes.

4.3 External Conditions

Possible effects on Thornton's raw water supplies that need to be considered and accounted for in planning for the future include reduced stream levels, flooding events, and higher water temperatures. Spillways at Cooley West complex will allow for frequent, controlled flooding into the reservoir These effects could be caused by either climate change or the over-appropriated conditions of upstream watercourses, and both of these effects could negatively impact the water quality conditions related to taste and odor such as geosmin, TP, and TIN. These diminished water quality conditions could be expected to persist for longer durations throughout the calendar year and or occur more frequently or more intensely. If so this would suggest that the need and importance for Thornton to manage the existing issues that have been identified and defined are increased and could further justify the recommendations that follow.

5. Water Quality Recommendations

Based on this water quality evaluation, future monitoring recommendations have been developed to help Thornton achieve a more complete understanding of the conditions that facilitate the growth of algae blooms, especially during the summer and fall seasons, that result in taste and odor issues for the WBWTP.

5.1 Improved Water Quality Monitoring

Currently, Thornton's monitoring program is designed to evaluate water quality conditions at locations where the transfer of water occurs from one water body to the next, which is typically near shore, or at the WBWTP intake structures. In reviewing the data, it was not possible to evaluate many of the dynamic limnological conditions that help guide lake management decisions, and other decisions related to raw water infrastructure improvements that could provide pre-treatment of the raw water prior to discharge to the water treatment plants. Many of the recommendations described below are, therefore, designed to gain a better understanding of the limnological conditions in the open water zones of the lakes as well as more high frequency data collection efforts that provide sufficient resolution of changing water quality conditions.

The duration of the recommended improved water quality monitoring program is difficult to predict. This new program is not intended to be a continuous, full-time program for the life of the gravel lakes system. The intent of this recommended program is to more fully understand the dynamic conditions of the gravel lakes system and to more fully understand and evaluate any of the proposed water quality improvement options that are described at the end of this section. The final details and duration of the program can be adapted to accommodate and/or focus on the needs of the water quality improvements that may result from this Master Plan, and to accommodate the capital cost and operating budgets that are available.

The following additions or changes are recommended to the current monitoring program:

1. **New Deep Monitoring Site at Each Lake:** For ST, EGL4, WGL2, and South Cooley Lake, add a monitoring site over the deepest location or at the center of each lake. Collect water quality sonde (any of various devices for testing physical conditions, often for remote or underwater locations) profiles to document water temperature, specific conductivity, pH, dissolved oxygen and oxidation reduction potentials on 1-meter increments from the surface to the near bottom water layer (i.e., within 0.5 meter of the sediment). Collect water samples at the

surface, middle, and bottom layers and analyze for nutrients (total and dissolved organic/inorganic nitrogen and phosphorus fractions) and chlorophyll-a conditions (surface and middle depths).

These data will increase the understanding of the limnological process that affects vertical density gradients (e.g., relative thermal resistance to mixing) and horizontal mixing (e.g., transfer of water via the interconnects) of the water column, and whether conditions are favorable for internal nutrient loading that may facilitate late season algae growth.

2. **Continued Nutrient Monitoring:** For all gravel lakes, continue monitoring the near shore locations at the interconnects for nutrients (i.e., total and dissolved organic/inorganic nitrogen and phosphorus fractions) and chlorophyll-a where the interconnects for water transfer occur from the upgradient lake to the downgradient lake or where the pump stations are located in a lake. This sampling will help document whether the natural attenuation of nutrients from upgradient to downgradient lakes will be an effective strategy to help reduce the influence of nutrients on algal production.

3. **South Lakes Monitoring:** For ST, EGL4, WGL2, and South Cooley Lake, the water quality sampling should occur on a weekly basis from April through October and monthly from November through March at the surface, middle, and bottom depths at both the near shore and center of the lake for nutrient (i.e., total and dissolved organic/inorganic nitrogen and phosphorus fractions), and chlorophyll-a conditions (surface and middle depths). Routine physicochemical profiles (i.e., temperature, pH, specific conductance, dissolved oxygen, and oxidation reduction potential) should also be collected at both stations.

4. **EGL4 Water Quality Sampling:** For EGL4, an integrated water column sample should be collected monthly for the identification, enumeration, and biovolume analysis of the phytoplankton assemblage to gain better insight into the species that influence taste and odor events. Separate water samples should be collected when geosmin and MIB analyses are collected but analyze the taxonomic composition only when the concentrations indicate a taste and odor event is occurring.

   Understanding the community structure during each month will help elucidate the seasonal changes that typically occur each year and the taxa (a group of one or more populations of an organism or organisms seen by taxonomists to form a unit) that are associated with toxin or taste and odor events.

5. **Geosmin, MIB Lake Sampling:** For EGL4, WGL2, and South Cooley Lake, geosmin, MIB, and microcystin-LR samples should be collected from the surface, middle, and bottom depths to help document the onset and duration of taste and odor and toxin events. These data should be paired with a phytoplankton sample, if the geosmin, MIB, or microcystin-LR data indicate an event. Notably, the measurement of taste and odor compounds or toxins is the only positive method for documenting their presence, because the presence of cyanobacteria does not necessarily indicate the presence of taste and odor or toxins.

6. **Geosmin, MIB Source Sampling:** For South Platte River @ Burlington Canal, geosmin and MIB samples should be collected from the inflows to help document the origin, onset and duration of taste and odor and toxin events in the gravel lake system. Soil bacteria from the riverine system could provide a source of taste- and odor-causing organisms or compounds.

7. **New EGL4 profiling System:** For EGL4, install a centrally located buoy mounted water quality profiling system to document water temperature, specific conductivity, pH, dissolved oxygen, and oxidation reduction potentials on 1-meter increments from the surface to the bottom waters. High frequency data (i.e., 4 values per day) from this system will substantially increase the understanding of the limnological or environmental processes that affect vertical and horizontal mixing of the water column and whether conditions are favorable for internal nutrient loading that may facilitate late season algae growth. High frequency profile data may also be used to determine selective water withdraw strategies to potentially circumvent the intake of poorer water quality.

8. **New Temperature Data Monitoring:** For EGL4, WGL2, and South Cooley Lake, install a thermistor string in the deepest location or at the center of each lake to collect high frequency (15-minute interval) water temperature data on 1-meter increments from the surface to the bottom layer. These data logger arrays are relatively inexpensive to install and maintain and will vastly improve the understanding of wind mixing events and vertical density gradients that affect chemical and biological processes in the lakes.

5.2 Future Studies to Support Lake Management

The comparable water quality data among each of the gravel lakes and the recommended improved water quality monitoring described above will provide a better understanding of the gravel lakes systems' ability to improve water quality before it reaches the WBWTP. The recommended monitoring efforts will help inform future decisions regarding which combination of management strategies will be the most cost-effective to reduce nutrients. To date, epilimnetic (top water above the thermocline or metalimnion) water circulation and algaecide treatments have been the two management strategies used to reduce algae biomass. The algaecide treatments have shown to provide the most effective short-term treatment to control algae and cyanobacteria growth, but for long-term benefits this strategy will need to be paired with a phosphorus reduction strategy. Water circulation may help to mix the buoyant cyanobacteria and reduce their ability to remain at the surface layer where they can rapidly grow and out-compete other algae, but in nutrient-rich waters, epilimnetic circulation also increases the growth of other algae. The mixing of algae through the photic zone creates a more uniform habitat where all algae grow well, thus elevated algae biomass is often a consequence of epilimnetic or whole lake circulation. Nonetheless, water horizontal and vertical circulation in the gravel lakes should be studied more closely to determine other water quality benefits/consequences of increasing water circulation.

5.2.1 Water Circulation Study

Due to the complexity of the gravel lake system, the physical shape of some lakes, and the spatial arrangements of the water-body interconnects, there may be many areas that achieve little circulation, which facilitates poorer water quality conditions, while in other cases, there may be some short-cycling of flow through the system. The limited data collected from the Burlington Canal, South Tani Reservoir, and East Gravel Lake #4, indicate a natural improvement in nutrient water quality concentrations as flow passes through the system, although there is no information regarding the potential improvement in water quality from the southern gravel lakes to the northern gravel lakes. Furthermore, there is little understanding of the hydrodynamics as flow passes from one gravel lake to the next. To help document the flow through characteristics, especially from the southern lakes to the northern lakes, a dye study would help document the dispersal and flow patterns, including documenting the areas where little circulation occurs. The results of a dye study would also provide information relative to water residence time and the potential dispersion of phytoplankton, nuisance blooms (a rapid increase of one or only a few species of phytoplankton, resulting in densities high enough to cause discoloration of the surface), or taste and odor events through the system. The addition of lakes may increase the reduction of nutrients beyond what the current two-lake route achieves. Mixing entire lakes and thus eliminating “dead zones” would increase the functionality of each lake in the multi-lake route.

The Solar Bee® Reservoir Circulators currently installed in ST, EGL4, and WGL2 are designed to mix the top layer (epilimnion) and prevent algae from remaining constantly in the photic zone. While mixing may occur here, the existing chlorophyll-a and algae data indicate that blooms are still occurring. In addition, the Solar Bees do not address the formation of hypoxia (i.e., reduced oxygen content of a body of water detrimental to aerobic organisms) at the sediment/water interface. In fact, the epilimnetic mixing may facilitate the dispersion of nutrients across the thermocline (also known as the thermal layer or the metalimnion in lakes, is a thin but distinct layer in a large body of fluid (e.g. water, as in an ocean or lake; or air, e.g. an atmosphere) in which temperature changes more rapidly with depth than it does in the layers above or below) and into the photic zone where they are accessible to algae. Finally, due to the lack of sufficient sampling data across the vertical lake profiles it is unknown if the Solar Bees are facilitating the mixing of inflow water in the reservoir or whether the inflows enter the lake at a certain elevation and flow through system. Considering the elevation of the waterbody interconnects, the hypolimnetic water of the upgradient lake may flow into the downgradient lake and seek a same density gradient and minimize any effective vertical mixing component. It is possible that the pipe interconnects may only facilitate horizontal mixing of poorer quality (i.e., nutrient-rich water) from one lake to the next. Depending on the strength of wind mixing events the lakes may remain stratified or mix periodically. Mixing of the nutrient-rich hypolimnetic waters would facilitate algae growth.

The monitoring recommendations, specifically one-meter interval sonde data and water temperature loggers, will provide a better understanding of water layer density and the relative mixing potential of lake and inflow water. At that time, the existing Solar Bee system may need to be modified and expanded to effectively circulate algae in the mixed water layer and disrupt surface water habitat for cyanobacteria.

5.2.2 Phosphorus Reduction Study

A key focus of the gravel lake management should be on the reduction of ortho-phosphorus concentrations from the source waters and through the gravel lake system. It is important to recognize that it will take multiple combined management strategies to reduce phosphorus rather than one strategy, alone. As noted above, there is natural attenuation in nutrient concentrations through the southern gravel lakes, but the relative ortho-phosphorus concentration is sufficient to support nuisance algae growth year-round. Furthermore, the stoichiometric ratios (used to find the right amount of one reactant to "completely" react with the other reactant in a chemical reaction—that is, the stoichiometric amounts that would result in no leftover reactants when the reaction takes place) indicate that ortho-phosphorus is in abundant supply compared to the inorganic nitrogen fraction. As a result, cyanobacteria are not limited by nutrient availability given their ability to fix atmospheric nitrogen when environmental conditions (e.g., water temperature and light availability) are conducive to rapid growth. Therefore, multiple lake management strategies that target phosphorus reduction should be considered.

It will be important to evaluate the external and internal phosphorus loading characteristics of the gravel lake system and the monitoring recommendations provided above will help document these conditions. The most effective phosphorus management strategies include the chemical precipitant (i.e., buffered aluminum sulfate or ferric salts) or binding (i.e., lanthanum modified bentonite clay) of ortho-phosphorus in combination with watershed pollutant reduction wetlands that effectively capture particulate phosphorus while the wetland plants incorporate ortho-phosphorus. Considering Thornton's situation, the watershed pollutant reduction wetlands are not a viable option; although wetland mitigation (e.g., biofiltration cells) may be a management option worth consideration. The limiting factor to fully develop a "pretreatment" wetland or biofiltration cells is lack of available space to achieve adequate water contact time, thereby settling out the particulates and allowing biological uptake to occur. These "pretreatment" wetlands essentially become biological reactors that help reduce suspended solids and nutrient concentrations. The addition of chemical precipitants to the biofiltration treatment system can increase the nutrient removal efficiency; although these combined biotreatment/chemical precipitant systems require additional operation and maintenance funds to maintain the function of the system.

Similar to the wetland "pretreatment" or a biofiltration strategy, source water inflows can be treated with a chemical precipitant to allow the settling of the precipitate to occur within the portion of a gravel lake or a settling basin, before flows circulate through the gravel lake system. The chemical precipitate formed during treatment is very stable in sediments and is not susceptible to redox (oxidation reduction) or pH conditions in the sediment. The chemical pretreatment of inflows has been effectively used in stormwater and lake management for more than 30 years in Florida (Harper 2017). Given the physical layout of the gravel lake system, the chemical pretreatment of inflows would be a more effective nutrient management strategy than trying to treat individual lakes to reduce nutrients. The chemical precipitant would provide a substantial reduction in suspended solids and phosphorus concentrations as flows enter the gravel lake system. When combined with the natural attenuation, flows could be passed through the entire gravel lake system with incremental water quality benefits occurring in each lake, and then pumped back to the WBWTP via the McKay pump station. This nutrient management strategy would be the most cost-effective in terms of phosphorus reduction.

Nutrient management strategies that rely on the chemical binding properties of lanthanum modified bentonite clay have been shown to be very effective as in-lake nutrient management of the sediment layer. In lakes where internal phosphorus loading is a substantial component of the total phosphorus load, the adsorbent clay (capable of accumulating ortho-phosphate on its surface) will permanently bind with ortho-phosphate in the water column and settle to the bottom sediments, forming a layer that prevents the subsequent release of phosphorus during reducing conditions. In lakes where internal nutrient loading also facilitates the growth of benthic cyanobacteria, the adsorbent clay will also help reduce their growth by controlling bioavailable phosphorus. This management strategy may be a viable treatment option for East Gravel Lake #4, if future monitoring determines the relative contribution of internal nutrient inputs from the sediments, as well as sources of cyanobacteria that contribute to taste and odor events.

5.2.3 Oxygenation Study

Depending on the stratification characteristics of East Gravel Lake #4, hypolimnetic oxygenation (a lake treatment designed to prevent hypolimnetic anoxia by supplying pure oxygen gas to bottom waters) should be considered as a lake management alternative. Oxygenation systems are designed to increase the dissolved oxygen concentrations in the bottom waters to reduce anaerobic conditions (the absence of oxygen, preventing normal life for organisms that depend on oxygen) that facilitate internal nutrient loading as well as the release of dissolved iron and manganese that cause drinking water treatment issues. Oxygenation systems differ from circulation systems in that destratification or layer mixing is not an outcome of oxygenation. These systems have been typically implemented in deeper lakes and reservoirs that have a well-established hypolimnion. However, the relative shallow nature of the gravel lakes and the lack of data regarding density gradients and a well-established hypolimnion may limit the effectiveness of oxygenation as an internal nutrient loading management strategy, but the additional monitoring would help elucidate these conditions and establish whether oxygenation could be an alternative management strategy.

The management strategies that target internal nutrient loading from the sediments, such as the adsorbent bentonite clay and hypolimnetic oxygenation, would also require special studies to quantify the sediment oxygen demand and the phosphorus release dynamics of the sediment. However, the addition of routine monitoring of nutrient water quality conditions near the sediment layer combined with increased measurement frequency of dissolved oxygen and thermal profiles, will provide a dataset that can be used to assess the need for sediment-based management strategies. The primary management focus should be reducing the inflow phosphorus concentrations and managing the flow/circulation of water through the entire gravel lake system to increase the natural attenuation benefit.

5.2.4 Water Quality Improvement Options

Based on the findings and recommendations detailed above, the following options were identified as possible improvements to water quality in the gravel lakes intended to maintain suitable taste and odor characteristics of the water supplied to the WBWTP. Table 1 summarizes the advantages and cost categories associated with each option. These options will be evaluated further in the water balance evaluation (modeling of the lake operations using GoldSim®) to identify the conceptual required performance, size, cost and similar metrics.

Option 1 – Lakes in Series

This option considers operating the gravel lakes in series, from WGL1 to the McKay Pump Station as follows:

- WBWTP and TWTP would continue to produce the historic quantities of treated water
- Water from WGL2 would be pumped to EGL4
- Most of the year, water needed at WGL2 would be supplied by the McKay Pump Station (from South Cooley West)
- When the supply needed at WBWTP would exceed 25 MGD (estimated capacity of McKay PS supply to WBWTP), EGL4 Pump Station would operate and provide supplemental water to WBWTP with water from EGL4.

Option 2: Precipitant Addition

This option considers the addition of a precipitant to sequester phosphorus within raw water flows entering the gravel lakes. The chemical precipitant would be added at Thornton's Burlington Canal intake, feeding into ST. The chemical addition would occur continuously when water is being diverted from the Burlington Canal. Additionally, the gravel lakes would be operated in series, as described in Option 1, to provide the greatest distance between the precipitant addition and the raw water pumping to the water treatment plants. WBWTP and TWTP would continue to produce the historic quantities of treated water.

Option 3: Precipitant Addition + Bypass

This option also considers operating the gravel lakes in series and adding precipitant at the Burlington Canal Intake. However, from August 1 to October 31, the water from Burlington Canal would bypass ST and EGL4 and would feed directly into South Dahlia. Phosphorous concentrations are at their peak during this time period. Raw water diversions to WBWTP and TWTP would continue in the same historical patterns.

Option 4: Maximizing Thornton WTP Production

This option does involve raw water quality improvement, but rather it considers the possibility of achieving finished (potable) water quality improvements (in the form of improved taste and odor). This option considers operating TWTP at its maximum capacity and only relying on WBWTP to supplement the water production as needed. TWTP maximum capacity is 20 MGD (22 MGD of water supplied to the plant). The raw water operations would be as follows:

- The gravel lakes would be operated in series, similarly to Option 1
- Water from WGL2 would be pumped to EGL4
- Water needed at WB WTP would be supplied by the McKay Pump Station (from South Cooley West)
- water from EGL4 would be sent to T WTP all year round (maximum rate of 15 MGD based on existing equipment)

Table 1: Water Quality Improvements Evaluation

Option #	Name	Advantages	Cost Categories
Option 1	Lakes in Series	Water from ST and EGL4 are being mixed and circulated through all the gravel lakes. Lagoons supernatant will be mixed and circulated with Burlington Canal water through all the gravel lakes	New interconnect from the McKay PS to feed WBWTP directly[1]. Increased pumping cost: - McKay PS to WB WTP - WGL2 to EGL4
Option 2	Precipitant Addition	A significant amount of phosphorus is removed from reaction with Nitrogen in the water supplied to the gravel lakes all year round. Water from ST and EGL4 are mixed and circulated through all the gravel lakes. Lagoons supernatant will be mixed and circulated with Burlington Canal water through all the gravel lakes.	Capital for chemical addition equipment. Labor and chemical costs for operational cost. Occasional maintenance necessary to remove sludge from bottom of ST New interconnect from the McKay PS to feed WBWTP directly[1]. Increased pumping cost: - McKay PS to WB WTP - WGL2 to EGL4
Option 3	Precipitant Addition + Bypass	A significant amount of phosphorus is removed from reaction with nitrogen in the water supplied to the gravel lakes. During phosphorous peak season from Burlington Ditch, EGL4 does not receive additional phosphorus loads. Water from ST and EGL4 are mixed and circulated through all the gravel lakes. Lagoons supernatant will be mixed and circulated with Burlington Canal water through all the gravel lakes.	Capital for chemical addition equipment. Labor and chemical costs for operational cost Occasional maintenance necessary to remove sludge from bottom of ST Bypass extended from EGL4 to South Dahlia New interconnect from the McKay PS to feed WB WTP directly[1]. Increased pumping cost: - McKay PS to WB WTP - WGL2 to EGL4
Option 4	Maximize Thornton WTP Production	WB WTP operations would be easier as the plant would be producing smaller flows. Quality of water produced may improve. Water from ST and EGL4 are being mixed and circulated through all the gravel lakes. Lagoons supernatant will be mixed and circulated with Burlington Canal water through all the gravel lakes.	New interconnect from the McKay PS to feed WB WTP directly[1]. Increased pumping cost: - EGL4 PS to T WTP - McKay PS to WB WTP - WGL2 to EGL4

[1] Temporary drawback to treating water from McKay PS directly at the WBWTP without mixing may include water high in mineral content delivered to customer taps.

6. Water Quantity Evaluation - GoldSim® Modeling

The water quality improvement options that were developed as part of the raw water quality evaluations will be evaluated using a mass balance computer simulation of hydraulic conditions within the gravel lakes. The existing and proposed future flow data at the water treatment plants and at water sources to the gravel lakes will be used as input for a mass balance computer model (GoldSim®) of the water movement through the gravel lakes. The computer simulations will reflect existing conditions, proposed conditions for the water quality improvement options, and future conditions that reflect alternative scenarios for operations of Thornton's raw water supply system. These water quantity evaluations will be performed and documented in a separate, formal Technical Memorandum.

7. References

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8. Figures and Tables

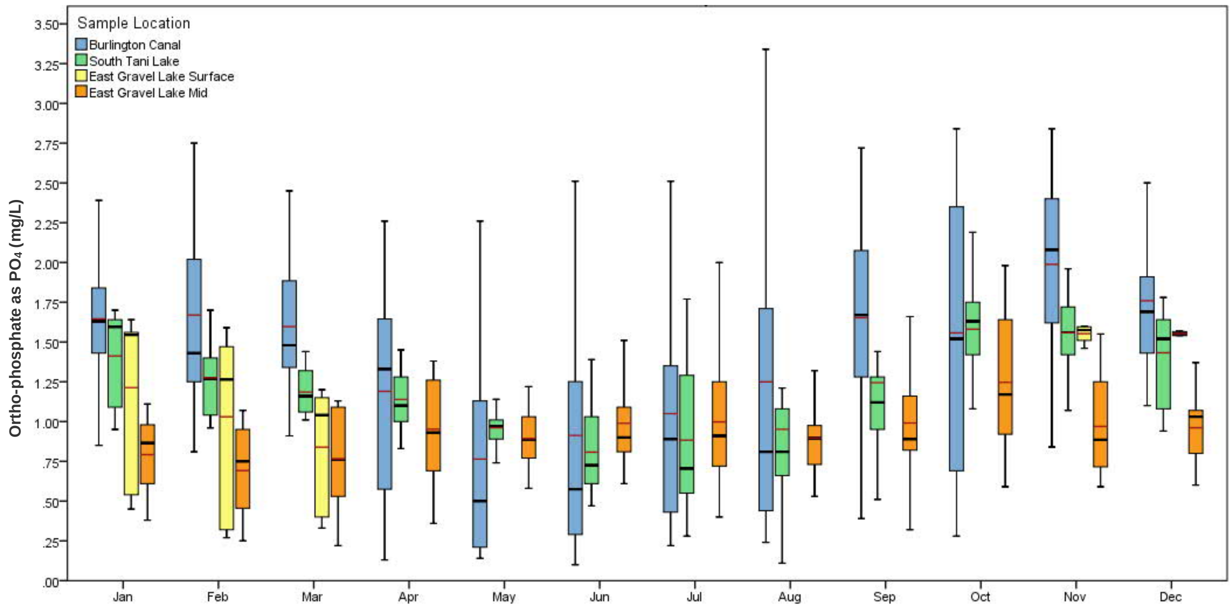

Figure 3: Ortho-phosphate as PO_4 (mg/L) by month and sample location at East Gravel Lake #4 from 2012 to 2017.

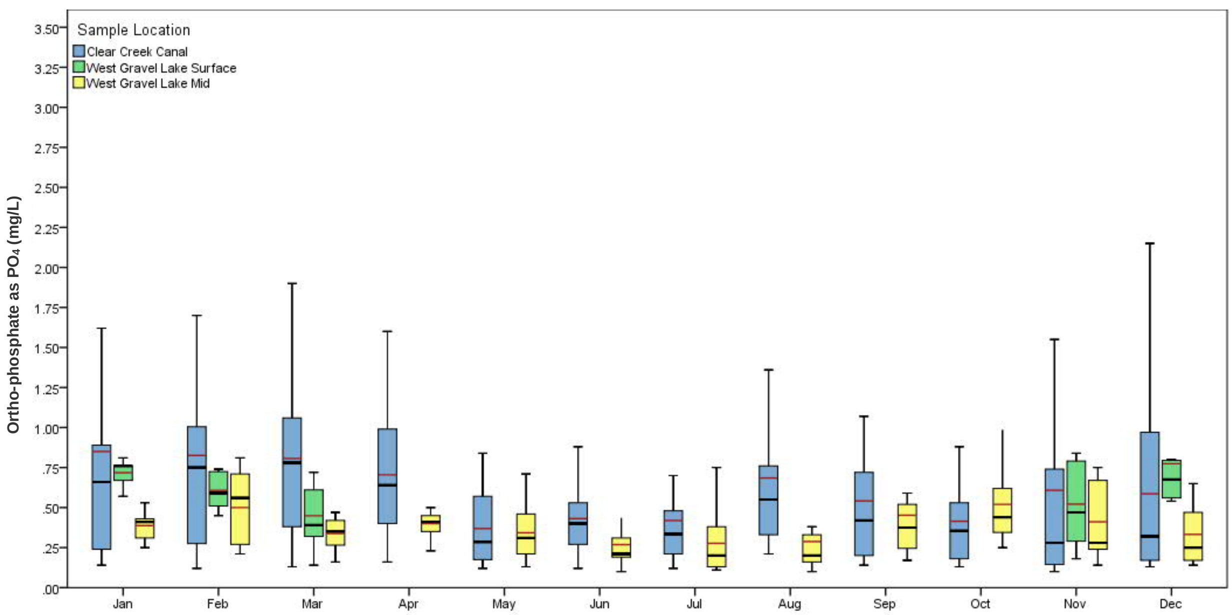

Figure 4: Ortho-phosphate as PO_4 (mg/L) by month and sample location at West Gravel Lake #2 from 2012 to 2017.

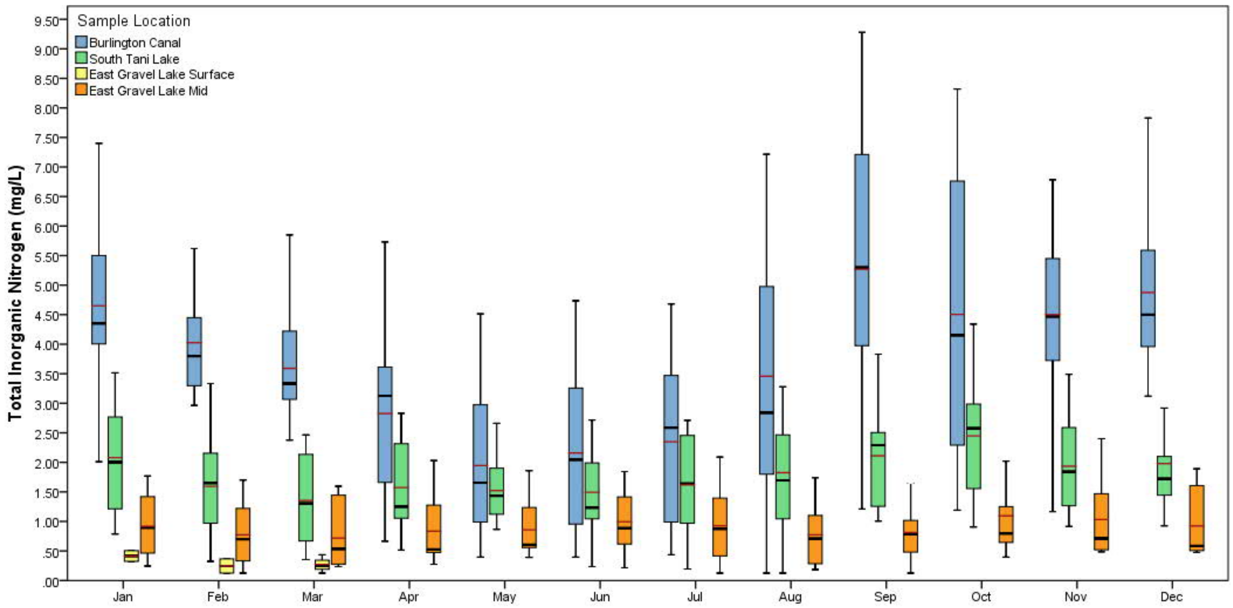

Figure 5: Total Inorganic Nitrogen (mg/L) by month and sample location at East Gravel Lake #4 from 2012 to 2017.

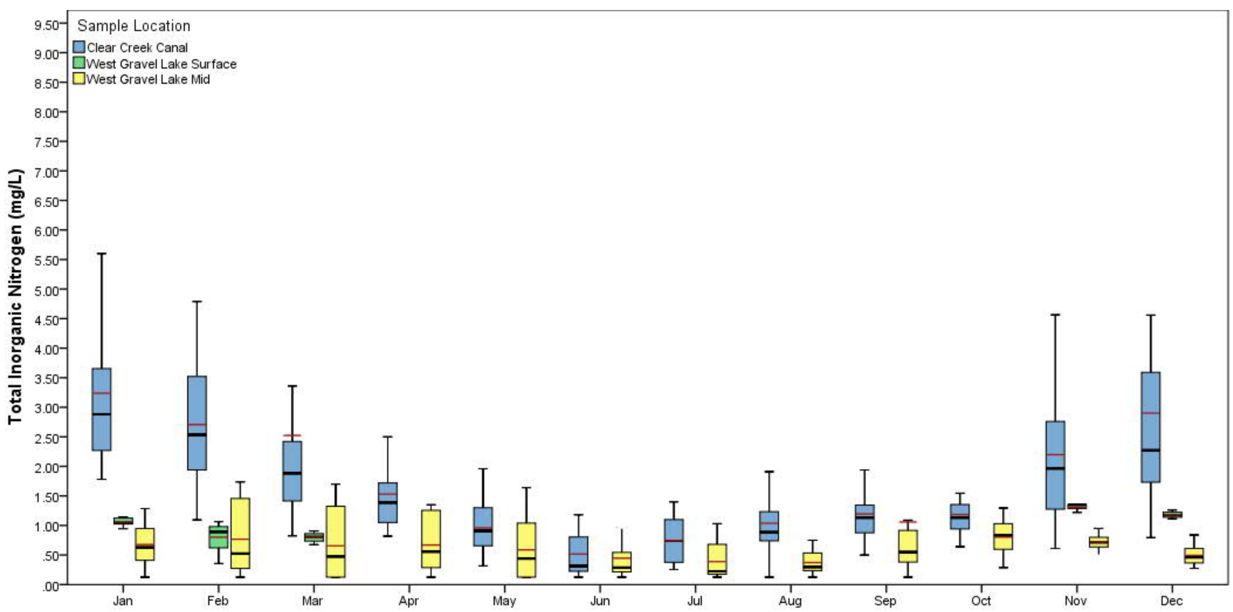

Figure 6: Total Inorganic Nitrogen (mg/L) by month and sample location at West Gravel Lake #2 from 2012 to 2017.

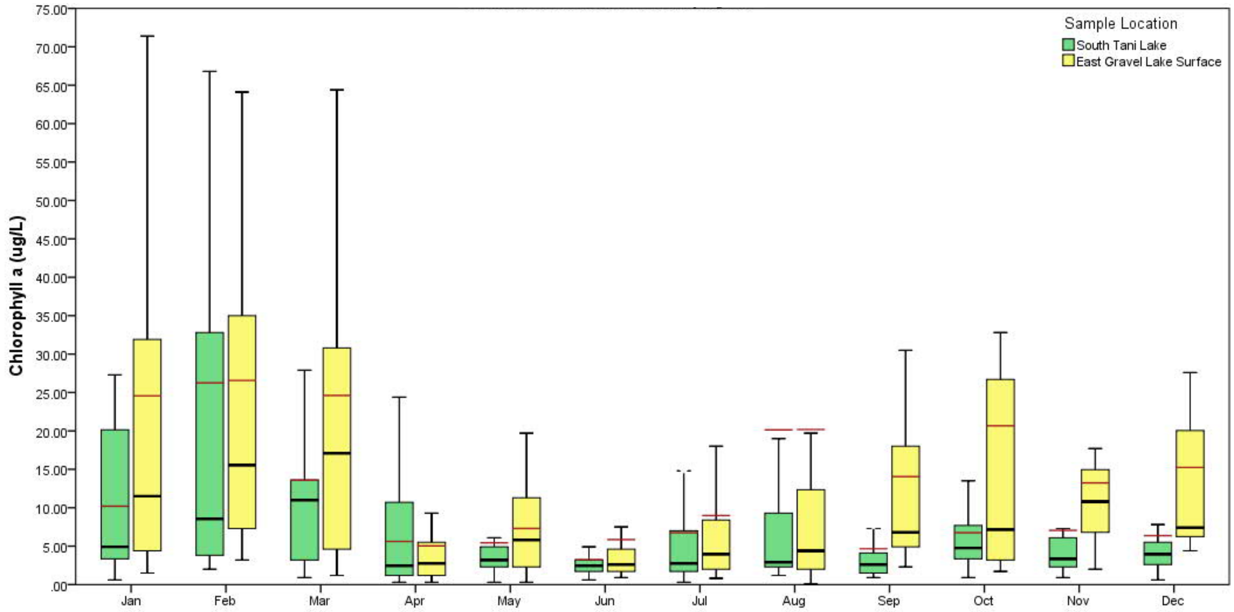

Figure 7: Chlorophyll-a (µg/L) by month and sample location at East Gravel Lake #4 from 2012 to 2017.

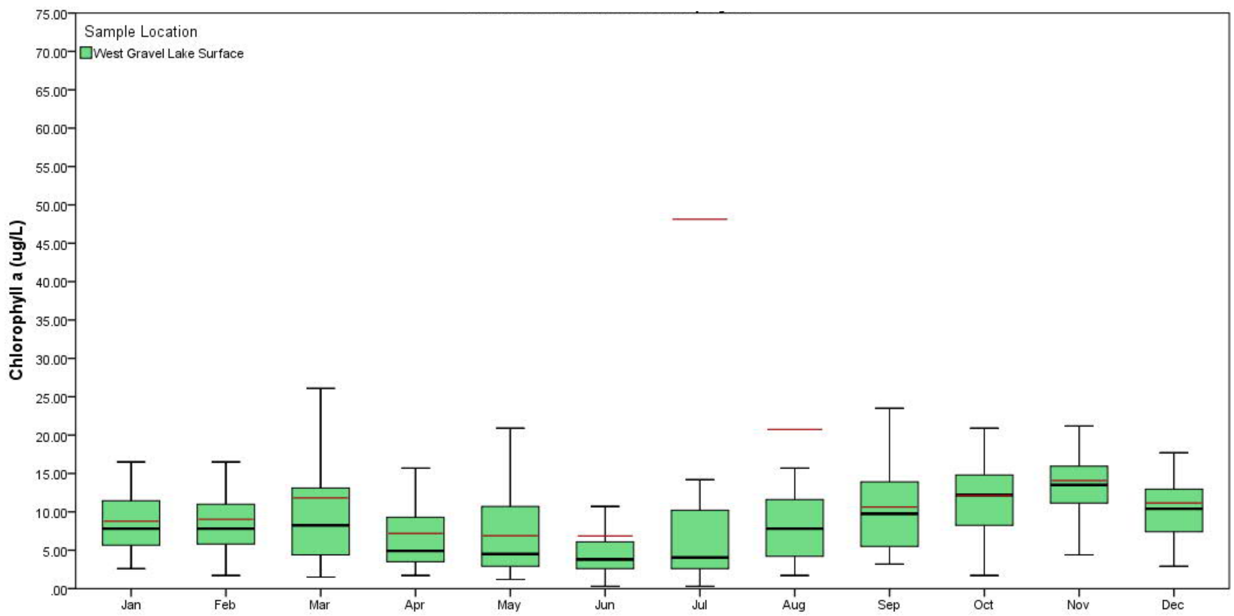

Figure 8: Chlorophyll-a (µg/L) by month and sample location at West Gravel Lake #2 from 2012 to 2017.

Table 2: Sampling frequency of available data at Thornton waterbodies from 2012 to 2017. Frequencies are approximate and addition and missing samples exist. Large deviations are noted. Insufficient or no Total Kjeldahl Nitrogen data exists.

	Physical Properties										Nutrients					Organics		Metals		Algae	
Sample Sites	Temperature	pH	Dissolved Oxygen	Conductivity	Alkalinity	Total Hardness	Turbidity	Secchi Disc Depth	Total Suspended Solids	Total Dissolved Solids	Total Phosphorous	Ortho-phosphorus	Ammonia as N	Nitrite	Nitrate	Total Organic Carbon	Dissolved Organic Carbon	Iron Total Recoverable[6]	Sulfate	Chlorophyll-a	Algae Density
East Gravel Lakes																					
Burlington Canal	BW	BW	BW	BW	BW	BW	BW	NA	Q[3]	Q	I[5]	BW	BW	BW	BW	BW	ID	M	BW	ND	ND
South Tani Reservoir	W	W	W	W	W	W	W	NA	Q[3]	Q	Q[5]	W	W	W	W	W	ND	ND	W	W	W
East Gravel #4 Surface	W	W	W	W	ID	ID	ID	W	ND	ND	ND	ID	ID	ID	ID	ID	ID	ND	ID	W	W
East Gravel #4 Middle	W[1]	W[1]	W[1]	W[1]	W[1]	W[1]	W[1]	NA	Q[2]	Q[4]	I[5]	W[1]	W[1]	W[1]	W[1]	W[1]	W[1]	ND	W[1]	ND	ND
East Gravel #4 Bottom	W[1]	W[1]	W[1]	W[1]	ND	ND	W[1]	NA	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
West Gravel Lakes																					
Lower Clear Creek Canal	W	W	W	W	W	W	W	NA	Q[3]	Q	I[5]	W	W	W	W	W	ND	ND	W	ND	ND
West Gravel #2 Surface	W	W	W	W	ID	ID	ID	W	ID	ID	ND	ID	ID	ID	ID	ID	ID	ND	ID	W	W
West Gravel #2 Middle	W[1]	W[1]	W[1]	W[1]	W[1]	W[1]	W[1]	NA	Q[2]	Q[4]	I[5]	W[1]	W[1]	W[1]	W[1]	W[1]	W[1]	ND	W[1]	ND	ND
West Gravel #2 Bottom	W[1]	W[1]	W[1]	W[1]	ND	ND	W[1]	NA	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

W = Weekly sampling, BW = Bi-weekly to weekly sampling, M = Monthly sampling, Q = Quarterly sampling, I = Intermittent sampling

ID = Insufficient quantity of data to be used in assessment, ND = No data collected, NA = Not Applicable and no data collected

[1] = Replaced by surface sampling in the winter when the lakes are well mixed, [2] = Not collected in 2012 to 2013, collected quarterly with intermittent additional months in 2014 to 2017, [3] = Collected most months in 2012 and 2013, collected quarterly with intermittent additional months in 2014 to 2017, [4] = Not collected in 2012 to 2013, collected quarterly months in 2014 to 2017, [5] = Collected most months in 2012 to 2013, quarterly in 2014 to 2015, and not sampled in 2016 to 2017.

[6] = Hach method results available for iron.

Appendix A – Water Quality Summary Metrics

Table A.1: Mean annual data for samples collected at East Gravel #4 Middle (EGL4@PS MID) and West Gravel #2 Middle (WGL2@PS MID) and Tier 1 & 2 raw water supply water quality criteria.

