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Utility Master Plan

Project No. 17-467

Volume III – Water Treatment Facilities Master Plan

The City of Thornton

Project Number: 60560104

March 2020

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Water Treatment Facilities Master Plan

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Executive Summary

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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
AWWA	American Water Works Association
CDPHE	Colorado Department of Public Health and Environment
CIP	Capital Improvement Program
EGL	East Gravel Lake
ENR	Engineering News-Record
FBRR	Filter Backwash Recycling Rule
FF	fire flow
fps	feet per second
ft	feet
GAC	granular activated carbon
gpm	gallons per minute
hr	hour(s)
ID	identification
in	inch
IESWTR	Interim Enhanced Surface Water Treatment Rule
Integrated MP	Integrated Master Plan
KPI	key performance index(ices)
LCR	Lead and Copper Rule
LT1ESWTR	Long-Term 1 Enhanced Surface Water Treatment Rule
LT2ESWTR	Long-Term 2 Enhanced Surface Water Treatment Rule
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
ng/l	nanograms per liter
NSDWR	National Secondary Drinking Water Regulations
NWTP	Northern Water Treatment Plant
O&M	operation and maintenance
PDWQ	Peak Dry Weather Flow
PHD	peak hour demand
PRV	pressure reducing valves
PS	pump station
psi	pounds per square inch
RTCR	Revised Total Coliform Rule
SDWA	Safe Drinking Water Act
Stage 1 D/DBPR	Stage 1 Disinfectants and Disinfection Byproducts Rule
Stage 2 D/DBPR	Stage 2 Disinfectants and Disinfection Byproducts Rule
SWTR	Surface Water Treatment Rule
TCR	Total Coliform Rule
TENORM	Technologically Enhanced Naturally Occurring Radioactive Material
Thornton	city of Thornton
TWTP	Thornton Water Treatment Plant
TM	technical memorandum
UMP	Utility Master Plan
WBWTP	Wes Brown Water Treatment Plant
WGL	West Gravel Lakes
WTP	water treatment plant
WTF CIP	Water Treatment Facilities Capital Improvement Program
WTF MP	Water Treatment Facilities Master Plan
W/WW	water and wastewater
W/WW IMP	Water/Wastewater Infrastructure Master Plan

1. Introduction

The city of Thornton (Thornton) has water treatment facilities that provide service to over 166,000 customers within the city as well as outside its limits, including service to Western Hills, Welby, Unincorporated Adams County, and Federal Heights (wastewater service only) communities. Thornton must serve its customer base in a cost effective manner and plan for future growth, while meeting high standards of service. At buildout (anticipated by 2065), the systems are expected to serve a population of 268,843 based on the Planning Area and Future Growth Analysis, Chapter 2, of the Water and Wastewater Infrastructure Master Plan.

This Water Treatment Facilities Master Plan (WTF MP) identifies the capital improvements required to meet buildout demands. The recommendations contained in this WTF MP were developed to provide water treatment facilities that meet identified performance criteria and anticipated buildout demands.

Utility Master Plan

Thornton's Utility Master Plan (UMP) includes planning analysis across the raw water supply, water treatment, water distribution, and wastewater collection systems. These planning evaluations and the subsequent capital improvement program (CIP) identified for each system were developed following a consistent planning basis and growth projections documented in the Planning Area and Future Growth Analysis, Chapter 2, of the Water and Wastewater Infrastructure Master Plan.

An individual master plan was developed for each of the systems, addressing the required capital improvements and system performance for three planning alternatives. Results from individual master plans were combined into the Integrated Master Plan (Integrated MP) that establishes the recommended alternative and related CIP, phasing, prioritization, and budgets for the UMP.

WTF MP Purpose

This WTF MP report presents the current state of Thornton's water treatment systems and infrastructure. This report presents the performance criteria used to determine the required improvements; treatment facility data source evaluation and regulatory conditions used in the evaluation; key findings from the system evaluations; and treatment facility improvements required to meet projected population growth and estimated demands for buildout conditions.

The proposed improvements for the Water Treatment Facilities Capital Improvement Program (WTF CIPs) are based on system and process upgrades identified as a result of data review and technical evaluations, including input from Thornton's staff. This report describes the results of these observations and analyses and provides strategies and recommendations, including cost opinions for the proposed improvements.

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 WBWTP has been included in all alternatives to address recommended upgrades identified during this WTF MP to improve the operational capacity, reliability and sustainability of the facility.

The WTF MP identifies the improvements required for each of the alternatives; however, selection of the preferred alternative was performed during completion of the Integrated MP; this process considered improvements recommended in this report as well as the raw water supply, water distribution and wastewater collection system improvements.

WTF MP Report Organization

This report is organized into five chapters, as described in Table 1. 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 to document the methodology and findings. Each chapter of this report is limited to the water treatment facilities and does not involve the raw water supply, water distribution, or wastewater collection systems, which are documented separately in the individual master plan reports.

Table 1. WTF MP Report Organization

Chapter	Description
1. System Performance Criteria	Description of the performance criteria used in evaluating Thornton's water treatment facilities.
2. Initial Data Review	Description of initial data review activities performed for the WTF MP.
3. Regulatory Compliance Evaluation	Description of the review of regulatory assessments previously completed for Thornton and identification of any applicable updates to federal and state regulations for potable water production (treatment) facilities.
4. Performance Evaluation of the WBWTP	Description of existing treatment process evaluations of WBWTP and identification of operational capacity of the individual unit processes as well as the overall facility.
5. Water Treatment Future Alternatives Evaluation	Description of the development and evaluation of alternatives. Includes identification of recommended improvements and associated capital costs for each of the three alternatives.

The individual chapters noted above were developed and finalized separately during the development of the WTF MP. 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. System Performance Criteria

Chapter 1 of this report discusses the performance criteria used in the WTF MP to evaluate existing facilities and future alternatives. Thornton's current treatment infrastructure encompasses two facilities, with a current total firm capacity of 68.1 million gallons per day (mgd) as rated by the Colorado Department of Public Health and Environment (CDPHE)[1]. The water treatment facility performance criteria have been divided into three tiers to establish 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 performance criteria include primary drinking water regulations and performance goals, which include secondary drinking water regulations. The three tiers are summarized as follows:

- Tier 1: Criteria that must be met by the system such as regulatory requirements;
- Tier 2: Criteria that represent best practice and should be met, but may not be required; and
- Tier 3: Criteria that are desired and should be met if practicable, but are not required.

3. Initial Data Review

Chapter 2 describes the initial review of data provided by Thornton to serve as the basis for water treatment facilities analyses. The data review included historical water treatment facility information in the City of Thornton 2009 Water and Wastewater Master Plan (2009 Plan) and discussions with Thornton regarding existing water treatment

[1] Rated capacity as determined by CDPHE with the largest unit out of service. Actual production capacity is higher, depending on water temperature. See Chapter 1 for additional information.

operations and equipment issues that were not otherwise identified in the data set or the 2009 Plan. The data review also included:

- Current and future water demands;
- Performance of the current treatment process;
- Original design criteria versus current state-of-the-treatment science;
- Regulatory compliance with current and anticipated future regulation requirements;
- As-builts, design drawings, and previous studies for existing infrastructure and equipment;
- Records pertaining to performance and maintenance for existing assets and systems; and
- Cost data that will be informative in assessing future capital, operations, and maintenance costs.

The data review served as a basis for the performance evaluation task in **Chapter 3**. Some data gaps were identified during the data review process, including selected process drawings and plant data. Resolution of these data gaps was completed with Thornton during the subsequent analyses.

4. Regulatory Compliance Evaluation

Chapter 3 provides an overview of the regulatory assessments, which was compiled by AECOM based on studies previously completed for Thornton by others consultants. The overview also identifies applicable updates to federal and state regulations for potable water production (treatment) facilities. Section 3.3 of the Water Treatment Plant Replacement Project CIP 15-468 Conceptual Design Report developed in November 2016 (Appendix A) identified the following applicable regulations for Thornton's water treatment facilities:

- Safe Drinking Water Act (SDWA) or National Primary Drinking Water Regulations (NPDWR);
- National Secondary Drinking Water Regulations (NSDWR);
- Lead and Copper Rule (LCR);
- Arsenic Rule;
- Radionuclides Rule;
- Total Coliform Rule (TCR);
- Revised Total Coliform Rule (RTCR);
- Surface Water Treatment Rule (SWTR);
- Interim Enhanced Surface Water Treatment Rule (IESWTR);
- Long-Term 1 Enhanced Surface Water Treatment Rule (LT1ESWTR);
- Long-Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR);
- Stage 1 Disinfectants and Disinfection Byproducts Rule (Stage 1 D/DBPR);
- Stage 2 Disinfectants and Disinfection Byproducts Rule (Stage 2 D/DBPR); and
- Filter Backwash Recycling Rule (FBRR).

Review of the regulatory framework and associated considerations that impact Thornton's water treatment facilities did not identify changes in regulations or emerging contaminants that would require modification to the treatment facilities or processes currently employed or planned by Thornton.