Parameters	Year	N		Min		Max		Mean		Std. Dev.		Criteria	
		East	West	East	West	East	West	East	West	East	West	**Tier I**	Tier II
Turbidity (NTU)	2012	50	52	0.1	0.4	4.9	6.8	1.5	1.2	1.1	1.0	0.1 – 50 NTU	0.1 – 25 NTU
	2013	48	48	0.1	0.5	6.6	6.7	2.2	1.7	1.4	1.5		
	2014	29	29	0.3	0.5	5.4	9.1	1.8	2.7	1.7	2.3		
	2015	34	34	0.1	0.2	6.3	2.5	1.1	1.2	1.0	0.7		
	2016	41	34	0.1	0.4	5.4	3.7	1.2	1.9	1.0	0.9		
	2017	47	42	0.1	0.3	3.0	6.2	1.1	1.5	0.7	1.1		
pH (STD)	2012	50	52	8.1	8.0	9.7	9.3	8.9	8.8	0.5	0.3	6.0 – 10 (STD)	NA
	2013	48	48	7.4	7.0	9.3	9.4	8.7	8.4	0.4	0.5		
	2014	29	29	7.9	7.8	9.0	9.2	8.4	8.4	0.2	0.4		
	2015	34	34	8.4	7.5	9.1	8.8	8.7	8.2	0.2	0.4		
	2016	41	33	8.0	6.2	8.9	8.9	8.5	8.2	0.2	0.5		
	2017	46	41	8.3	7.5	8.9	8.8	8.6	8.2	0.2	0.4		
Temperature (°C)	2012	50	52	2.9	2.4	25.0	24.4	13.1	13.1	7.5	7.7	0.5 – 27 (°C)	NA
	2013	48	47	3.0	2.9	23.3	24.1	12.8	12.8	7.5	7.6		
	2014	29	29	7.9	8.0	23.7	23.2	17.4	18.1	4.4	4.0		
	2015	34	34	10.9	10.3	23.7	23.8	17.9	18.2	4.1	4.4		
	2016	41	33	2.8	7.6	24.0	23.4	16.8	18.4	6.5	4.3		
	2017	46	41	3.3	8.3	24.8	23.3	15.2	16.5	6.6	5.2		
Alkalinity (mg/L)	2012	50	52	107	119	175	158	148	137	17.6	12.2	35 – 250 mg/L as $CaCO_3$	NA
	2013	52	52	112	89	177	216	146	137	18.8	43.4		
	2014	42	43	133	52	156	131	142	93	4.9	21.8		
	2015	34	34	121	79	154	195	134	116	10.2	22.3		
	2016	41	34	112	79	152	144	130	110	11.0	20.7		
	2017	47	42	125	82	155	150	139	121	7.8	21.7		
Total Organic Carbon (mg/L)	2012	50	52	4.2	3.6	5.4	5.8	4.8	4.7	0.3	0.5	0.5 – 9.0 mg/L	NA
	2013	52	52	4.5	3.1	7.6	7.7	5.3	5.0	0.5	1.1		
	2014	37	44	4.5	2.6	7.5	5.0	5.3	3.8	0.6	0.6		
	2015	34	34	4.4	3.4	5.8	5.1	4.9	4.2	0.3	0.4		
	2016	41	34	4.1	2.5	5.5	5.2	5.0	4.4	0.3	0.5		
	2017	39	34	4.7	3.9	6.7	6.5	5.5	5.0	0.6	0.8		
Dissolved Organic Carbon (mg/L)	2012	50	52	4.1	3.7	5.0	5.4	4.7	4.6	0.2	0.4	0.5 – 9.0 mg/L	0.5 – 4.5 mg/L
	2013	52	52	3.1	2.5	7.1	7.4	5.1	4.9	0.6	1.1		
	2014	43	44	4.5	2.6	6.1	4.7	5.1	3.7	0.4	0.6		
	2015	34	34	4.4	3.4	5.6	4.7	4.9	4.1	0.3	0.3		

	2016	41	34	4.1	3.4	5.4	5.0	5.0	4.4	0.3	0.4		
	2017	43	38	4.5	1.9	6.5	6.2	5.3	4.8	0.5	0.9		
Total Hardness (mg/L)	2012	50	52	208	180	320	264	266	219	29.1	18.7	60 – 350 mg/L as $CaCO_3$	60 – 250 mg/L as $CaCO_3$
	2013	51	51	132	112	328	300	266	208	32.2	58.4		
	2014	42	43	230	96	276	224	250	150	9.4	34.8		
	2015	34	34	200	132	256	204	225	179	17.3	19.9		
	2016	41	34	134	136	256	224	225	183	20.6	28.0		
	2017	47	42	208	132	280	262	243	188	18.2	32.5		
Total Dissolved Solids (mg/L)	2014	4	4	496	168	583	378	548	272	38.3	85.8	50 – 750 mg/L	NA
	2015	3	3	389	324	523	380	466	359	69.3	30.3		
	2016	2	2	422	297	504	443	463	370	58.0	103.2		
	2017	3	3	450	333	524	523	481	418	38.3	96.5		
Bromide (mg/L)	2012	50	52	0.2	0.1	0.3	0.3	0.3	0.2	0.0	0.1	0 – 0.5 mg/L	NA
	2013	52	52	0.2	0.1	0.3	0.2	0.3	0.1	0.0	0.1		
	2014	43	44	0.1	0.1	0.3	0.2	0.2	0.1	0.1	0.0		
	2015	34	34	0.1	0.1	0.2	0.3	0.2	0.1	0.0	0.1		
	2016	41	34	0.1	0.2	0.3	0.4	0.2	0.3	0.0	0.1		
	2017	43	38	0.1	0.1	0.4	0.4	0.2	0.3	0.1	0.1		
Ortho Phosphate as PO_4 (mg/L)	2012	50	52	0.1	0.1	2.0	1.2	1.0	0.6	0.5	0.3	0 – 3.0 mg/L	NA
	2013	52	52	0.3	0.1	1.4	0.8	0.9	0.4	0.2	0.2		
	2014	43	44	0.8	0.1	1.9	0.6	1.2	0.2	0.3	0.1		
	2015	34	34	0.6	0.1	2.0	0.4	1.1	0.2	0.3	0.1		
	2016	41	34	0.6	0.1	1.0	0.7	0.8	0.3	0.1	0.2		
	2017	43	38	0.3	0.1	0.9	0.6	0.7	0.3	0.2	0.2		
Nitrate as N (mg/L)	2012	50	52	0.4	0.2	2.0	1.2	1.1	0.6	0.4	0.2	0 – 3.0 mg/L	0 – 1.5 mg/L
	2013	52	52	0.1	0.2	1.8	1.7	0.9	0.7	0.6	0.4		
	2014	43	44	0.1	0.1	0.6	0.5	0.3	0.1	0.1	0.1		
	2015	34	34	0.1	0.1	1.3	0.3	0.3	0.2	0.2	0.1		
	2016	41	34	0.3	0.1	0.9	1.0	0.7	0.3	0.2	0.3		
	2017	43	38	0.1	0.1	1.1	0.7	0.4	0.4	0.3	0.2		
Geosmin & MIB (ng/L)	2012	--	--									0 -50 ng/L	0 - 5 ng/L
	2013	--	--										
	2014	--	--										
	2015	--	--										
	2016	--	--										
	2017	--	--										

Existing Raw Water System Evaluation

Chapter 4

Utility Master Plan

Project No. 17-467

Raw Water Supply Master Plan

Existing Raw Water System Evaluation

The City of Thornton

Project number: 60560104

AECOM

July 25, 2019

FINAL

Quality information

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Tables

List of Acronyms and Abbreviations

Cooley West	Cooley West Reservoir Complex
EGL	East Gravel Lakes
EGL4	East Gravel Lake #4
East Sprat	East Sprat-Platte Reservoir
mgd	million gallons per day
North Dahlia	North Dahlia Reservoir
Operational Model	Operational Model for the Southern Gravel Lakes System
PS	Pump Station
RJH	RJH Consultants, Inc.
RWGLS	Raw Water Gravel Lakes System
South Dahlia	South Dahlia Reservoir
ST	South Tani Reservoir
TM	Technical Memorandum
Thornton	City of Thornton
TWTP	Thornton Water Treatment Plant
WBWTP	Wes Brown Water Treatment Plant
WGL	West Gravel Lakes
WGL1	West Gravel Lake #1
WGL2	West Gravel Lake #2
WGL3	West Gravel Lake #3
WSEL	Water Surface Elevation
West Sprat	West Sprat-Platte Reservoir
WTP	Water Treatment Plant

1. Introduction

This technical memorandum (TM) summarizes the engineering evaluation of the city of Thornton (Thornton) operations of its Raw Water Gravel Lakes System (RWGLS) and each lake's raw water deliveries to the existing Thornton Water Treatment Plant (TWTP) and the Wes Brown Water Treatment Plant (WBWTP). The evaluations comprise Thornton's RWGLS along the South Platte River, which include the lakes listed in Table 1.

Table 1: Thornton's Raw Water Gravel Lakes System

System	Lake
Cooley West Reservoir Complex (WGLs)	West Gravel Lake #1 (WGL1)
	West Gravel Lake #2 (WGL2)
	West Gravel Lake #3 (WGL3)
East Gravel Lakes (EGLs)	South Tani Reservoir (ST)
	East Gravel Lake #4 (EGL4)
	South Dahlia Reservoir (South Dahlia)
	North Dahlia Reservoir (North Dahlia)
	East Sprat-Platte Reservoir (East Sprat)
	Cooley West Reservoir Complex (Cooley West)
	West Sprat-Platte Reservoir (West Sprat)

The operations of Thornton's RWGLS were evaluated using computer simulations of the water surface level variations of each lake as the system responds to the demands of the water treatment plants (WTPs). A proprietary water balance computer model (GoldSim®) was used to simulate the full gravel lake system operations of each of these options to identify the concept level size and performance characteristics of the required infrastructure. In order to compare the various options, a model was created to represent normal, most common, average operations. The results of this evaluation will be integrated with the recommendations outlined in the Gravel Lakes Water Quality Evaluation TM (July 2019) as part of the evaluation of the total existing RWGLS operations.

2. Summary of Water Quality Operational Modifications

Based on the findings and recommendations detailed in the Gravel Lakes Water Quality Evaluation TM (July 2019), the following options for modifications to gravel lakes operations were identified that could result in improvements to water quality. The water quality improvements are intended to maintain or improve the taste and odor characteristics of the raw water supplied to the WBWTP. All options would require new infrastructure, or modifications to existing infrastructure. This section summarizes the advantages of each option and the related infrastructure modifications needed to accommodate the changes to gravel lake operations. The capital costs for the infrastructure modifications, including capital expenditures and life cycle costs for the gravel lakes operations, will be addressed in a subsequent TM.

2.1 Option 0: Existing Operation

The baseline condition was developed for an average drought year and an average non-drought year and was used to compare the results for each of the four options in terms of level of improvement.

The existing operations illustrated on Figure 1 are as follows:

- Flows to WBWTP and TWTP are based on historic quantities of treated water.
- Water from Lower Clear Creek is diverted to WGL1, then to WGL3, and finally to WGL2 where it is pumped to feed the WBWTP.
- Water from Burlington Ditch is diverted to ST and then to EGL4 where it is pumped to feed the WBWTP.
- TWTP is only fed by Standley Lake water.
- WTP lagoon supernatant flows into WGL1.

2.2 Option 1: Gravel Lakes Operate in Series

This option considers operating the gravel lakes in series, from WGL1 to the McKay Pump Station (PS) as illustrated in Figure 2. The intent of this option is to achieve nutrient reduction through the increased water detention time in the gravel lakes. The water quality data collected from the Burlington Canal, South Tani Reservoir (ST), and EGL4, indicate a natural improvement (reduction) in nutrient water quality concentrations as flow passes through the system, and it is anticipated that water quality with respect to nutrients will improve with longer detention time. The WTP lagoon supernatant will also be mixed and circulated with Burlington Canal water through the gravel lakes, thereby increasing the detention time of the lagoon supernatant and decreasing the opportunity for the lagoon supernatant to short-circuit through the gravel lakes and return to the WTP intake.

The gravel lakes operations would be as follows:

- WBWTP and TWTP would continue to produce the historic quantities of treated water.
- Water from WGL2 would be pumped to EGL4 when city water rights will allow. It is anticipated that pumping from WGL2 to EGL 4 can occur during typical RWGLS operations. However, discussions with the city indicate that occasional, unique circumstances involving specific water rights could limit the duration and volume of water that could be pumped from WGL2 to EGL4. These intermittent interruptions to pumping from WGL2 to EGL4 are not expected to influence the overall operation of the RWGLS in series.
- For most of the year, water needed at the WBWTP would be supplied by the McKay PS (from the South Cell of Cooley West).
- When the supply needed at WBWTP exceeds 25 million gallons per day (mgd) (estimated capacity of the McKay PS supply to WBWTP), EGL4 PS would operate and provide supplemental water to WBWTP from EGL4.

2.3 Option 2: Precipitant Addition

This option uses the same gravel lakes operations as for Option 1 in conjunction with the addition of a precipitant to sequester phosphorus within raw water flows entering the gravel lakes. The intent of this option is to reduce the amount of phosphorus available for reaction in the lake water column. The reduced phosphorus levels would be expected to produce less favorable conditions for algae formation. Operating the lakes in series (Option 1) will provide general improvement in water quality with respect to nutrients, and the precipitant addition proposed for Option 2 will specifically target phosphorus removal. The phosphorus will react with the precipitant to form a solid and settle out. The settled solids may require removal from the gravel lakes in the future.

The chemical precipitant would be added at Thornton's Burlington Canal intake, feeding into ST, as shown in Figure 3. The chemical addition could occur continuously throughout the year or seasonally to address the seasonal variations of phosphorous concentrations in Burlington Canal. The precipitant addition would include the creation of a mixing zone and a settling zone at the upstream end of ST to achieve maximum benefit from the precipitant. It is presumed that the below surface berm near the Burlington Canal discharge location could be used to establish the settling zone. Since this option involves the same lake operations as Option 1, the GoldSim® model results for Option 1 were also used for this option.

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Figure 1
Option 0: Existing Operation

4/24/2019

1 inch = 1,328 feet

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Figure 2
Option 1: Lakes in Series

4/24/2019

1 inch = 1,328 feet

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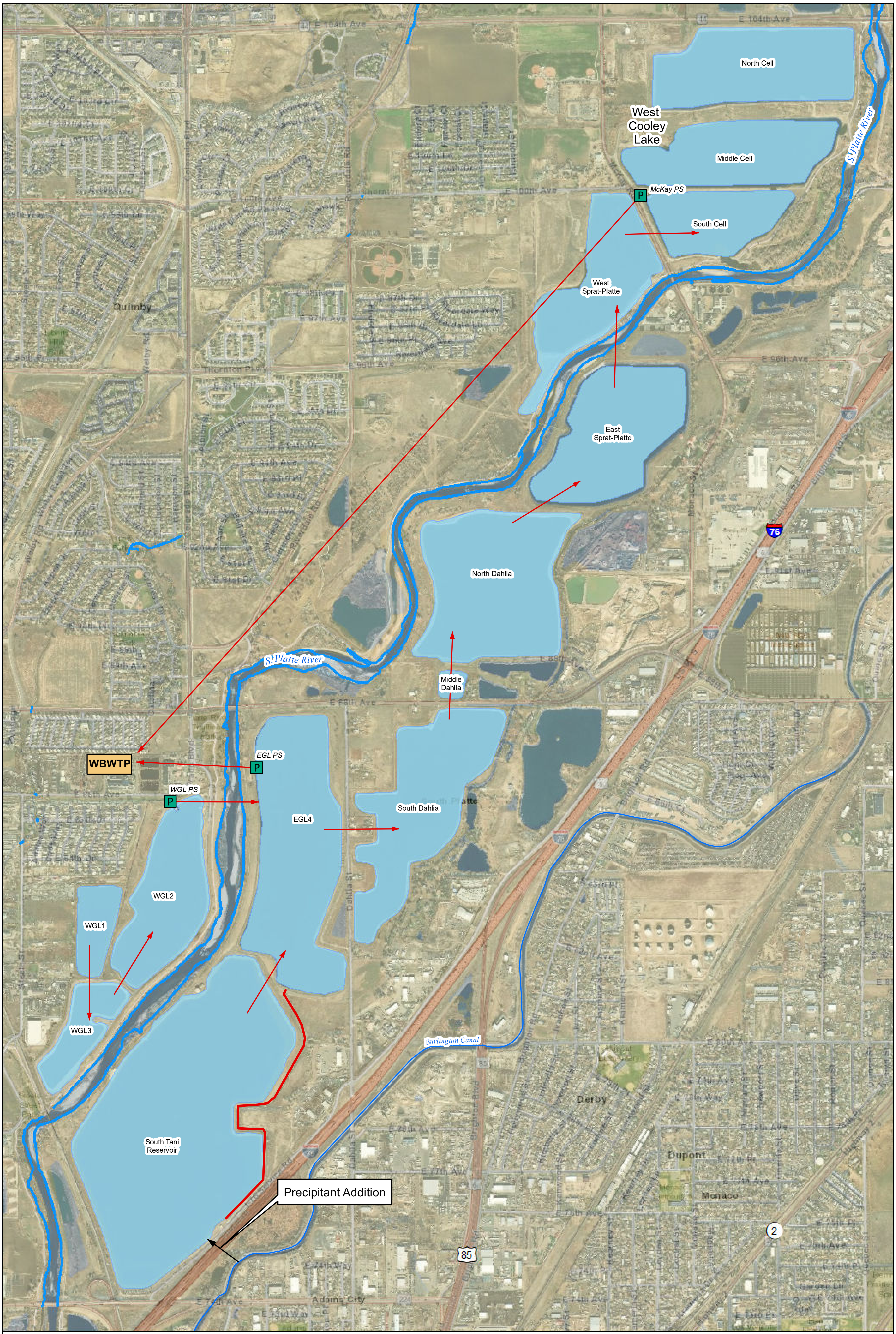

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Figure 3
Option 2: Lakes in Series
Precipitant Addition

7/25/2019

1 inch = 1,328 feet

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2.4 Option 3: Precipitant Addition and Burlington Canal Bypass

This option builds upon the seasonal operation of the existing bypass ditch from approximately August 1 to October 31 each year by physically extending the bypass ditch as shown in Figure 4. The existing bypass ditch would be extended to allow it to divert the Burlington Canal inflows into the gravel lakes to bypass ST and EGL4 and to feed directly into South Dahlia. The phosphorous concentrations in the Burlington Canal water are at their peak during this time period, and the intent of the bypass is to provide the longest practical gravel lake detention time by diverting it around ST and EGL4 to South Dahlia.

In addition to the Burlington Canal bypass, the gravel lakes would be operated in series as described in Option 1 and would include precipitant addition to Burlington Canal raw water diversions as described in Option 2. Raw water flow rates to WBWTP and TWTP would continue in the same historical patterns.

2.5 Option 4: Maximizing Thornton Water Treatment Plant Production

The RWGLS operations for Option 4 are based on operating the lakes in series with precipitant addition and the Burlington Canal bypass as described for the other options. It also includes achieving improvements to finished (potable) water quality (in the form of improved taste and odor) by operating TWTP as the base load WTP and only relying on WBWTP to supplement the treated water production as needed, since TWTP will more reliably produce higher quality water. It is recommended that this operation be continuous year round for this option. The TWTP maximum capacity is 20 mgd (22 mgd of water supplied to the plant). The raw water operations for Option 4 would be as follows:

- The gravel lakes would be operated in series as described in Option 1.
- Water from WGL2 would be pumped to EGL4 using the existing WGL PS.
- Water needed at WBWTP would be supplied by the McKay PS (from South Cell of Cooley West).
- Water from EGL4 would be sent to TWTP all year round (maximum rate of 15 mgd based on existing equipment).
- WBWTP would be fed from existing McKay PS and EGL PS at high demands.
- TWTP would be fed from Standley Lake through the existing Standley Lake pipeline.

Since this option involves the same RWGLS modifications as Option 3, the improvements noted in Figure 4 also apply for this option.

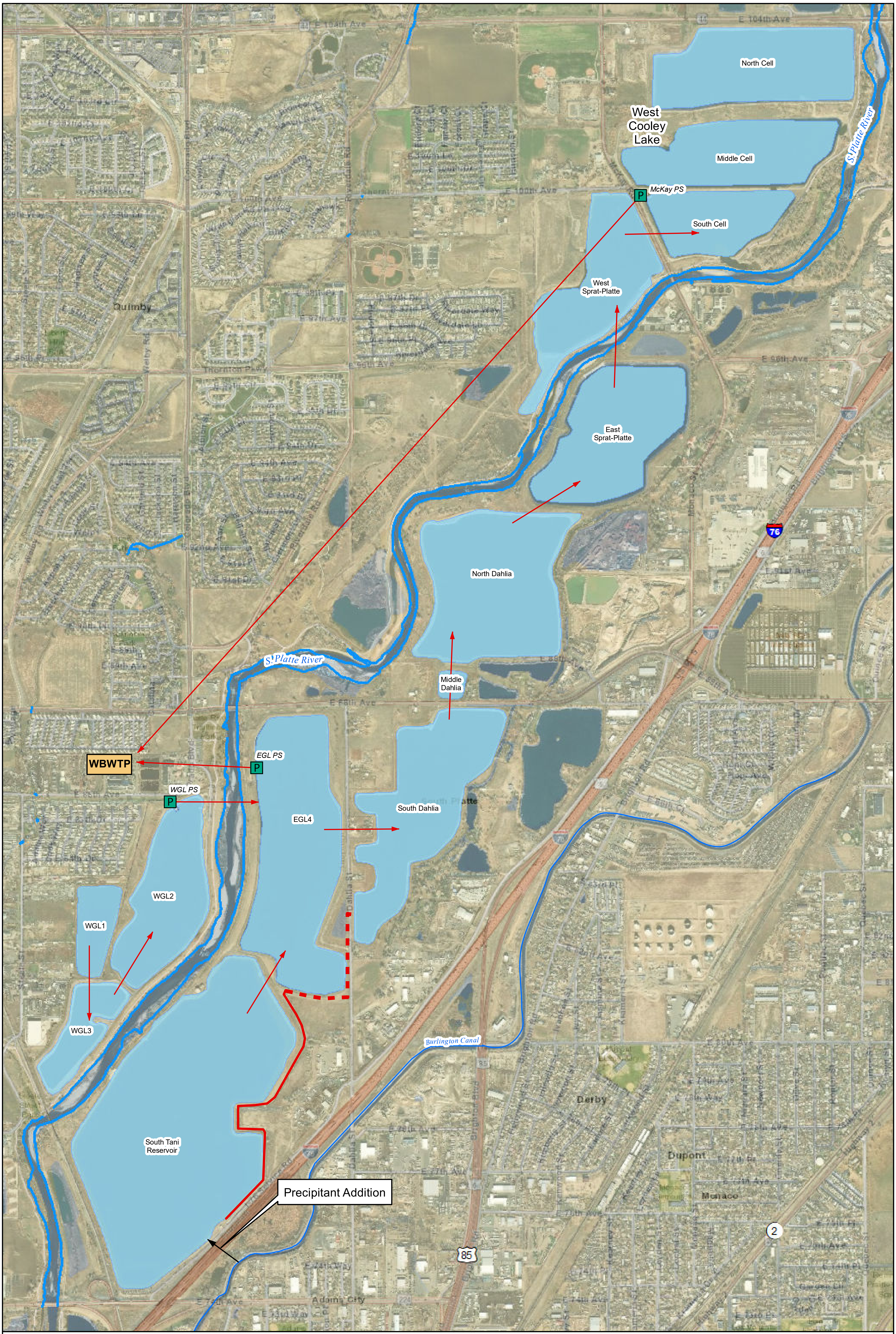

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Figure 4
Option 3: Lakes in Series, Precipitant Addition, and Burlington Canal Bypass

7/25/2019

1 inch = 1,328 feet

\\Denver.na.aecomnet.com\Denver\DCS\Projects\WTR\60560104_Thornton M\900-CAD-GIS\920-GIS\Raw Water\MXD files\Raw Water System Overview Portrait Layout - Option 3.mxd

2.6 Water Quality Operational Modifications – Options Summary

Table 2 describes the advantages of each option as well as associated cost considerations.

Table 2: Water Quality Operational Modifications Options

Option No.	Name	Advantages	Cost Considerations
Option 1	Gravel Lakes Operate in Series	Water from ST and EGL4 are mixed and circulated through all the gravel lakes. Lagoons supernatant will be mixed and circulated with Burlington Canal water through all the gravel lakes	New pipeline interconnections to directly feed WBWTP from McKay PS would need to be constructed. Miscellaneous capital and labor costs for increased operation and monitoring of the RWGLS. Improvements to the McKay PS, including the addition of Variable Frequency Drives and possibly additional pumps, are required. Increased pumping cost: • McKay PS to WBWTP • WGL2 to EGL4
Option 2	Precipitant Addition	A significant amount of phosphorus may be removed from the water column to reduce the potential for reaction with nitrogen in the water supplied to the gravel lakes all year round. Water from ST and EGL4 are mixed and circulated through all the gravel lakes. Lagoons supernatant will be mixed and circulated with Burlington Canal water through all the gravel lakes.	Capital for chemical addition equipment. Labor and chemical costs for operational cost. Occasional maintenance necessary to remove sludge from bottom of ST. New pipeline from the McKay PS to directly feed WBWTP would need to be constructed. Increased pumping cost: • McKay PS to WBWTP • WGL2 to EGL4
Option 3	Precipitant Addition and Burlington Canal Bypass	A significant amount of phosphorus may be removed from reaction with nitrogen in the water supplied to the gravel lakes. During phosphorous peak season from Burlington Canal, phosphorus load to EGL4 is reduced significantly. Water from ST and EGL4 are mixed and circulated through all the gravel lakes. Lagoons supernatant will be mixed and circulated with Burlington Canal water through all the gravel lakes.	Capital for chemical addition equipment. Labor and chemical costs for operational cost. Periodic (5 to 20 years) maintenance necessary to remove sludge from bottom of ST. Bypass extended from EGL4 to South Dahlia. New pipeline from the McKay PS to directly feed WBWTP would need to be constructed. Increased pumping cost: • McKay PS to WBWTP • WGL2 to EGL4
Option 4	Maximizing Thornton Water Treatment Plant Production	Quality of finished water may improve by producing more water at TWTP and less at WBWTP. Water from ST and EGL4 are being mixed and circulated through all the gravel lakes. Lagoons supernatant will be mixed and circulated with Burlington Canal water through all the gravel lakes.	New pipeline interconnections to directly feed WBWTP from McKay PS would need to be constructed. Miscellaneous capital and labor costs for increased operation and monitoring of the RWGLS. Improvements to the McKay PS, including the addition of Variable Frequency Drives and possibly additional pumps, are required. Increased pumping cost: • EGL4 PS to TWTP • McKay PS to WBWTP • WGL2 to EGL4

Note: Option 0: Existing Operation was not included because it represents baseline conditions.

3. Hydraulic Model Development

An existing operational model, developed by RJH Consultants, Inc. (RJH) in 2010 and revised in 2012, was used as the basis for developing the GoldSim® model for Thornton's Raw Water Gravel Lakes. GoldSim® is a graphical, object-oriented computer program for carrying out dynamic, probabilistic simulations to support decision making. GoldSim® enables simulation of a complex process through a buildup of simple object relationships, incorporates Monte-Carlo stochastic methods, and includes dynamic, interactive user interfaces. The model can simulate a dynamic, computationally intensive but well-defined networked model with uncertain inputs into the system, such as a water balance.

The RJH model, called "Operational Model for the Southern Gravel Lakes System" (Operational Model), consists of a Microsoft Excel-based mass balance of the system reservoir and hydraulic capacities. It did not include WGL1, WGL2, or WGL3, which were added by AECOM to the GoldSim® model based on data provided by Thornton.

3.1 Modeling Components

The GoldSim® model that was developed for the Thornton Raw Water Gravel Lakes includes the existing features and components outlined in Table 3.

Table 3: Existing Model Features and Components

Facility Type	Facility
Water Supply	Burlington Canal
	Lower Clear Creek
	Standley Lake
Water Treatment Plants	TWTP
	WBWTP
Pump Stations	McKay PS – South Cell of Cooley West to EGL4 (25 mgd maximum)
	WGL PS – WGL2 to WBWTP or ST and/or EGL4 (30 mgd maximum)
	EGL PS – EGL4 to WBWTP and/or TWTP (50 mgd maximum)
Reservoir	South Tani Reservoir (ST)
	East Gravel Lake #4 (EGL4)
	South Dahlia Reservoir (South Dahlia)
	North Dahlia Reservoir (North Dahlia)
	East Sprat-Platte Reservoir (East Sprat)
	Cooley West Reservoir Complex (Cooley West)
	West Sprat-Platte Reservoir (West Sprat)
	West Gravel Lake #1 (WGL1)
	West Gravel Lake #2 (WGL2)
	West Gravel Lake #3 (WGL3)

3.2 Modeling Operations

Each reservoir was modeled as a "Reservoir" element based on elevation-storage relationships included in the Operational Model. It should be noted that the elevation-storage relationship for East Sprat Platte Reservoir was adopted for West Sprat Platte Reservoir, because the elevation-storage relationship for West Sprat Platte Reservoir was not available in the Operational Model developed by RJH. West Sprat is a recently completed reservoir that did not exist at the time the RJH model was developed.

Inflows to the system include water supplied from Burlington Canal (discharging into ST), Lower Clear Creek (discharging into WGL1), and Standley Lake (discharging into TWTP), as well as precipitation runoff into the lakes. Outflows from the system include withdrawals to WBWTP and TWTP as well as evaporation and overflow to the South Platte River. The model inputs for water supply and WTP withdrawals varied for each option modeled as described in Section 4. Precipitation and evaporation were estimated based on historic average monthly rates.

Gravity flow through the pipe interconnections between each lake was modeled based on conduit rating curves obtained from the existing Operational Model (RJH). For the purposes of this analysis, all connecting conduits within the RWGLS were assumed to be either fully open or fully closed, depending on the operating scenario.

A water transfer from each lake was assumed to report to the next lake in series, with the exceptions of Cooley West North Cell and WGL2. Overflow from Cooley West North Cell was assumed to report to the South Platte River and overflow from WGL2 was assumed to be pumped to EGL4.

Model inputs included the following:

- Initial reservoir elevations
- Water treatment plant withdrawal time series
- Water supply time series

Groundwater inflows, infiltration, and water quality biochemistry were not simulated. The computation time step was set to one hour, with results summarized daily, monthly, and annually.

3.3 Model Validation

The GoldSim® model was validated to confirm its ability to accurately simulate historic conditions. Validation was performed by simulating one year of operations based on historic data from 2016 and comparing simulated and recorded reservoir water surface elevations. Available historic data included:

- Recorded precipitation for Thornton,
- Flows from Burlington Canal to ST,
- Flows from Lower Clear Creek to WGL,
- Backwash flows released from WBWTP to WGL,
- Flows released from ST to WGL,
- Flows pumped from WGL to ST,
- Flows pumped from EGL4 to the WBWTP,
- Flows pumped from WGL2 to the WBWTP,
- Flows released from Standley Lake to TWTP, and
- Recorded reservoirs water surface elevations at the beginning of the year and at the end of the year.

The model validation process required comparison of the raw water supply flow records with the WTP flow records to resolve differences between raw water supply flow volumes and treated water flow volumes for the same time period. Comparison of the metered flow records indicate an “unaccounted for water” flow difference between the volume of water produced at the WTPs as compared to the flow meter records for the raw water supply. The flow record comparison indicated that the raw water supply flow meters were underreporting the raw water supply flows. This unaccounted for water difference was also confirmed by the initial validation modeling results, which calculated gradual drops in the RWGLS water surface elevations for time periods where the measured and recorded water surface elevations for the same time period did not significantly change.

The model validation process involved making pro rata adjustments to the raw water supply flow meter records to balance them with the flow rate of water produced at the WTPs (including allowances for WTP production losses). The adjusted raw water flow volumes were used in the validation model and the calculated lake water surface elevations were compared to the measured lake water surface elevations. The differences between the calculated lake water surface elevations and the measured lake water surface elevations were within the acceptable level of accuracy for the model, and the model results confirmed that the model accuracy is appropriate for the planning purposes of this TM and the Raw Water Master Plan.

Final confirmation of the model validation was accomplished by comparing the adjusted raw water supply flow volumes with the reported raw water supply flow volumes. The differences between the metered flows and the adjusted flows was within the acceptable flow metering accuracy standards for open channel flow metering, confirming the reasoning that the raw water flow meters are underreporting the RWGLS inflows. Based on the validation process, AECOM recommends that the flow meters at the Burlington Canal and Lower Clear Creek raw water supply locations should be recalibrated or replaced.

3.4 Model Observations

Observations associated with the GoldSim® model include the following:

- Data pertaining to groundwater inflows and infiltration were not available and were not included in the modeling. All of the gravel lakes were permitted by the State of Colorado as Water Storage Reservoirs and were subjected to leakage testing. The measured leakage for each of the lakes is insignificant when compared to water inflows and outflows.
- Water quality biochemistry was not modeled due to insufficient water quality data and project scope. The model can be adapted for future water quality biochemistry analyses when additional data is available.
- Historic records of the operations of the lake interconnects were unavailable. Thornton should develop an operations recording program to allow future modeling to include the interconnect operations.

4. Flows to Water Treatment Plants

In the Water and Wastewater Infrastructure Master Plans Planning Area and Future Growth Analysis TM (September 2018), two existing operational conditions have been defined: drought and non-drought. Non-drought operational conditions represent flow requirements under typical climatic conditions and drought conditions reflect an increase in flow requirements that has historically occurred due to increase in outdoor potable use due to dry climatic conditions. Drought conditions were defined by the historical water demand experienced in 2012. The non-drought conditions were defined by an average of the historical water demands experienced from 2009 to 2011 and from 2013 to 2017. The daily water flows associated with these two conditions were used in the model as a total required flow that should be delivered to the WTPs. A daily flow pattern was developed from a seasonal four-week pattern based on 2018 data. This daily flow corresponds to the sum of the flow sent to the WBWTP and the flow sent to the TWTP.

The following additional constraints were applied to individual WTPs:

- The WBWTP has historically been removed from service approximately three months every year. In the model, it was assumed that the WBWTP was operational from March 1 to November 30 under drought and non-drought conditions.
- The assumption was made in the model that the new TWTP was in service with a limited treatment capacity of 20 mgd (with 22 mgd of raw water supplied to the WTP).
- Standley Lake supply was limited to 6,000 acre-feet (acre-ft) per year during a drought year, and to 10,000 acre-ft during a non-drought year.

Table 4 summarizes the annual flows required from each plant during a drought and a non-drought year.

Table 4: Annual Water Flows to Each Water Treatment Plants – Existing Conditions

Annual flow to	Existing Conditions Drought	Existing Conditions Non-Drought
WBWTP (acre-feet)	24,000	15,100
TWTP (acre-feet)	6,000	10,000
TOTAL (acre-feet)	**30,000**	**25,100**

The variation of the daily flow to each plant (and their sum) as modeled in the GoldSim® model is shown on Figure 5 and Figure 6. During three winter months, the TWTP produces all the required water. These figures illustrate that during the summer the operations of the TWTP are limited by the restricted supply from Standley Lake; therefore, requiring WBWTP to produce most of the required water. The maximum daily flow treated by WBWTP during a non-drought year is 36 mgd with 40 mgd supplied to the plant. The issue is more critical during a drought year, based on increased demand and less supply available at Standley Lake; the maximum daily finished water required from WBWTP become 50 mgd capacity with 55 mgd supplied to the plant.

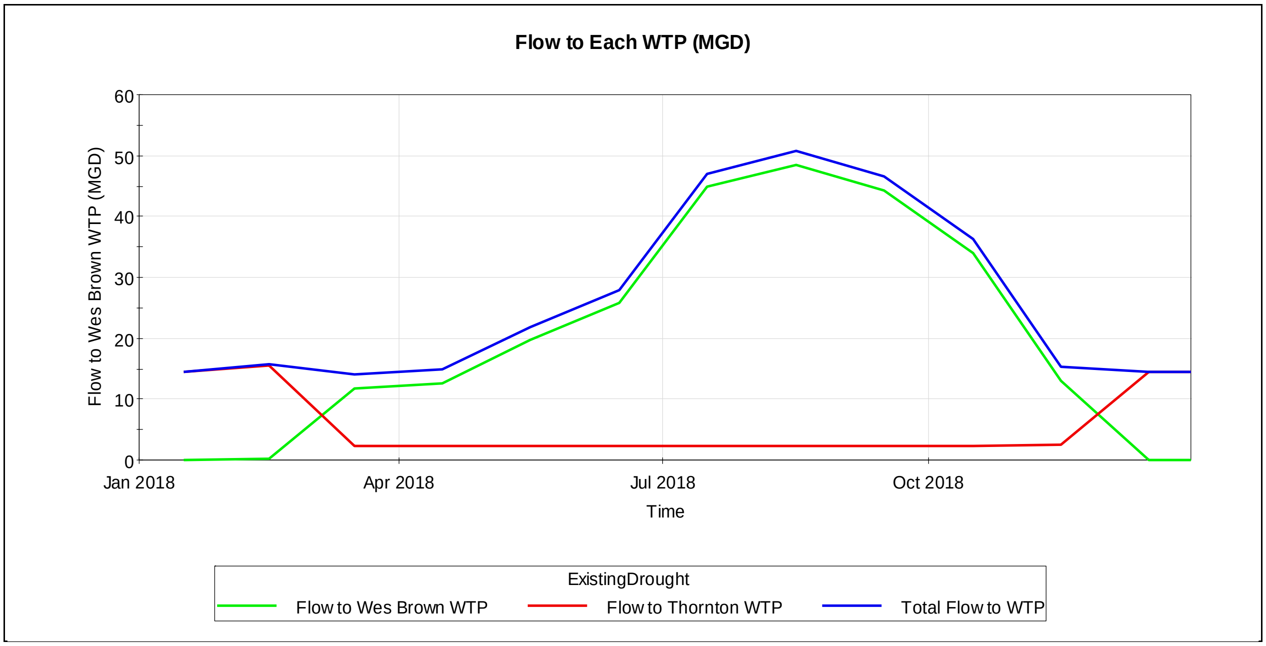

Figure 5: Flows to Water Treatment Plants – Existing Conditions / Drought

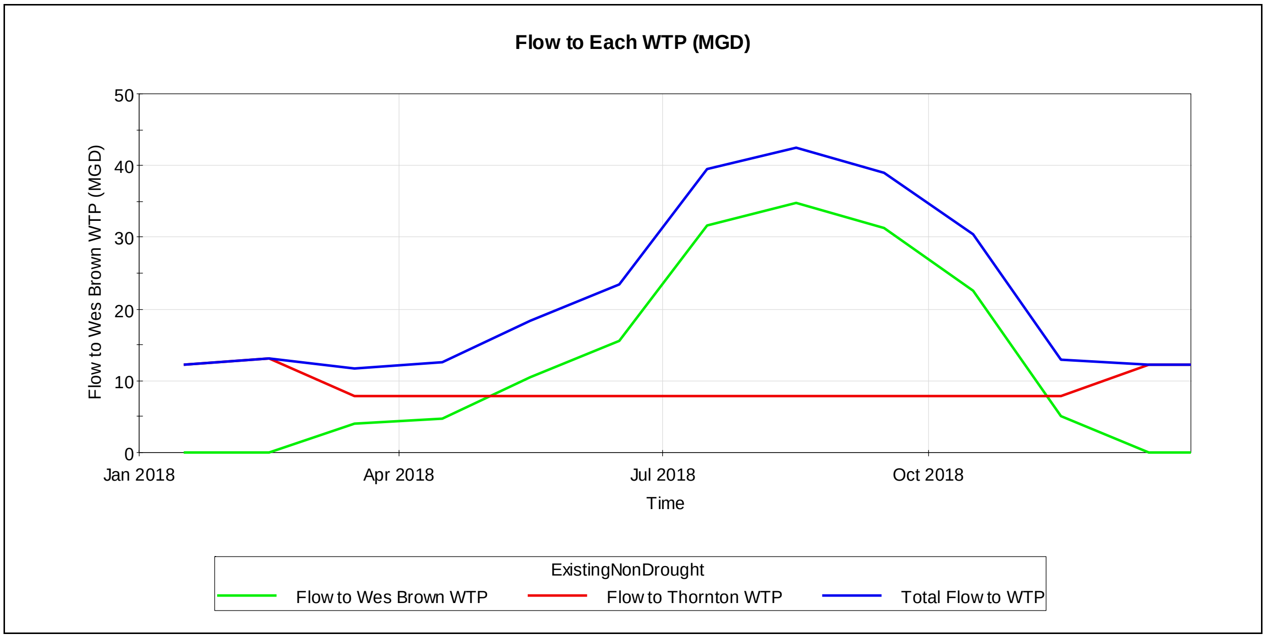

Figure 6: Flows to Water Treatment Plants – Existing Conditions / Non-Drought

5. Flows from Raw Water Supplies

The historical, recorded daily flow of raw water supplies from the years 2009 to 2017 were used as an input for the model. For a drought year, the historical flows from 2012 were used. And for a non-drought year, an average of the daily flows from 2009 to 2011 and from 2013 to 2017 was used. In addition, and as discussed in Section 3.3, the daily flows from Burlington Canal and from Lower Clear Creek were adjusted as established during model validation. The model results listed in Table 5 summarize the annual flows from each supply source under drought and non-drought conditions.

Table 5: Annual Water Flows from Each Supply Source – Existing Conditions

	Existing Conditions Drought	Existing Conditions Non-Drought
Burlington Canal (acre-feet)	13,300	11,900
Lower Clear Creek (acre-feet)	4,800	4,600
Standley Lake (acre-feet)	6,000	10,000
Total (acre-feet)	**24,100**	**26,500**

6. Water Quality Improvement Options Evaluation

The validated GoldSim® model was used to evaluate four options for proposed modified operations of the RWGLS. The modified operations were developed with the intent of improving the quality of the raw water in the gravel lakes. The options for modified operations were identified as part of the evaluation of the existing water quality of the gravel lakes, and their focus was on addressing the raw water taste and odor issues that were identified as Tier 2 water quality criteria. Reduction of raw water nutrient levels available within the lake water column, particularly phosphorus, was identified as the primary method for reducing taste and odor issues.

The GoldSim® model produced the following information for each option:

- Individual lake water surface elevation variations throughout the year – This data can guide future operations and highlight potential issues, including high water levels or depleted lake levels.
- Quantity of water pumped daily at each pump station (WGL PS, EGL PS, and McKay PS) – The flow pumped can then be translated into electrical operating cost for each option.
- Quantity of water stored in the system after a one-year or a three-year drought, providing a measure of the resiliency of the raw water storage system.
- Quantity of water to be delivered to each WTP – this data can guide future operations and inform water quality concerns.

6.1 Option 0: Existing Operation

The Option 0, current RWGLS component operations, was modeled as follows:

- Raw water flows from Lower Clear Creek to WGL1, then to WGL3, and finally to WGL2, where it is pumped to the WBWTP.
- Water flows from Burlington Canal to ST, to EGL4, where it is pumped to the WBWTP. Some water is sent from EGL4 to South Dahlia and the downstream reservoirs to compensate for evaporation losses and maintain reservoirs levels.
- Water flows from Standley Lake to TWTP.

The initial reservoir water surface elevations for the Option 0 model were assumed to be the average of the water surface elevation of each individual lake for years 2015 to 2017 on January 1. The water stored in the reservoirs at these water elevations correspond to an approximate total storage volume of 17,000 acre-ft (approximately 70 percent (%) of the maximum total RWGLS storage volume).

The computer model data graphed in Figure 7 and Figure 8 illustrate the calculated variation of the water surface elevation for each individual lake during three years of drought conditions and non-drought conditions, respectively. While non-drought conditions maintain the same year-over-year reservoir water elevations, the lake water surface elevations decrease over a three-year period during drought conditions. After a one-year drought, the total water stored is reduced to only slightly more than 10,000 acre-ft. The volume of water in storage is diminished to 4,000 acre-ft after a two-year drought.

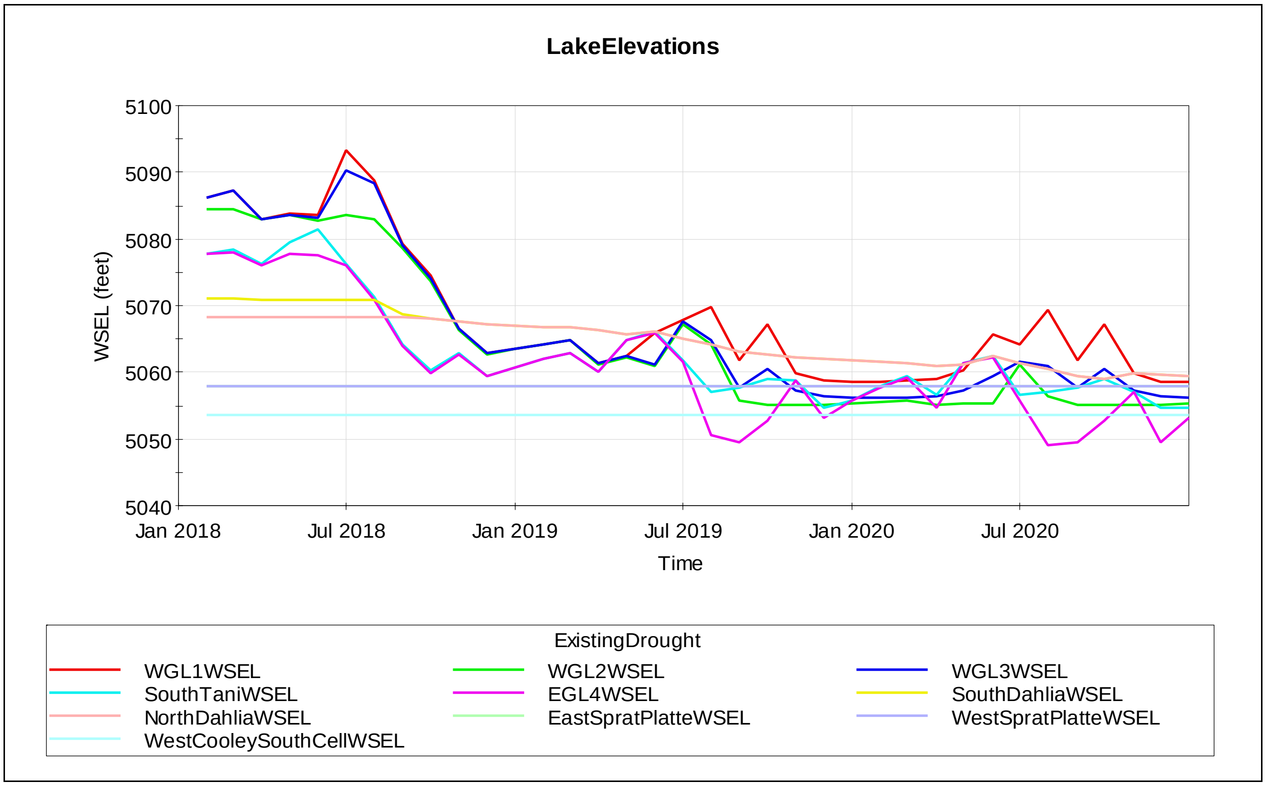

Figure 7: GoldSim® Model Lake Elevations – Option 0 / Drought

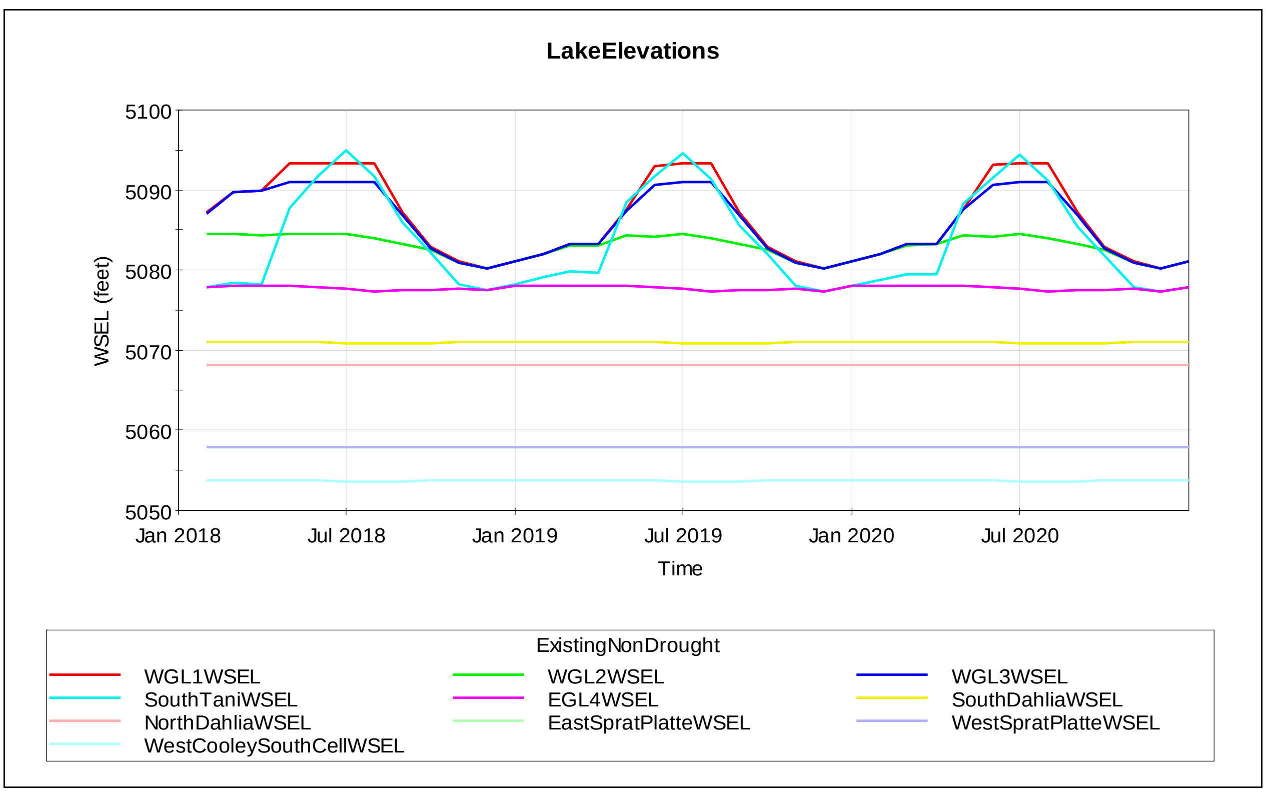

Figure 8: GoldSim® Model Lake Elevations – Option 0 / Non-Drought

The model data graphed in both Figure 8 and Figure 9 indicate that the reservoir surface elevations calculated by the model for gravel lakes downstream of EGL4 (South Dahlia, North Dahlia, East Sprat, West Sprat, and the South Cell of Cooley West) experience moderate decreases in water surface elevations. In fact these lakes are not used for operations and the decrease in water surface elevation is directly associated with evaporation. This relatively stable, slightly decreasing storage volume calculated by the model for these lakes is corroborated by the recorded water surface elevations of the lakes. The lakes downstream of EGL4 contain approximately 47% of the total, maximum storage volume of the RWGLS, but the existing system operations do not utilize these lakes.

The total pumped flows calculated by the model for each pump station are indicated in Table 6 for both a drought and a non-drought year. These flows are representative of the annual pumping rates under the existing conditions (Option 0). The total flows pumped are approximatively 24,000 acre-ft and 15,000 acre-ft during drought and non-drought conditions, respectively.

Table 6: Monthly Pumping Flows – Option 0

	EGL4 to WBWTP Drought	WGL2 to WBWTP Drought	EGL4 to WBWTP Non-Drought	WGL2 to WBWTP Non-Drought
January (acre-feet)	0	0	0	0
February (acre-feet)	12	6	4	2
March (acre-feet)	766	360	259	122
April (acre-feet)	794	374	295	139
May (acre-feet)	1,272	598	683	321
June (acre-feet)	1,610	758	978	460
July (acre-feet)	2,902	1,366	2,048	964
August (acre-feet)	3,140	1,478	2,248	1,058
September (acre-feet)	2,775	1,306	1,954	920
October (acre-feet)	2,204	1,037	1,464	689
November (acre-feet)	812	382	316	149
December (acre-feet)	0	0	0	0
Total per Pump Station (acre-feet)	**16,287**	**7,665**	**10,249**	**4,824**

For this option, the theoretical average hydraulic retention times are 196 days and 312 days for a drought year and a non-drought year, respectively. The theoretical averages were calculated based on annual flows from each pump station and total storage volume for each lake.

6.2 Option 1: Gravel Lakes Operate in Series

The validated model was modified to simulate the RWGLS in series operations as described in Section 2.2. The operation of all lakes in series increases the total maximum storage volume of the lakes by approximately 89% (from 12,888 acre-ft to 24,314 acre-ft). This increase in total storage volume has a corresponding 89% increase in the hydraulic detention time of the water in the lakes. The water quality evaluation of the gravel lakes has previously concluded that increased detention time results in a reduction of nutrient levels within the lake water column, thereby reducing the raw water potential for taste and odor issues.

The lake water surface elevation data graphs in Figure 9 and Figure 10 illustrate the calculated water surface elevations of the various lakes during drought and non-drought conditions when the RWGLS is operated in series. The calculated water surface elevations for Option 1 do not indicate operational issues within the RWGLS that would result from the new operation in series, as all of the lakes maintain a minimum water depth of approximately 10 feet or more even at the end of a three-year drought. Similar to the existing operations, the lake water surface elevations are maintained year-over-year during non-drought years, but they decrease during drought years. After a one-year drought the total calculated volume of raw water in storage has decreased from the same amount as for Existing Conditions (reduced from 17,000 acre-ft to 10,000 acre-ft). The annual water surface elevation peaks that occur in ST and to a lesser degree in WGL1 and WGL3, shown in Figure 10, illustrate the large raw water flow diversions into the RWGLS in the May through October time period of each year.

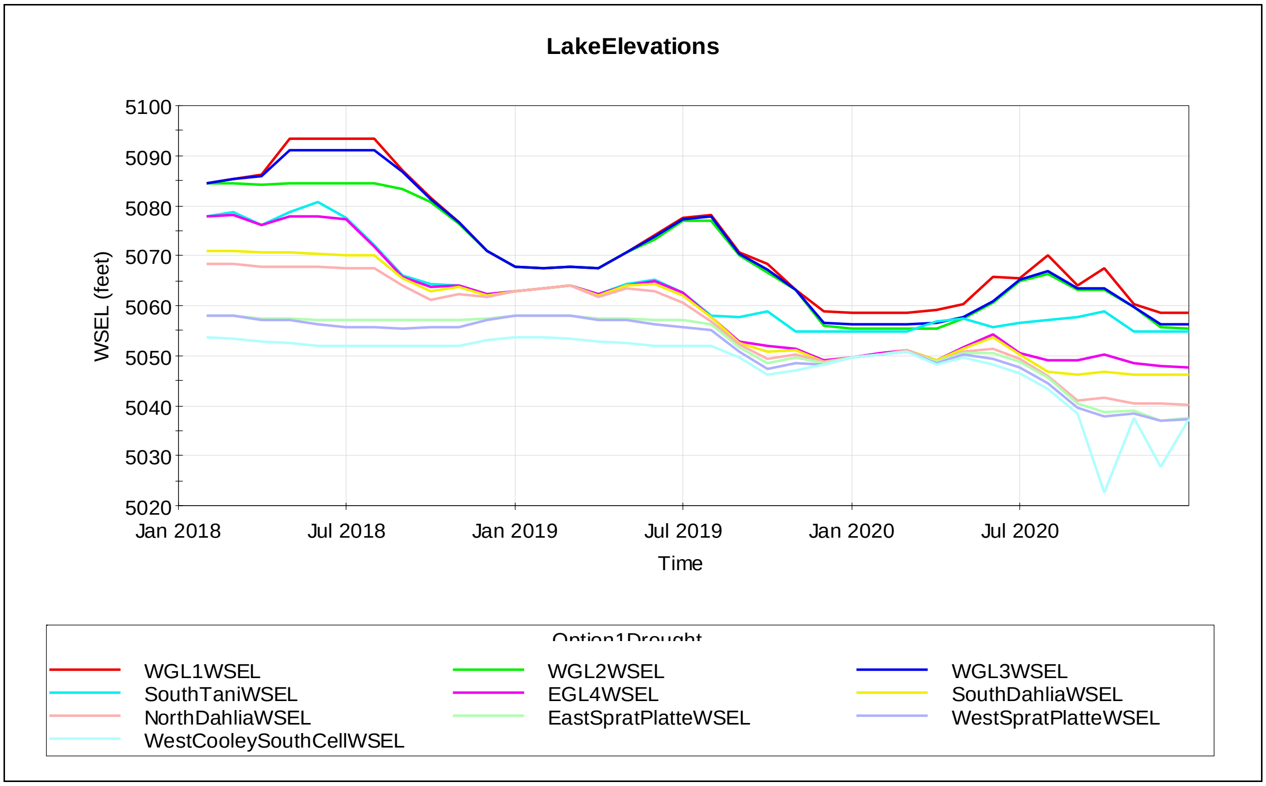

Figure 9: Calculated Lake Water Surface Elevations – Option 1 / Drought

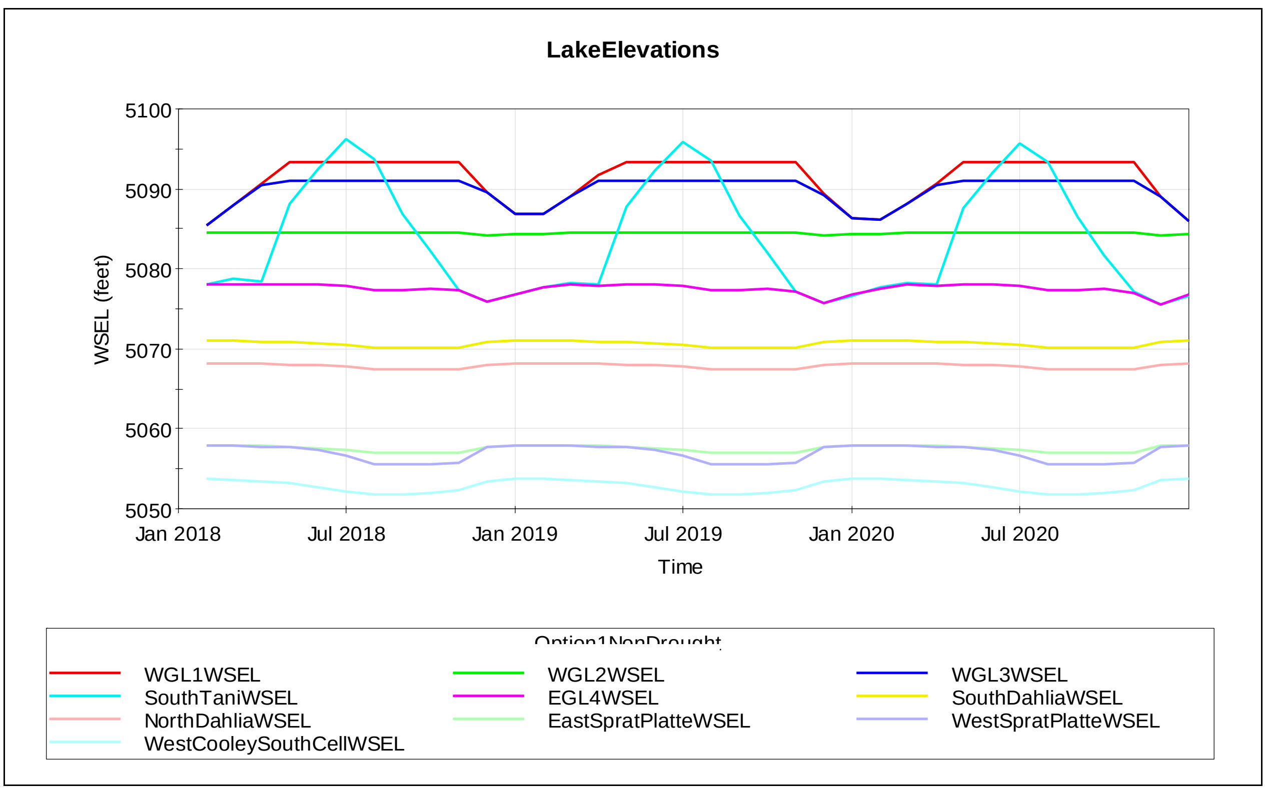

Figure 10: Calculated Lake Water Surface Elevations – Option 1 / Non-Drought

Pumping operations are significantly increased for Option 1, since most of the flow from Lower Clear Creek has to be pumped to EGL4. In addition, pumping from McKay PS to the WBWTP requires more energy than pumping from EGL4 to the WBWTP due to the significant difference in distance and ground elevation. Monthly pumping flows from EGL4 PS, WGL2 PS, and McKay PS are summarized in Table 7.

The total pumping volume of flow is increased by 31% as compared to pumping volumes under Existing Conditions during a drought-year, and the pumping volume of flow is increased by 34% during a non-drought year. The actual increase in pumping energy used must also address the increased hydraulic requirements of the increased pumping. The corresponding increase in pumping energy costs will be addressed in the capital cost and life cycle cost evaluations in a separate TM for the Raw Water Master Plan.

Table 7: Monthly Pumping Flows – Option 1

	EGL4 to WBWTP Drought	WGL2 to EGL4 Drought	McKay to WBWTP Drought	EGL4 to WBWTP Non-Drought	WGL2 to EGL4 Non-Drought	McKay to WBWTP Non-Drought
January (acre-feet)	0	72	0	0	75	0
February (acre-feet)	0	2	18	0	1	6
March (acre-feet)	0	88	1,126	0	10	381
April (acre-feet)	0	158	1,168	0	306	434
May (acre-feet)	2	537	1,869	0	502	1,004
June (acre-feet)	162	1,161	2,205	5	863	1,434
July (acre-feet)	1,889	1,176	2,378	673	932	2,338
August (acre-feet)	2,239	1,170	2,378	942	794	2,364
September (acre-feet)	1,779	1,223	2,302	612	703	2,262
October (acre-feet)	878	841	2,364	31	519	2122
November (acre-feet)	0	597	1,194	0	207	464
December (acre-feet)	0	293	0	0	190	0
Total per Pump Station (acre-feet)	**6,949**	**7,318**	**17,002**	**2,263**	**5,102**	**12,809**

The operation of the WGL and EGL in series will significantly increase (+89%) the theoretical hydraulic retention time in the RWGLS. The increased detention time is expected to result in a corresponding decreased availability of nutrient concentrations in the lake water column. For this option the theoretical average hydraulic retention times are 397 days and 527 days for a drought year and a non-drought year, respectively. An additional benefit will be the increased dilution of the WTP lagoons supernatant through increased detention time through all the gravel lakes.

6.3 Option 2: Precipitant Addition

The RWGLS improvements for Option 2 utilize the same gravel lakes operations as for Option 1, with the addition of chemical feed equipment to introduce a precipitant that will sequester phosphorus within Burlington Canal raw water flows entering the gravel lakes. These improvements are as described in Section 2.3. The precipitant addition improvements would also ideally include mixing and settling improvements to achieve a high-level of performance from the precipitant addition. Other water quality improvements from increased gravel lakes residence time and increased lagoons supernatant dilution are similar to Option 1. The theoretical average hydraulic retention times are similar to those achieved for Option 1. In addition, removing phosphorous from the water diverted from Burlington Canal is expected to further reduce water quality issues within the gravel lakes.

6.4 Option 3: Precipitant Addition and Burlington Canal Bypass

The validated model that simulated Option 1 was modified to simulate the RWGLS with Burlington Canal bypass operations as described in Section 2.4. The Burlington Canal bypass around ST was simulated in the model by removing the Burlington Canal inflows into ST and transferring them to South Dahlia. The Burlington Canal diversions were transferred to South Dahlia for the 3-month period from and including August to October, when phosphorus concentrations in the Burlington Canal diversions are typically at their highest levels. The computer model data graphed in Figure 11 and Figure 12 illustrate the water surface elevations of the various reservoirs during drought and non-drought conditions when all the reservoirs are operated in series.

The results of the model simulations for Option 3, and shown graphically in Figure 11 and Figure 12, do not appear to create hydraulic operations issues within the reservoirs. Similar to the existing operations, the reservoir water elevations are maintained during non-drought years, but decrease during drought years. After a one-year drought the total water stored is decreased from the same amount as for Existing Conditions (from 17,000 acre-ft to 10,000 acre-ft).

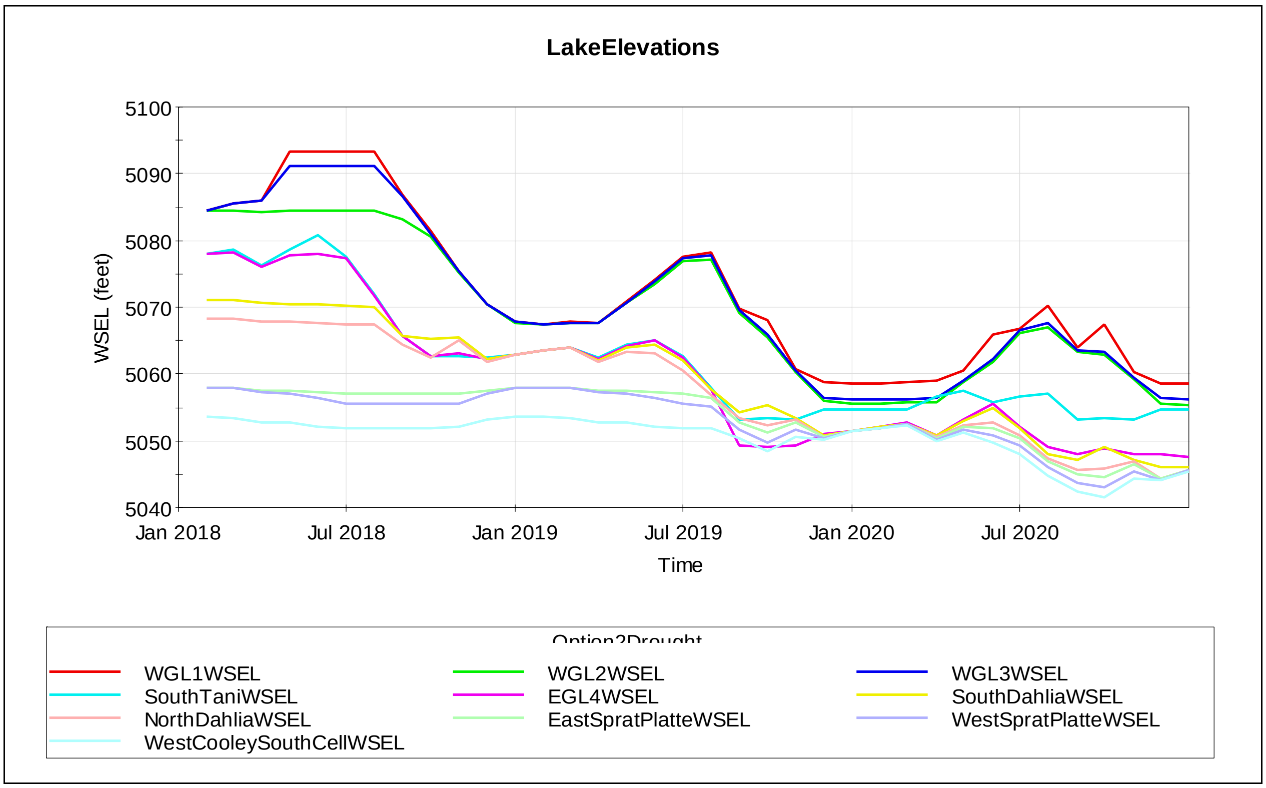

Figure 11: Calculated Lake Water Surface Elevations – Option 3 / Drought

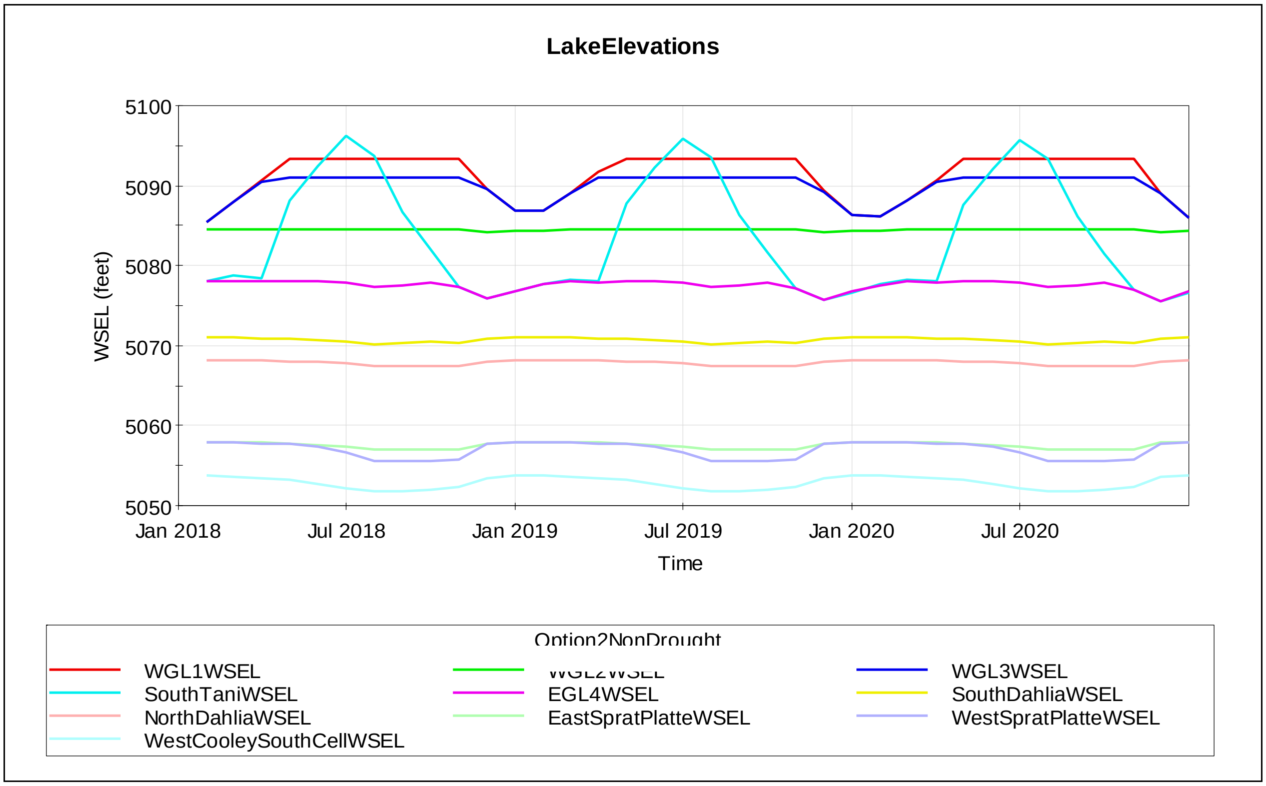

Figure 12: Calculated Lake Water Surface Elevations – Option 3 / Non-Drought

Pumping operations are similar to those modeled for Option 1. Monthly pumping flows from EGL4 PS, WGL2 PS, and McKay PS are summarized in Table 8.

Table 8: Calculated Monthly Pumping Flows – Option 3

	EGL4 to WBWTP Drought	WGL2 to EGL4 Drought	McKay to WBWTP Drought	EGL4 to WBWTP Non-Drought	WGL2 to EGL4 Non-Drought	McKay to WBWTP Non-Drought
January (acre-feet)	0	72	0	0	75	0
February (acre-feet)	0	2	18	0	1	6
March (acre-feet)	0	88	1,126	0	10	381
April (acre-feet)	0	158	1,168	0	306	434
May (acre-feet)	2	537	1,869	0	502	1,004
June (acre-feet)	162	1,161	2,205	5	863	1,434
July (acre-feet)	1,889	1,176	2,378	673	932	2,338
August (acre-feet)	2,239	1,173	2,378	942	794	2,364
September (acre-feet)	1,779	1,239	2,302	612	703	2,262
October (acre-feet)	878	936	2,364	31	519	2,122
November (acre-feet)	0	516	1,194	0	208	464
December (acre-feet)	0	266	0	0	190	0
Total per Pump Station (acre-feet)	**6,949**	**7,324**	**17,002**	**2,263**	**5,103**	**12,809**

The quantities of water bypassed from Burlington Canal to South Dahlia are summarized in Table 9 below. The bypass canal should be sized to accommodate the associated flows.

Table 9: Calculated Monthly Flow Bypassed – Option 3

	Option 3 Drought	Option 3 Non-Drought
August (acre-feet)	1,332	1,366
September (acre-feet)	1,977	1,465
October (acre-feet)	2,739	869
Total (acre-feet)	**6,048**	**3,700**

Improvements due to increased gravel lakes residence time and increased lagoons supernatant dilution are similar to Options 1 and 2. For this option the theoretical average hydraulic retention times are 328 days and 431 days for a drought year and a non-drought year, respectively. Removing phosphorous from the water diverted from Burlington Canal with the use of a precipitant is expected to reduce water quality issues within the gravel lakes, similar to Option 2. The use of the Burlington Canal bypass during later summer and fall should achieve a further decrease in nutrients within ST and EGL4.

6.5 Option 4: Maximizing Thornton Water Treatment Plant Production

The RWGLS improvements for Option 4 utilize the same gravel lakes operations as for Option 1, with the operational change of increasing the use of TWTP to take advantage of the advanced treatment process at the plant. This Option would achieve increased nutrient reduction through operation of the RWGLS in series similar to Option 1, but the nutrient reductions would not be expected to be as great as those achieved with the Burlington Canal bypass (Option 3). Additional water quality improvement to the finished water entering the water distribution system would be expected to be achieved through the increased level of treatment that can be accomplished at the TWTP.

For this option, the daily flows from each supply source did not change, and the total flow to the WTPs does not change. However, the split of the flows to each treatment plant was modified as described by the flow totals shown in Table 10. The model simulations reflected increased operations of the TWTP and reduced operations of the WBWTP.

Table 10: Annual Water Flows to Each Water Treatment Plants – Option 4

	Option 4 Drought	Option 4 Non-Drought
Annual Flow to WBWTP (acre-feet)	9,500	6,200
Annual Flow to TWTP (acre-feet)	20,500	18,900
Annual Flow to treatment plants (acre-feet)	**30,000**	**25,100**

Figure 13 and Figure 14 illustrate the variations of the new flows to each treatment plant during a drought year and a non-drought year. During about 5 months in the winter, the TWTP is used to produce all of the water demand. In the summer, the TWTP is used at its maximum capacity of 20 mgd. WBWTP is only used as a peaking plant and therefore maximum flows through WBWTP are significantly reduced compare to Existing Conditions. The maximum flows treated by WBWTP are approximatively 30 and 18 mgd for a drought and a non-drought year, respectively.

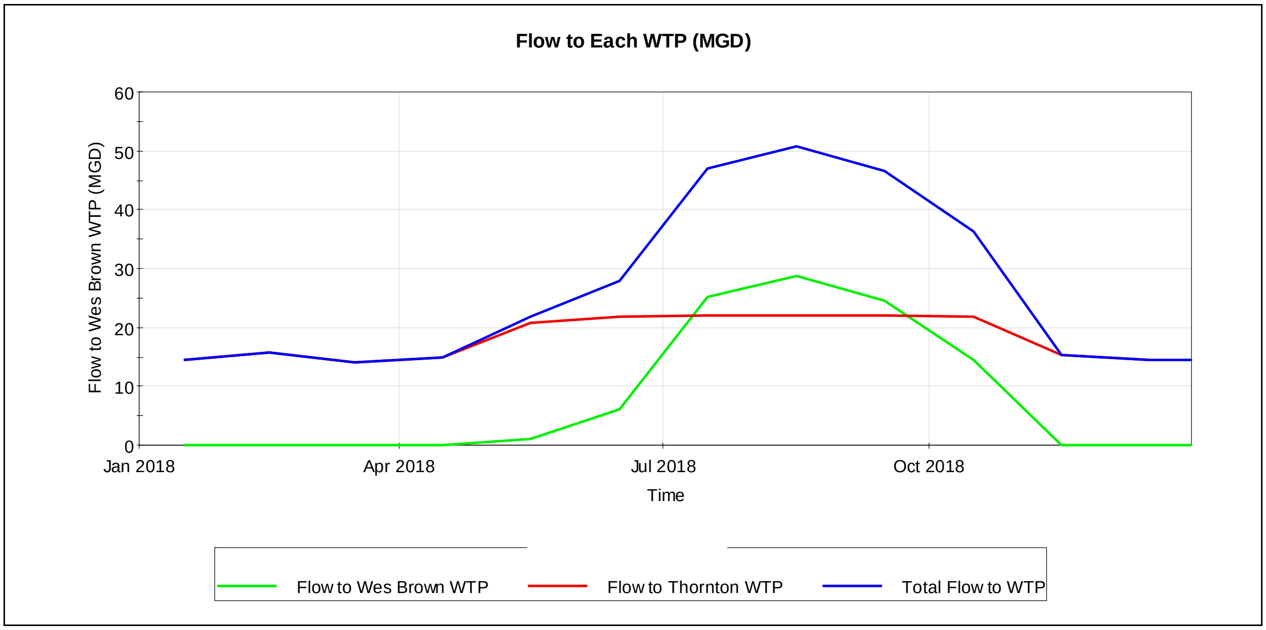

Figure 13: Calculated Flows to Water Treatment Plants – Option 4 / Drought

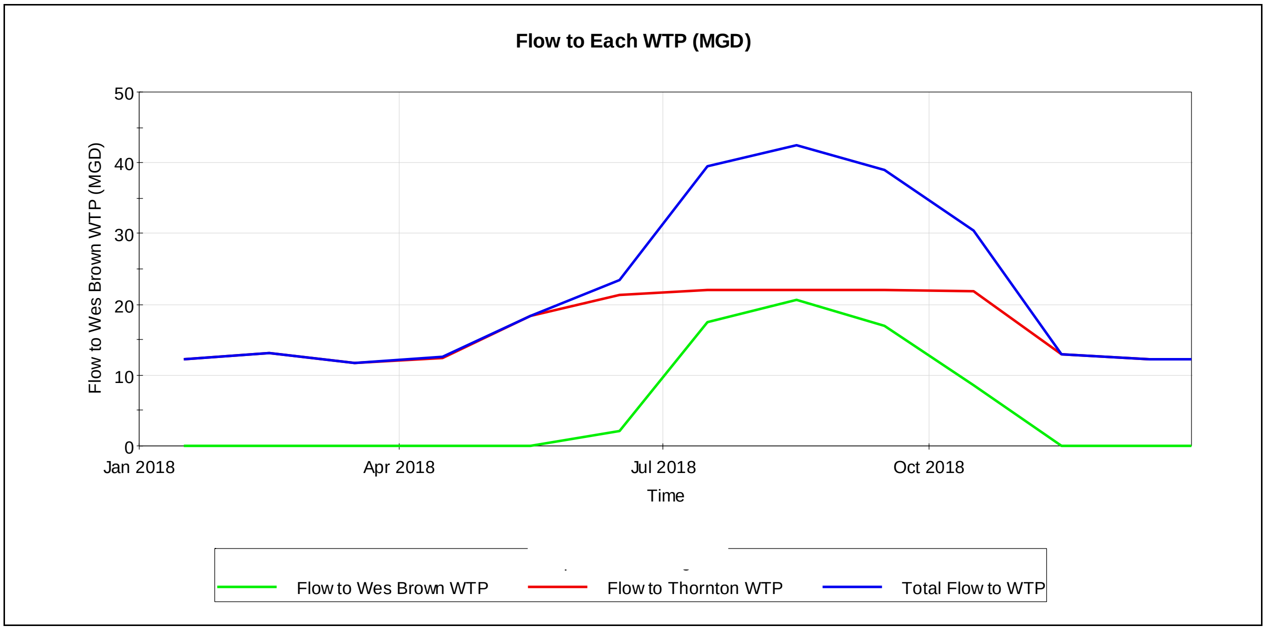

Figure 14: Flows to Water Treatment Plants – Option 4 / Non-Drought

Monthly pumping flows from EGL4 PS, WGL2 PS, and McKay PS are summarized in Table 11. Pumping operations at WGL2 are similar to the ones modeled for Options 1 and 3. Pumping at McKay PS is reduced compare to Option 1 and 3 due to the fact that the WBWTP is used significantly less. For the same reason pumping from EGL4 to WBWTP also decreases. However, an increase in pumping is required at EGL4 PS to send water to the TWTP.

Table 11: Monthly Pumping Flows – Option 4

	EGL4 to TWTP Drought	EGL4 to WBWTP Drought	WGL2 to EGL4 Drought	McKay to WBWTP Drought	EGL4 to TWTP Non-Drought	EGL4 to WBWTP Non-Drought	WGL2 to EGL4 Non-Drought	McKay to WBWTP Non-Drought
January (acre-feet)	1,237	0	209	0	0	0	75	0
February (acre-feet)	1,109	0	270	0	6	0	2	0
March (acre-feet)	673	0	250	0	380	0	15	1
April (acre-feet)	730	0	98	0	433	0	256	1
May (acre-feet)	1,319	0	164	98	999	0	447	6
June (acre-feet)	1,362	0	715	567	1,242	0	795	196
July (acre-feet)	1,633	206	1,073	2,181	1,351	0	858	1,661
August (acre-feet)	1,892	465	1,161	2,273	1,360	9	720	1,945
September (acre-feet)	1,554	173	1,118	2,088	1,307	0	631	1,566
October (acre-feet)	1,417	0	725	1,372	1,337	0	448	816
November (acre-feet)	782	0	445	0	464	0	362	0
December (acre-feet)	1,237	0	343	0	0	0	214	0
Total per Pump Station (acre-feet)	**14,945**	**844**	**6,571**	**8,579**	**8,879**	**9**	**4,823**	**6,192**

Improvements due to increased gravel lakes residence time and increased lagoons supernatant dilution are similar to Options 1 and 2. For this option the calculated theoretical average hydraulic retention times are 474 days and 309 days for a drought year and a non-drought year, respectively. Quality of finished water may improve by producing more water at TWTP and less at WBWTP.

6.6 Options Comparison

Each of the four options that were modeled were compared to the modeled existing conditions (Option 0). A summary of the comparison is presented in Table 12 below. Operational Costs comparison is qualitative and is based on both electrical pumping costs as well as additional chemical use. Capital Costs are compared based on the new infrastructure required for each option as described in Table 2. The following water indicators were used:

- Nutrient Load of the Gravel Lakes: the presence of nutrients in the gravel lakes is creating operational issues at the WBWTP and in the produced water quality. Removing nutrient loading within the gravel lakes prior to transfer of the water to the WTPs is expected to improve these issues.
- Lagoons Supernatant Dilution: the recirculation relatively short residence time of the lagoons supernatant within the WGL is associated with difficult membrane cleanings at the WBWTP. Diluting the supernatant flow and increasing the residence time of the water through series operation of the gravel lakes is expected to improve membrane operations and may improve produced water quality.

- Gravel Lakes Residence Time: Analysis of RWGLS water quality data indicates the residence time is related to water quality. Increased residence time results in decreased nutrient concentrations within the water column of the lakes. In fact the lakes may function as a nutrient reduction pretreatment process. Nutrients concentrations are expected to decrease with increased residence time throughout the lakes.
- Flows to WTPs: WBWTP has historically experienced poor water quality events due to taste and odors and membrane filtration performance limitations. As TWTP has been recently modified with a robust treatment process to remove taste and odors, it is believed that finished water produced at TWTP will potentially be of a better water quality than water produced at WBWTP. This indicator corresponds to the proportion of the water produced by TWTP versus the quantity of water produced by WBWTP.

Table 12. Options Results Comparisons – Costs and Water Quality Indicators

Option No.	Name	Costs		Water Quality Indicators			
		Operational Cost	Capital Cost	Nutrients Loads to Gravel Lakes	Lagoons Supernatant Dilution	Gravel Lakes Residence Time	Flows to WTPs
Option 0	**Existing Operation**	$ (pumping)	N/A	N/A	N/A	N/A	N/A
Option 1	**Gravel Lakes Operate in Series**	$$ (pumping)	$	+	+	+	=
Option 2	**Precipitant Addition**	$$ (pumping+chemical)	$$	++	+	+	=
Option 3	**Precipitant Addition and Burlington Canal Bypass**	$$ (pumping+chemical)	$$$	+++	+	+	=
Option 4	**Maximizing TWTP Production**	$$$ (pumping)	$	+	+	+	+

As illustrated in Table 12, Options 3 and 4 are expected to be most effective in improving water quality. However, Option 3 has the highest capital cost with three new infrastructures: a new pipe interconnect to the pipeline from the McKay PS to directly feed WBWTP, a new permanent chemical addition system, and a new bypass canal from EGL4 to South Dahlia. Option 4 has the highest operational cost due to increase pumping. AECOM recommends the following:

- Option 1 should be implemented to improve water quality in the raw water system,
- A study should be completed to determine effectiveness and operational cost of precipitant addition on the Burlington Canal water, and
- Cost of improvements associated with Options 2, 3, and 4 should be developed and examined with other improvements at the WTPs and within the water distribution system.

6.7 Additional RWGLS Improvement Scenarios

A high-level review of additional possible scenarios for improving the operations and the water quality of the RWGLS resulted in the identification of two possible scenarios that could be implemented:

1. The use of floating solar panels on the gravel lakes.
2. The use of sonic algae control.

6.7.1 Floating Solar Panels

The use of floating solar panels is in development and is being evaluated in many locations that experience above-average sunshine levels and where solar power is proven cost effective. New applications of floating solar panels have occurred in Florida, California, and Arizona. The generation of solar power at the RWGLS could have a number of known benefits:

- The shade provided by the floating solar panels would decrease the amount of water lost to evaporation.
- The shade from the solar panels would reduce the temperature of the water, which would thereby reduce the algae production within the water.
- The energy power produced by the solar panels could be used to directly power the pumping stations adjacent to the gravel lakes.

The use of floating solar panels is a relatively new concept, and all evaluations of their feasibility and effectiveness must address site specific issues for every application. Considerations of concern at some of the existing floating solar panel installations include the degradation of fabrication materials and the leaching or dissolution of these materials into the water. Site-specific considerations of concern for floating solar panels at the RWGLS could include methods for anchoring the panels without damage to the reservoir linings and possible conflict with the use of algaecide.

6.7.2 Sonic Algae Control

Sonic algae control is a relatively new (less than 15 years old) technique that has been employed to control algae in water retention ponds. Existing sonic algae control applications include public and private installations for golf course ponds, residential development ponds, aquaculture ponds, and municipal raw water and wastewater treatment plant ponds. Suppliers of sonic algae control equipment advertise many testimonials and successful applications of their equipment to reduce algae. This anecdotal evidence provides a small level of optimism for the use of sonic algae control in the RWGLS, with the following caveats:

- Sonic algae control is not effective for all types of algae.
- Sonic algae control is described as one tool or technique that can be used in combination with other methods to achieve total control of algae.
- AECOM was unable to identify documented independent research or testimony related to the ability of sonic algae methods to control colonial algae mass or the effects of turbidity and colloidal materials on the effectiveness of sonic algae methods.
- The use of sonic algae control for the RWGLS would be one of the largest (and likely the largest) applications of sonic algae control. The effectiveness of sonic methods to control algae within reservoirs as large as those within the RWGLS requires a site-specific evaluation.