There has been instances of elevated levels of radioactive species found in the sludge at the lagoons at the WBWTP. While no specific cause has been identified for this condition, there is concern that changes in the levels of Technologically Enhanced Naturally Occurring Radioactive Material (TENORM) in source water could result in elevated levels, thereby requiring changes in disposal practices if radioactivity levels continue to be above the regulatory limits for land application. The elevated level of radioactivity (above disposal standards) in the sludge has been detected in two lagoons, with a third lagoon also showing elevated levels of radioactivity. The cause has been attributed to the source water, which indicates that enhanced monitoring of TENORM in the source water is warranted. Increases in frequency or concentration of radioactivity in the sludge could lead to the need to evaluate alternative dewatering and disposal practices for the treatment residuals.

5. Performance Evaluation of Wes Brown Water Treatment Plant

Chapter 4 describes the analyses of Thornton's WBWTP evaluation completed for Thornton as part of the WTF MP. Thornton also operates the TWTP as part of their water treatment facilities, but the site is scheduled to be decommissioned and replaced with a new treatment plant currently under construction. As such, analysis of the existing TWTP is not appropriate for this WTF MP and has been excluded from this evaluation.

The evaluation of WBWTP included review of previous studies, analysis of the treatment processes, operations, and supervisory control and data acquisition (SCADA) system data provided by Thornton, and interviews with the plant operators and maintenance staff. The following documents were provided by Thornton for use in this evaluation:

- 2016[2] Monthly Operator Records
- 2016 SCADA System Data
- Public Water System Record of Approved Waterworks
- 2016-2017 Analytical Data, Consisting of SCADA System Output, Laboratory Analytical Samples, and Operator Process Control Testing
- WBWTP Design Drawings
- 2014 Wes Brown WTP Operations Study by CH2M Hill
- 2017 Wes Brown Water Treatment Plant Alternative Coagulant and Ammonia Injection Study by Carollo Engineers
- 2016 Ultrafiltration Fiber Analysis Report by Avista Technologies
- Thornton Water Treatment Plant Basis of Design Report and 80 Percent Drawings

More information on each of these documents is provided in **Chapter 2**. The results of the process evaluation include identification of improvements to improve the operational capacity, reliability and sustainability of WBWTP.

System evaluations included a process capacity evaluation and water quality performance assessment. The results of these analyses were compared against the performance criteria described in **Chapter 1** to identify deficiencies and to support development of recommendations for facility improvements.

Process Capacity Evaluation

WBWTP water production has met distribution requirements to-date for finished water quality and production capacity on a continuous basis, including meeting the majority of the Tier 1, 2, and 3 Performance Criteria identified in **Chapter 1**. However, analyses of the individual treatment unit processes at WBWTP indicate that the facility would be unlikely to sustainably meet future production expectations as defined by Tier 1 criteria for total treatment system design production or unit process capacity, primarily due to performance challenges with the membrane system. This is discussed further in Appendix A of **Chapter 4**.

[2] 2016 was selected as a model year for evaluation to best reflect consistent operations at the WBWTP over the course of a calendar year. Data from 2017 included significant process changes that would have resulted in more significant data anomalies.

There is an additional gap in production criteria associated with the Tier 2 and 3 requirements for standby power. At present the facility does not have a permanent dual power supply nor an installed emergency power[3] generator[4]. The facility staff reported that they have been able to mobilize a portable generator in the past, such that there were no reported instances of power loss leading to failure to meet distribution system demands; however, the current power supply presents a risk that the facility may not meet production requirements during power outages[5].

Water Quality Performance Analysis

WBWTP finished water quality continuously meets all federal, state, and local requirements. Additionally, the facility meets the Tier 1 criteria for water quality based on the data evaluated as part of this study. However, operations staff has indicated performance issues related to the treatment[6] for taste and odor within the finished water, which denotes a failure of the facility to consistently meet the Tier 2 and Tier 3 criteria of less than 3 nanograms per liter (ng/L) for geosmin or 2-Methylisoborneol (MIB). The majority of the taste and odor issues occur in late summer when there are a higher concentration of taste and odor compounds found in the raw water supply, particularly East Gravel Lake (EGL). There were also indications of limited occurrence of aesthetic issues related to color, most frequently as a result of potassium permanganate overfeed, but there were no data to support an exceedance of the Tier 2 criteria for color or manganese. The plant was taken offline and drained when this occurrence took place.

While West Gravel Lake (WGL) has been shown to have lower concentrations of taste and odor compounds, use of this supply source has been shown to have a significant impact on production, most notably for an increased rate of fouling in the membrane systems. The sources of the fouling are not fully understood and are being further evaluated by Thornton and the membrane manufacturer.

Conclusions

The following are summary conclusions from the water treatment evaluation of the WBWTP:

1. The inlet works systems are adequately sized for the current production and regulatory requirements, but there is insufficient contact time for the potassium permanganate feed from the WGL Pump Station (PS).
2. The injection points of hypochlorite and powdered activated carbon (PAC) at the inlet works are too close to one another, resulting in competition and reduced effectiveness of both systems.
3. The coagulant addition system in the inlet works is adequately sized for current production and regulatory requirements, but the mixing method is ineffective, which results in maldistribution to the clarifiers. Projects have been completed in 2018 and 2019 to address these issues.
4. The clarifiers are adequately sized for current regulatory requirements; however, there is uneven flow distribution between the units, resulting in variable performance. WBWTP staff are evaluating whether the clarifiers are adequately sized to maintain stable membrane performance. Further study is required to stabilize clarifier performance and how to best address the hydraulic maldistribution. A new mixing system is scheduled to be installed during the winter 2019/2020 shutdown in order to potentially address maldistribution concerns.
    a. WBWTP has switched to an aluminum chlorohydrate-based coagulant, which has resulted in settling problems with the floc in the clarifiers and increased carryover to the membranes. Thornton is considering options to improve settling such as adding ferric chloride during high flow demands or replacing the clarifier tube settlers with plate settlers (this will decrease the effective loading rate from 0.62 gallons per minute per square foot (gpm/sf) to 0.43 gpm/sf at 12.5 million gallons per day per clarifier).
5. The membrane system capacity is in accordance with regulatory requirements; however, the associated design flux has been demonstrated to result in rapid membrane fouling and loss of permeability, demonstrating that the

[3] In accordance with the National Electric Code, an Emergency Generator must be capable of starting and producing power within 15 seconds of loss of primary power
[4] WBWTP currently has a generator but it is only sized for 50% of the plant capacity, which does not meet the Tier 1 criteria for production.
[5] City of Thornton will be conducting a WBWTP generator power study during the winter shutdown of 2020 to determine if additional equipment can be connected to the system during a primary power outage.
[6] WBWTP are conducting additional tests to see if higher levels of PAC can achieve the Tier 2 and Tier 3 criteria for taste compounds without adversely impact membrane performance.

design value is unsustainable for current operations. Based on analyses of other facilities equipped with this membrane technology, the sustainable operating flux would likely result in a peak production capacity closer to 30 mgd with all membrane modules populated. Significant increase in production capacity will either require operational changes to reduce membrane fouling, more frequent membrane maintenance, or the construction of additional membrane trains to provide larger surface area.

6. The unsoftened carrier water associated with the sodium hydroxide system is leading to extra maintenance.
7. The lagoon systems are inadequately sized for current production. Additionally, the return of CIP wastes and decant water from two facilities to WGL is believed to be contributing to the accumulation of significant fouling elements.

The following section includes the identified recommended improvements from the WTF MP required for enhancing existing facilities to meet the performance requirements, which are presented in **Chapter 4**. The improvements are anticipated to be required regardless of the selection of a future alternative to increase production as part of the Integrated MP.

Recommendations

The following are recommendations for WBWTP equipment and process data to improve system performance:

1. Continue to monitor manganese removal performance after implementing other treatment process improvements at the inlet works to determine if increased contact time for potassium permanganate feed from the WGL pump station is needed.
2. Discontinue the use of sodium hypochlorite for manganese oxidation at the inlet works and throughout treatment processes. The current introduction of potassium permanganate is more favorable for the naturally occurring manganese, and the change to aluminum-based coagulants is anticipated to reduce the introduction of secondary manganese. If the change in coagulants is insufficient, it is recommended to evaluate the opportunity to add a secondary potassium permanganate feed point downstream of the PAC addition to improve reaction kinetics.
3. The coagulant mixing system is planned to be replaced with a new flash mix system, which is anticipated to address the identified mixing concerns.
4. Monitor the hydraulic maldistribution between clarifiers after the replacement of the mixing system to determine if further process improvements are needed.
5. Equip all membrane basins with the maximum number of membrane cassettes in order to operate the systems at a lower flux.
6. Conduct a study on the residuals management to identify the most appropriate methods to address the capacity gap in the existing lagoons.
7. Cease discharge of membrane CIP to the residuals lagoons; this waste should be neutralized and disposed of offsite.
8. Monitor fouling rates after eliminating the return of CIP wastes. If there is not sufficient improvement, investigate redirecting decant water from the WBWTP lagoons to a location downstream of WGL.