The use of sonic algae control at the RWGLS may be worthy of evaluation as independent documentation of the performance at existing installations becomes available and after the recommended improvements for the RWGLS are implemented.

7. Conclusions and Recommendations

The evaluation of the existing raw water system indicates that there are options for improving the operations of the gravel lakes, with the goal of improving the quality of the water that is delivered to the WTPs. The primary goal of the improved operations is to reduce the taste and odor issues related to the nutrient loadings within the raw water. Based on the engineering evaluations and the GoldSim® modeling results, preliminary conclusions and recommendations include the following:

- Operating the RWGLS in series will increase the residence time of the raw water and result in reduced nutrient concentrations within the lake water column.
- The lagoon supernatant of the WTPs could be sent offsite rather than delivered to the RWGLS. This recommendation requires coordination with the Water Treatment Plant MP and consideration of future sludge disposal regulations.
- The delivery of the lagoon supernatant to the RWGLS could be modified to deliver the supernatant to the EGL system (ST or EGL4). This improvement would provide increased dilution if the RWGLS are operated in series.
- Option 4 is evaluated to achieve the highest level of finished water quality improvements, but it relies on the new TWTP's ability to treat EGL4 water quality. AECOM recommends that the results of the pilot plant testing at Thornton WTP be evaluated to confirm the effectiveness of the plant performance with taste and odor issues in the raw water.
- Option 4 pumping costs could be reduced depending on what flow rates are acceptable through the WBWTP. Pumping to TWTP could be performed only during periods when WBWTP is experiencing a taste and odor issue. Pumping to TWTP could also be used periodically to diminish the flow rate through WBWTP.
- Based on the modeling results and review of flow metering records AECOM recommends that the flow meters at the Burlington Ditch and Lower Clear Creek intakes be recalibrated or replaced.
- Option 2 has the potential to improve the raw water quality of the RWGLs with the lowest capital cost investment. AECOM recommends that pilot plant testing be performed to assess the effectiveness and operating costs for precipitant addition at the Burlington Canal diversion.

The capital costs and life cycle costs for implementing the proposed improvements are a critical component of the decision making process for modifying the RWGLS operations. Cost estimates for capital requirements and life cycle costs for the improvements are addressed in a separate TM that is part of this Master Plan.

Appendix A – Model Inputs Summary for Existing Conditions

Existing Conditions

Inputs to the model are summarized in Table A-1 below. Inputs include water production at the two water treatment plants, quantity of water supplied from Burlington Ditch, Lower Clear Creek, Standley Lake, and operational constraints.

Table A-1: GoldSim® Model Inputs – Existing Conditions

Water to the Treatment Plants	
Annual Daily Demand (ADD)	22.4 mgd (based on Planning and Future Growth Analysis TM)
ADD - Drought	26.7 mgd (based on Planning and Future Growth Analysis TM)
Daily Pattern	2017 monthly flow pattern - daily pattern based on a seasonal 4-week pattern of 2018 data
Treatment Plants Operations	
WBWTP - Flow	Limited to 50 mgd capacity (55 mgd supplied to WTP) Historical data shows maximum day at 50 mgd during drought year (55 mgd supplied) and 36 mgd during non-drought (40 supplied)
WBWTP - Operations	From March 1 to November 30
TWTP - Flow	Limited to 20 mgd capacity (22 mgd supplied to WTP)
TWTP - Operations	All year round
Water Supply	
Standley Lake - Flow	Limited to 6,000 acre-ft/year during drought, 10,000 acre-ft during non-drought
Standley Lake - Operations	All year round
Burlington Ditch - Flow	Historical data + Validation flow added [1]
Burlington Ditch - Operations	April 1 to October 31
Lower Clear Creek - Flow	Historical data + Validation flow added [1]
Lower Clear Creek - Operations	April 1 to October 31
WTP Backwash - Flow	5.5% of water to treatment plants (TWTP + WBWTP)
WTP Backwash - Operations	All year round
Gravel Lakes Levels - Drought	Lakes elevations at similar after 3 years
Gravel Lakes Levels - non-Drought	Lakes are 25% to 60% full at the end of the year (December 31)
Water Supply Path	
Lower Clear Creek	Lower Clear Creek to WGL1 to WGL3 to WGL2 and pumped to WBWTP
Burlington Ditch	Burlington Ditch to ST to EGL4 and pumped to WBWTP
Standley Lake	Standley Lake to TWTP

Note:

[1] See discussion in Section 3.4.

Appendix B – Model Inputs Summary for Each Water Quality Improvement Option

Option 1: Gravel Lakes Operate in Series

Inputs to the model are summarized in Table B-1 below. Inputs include water production at the two water treatment plants, quantity of water supplied from Burlington Ditch, Lower Clear Creek, Standley Lake, and operational constraints.

Table B-1: GoldSim® Model Inputs – Option 1

Water to the Treatment Plants	
Annual Daily Demand (ADD)	22.4 mgd (based on Planning and Future Growth Analysis TM)
ADD - Drought	26.7 mgd (based on Planning and Future Growth Analysis TM)
Daily Pattern	2017 monthly flow pattern - daily pattern based on a seasonal 4-week pattern of 2018 data
Treatment Plants Operations	
WBWTP - Flow	Limited to 50 mgd capacity (55 mgd supplied to WTP) Historical data shows maximum day at 50 mgd during drought year (55 mgd supplied) and 36 mgd during non-drought (40 supplied)
WBWTP - Operations	From March 1 to November 30
TWTP - Flow	Limited to 20 mgd capacity (22 mgd supplied to WTP)
TWTP - Operations	All year round
Water Supply	
Standley Lake - Flow	Limited to 6,000 acre-ft/year during drought, 10,000 acre-ft during non-drought
Standley Lake - Operations	All year round
Burlington Ditch - Flow	Historical data + Validation flow added [1]
Burlington Ditch - Operations	April 1 to October 31
Lower Clear Creek - Flow	Historical data + Validation flow added [1]
Lower Clear Creek - Operations	April 1 to October 31
WTP Backwash - Flow	5.5% of water to treatment plants (TWTP + WBWTP)
WTP Backwash - Operations	All year round
Gravel Lakes Levels - Drought	Lakes elevations at similar after 3 years
Gravel Lakes Levels - non-Drought	Lakes are 25% to 60% full at the end of the year (December 31)
Water Supply Path	
Lower Clear Creek	Lower Clear Creek to WGL1 to WGL3 to WGL2 and pumped to EGL4
WGL PS - Flow	Limited to 30 mgd
Burlington Ditch	Burlington Ditch to ST to EGL4 to South Dahlia to North Dahlia to East Spratt Platte to West Spratt Platte to Cooley West South to McKay PS and pumped to WBWTP
McKay PS - Flow	Limited to 25 mgd
	EGL4 to EGL4 PS and pumped to WBWTP (when additional water needed)
Standley Lake	Standley Lake to TWTP

Note:

[1] See discussion in Section 3.4.

Option 3: Precipitant Addition and Burlington Canal Bypass

Inputs to the model are summarized in Table B-2 below. Inputs include water production at the two water treatment plants, quantity of water supplied from Burlington Ditch, Lower Clear Creek, Standley Lake, and operational constraints.

Table B-2: GoldSim® Model Inputs – Option 3

Water to the Treatment Plants	
Annual Daily Demand (ADD)	22.4 mgd (based on Planning and Future Growth Analysis TM)
ADD - Drought	26.7 mgd (based on Planning and Future Growth Analysis TM)
Daily Pattern	2017 monthly flow pattern - daily pattern based on a seasonal 4-week pattern of 2018 data
Treatment Plants Operations	
WBWTP - Flow	Limited to 50 mgd capacity (55 mgd supplied to WTP) Historical data shows maximum day at 50 mgd during drought year (55 mgd supplied) and 36 mgd during non-drought (40 supplied)
WBWTP - Operations	From March 1 to November 30
TWTP - Flow	Limited to 20 mgd capacity (22 mgd supplied to WTP)
TWTP - Operations	All year round
Water Supply	
Standley Lake - Flow	Limited to 6,000 acre-ft/year during drought, 10,000 acre-ft during non-drought
Standley Lake - Operations	All year round
Burlington Ditch - Flow	Historical data + Validation flow added [1]
Burlington Ditch - Operations	April 1 to October 31
Lower Clear Creek - Flow	Historical data + Validation flow added [1]
Lower Clear Creek - Operations	April 1 to October 31
WTP Backwash - Flow	5.5% of water to treatment plants (TWTP+ WBWTP)
WTP Backwash - Operations	All year round
Gravel Lakes Levels - Drought	Lakes elevations at similar after 3 years
Gravel Lakes Levels - non-Drought	Lakes are 25% to 60% full at the end of the year (Dec 31)
Water Supply Path	
Lower Clear Creek	Lower Clear Creek to WGL1 to WGL3 to WGL2 to WGL PS and pumped to EGL4
WGL PS - Flow	Limited to 30 mgd
Burlington Ditch - January 1 to July 31 / November 1 to December 31	Burlington Ditch to ST to EGL4 to South Dahlia to North Dahlia to East Spratt Platte to West Spratt Platte to Cooley West South to McKay PS and pumped to WBWTP
Burlington Ditch - August 1 to October 31	Burlington Ditch to South Dahlia to North Dahlia to East Spratt Platte to West Spratt Platte to Cooley West South to McKay PS and pumped to WBWTP
McKay PS - Flow	Limited to 25 mgd
	EGL4 to EGL4 PS and pumped to WBWTP (when additional water needed)
Standley Lake	Standley Lake to TWTP

Note:
[1] See discussion in Section 3.4.

Option 4: Maximizing Thornton Water Treatment Plant Production

Inputs to the model are summarized in Table B-3 below. Inputs include water production at the two water treatment plants, quantity of water supplied from Burlington Ditch, Lower Clear Creek, Standley Lake, and operational constraints.

Table B-3: GoldSim® Model Inputs – Option 4

Water to the Treatment Plants	
Annual Daily Demand (ADD)	22.4 mgd (based on Planning and Future Growth Analysis TM)
ADD - Drought	26.7 mgd (based on Planning and Future Growth Analysis TM)
Daily Pattern	2017 monthly flow pattern - daily pattern based on a seasonal 4-week pattern of 2018 data
Treatment Plants Operations	
WBWTP - Flow	Limited to 55 mgd capacity (44 mgd supplied to WTP) Historical data shows max day at 50 mgd during drought year (55 mgd supplied) and 36 mgd during non-drought (40 supplied)
WBWTP - Operations	From March 1 to November 30
TWTP - Flow	At maximum 20 mgd capacity (22 mgd supplied to WTP) all summer
TWTP - Operations	All year round
Water Supply	
Standley Lake - Flow	Limited to 6,000 acre-ft/year during drought, 10,000 acre-ft during non-drought
Standley Lake - Operations	All year round
Burlington Ditch - Flow	Historical data + Validation flow added [1]
Burlington Ditch - Operations	April 1 to October 31
Lower Clear Creek - Flow	Historical data + Validation flow added [1]
Lower Clear Creek - Operations	April 1 to October 31
WTP Backwash - Flow	5.5% of water to treatment plants (TWTP + WBWTP)
WTP Backwash - Operations	All year round
Gravel Lakes Levels - Drought	Lakes elevations at similar after 3 years
Gravel Lakes Levels - non-Drought	Lakes are 25% to 60% full at the end of the year (December 31)
Water Supply Path	
Lower Clear Creek	Lower Clear Creek to WGL1 to WGL3 to WGL2 to WGL PS and pumped to EGL4
WGL PS - Flow	Limited to 30 mgd
Burlington Ditch	Burlington Ditch to ST to EGL4 to South Dahlia to North Dahlia to East Spratt Platte to West Spratt Platte to Cooley West South to McKay PS and pumped to WBWTP
McKay PS - Flow	Limited to 25 mgd
	EGL4 to EGL4 PS and pumped to WBWTP (when additional water needed)
	EGL4 to EGL4 PS and pumped to TWTP (when additional water needed)
Standley Lake	Standley Lake to TWTP

Note:
[1] See discussion in Section 3.4.

Raw Water Future Alternatives Evaluation

Chapter 5

Utility Master Plan

Project No. 17-467

Raw Water Supply Master Plan

Raw Water Future Alternatives Evaluation

The City of Thornton

Project number: 60560104

AECOM

November 27, 2019

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Tables

Figures

List of Acronyms

ADD	average daily demand
BC	Burlington Canal
CDPHE	Colorado Department of Public Health and Environment
CIP	Capital Improvement Program
DO	dissolved oxygen
EGL4	East Gravel Lake #4
KPIs	key performance indices
M	million gallons
MDD	maximum daily demand
mgd	million gallons per day
MIB	2-methylisoborneol
NWTP	Northern Water Treatment Plant
pH	alkalinity
PS	Pump Station
psi	pounds per square inch
RWGLS	Raw Water Gravel Lakes System
South Dahlia	South Dahlia Lake
ST	South Tani Reservoir
Thornton	City of Thornton
TM	Technical Memorandum
TWP	Thornton Water Project
TWTP	Thornton Water Treatment Plant
WBWTP	Wes Brown Water Treatment Plant
WGL2	West Gravel Lake #2
WP	Water Project
WTP	Water Treatment Plant
WTP	Water Treatment Plant

1. Introduction

This Technical Memorandum (TM) evaluates alternatives that the city of Thornton (Thornton) is considering for modification to their existing raw water infrastructure. The goal of the modifications is to maintain and improve the raw water quality and to increase the raw water delivery capacity to satisfy buildout water demand requirements. This TM is one of five TMs that are included in the Raw Water Master Plan. Previous evaluations that were completed as part of the Raw Water Supply Master Plan have identified and recommended operational and infrastructure improvement options to meet the System Performance Criteria identified in the Raw Water Supply Master Plan Design Criteria. The Gravel Lakes Water Quality Evaluation TM and the Existing Raw Water System Evaluation TM identified the modifications to existing infrastructure and operations necessary to address known issues that negatively impact the production capacity and finished water quality of the Wes Brown Water Treatment Plant (WBWTP).

The proposed improvements to the Raw Water Gravel Lake System (RWGLS) and the three future alternatives evaluated in this TM are intended to address the raw water quality issues and to increase the raw water supply to satisfy buildout water demand. The alternatives were identified in coordination with the Water Treatment Master Plan and the Water and Wastewater Master Plan. The three alternatives are summarized as follows:

- Alternative 1 – Construct a new Northern Water Treatment Plant (NWTP) located in north Thornton (final location to be determined) to meet future additional system demands.
- Alternative 2 – Expand the new Thornton Water Treatment Plant (TWTP) to meet the additional system demands.
- Alternative 3 – Expand the WBWTP to meet the additional system demands.

This TM also describes the capital improvements projects needed for implementation of the RWGLS operations improvements.

The TM is organized into six primary sections:

- Section 1: Introduction
- Section 2: Existing RWGLS Improvements
- Section 3: Future Treatment Requirements
- Section 4: Alternatives Development
- Section 5: Alternatives Evaluation
- Section 6: Capital Improvement Program (CIP)

2. Existing RWGLS Improvements

There are three categories of improvements recommended for the RWGLS described in this section: operations; monitoring; and studies. Operations improvements include modifications to the current RWGLS operations methods to improve raw water quality. Monitoring improvements include expansion of the current raw sampling and monitoring program to supplement the existing raw water quality database with additional critical water quality data that will support future operations decisions, thereby allowing development of more informed and effective RWGLS operations procedures. Studies for water quality enhancements include additional analyses and evaluations that Thornton should consider as opportunities to collect additional information on opportunities to improve the performance of the RWGLS. The RWGLS improvements are described in this Section.

Operations Improvements

The Existing Raw Water System Evaluation TM assessed the current operations of the RWGLS. The operations of Thornton's RWGLS were evaluated using computer simulations of the water surface level variations for each lake of the RWGLS as the system responded to the demands of the water treatment plants (WTPs). The evaluations identified and evaluated four options to modify the RWGLS operations that could result in improved raw water quality. The potential raw water quality improvements for each option were compared to the baseline raw water quality conditions to identify the differentiators of each option.

As illustrated in Table 1, Options 3 and 4 are expected to be most effective in improving water quality. However, Option 3 has the highest estimated capital cost, which requires the following infrastructure improvements: a new pipeline from the McKay Pump Station (PS) to directly feed the WBWTP, a new permanent chemical addition system, and a new bypass canal from East Gravel Lake 4 (EGL4) to South Dahlia Lake (South Dahlia). Option 4 has the highest operational costs due to increased pumping requirements.

The information in the following tables have been annotated to identify potential differentiators with a "±" used to indicate no advantage, a "+" used to indicate an advantage relative to the other options, and a "-" used to indicate a disadvantage relative to the other options.

Table 1: Options Results Comparisons – Costs and Water Quality Indicators

Option No.	Name	Costs		Water Quality Indicators			
		Operational Cost	Capital Cost	Nutrients Loads to Gravel Lakes	Lagoons Supernatant Dilution	Gravel Lakes Residence Time	Flows to WTPs
Option 0	**Existing Operation**	$ (pumping)	N/A	N/A	N/A	N/A	N/A
Option 1	**Gravel Lakes Operate in Series**	$$ (pumping)	$	+	+	+	±
Option 2	**Precipitant Addition**	$$ (pumping+chemical)	$$	++	+	+	±
Option 3	**Precipitant Addition and Burlington Canal Bypass**	$$ (pumping+chemical)	$$$	+++	+	+	±
Option 4	**Maximizing TWTP Production**	$$$ (pumping)	$	+	+	+	+

Based on this evaluation, AECOM recommends that Option 1 be implemented to improve water quality in the raw water system and a pilot plant study be performed to determine the effectiveness and operational costs of precipitant addition on the Burlington Canal diversions. Buffered aluminum sulfate or various other precipitants could be tested. The buffered aluminum sulfate would not be expected to impact the alkalinity (pH) of the raw water. The pilot study should be designed for location in a side channel or forebay before entering South Tani Reservoir (ST). The intent of precipitant addition is to remove as much external total suspended solids and phosphorous load before the raw water enters the gravel lake system. The existing bypass channel could also be adapted for use in the pilot study, or a self-contained skid-mounted tank and chemical feed could be used. Alternatively, treatment could occur in ST as Burlington Canal (BC) flows enter the lakes; however, there is concern regarding the solids deposition and accumulation that will occur, with a commensurate reduction in storage volume, and the possible need for removal in the future.

The need for implementation of Options 2, 3, and 4 should be evaluated once the costs for each have been developed and after the benefits of Option 1 have been further quantified. In addition to Option 1, the monitoring improvements that were recommended in the Existing System Evaluation TM should also be implemented. The data collected as part of the monitoring improvements will support the evaluation and quantification of the benefits of implementing Option 1. If the water quality improvements experienced from the implementation of Option 1 are sufficient, the implementation of Options 2, 3, and 4 may be postponed or eliminated.

Option implementation will involve initial capital costs for infrastructure improvements or additions and continuous energy-related operational costs pertaining to new equipment or chemical feed operations. Table 2 provides a summary of the capital costs for improvements associated with each option. In addition to the capital costs for improvements, Table 3 outlines the operational impacts of the improvements.

Table 2: Summary of Capital Costs for Water Quality Improvements

Water Quality Option	Recommended Improvement
Options 1, 2, 3, & 4	New pipeline from the McKay PS to directly feed WBWTP. New gravel lake interconnect pipeline to transfer raw water from the West Gravel Lake system to the East Gravel Lake system
Options 2 & 3	New chemical feed system at Burlington Ditch
Option 3	Extending bypass around EGL4

Table 3: Summary of Operational Costs for Water Quality Improvements

Process	Recommended Improvement
Option 1	Increased electrical demands for the various raw water pumps stations
Option 2	Increased electrical demands for the various raw water pumps stations
Option 3	Increased electrical demands for the various raw water pumps stations
Option 4	Increased electrical demands for the various raw water pumps stations
Options 2 & 3	Annual chemical cost (phosphorous precipitant)

Monitoring Improvements

The Existing System Evaluation TM evaluated the water quality of the RWGLS and developed a recommendation for additional water quality monitoring. The following water quality monitoring enhancements were recommended in the Existing System Evaluation TM:

1. **New Deep Monitoring Site at Each Lake:** For ST, EGL4, West Gravel Lake #2 (WGL2), and South Cell – Cooley West , add a monitoring site over the deepest location or at the center of each lake. Collect water quality sonde (e.g., any of various devices for testing physical conditions, often for remote or underwater locations) profiles to document water temperature, specific conductivity, alkalinity (pH), and dissolved oxygen and oxidation reduction potentials in one-meter increments from the surface to the near bottom water layer (i.e., within 0.5 meter of the sediment). Collect water samples at the surface, middle, and bottom layers and analyze for nutrients (i.e., total and dissolved organic/inorganic nitrogen and phosphorus fractions) and at the surface and middle depths for chlorophyll-a conditions.

These data will increase the understanding of the limnological process that affects vertical density gradients (e.g., relative thermal resistance to mixing) and horizontal mixing (e.g., transfer of water via the interconnects) of the water column, and whether conditions are favorable for internal nutrient loading that may facilitate late season algae growth and related taste and odor events. It is valuable to understand the timing of external versus internal loading for the RWGLS, which will aid in identifying modifications to the RWGLS operations to reduce the seasonal algae growth. Thornton typically does not take BC water during the late summer (or at least that is not preferred) due to the low flow and high nutrient concentrations (i.e., poorer dilution and water quality). However, late summer is when the reservoirs likely go anoxic, and there is a high internal nutrient loading that fuels algae growth in the late August-September time period. The gravel lakes experience high algal growth and taste and odor issues in late summer; this is often when BC water is not entering the system but when internal loading is occurring. A holistic approach requires that the external loads be addressed first, but there will also likely need to be some effort to control internal loads.

2. **Continued Nutrient Monitoring:** For all gravel lakes, continue monitoring the nearshore locations at the interconnects for nutrients (i.e., total and dissolved organic/inorganic nitrogen and phosphorus fractions) and chlorophyll-a where the interconnects for water transfer occur from the upgradient lake to the downgradient lake or where the PSs are located for a given lake. This sampling will help document whether the natural attenuation of nutrients from upgradient to downgradient lakes will be an effective strategy to help reduce the influence of nutrients on algal production and correspondingly reduce algal concentrations.

3. **South Lakes Monitoring:** For ST, EGL4, WGL2, and South Cell - Cooley West, the water quality sampling should be completed on a weekly basis from April through October and monthly from November through March at the surface, middle, and bottom depths at both the nearshore and center of the lake for nutrient (i.e., total and dissolved organic/inorganic nitrogen and phosphorus fractions) and at surface and middle depths for chlorophyll-a conditions. Routine physicochemical profiles (i.e., temperature, pH, specific conductance, dissolved oxygen, and oxidation reduction potential) should also be collected as weather and icing conditions on the water surfaces allow.

4. **EGL4 Water Quality Sampling:** For EGL4, an integrated water column sample should be collected monthly for the identification, enumeration, and biovolume analysis of the phytoplankton assemblage to gain better insight into the species that influence taste and odor events. Separate water samples should be collected when geosmin and 2-methylisoborne (MIB) analyses are collected; however; analysis of the taxonomic composition should only be completed when the concentrations indicate a taste and odor event is occurring.

   Understanding the community structure during each month will help elucidate the seasonal changes that typically occur each year and the taxa (a group of one or more populations of an organism or organisms seen by taxonomists to form a unit) present that are associated with toxin or taste and odor events.

5. **Geosmin, MIB Lake Sampling:** For EGL4, WGL2, and South Cell - Cooley West Lake, geosmin, MIB, and microcystin-LR samples should be collected from the surface, middle, and bottom depths to document the onset and duration of taste and odor and toxin events. These data should be paired with a phytoplankton sample if the geosmin, MIB, or microcystin-LR data indicate an event. Notably, the measurement of taste and odor compounds or toxins is the only positive method for documenting their presence because the presence of cyanobacteria does not necessarily indicate the presence of taste and odor or toxins.

   The geosmin, MIB lake sampling will help identify the sources of taste and odor issues. Thornton has not been able to identify whether benthic cyanobacteria, soil actinomycetes, diatoms, or pelagic cyanobacteria from internal or external sources are causing the taste and odor issues. Depending on the source, the treatment options could be different whether derived from benthic organisms or other sources. It is recommended that this sampling should occur over a one-year period to gain a better understanding of the source of the taste and odor issues rather than just acknowledging that a taste and odor event has occurred without any consideration of source/cause. If a taste and odor event has a benthic cause, there are other treatment options that may be considered.

6. **Geosmin, MIB Source Sampling:** For the South Platte River at Burlington Canal, geosmin and MIB samples should be collected from the inflows to help document the origin, onset, and duration of taste and odor and toxin

events in the gravel lake system. Soil bacteria from the riverine system could provide a source of taste- and odor-causing organisms or compounds.

7. **New Profiling System:** For EGL4, ST, WGL2, and South Cell – Cooley West, install a centrally located buoy-mounted water quality profiling system to document water temperature, specific conductivity, pH, dissolved oxygen, and oxidation reduction potentials in one-meter increments from the surface to the bottom water layer. These profiling systems have greatly advanced the understanding of lake behavior in all cases where they have been installed. High frequency data (e.g., four values per day) from this system will substantially increase the understanding of the limnological and/or environmental processes that affect vertical and horizontal mixing of the water column and whether conditions are favorable for internal nutrient loading that may facilitate late season algae growth. High frequency profile data may also be used to determine selective water withdrawal strategies to potentially circumvent the intake of poorer water quality. The profiling system data should be downloaded and reviewed on a monthly basis.

8. **New Temperature Data Monitoring:** For EGL4, WGL2, and South Cell - Cooley West, install a thermistor string in the deepest location or at the center of each lake to collect high frequency (e.g., 15-minute interval) water temperature data in one-meter increments from the surface to the bottom layer. These data logger arrays are relatively inexpensive to install and maintain and will vastly improve the understanding of wind mixing events and vertical density gradients that affect chemical and biological processes in the lakes. The data should be downloaded at least monthly to minimize potential data loss due to logistical issues (e.g., dead batteries, etc.). Data should be evaluated monthly to better understand the physical mixing of the lakes. The first year will provide a baseline for lake mixing and mechanisms of initiating events (i.e., wind rain, seasonal inflows); by Years 2, 3, and 4, it is expected that well-defined patterns and mechanisms for mixing will become evident.

Studies for Water Quality Enhancements

This section identifies potential additional studies for Thornton's consideration.

Water Circulation Study: The monitoring recommendations, specifically one-meter interval sonde data and water temperature loggers, will provide a better understanding of water layer density and the relative mixing potential of lake and inflow water. At the time that algae growth conditions are high, the existing Solar Bee system for water mixing may need to be modified and expanded to effectively circulate algae in the mixed water layer and disrupt surface water habitat for cyanobacteria.

Dissolved Oxygen Study: The addition of routine monitoring of nutrient water quality conditions near the sediment layer combined with increased measurement frequency of dissolved oxygen and thermal profiles will provide a dataset that can be used to assess the need for sediment-based management strategies. There is no existing data that characterizes the anoxic conditions or the temporal dissolved oxygen changes near the water sediment boundary (i.e., ≤ 1m from sediment). It is presumed that most of the lakes in the RWGLS become anoxic, thus facilitating internal nutrient and metals release. Controlling dissolved oxygen (DO) levels (through increase in DO concentration) is a management strategy to counteract anoxia that increases internal nutrient loading along with manganese and other metals, and possibly taste and odor compounds. A dissolved oxygen pilot study would be the first step subsequent to documenting the need to address anoxia.

Pilot Study for Precipitant Addition / Phosphorous Reduction Study: Water Quality Options 2 and 3 include the addition of chemical feed equipment to introduce a precipitant that will sequester phosphorus within Burlington Canal raw water flows entering the gravel lakes. In order to assess the effectiveness and related operating costs for precipitant addition at the Burlington Canal diversion, AECOM recommends a pilot study be performed. The pilot study can be a bench scale study to quantify the alum dose needed to achieve a desired reduction in P in the surface water. The study can include toxicology tests to document "no harm" to aquatic life use during the dosing when buffered or non-buffered alum is used. If the goal of alum is to control internal nutrient loading, then additional sediment studies should be performed to quantify sediment-bound P. The dosing studies could be performed in-house by Thornton; however, the toxicology or sediment studies would need to be performed by a specialty contractor. Therefore, the dosing could be conveniently performed by the specialty contractor concurrently with the treatment study. This recommendation will be associated with a CIP and a budgetary cost in Section 6.

Floating Solar Energy Study: AECOM performed a high-level review of an additional possible scenario to improve the operations and water quality of the RWGLS. This possible scenario was identified by Thornton, and it is a relatively new renewable energy application development. The use of floating solar panels is in early development in North America and is being evaluated in locations that experience above-average sunshine levels and where solar power has proven cost effective. New applications of floating solar panels in North America have been used in Florida, California, and Arizona.

The generation of solar power at the gravel lakes has the primary benefit of providing energy that could power the raw water pumping stations adjacent to the gravel lakes. Secondary raw water quality-related benefits of floating solar power include the following:

- Shade provided by the floating solar panels would decrease the amount of water lost to evaporation.
- Shade from the solar panels would reduce the temperature of the water, thereby reducing algae production within the water, potentially effecting a related reduction in taste and odor events.

The use of floating solar panels is a relatively new concept, and evaluations of their feasibility and effectiveness must address site-specific issues for each application. Concerns at some of the existing floating solar panel installations include the degradation of floating-related materials, the panel connections, and the leaching or dissolution of these materials into the water. Site-specific concerns for the RWGLS would also include the stability of the panels during fluctuating water levels in the lakes, ice formation on the lake surfaces, possible conflicts with reservoir algaecide treatments, and the need for backup power at each primary WTP supply PS in case of solar power electric supply loss.

3. Future Treatment Requirements

Future Production Requirements

The existing and future system demands, distribution losses, and production losses were reviewed and developed in the Water and Wastewater Future Growth and Planning TM and Water Treatment Future Alternatives Evaluation TM. These TMs identified the future system demands, production requirements, and raw water requirements that serve as the basis for the integrated master planning efforts. The future system requirements were developed for non-drought and drought conditions, where non-drought conditions represent anticipated flow requirements under typical climatic conditions, and drought conditions reflect an increase in flow requirements, which have historically occurred largely resulting from an increase in outdoor potable water use due to dry climatic conditions and serve as the planning basis. The required total flow rates for each alternative by WTP, expressed in million gallons per day (mgd), are summarized below in Table 4.

Table 4: Alternative WTP Production Requirements

Facility	WBWTP (mgd)	TWTP (mgd)	NWTP (mgd)	Total (mgd)
Alternative 1 – New NWTP	54.8	20	21.5	**96.3**
Alternative 2 – Expand TWTP	54.8	41.5	-	**96.3**
Alternative 3 – Expand WBWTP	76.3	20	-	**96.3**

Water production losses through the WBWTP and TWTP are based on historical data that were determined to be 10% for WBWTP and 6% for TWTP, respectively. The losses through a new NWTP, which is further described in Section 4.1 as Expansion Alternative 1, are estimated to be similar to the losses through TWTP, as it has been assumed a new water treatment facility would use conventional filtration. The required relative raw water supply rates to WBWTP are higher than TWTP due to higher production losses associated with membrane filtration. A more detailed breakdown of the required raw water supply requirements is presented in Table 5.

Table 5: Future Production Requirements

Parameter	Non-drought	Drought
Distribution System Demands (mgd)[1]		
Minimum Month	18.6	18.6
Average Daily Demand (ADD)	32.9	39.1
Maximum Daily Demand (MDD)	71.6	85.6
Treatment Production Requirements (mgd)[2]		
Minimum Month	20.9	20.9
ADD	36.9	43.9
MDD	80.5	96.3
Production Loss Through the Treatment Plant (%)[3]		
WBWTP	10%	10%
TWTP	6%	6%
NWTP	6%	6%

[1]Reference Future Growth and Planning Analysis TM for basis of future flows
[2]Accounts for 13% losses in the distribution system omitting 1.8 mgd for Brighton Interconnect
[3]Based on supply versus production data from 4/1/2017 to 6/30/2017

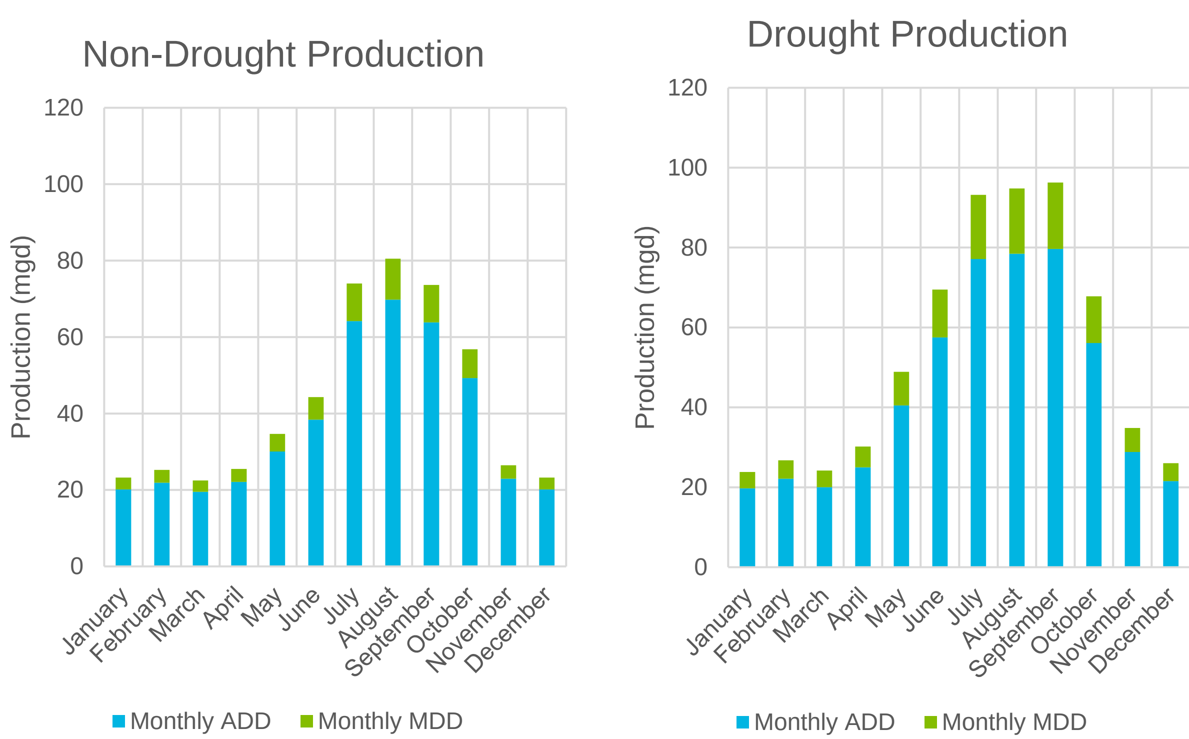
Monthly Demand Patterns

To evaluate the seasonal impacts on production requirements, the annual ADD and MDD were estimated as part of the Planning Area and Future Growth Analysis TM in order to identify the required water treatment capacity. The estimated ADD and MDD were extrapolated to estimate the ADD and MDD by month to reflect seasonal impact as follows:

- A non-drought monthly ADD pattern was developed based on the 2017 monthly production data.
- A drought monthly ADD pattern was developed based on the 2012 monthly production data.
- The monthly MDD/ADD demand was developed based on the estimated maximum month MDD/ADD.

The anticipated monthly ADD and monthly MDD values are identified on Figure 1. The MDD in a drought year is anticipated to be 96.3 mgd, and is, therefore, the driving hydraulic criteria for future infrastructure. Historic demand patterns indicate that MDD can occur in July, August, or September.

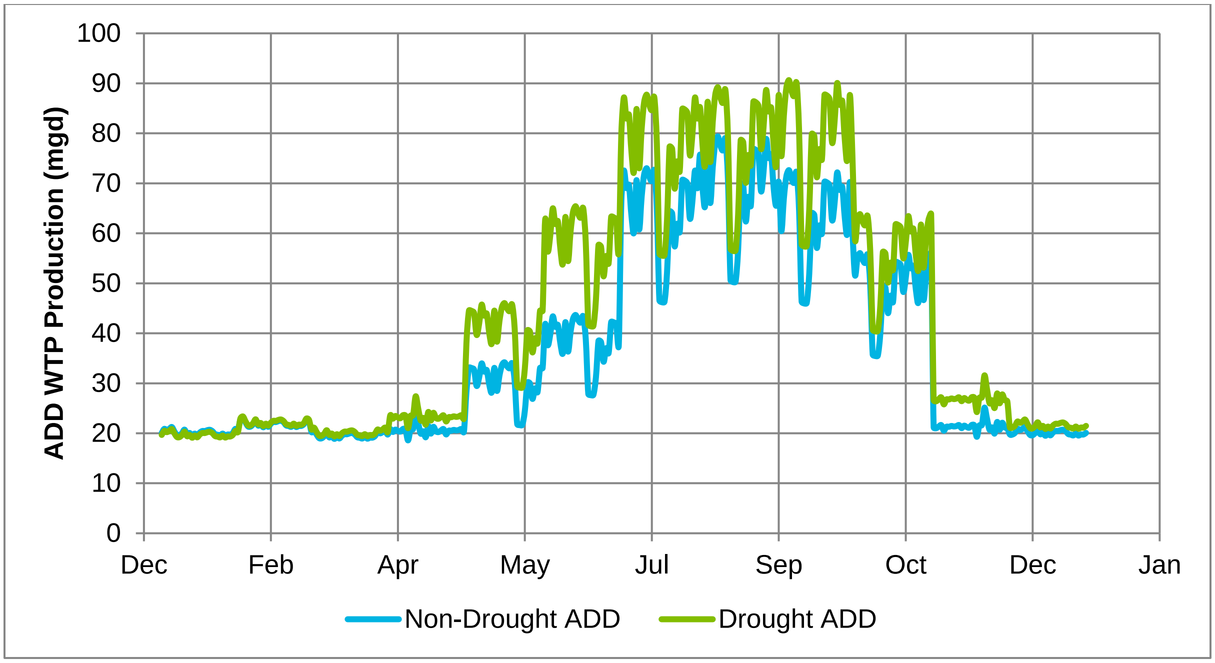
Figure 1: Anticipated Future Production Monthly ADD and Monthly MDD for Non-Drought and Drought Conditions



Annual Demand Patterns

While pipelines and treatment plants need to be designed for the maximum flows, raw water supply need considerations include the total amount of water required in a given year and the seasonal demand patterns. For the Existing Raw Water Existing System Evaluation TM, a daily flow pattern was developed from a seasonal four-week pattern based on actual water usage data in 2018. This flow pattern was applied to the monthly ADD shown on Figure 1, producing daily flows under non-drought and drought conditions as shown on Figure 2. The future alternatives presented in Section 4 have been developed and evaluated based on the seasonal flow patterns and the total amount of water required annually.

Figure 2: Seasonal Four-Week ADD Pattern for Non-Drought and Drought Conditions



4. Alternatives Development

The three following alternatives have been identified as potential solutions to meet the future system demands:

- Alternative 1 – Construct a new NWTP to meet future additional system demands.
- Alternative 2 – Expand the TWTP to meet the additional system demands.
- Alternative 3 – Expand the WBWTP to meet the additional system demands.

Based on the analysis performed for the Water Distribution System Master Plan, each alternative must be capable of producing 96.3 mgd to meet MDD; this will require an additional 21.5 mgd of production that is not currently available in the total Thornton water treatment facility capacity. The analysis of modifications to existing treatment infrastructure for each alternative to meet the buildout production capacities has been based on the MDD requirements indicated in Table 6. The capacities listed in Table 6 are required to supply peak flows for each facility. The peak flows to the different facilities are not expected to occur simultaneously, and the values are not additive.

Table 6: Thornton Water Project Pipeline Capacities by Alternative

	Unit	Alternative 1	Alternative 2	Alternative 3
Max Flow from Thornton Water Project (TWP) to NWTP	mgd	22.8	-	-
Max Flow from TWP to TWTP	mgd	21.2	40.0	21.2
Max Flow from TWP to WBWTP	mgd	40.0	40.0	40.0

Assumptions:

1. Annual Standley Lake supply is limited to 6,000 acre-feet under most stringent conditions.
2. If not all the available water from Standley Lake is used by TWTP, the leftover will be sent to WBWTP in order to use all volume of available supply from Standley Lake.
3. Annual Lower Clear Creek flows are limited to existing use (4,800 acre-feet under most stringent conditions).
4. Annual TWP flows are limited to 14,000 acre-feet and maximum daily flow is limited to 40 mgd.
5. Available TWP water will be sent to the three WTPs before additional water is taken from Burlington Canal.

Table 7: Required WTP Production Requirements by Alternative

Facility	WBWTP	TWTP	NWTP	Total
Alternative 1 (mgd)	54.8	20	21.5	96.3
Alternative 2 (mgd)	54.8	41.5	-	96.3
Alternative 3 (mgd)	76.3	20	-	96.3

Alternative 1 – Construct a new NWTP

Alternative 1 includes construction of a new water treatment plant (NWTP) to better serve the northern portion of the system. The location of the NWTP was evaluated considering viable locations identified by Thornton, ease of land acquisition, proximity to existing distribution tanks, efficiency of mixing in the distribution system, and ease of raw water supply conveyance. Based on this review, the parcel north of 140th Ave in between Colorado Boulevard and Holly Street was identified as the preferred location for construction of the NWTP.

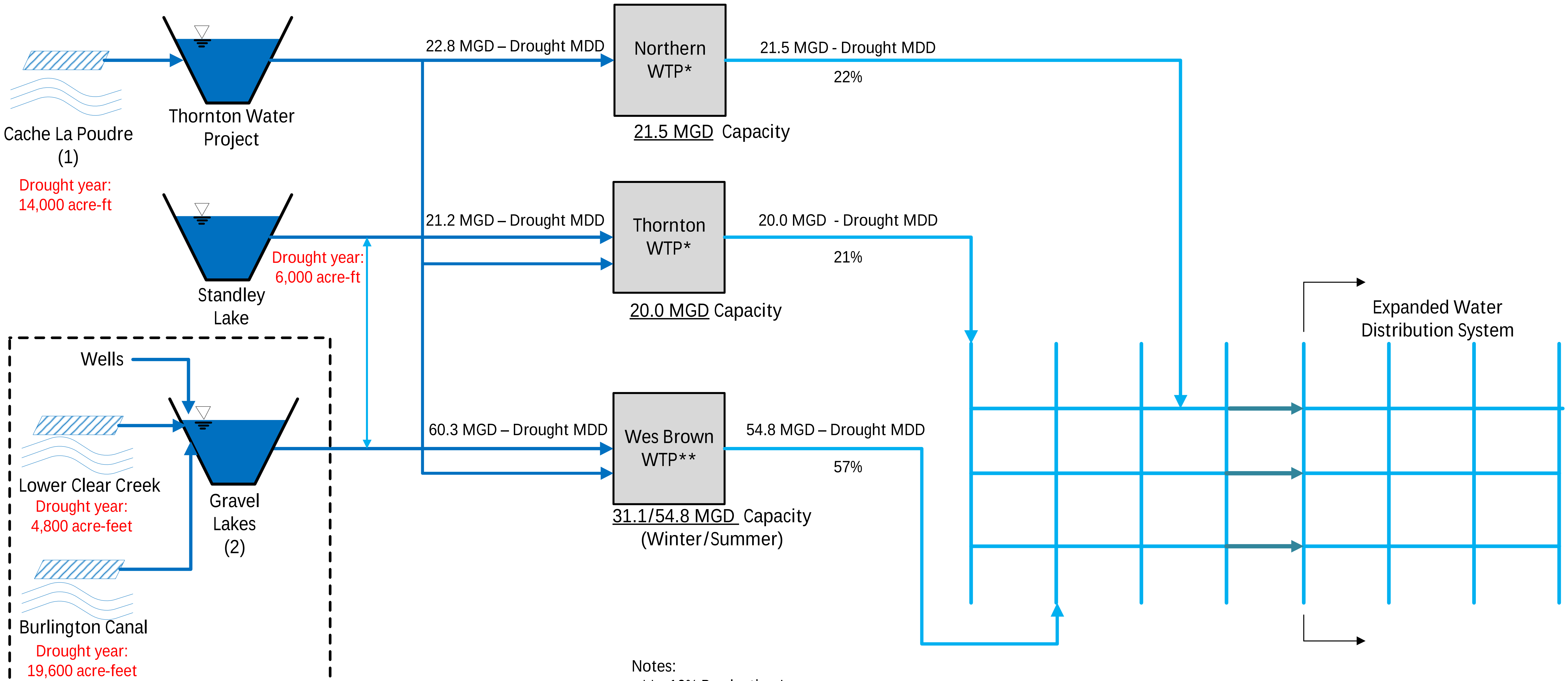
Figure 3 illustrates the raw water supplies and required infrastructure for Alternative 1. The NWTP would have a single raw water supply from the TWP. Additional infrastructure would be needed to provide a redundant raw water source to the NWTP. The TWP raw water supply would serve all three of the Thornton WTPs.

The RWGLS would operate as recommended in Section 2 and will supply water to the WBWTP and the TWTP. Standley Lake water would also supply raw water to both the WBWTP and the TWTP. A new water supply from the Cache La Poudre River would supply additional raw water via the Northern Water Project (WP) pipeline. The pipeline is already in the planning and preliminary design stages.

Figure 3 also includes the amount of raw water required for each plant based on the losses described in Table 65. The raw water supply distributions to the water treatment plants are:

- 22.8 mgd – TWP to NWTP
- 21.2 mgd – TWP to TWTP
- 60.3 mgd – TWP to WBWTP
- Total raw water supply required: 104.3 mgd

(1) Also supplied from "High Mountain Reservoirs"
(2) Gravel Lakes water supply can be sent to Wes Brown WTP by WGL PS, EGL PS or McKay PS.



Notes:
** - 10% Production Loss
* - 6% Production Loss

REV	DESCRIPTION OF REVISION	BY	DATE
A	Issued for Comments	BH	5/3/18

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Figure 3. Alternative 1 Schematic Completion of Northern Water Treatment Plant

SCALE	N/A
DESIGNED	BH
DRAWN	BMS
CHECKED	BH
PEER REVIEWED	
DATE	6/26/2019

Thornton Utility Master Plan

REVISION	D
PROJECT	Utility Master Plan
FIGURE	1
SHEET	1 of 1

Figures 4 and 5 illustrate the monthly daily average raw water supply flow rates required for Alternative 1 in drought and non-drought scenarios, respectively. For the purposes of the flow modeling it was assumed that the WBWTP would be used to supply base load demands through winter and early spring, and the additional WTP(s) would supplement the supply during periods of increased demand. Either of the two existing or the third new WTP, however, could be used to supply the base load demands during the winter and early spring without changing the impacts to the RWGLS conditions.

Figure 4: Alternative 1 – Flows to Water Treatment Plants / Drought

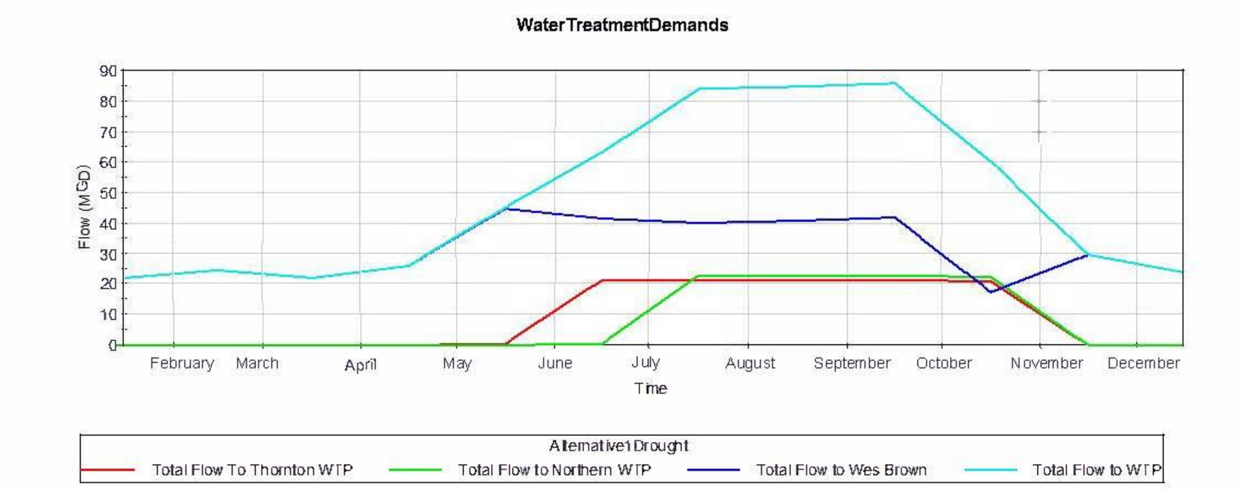
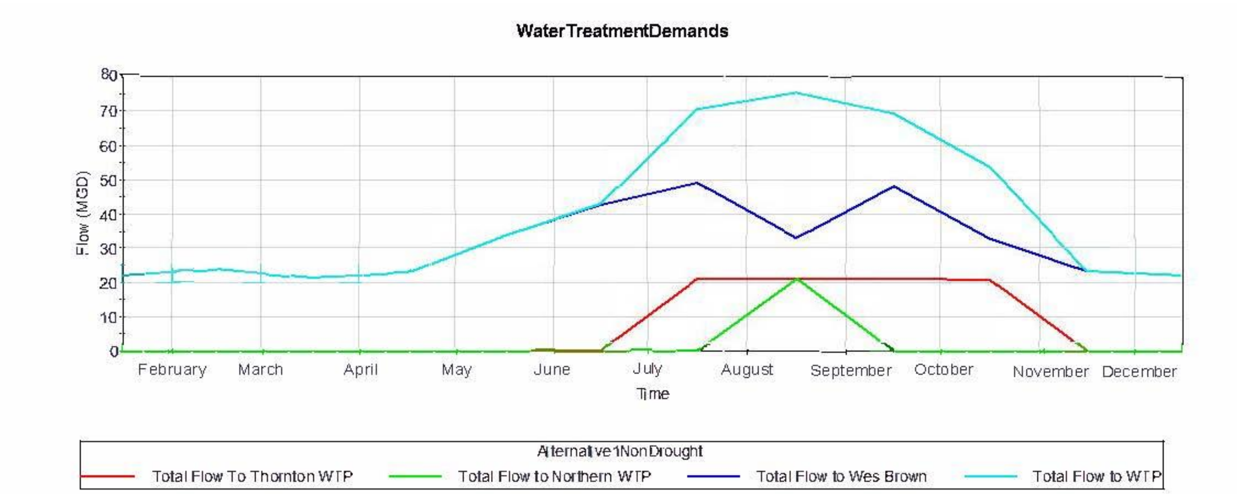


Figure 5: Alternative 1 – Flows to Water Treatment Plants / Non-Drought



Tables 8 and 9 list the required raw water pumping by month for Alternative 1 in drought and non-drought scenarios, respectively. In a drought condition, a total of 52,002 acre-feet of water need to be pumped. In a non-drought year 41,176 acre-feet need to be pumped.

Table 8: Alternative 1 – Monthly Pumping Flows / Drought

	WGL2 to EGL4	EGL4 to WBWTP	McKay to WBWTP	Thornton Project to NWTP	Thornton Project to TWTP	Thornton Project to WBWTP	Total
January (acre-feet)	0	0	2,075	0	0	0	2,075
February (acre-feet)	0	3	2,086	0	0	0	2,089
March (acre-feet)	0	0	2,106	0	0	0	2,106
April (acre-feet)	192	37	881	0	0	1,469	2,579
May (acre-feet)	434	1,884	2,378	0	12	0	4,708
June (acre-feet)	1,032	1,512	2,293	34	775	0	5,646
July (acre-feet)	1,061	1,502	2,298	2,168	801	0	7,830
August (acre-feet)	724	1,565	2,309	2,168	801	0	7,567
September (acre-feet)	748	1,593	2,240	2,098	775	0	7,454
October (acre-feet)	366	6	1,624	2,109	789	0	4,894
November (acre-feet)	43	413	2,301	0	0	0	2,757
December (acre-feet)	47	0	2,250	0	0	0	2,297
Total per PS (acre-feet)	**4,647**	**8,515**	**24,841**	**8,577**	**3,953**	**1,469**	**52,002**

Table 9: Alternative 1 – Monthly Pumping Flows / Non-Drought

	WGL2 to EGL4	EGL4 to WBWTP	McKay to WBWTP	Thornton Project to NWTP	Thornton Project to TWTP	Thornton Project to WBWTP	Total
January (acre-feet)	0	0	2,115	0	0	0	2,115
February (acre-feet)	0	0.93	2,066	0	0	0	2,067
March (acre-feet)	0	0	2,050	0	0	0	2,050
April (acre-feet)	346	0	0	0	0	2,101	2,447
May (acre-feet)	447	0	5	0	0	3,177	3,629
June (acre-feet)	784	0	326	0	0	3,579	4,688
July (acre-feet)	768	359	1,183	34	0	3,115	5,458
August (acre-feet)	722	910	2,224	1,995	0	0	5,851
September (acre-feet)	545	2,120	2,302	0	0	0	4,967
October (acre-feet)	401	791	2,306	0	0	0	3,497
November (acre-feet)	54	7	2,158	0	0	0	2,219
December (acre-feet)	81	0	2,106	0	0	0	2,187
Total per PS (acre-feet)	**4,147**	**4,187**	**18,841**	**2,029**	**0**	**11,972**	**41,176**

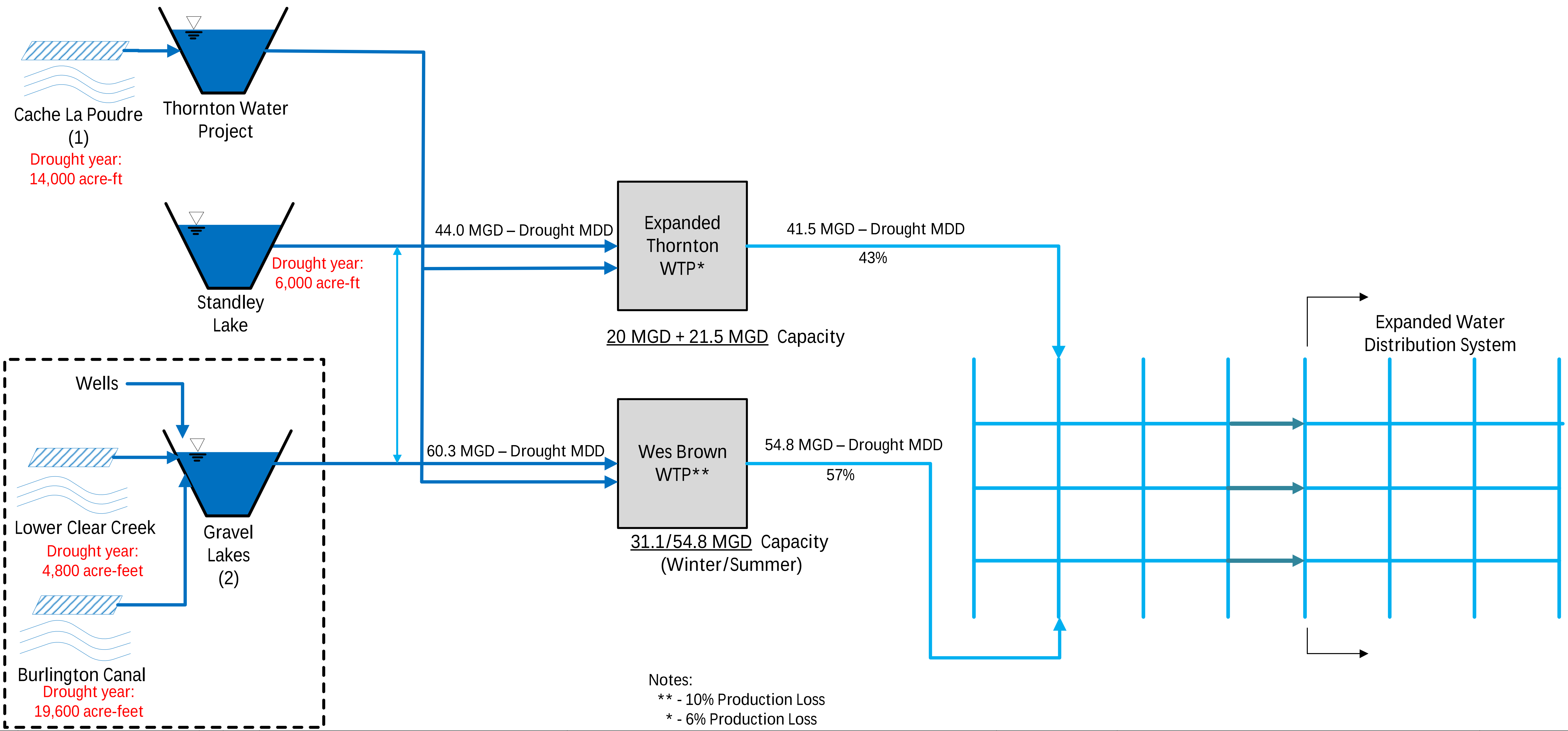
Alternative 2 – TWTP Expansion

Alternative 2 is based on expansion of the new TWTP to supply buildout demands as development occurs. The new TWTP is a conventional plant currently under construction and will have a firm capacity of 20 mgd. Figure 6 illustrates the raw water supplies and required infrastructure for Alternative 2. RWGLS, Standley Lake, and TWP water would all be used to supply water to the WBWTP and TWTP.

Figure 6 also shows the amount of raw water required for each plant based on the losses described in Table 5. The raw water supply distributions to the water treatment plants are:

- 44 mgd – Thornton WTP
- 60.3 mgd Wes Brown WTP
- Total Raw Water Supply Required: 104.3 mgd

(1) Also supplied from "High Mountain Reservoirs"
(2) Gravel Lakes water supply can be sent to Wes Brown WTP by WGL PS, EGL PS or McKay PS.



Notes:
** - 10% Production Loss
* - 6% Production Loss

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A	Issued for Comments	BH	5/3/18

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6200 S. Quebec St
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Figure 6. Alternative 2 Schematic Expansion of Thornton WTP

SCALE	N/A
DESIGNED	BH
DRAWN	BMS
CHECKED	BH
PEER REVIEWED	
DATE	6/26/2019

Thornton Utility Master Plan

REVISION	D
PROJECT	Utility Master Plan
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Figures 7 and 8 illustrate the monthly daily average raw water supply flow rates required for Alternative 2 in drought and non-drought scenarios, respectively. For the purposes of the flow modeling it was assumed that the WBWTP would be used to supply base load demands through winter and early spring, and the additional WTP(s) would supplement the supply during periods of increased demand. Either of the two existing or the third new WTP, however, could be used to supply the base load demands during the winter and early spring without changing the impacts to the RWGLS conditions.

Figure 7: Alternative 2 – Flows to Water Treatment Plants / Drought

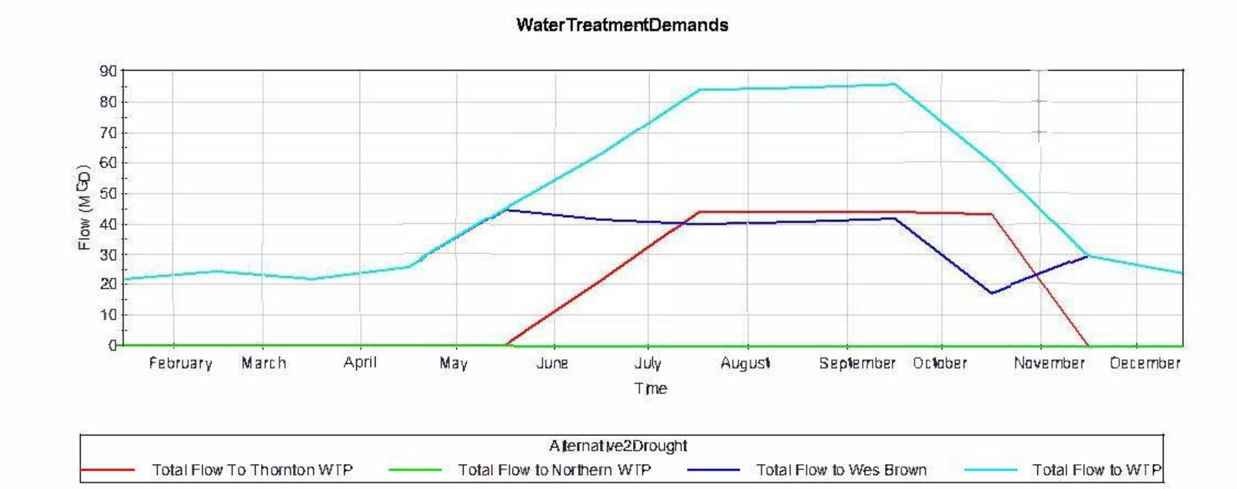
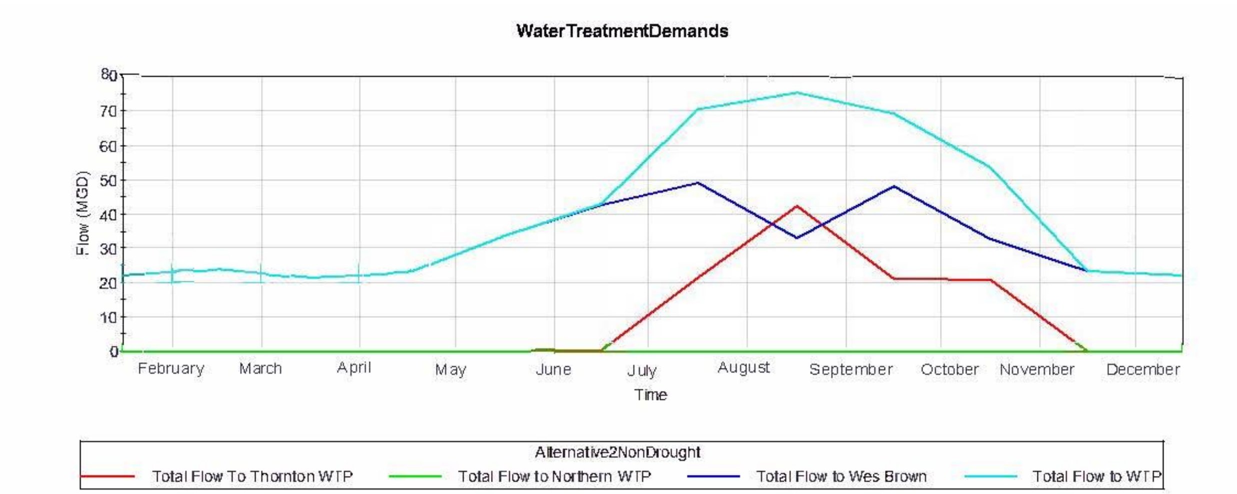


Figure 8: Alternative 2 – Flows to Water Treatment Plants / Non-Drought



Tables 10 and 11 list the required raw water pumping by month for Alternative 2 in drought and non-drought scenarios, respectively. In a drought condition, a total of 51,531 acre-feet of water need to be pumped. In a non-drought year 41,064 acre-feet need to be pumped.

Table 10: Alternative 2 – Monthly Pumping Flows / Drought

	WGL2 to EGL4	EGL4 to WBWTP	McKay to WBWTP	TWP to TWTP	TWP to WBWTP	Total
January (acre-feet)	0	0	2,075	0	0	2,075
February (acre-feet)	0	3	2,086	0	0	2,089
March (acre-feet)	0	0	2,106	0	0	2,106
April (acre-feet)	192	37	881	0	1,469	2,579
May (acre-feet)	434	1,884	2,378	12	0	4,709
June (acre-feet)	1,030	1,512	2,293	809	0	5,644
July (acre-feet)	942	1,502	2,298	2,969	0	7,711
August (acre-feet)	605	1,565	2,309	2,969	0	7,448
September (acre-feet)	633	1,593	2,240	2,873	0	7,339
October (acre-feet)	250	6	1,624	2,898	0	4,778
November (acre-feet)	43	413	2,301	0	0	2,757
December (acre-feet)	47	0	2,250	0	0	2,297
Total per PS (acre-feet)	**4,176**	**8,515**	**24,841**	**12,530**	**1,469**	**51,531**

Table 11: Alternative 2 – Monthly Pumping Flows / Non-Drought

	WGL2 to EGL4	EGL4 to WBWTP	McKay to WBWTP	TWP to TWTP	TWP to WBWTP	Total
January (acre-feet)	0	0	2,115	0	0	2,115
February (acre-feet)	0	0.93	2,066	0	0	2,067
March (acre-feet)	0	0	2,050	0	0	2,050
April (acre-feet)	346	0	0	0	2,101	2,447
May (acre-feet)	447	0	5	0	3,177	3,629
June (acre-feet)	784	0	326	0	3,579	4,688
July (acre-feet)	766	359	1,183	34	3,115	5,457
August (acre-feet)	612	910	2,224	1,995	0	5,741
September (acre-feet)	545	2,120	2,302	0	0	4,967
October (acre-feet)	401	791	2,306	0	0	3,497
November (acre-feet)	54	7	2,158	0	0	2,219
December (acre-feet)	81	0	2,106	0	0	2,187
Total per PS (acre-feet)	**4,035**	**4,187**	**18,841**	**2,029**	**11,972**	**41,064**

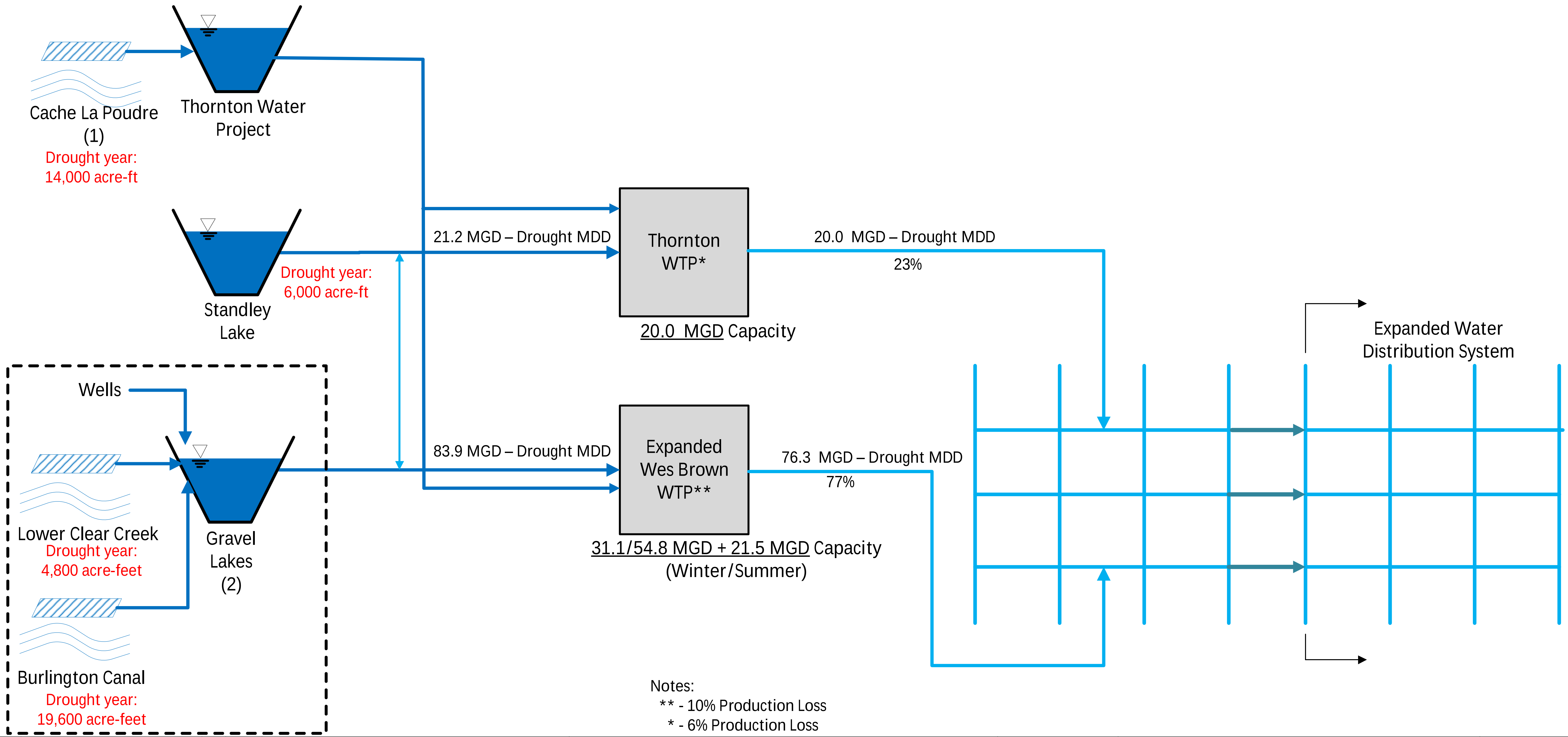
Alternative 3 – Wes Brown WTP Expansion

For Alternative 3, WBWTP would be expanded from a firm capacity of 54.8 mgd to 76.3 mgd to meet buildout production requirements. Figure 9 illustrates the raw water supplies for Alternative 3. RWGLS, Standley Lake, and TWP water would all be used to supply water to the WBWTP and TWTP.

Figure 9 also shows the amount of raw water required for each plant based on the water treatment plant losses listed in Table 5. The raw water supply distributions to the water treatment plants are:

- 21.2 mgd - TWTP
- 83.9 mgd - WBWTP
- Total Raw Water Supply Required: 105.1 mgd

(1) Also supplied from "High Mountain Reservoirs"
(2) Gravel Lakes water supply can be sent to Wes Brown WTP by WGL PS, EGL PS or McKay PS.



Notes:
** - 10% Production Loss
* - 6% Production Loss

REV	DESCRIPTION OF REVISION	BY	DATE
A	Issued for Comments	BH	5/3/18

AECOM
6200 S. Quebec St
Denver, CO 80130
303-740-2600

Figure 9. Alternative 3 Schematic Expansion of Wes Brown WTP

SCALE	N/A
DESIGNED	BH
DRAWN	BMS
CHECKED	BH
PEER REVIEWED	
DATE	6/26/2019

Thornton Utility Master Plan

REVISION	D
PROJECT	Utility Master Plan
FIGURE	1
SHEET	1 of 1

Figures 10 and 11 illustrate the monthly daily average raw water supply flow rates required for Alternative 3 in drought and non-drought scenarios respectively. For the purposes of the flow modeling it was assumed that the WBWTP would be used to supply base load demands through winter and early spring, and the additional WTP(s) would supplement the supply during periods of increased demand. Either of the two existing or the third new WTP, however, could be used to supply the base load demands during the winter and early spring without changing the impacts to the RWGLS conditions.

Figure 10: Alternative 3 – Flows to Water Treatment Plants / Drought

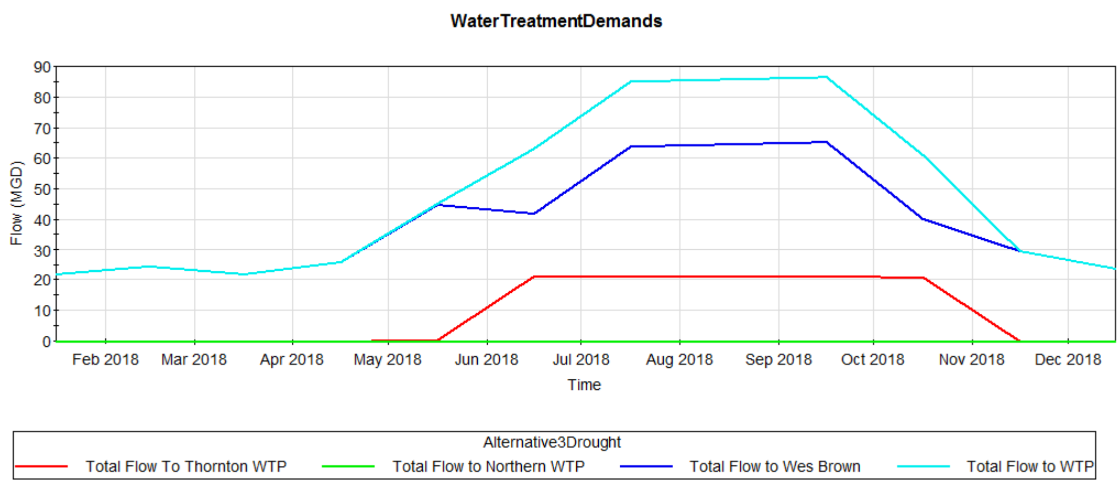
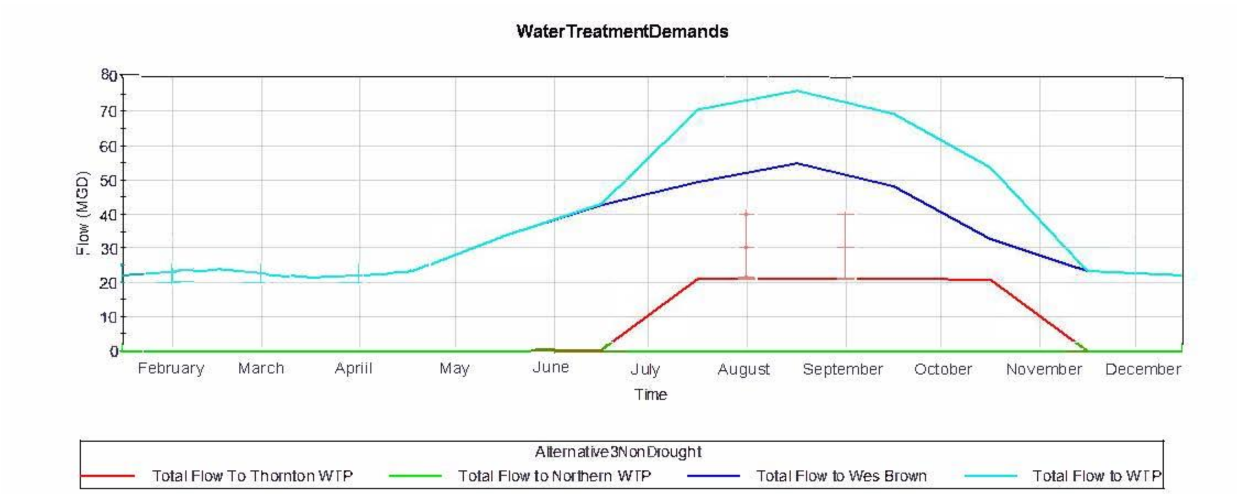


Figure 11: Alternative 3 – Flows to Water Treatment Plants / Non-Drought



Tables 12 and 13 list the required raw water pumping by month for Alternative 3 in drought and non-drought scenarios, respectively. In a drought condition a total of 51,853 acre-feet of water need to be pumped. In a non-drought year, 41,139 acre-feet need to be pumped.

Table 12: Alternative 3 – Monthly Pumping Flows / Drought

	WGL2 to EGL4	EGL4 to WBWTP	McKay to WBWTP	TWP to TWTP	TWP to WBWTP	Total
January (acre-feet)	0	0	2,075	0	0	2,075
February (acre-feet)	0	3	2,086	0	0	2,089
March (acre-feet)	0	0	2,106	0	0	2,106
April (acre-feet)	192	0	0	0	2,387	2,579
May (acre-feet)	434	0	533	12	3,729	4,709
June (acre-feet)	1,030	0	799	775	3,041	5,645
July (acre-feet)	942	2,806	2,354	801	889	7,792
August (acre-feet)	605	3,745	2,378	801	0	7,529
September (acre-feet)	633	3,708	2,302	775	0	7,418
October (acre-feet)	250	1,457	2,361	789	0	4,857
November (acre-feet)	43	413	2,301	0	0	2,757
December (acre-feet)	47	0	2,250	0	0	2,297
Total per PS (acre-feet)	**4,176**	**12,132**	**21,545**	**3,953**	**10,046**	**51,853**

Table 13: Alternative 3 – Monthly Pumping Flows / Non-Drought

	WGL2 to EGL4	EGL4 to WBWTP	McKay to WBWTP	TWP to TWTP	TWP to WBWTP	Total
January (acre-feet)	0	0	2,115	0	0	2,115
February (acre-feet)	0	0.93	2,066	0	0	2,067
March (acre-feet)	0	0	2,050	0	0	2,050
April (acre-feet)	346	0	0	0	2,101	2,447
May (acre-feet)	447	0	5	0	3,177	3,629
June (acre-feet)	784	0	326	0	3,579	4,688
July (acre-feet)	766	0	989	0	3,702	5,458
August (acre-feet)	612	1,571	2,191	0	1,441	5,815
September (acre-feet)	545	2,120	2,302	0	0	4,967
October (acre-feet)	401	791	2,306	0	0	3,497
November (acre-feet)	54	7	2,158	0	0	2,219
December (acre-feet)	81	0	2,106	0	0	2,187
Total per PS (acre-feet)	**4,035**	**4,490**	**18,614**	**0**	**14,000**	**41,139**

5. Alternatives Evaluation

The alternatives evaluation involved identification and evaluation of the proposed infrastructure improvements needed to satisfy key performance indices (KPIs) that are not currently satisfied under existing conditions. This evaluation includes estimating the costs to implement the alternative improvements. The implementation costs are described in Section 6 of this TM. The comparative costs for each alternative will allow evaluation of the benefits of each improvement relative to its cost. The cost evaluations help differentiate between the various alternatives and facilitate informed decision making to identify improvements that should be implemented.

The alternative benefits were evaluated against the performance criteria established in the Existing Raw Water System Performance Criteria TM prepared as a part of the Raw Water Master Plan. Below are the KPIs for the RWGLS based on raw water delivery and water quality. The evaluation, therefore, is intended to indicate if any particular alternative may satisfy a KPI in a manner that provides greater benefit to Thornton residents relative to the other alternatives.

One of the critical performance parameters required of the RWGLS is the capacity to provide the future total water treatment demands of the Thornton WTPs. Estimates of Thornton's future water treatment demands were developed in coordination with the Water Treatment Master Plan and the Water Distribution System Master Plan. The final estimates for the required future raw water delivery capacity to Thornton's WTPs are listed in Table 14 below. The future water demand estimates are based on the water supply assumptions listed at the bottom of the table.

Table 14: Maximum Required Raw Water Deliveries by Alternative

	Unit	Alternative 1	Alternative 2	Alternative 3
Max Flow from Thornton Project to NWTP	mgd	22.8	-	-
Max Flow from Thornton Project to TWTP	mgd	21.2	40.0	21.2
Max Flow from Thornton Project to WBWTP	mgd	40.0	40.0	40.0

Assumptions:

1. Annual Standley Lake supply is limited to 6,000 and 10,000 acre-feet under drought and non-drought conditions, respectively.
2. If not all the available water from Standley Lake is used by TWTP, the leftover will be sent to WBWTP in order to use all 6,000/10,000 acre-feet of available supply.
3. Annual Lower Clear Creek flows are limited to existing use (4,800 and 4,600 acre-feet under drought and non-drought conditions, respectively).
4. Annual Northern Project flows are limited to 14,000 acre-feet under any conditions.
5. Available Northern Project water will be sent to the WTPs before additional water is taken from Burlington canal (existing use is 13,300 and 11,900 acre-feet under drought and non-drought conditions, respectively).

While the alternative evaluation was focused on meeting the required production and Tier 1 criteria, there are other factors that may influence the interpretation of satisfying the criteria. These factors provide an additional means to differentiate between alternatives. The information in the following tables has been annotated to identify potential differentiators between alternatives, with a "±" used to indicate no advantage, a "+" used to indicate that the alternative has an advantage relative to the other options, and a "-" used to indicate that the alternative has a disadvantage relative to the other options.

Selection of a preferred alternative will occur through the decision-making process outlined in the Integrated Master Plan, and consideration of the results of alternatives analyses for the raw water supply system, the water distribution system, and the water treatment facilities. Since the configuration of the alternatives at this stage of analysis have been configured to meet Tier 1 criteria, determination of a preferred approach to implementing an alternative is focused on determining the preferred life-cycle cost based on the capital and operating costs for each alternative.

Table 15 summarizes the performance of each alternative relative to the Tier 1 criteria for raw water supply performance. Each alternative has been developed to meet all Tier 1 production requirements; therefore, the alternatives are comparable with a few key differentiators. For all alternatives, the 40 mgd supply from the TWP will be distributed to any of the WTPs depending on the demands placed on each WTP. Water supply from the TWP to the NWTP, Alternative 1, will be more difficult to blend across the entire distribution system as compared to the other alternatives. Alternative 2 may produce lower quality finished water due to the larger proportion of gravel lakes water being delivered to the

WBWTP. Alternative 3, expanding the WBWTP, requires the largest raw water supply due to the higher loss rates at the WBWTP.

Table 15: Tier 1 Raw Water Supply Infrastructure Performance Criteria

Performance Parameter	Criteria	Criteria Description	Alternative 1	Alternative 2	Alternative 3	Notes
Total Delivery Capacity (Annual Basis)	Equal to one year of ADD under supply drought conditions	Essential capacity to provide water for increased demand due to a supply drought period	±	±	±	It is assumed that Thornton will be able to secure as much water as is needed
Operational Storage Capacity	Raw Water Operational Storage Capacity equal to 1.0 x Annual Demand	Essential capability to ensure robust supply availability	±	±	±	Each alternative offers the same amount of raw water storage
Water Rights Firm Yield	Adequate water rights and storage to meet three-year demand with restrictions	Essential to secure water rights to meet demand	±	±	**-** **WBWTP operations will require additional 300 acre-feet per year of water supply**	Expanding WBWTP would have more loss
Water Delivery	Comparable water quality to all customers through blending of the following supplies if necessary, or other suitable means: • TWP water to all WTPs • Gravel Lakes water to all WTPs Burlington Canal water to all WTPs	Necessary to ensure delivery of comparable water quality to all customers	-	±	±	Same water quality is being delivered to each WTP. Alternative 1 is harder to blend because of the location of the TWP WTP Alternative 2 may produce lower quality finished water due to larger portion of gravel lakes water goes to WBWTP
PSs Firm Capacity to WTPs	Equal to MDD	Required for conveyance to WTPs	- WGL2 to EGL4: 11 mgd - EGL4 to WBWTP: 20 mgd (23) - McKay to WBWTP: 25 mgd - TWP PS: 40 mgd	- WGL2 to EGL4: 11 mgd - EGL4 to WBWTP: 20 mgd (23) - McKay to WBWTP: 25 mgd - TWP PS: 40 mgd	WGL2 to EGL4: 11 mgd - EGL4 to WBWTP: 40 mgd - McKay to WBWTP: 25 mgd - TWP PS: 40 mgd	

Performance Parameter	Criteria	Criteria Description	Alternative 1	Alternative 2	Alternative 3	Notes
Primary WTP Supply PSs Standby Power	Ability to mobilize / activate sufficient backup power within 4 hours of loss of power in order to meet production requirements	Required to provide production associated with Water Treatment System Capacity	+	+	+	All will be the same and mobile back up power will be added to the CIP
Water Supply Equipment Redundancy (Critical equipment to meet capacity requirements)	Firm installed capacity to meet production with one pump out of service	Redundancy requirement of N+1 essential for operations and maintenance	- TWP PS: 40 mgd firm capacity - McKay PS: one 10mgd additional pump required	TWP PS: 40 mgd firm capacity - McKay PS: one 10mgd additional pump required	TWP PS: 40 mgd firm capacity - McKay PS: one 10mgd additional pump required	

Table 16 summarizes the performance of each alternative relative to the Tier 2 criteria for raw water supply performance. The three alternatives have similar redundancy, water rights, and capacity requirements.