6. Water Treatment Future Alternatives Evaluation

Chapter 5 develops and evaluates alternatives for improving existing treatment processes[7] for water quality performance and for increasing production capacity to meet buildout water demand requirements. Recommended improvements have been segmented into the following primary categories:

- Process enhancements, which are identified in **Chapter 4**, further define modifications to WBWTP in order to achieve improvements in water quality performance to meet the system performance criteria.
- TWTP sludge line replacement analysis, which includes the evaluation of the required sizing based on current and future flows as well as the effectiveness of the current infrastructure used to transfer residuals from TWTP to WBWTP.
- Other miscellaneous improvements, which include work that may not directly impact production quality or quantity but have been identified as opportunities to improve the service life of equipment, improve operational efficiency, and/or reduce maintenance activities.
- Future production requirements, which identify the modifications to the facility production capacity to address existing process deficiencies in order to achieve a more sustainable operation.

Three alternatives were identified in conjunction with the Raw Water Supply and the Water and Wastewater Infrastructure Master Plans to meet future production requirements, which are summarized as follows:

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

Table 2 summarizes the production requirements for the three alternatives during maximum day demand (MDD) events. The existing treatment capacity at WBWTP for each alternative is assumed to be 54.8 mgd based on the estimated sustainable flux with the proposed existing improvements to WBWTP and the manufacturer design flux which is discussed further in Section 2.1.1 of **Chapter 5**.

Table 2. Summary of Future Alternative Production Requirements

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

Process Enhancements

Table 3 summarizes the recommended improvements for the existing unit processes at WBWTP to meet quality and production system performance criteria, as identified in **Chapter 1** and **Chapter 4**.

[7] The new TWTP is currently under construction; therefore, no performance improvements were available to be evaluated. For the purposes of the WT MP, it is assumed that the new TWTP is operational and capable of producing finished water consistent with the design criteria. The process evaluation was limited to performance of the WBWTP .

Table 3. Recommended WBWTP Existing Process Improvements

Process	Recommended Improvement	Comments
Manganese Removal	Reduce and/or eliminate the hypochlorite feed for manganese control	This recommendation is based on improved manganese control anticipated to be achieved by relocating disinfection, lowered PAC doses, and potential elimination of secondary manganese control systems along with a change to aluminum-based coagulants. Further monitoring of manganese removal is recommended after the relocation of disinfection.
Manganese Reduction	Convert to aluminum-based coagulation	This recommendation is made to reduce the introduction of secondary manganese that is common with iron coagulants. The existing feed equipment is adequate for the aluminum coagulant, so this change is primarily an operational cost change. This change was completed in 2019
Taste and Odor	Relocate the hypochlorite feed and monitor system improvements	This recommendation is based on switching to post-filtration disinfection, which is already planned; this is anticipated to curtail the competition between hypochlorite and PAC, increasing the removal efficiency. Work is also being completed as part of the Raw Water Master Plan to better manage raw water supplies, focusing on reducing the formation of taste and odor compounds. PAC is anticipated to be able to achieve 1-log reduction (90%), which will meet the Tier 1 criteria if the influent can be maintained below 50 ng/L. Further monitoring of the impact to taste and odor management is recommended after implementing the relocation of disinfection and raw water management strategies. If the Tier 1 criteria cannot be met, further evaluation of the installation of granular activated carbon (GAC) with or without advanced oxidation processes would be necessary.
Coagulant Mixing	Replace the existing inline mixer with a new flash mix system	This recommendation is already planned. Further monitoring of clarifier performance after implementation is recommended to confirm that differential performance issues have been adequately addressed.
Clarifier	Convert to aluminum-based coagulation	This recommendation is made to reduce the risk associated with iron fouling of the membranes. The existing feed equipment is adequate for the aluminum coagulant, so this change is primarily an operational cost change. This change was completed in 2019, but it has resulted in slower settling for floc and increased carryover to the membrane system. Additional study is being conducted to optimize clarifier performance with the aluminum coagulant to improve capture of solids.
Membranes	Implement operational changes to achieve more sustainable flux	Fully populate empty cassettes within the existing membranes trains. Elimination or treatment of return or reject waste to remove foulants. If required to meet a target production, increase membrane area to coincide with the reduction in flux.

Sludge Line from TWTP to WBWTP

Under current operations, all sludge generated at the TWTP is collected and conveyed to the WBWTP lagoons via the TWTP sludge line. The existing sludge line is 16 inches in diameter and 14,600 feet in length. The discharge elevation at TWTP is 5365.5 feet, and the intake elevation at the WBWTP lagoon, based on embankment elevation, is 5102.2 feet. The maximum theoretical sludge flow that can be conveyed from TWTP to WBWTP in the existing sludge line is 5,000 gallons per minute (gpm). However, previous testing completed for Thornton has demonstrated that the hydraulic capacity of the line is limited to between 1,000 to 1,500 gpm, attributed to piping dynamics, sludge blockages, and additional factors that are not captured in the hydraulic calculations. Based on the field observations, the existing sludge line does not provide sufficient capacity to allow for reliable operations of the new TWTP and requires replacement.

Other Miscellaneous Improvements

Table 4 provides a summary of the additional elements that are intended to be incorporated into the CIP as a result of the WTF MP.

Table 4. Miscellaneous Treatment Plant Improvements, Maintenance Projects, and Studies

Process	Recommended Improvement	Comments
Chemical Feed	Coagulant tank modifications	Maintenance project to address risk of cracking when the tank is filled to capacity.
Taste and Odor	PAC line improvements	Maintenance project to reduce the potential for plugging of PAC lines.
Taste and Odor	PAC storage improvements	Operational enhancement project to increase onsite storage of PAC to avoid supply disruption.
Taste and Odor	WBWTP alternatives analysis for GAC or advanced oxidation process	Alternatives study regarding taste and odor mitigation if the improvements recommended in Section 2.1 do not resolve the taste and odor issues satisfactorily.
Clarifiers	Complete recoating of the clarifiers	Maintenance project identified by Thornton in order to maintain the service life of clarification equipment.
Clarifier	Flow distribution study	Study to evaluate impact of improving flow balance between clarifiers to improve performance.
Membranes	Air compressor	Capital project to add additional air compressors to improve redundancy.
Membranes	Membrane replacement	Operational cost associated with replacement of membranes due to age and lost functionality.
Membranes	Train 8 modifications	Capital project to modify Train 8 to match the capacity of Train 1-7 as well as adding ancillary equipment for full redundancy.
Finished Water	Clearwell lining	Capital project to add lining system to clearwell to reduce leakage and increase longevity of the system.
Solids Management	Study of relocation of return water downstream of gravel lakes	Study of the impacts of sending lagoon return water to a point on the system that is downstream of the source supplies for WGL and EGL, which would eliminate the potential for recycling of fouling compounds. This approach could be considered after implementing other improvements in the event that the rate of fouling has not been adequately addressed.
Solids Management	Study application of treatment approaches to the return water	Introduction of an oxidant (sodium hypochlorite or ozone) to address fouling compounds including polymers. OR Introduction of a coagulant or settling agent to convert colloidal material to convert to a settable solid.
Solids Management	Evaluate opportunity to install solids management infrastructure into the new TWTP	Study to determine if enhancement to the new TWTP would improve overall treatment operations by reducing loading to the WBWTP lagoons.
Safe Drinking Water Act Amendment	Risk & resilience assessment	Community water system serving a population of greater than 3,300 persons shall conduct an assessment of the risks to, and resilience of, its system as part of Section 2013 of the America's Water Infrastructure Act.

Future Production Requirements

The conceptual treatment facility elements for Alternatives 1, 2, and 3 to meet future production requirements are summarized in Tables 5-7. Additional details are available in **Chapter 5.**

Table 5. Alternative 1 (New NWTP) Conceptual Treatment Facility Elements

Area	Approach
Conventional Treatment Process	• Raw water pipeline • Pretreatment: Flash mixing, inline with raw water • Flocculation: Two trains at 100% capacity each. Each train includes three stages of flocculation. • Sedimentation: Two trains at 100% capacity each. Each train includes three zones of sedimentation. • Ozone: Two ozone generators with companion feed and destruct systems, oxygen storage and feed equipment, two parallel contact basins • Biological Filtration: Six filters loaded GAC. Each filter sized for 20% of the plant rated capacity • Clearwell: 0.7 Baffle Factor, 1.5 Safety Factor, designed to work with 12.5% sodium hypochlorite to achieve 0.5 log giardia and 2.0 log virus disinfection contact time • Filter Backwash: supply tank, pumps (1 operational, 1 standby), backwash waste tank
Finished Water Supply	• Finished Water Pumps: Two operational, one standby • Finished Water Pipeline: Existing tank, proposed tank
Solids Handling	• Return Water Pumps: Two operational, one standby • Mechanical Dewatering System
Site Work	• Site Acquisition: Private property in unincorporated Adams County • Site Area: 14.5 acres northwest of east 140th Avenue and Dahlia Way • Access: Dahlia Way

Table 6. Alternative 2 (TWTP Expansion) Conceptual Treatment Facility Elements

Area	Approach
Process Expansion	• Raw Water Pipeline: Reconfigure for expansion • Pretreatment: Expand to meet enhanced capacity • Treatment: Construct two additional parallel trains east of current facilities • Flocculation: Two trains at 100% capacity each. Each train includes three stages of flocculation • Sedimentation: Two trains at 100% capacity each. Each train includes three zones of sedimentation • Ozone: One additional ozone generators with companion feed and destruct systems, oxygen storage and feed equipment, two additional parallel contact basins • Biological Filtration: Six filters loaded with GAC. Each filter sized for 20% of the plant rated capacity • Clearwell: Construct second clearwell south of existing clearwell, matching 0.7 Baffle Factor, 1.5 Safety Factor, designed to work with 12.5% NaOCl to achieve 0.5 Log Giardia and 2.0 Log Virus disinfection contact time • Filter Backwash: Construct second backwash facility with second clearwell • Chemicals: Install additional storage equipment in expansion west of building
Finished Water Supply	• Finished Water Pipeline: Install gravity line from second clearwell to existing Clearwell No. 2
Solids Handling	• Return Water Pumps: Two operational, one standby • Lagoons: Configured for external sludge removal • Return Water Pumps: Two operational, one standby • Solids Detention: Existing detention basin • Solids Pipeline: Replace existing 16 inch sludge piping with new 24 inch pipeline to Wes Brown lagoons

Table 7. Alternative 3 (Expanded WBWTP) Conceptual Treatment Facility Elements

Area	Approach
Process Expansion	• Clarifier: Two additional • Membrane: Four additional trains • Ozone: Two ozone generators with companion feed and destruct systems, oxygen storage and feed equipment, two parallel contact basins • Post Filtration Contactors: Six filters loaded GAC. Each filter sized for 20% of the plant rated capacity
Site Work	• Site Acquisition: additional property adjacent to WBWTP as required to facilitate additional lagoons • Facility Improvements to address aging infrastructure
Solids Handling	• Mechanical Dewatering System

Capital Improvement Program

Existing Improvements

Table 8 summarizes costs associated with improvements to existing infrastructure at WBWTP as identified in **Chapter 4**. Improvements that were identified that have already been completed by Thornton are not included.

Table 8. Existing WBWTP Improvements CIP Cost Summary

Recommended Improvement[8]	Budgetary Cost
Convert to Aluminum-based Coagulation	$0
Taste & Odor Removal Improvements (PAC Feed & Storage Improvements)	$710,000
Membrane Surface Area Increase	$0
Residuals Management Improvements	$1,100,000
Clarifier Flow Distribution Study	$30,000
Study to Eliminate Recycling for Clean-in-Place Wastes	$30,000
Return Water Discharge Study	$50,000
Thornton Water Treatment Residuals Management Study	$110,000
Clarifier Coatings Rehabilitation	$500,000
Coagulant Tank Repairs	$40,000
Additional air compressor and reject pump	$500,000
Expansion of Train 8 by 5 cassettes along with vacuum pumps and blowers.	$1,840,000
TOTAL	$4,910,000

Future Improvements

Project costs for identified improvements were developed water treatment infrastructure, support facilities, and land acquisition for each of the future alternatives. Table 9 summarizes the treatment facility improvements costs for each alternative. A detailed list of the improvements in each category is provided in **Chapter 5**.The costs in Table 9 have been updated to include mechanical dewatering for Alternatives 1 and 2 which are not reflected in **Chapter 5**.

[8] The identified improvements to WBWTP are intended to address performance elements; additional elements of the facility does not provide full redundancy, such as the inlet pipeline, membrane distribution channel, and minor chemical systems. These elements should be further evaluated as part of an expansion design project to determine if the additional redundancy is warranted.

Table 9. Water Treatment Facilities CIP Cost Summary

Type	Alternative 1	Alternative 2	Alternative 3
Tier 1	$100,790,000	$102,640,000	$100,660,000
Tier 2	$1,330,000	$1,330,000	$1,330,000
Tier 3	$220,000	$220,000	$200,000
Total	$102,000,000	$104,000,000	$102,000,000
20 Year Net O&M	$10,000,000	$0	$30,000,000

System Performance Criteria

Chapter 1

Utility Master Plan

Project No. 17-467

Water Treatment Facilities Master Plan

System Performance Criteria

The City of Thornton

Project number: 60560104

AECOM

June 20, 2018

FINAL

Quality information

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Tables

List of Acronyms

µg/L – Microgram per Liter
CIP – Capital Improvement Program
cu – Color Unit
D/DBPR – Disinfectants and Disinfection Byproducts Rule
LRAA – Locational Running Annual Average
mg/L – Milligram per Liter
MCL – Maximum Contaminant Level
MGD – Million Gallon per Day
MIB – 2-Methylisoborneol
ng/L – Nanogram per Liter
NEC – National Electric Code
NTU – Nephelometric Turbidity Unit
SMCL – Secondary Maximum Contaminant Level
TBD – To be determined
T&O – Taste and Odor
TM – Technical Memorandum
TON – threshold odor number
US EPA – United States Environmental Protection Agency
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) water treatment facilities. The intent of these criteria is to establish a basis is to assess the performance of the existing treatment facilities, and to identify current constraints and future improvements. The criteria have been developed based on a thorough review of the 2009 Water and Wastewater Master Plan (2009 Plan); City, State, and Federal standards; applicable industry standards; the Water Treatment Plant Replacement Project CIP 15-468 Conceptual Design Report (November 2016 *Carollo),* and the Water Treatment Plant Replacement Project CIP 15-468 Basis of Design Report (October 2017 *Burns & McDonnell)*. The criteria includes factors related to resiliency, which is an important consideration necessary to ensure adequate reliability of delivering the finished water supply and quality to meet the needs of Thornton's current and future customers.

The criteria for the treatment systems are divided into three tiers, recognizing differences in the levels of system performance that may be required based on regulatory standards versus performance goals that are established based on secondary standards. Separating these requirements is intended to provide Thornton guidelines related to varying service level goals for each tier, which can then allow for discretion to be used in selecting which improvements should be implemented. The three tiers are 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 production criteria that include capacities and resiliency considerations. Section 3 summarizes the water quality criteria for influent, settled and finished water.

2. Water Treatment Facilities Production Criteria

Based on a review of system requirements and industry standards, selected criteria have been identified for Tier 1, 2, and 3 associated with overall production quantity.

Tier 1 Criteria

The focus of Tier 1 is to identify minimum system requirements for treatment criteria that must be met by the system. Failure to meet these criteria would result in Thornton having to curtail finished water deliveries to customers.

The Tier 1 water treatment facilities performance criteria that will be used in the Water Treatment Master Plan are described in Table 1.

Table 1: Tier 1 Water Treatment Facilities Performance Criteria

Performance Parameter	Criteria	Criteria Source
Total Treatment System Capacity	Total Production Capacity equal to System Maximum Daily Demand during drought[1] period with a full treatment unit out of service at each treatment facility	City delivery requirement to produce sufficient capacity of potable water on a daily basis during a drought period
Unit Process Capacity	Firm installed capacity to meet production with one unit of each critical processes out of service	Redundancy requirement of N+1 essential for operations and maintenance

Performance Parameter	Criteria	Criteria Source
Wes Brown WTP - Critical treatment processes sized to meet capacity requirements	Various; established by previous approved design basis from various sources	To be included in Wes Brown WTP Evaluation TM
New Thornton WTP – Critical treatment processes sized to meet capacity requirements	Various for each process, established by design basis report (see criteria source)	Section 3 - Water Treatment Plant Replacement Project CIP 15-468 Basis of Design Report (November 2017), *Burns & McDonnell*
New future WTP (TBD if required) - Critical treatment processes sized to meet capacity requirements	Various, established by design basis utilized for new Thornton WTP (see criteria source)	Section 3 - Water Treatment Plant Replacement Project CIP 15-468 Basis of Design Report (November 2017), *Burns & McDonnell*
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 required System Capacity

[1]Max Day Drought condition is approximately 12.5% greater than the Max Day Non-Drought, which reflects a higher demand used for planning purposes.

Tier 2 Criteria

The focus of Tier 2 is to identify recommended system requirements for treatment criteria that should be met by the system and are industry best practices. Failure to meet these criteria may not be expected to result in Thornton having to curtail finished 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 water treatment facilities performance criteria that will be used in the Water Treatment Master Plan are described in Table 2.

Table 2: Tier 2 Water Treatment Facilities Performance Criteria

Performance Parameter	Criteria	Criteria Source
Redundancy for non-critical equipment (optional equipment excluded)	Reserved space to allow for installation of temporary systems to provide flexibility in operations and maintenance with one unit of each non-critical processes out of service	Redundancy requirement of N+1 for operations and maintenance
Standby Power	Dual power source available in order to meet production requirements without service interruption	Recommended to provide production associated with System Capacity

Tier 3 Criteria

The focus of Tier 3 is to identify recommended system goals for treatment criteria to improve performance and ease operations. Failure to meet these criteria is not expected to result in Thornton having to curtail finished water deliveries to customers but may increase risk of disruption to Operations and Maintenance activities that temporarily increase production costs.

The Tier 3 water treatment facilities performance criteria that will be used in the Water Treatment Master Plan are described in Table 3.