Table 16: Tier 2 Raw Water Supply Infrastructure Performance Criteria

Performance Parameter	Criteria	Criteria Description	Alternative 1	Alternative 2	Alternative 3	Notes
System Redundancy	Delivery capacity equal to 0.5 x Annual Demand under drought supply conditions with the largest supply system down for up to 12 months	Essential capacity to provide water during a major outage assuming mandatory outdoor water use restrictions	± 0.5 x Annual Demand under Drought = 26,679 acre-feet Supply without BC = 24,816 acre-feet 10% of maximum storage is available (2,400 acre-feet)	± 0.5 x Annual Demand under Drought = 26,679 acre-feet Supply without BC = 24,790 acre-feet 10% of maximum storage is available (2,400 acre-feet)	± 0.5 x Annual Demand under Drought = 26,840 acre-feet Supply without BC = 24,423 acre-feet 10% of maximum storage is available (2,400 acre-feet)	Burlington Canal is the largest supply system Assume storage levels will lower They have about one average day demand in storage Raw water demand for Alternative 3 is higher due to higher water rejection through the WBWTP membranes
Water Rights Firm Yield	Adequate water rights and storage to meet three-year demand without restrictions	Important to secure water rights to meet demand	± Total Water sent to treatment plants: 45,029 acre-feet	± Total Water sent to treatment plants: 45,029 acre-feet	± Total Water sent to treatment plants: 45,106 acre-feet	Raw water demand for Alternative 3 is higher due to higher water rejection through the WBWTP membranes

Performance Parameter	Criteria	Criteria Description	Alternative 1	Alternative 2	Alternative 3	Notes
Operational Storage Capacity	Raw Water Operational Storage Capacity equal to 1.5 x Annual Demand	Important capability to ensure robust supply availability	± Storage = 24,300 acre-feet 1.5 x Annual Demand to WTP (non-Drought): 1.5 x 45,000 = 67,500 acre-feet	± Storage = 24,300 acre-feet 1.5 x Annual Demand to WTP (non-Drought): 1.5 x 45,000 = 67,500 acre-feet	± Storage = 24,300 acre-feet 1.5 x Annual Demand to WTP (non-Drought): 1.5 x 45,100 = 67,650 acre-feet	Raw water demand for Alternative 3 is higher due to higher water rejection through the WBWTP membranes
Primary WTP Supply PSs Standby Power	Dual power source available in order to meet production requirements without service interruption	Recommended to provide production associated with Water Treatment System Capacity	±	±	±	All will be the same and cost for backup power will be addressed in the CIP

Table 17 summarizes the performance of each alternative relative to the Tier 3 criteria for raw water supply performance. The RWGLS improvements will be undertaken in either of the three future alternative that is selected, resulting in all three alternatives performing similarly for all criteria.

Table 17: Tier 3 Raw Water Supply Infrastructure Performance Criteria

Performance Parameter	Criteria	Criteria Description	Alternative 1	Alternative 2	Alternative 3	Notes
Water Rights Firm Yield	Adequate water rights and storage to meet four-year demand without restrictions	Desired capability to ensure robust supply availability	187,000 acre-feet	187,000 acre-feet	187,000 acre-feet	To Be Added in CIP
Total Raw Water Storage Capacity	Raw Water Storage Capacity equal to 4 x Annual Demand	Desired capability to ensure robust supply availability and to develop water supply yield	± Storage = 24,300 acre-feet 4 x Annual Demand to WTP (non-Drought): 4 x 45,000 = 180,000 acre-feet	± Storage = 24,300 acre-feet 4 x Annual Demand to WTP (non-Drought): 4 x 45,000 = 180,000 acre-feet	± Storage = 24,300 acre-feet 4 x Annual Demand to WTP (non-Drought): 4 x 45,100 = 180,000 acre-feet	To Be Added in CIP
Primary WTP Supply PSs Standby Power	A reliable power source meeting the requirements of the NEC for Emergency Power available for immediate use at each treatment plant.	Recommended to provide production associated with System Capacity	-	-	-	To Be Added in CIP

Performance Parameter	Criteria	Criteria Description	Alternative 1	Alternative 2	Alternative 3	Notes
System Redundancy	Parallel supply pipelines to avoid downtime due to individual pipe failures	Desired to secure water rights to meet demand	-	-	-	To Be Added in CIP Thornton could investigate installing parallel lines for future projects, e.g., the northern supply line could be installed with a 36-inch line now and then a future 36-inch line
Sustainability	Possible locations for mini-hydro systems should be considered	Desired to minimize the operations impacts	-	-	-	To Be Added in CIP
Sustainability	Water evaporation should be minimized	Important to minimize the operations impacts	-	-	-	All alternatives could utilize technology to reduce water evaporation A future analysis could evaluate the cost-benefit of various technologies
Sustainability	Energy efficient/alternative power sourced pumps and facilities	Desired to improve environmental impact of facilities	-	-	-	A future analysis could evaluate the cost-benefit of various technologies

6. Capital Improvement Program

The raw water system evaluation results were reviewed with Thornton to develop CIPs necessary to meet the specified design criteria and to meet buildout conditions. The identified improvements are intended to provide Thornton with the opportunity to establish budgetary elements as part of Capital Planning. These CIPs were categorized as existing or future improvements required to meet Tier 1, Tier 2, and Tier 3 performance. The future improvements were developed for each of the three evaluated alternatives.

Project cost was developed by applying unit costs and engineering estimates for the various projects. The costs are consistent with AACE Class V estimating guidance. The developed cost is based on conceptual design and the basis of estimate summarized in this report. The cost development is summarized in Appendix A. The estimated total project cost is the sum of construction costs with additional allowances for direct and indirect costs. The indirect costs include engineering design, legal and administrative, construction management, and contingency.

Detail development of each project cost is provided in Appendix B. A summary of the existing and future CIP costs are provided in Table 18 and Table 19, respectively.

Table 18. Existing CIP Cost Summary

Type	Cost
CIP	$ 27,930,000
O&M	$ 177,640 / yr

Table 19. Future CIP Cost Summary

Alternative	Tier 1	Tier 2	Tier 3	Total
Alternative 1	$ 102,470,000	$ 12,110,000	$ 145,540,000	$ 260,120,000
Alternative 2	$ 92,310,000	$ 12,110,000	$ 135,380,000	$ 239,800,000
Alternative 3	$ 92,310,000	$ 28,580,000	$ 135,380,000	$ 256,270,000

Existing Improvements

Table 20 summarizes costs associated with improvements to existing infrastructure at the RWGLS as identified in Section 2. Table 21 summarizes estimates of additional annual operating and maintenance (O&M) costs associated with additional water quality monitoring that should be performed at the RWGLS. The estimated costs in these tables represent improvements to the RWGLS that are recommended for implementation regardless of which future alternative is selected.

Table 20: Existing CIPs

#	Description	Cost
1	EGL4 pipe interconnect (McKay PS to WBWTP)	$ 8,530,000
2	WGL2 to EGL4 with Pump Station (include river crossing)	$6,840,000
3	Pilot study for precipitant addition / Phosphorous reduction	$ 70,000
4	Study to evaluate the costs, benefits, and issues related to a floating solar panel installation on the RWGLS.	$ 70,000
5	Mobile PS Back-up Power and PS upgrades as needed.	$ 11,940,000
6	New Profiling and Temperature Monitoring Equipment	$ 480,000
	Total	**$ 27,930,000**

Table 21: Existing Improvements Annual O&M Cost

#	Description	Cost
1	Additional RWGLS Water Quality sampling labor (per year)	$ 81,000
2	Geosmin, MIB Lake Sampling and Testing (per year)	$ 32,400
3	Added Pumping Costs for Series Operations (per year)	$ 64,240
	TOTAL	**$ 177,640**

Future Improvements

The capital costs associated with each Future Alternative are presented in Table 22, Table 23, and

Table 24. The costs were developed based on the specified design criteria and are classified as Tier 1, Tier 2 and Tier 3. The future improvements below assume that the existing improvements have been completed and represent additional improvements necessary for each alternative.

Table 22: Alternative 1 CIPs

Tier 1		
#	Recommended Improvement	Cost
1	TWP pipeline from 168th to McKay PS, Thornton Reach	$65,000,000
2	TWP Pipeline - McKay PS to Wes Brown WTP	$ 11,970,000
3	TWP Pipeline to Thornton WTP	$ 15,130,000
4	TWP Pipeline to new Northern WTP	$ 10,160,000
5	McKay PS capacity increase	$ 210,000
	Total	**$ 102,470,000**
Tier 2		
#	**Recommended Improvement**	**Cost**
6	Backup Power Supply at EGL4	$ 12,110,000
	Total	**$ 12,110,000**

Tier 3		
#	**Recommended Improvement**	**Cost**
7	Redundant Pipeline – McKay PS to Wes Brown WTP	$ 11,970,000
8	Redundant Pipeline – McKay PS to Thornton WTP	$ 15,130,000
9	Redundant Pipeline – to new Northern WTP	$ 10,160,000
10	Redundant Pipeline – Standley Lake to Thornton WTP, 48” portion	$ 43,830,000
11	Redundant Pipeline – Standley Lake to Thornton WTP, 36” portion	$ 19,580,000
12	Redundant Pipeline – EGL4 to Thornton WTP	$ 21,600,000
13	Redundant Pipeline – EGL4 to Wes Brown WTP	$ 8,000,000
14	McKay to WBWTP Parallel	$ 15,160,000
15	Studies – Micro Hydropower and Evaporation Reduction Technologies	$ 110,000
	Total	**$ 145,540,000**

Table 23. Alternative 2 CIPs

Tier 1		
#	**Recommended Improvement**	**Cost**
1	TWP pipeline from 168th to McKay PS, Thornton Reach	$ 65,000,000
2	TWP Pipeline - McKay PS to Wes Brown WTP	$ 11,970,000
3	TWP Pipeline to Thornton WTP	$ 15,130,000
4	McKay PS capacity increase	$ 210,000
	Total	**$ 92,310,000**
Tier 2		
#	**Recommended Improvement**	**Cost**
5	Backup Power Supply at EGL4	$ 12,110,000
	Total	**$ 12,110,000**
Tier 3		
#	**Recommended Improvement**	**Cost**
6	Redundant Pipeline – McKay PS to Wes Brown WTP	$ 11,970,000
7	Redundant Pipeline – McKay PS to Thornton WTP	$ 15,130,000
8	Redundant Pipeline – Standley Lake to Thornton WTP, 48” portion	$ 43,830,000
9	Redundant Pipeline – Standley Lake to Thornton WTP, 36” portion	$ 19,580,000
10	Redundant Pipeline – EGL4 to Thornton WTP	$ 21,600,000
11	Redundant Pipeline – EGL4 to Wes Brown WTP	$ 8,000,000
12	McKay to WBWTP Parallel	$ 15,160,000
13	Studies – Micro Hydropower and Evaporation Reduction Technologies	$ 110,000
	Total	**$ 135,380,000**

Table 24: Alternative 3 CIPs

Tier 1		
#	Recommended Improvement	Cost
1	TWP pipeline from 168th to McKay PS, Thornton Reach	$ 65,000,000
2	TWP Pipeline - McKay PS to Wes Brown WTP	$ 11,970,000
3	TWP Pipeline to Thornton WTP	$ 15,130,000
4	McKay PS capacity increase	$ 210,000
	Total	**$ 92,310,000**
Tier 2		
#	**Recommended Improvement**	**Cost**
5	Additional 300 acre-feet Water Rights	$ 16,470,000
6	Backup Power Supply at EGL4	$ 12,110,000
	Total	**$ 28,580,000**
Tier 3		
#	**Recommended Improvement**	**Cost**
7	Redundant Pipeline – McKay PS to Wes Brown WTP	$ 11,970,000
8	Redundant Pipeline – McKay PS to Thornton WTP	$ 15,130,000
9	Redundant Pipeline – Standley Lake to Thornton WTP, 48" portion	$ 43,830,000
10	Redundant Pipeline – Standley Lake to Thornton WTP, 36" portion	$ 19,580,000
11	Redundant Pipeline – EGL4 to Thornton WTP	$ 21,600,000
12	Redundant Pipeline – EGL4 to Wes Brown WTP	$ 8,000,000
13	McKay to WBWTP Parallel	$ 15,160,000
14	Studies – Micro Hydropower and Evaporation Reduction Technologies	$ 110,000
	Total	**$ 135,380,000**

7. References

The following references were used to compile the data in this report:

- *2009 Water and Wastewater Systems Master Plan*, The Engineering Company, 2010.
- *Planning Area and Future Growth Analysis TM*, AECOM, 2018.
- *Public Water System Record of Approved Waterworks*, Colorado Department of Public Health and Environment (CDPHE), 2017.
- *Regulatory Compliance Evaluation TM*, AECOM, 2018.
- *Thornton Water Project Hydraulic and Economic Analysis*, CH2MHILL, 2017.
- *Thornton Water Treatment Plant Replacement Project – Basis of Design Report*, Burns and McDonnell, 2017.

Appendix A Cost Assumptions

AECOM was requested by the city of Thornton (Thornton) to develop project costs for identified Capital Improvement Programs (CIP) as part of the Raw Water Supply Master Plan. Unit and lump sum costs were developed to account for the various components that comprise the identified CIP costs. This section presents the summary of assumptions and the approach used to develop the project costs.

1. Summary

The following summarizes the methodology used to develop the costs for capital improvements, including improvements to the RWGLS to address existing raw water quality issues as well as installation of new pipelines, booster pumps, and additional raw water rights required to meet the future demands.

AECOM has developed the costs in accordance with AACE Class V estimating guidance. This opinion of probable costs is based on conceptual design and the basis of estimate summarized in this report. All costs have been adjusted to reflect in June 2019 dollars based on an ENR Construction Cost Index of 7542. All project descriptions and cost estimates in this CIP represent planning-level accuracy and opinions of costs (+50%, -30%).

The cost estimates have been developed based on reference information including:

- Local vendor estimates for specialized materials and equipment;
- Construction and installation costs from similar AECOM projects in the Denver Metro Area; and
- Historical data and prices for similar facilities designed and/or constructed based on AECOM estimates from senior engineers with construction experience.

The cost estimate reflects an opinion of probable construction costs based on information available to AECOM at the time the document was prepared. AECOM does not have the ability to predict changes in construction labor, materials, or equipment. The methodology employed by AECOM may not fully align contractors' methods of determining prices and are not intended to predict the outcome of the construction bidding. The accuracy of the estimates is not guaranteed.

The estimated cost includes the sum of materials, labor, and equipment of reasonably identified features of a project. The estimated total project cost is the sum of construction costs with additional allowances for direct and indirect costs and contingencies. In general, the following items are not sufficiently defined at this level of project definition and have been excluded: permitting and right-of-way acquisition, finance charges associated with the planning, design, or construction of improvements, remediation or fines associated with system violations, and operation, maintenance and energy costs or temporary facilities. No costs were inflated or discounted to account for future pricing.

The opinion of probable costs has been developed for the following major elements:

- Pipelines
- Water Rights
- Open Channel Expansion
- Pump Station Upgrades
- Water Quality Monitoring Plan and Equipment
- Feasibility Studies of Possible Future CIPs
- Electrical System Improvements
- Operations and Maintenance Costs

- Additional Costs: Direct Cost, Indirect Costs, and Contingencies

2. Pipelines

Water pipeline unit costs have been developed based on diameter, project location category, and pipe material costs, and are assumed to be constructed within public right-of-way. An additional lump sum pipeline cost of $500,000 was assumed for river crossings.

The estimated unit cost for pipelines includes the following reasonably identified features:

- Piping, fittings, valves, and water service connections
- Excavation
- Waste of material associated with trenching
- Imported bedding and zone material
- Native backfill
- Testing and disinfection
- Abandonment of the existing pipe for existing water pipelines
- Surface restoration
- Dewatering groundwater
- Contractor overhead and profit

Pipeline unit costs are presented in Table 1.

Table 1: Water Pipelines Unit Costs Opinions

Diameter (in)	Construction Costs
8	$201
10	$212
12	$257
16	$333
20	$363
24	$423
30	$484
36	$560
42	$650
48	$756
54	$877
60	$998
66	$1,150
72	$1,331

3. Water Rights

The annual cost of leasing additional water rights on Burlington Canal was assumed to $700/acre-foot.

4. Open Channel Expansion

The unit cost of channel expansion of $8/CF/LF was developed from AECOM’s project experience.

5. Pump Stations

The improvements related to pump stations include increase in pump station capacity and the construction of new pumping facilities.

Increasing the capacity of existing facilities will require the replacement of current pumps with larger pumps or, space allowing, increasing the number of pumps. The construction cost includes:

- Removal of the existing pump(s);
- Addition of new pump, motor;
- Modifications to pipes and valves; and
- Modification to existing electrical system and telemetry.

The unit costs for PS upgrade are summarized in Table 5. A representative unit cost per HP was developed based on recent projects and unit cost used by other utilities in the Denver Metro Area. Table 5 summarizes the estimated cost for different pump sizes. Project Cost includes direct and indirect additional costs.

Table 5: Pump Station Upgrade Unit Costs

HP	Unit Construction Cost ($/HP)	Construction Cost
50	$1,230	$61,502.63
100	$1,230	$123,005
150	$1,230	$184,508
200	$1,230	$246,011

Project Cost includes direct and indirect costs.

The construction cost of a new pumping facility was assumed to be double the construction cost of an existing pump station of the same capacity.

6. Water Quality Monitoring Plan and Equipment

The cost of the new water quality monitoring equipment identified in Section 2 was obtained from local vendors. The new equipment includes a buoy mounted profiling system with a remote profiler and two sets of multiprobes, and 30 temperature monitors and data loggers. Additional sampling and operation costs were provided by Thornton.

7. Feasibility Studies

Listed below are studies identified in the Raw Water Master Plan and the assumed cost for each project.

- Pilot Study on the effectiveness and operational cost of the addition of precipitant to the Burlington Canal for phosphorus reduction. Assumed cost is $40,000.
- Investigative Study on the feasibility of installing solar panels on the gravel lakes. Assumed cost is $40,000.
- Feasibility Study on the installation of a micro hydro power station on the pipeline serving TWTP from Stanley Lake. Assumed cost is $25,000.
- Investigative Study on the options of adding shade to the gravel lakes for the reduction of algae production and reduction of taste and odor events. Assumed cost is $40,000.

8. Electrical System Improvements

Tier 2 and Tier 3 design criteria for the PS electric systems included the addition of mobile generators. An estimate has been provided for mobile generators; however, the systems currently available for standby power do not meet the size requirements for the raw water pump stations. The design criteria and cost estimates for the electrical system improvements will need refinement should Thornton wish to pursue the CIPs further.

9. Operations and Maintenance

An average elevation difference of 200 feet was assumed for the purpose of calculating raw water pumping costs. A pump efficiency of 70% was assumed. Cost of electricity was assumed to be $0.10/kw-hr.

10. Additional Costs

The following additional direct and indirect costs were assumed for each CIP:

Direct:

- Erosion Control 5%
- Mobilization and Site Setup 5%

Indirect:

- Engineering Design 15%
- Legal and Administrative 5%
- Construction Management 10%
- Contingencies 25% (AACE Class V)

Appendix B Cost Tables

City of Thornton Raw Water System CIP Cost Estimate

Multiplier (D+I+C)	1.705

Existing System CIPs: Improvements to RWGLS	Type of Cost	Size	Size Units	Quantity	Units	Unit Cost	Direct Cost	Project Cost				Notes
EGL4 pipe interconnect (McKay PS to WBWTP)	Capital			1	LS	$5,000,000	$5,000,000	$8,530,000				Connection between existing 36 in (from McKay to EGL4) and existing 42 in (from EGL4 to WBWTP), no river crossing, assumed lump sum due to complicated nature of project: crowded utility area, connection includes several remotely operated valves that will require connection to SCADA system
WGL2 to EGL4 w/PS (include river crossing)	Capital	-	LS	1	LS	$4,010,000	$4,010,000	$6,840,000				
Study: Precipitant Addition to Burlington Canal	Study			1	LS		$40,000	$70,000				Pilot study on effectiveness and operational cost of precipitant addition on the Burlington Canal water for Phosphorus reduction
Study: Feasibility of Floating Solar Panel Installation on Gravel Lakes	Study			1	LS		$40,000	$70,000				Evaluation of feasibility of installing floating solar panels on Gravel Lakes. Benefits of the solar panels are renewable power generation for operation of adjacent pump stations, reduction of water temperature, algae production and taste and odor events, and reduction of water evaporation.
Mobile Pump Stations Back-up Power	Capital						$7,000,000	$11,940,000				Min 4 mobile generator set and modifications to PS electrical distribution to accommodate mobile gensets
Additional WQ Monitoring Equipment												
New EGL4 profiling System - buoy mounted WQ profiling system and Temperature Data Monitoring (EGL4, WGL2, and South Cooley Lake)	Capital			4	LS		$280,000	$480,000				Remote profiler, Two sets of multiprobes for profiler (1 duty, 1 backup and calibration). Monitors/data loggers (10 temporary loggers per lake over 3 lakes)
Total							**$16,370,000**	**$27,930,000**				

O&M Costs Associated with Existing CIPs							
One additional employee to perform all additional monitoring	O&M				$/yr	$81,000	$81,000
Geosmin, MIB Lake Sampling - Microcystin testing for 9 samples	O&M				$/mo	$2,700	$32,400
Additional Pumping for Existing System CIPs from current operations	O&M	7300	acre-ft/yr		$/day	$176	$64,240.00
Total / Year							**$177,640**

CAPITAL IMPROVEMENT PROJECTS												
Alternative 1	**Type of Cost**	**Size**	**Units**	**Quantity**	**Units**	**Unit Cost**	**Construction Cost**	**Project Cost**	**Project Cost Tier 1**	**Project Cost Tier 2**	**Project Cost Tier 3**	**Notes**
TWP pipeline from 168th to McKay PS, Thornton Reach	Capital	42	inch dia	1	LS	-		$65,000,000	$65,000,000			Cost provided by COT
TWP pipeline from McKay PS to WBWTP	Capital	42	inch dia	10,800	ft	$650	$7,020,000	$11,970,000	$11,970,000			Unit cost from COT to match TWP costs
TWP pipeline from McKay PS to TWTP	Capital	36	inch dia	15,840	ft	$560	$8,872,833	$15,130,000	$15,130,000			Unit cost from COT to match TWP costs
TWP Pipeline from Quebec to NWTP	Capital	36	inch dia	10,635	ft	$560	$5,957,233	$10,160,000	$10,160,000			Unit cost from COT to match TWP costs
Mc Kay PS – 1 x 10 MGD, 100 HP	Capital	100	HP	1	$/hp	$1,230	$123,000	$210,000	$210,000			Unit cost from COT Water and Wastewater Infrastucture Master Plan
Back-up power supply at EGL4 and TWP PS (assuming circulation of GLs is halted)	Capital						$7,100,000	$12,110,000		$12,110,000		EGL4: 2 gensets a@1.5MW ea.+modifications to electrical distribution to accommodate gensets. TWP: 2 gensets a@1.5MW ea.+ additions to electrical distribution to accommodate gensets. Include transfer switch, conduit.conductors for both PS's.
Redundant pipelines for existing (Tier 3):												
TWP pipeline from McKay PS to WBWTP	Capital	42	inch dia	10,800	ft	$650	$7,020,000	$11,970,000			$11,970,000	Unit cost from COT to match TWP costs
TWP pipeline from McKay PS to TWTP	Capital	36	inch dia	15,840	ft	$560	$8,872,833	$15,130,000			$15,130,000	Unit cost from COT to match TWP costs
TWP Pipeline from Quebec to NWTP	Capital	36	inch dia	10,635	ft	$560	$5,957,233	$10,160,000			$10,160,000	Unit cost from COT to match TWP costs
Standley Lake to TWTP												
48 inch portion	Capital	48	inch dia	33,978	ft	$756	$25,703,835	$43,830,000			$43,830,000	2009 MP, # given, Unit cost from COT to match TWP costs
36 inch portion	Capital	36	inch dia	20,500	ft	$560	$11,483,148	$19,580,000			$19,580,000	2009 MP, # given, Unit cost from COT to match TWP costs
EGL4 to TWTP (include river crossing)	Capital	36	inch dia	17,260	ft	$560	$12,668,251	$21,600,000			$21,600,000	2009 MP, # given, Unit cost from COT to match TWP costs+ $3M for slurry trench wall
EGL4 to WBWTP (include river crossing)	Capital	42	inch dia	2,604	ft	$650	$4,692,600	$8,000,000			$8,000,000	2009 MP - Google Earth, Unit cost from COT to match TWP costs+ $3M for slurry trench wall
McKay to WBWTP (parallel existing 36 inch to EGL#4, no river crossing)	Capital	42	inch dia	13,681	ft	$650	$8,892,650	$15,160,000			$15,160,000	24 ft elev change, 2014 As Builts Burnes&McDonnell & Google Earth & 2009 MP, Unit cost from COT to match TWP costs
Study: Micro-Hydro Power on Standley Lake Supply Pipeline	Study			1	LS	-	$25,000	$40,000			$40,000	Study to determine if micro-hydro power is possible on Standley Lake to TWTP
Study: Water Evaporation Reduction Technologies on RWGLS	Study			1	LS	-	$40,000	$70,000			$70,000	Future analysis to evaluate the cost-benefit of various water evaporation reduction technologies
Total							$114,428,617	$260,120,000	$102,470,000	$12,110,000	$145,540,000	

Alternative 2	Type of Cost	Size	Units	Quantity	Units	Unit Cost	Construction Cost	Project Cost				Notes
TWP pipeline from 168th to McKay PS, Thornton Reach	Capital	42	inch dia	1	LS	-		$65,000,000	$65,000,000			Cost provided by COT
TWP pipeline from McKay PS to WBWTP	Capital	42	inch dia	10,800	ft	$650	$7,020,000	$11,970,000	$11,970,000			Unit cost from COT to match TWP costs
TWP pipeline from McKay PS to TWTP	Capital	36	inch dia	15,840	ft	$560	$8,872,833	$15,130,000	$15,130,000			Unit cost from COT to match TWP costs
Mc Kay PS – 1 x 10 MGD, 100 HP	Capital	100	HP	1	$/hp	$1,230	$123,000	$210,000	$210,000			Unit cost from COT Water and Wastewater Infrastucture Master Plan
Back-up power supply at EGL4 and TWP PS (assuming circulation of GLs is halted)	Capital						$7,100,000	$12,110,000		$12,110,000		EGL4: 2 gensets a@1.5MW ea.+modifications to electrical distribution to accommodate gensets. TWP: 2 gensets a@1.5MW ea.+ additions to electrical distribution to accommodate gensets. Include transfer switch, conduit.conductors for both PS's.
Redundant pipelines for existing (Tier 3):												
TWP pipeline from McKay PS to WBWTP	Capital	42	inch dia	10,800	ft	$650	$7,020,000	$11,970,000			$11,970,000	Unit cost from COT to match TWP costs
TWP pipeline from McKay PS to TWTP	Capital	36	inch dia	15,840	ft	$560	$8,872,833	$15,130,000			$15,130,000	Unit cost from COT to match TWP costs
Standley Lake to TWTP												
48 inch portion	Capital	48	inch dia	33,978	ft	$756	$25,703,835	$43,830,000			$43,830,000	2009 MP, # given, Unit cost from COT to match TWP costs
36 inch portion	Capital	36	inch dia	20,500	ft	$560	$11,483,148	$19,580,000			$19,580,000	2009 MP, # given, Unit cost from COT to match TWP costs
EGL4 to TWTP (include river crossing)	Capital	36	inch dia	17,260	ft	$560	$12,668,251	$21,600,000			$21,600,000	2009 MP, # given, Unit cost from COT to match TWP costs+ $3M for slurry trench wall
EGL4 to WBWTP (include river crossing)	Capital	42	inch dia	2,604	ft	$650	$4,692,600	$8,000,000			$8,000,000	2009 MP - Google Earth, Unit cost from COT to match TWP costs+ $3M for slurry trench wall
McKay to WBWTP (parallel existing 36 inch to EGL#4, no river crossing)	Capital	42	inch dia	13,681	ft	$650	$8,892,650	$15,160,000			$15,160,000	24 ft elev change, 2014 As Builts Burnes&McDonnell & Google Earth & 2009 MP, Unit cost from COT to match TWP costs
Study: Micro-Hydro Power on Standley Lake Supply Pipeline	Study			1	LS	-	$25,000	$40,000			$40,000	Study to determine if micro-hydro power is possible on Standley Lake to TWTP
Study: Water Evaporation Reduction Technologies on RWGLS	Study			1	LS		$40,000	$70,000			$70,000	Future analysis to evaluate the cost-benefit of various water evaporation reduction technologies
Total							$102,514,150	$239,800,000	$92,310,000	$12,110,000	$135,380,000	

Alternative 3	Type of Cost	Size	Units	Quantity	Units	Unit Cost	Construction Cost	Project Cost				Notes
TWP pipeline from 168th to McKay PS, Thornton Reach	Capital	42	inch dia	1	LS	-		$65,000,000	$65,000,000			Cost provided by COT
TWP pipeline from McKay PS to WBWTP	Capital	42	inch dia	10,800	ft	$650	$7,020,000	$11,970,000	$11,970,000			Unit cost from COT to match TWP costs
TWP pipeline from McKay PS to TWTP	Capital	36	inch dia	15,840	ft	$560	$8,872,833	$15,130,000	$15,130,000			Unit cost from COT to match TWP costs
Mc Kay PS – 1 x 10 MGD, 100 HP	Capital	100	HP	1	$/hp	$1,230	$123,000	$210,000	$210,000			Unit cost from COT Water and Wastewater Infrastucture Master Plan
300 acre-feet of additional water rights leased per year for 46 years (Tier 1)	Capital			300	acre-ft	$700	$9,660,000	$16,470,000		$16,470,000		$700 acre-ft/yr from 2019 to 2065 (46 years) to lease rights from BC. Cost of purchasing new water rights at 300 acre-ft/yr for 46 yr = $9.7M. Entered lease option cost
Back-up power supply at EGL4 and TWP PS (assuming circulation of GLs is halted)	Capital						$7,100,000	$12,110,000		$12,110,000		EGL4: 2 gensets a@1.5MW ea.+modifications to electrical distribution to accommodate gensets. TWP: 2 gensets a@1.5MW ea.+ additions to electrical distribution to accommodate gensets. Include transfer switch, conduit.conductors for both PS's.
Redundant pipelines for existing (Tier 3):												
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McKay to WBWTP (parallel existing 36 inch to EGL#4, no river crossing)	Capital	42	inch dia	13,681	ft	$650	$8,892,650	$15,160,000			$15,160,000	24 ft elev change, 2014 As Builts Burnes&McDonnell & Google Earth & 2009 MP, Unit cost from COT to match TWP costs
Study: Micro-Hydro Power on Standley Lake Supply Pipeline	Study			1	LS	-	$25,000	$40,000			$40,000	Study to determine if micro-hydro power is possible on Standley Lake to TWTP
Study: Water Evaporation Reduction Technologies on RWGLS	Study			1	LS		$40,000	$70,000			$70,000	Future analysis to evaluate the cost-benefit of various water evaporation reduction technologies
Total							$112,174,150	$256,270,000	$92,310,000	$28,580,000	$135,380,000	

Gravel Lakes Management Plan

Chapter 6

Utility Master Plan

Project No. 17-467

Raw Water Supply Master Plan

Gravel Lakes Management Plan

The City of Thornton

Project number: 60560104

AECOM

January 8, 2020

Quality information

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Revision	Revision date	Details	Authorized	Name	Position

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Table of Contents

Tables

Figures

List of Acronyms and Abbreviations

µg/L	micrograms per liter
BC	Burlington Canal
CDPHE	Colorado Department of Public Health and Environment
DO	dissolved oxygen
DOC	dissolved organic carbon
EGL4	East Gravel Lake #4
LCC	Lower Clear Creek Canal
Management Plan	Raw Water System Management Plan
McKay PS	McKay Pump Station
mg/L	milligrams per liter
MGD	million gallons per day
MIB	2-methylisoborneol
OP	ortho-phosphorus
RWGLS	Raw Water Gravel Lakes System
South Dahlia	South Dahlia Reservoir
ST	South Tani Reservoir
TDS	total dissolved solids
TM	Technical Memorandum
Thornton	City of Thornton
TIN	total inorganic nitrogen
TN	total Nitrogen
TOC	total organic carbon
TP	total phosphorus
TSS	total suspended solids
TWTP	Thornton Water Treatment Plant
WGL1	West Gravel Lake #1
WGL2	West Gravel Lake #2
WGL3	West Gravel Lake #3
WQCC	Colorado Water Quality Control Commission
WBWTP	Wes Brown Water Treatment Plant
West Cooley	West Cooley Lake
WTP	Water Treatment Plant

1. Introduction

This Technical Memorandum (TM) presents a proposed Water System Management Plan (Management Plan) for the city of Thornton's (Thornton) Raw Water Gravel Lakes System (RWGLS). The proposed Management Plan was developed subsequent to the water quality and existing gravel lakes system evaluation documented in the Existing Raw Water System Evaluation TM. The Management Plan has two focuses:

1. **Monitoring** – Improved water quality monitoring within the RWGLS to facilitate a more complete understanding of the limnological conditions of the lakes, and development of a water quality index framework to guide lake operations.

2. **Operations** – Strategic RWGLS operations strategies for improving control of the water quality delivered from the RWGLS to the Thornton water treatment plants (WTPs).

This Management Plan includes a Water Quality Monitoring Program (Monitoring Program) and an RWGLS Operations Plan. The Monitoring Program is designed to gain a better understanding of the limnological conditions in the open water zones of the lakes as well as the seasonal changes in water quality conditions. The purpose of the Monitoring Program is to develop a water quality index framework for the water stored within the RWGLS based on key water quality parameters and conditions. The water quality index will be a tool to analyze source water quality and allow facility operators to make informed decisions to improve operations, ultimately leading to improved finished water quality distributed to Thornton's water customers.

The Operations Plan is a tool that Thornton's water system operators can use to modify system operations in response to changes in the quality of the raw water in the RWGLS or changes to the quality of the influent raw water supplies. The options for modifications to the RWGLS operations are described in detail in this TM and include:

- Operating the RWGLS in series;
- Adding precipitant to the Burlington Canal (BC) diversions into the RWGLS;
- Bypassing BC diversions around South Tani Reservoir (ST) and East Gravel Lake #4 (EGL4) and discharging into South Dahlia Reservoir (South Dahlia); and
- Maximizing finished water production at the Thornton WTP (TWTP).

This Management Plan combines the Operations Plan with the data collected from the Monitoring Program to achieve improved water quality. The Operations Plan provides Thornton with guidance on RWGLS management and, ultimately, improved quality of the finished water delivered to Thornton's water customers.

2. Background

Thornton's existing RWGLS consists of a series of gravel lakes along the South Platte River that were developed through conversion of gravel pits into water storage facilities shown on Figure 1 and listed in Table 1.

Table 1: Raw Water Gravel Lakes System

System	Reservoirs
West Gravel Lakes (WGLs)	West Gravel Lake #1 (WGL1)
	West Gravel Lake #2 (WGL2)
	West Gravel Lake #3 (WGL3)
East Gravel Lakes (EGLs)	South Tani Reservoir (ST)
	East Gravel Lake #4 (EGL4)
	South Dahlia Reservoir (South Dahlia)
	North Dahlia Lake (North Dahlia)
	East Sprat-Platte Lake (East Sprat)
	West Cooley Lake (West Cooley)
	West Sprat-Platte Lake (West Sprat)

The conversions from gravel pits to water storage reservoirs consisted of installation of clay linings around the gravel pits. Several of the reservoirs were formed by construction of vertical slurry trench walls around the perimeter of the gravel pits. (WGL1, WGL2, and WGL3, and EGL4 were formed by the installation of a clay lining along the slopes of each gravel pit.

The development of the RWGLS has occurred gradually over several years, and it is only recently that the reservoirs have been available to operate as a complete system. The historical operations of the RWGLS, as described in the Existing Raw Water System Evaluation TM, have limited the use of raw water within the RWGLS to the five reservoirs at the southern (upstream) end of the system (WGL1, WGL2, WGL3, ST, EGL4). The five other reservoirs, east and north of ST, have been used only for storage and have not contributed as a water source to the Thornton WTPs. Additionally, the recent commissioning of the McKay Pump Station (McKay PS) at West Cooley now allows water to be returned to EGL4 (which is upstream of Dahlia, Spat and Cooley reservoirs).

The following related evaluations of the existing RWGLS have been prepared as separate TMs and are referenced throughout this TM:

1. Existing Raw Water System Evaluation TM (July 2019)
2. Gravel Lakes Water Quality Evaluation TM (July 2019)
3. Raw Water Future Alternatives Evaluation TM (Draft July 2019)

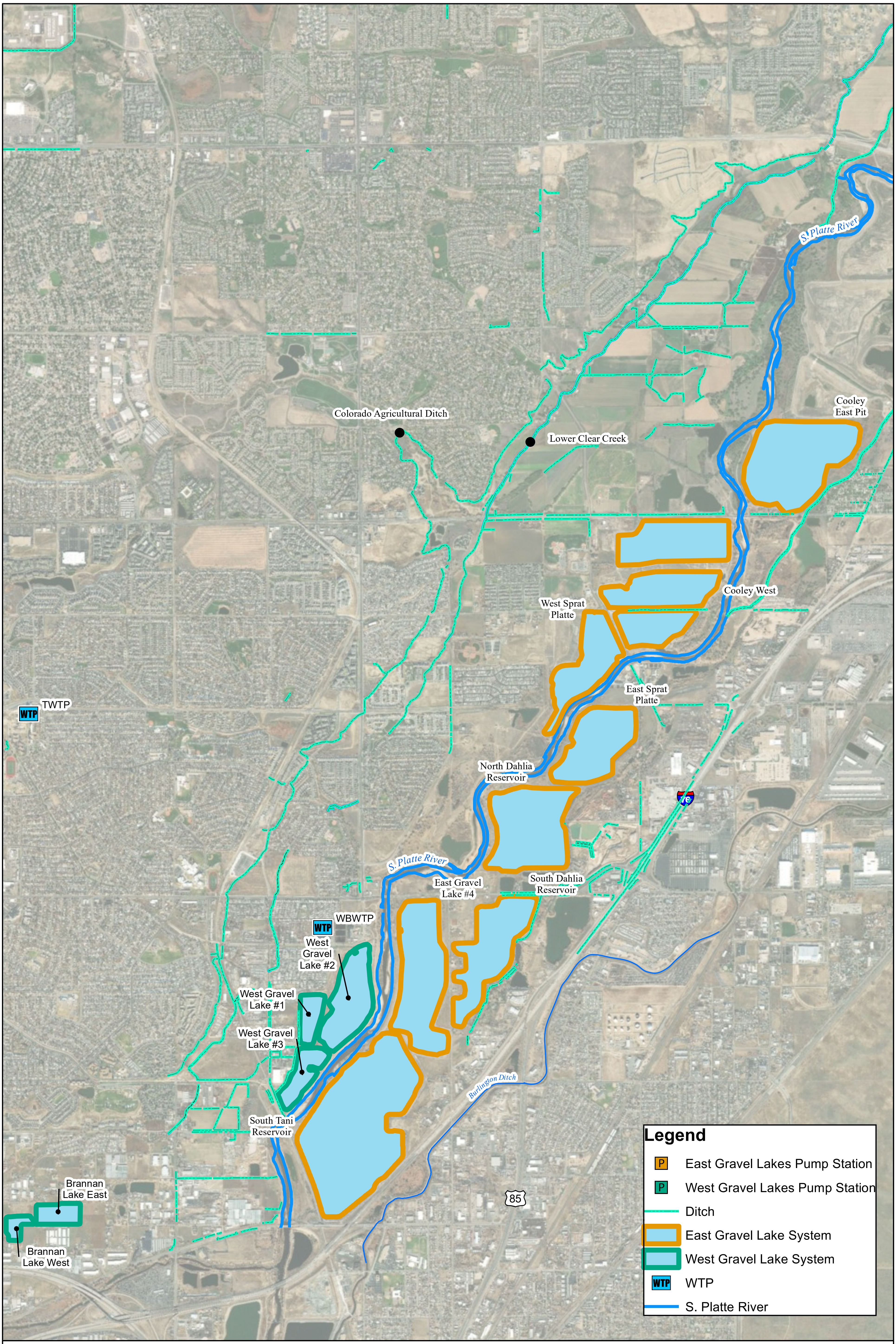

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Figure 1
Gravel Lakes Raw Water Storage System

1/7/2020
1 inch = 2,500 feet

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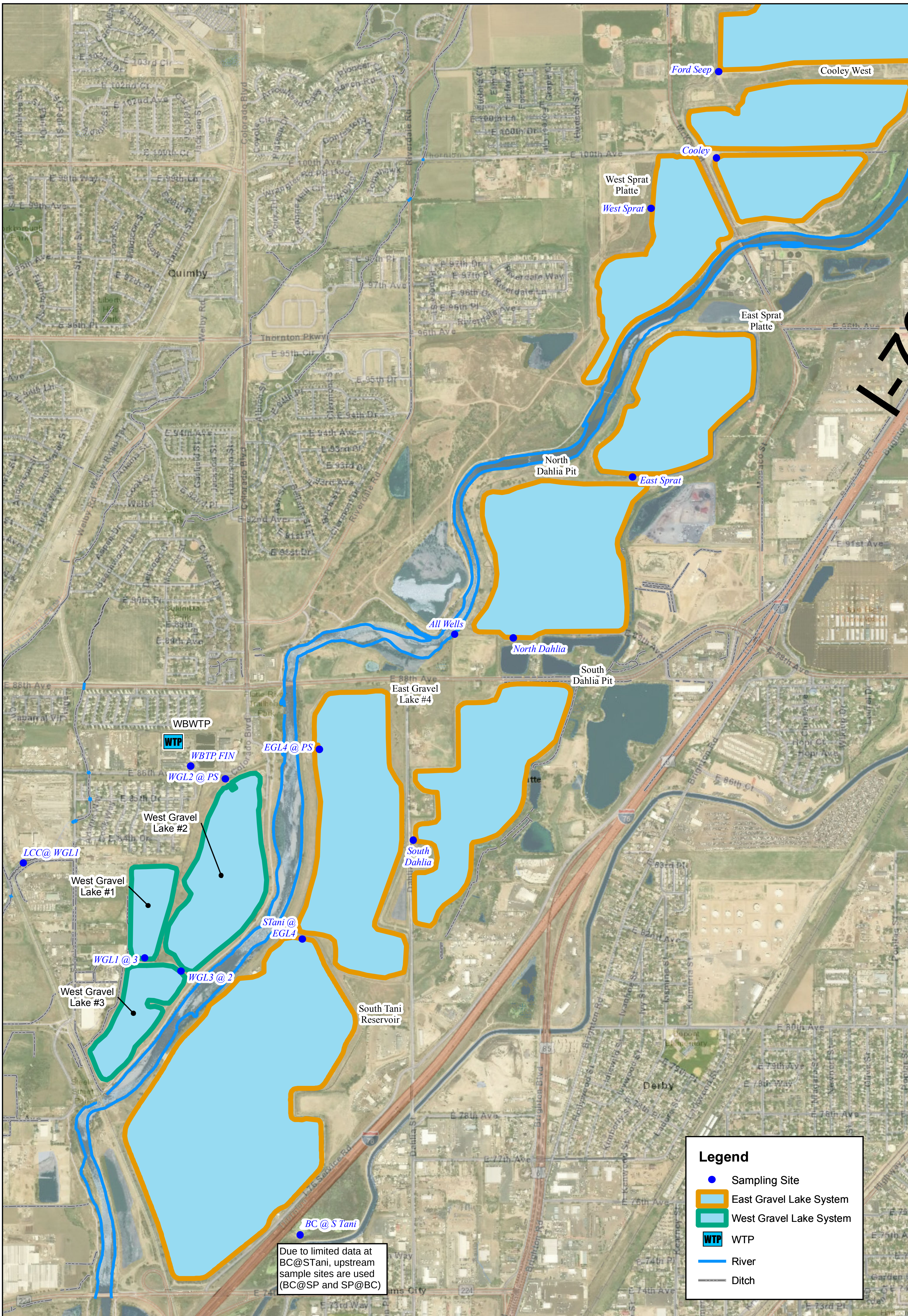
3. Water Quality Monitoring Program

Current Water Quality Monitoring

Thornton's current routine raw water quality monitoring is primarily focused on the southern reservoirs that include the WGLs (WGL1, WGL2, and WGL3), ST, and EGL4. Thornton regularly recorded surface water elevations for each gravel lake and recorded analytical data from 2012 through 2017. The data included measurements at Lower Clear Creek Canal (LCC), WGL2, BC, ST, and EGL4. The physical monitoring locations are shown on Figure 2. At the WGL2 and EGL4 PSs, water quality samples were collected from three levels in the water column (surface, middle, and bottom) and from the surface at the ST interconnect with EGL4. The data contained 151 analytes including: anion/cation chemistry (e.g., pH, sulfate, hardness), inorganic and organic nutrients (nitrogen and phosphorus), solids (suspended and dissolved), metals (arsenic, copper, zinc), and an extensive list of organochlorine/organic compounds found in herbicides, pesticides, and petroleum products. Because the focus was on nutrients, algae production, and the factors that contribute to algae growth, 23 analytes were selected for the water quality evaluation (Appendix A; Table A.1). The sample collection frequency varied by location and analyte, ranging from twice a week to quarterly. Except for physicochemical factors (e.g., temperature, pH, dissolved oxygen [DO], and conductivity), water quality conditions in the surface and bottom water layers were monitored infrequently.