Table 3: Tier 3 Water Treatment Facilities Performance Criteria

Performance Parameter	Criteria	Criteria Source
System Capacity when largest plant is down	Production Capacity equal to System Average Daily Demand during non-drought period with a full treatment unit out of service at each treatment facility - Assuming a mandatory outdoor water use restriction during this period	City delivery requirement to produce sufficient capacity of potable water on a daily basis during a major outage
Redundancy for optional equipment	Firm installed capacity to allow for ease of operations and maintenance with one unit of each optional processes out of service	Redundancy requirement of N+1 for operations and maintenance
Emergency 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

3. Water Treatment Facilities Water Quality Criteria

Based on a review of regulatory requirements associated with US EPA Safe Drinking Water Act Standards as well as recommendations associated with secondary standards, selected criteria for water quality have been identified in for Tier 1, 2, and 3. The quality standards apply to various stages within the treatment associated with either raw water, settled water and finished water.

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 primary performance standards. Failure to meet any National Primary Drinking Water Regulation would result in Thornton having to issue advisory orders to customers that the treated water does not meet requirements. Failure to meet other Tier 1 criteria could result in water quality that fails to meet aesthetic goals established by City of Thornton for its customers.

The Tier 1 water treatment facilities water quality criteria are described in Table 4. The National Primary Drinking Water Regulations are listed in Appendix A.

Table 4: Tier 1 Water Treatment Facilities Water Quality Criteria

Performance Parameter	Criteria	Criteria Source
Influent Water Quality - Turbidity	≤ 50 NTU	Standley Lake and EGL4 Historical Source Water Quality - Water Treatment Plant Replacement Project CIP 15-468 Conceptual Design Report (November 2016), *Carollo*
Influent Water Quality – pH	6.0 – 10	Standley Lake and EGL4 Historical Source Water Quality - Water Treatment Plant Replacement Project CIP 15-468 Conceptual Design Report (November 2016), *Carollo*

Performance Parameter	Criteria	Criteria Source
Influent Water Quality - Temperature	0.5 – 27 degrees C	Standley Lake and EGL4 Historical Source Water Quality - Water Treatment Plant Replacement Project CIP 15-468 Conceptual Design Report (November 2016), *Carollo*
Influent Water Quality - Alkalinity	35 – 250 mg/L as $CaCO_3$	Standley Lake and EGL4 Historical Source Water Quality - Water Treatment Plant Replacement Project CIP 15-468 Conceptual Design Report (November 2016), *Carollo*
Influent Water Quality - Total Organic Carbon	0.5 – 9.0 mg/L	Standley Lake and EGL4 Historical Source Water Quality - Water Treatment Plant Replacement Project CIP 15-468 Conceptual Design Report (November 2016), *Carollo*
Influent Water Quality - Dissolved Organic Carbon	0.5 – 9.0 mg/L	Standley Lake and EGL4 Historical Source Water Quality - Water Treatment Plant Replacement Project CIP 15-468 Conceptual Design Report (November 2016), *Carollo*
Influent Water Quality - Total Hardness	60 – 350 mg/L as $CaCO_3$	Standley Lake and EGL4 Historical Source Water Quality - Water Treatment Plant Replacement Project CIP 15-468 Conceptual Design Report (November 2016), *Carollo*
Influent Water Quality - Total Dissolved Solids	50 – 750 mg/L	Standley Lake and EGL4 Historical Source Water Quality - Water Treatment Plant Replacement Project CIP 15-468 Conceptual Design Report (November 2016), *Carollo*
Influent Water Quality - Iron (Dissolved)	≤1.5 mg/L	Standley Lake and EGL4 Historical Source Water Quality - Water Treatment Plant Replacement Project CIP 15-468 Conceptual Design Report (November 2016), *Carollo*
Influent Water Quality - Manganese (Dissolved)	≤1.0 mg/L	Standley Lake and EGL4 Historical Source Water Quality - Water Treatment Plant Replacement Project CIP 15-468 Conceptual Design Report (November 2016), *Carollo*
Influent Water Quality - Bromide	≤0.5 mg/L	Standley Lake and EGL4 Historical Source Water Quality - Water Treatment Plant Replacement Project CIP 15-468 Conceptual Design Report (November 2016), *Carollo*
Influent Water Quality - Geosmin	≤300 ng/L	Standley Lake and EGL4 Historical Source Water Quality - Water Treatment Plant Replacement Project CIP 15-468 Conceptual Design Report (November 2016), *Carollo*

Performance Parameter	Criteria	Criteria Source
Influent Water Quality - MIB	≤500 ng/L	Standley Lake and EGL4 Historical Source Water Quality - Water Treatment Plant Replacement Project CIP 15-468 Conceptual Design Report (November 2016), *Carollo*
Influent Water Quality - Orthophosphate as Phosphates	≤3.0 mg/L	Standley Lake and EGL4 Historical Source Water Quality - Water Treatment Plant Replacement Project CIP 15-468 Conceptual Design Report (November 2016), *Carollo*
Influent Water – Nitrate as N	≤3.0 mg/L	Standley Lake and EGL4 Historical Source Water Quality - Water Treatment Plant Replacement Project CIP 15-468 Conceptual Design Report (November 2016), *Carollo*
Finished Water – Nitrate as N	≤3.0 mg/L	Standley Lake and EGL4 Historical Source Water Quality - Water Treatment Plant Replacement Project CIP 15-468 Conceptual Design Report (November 2016), *Carollo*
Influent Water Quality - Various	Various – see Appendix A	National Primary Drinking Water Regulations
Finished Water - Chloramines Residual (as Cl2)	0.5 to 4 mg/L	City Treatment Goal - Water Treatment Plant Replacement Project CIP 15-468 Basis of Design Report (November 2017), *Burns & McDonnell*
Finished Water - Color	≤15 true color units (cu)	National Secondary Drinking Water Regulations
Finished Water - Copper	≤1.0 mg/L	National Secondary Drinking Water Regulations
Finished Water - Corrosivity	Non-corrosive Langelier Saturation Index = 0.0 +/- 0.1	National Secondary Drinking Water Regulations
Finished Water - Fluoride	≤2.0 mg/L	National Secondary Drinking Water Regulations
Finished Water - Iron	≤0.3 mg/L	National Secondary Drinking Water Regulations
Finished Water - Manganese	≤0.05 mg/L	National Secondary Drinking Water Regulations
Finished Water - Odor	MIB / Geosmin concentration < 5 ng/L	National Secondary Drinking Water Regulations
Finished Water - pH	7.2 – 8.5	National Secondary Drinking Water Regulations City Treatment Goal - Water Treatment Plant Replacement Project CIP 15-468 Basis of Design Report (November 2017), *Burns & McDonnell* (Lead and Copper corrosivity requirement)
Finished Water – Alkalinity	> 44 mg/L as $CaCO_3$	City Treatment Goal - Water Treatment Plant Replacement Project CIP 15-468 Basis of Design Report (November 2017), *Burns & McDonnell* (Lead and Copper corrosivity requirement)

Tier 2 Criteria

The focus of Tier 2 is 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 water treatment facilities water quality criteria are described in Table 5.

Table 5: Tier 2 Water Treatment Facilities Water Quality Criteria

Performance Parameter	Criteria	Criteria Source
Settled Water – Total Organic Carbon	Removal per Stage 1 D/DBPR for conventional treatment plants	City Treatment Goal - Water Treatment Plant Replacement Project CIP 15-468 Basis of Design Report (November 2017), *Burns & McDonnell*
Settled Water - Manganese	< 0.03 mg/L (60% of SMCL)	City Treatment Goal - Water Treatment Plant Replacement Project CIP 15-468 Basis of Design Report (November 2017), *Burns & McDonnell*
Finished Water - Turbidity	< 0.10 NTU 95% of the time	City Treatment Goal - Water Treatment Plant Replacement Project CIP 15-468 Basis of Design Report (November 2017), *Burns & McDonnell*
Finished Water - Chlorite	< 0.5 mg/L (50% of MCL)	City Treatment Goal - Water Treatment Plant Replacement Project CIP 15-468 Basis of Design Report (November 2017), *Burns & McDonnell*
Finished Water - Manganese	< 0.03 mg/L (60% of SMCL)	City Treatment Goal - Water Treatment Plant Replacement Project CIP 15-468 Basis of Design Report (November 2017), *Burns & McDonnell*
Finished Water - T&O	< 3 ng/L for Geosmin and MIB	City Treatment Goal - Water Treatment Plant Replacement Project CIP 15-468 Basis of Design Report (November 2017), *Burns & McDonnell*
Finished Water - Langelier Saturation Index	> 0	City Treatment Goal - Water Treatment Plant Replacement Project CIP 15-468 Basis of Design Report (November 2017), *Burns & McDonnell*
Finished Water - Chloramines Residual (as Cl2) Tolerance	± 0.1 mg/L of Setpoint	City Treatment Goal - Water Treatment Plant Replacement Project CIP 15-468 Basis of Design Report (November 2017), *Burns & McDonnell*
Finished Water – Aluminum	0.05 - 0.2 mg/L	National Secondary Drinking Water Regulations
Finished Water - Chloride	≤250 mg/L	National Secondary Drinking Water Regulations
Finished Water - Foaming Agents	≤0.5 mg/L	National Secondary Drinking Water Regulations
Finished Water - Silver	≤0.1 mg/L	National Secondary Drinking Water Regulations
Finished Water - Sulfate	≤250 mg/L	National Secondary Drinking Water Regulations
Finished Water - Zinc	≤5 mg/L	National Secondary Drinking Water Regulations
Finished Water - Total Trihalomethanes (TTHM)	< 40 µg/L (50% of LRAA MCL)	City Treatment Goal - Water Treatment Plant Replacement Project CIP 15-468 Basis of Design Report (November 2017), *Burns & McDonnell*
Finished Water - Haloacetic Acids (HAA5)	< 30 µg/L (50% of LRAA MCL)	City Treatment Goal - Water Treatment Plant Replacement Project CIP 15-468 Basis of Design Report (November 2017), *Burns & McDonnell*
Finished Water - Bromate	< 5 µg/L (50% of MCL)	City Treatment Goal - Water Treatment Plant Replacement Project CIP 15-468 Basis of Design Report (November 2017), *Burns & McDonnell*
Finished Water - Cylindrospermopsin	< 0.7 µg/L	10-day Health Advisory for infants (2015)
Finished Water - Microcystins	< 0.3 µg/L	10-day Health Advisory for infants (2015)

Tier 3 Criteria

The focus 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 water treatment facilities criteria are described in Table 6.

Table 6: Tier 3 Water Treatment Facilities Water Quality Criteria

Performance Parameter	Criteria	Criteria Source
Settled Water – Turbidity, Each Treatment Train	< 1.0 NTU 95% of the time	City Treatment Goal - Water Treatment Plant Replacement Project CIP 15-468 Basis of Design Report (November 2017), *Burns & McDonnell*
Settled Water – pH Tolerance, Each Treatment Train	± 0.1 of Setpoint	City Treatment Goal - Water Treatment Plant Replacement Project CIP 15-468 Basis of Design Report (November 2017), *Burns & McDonnell*
Finished Water - Free Ammonia as N	0.01 to 0.05 mg/L	City Treatment Goal - Water Treatment Plant Replacement Project CIP 15-468 Conceptual Design Report (November 2016), Carollo
Finished Water - Calcium Carbonate Precipitation Potential	3 to 8 mg/L	City Treatment Goal - Water Treatment Plant Replacement Project CIP 15-468 Basis of Design Report (November 2017), *Burns & McDonnell*
Finished Water - pH Tolerance	± 0.1 of Setpoint	City Treatment Goal - Water Treatment Plant Replacement Project CIP 15-468 Basis of Design Report (November 2017), *Burns & McDonnell*
Finished Water - Iron	< 0.1 mg/L	City Treatment Goal - Water Treatment Plant Replacement Project CIP 15-468 Basis of Design Report (November 2017), *Burns & McDonnell*

Appendix A – Water Quality Criteria from Primary Drinking Water Regulations

This document summarizes the finished water criteria associated with the National Primary Drinking Water Regulations as documented in the *Regulatory Evaluation Technical Memorandum*.

Table A.1: Water Quality Criteria from Primary Drinking Water Regulations

Performance Parameter	Criteria	Criteria Source
Finished Water - Cryptosporidium	2 log reduction	National Primary Drinking Water Regulations
Finished Water - Giardia lamblia	3 log reduction	National Primary Drinking Water Regulations
Finished Water - Heterotrophoc Plate Count (HPC)	< 500 bacterial colonies/mL	National Primary Drinking Water Regulations
Finished Water - Legionella	0 mg/L	National Primary Drinking Water Regulations
Finished Water - Fecal Coliform/E. Coli	Non-Detect	National Primary Drinking Water Regulations
Finished Water - Total Coliforms	Non-Detect	National Primary Drinking Water Regulations
Finished Water - Turbidity	Varies depending on treatment technique (Must comply with Primary Drinking Water Regulations): - Conventional treatment: ≤ 0.3 NTU 95% of the time, never to exceed 1 NTU - Membrane treatment: ≤ 0.1 NTU 95% of the time, never to exceed 0.5 NTU	National Primary Drinking Water Regulations
Finished Water - Viruses (Enteric)	4 log reduction	National Primary Drinking Water Regulations
Finished Water - Bromate	10 µg/L	National Primary Drinking Water Regulations
Finished Water - Chlorite	0.8 mg/L	National Primary Drinking Water Regulations
Finished Water - Haloacetic Acids (HAA5)	0.060 mg/L	National Primary Drinking Water Regulations (locational running annual average)
Finished Water - Total Trihalomethanes (TTHM)	0.080 mg/L	National Primary Drinking Water Regulations (locational running annual average)
Finished Water - Chloramines (as Cl_2)	0.2-4.0 mg/L	National Primary Drinking Water Regulations
Finished Water - Chlorine (as Cl_2)	0.2-4.0 mg/L	National Primary Drinking Water Regulations
Finished Water - Chlorine Dioxide (as Cl_2)	≤0.8 mg/L	National Primary Drinking Water Regulations
Finished Water - Benzene	0.005 mg/L	National Primary Drinking Water Regulations
Finished Water - Carbon Tetrachloride	0.005 mg/L	National Primary Drinking Water Regulations
Finished Water - 1,2-Dichloroethane	<0.005 mg/L	National Primary Drinking Water Regulations
Finished Water - 1,2-Dichloroethylene	≤0.007 mg/L	National Primary Drinking Water Regulations

Performance Parameter	Criteria	Criteria Source
Finished Water - cis-1,2-Dichloroethylene	≤0.07 mg/L	National Primary Drinking Water Regulations
Finished Water - trans-1,2-Dichloroethylene	≤0.1 mg/L	National Primary Drinking Water Regulations
Finished Water - Dichloromethane	<0.005 mg/L	National Primary Drinking Water Regulations
Finished Water - 1,2 Dichloropropane	<0.005 mg/L	National Primary Drinking Water Regulations
Finished Water - Ethylbenzene	≤0.7 mg/L	National Primary Drinking Water Regulations
Finished Water - Monochlorobenzene	≤0.1 mg/L	National Primary Drinking Water Regulations
Finished Water - o-Dichlorobenzene	≤0.6 mg/L	National Primary Drinking Water Regulations
Finished Water - p-Dichlorobenzene	≤0.075 mg/L	National Primary Drinking Water Regulations
Finished Water - Styrene	≤0.1 mg/L	National Primary Drinking Water Regulations
Finished Water - Tetrachloroethylene (PCE)	<0.005 mg/L	National Primary Drinking Water Regulations
Finished Water - Toluene	≤1 mg/L	National Primary Drinking Water Regulations
Finished Water - 1,2,4-Trichlorobenzene	≤0.07 mg/L	National Primary Drinking Water Regulations
Finished Water - 1,1,2-Trichloroethane	≤0.003 mg/L	National Primary Drinking Water Regulations
Finished Water - 1,1,1-Trichloroethane	≤0.2 mg/L	National Primary Drinking Water Regulations
Finished Water - Trichloroethylene (TCE)	<0.005 mg/L	National Primary Drinking Water Regulations
Finished Water - Vinyl Chloride	<0.002 mg/L	National Primary Drinking Water Regulations
Finished Water - Xylenes (Total)	≤10 mg/L	National Primary Drinking Water Regulations
Finished Water - 2,3,7,8-TCDD (Dioxin)	<0.03 ng/L	National Primary Drinking Water Regulations
Finished Water - 2,4,5-TP (Silvex)	≤0.05 mg/L	National Primary Drinking Water Regulations
Finished Water - 2,4-D	≤0.07 mg/L	National Primary Drinking Water Regulations
Finished Water - Acrylamide	Amount in the polymeric coagulant aids is limited to 0.05% by weight, and the dosage of polymeric coagulant aid which can be added to raw water to remove particulates is limited to 1 part per million.	National Primary Drinking Water Regulations
Finished Water - Adipates	≤0.4 mg/L	National Primary Drinking Water Regulations
Finished Water - Alachlor (Lasso)	<0.002 mg/L	National Primary Drinking Water Regulations
Finished Water - Atrazine (Atranex, Crisazina)	≤0.003 mg/L	National Primary Drinking Water Regulations
Finished Water - Benzo(a)pyrene	<0.0002 mg/L	National Primary Drinking Water Regulations
Finished Water - Carbofuran (Furadan 4F)	≤0.04 mg/L	National Primary Drinking Water Regulations
Finished Water - Chlordane	<0.002 mg/L	National Primary Drinking Water Regulations
Finished Water - Dalapon	≤0.2 mg/L	National Primary Drinking Water Regulations