The frequency of data collection varied greatly for the selected list of 23 analytes between sites, and many analytes were not collected at depths that would provide important information regarding limnological conditions, relating to the scientific study of bodies of fresh water, such as lakes, that influence lake dynamics. Total inorganic nitrogen (TIN) was also calculated using the available data by adding ammonia, nitrite, and nitrate when at least both ammonia and nitrate data were available for a location. Nitrite was often omitted from this calculation as the values were generally lower than method detection limits. Inorganic nitrogen and ortho-phosphorus (OP) are both bioavailable (e.g., degree and rate at which a substance such as phosphorus is absorbed into a living system) nutrient forms that could contribute to algae blooms because they are readily incorporated into algae or cyanobacteria biomass.



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Greenwood Village, Colorado 80111

Figure 2
Raw Water Monitoring Locations

1/7/2019

1 inch = 1,333 feet

C:\Users\evon.harmon\Documents\Figure 2 Raw Water Monitoring Locations.mxd

Water Quality Monitoring Improvement Strategies

Understanding the frequency and strength of stratification is important when evaluating mechanisms that may trigger late summer algae blooms. If weakly stratified conditions are eroded by wind mixing events, then the soluble TIN and OP can become immediately available for algae growth during the summer season, whereas, if stratification is persistent through the summer, soluble nutrients will be trapped in the hypolimnion (i.e., bottom layer) during the summer. The hypolimnion (or under lake) is the dense, bottom layer of water in a thermally stratified lake. It is the layer that lies below the thermocline. Typically the hypolimnion is the coldest layer of a lake in summer, and the warmest layer during winter. When fall turnover occurs, the trapped soluble nutrients are released into the photic zone (i.e., uppermost layer of water in a lake or ocean that is exposed to intense sunlight) and can trigger a fall season algae bloom. Characterizing the low DO conditions in the bottom waters also becomes important when considering the potential to support aquatic life use for recreational purposes. While anoxic bottom waters are a natural phenomenon in lakes and reservoirs, the areal and vertical extent of anoxia, a total depletion in the level of dissolved oxygen, can decrease useable lake habitat in shallow lakes as fish seek refuge during the warm summer months. The gravel lakes are not currently designated for recreational purposes, although limited recreational fishing occurs on some of the lakes, such as the WGL system (WGL2 and WGL3) and West Sprat. However, as the connectivity of greenways increases along the Colorado Front Range Trail, the recreational fishing uses may become an important part of the planning and management process for the RWGLS.

It is important to evaluate the general magnitude of concentrations of critical water quality parameters of the inflow to the RWGLS, and to understand how concentrations change as flow circulates and disperses through the system. Monitoring the combination of magnitude and the temporal/spatial changes will help guide practicable water quality management options. Gaining insight into the conditions or mechanisms that result in higher OP concentrations in EGL4 during the summer will be an important aspect of managing the raw water supply.

Summer blooms, which are often dominated by cyanobacteria and diatoms, can also create water treatment issues. In response to various physical or biological conditions, these algae can produce geosmin or 2-methylisoborneol (MIB), which can be released into the water column upon algae rupture or death, causing taste and odor events (Zhang et al. 2013; Pattanaik and Lindberg 2015). In addition, dead algae will settle to the lake bottom substrate where they decompose with the help of bacteria (e.g., actinomycetes), which can also produce taste and odor compounds. These compounds can be recognized by their muddy/earthy smell, which has a very low threshold for human perception in the range of 4 to 6 parts per trillion (i.e., geosmin – 4 ng/L and MIB – 6 ng/L; Kaloudis and Hiskia 2016).

While the measurement of geosmin and MIB provides rapid identification of a taste and odor event, often this information is ascertained too late in the process to effectively manage a bloom or other conditions that may trigger the event. A key component to understanding the mechanisms behind a taste and odor event is documenting the algae assemblage using a high-resolution technique, including a phycologist who can identify cyanobacteria to the species level. Pairing geosmin and MIB results with species-level data will provide insight into the organisms responsible and the mechanisms that initiate the event. Because geosmin production is species-specific (Jüttner and Watson 2007; Taylor et al. 2006), a routine monitoring program should focus closely on cyanobacteria enumeration and identification to the species level such that the data can be used in a more proactive treatment approach. Notably, species level taxonomic data can be cost prohibitive to pair with each chemical analysis of geosmin and MIB. Therefore, it is best to collect and analyze algae identification samples when conditions warrant further examination. Repetitive annual patterns in the data will likely be evident and surrogate or indicator measurements such as water temperature, seasonal timing, or quiescent periods will be useful to inform water quality management strategies, including intake water elevations, blending of other source waters, or being able to switch from a southern gravel lake to a northern gravel lake.

Water Quality Monitoring Recommendations

Future water quality monitoring recommendations have been developed to help Thornton achieve a more complete understanding of the conditions that facilitate the growth of algae blooms in the RWGLS, especially during the summer and fall seasons, that result in taste and odor issues for the WBWTP. The Monitoring Program is designed to provide a better understanding of the limnological conditions in the open water zones of the lakes as well as additional high frequency data collection efforts that provide sufficient resolution to identify changing water quality conditions. The new program is not intended to be a continuous, full-time program for the life of the RWGLS; however; the required duration of the recommended improved water quality monitoring program is difficult to predict and will need to be adapted based on the quality of the data collected and the sampling budget. The intent of this recommended program is to more fully understand the dynamic conditions of the RWGLS and to evaluate the proposed water quality improvement options that are described in Section 4 of this TM. The final details and duration of the program can be adapted to accommodate and/or focus on the needs of the water quality improvements that may result from implementation of the recommendations of the Raw Water System Master Plan, and to accommodate the capital cost and operating budgets that are available.

The following additions and/or changes are recommended for the current monitoring program:

1. **New Deep Monitoring Site at Each Reservoir:** For ST, EGL4, WGL2, and West Cooley, add a monitoring site over the deepest location or at the center of each reservoir. Collect water quality sonde (i.e., any of various devices for testing physical conditions, often for remote or underwater locations) profiles to document water temperature, specific conductivity, pH, dissolved oxygen and oxidation reduction potentials on 1-meter increments from the surface to the near bottom water layer (i.e., within 0.5 meter of the sediment). Collect water samples at the surface, middle, and bottom layers of each reservoir and analyze for nutrients, including total and dissolved organic/inorganic nitrogen and phosphorus fractions) and chlorophyll-a conditions at surface and middle depths.

   This data will increase the understanding of the limnological process that affects vertical density gradients (e.g., relative thermal resistance to mixing) and horizontal mixing (e.g. transfer of water via the interconnects) of the water column, and whether conditions are favorable for internal nutrient loading that may facilitate late season algae growth.

2. **Continued Nutrient Monitoring:** For all reservoirs, continue monitoring the near shore locations at the interconnects for nutrients (i.e. total and dissolved organic/inorganic nitrogen and phosphorus fractions), and measure chlorophyll-a where the interconnects for water transfer occur from the upgradient lake to the downgradient lake or where the pump stations are located on a lake. This sampling will help document whether the natural attenuation of nutrients from upgradient to downgradient lakes will be an effective strategy to help reduce the influence of nutrients on algal production.

3. **South Reservoir Monitoring:** For ST, EGL4, WGL2, and Cooley West, the water quality sampling should occur on a weekly basis from April through October and monthly from November through March at the surface, middle, and bottom depths at both the near shore and center of the lake for nutrient (i.e. total and dissolved organic/inorganic nitrogen and phosphorus fractions) and chlorophyll-a conditions (surface and middle depths). Routine physicochemical profiles (i.e. temperature, pH, specific conductance, DO, and oxidation reduction potential) should also be collected at both stations.

4. **EGL4 Water Quality Sampling:** For EGL4, an integrated water column sample should be collected monthly for the identification, enumeration, and biovolume analysis of the phytoplankton assemblage to gain better insight into the species that influence taste and odor events. Separate water samples should be collected when geosmin and MIB analyses are collected; taxonomic composition should be analyzed only when the concentrations indicate a taste and odor event is occurring.

   Documenting the community structure each month will help establish the seasonal changes that typically occur each year and the taxa (i.e., a group of one or more populations of an organism or organisms determined by taxonomists to form a unit) that are associated with toxin or taste and odor events.

5. **Geosmin and MIB Reservoir Sampling:** For EGL4, WGL2 and West Cooley, geosmin, MIB and microcystin-LR samples should be collected from the surface, middle, and bottom depths to help document the onset and duration of taste and odor and toxin events. These data should be paired with a phytoplankton sample if the geosmin, MIB or microcystin-LR data indicate an event. Notably, the measurement of taste and odor compounds or toxins is the only positive method for documenting their presence, because the presence of cyanobacteria does not necessarily indicate the presence of taste and odor or toxins.

6. **Geosmin and MIB Source Sampling:** For South Platte River at BC, geosmin and MIB samples should be collected from the inflows to help document the origin, onset, and duration of taste and odor as well as toxin events in the RWGLS. Soil bacteria from the riverine system could provide a source of taste and odor causing organisms or compounds.
7. **New Profiling Systems:** For EGL4, ST, WGL2, and West Cooley, install centrally located buoy-mounted water quality profiling systems to document water temperature, specific conductivity, pH, dissolved oxygen, and oxidation reduction potentials in 1-meter increments from the surface to the bottom waters. High frequency data (e.g., 4 values per day) from this system will substantially increase the understanding of the limnological or environmental processes that affect vertical and horizontal mixing of the water column and whether conditions are favorable for internal nutrient loading that may facilitate late season algae growth. High frequency profile data may also be used to determine selective water withdrawal strategies to potentially circumvent the intake of poorer water quality.
8. **New Temperature Data Monitoring:** For EGL4, WGL2, and South Cooley Lake, install a thermistor string in the deepest location or at the center of each reservoir to collect high frequency (e.g., 15-minute interval) water temperature data in 1-meter increments from the surface to the bottom layer. These data logger arrays are relatively inexpensive to install and maintain, and they will vastly improve the understanding of wind mixing events and vertical density gradients that affect chemical and biological processes in the reservoirs. The collected data should be downloaded from the data loggers at least once every thirty days.

Future Studies to Support Lake Management

The water quality monitoring recommendations described above will provide a better understanding of the RWGLS ability to improve water quality before it reaches the WBWTP. The recommended monitoring efforts will also help inform future decisions regarding which combination of management strategies will be the most cost-effective to reduce nutrients. Additional insight into the water quality aspects and potential improvements that could improve the water quality of the RWGLS could be achieved through supplemental studies:

- Water Circulation Study
- Phosphorus Reduction Study (working with phosphorous reduction experts to determine viability of reduction strategies)
- Oxygenation Study

Detailed descriptions of the scopes, purpose, and value of these studies are included in the Existing Raw Water System Evaluations TM.

4. RWGLS Operations Plan

The water quality improvement options that were developed as part of the Existing Raw Water System Evaluation TM have been incorporated into an Operations Plan that addresses the varying water quality conditions in the RWGLS. The RWGLS experiences summer algae blooms and subsequent taste and odor events that affect raw and drinking water quality, which can then affect customer satisfaction and confidence in water treatment and water supply. A complex interaction of environmental conditions affects algae and cyanobacteria growth, including a range of physical, chemical, and biological interactions. Physical conditions include the shape and depth of the waterbody, water column stability, inflow and outflow rates, horizontal and vertical mixing due to flow and wind, light availability, and water temperature. Chemical conditions include nutrient availability (i.e., nitrogen, phosphorus, iron), pH levels, and carbonates. Biological conditions include competition with other algae, and predation from zooplankton (i.e., typically, the tiny animals found near the surface in aquatic environments). Of these conditions, nutrient availability, water column mixing, and flow are the most easily targeted by raw water management strategies.

Operation Improvement Options

Based on the findings and recommendations detailed in the Existing Raw Water System Evaluation TM, the following three options were identified as recommended RWGLS operations modifications to improve the water quality in the RWGLS. A fourth option relies on improved water treatment processes at TWTP to provide improved water quality deliveries to Thornton water customers. These options require improvements to existing raw water infrastructure or increases to system operating costs. The actual extent and duration of the implementation of these options is dependent on capital and operating budgets that are reviewed separately in the Raw Water Master Plan Future Alternatives Evaluation TM that is part of the Water Infrastructure Master Plan.

Option 1: Lakes in Series

This option considers operating the RWGLS in series from WGL1 to the McKay PS as follows:

- WBWTP and TWTP would continue to produce the historic quantities of treated water;
- Water from WGL2 would be pumped to EGL4;
- Most of the year, water needed at WBWTP would be supplied by the McKay Pump Station (from South Cooley West); and
- When the supply needed at WBWTP would exceed 25 million gallons per day (MGD) (estimated capacity of McKay PS supply to WBWTP), EGL4 PS would operate and provide supplemental water to WBWTP from EGL4.

Option 2: Precipitant Addition

Option 2 considers the addition of a precipitant to sequester phosphorus within raw water flows entering the RWGLS. The chemical precipitant would be added at the BC intake feeding into ST. The chemical addition would occur continuously when water is being diverted from BC. Additionally, the RWGLS would be operated in series, as described in Option 1, to provide the greatest distance between the precipitant addition and the raw water pumping to the WTPs. WBWTP and TWTP would continue to produce the historic quantities of treated water.

A pilot study to evaluate different precipitants, to identify effective dosages, and to evaluate the volume and characteristics of the resulting solid precipitants could be performed prior to implementation of Option 2. A consultant familiar with chemical precipitation and solids production should provide specific recommendations for the pilot study and should provide guidance and advice on the pilot plant durations, costs and configuration. Additionally, the effectiveness and results of Option 1 may reduce or eliminate the need for Option 2.

Option 3: Precipitant Addition + Bypass

Similar to Option 2, Option 3 also considers adding precipitant at the BC intake, but the RWGLS would not be operated in series for brief periods that could typically occur between August 1 to October 31. The bypass would discharge the BC diversions to the RWGLS downstream of ST. The BC diversions could be accomplished through an extension of the existing bypass ditch at the BC diversion. Triggers for implementing Option 3 operations could include, but not be limited to:

- Unusually high P concentrations in BC diversions,
- Algae bloom(s) in the RWGLS,
- Special operating conditions at any of the WTPs, or
- Any combination of the above triggers.

The results of the precipitant addition pilot study and future experience with the RWGLS operations will provide guidance on the effectiveness and the timing of the future Option 3 operating periods. During those Option 3 operating periods, the water from BC would bypass ST and EGL4 and would feed directly into South Dahlia.

Phosphorous concentrations in the BC diversions are at their peak during this time period. Raw water diversions to WBWTP and TWTP would continue in the same historical patterns.

Option 4: Maximize TWTP Production

Option 4 does not involve raw water quality improvement but rather controlling supply to maximize production at TWTP and minimizing production at WBWTP to improve potable water quality. This option considers operating TWTP at its maximum capacity and only relying on WBWTP to supplement the water production as needed. TWTP maximum production capacity is 20 MGD (22 MGD supply, accounting for treatment losses). The raw water operations would be as follows:

- The RWGLS would be operated in series, similar to Option 1;
- Water from WGL2 would be pumped to EGL4;
- Water needed at WBWTP would be supplied by the McKay PS (from West Cooley); and
- Water from EGL4 would be sent to TWTP all year round (maximum rate of 15 MGD based on existing equipment).

The RWGLS operations may require additional attention during Option 4 operations to avoid or minimize the possible effects of flow short-circuiting within the reservoirs.

RWGLS Operations Scenarios

The Operations Plan for the RWGLS is based on various water quality and water quantity scenarios that occur as part of typical RWGLS operations. The scenarios can be defined by specific water quality and water quantity conditions in the reservoirs. The intent of the Operations Plan is to anticipate water quality scenarios that would result in reduced quality water deliveries to the WTPs (i.e., trigger events) and to define modifications to the RWGLS operations that could reduce or eliminate the impacts of a trigger event. There are three categories of operating scenarios: General Operations; Water Source Degradation; and Potential Taste and Odor. This plan and the defined scenarios should be reviewed and modified regularly (at least annually) as operating experience and analyses of the water quality data allows improved background and understanding of the water quality dynamics of the RWGLS. The RWGLS operating scenarios are as follows.

General Operations Scenario

The General Operations Scenario may be characterized by numerous different conditions related to the influent water supply, RWGLS water quality, and water surface levels within the RWGLS; however, the most important consideration is that a taste and odor event is not imminent and the prevailing water quality within the RWGLS is “better than average”. Past operating experience by Thornton and review of the seasonal variations in the water quality data indicate that this scenario typically occurs during the winter, spring, and early summer. RWGLS operations for this scenario could follow one of the following two methodologies regardless of the status of the WTP operations:

- RWGLS operations would be similar to past operations with raw water deliveries to the WTPs being pumped from the EGL4 and WGL2 pump stations. The flow through the RWGLS would not operate in series to minimize the operational cost of the McKay PS.
- RWGLS operations would flow in series (Option 1) and the water delivery to the WTPs would be pumped from the McKay PS through modified transmission piping interconnections. The prevailing water quality within the RWGLS would be expected to improve due to the increased water detention time from operating the lakes in series. Operating costs would be increased due to the added costs of operating the McKay PS.

The water quality data collected in the RWGLS monitoring program can be used to identify when the conditions in the RWGLS satisfy the characteristics of the General Operations Scenario. The decision on whether to operate the RWGLS in series (rather than in current operating mode) is dependent on both operating cost considerations and water quality considerations. As the water quality improvements associated with operating the RWGLS in series is quantified, the increased cost of operations can be compared to the improved water quality, and an informed decision on the preferred operating mode can be determined. The increased cost of operations will be estimated as part of the Capital Improvement Programs (CIP) analyses and by Thornton operations staff monitoring of operating costs and water quality data in the future.

Water Source Degradation Operations Scenario

The Water Source Degradation Operations Scenario may be characterized by a degradation of water quality at any raw water supply to the RWGLS. A degradation of the supply water quality could involve various different water quality metrics, including but not limited to temperature, elevated nutrient concentration, or decreased DO. Past operating experience by Thornton and review of the seasonal variations in the supply water quality data indicate that this scenario typically occurs through the summer and fall seasons. The most common supply water quality issue is increased nutrient concentrations in the BC diversions and the internal nutrient recycling from the lake sediments. RWGLS operations for this scenario could follow one or a combination of the following methodologies regardless of the status of the WTP operations:

- The RWGLS operations would operate in series (Option 1), and the raw water deliveries to the WTPs would be pumped from the McKay PS through modified transmission piping interconnections. The prevailing water quality within the RWGLS would be expected to improve due to the increased water detention time from operating the lakes in series. Operating costs would be increased due to the added costs of operating the McKay PS.
- The addition of a precipitant to sequester phosphorus from the BC supply as it enters the RWGLS (Option 2). The chemical precipitant would be added at the BC intake feeding into ST. The chemical addition would occur continuously when raw water being diverted from the BC has elevated nutrient concentrations. The type of precipitant to be used and its dosing rate should be determined through a pilot study by Thornton operations staff on the BC diversions. The pilot study would also provide operating cost data to guide the decision regarding frequency and duration of precipitant addition.
- If the RWGLS operations are not operating in series and a short term water quality degradation of the BC diversions is occurring or anticipated, then the BC diversions could bypass ST (Option 3) through diversions around the upstream reservoirs. The bypass would discharge the BC diversions to the RWGLS downstream of ST. The BC diversions could be accomplished through an extension of the existing bypass ditch at the BC diversion. Operations under this scenario would be relatively short duration (2 to 3 months) and would be followed by operation of the RWGLS in series (Option 1) to allow recovery of the water volumes (and related water surface elevations) in ST.

The water quality data collected in the monitoring program would identify when the conditions in the RWGLS satisfy the characteristics of the Water Source Degradation Operations Scenarios. The decisions to operate the RWGLS in series, to use precipitant addition, and/or to bypass the BC diversions around ST are dependent on balancing operating costs and water quality improvements. As these different options are performed and operational cost and water quality data are collected, then the cost-benefit of operations can be quantified to identify the preferred operating mode under the various conditions. The increased cost of operations will be estimated in the Raw Water Master Plan Future Alternatives Evaluation TM and by Thornton operations staff through the future monitoring of operating costs and water quality data.

Potential Taste and Odor Scenario

A Potential Taste and Odor Scenario may be characterized by a number of water quality parameters that potentially contribute to algae growth and degradation of water quality within any of the reservoirs in the RWGLS. The water quality parameters that could contribute to algae growth or that are indicators of conditions that could promote algae growth include, but are not limited to:

- Water column temperatures;
- Reservoir water depths;
- Secchi Depth;
- Algae concentrations;

- Chlorophyll concentrations; and
- Phosphorus concentrations.

Past operating experience by Thornton and review of the seasonal variations in the RWGLS water quality indicate that a potential taste and odor scenario typically occurs through the summer and fall seasons. A potential taste and odor scenario could result from a combination of interrelated factors, making it difficult to precisely predict the conditions that will result in a taste and odor scenario. One scenario that may be readily predictable, pending the collection of more detailed and comprehensive data through the Monitoring Program, is reservoir turnover. Past operating experience indicates that reservoir turnover frequently results in a taste and odor condition, and the ability to predict reservoir turnover could provide genuine guidance for modifying the RWGLS operations to reduce or eliminate the effects of a taste and odor event. RWGLS operations for taste and odor conditions could follow one or a combination of the following methodologies:

- Maximize use of the TWTP. This option is expected to provide the most effective defense against the effects of potential taste and odor conditions. The new TWTP has been designed to address taste and odor issues within the RWGLS, and the use of the TWTP is expected to address the wide range of conditions that present a potential taste and odor event.
- Modify the raw water supplies (RWGLS, Standley Lake, Thornton Water Project) to the WTPs. The modified operations could include supplying higher quality raw water (from Standley Lake or Thornton Water Project) to the Wes Brown WTP and supplying RWGLS water to be treated by advanced treatment processes at the Thornton WTP. This option can be effective for taste and odor conditions that are identified within a specific reservoir. The ability to supply the WTPs from either EGL4, WGL2, or the McKay PS provides some flexibility to avoid supplying the raw water that is experiencing taste and odor conditions to the WTPs. This option is likely to provide only short-term relief from the taste and odor conditions.

The water quality data collected in the monitoring program would identify when the conditions in the RWGLS indicate a potential taste and odor condition. The decision on whether to optimize the use of the TWTP, operate the ST bypass, or to use precipitant addition, is dependent on balancing operating costs and water quality improvements. As these different options are performed and operational cost and water quality data is collected, then the cost-benefit of operations can be quantified to identify the preferred operating mode under the various conditions. The increased cost of operations will be estimated in the Raw Water Master Plan Future Alternatives Evaluation TM and by Thornton operations staff through the monitoring of operating costs and water quality data in the future.

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Appendix A – Water Quality Summary Metrics

Table A.1. Mean annual data for samples collected at EGL4 Middle (EGL4@PS MID) and WGL2 Middle (WGL2@PS MID) and Tier 1 & 2 raw water supply water quality criteria.

Parameters	Year	N		Min		Max		Mean		Std. Dev.		Criteria	
		East	West	East	West	East	West	East	West	East	West	Tier I	Tier II
Turbidity (NTU)	2012	50	52	0.1	0.4	4.9	6.8	1.5	1.2	1.1	1.0	0.1 – 50 NTU	0.1 – 25 NTU
	2013	48	48	0.1	0.5	6.6	6.7	2.2	1.7	1.4	1.5		
	2014	29	29	0.3	0.5	5.4	9.1	1.8	2.7	1.7	2.3		
	2015	34	34	0.1	0.2	6.3	2.5	1.1	1.2	1.0	0.7		
	2016	41	34	0.1	0.4	5.4	3.7	1.2	1.9	1.0	0.9		
	2017	47	42	0.1	0.3	3.0	6.2	1.1	1.5	0.7	1.1		
pH (STD)	2012	50	52	8.1	8.0	9.7	9.3	8.9	8.8	0.5	0.3	6.0 – 10 (STD)	NA
	2013	48	48	7.4	7.0	9.3	9.4	8.7	8.4	0.4	0.5		
	2014	29	29	7.9	7.8	9.0	9.2	8.4	8.4	0.2	0.4		
	2015	34	34	8.4	7.5	9.1	8.8	8.7	8.2	0.2	0.4		
	2016	41	33	8.0	6.2	8.9	8.9	8.5	8.2	0.2	0.5		
	2017	46	41	8.3	7.5	8.9	8.8	8.6	8.2	0.2	0.4		
Temperature (°C)	2012	50	52	2.9	2.4	25.0	24.4	13.1	13.1	7.5	7.7	0.5 – 27 (°C)	NA
	2013	48	47	3.0	2.9	23.3	24.1	12.8	12.8	7.5	7.6		
	2014	29	29	7.9	8.0	23.7	23.2	17.4	18.1	4.4	4.0		
	2015	34	34	10.9	10.3	23.7	23.8	17.9	18.2	4.1	4.4		
	2016	41	33	2.8	7.6	24.0	23.4	16.8	18.4	6.5	4.3		
	2017	46	41	3.3	8.3	24.8	23.3	15.2	16.5	6.6	5.2		
Alkalinity (mg/L)	2012	50	52	107	119	175	158	148	137	17.6	12.2	35 – 250 mg/L as $CaCO_3$	NA
	2013	52	52	112	89	177	216	146	137	18.8	43.4		
	2014	42	43	133	52	156	131	142	93	4.9	21.8		
	2015	34	34	121	79	154	195	134	116	10.2	22.3		
	2016	41	34	112	79	152	144	130	110	11.0	20.7		
	2017	47	42	125	82	155	150	139	121	7.8	21.7		
Total Organic Carbon (mg/L)	2012	50	52	4.2	3.6	5.4	5.8	4.8	4.7	0.3	0.5	0.5 – 9.0 mg/L	NA
	2013	52	52	4.5	3.1	7.6	7.7	5.3	5.0	0.5	1.1		
	2014	37	44	4.5	2.6	7.5	5.0	5.3	3.8	0.6	0.6		
	2015	34	34	4.4	3.4	5.8	5.1	4.9	4.2	0.3	0.4		
	2016	41	34	4.1	2.5	5.5	5.2	5.0	4.4	0.3	0.5		
	2017	39	34	4.7	3.9	6.7	6.5	5.5	5.0	0.6	0.8		
Dissolved Organic	2012	50	52	4.1	3.7	5.0	5.4	4.7	4.6	0.2	0.4	0.5 – 9.0 mg/L	0.5 – 4.5 mg/L
	2013	52	52	3.1	2.5	7.1	7.4	5.1	4.9	0.6	1.1		

Parameters	Year	N		Min		Max		Mean		Std. Dev.		Criteria	
		East	West	East	West	East	West	East	West	East	West	Tier I	Tier II
Carbon (mg/L)	2014	43	44	4.5	2.6	6.1	4.7	5.1	3.7	0.4	0.6		
	2015	34	34	4.4	3.4	5.6	4.7	4.9	4.1	0.3	0.3		
	2016	41	34	4.1	3.4	5.4	5.0	5.0	4.4	0.3	0.4		
	2017	43	38	4.5	1.9	6.5	6.2	5.3	4.8	0.5	0.9		
Total Hardness (mg/L)	2012	50	52	208	180	320	264	266	219	29.1	18.7	60 – 350 mg/L as $CaCO_3$	60 – 250 mg/L as $CaCO_3$
	2013	51	51	132	112	328	300	266	208	32.2	58.4		
	2014	42	43	230	96	276	224	250	150	9.4	34.8		
	2015	34	34	200	132	256	204	225	179	17.3	19.9		
	2016	41	34	134	136	256	224	225	183	20.6	28.0		
	2017	47	42	208	132	280	262	243	188	18.2	32.5		
Total Dissolved Solids (mg/L)	2014	4	4	496	168	583	378	548	272	38.3	85.8	50 – 750 mg/L	NA
	2015	3	3	389	324	523	380	466	359	69.3	30.3		
	2016	2	2	422	297	504	443	463	370	58.0	103.2		
	2017	3	3	450	333	524	523	481	418	38.3	96.5		
Bromide (mg/L)	2012	50	52	0.2	0.1	0.3	0.3	0.3	0.2	0.0	0.1	0 – 0.5 mg/L	NA
	2013	52	52	0.2	0.1	0.3	0.2	0.3	0.1	0.0	0.1		
	2014	43	44	0.1	0.1	0.3	0.2	0.2	0.1	0.1	0.0		
	2015	34	34	0.1	0.1	0.2	0.3	0.2	0.1	0.0	0.1		
	2016	41	34	0.1	0.2	0.3	0.4	0.2	0.3	0.0	0.1		
	2017	43	38	0.1	0.1	0.4	0.4	0.2	0.3	0.1	0.1		
Ortho Phosphate as PO_4 (mg/L)	2012	50	52	0.1	0.1	2.0	1.2	1.0	0.6	0.5	0.3	0 – 3.0 mg/L	NA
	2013	52	52	0.3	0.1	1.4	0.8	0.9	0.4	0.2	0.2		
	2014	43	44	0.8	0.1	1.9	0.6	1.2	0.2	0.3	0.1		
	2015	34	34	0.6	0.1	2.0	0.4	1.1	0.2	0.3	0.1		
	2016	41	34	0.6	0.1	1.0	0.7	0.8	0.3	0.1	0.2		
	2017	43	38	0.3	0.1	0.9	0.6	0.7	0.3	0.2	0.2		
Nitrate as N (mg/L)	2012	50	52	0.4	0.2	2.0	1.2	1.1	0.6	0.4	0.2	0 – 3.0 mg/L	0 – 1.5 mg/L
	2013	52	52	0.1	0.2	1.8	1.7	0.9	0.7	0.6	0.4		
	2014	43	44	0.1	0.1	0.6	0.5	0.3	0.1	0.1	0.1		
	2015	34	34	0.1	0.1	1.3	0.3	0.3	0.2	0.2	0.1		
	2016	41	34	0.3	0.1	0.9	1.0	0.7	0.3	0.2	0.3		
	2017	43	38	0.1	0.1	1.1	0.7	0.4	0.4	0.3	0.2		
Geosmin & MIB (ng/L)	2012	--	--									0 -50 ng/L	0 - 5 ng/L
	2013	--	--										
	2014	--	--										
	2015	--	--										
	2016	--	--										
	2017	--	--										

Thornton Water Project Pipeline Corridor Evaluation - Quebec Street

Chapter 7

Utility Master Plan

Project No. 17-467

Raw Water Supply Master Plan

Thornton Water Project Pipeline Corridor Evaluation – Quebec Street

The City of Thornton

Project number: 60560104

AECOM

October 30, 2018

Quality information

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List of Acronyms

GIS – Geographic Information System
ROW – Right-of-Way
Thornton – City of Thornton
TM – Technical Memorandum
TWP – Thornton Water Project
TWTP – Thornton Water Treatment Plant
WBWTP – Wes Brown Water Treatment Plant

Attachments

Figure 1 - Quebec Street Corridor Review Map

1. Introduction

The purpose of this Technical Memorandum (TM) is to identify the preferred corridor for completion of the Thornton Water Project (TWP) pipeline from 160th Avenue to 120th Avenue. The TWP will deliver water to the city of Thornton's (Thornton) two water treatment facilities:

1. Wes Brown Water Treatment Plant (WBWTP)
2. Thornton Water Treatment Plant (TWTP)

A possible third location for TWP water delivery would be a new water treatment plant that may be located within Thornton. This option will be evaluated further during future alternatives analysis.

A pipeline corridor from Thornton's northern boundary at 160th Avenue and Quebec Street to the water treatment facilities will traverse a general north-south direction. The minimum required permanent pipeline easement width is twenty feet, or a width of at least two times the depth to the invert, to allow for safe operation and maintenance of the pipeline. Additional easement width may be needed or recommended based on the final pipeline diameter and other external factors. The final determination of pipeline diameter and required easement width will be determined during the pipeline design phase, by others.

Based on existing development within Thornton, the segment of Quebec Street from 160th Avenue to 120th Avenue is considered relatively attractive as a possible north-south corridor for construction of a new pipeline. Figure 1 shows the Quebec Street corridor and its approximate 150-feet wide Right-of-Way (ROW). A site review was conducted to evaluate the viability of the Quebec Street corridor for the TWP pipeline.

2. Objective

The objective of the site review was to evaluate whether the Quebec Street ROW corridor from 160th Avenue to 120th Avenue can serve as a feasible corridor for the construction of the TWP pipeline. The review involved comparing the Quebec Street TWP pipeline segment from 160th Avenue to 120th Avenue against other north-south road corridors including Colorado Boulevard and Holly Street. The current fast pace of land development along the Quebec Street corridor could quickly limit Thornton's ability to preserve or secure space for a pipeline within the ROW. A minimum easement width of twenty feet is recommended to be reserved for the proposed pipeline, and additional easement width may be identified as needed during the design phase of the pipeline.

The purpose of this evaluation is to provide Thornton with the background and understanding of the need for reserving a pipeline location within the Quebec Street ROW. The following sections of this TM describe general observations of surface improvements and available utility information that may impact the pipeline routing and design based on the site review and information available at the time of the evaluation. All utilities should be verified during preliminary design and any pipeline routing concepts described in this TM are subject to refinement and/or revision given more detailed information. The northern segments of the roadway corridor are actively being developed. With these development improvements, utilities and other features that impact the location and design of a pipeline will likely vary significantly with time.

3. Quebec Street Evaluation from 160th Avenue to 120th Avenue

On August 3, 2018 AECOM conducted a high level site review of the Quebec Street corridor as a potential route for the proposed TWP pipeline between 160th Avenue and 120th Avenue. Utility mapping information available at the time of the field review included Thornton's water and sewer utility location geographic information system (GIS) information. The GIS utility review was limited to the information available and provided by Thornton. Other utility information that may impact the TWP pipeline alignment, including gas line mapping, was not available at the time of this evaluation. Additional utility information was noted in the field with observable landmarks such as manhole covers, waterline valve boxes, and utility marker posts. In some areas, remnants of previous utility location paint marking and flagging were found.

Additionally, the 2009 city of Thornton Transportation Master Plan was referenced for information related to the Quebec Street ROW width. The Master Plan indicates a plan for 150-feet wide ROW along the study area segment of Quebec Street. GIS mapping of Quebec Street, with a geo-referenced aerial image as background, indicates that if the 150-feet ROW is centered over Quebec Street the ROW will encroach on existing residential structures adjacent to Quebec Street as shown in Figure 1 (attached). Detailed mapping of the Quebec Street ROW was not available for this review.

The following discussion documents the findings and opinion of the Quebec Street corridor starting at 160th Avenue moving south to 120th Avenue based on the site review and available GIS information.

From East 160th Avenue to East 140th Avenue, the west side of the Quebec Street ROW is undeveloped and appears to provide the best opportunity for the proposed TWP pipeline alignment (see Image 1).

Image 1. Just North of E-470 Traveling on Quebec Street Looking North Indicating Undeveloped Opportunity on the West side of Street ROW

There are existing water and sewer utilities present in this area along with overhead power lines from about East 160th Avenue to East 152nd Avenue. Conversely, along this same reach, the east side of the corridor is much more developed with curb and gutter, a bike path and parkway, and relatively intensive development in progress from approximately East 160th Avenue to Ehler Parkway. In addition, there is at least one larger diameter gas line that appears to run continuously along the east side of Quebec Street. This stretch of the Quebec Street corridor also includes a crossing of a drainage channel south of 152nd Avenue, and the crossing of E-470 Tollway north of East 144th Avenue. The E-470 Tollway crossing will require a trenchless, tunneled crossing below the E-470 ROW. Both of these crossings will be challenging regardless of which side of Quebec Street they are on.

At East 140th Avenue extended, for approximately 0.2 miles Quebec Street sweeps toward the west around an existing antenna facility. Pending information from further utility investigation and plans for the future Quebec Street, it would appear that continuing the pipeline alignment straight through this section (along the east edge of the antenna facility) would be preferred (see Image 2).

Image 2. Just North of East 136th Avenue Traveling on Quebec Street Looking North at Antenna Facility

On the south side of East 140th Avenue extended and East 136th Avenue, there is existing development on both sides of Quebec Street and the existing roadway corridor is much narrower. Routing the pipeline through this section of roadway will have to contend with numerous utilities and surface improvements. Towards the southern end of this section, from East 136th Avenue to approximately East 131st Avenue extended, it appears there are fewer utility conflicts for pipeline construction.

At East 131st Drive extended, there is a significant drainage crossing. South of this drainage to East 128th Avenue, the northbound lanes of Quebec Street, or the area behind the east curb in the open space with the bike path, appears to be the preferred alignment. The best route will depend on existing utilities and the cost of removals and replacement, and traffic control.

From East 128th Avenue to East 120th Avenue, the Quebec Street corridor is fairly undeveloped along the northern half and more fully developed for the southern half, on both sides of Quebec Street. Maintaining the pipeline alignment on the east side of Quebec Street through this stretch appears feasible. There is a drainage crossing a short distance north of East 124th Avenue that has a partially completed pedestrian underpass that may require a tunneled, trenchless crossing. Additionally, there is a completed pedestrian underpass on the north side of East 120th parkway that may require a tunneled crossing, depending on the decision for the remainder of the pipeline alignment south of East 120th parkway.

4. Summary

The Quebec Street Corridor from 160th Avenue to 120th Avenue is a preferable pipeline corridor when compared to alternative north-south corridors within Colorado Boulevard or Holly Street. Both the Holly Street and Colorado Boulevard corridors are more fully developed than Quebec Street, and the Colorado Boulevard corridor south of East 140th Avenue is much more developed. Development of properties adjacent to Quebec Street is proceeding rapidly, and the availability of potential pipeline easement width is decreasing proportionally to the amount of development. The Quebec Street alignment will include some notable crossings including E-470, drainage crossings and at least 5 pedestrian underpasses that may require special construction considerations. Additional study is needed during preliminary design to better define the ROW limits of Quebec Street, the minimum easement width requirements of the proposed pipeline, and possible conflicts with other buried utilities to determine a preferred pipeline alignment within the Quebec Street corridor.

Thornton Water Project Pipeline Corridor Evaluation - 120th Avenue to Water Treatment Plants

Chapter 8

AECOM Imagine it. Delivered.

Utility Master Plan

Project No. 17-467

Raw Water Supply Master Plan

Thornton Water Project Pipeline Corridor Evaluation – 120th Avenue to Water Treatment Plants

The City of Thornton

Project number: 60560104

AECOM

April 15, 2019

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List of Acronyms

HGL – Hydraulic Grade Line
ROW – Right-of-Way
Thornton - City of Thornton
TM – Technical Memorandum
TWP – Thornton Water Project
TWTP – Thornton Water Treatment Plant
WBWTP – Wes Brown Water Treatment Plant
WTP – Water Treatment Plant

1. Introduction and Purpose

The purpose of this Technical Memorandum (TM) is to identify a preferred pipeline corridor for completion of the Thornton Water Project (TWP) pipeline connections to the city of Thornton's (Thornton) water treatment plants (WTPs). The TWP will deliver water to Thornton's two existing WTPs as follows:

1. Wes Brown Water Treatment Plant (WBWTP)
2. Thornton Water Treatment Plant (TWTP)

A possible third location for water delivery would be a new water treatment plant (WTP) that may be located within the city boundaries. This option will be evaluated further during the alternatives analysis.

A pipeline corridor from Thornton's northern boundary to the intersection of Quebec Street and 120th Avenue was evaluated in a previous TM (*Thornton Water Project Pipeline Corridor Evaluation – Quebec Street*, October 30, 2018, AECOM). The evaluation concluded that the Quebec Street corridor, comprised of a 150 feet wide ROW, from 160th Avenue to 120th Avenue is a preferred pipeline corridor to extend the TWP pipeline south to 120th Avenue.

The focus of this TM is to identify a preferred TWP pipeline corridor south from the 120th Avenue and Quebec Street intersection to the two existing WTPs. The TWP pipeline will traverse a general southwest direction from 120th Avenue and Quebec Street to either of the existing WTPs. Figure 1 shows the study area under consideration for the possible TWP pipeline alignments that are evaluated herein.