Performance Parameter	Criteria	Criteria Source
Finished Water - Dibromochloropropane (DBCP)	<0.0002 mg/L	National Primary Drinking Water Regulations
Finished Water - Diethylhexyl Phthalate (DEHP)	<0.006 mg/L	National Primary Drinking Water Regulations
Finished Water - Dinoseb	≤0.007 mg/L	National Primary Drinking Water Regulations
Finished Water - Diquat	≤0.02 mg/L	National Primary Drinking Water Regulations
Finished Water - Endothall	≤0.1 mg/L	National Primary Drinking Water Regulations
Finished Water - Endrin	≤0.002 mg/L	National Primary Drinking Water Regulations
Finished Water - Epichlorohydrin	Amount in the polymeric coagulant aids is limited to 0.01% by weight, and the dosage of polymeric coagulant aid which can be added to drinking water to remove particulates is limited to 20 parts per million.	National Primary Drinking Water Regulations
Finished Water - Ethylene Dibromide	<0.00005 mg/L	National Primary Drinking Water Regulations
Finished Water - Glyphosate	≤0.7 mg/L	National Primary Drinking Water Regulations
Finished Water - Heptachlor (H-34, Heptox)	<0.0002 mg/L	National Primary Drinking Water Regulations
Finished Water - Heptachlor Epoxide	<0.0002 mg/L	National Primary Drinking Water Regulations
Finished Water - Hexachlorobenzene	<0.001 mg/L	National Primary Drinking Water Regulations
Finished Water - Hexachlorocyclopentadiene	≤0.05 mg/L	National Primary Drinking Water Regulations
Finished Water - Lindane	≤0.0002 mg/L	National Primary Drinking Water Regulations
Finished Water - Methoxychlor (Marlate)	≤0.04 mg/L	National Primary Drinking Water Regulations
Finished Water - Oxyamyl (Vydate)	≤0.2 mg/L	National Primary Drinking Water Regulations
Finished Water - Pentachlorophenol	<0.001 mg/L	National Primary Drinking Water Regulations
Finished Water - Picloram	≤0.5 mg/L	National Primary Drinking Water Regulations
Finished Water - Polychlorinated Biphenyls	<0.0005 mg/L	National Primary Drinking Water Regulations
Finished Water - Simazine	≤0.004 mg/L	National Primary Drinking Water Regulations
Finished Water - Toxaphene	<0.003 mg/L	National Primary Drinking Water Regulations
Finished Water - Antimony	≤0.006 mg/L	National Primary Drinking Water Regulations
Finished Water - Arsenic	<0.010 mg/L	National Primary Drinking Water Regulations
Finished Water - Asbestos (Fibers > 10 μm)	≤7 Million Fiber >10 μm per Liter	National Primary Drinking Water Regulations
Finished Water - Barium	≤2 mg/L	National Primary Drinking Water Regulations
Finished Water - Beryllium	≤0.004 mg/L	National Primary Drinking Water Regulations
Finished Water - Cadmium	≤0.005 mg/L	National Primary Drinking Water Regulations
Finished Water - Chromium	≤0.1 mg/L	National Primary Drinking Water Regulations

Performance Parameter	Criteria	Criteria Source
Finished Water - Copper	≤ 1.3 mg/L	National Primary Drinking Water Regulations
Finished Water - Cyanide	≤0.2 mg/L	National Primary Drinking Water Regulations
Finished Water - Fluoride	≤4 mg/L	National Primary Drinking Water Regulations
Finished Water - Lead	Requires water systems to control the corrosivity of the water. The regulation also requires systems to collect tap samples from sites served by the system that are more likely to have plumbing materials containing lead. If more than 10% of tap water samples exceed the lead action level of 15 parts per billion, then water systems are required to take additional actions.	National Primary Drinking Water Regulations
Finished Water - Mercury	≤0.002 mg/L	National Primary Drinking Water Regulations
Finished Water - Nitrate (as N)	≤10 mg/L	National Primary Drinking Water Regulations
Finished Water - Nitrite (as N)	≤1 mg/L	National Primary Drinking Water Regulations
Finished Water - Selenium	≤0.05 mg/L	National Primary Drinking Water Regulations
Finished Water - Thallium	≤0.0005 mg/L	National Primary Drinking Water Regulations
Finished Water - Combined Radium (226/228)	<5 picoCuries per liter	National Primary Drinking Water Regulations
Finished Water - Gross Alpha	<15 picoCuries per liter	National Primary Drinking Water Regulations
Finished Water - Beta Particles and Emitters	<4 millirems per year	National Primary Drinking Water Regulations
Finished Water - Uranium	<0.030 mg/L	National Primary Drinking Water Regulations

Appendix B – Equipment List

The table below summarizes the critical and non-critical process equipment at the Wes Brown WTP. Various criteria apply to the redundancy of the equipment as noted in Sections 2 and 3.

Table B.1: Process Equipment at the Wes Brown WTP

Equipment	Number of Units	Critical / Non-critical / Optional
Coagulant Induction Mixer	1	Critical
Flash Mix (future)	2	1 critical, 1 optional
Clarifiers	4	3 critical, 1 optional
Membranes	8	7 trains critical, 1 optional
Membrane Blowers	5	2 critical, 1 optional
Membrane Vacuum Pumps	1	Optional
Membrane Permeate Pumps	8	Optional in MGF Critical at higher production
Membrane Reject Pumps	2	2 critical, need 1 optional for N+1
Membrane CIP Pumps	2	1 critical, 1 optional
UV System	2	Optional
Backwash Storage tank	1	Critical
PAC Feed Pumps	2	Critical
PAC Storage bunker	1	Critical
Ferric Feed Pumps	3	1 critical, 1 optional
Ferric Storage Tanks	3	1 critical, 2 non-critical
Sulfuric Acid Feed Pumps	2	2 non-critical
Sulfuric Acid Storage Tanks	1	Non-critical
Ammonia Feed Pumps	3	1 critical, 2 non-critical
Ammonia Storage Tanks	1	Critical
Citric Acid Feed Pumps	2	2 non-critical
Citric Acid Storage Tanks	1	1 non-critical
Sodium Bisulfite Feed Pumps	2	2 non-critical
Sodium Bisulfite Storage Tanks	1	Non-critical
Sodium Hydroxide Feed Pumps	3	1 critical, 2 non-critical
Sodium Hydroxide Storage Tanks	2	1 critical, 1 non-critical
Sodium Hypochlorite Feed Pumps	3	1 critical, 2 non-critical
Sodium Hypochlorite Storage Tanks	3	1 critical, 2 non-critical

The table below summarizes the critical and non-critical process equipment at the new Thornton WTP. Various criteria apply to the redundancy of the equipment as noted in Sections 2 and 3.

Table B.2: Process Equipment at the New Thornton WTP

Equipment	Number of Units	Critical / Non-critical / Optional
Raw Water Flow Control (Standley Lake)	1	Critical

Equipment	Number of Units	Critical / Non-critical / Optional
Flash Mix	2	1 critical, 1 optional
Flocculation Trains	2	1 critical, 1 optional
Flocculators	3 per stage	2 critical, 1 optional
Sedimentation Trains	2	1 critical, 1 optional
Ozone Storage Tank	1	Optional (critical only for EGL water)
Ozone Vaporizers	3	3 optional (critical only for EGL water)
Ozone Generators	2	2 optional (critical only for EGL water)
Ozone sidestream Pumps	2	2 optional (critical only for EGL water)
Ozone Contactor Basin	1	Optional (critical only for EGL water)
Ozone Destruction System	1	Optional (critical only for EGL water)
Biological Filters	6	5 critical, 1 optional
Biological Filters Drain Pumps	1	Non-critical
Backwash Air Scour Blowers	2	1 critical, 1 optional
Sodium Permanganate Feed Pumps	2	2 non-critical
Sodium Permanganate Storage Tanks	2	2 non-critical
Ferric Feed Pumps	3	2 critical, 1 non-critical
Ferric Storage Tanks	2	1 critical, 1 non-critical
Caustic Soda Feed Pumps	5	5 non-critical
Caustic Soda Storage Tanks	3	3 non-critical
Coagulant Aid Feed Pumps	3	3 non-critical
Coagulant Aid Storage Tanks	2	2 non-critical
Flocculant Aid Polymer Feed Pumps	7	7 non-critical
Hydrogen Peroxide Feed Pumps	2	1 critical, 1 non-critical
Hydrogen Peroxide Storage Tanks	3	1 critical, 2 non-critical
Sodium Bisulfite Feed Pumps	2	1 critical, 1 non-critical
Sodium Bisulfite Storage Totes	3	1 critical, 2 non-critical
Phosphoric Acid Feed Pumps	2	1 critical, 1 non-critical
Phosphoric Acid Storage Drums	2	1 critical, 1 non-critical
Sodium Hypochlorite Feed Pumps	2	1 critical, 1 non-critical
Sodium Hypochlorite Storage Tanks	3	1 critical, 2 non-critical
Ammonium Sulfate Feed Pumps	3	2 critical, 1 non-critical
Ammonium Sulfate Storage Tanks	2	1 critical, 1 non-critical

Initial Data Review

Chapter 2

Utility Master Plan

Project No. 17-467

Water Treatment Facilities Master Plan

Initial Data Review

The City of Thornton

Project number: 60560104

AECOM

April 11, 2018

FINAL

Quality information

Prepared by	Checked by	Verified by	Approved by
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Table of Contents

List of Acronyms

ACH – Aluminum Chlorohydrate
CIP – Capital Improvement Program
COT – City of Thornton
CT – Contact Time
EGL – East Gravel Lake
FRP – Fiberglass Reinforced Plastic
MGD – Million Gallon per Day
PAC – Powder Activated Carbon
TM – Technical Memorandum
TMP – Trans-membrane pressure
TOC – Total Organic Carbon
TWTP – Thornton Water Treatment Plant
UF – Ultrafiltration
UV – Ultraviolet
VFD – Variable Frequency Drive
WBWTP – Wes Brown Water Treatment Plant
WGL – West Gravel Lake

1. Introduction

This technical memorandum (TM) describes the initial data review for the water treatment facilities performed for the Utility Master Plan project (Project) for the City of Thornton (COT, or Thornton). The initial data provided by Thornton on December 14, 2017, as well as additional data provides an understanding of system records to date, and will serve as the basis for subsequent water treatment facilities analyses. The initial data review included the 2009 Water and Wastewater Master Plan (2009 Plan) and relevant historical water treatment plants data. In addition, Sections 3 and 4 of this TM provide documentation of discussions to date with Thornton regarding existing water treatment operations and equipment issues that are not otherwise covered in the initial review. This information will be considered further during the performance evaluation to be completed during the Project.