2. Scope and Approach

The scope of this pipeline corridor review is to identify and evaluate possible pipeline corridors for the TWP pipeline to connect from the south end of the Quebec Street pipeline corridor at 120th Avenue to both of Thornton's WTPs. This involves a review of the study area bounded by I-25 on the west, 120th Avenue on the north, 84th Avenue on the south, and the South Platte River on the east. This area encompasses Thornton's existing WTPs, and it includes several potential corridors for construction of the proposed TWP pipeline. The study area is comprised of primarily urban development with relatively dense residential and commercial land uses. The exception to the urban development is the land heading east from Riverdale Road to the South Platte River.

The evaluation of pipeline corridors involves identification and ranking of significant favorable or unfavorable conditions for pipeline construction, including considerations related to:

1. Areas sensitive to temporary pipeline construction impacts (e.g., traffic disruption, excessive noise, and dust pollution). These areas include residential areas, public facilities, including schools and hospitals, and high-traffic commercial areas.
2. Areas with buried utilities or surface features that are costly to mitigate or remove and replace. This includes areas with major and arterial roadways, significant buried infrastructure, and areas of significant historical or environmental sensitivity.
3. Areas that could subject a large diameter pipeline to harmful external conditions, such as large external loads (roads or railroads), high groundwater table, or unsuitable soil conditions.
4. Favoring areas that have been previously disturbed and that have land uses conducive to large diameter pipeline construction and maintenance. This includes existing utility corridors, railroad right-of-way (ROW), and some trails and hiking paths, parks, and golf courses.

The following sections describe the general preliminary observations of surface features and available land use information that may impact the pipeline routing and design. Any pipeline routing concepts described in this TM are subject to revision; these evaluations are based on current development conditions, and changes to land use or surface features that impact the location and design of a pipeline may vary with time and may, therefore, require reconsideration of the recommendations described herein.

This study has assumed that the pipeline hydraulics, pressures, hydraulic grade line (HGL), and related considerations for each pipeline corridor are suitable for necessary operation of the TWP.

3. TWP Pipeline Corridor Evaluation (120th Street to Water Treatment Plants)

Identification of Pipeline Corridors

A high-level desktop-based mapping review of the study area was conducted to identify potential pipeline corridors for the proposed TWP pipeline between the 120th Avenue and Quebec Street intersection and the existing WTPs. Mapping information used for this study included Google Earth digital mapping, Thornton water, storm, and sewer utility location GIS information, Thornton mapping of existing raw water pipelines, the Thornton Transportation Master Plan (*City of Thornton Transportation Plan*, C.D. No. 2009-121 July 2009), and the Riverdale Road Corridor Plan (*Riverdale Road Corridor Plan*, Adams County Colorado, PRJ2005-00024, April 2005). GIS mapping of the study area was geo-referenced with an aerial image as background to facilitate identification of surface features prevalent within the pipeline corridors.

The study area includes many miles of potential pipeline corridor segments within existing recreation trails, parks, and hiking paths, utility corridors, railroad ROW, and major and arterial roadways.

Figure 1 shows the study area with identified segments of trails, roadways, and utility corridors that may be used to develop potential pipeline corridors. This evaluation combined the identified segments to develop a full-length corridor that connects the intersection of 120th Avenue and Quebec Street to the existing water treatment facilities.

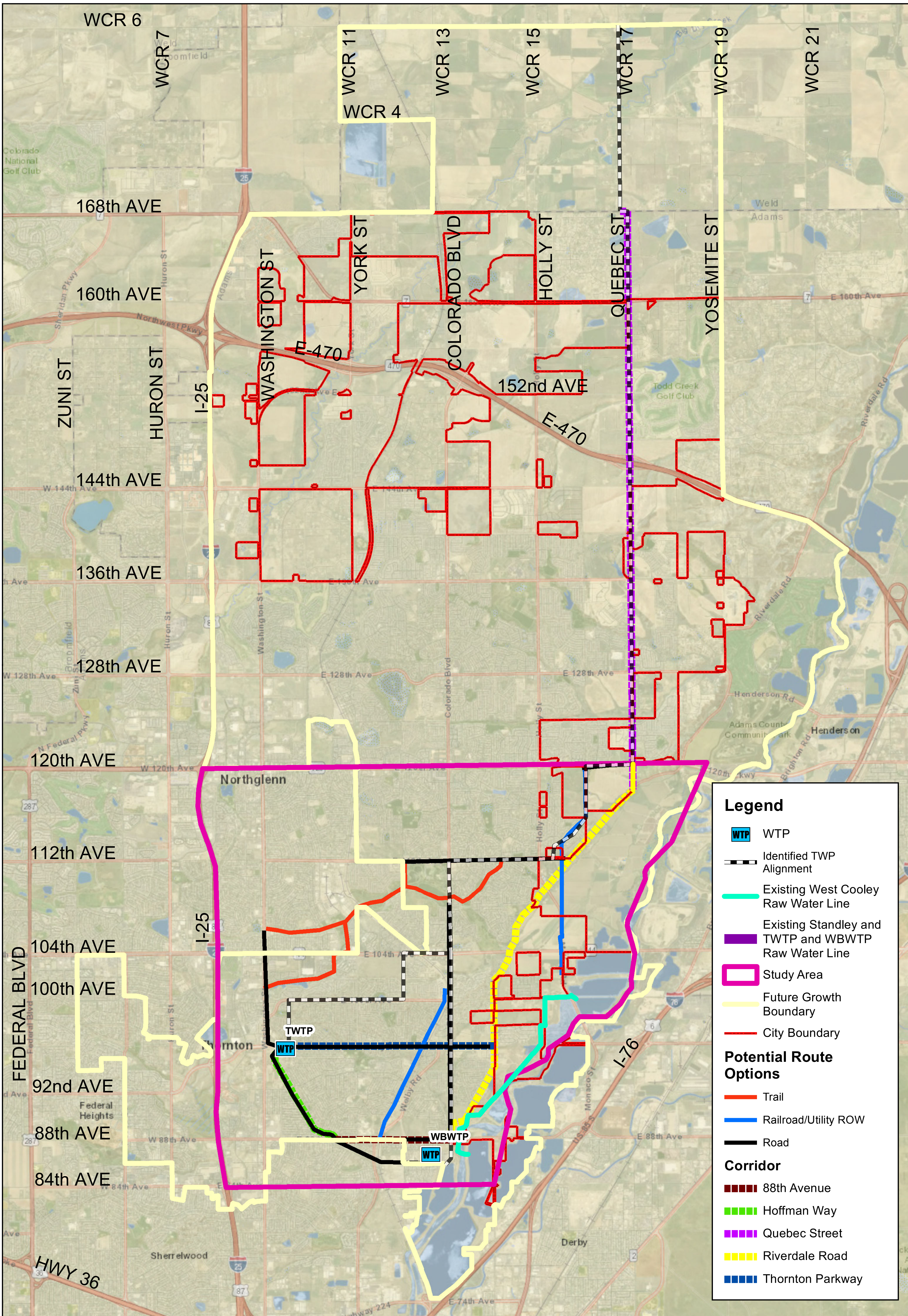

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Figure 1 -TWP Alignment Review
120th Ave to Water Treatment Plants

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Greenwood Village, Colorado 80111

1 inch = 5,000 feet

M:\DCS\Resources\WTR\WWW\Staff\Evon Harmon\Thornton Alignments\Figure 1 120TH TO WTP PLANTS.mxd

CH2M-Identified TWP Corridor

The development of full-length pipeline corridors from 120th Avenue to the WTPs started with the "baseline" pipeline corridor that was identified as a possible pipeline corridor in an earlier TWP Hydraulic and Economic Analysis prepared by CH2M (*Thornton Water Project, Hydraulic and Economic Analysis*, Rev 10 July 2017, CH2M). This baseline pipeline corridor is denoted in Figure 2 as the Identified TWP Corridor. This corridor is comprised primarily of ROW within major and minor roadways and uses a short length of existing utility ROW between 120th Avenue and 112th Avenue. An advantage of this potential corridor is the extensive use of public ROW and a limited need for permanent ROW to be procured from existing land owners. A disadvantage of this corridor is the length of pipeline passing through dense urban areas. Routing the pipeline through these areas typically involves the development and use of maintenance of traffic plans during construction along with surface restoration of roadway, sidewalks and other developed surface features disturbed during pipeline construction.

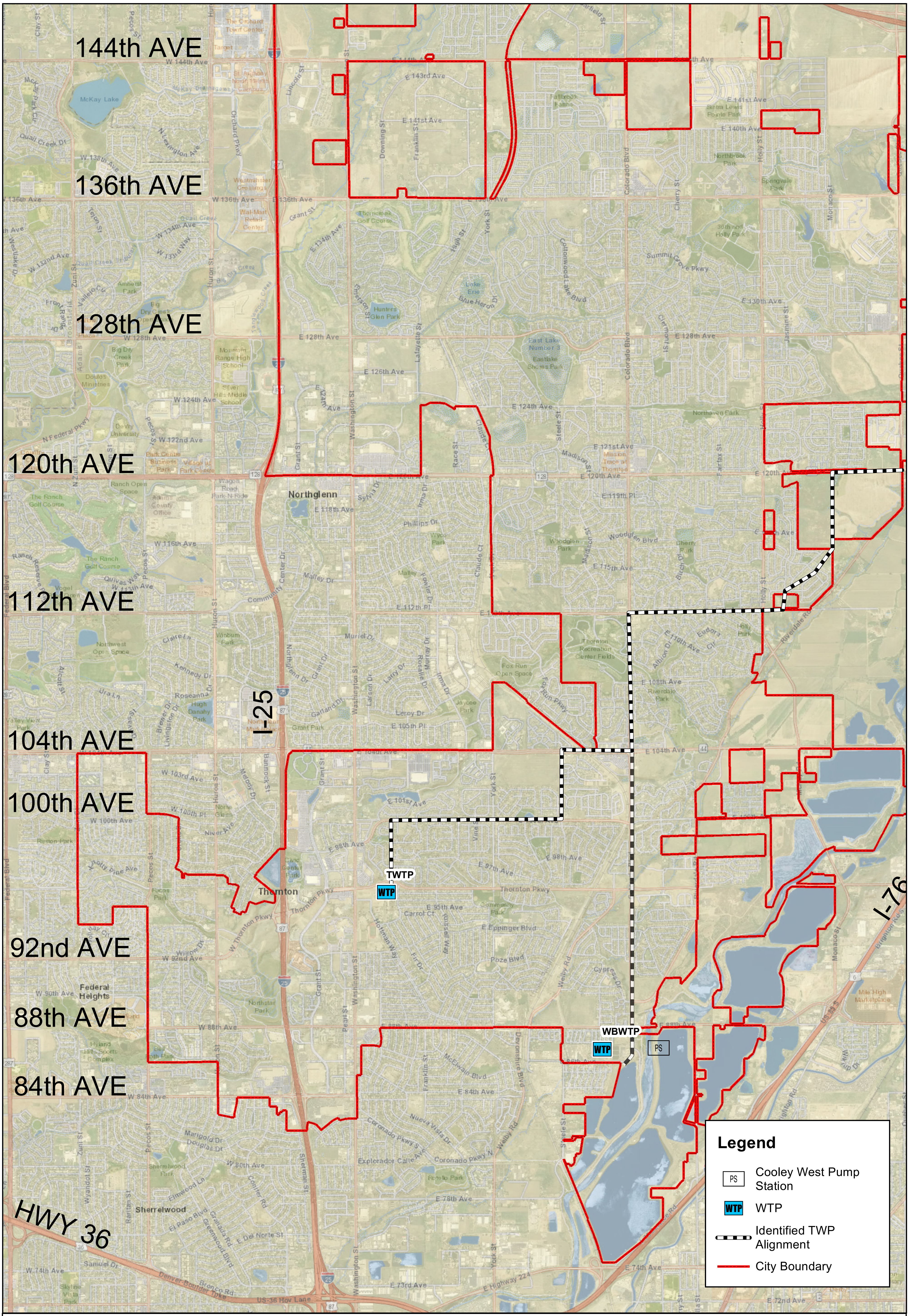

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Figure 2 -TWP Alignment Review
Identified TWP Corridor

1 inch = 3,333 feet

M:\DCS\Resources\WTR\WWW\Staff\Evon Harmon\Thornton Alignments\Figure 2 Identified TWP Corridor.mxd

Riverdale Road Corridor

A second potential pipeline corridor was developed based on the premise that an ideal pipeline alignment is a straight line between the beginning point (120th Avenue and Quebec Street) and the destination(s) (WTPs). A literal straight line corridor is not feasible due to existing structures and land ownership obstacles, but a reasonable approximation of a straight line corridor is represented by the use of the Riverdale Road ROW as a pipeline corridor. This corridor is described as the Riverdale Road Corridor and is denoted in Figure 3 as such. Riverdale Road is classified as a Rural Collector Street by Adams County Public Works. Riverdale Road includes segments that are in unincorporated (Adams County) and incorporated (Thornton) jurisdictions.

The Riverdale Road Corridor is comprised primarily of ROW within a minor roadway (Riverdale Road), and uses a short length of existing utility ROW between 120th Avenue and 112th Avenue. This corridor provides an almost direct connection to the WBWTP from the Quebec Street and 120th Avenue intersection, and it allows for two reasonable, optional pipeline spur connections to the TWTP along either 88th Avenue and Hoffman Way, or along 96th Avenue (Thornton Parkway) to the TWTP. Advantages of this potential corridor are the ample use of public ROW and a limited need for permanent ROW to be procured from existing land owners as well as the reduced length of pipeline (relative to other corridors) accorded by the straight-line approximation of the corridor. Disadvantages of this corridor are the possible permitting challenges associated with the Adams County Scenic Byway designation for Riverdale Road, and existing irrigation ditches that are parallel to and on both sides of Riverdale Road, and multiple drainage crossings at road intersections along Riverdale Road. To address these issues, increased pipeline construction costs are assumed.

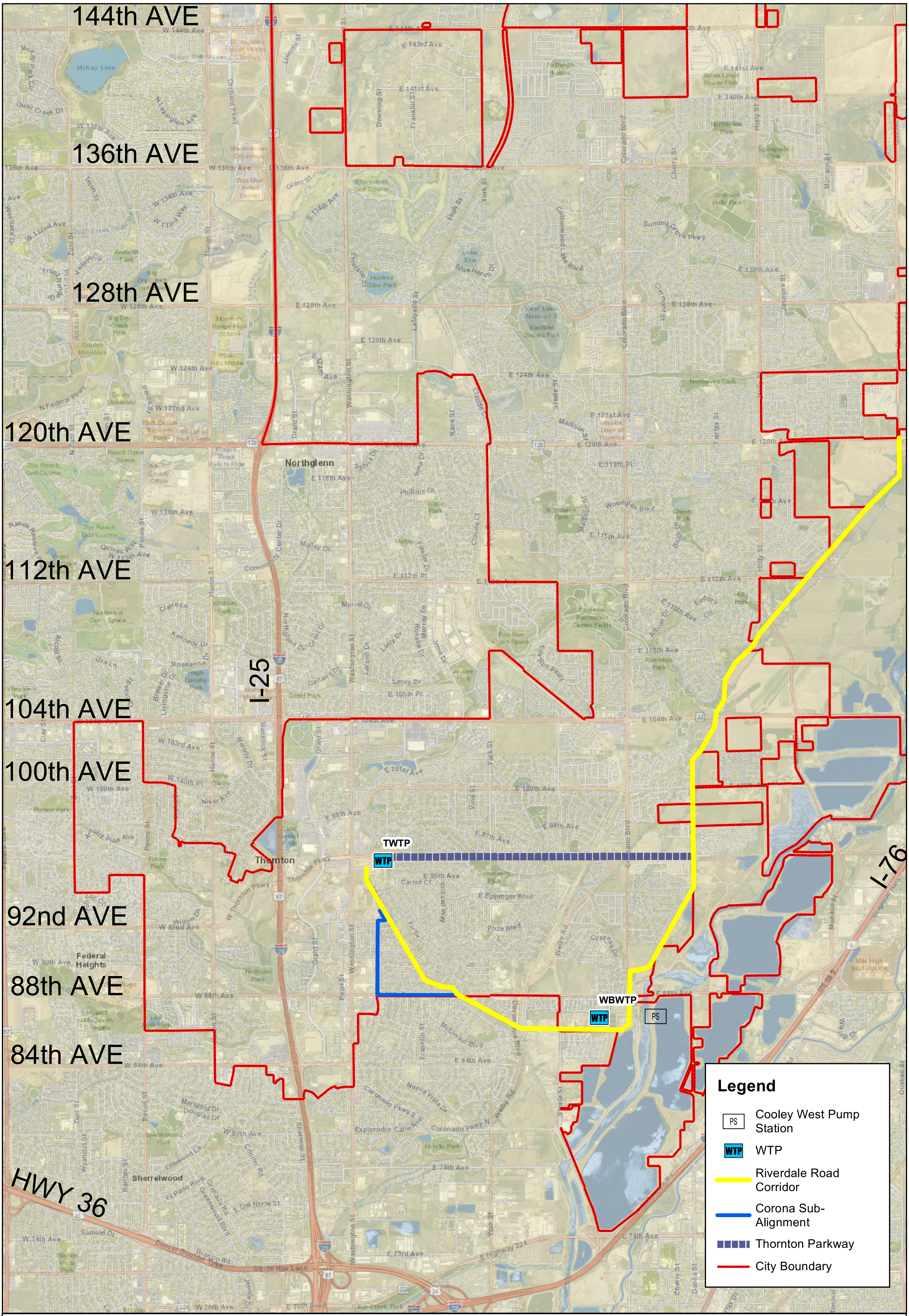

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Figure 3 -TWP Alignment Review
Riverdale Road Corridor

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1 inch = 3,333 feet

Minimized Roadway Corridor

A third potential pipeline corridor was developed based on the premise of reducing the length of pipeline within roadway ROW (as compared to the CH2M-Identified TWP Corridor) and increasing the use of trails or utility ROW. It was expected that the use of trails and utility ROW would reduce the total disruption to the public as compared to the extensive use of roadway ROW in the CH2M-Identified TWP Corridor. This corridor is denoted in Figure 4, and would use either Quebec Street and Riverdale Road, or 120th Avenue and existing utility ROW to traverse south to 112th Avenue. The corridor would extend west approximately 3,900 feet along 112th Avenue to the intersection with Dahlia Drive. The corridor would turn to a southwesterly bearing along Dahlia Drive, and would extend beyond the end of Dahlia Drive into Grange Creek Park. The corridor would continue southwesterly and follow the trail or other available park space to the park border on Colorado Boulevard. The corridor could then follow the same path as the CH2M-Identified TWP Corridor south along Colorado Boulevard, or it could follow the railroad ROW or the existing Standley Lake pipeline easement to the WBWTP and the TWTP. An advantage of this corridor is the reduced reliance on roadway ROW (as compared to the CH2M-Identified TWP Corridor). Disadvantages to this corridor are the additional permitting and easement acquisition required for the pipeline lengths within the park and potentially other ROW.

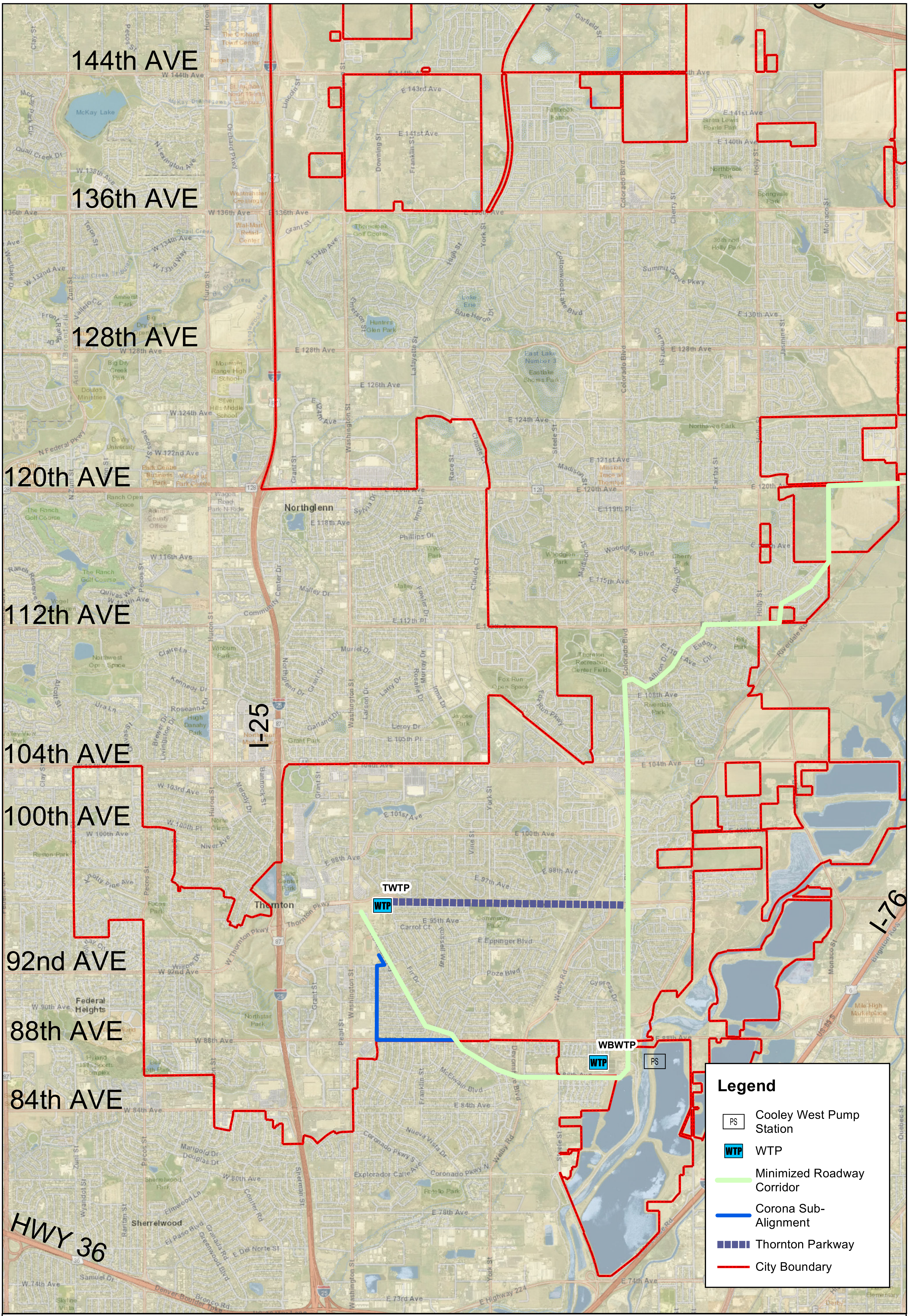

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Figure 4 -TWP Alignment Review
Minimized Roadway Corridor

1 inch = 3,333 feet

M:\DCS\Resources\WTR\WWW\Staff\Evon Harmon\Thornton Alignments\Figure 4 Minimized Roadway Corridor AS.mxd

McKay Road – Existing Pipeline Corridor

The fourth and final potential pipeline corridor identified and evaluated in this TM is described as the McKay Road – Existing Pipeline Corridor. This corridor is denoted in Figure 5. This corridor takes advantage of two favorably located utility easements within the study area including:

1. The existing easement for overhead power transmission lines that run in a generally north-south direction from 120th Avenue to 100th Avenue. This easement is approximately parallel to McKay Road from 108th Place to 100th Avenue; and
2. The existing easement for Thornton's existing 42-inch diameter and 36-inch diameter water pipelines that extend south and west from the McKay Pump Station to East Gravel Lake #2. Use of this easement would likely require acquisition of adjacent temporary construction easements to facilitate installation of the new pipeline and restrictions on construction methods to avoid impacts to the existing pipelines.

These two utility easements provide a virtually continuous pipeline corridor within utility easement from 120th Avenue to 88th Avenue. This corridor only requires short stretches of new pipeline outside of the easements for the segment along 120th Avenue from Quebec Street to the overhead power transmission line easement and for crossing Colorado Boulevard at 88th Avenue to connect to WBWTP. An advantage of this corridor is the extensive length of pipeline construction within a previously disturbed utility ROW. The general feasibility of TWP pipeline construction within the overhead power transmission line easement is apparent in the Google Earth street view images below. These images show the easement looking north from 112th Avenue and south from 104th Avenue.

One disadvantage of this corridor is the requirement for cathodic protection that will be required for construction and maintenance of the new steel pipeline within the overhead powerline easement. Stray and induced currents from the powerlines will require additional consideration for cathodic protection of the pipeline. Additionally, new pipeline installation within the existing pipeline easement may require special techniques to limit impacts to the existing pipelines within the corridor. One additional disadvantage is that short sections of the pipeline corridor along McKay Road and along the existing pipeline easement are within Adams County jurisdiction. The segments within Adams County jurisdiction include:

- Approximately 3,000 feet of pipe south of 112th Avenue within the overhead powerline easement;
- Approximately 4,600 feet of pipe south of East 98th Place (extended) to East 91st Drive (extended) within the easement of the existing pipeline;
- Approximately 1,000 feet of pipe east of Riverdale Road and north of 88th Avenue; and
- Approximately 5,500 feet of pipe along 86th Avenue west from the WBWTP to Welby Road and then northwesterly to 88th Avenue. This segment is optional and may not be needed if 88th Avenue is used for a pipeline corridor to connect WBWTP and TWTP.

Actual lengths of the new pipeline within Adams County can be reduced with slight deviations in the corridor to stay within Thornton jurisdiction.

Final connection of the TWP to the TWTP could be accomplished with a pipeline connection from WBWTP to TWTP. This final segment of the corridor is common to all of the corridors. The connecting pipeline could travel west from WBWTP along either 88th Avenue or 86th Avenue and angle in a northwesterly direction along Hoffman Way to a location on the site of the TWTP. The Hoffman Way corridor provides the shortest distance between WBWTP and TWTP, but it is also a common corridor for several other buried utilities. If the Hoffman Way corridor is considered unsuitable for new pipeline installation, the Corona Street ROW could be used as an alternate corridor. Corona Street is approximately 1,000 feet east of, and parallel to Washington Street.

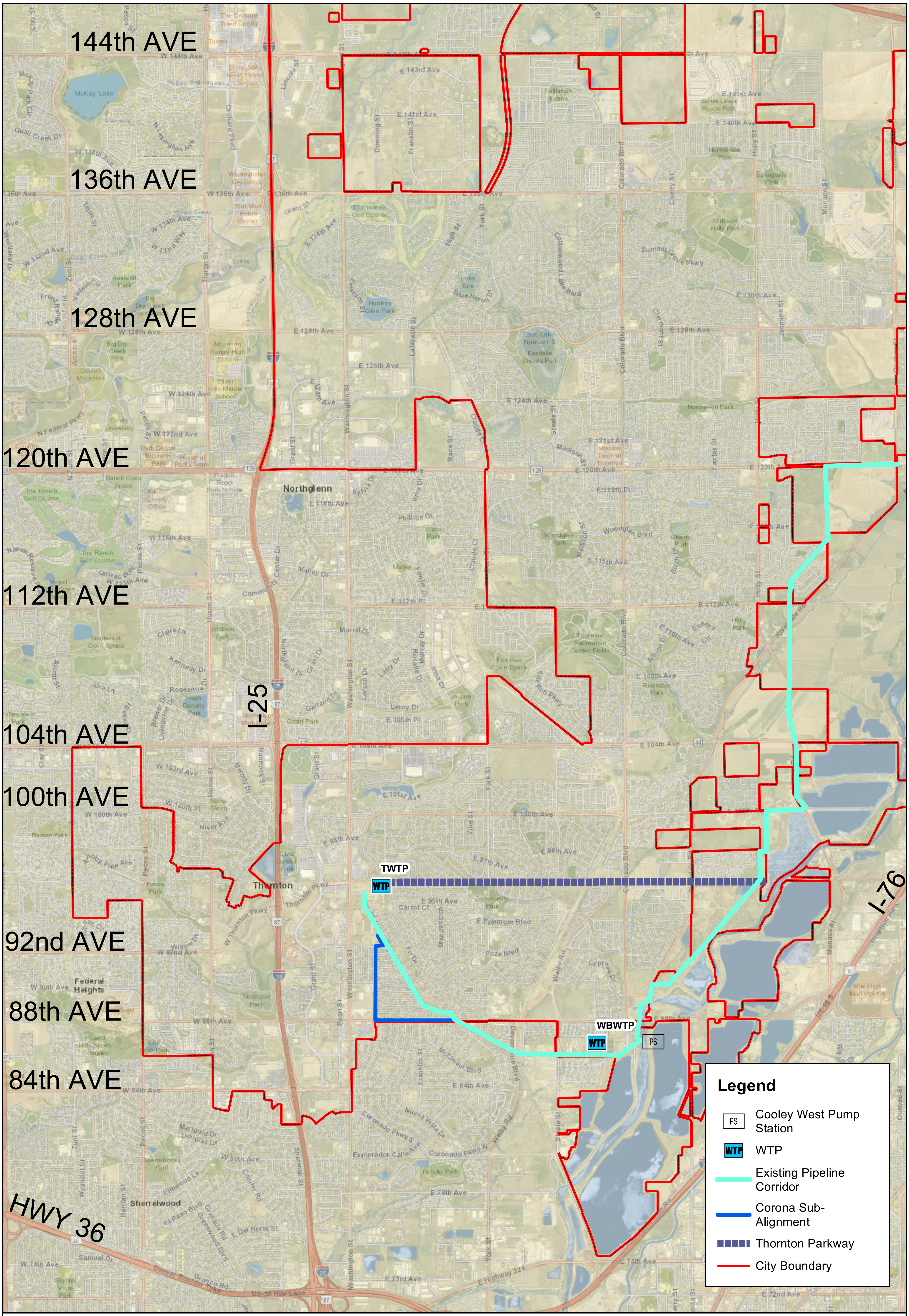

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Figure 5 -TWP Alignment Review
McKay Road - Existing Pipeline Corridor

1 inch = 3,333 feet

M:\DCS\Resources\WTR\WWW\Staff\Evon Harmon\Thornton Alignments\Figure 5 McKay Road Alignment AS.mxd

Figure 6: McKay Road – Existing Pipeline Corridor.
Existing overhead power lines looking north from 112th Avenue.

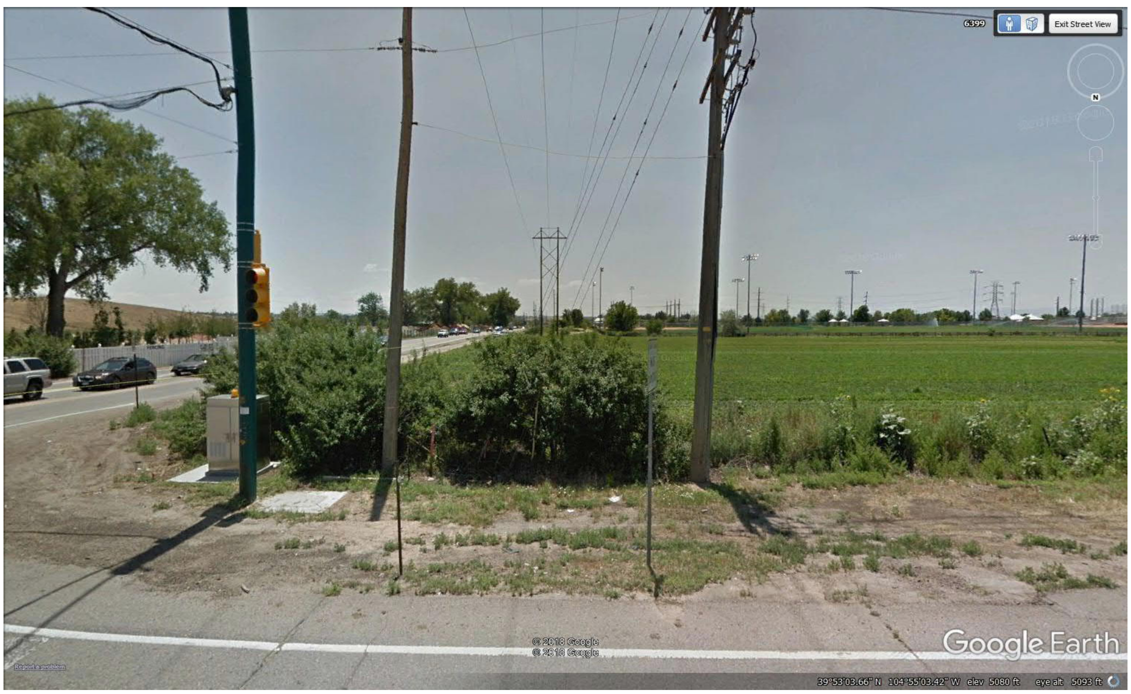

Figure 7: McKay Road – Existing Pipeline Corridor.
Looking south from 104th Avenue along the west side of McKay Road.

Evaluation of Pipeline Corridors

The focus of this TWP pipeline corridor evaluation was to subjectively compare various factors related to the suitability of each corridor for the construction, operation, and maintenance of a 48-inch diameter water pipeline. A subjective, relative score range of 1 (best) through 4 (worst) was used to compare the attributes of each type of pipeline corridor segment.

Four separate factors were defined and used to develop a relative score for pipeline construction, operation, and maintenance considerations:

1. Disruption to the public caused by traffic delays, noise, and dust. Areas including residential housing, public facilities such as schools and hospitals, and high-traffic commercial areas would be most impacted by this factor. This factor was judged to be worst (least desirable; a relative score of 4) for corridors through dense residential or commercial development. This factor was judged to be best (most desirable; a relative score of 1) for corridors that use utility or railroad ROW. Trails and minor roadways were judged to have intermediate scores between 1 and 4 for this factor.
2. Impacts (increases) to the cost of construction required by the removal and replacement of surface features or avoidance of other buried obstacles during pipeline construction. Major roadways would be most impacted by this factor. This factor was judged to be worst (least desirable; a relative score of 4) for corridors through major roadway ROW. This factor was judged to be best (most desirable; a relative score of 1) for corridors that use utility or railroad ROW. Trails and minor roadways are judged to have moderate scores between 1 and 4 for this factor.
3. Requirements and schedule and cost impacts of environmental and access permits to gain permission for construction. Areas including utility ROW would be least impacted by this factor. This factor was judged to be worst (least desirable; a relative score of 4) for railroad ROW. This factor was judged to be best (most desirable; a relative score of 1) for corridors through utility ROW. Trails and major and minor roadways are judged to have moderate scores between 1 and 4 for this factor.
4. An additional evaluation factor was used to develop a relative score for pipeline operation and maintenance and external loading considerations. Corridors including utility ROW and trails would be least impacted by this factor, and major roadways would be most impacted by this factor. Pipeline corridor conditions that negatively impact the operation and maintenance of a pipeline or that expose the pipe to consistent traffic loads were judged to be worst (least desirable; a relative score of 4) for major roadway ROW. Pipeline corridor conditions that only have minor impacts to the operation and maintenance or external loadings of a pipeline were judged to best (most desirable; a relative score of 1) for trails and utility ROW. Minor roadways and railroad ROW are judged to have moderate scores between 1 and 4 for this factor.

A summary of the relative score values that were used for each type of corridor segment is shown in the following table:

Table 1: TWP Corridor Evaluation Scoring Summary

Scoring Factor	Segment Type				
	Trail	Major Roadways	Minor Roadways	Utility ROW	Railroad ROW
Public Disruption	2.00	4.00	3.00	1.00	1.00
Surface Restoration	2.00	4.00	3.00	1.00	1.00
Environmental/Access Permit	2.00	2.00	2.00	1.00	4.00
Pipe O&M	1.00	4.00	3.00	1.00	2.50

A weighted average comparative score for each of the four identified pipeline corridors was developed by measuring the length of each type of corridor segment (Trail, Major Roadway ROW, Minor Roadway ROW, Utility ROW, and Railroad ROW) within each corridor option. The relative score for each of the corridor segment types was applied to each segment length, and the length-based weighted average score for each corridor segment was summed to determine a total score for each pipeline corridor. Based on the relative scoring values of 4 for worst condition and 1 for best condition, the corridor with the lowest comparative score is considered most preferable, and the corridor with the highest comparative score is considered least preferable. The weighted average relative scores for each of the four evaluated pipeline corridors are shown in the following table. The corridor inventories and scoring calculation table for each of the corridors are included in Appendix 1.

Table 2: TWP Corridor Weighted Average Evaluation Scoring Results

	CH2M-Identified TWP Corridor	Riverdale Road Corridor	Minimized Roadway Corridor	McKay Road – Existing Pipeline Corridor
Pipe Lengths				
Total Length (ft)	46,810	42,230	44,200	43,280
Length in Trail/Greenbelt (ft)	0	0	2,590	0
Length in Major Roadways (ft)	35,390	12,790	23,900	6,440
Length in Minor Roadways (ft)	5,350	23,890	9,150	8,100
Length in Utility ROW (ft)	6,070	4,980	6,070	24,020
Length in Railroad ROW (ft.)	0	0	0	0
Length in other area (ft)	0	570	2,490	4,720
Length outside COT Boundary (ft)	0	14,100	4,280	4,280
Evaluation Factor Scoring				
Overall Score	11.73	10.93	10.81	6.36

4. Summary and Conclusions

There are multiple potential pipeline corridors through the study area, but most segments pass through dense urban areas that would typically involve maintenance of traffic plans and surface restoration costs as part of the pipeline installation. This pipeline corridor evaluation identified two corridors that involve reduced public disruption and surface restoration costs relative to the other potential corridors. The McKay Road-Existing Pipeline Corridor is the preferred pipeline corridor by a large margin. The McKay Road-Existing Pipeline Corridor has a relative score that is approximately 40% more favorable than the second-ranked corridor, and almost 50% more favorable than the other corridors. This corridor has several significant advantages over the other corridors including:

- Maximizing the use of existing utility corridors;
- Minimizing the use of existing roadways;
- Involving the least pipeline length within dense urban areas; and
- Providing an almost direct connection to the WBWTP from Quebec Street and 120th Avenue.

The McKay Road - Existing Pipeline corridor allows for two reasonable, optional spur pipeline connections to the TWTP along either 88th Avenue and Hoffman Way, or along 96th Avenue (Thornton Parkway). It is recommended that Thornton pursue the McKay Road – Existing Pipeline Corridor as the preferred pipeline corridor. Additional study is needed to better define the requirements and constraints of the easement for the existing 48-inch diameter pipeline and to pursue easement rights within the easement for the existing overhead power line parallel to McKay Road from approximately 114th Avenue to 102nd Avenue.

The second-ranked pipeline corridor, described as the Minimized Roadway Corridor, has some advantages over each of the other pipeline corridors in the study area. This corridor could be used if fatal flaws or other constraints do not allow the use of the McKay Road – Existing Pipeline Corridor.

Appendix 1

Identified TWP Corridor

Notes The Identified TWP Corridor was described by CH2M TWP Hydraulic and Economic Analysis July 2017

Alignment Breakdown

Total Alignment Length: Percentage of Segment Overall

Trail			
Trail	0	feet	0%
Major Roadways			
120th Ave	2900	feet	76%
112th Ave	5900	feet	
Colorado Blvd	17400	feet	
104th	2690	feet	
100th Ave	6500	feet	
Minor Roadways			
Downing St.	2680	feet	6%
Steele St.	2670	feet	
Utility ROW			
Utility ROW	6070	feet	13%
Other			
Other	0	feet	0%
TOTAL	46810	feet	

Total Length of Alignment Outside of COT: 0 feet

Scoring Matrix

	CH2M Alignment
Public Disruption	3.33
Surface Restoration	3.33
Environmental Permit	1.76
Pipe	3.33
Total	11.73

Riverdale Alignment

Notes The Riverdale Alignment follows a Scenic Byway

Alignment Breakdown

Total Alignment Length: Percentage of Segment Overall

Trail			
Trail	0	feet	0%
Major Roadways			
120th Ave	2900	feet	30%
112th Ave	780	feet	
88th Ave	6520	feet	
Colorado Blvd	2590	feet	
Minor Roadways			
Riverdale Road	17620	feet	57%
Hoffman Way	6270	feet	
Utility ROW			
Utility ROW	4980	feet	12%
Other			
Other	570	feet	1%
TOTAL	42230	feet	

Total Length of Alignment Outside of COT: 14,100 feet

Scoring Matrix

	Riverdale Alignment
Public Disruption	3.03
Surface Restoration	3.03
Environmental Permit	1.86
Pipe	3.03
Total	10.93

Minimize Roadway

Notes: This alignment is a combination of the CH2M alignment and a new alignment that follows trails to the Thornton WTP.

Alignment Breakdown

Total Alignment Length: Percentage of Segment Overall

Trail			
Trail	2590	feet	6%
Major Roadways			
120th Ave	2900	feet	54%
112th Ave	2800	feet	
Colorado Blvd	14700	feet	
86th Ave	3500	feet	
Minor Roadways			
Hoffman Way	6740	feet	21%
Dahlia Drive	1610	feet	
McDougal Street	800	feet	
Utility ROW			
Utility ROW	6070	feet	14%
Other			
Other	2490	feet	5%
TOTAL	44200	feet	

Total Length of Alignment Outside of COT: 4280 feet

Scoring Matrix

	Minimize Roadway Alignment
Public Disruption	3.04
Surface Restoration	3.04
Environmental Permit	1.75
Pipe	2.98
Total	10.81

McKay Road - Existing Pipeline Corridor

Notes

The McKay Road - The Pipeline Corridor includes a segment that is parallel to the existing 42" alignment from 100th Avenue (near McKay PS) to Wes Brown Water Treatment Plant

Alignment Breakdown

Total Alignment Length:

Percentage of Segment Overall

Trail			
Trail	0	feet	0%
Major Roadways			
120th Ave	2720	feet	15%
112th Ave	0	feet	
88th Ave	3720	feet	
Colorado Blvd	0	feet	
Minor Roadways			
McKay Road	0	feet	19%
100th Ave	1360	feet	
Hoffman Way	6740	feet	
Utility ROW			
Utility ROW	24020	feet	55%
Other			
Other	4720	feet	11%
TOTAL	43280	feet	

Total Length of Alignment Outside of COT: 4280 feet

Scoring Matrix

	McKay Road - 42"Alignment
Public Disruption	1.71
Surface Restoration	1.71
Environmental Permit	1.23
Pipe	1.71
Total	6.36