An initial data review TM for the Raw Water Supply Master Plan and the Water and Wastewater Infrastructure Master Plan will be provided separately.

2. Overview

The initial data provided by Thornton and reviewed primarily includes: drawings, plant data, previous studies, reports, and regulatory documents as summarized in Appendix A. This data will serve as the basis for development of the Water Treatment Facilities Master Plan. The initial data review has provided an understanding of the existing treatment plants relative to the Project scope, summarized as follows:

- Current and future water demands: This information is being developed under the Water and Wastewater Infrastructure Master Plan and will be incorporated in subsequent tasks in this Water Treatment Facilities Master Plan.
- General performance of the current treatment process, design criteria and state of the treatment science: Information was collected through discussions with Thornton treatment staff during site visits and also through review of files received as detailed in Appendix A.
- Regulatory compliance with current and anticipated future regulation requirements: Information was collected from the Conceptual Design Report for the Water Treatment Plant Replacement Project CIP 15-468, dated November 2016 and from the Alternative Coagulant and Ammonia Injection Study Report for the Wes Brown Water Treatment Plant, dated May 2017. The regulatory compliance evaluation task will be based on the review of these two documents.
- As-builts, design drawings and previous studies for existing infrastructure and equipment: This information was provided by Thornton and augmented thought discussions during site visits. A list of the files received is detailed in Appendix A.
- Records pertaining to existing assets and systems: This information was provided by Thornton and a list of the associated files is detailed in Appendix A
- Cost data that will be informative in assessing future capital, operations, and maintenance costs: Thornton's 2018 adopted budget provides cost information under the water fund related to treatment projects over the next 5 year in the Capital Improvement Program (CIP). No additional data has been received from Thornton at this time.

Some data gaps including selected process drawings and plant data were identified during the data review process. Resolution of these issues is expected to be completed with Thornton during the performance evaluation task.

3. Wes Brown Water Treatment Plant Review

A site visit of the Wes Brown Water Treatment Plant (WBWTP) occurred on December 20, 2017 and again on January 3rd, 2018 and included discussion of water quality and treatment operations. The following is a summary of the treatment process discussion as well as the issues and planned changes identified by Thornton that were discussed for each treatment process.

Influent

Treatment plant influent is a blend of water received from a series of storage impoundments known as West Gravel Lakes (WGLs) and East Gravel Lakes (EGLs):

- EGL water has been analyzed to have high levels of taste and odor compounds. The concentrations of the taste and odor compounds increase substantially during certain periods in spring and summer.
- WGL water supply has lower taste and odor concentrations than EGL water but has been shown that higher percentages of WGL in the influent contribute more significantly to membrane fouling. The WGLs receive decant from the WBWTP lagoons and have been observed to have short-circuiting of the lagoon decant return to the WGL pump station, which loses some of the intended mixing goals within WGL.
- Neither of the gravel lakes currently have an effective means to circulate water and homogenize the supply water or manage water age.

Chemical Feed at Plant Influent

Influent from the gravel lakes is treated with:

- Potassium permanganate to manage naturally occurring manganese that exists in a reduced oxidation state;
- Sodium hypochlorite for disinfection contact time (CT) and also to manage reduced manganese species introduced with the ferric coagulant; and
- Powder activated carbon to manage taste and odor compounds.

The introduction of these chemicals occurs very close together, with limited CT between chemical injection points and poor mixing. As a result, the hypochlorite dosage is elevated significantly to counteract losses from interaction with the powder activated carbon (PAC). Introduction of ferric chloride has also been demonstrated to be challenging, resulting in uneven distribution that impacts performance of the clarifiers.

The plant is completing multiple modifications to current operations in order to optimize treatment and reduce membrane fouling. Phase 1 modifications include adding a new chlorine contact pass into the clearwell, which will allow moving the chlorine dosing for disinfection CT away from the PAC feed point. This will reduce the sodium hypochlorite dosage at the influent from 8-20 mg/L to approximately 3 mg/L (as required to maintain removal of reduced manganese introduced with the ferric chloride coagulant addition). An additional dose of up to 2 mg/L of sodium hypochlorite will be added after clarification to maintain a residual at the membrane feed of 0.2 mg/L to reduce potential fouling. As a further benefit, the 2017 Alternative Coagulant Study has shown that PAC will be approximately 75% more efficient at removing taste and odors once negative impacts of the adjacent addition of sodium hypochlorite is reduced, which may result in reduced PAC dosage. The construction to complete the modifications to the clearwell are planned for the winter shutdown of the WBWTP starting in November of 2018; and the new facilities will begin starting operations in March 2019. The coagulant mixing and CIP neutralization changes are intended (if there is sufficient funding) to be completed during the winter shutdown starting in November 2019.

Clarifiers

As noted in the previous section, ferric chloride is added upstream of the clarifiers, but the injection utilizes an inline propeller mixer upstream of the injection location. This results in very poor mixing which causes performance differences in each clarifier since they don't get the same amount of ferric chloride. Phase 1 modifications include improving the ferric chloride mixing by replacing the current mixer with a flash mixing system. This modification may not be constructed until years 2019-2020.

The plant has conducted a coagulant replacement study to determine if there would be benefit for reducing membrane fouling. As a result of the study, the plant has determined that replacing the ferric chloride with aluminum chlorohydrate (ACH) would be beneficial. However, this will have a consequence of eliminating the option to use land application for sludge disposal, which is the current practice. Also, pilot studies conducted with ACH have shown significant improvements in reducing membrane fouling, but ACH requires a higher dosage for total organic carbon (TOC) removal. This change is not currently scheduled to be implemented, but it may be revisited as a result of increased radionuclides found in the lagoon sludge, which may result in losing the ability to use land application for disposal.

Additional studies conducted by the plant staff identified that the optimal TOC reduction occurs at 45 mg/L ACH. In the event that the plant does not implement a change in coagulant, the ferric chloride equivalent to this ACH dosage is 70 mg/L to achieve equivalent TOC removal. However, this dosage would likely result in the need for caustic addition to raise finished water pH and may also lead to additional chemicals being required to manage corrosivity in the water due to the high chloride content. A benchtop filtration study has been conducted, but no continuous flow piloting has been conducted to evaluate the impact to the membranes, indicating that this change should be evaluated more in detail prior to implementation to assess the potential impacts to membrane fouling. Additionally, the higher dose would increase the quantity of manganese that is introduced into the system, which could create an additional water quality challenge.

The plant uses solids contact clarifiers for the sedimentation process. The plant is operated as a peaking plant, so the influent flow rate fluctuates multiple times throughout the day, with the peak usage usually in the evenings due to possible inadequate storage in the distribution system, which has complicated process control through the clarifiers. The clarifier units have traditionally been operated using the sludge blanket level for control and determination of wasting, but staff have directed the plant to operate the clarifiers based on monitoring center cone solids concentration.

The sludge pipes at the bottom of the clarifiers are 8-inches in diameter, which were considered a process constraint in the past due to the high volume involved in wasting sludge. The plant considered increasing these pipes to 12-inches in diameters, but the blowdown operations were improved since 2017. In fact the blowdown time was adjusted from five minutes to one minute, which resulted in the blowdown primarily removing thickened sludge with less dilute water being discharged to the lagoon. This significantly reduces water volume that needs to be recycled. The plant maintenance staff flush sludge pipes on a regular basis (typically once a month) to prevent accumulation of solids.

Each clarifier effluent stream is combined in a common distribution channel that is used to feed the membranes. The channel does not provide good mixing, so the membrane influent is largely composed of the clarifier effluent that is physically closest to the bank. This results in differential performance across the membranes associated with the uneven performance observed in the clarifiers. As noted in previous paragraphs, plant staff are evaluating the best means to manage sodium hypochlorite in the clarifier effluent to maintain chlorine residual in the membrane influent.

Membranes

The plant operates using Zenon ZeeWeed® submerged ultrafiltration (UF) membranes with a design capacity of 50 million gallons per day (MGD). The plant has struggled to meet this design capacity primarily due to performance limitations from lost membrane flux and has only been able to produce a maximum of 41 MGD. Plant staff has indicated that the membranes have been very labor-intensive to maintain due the work associated with cleaning, inspecting, and maintaining the membrane fibers.

Membrane fouling has created a been shown to create a reduction in plant production capacity. The membrane permeate production is driven both by tanks water elevation as well as the permeate pumps (connected to the bottom of air/water separator tanks connected to each train effluent). The combination of tank elevation and permeate pump operations create trans-membrane pressure (TMP) across the membrane fiber, which provides the driving force for permeate production. As membrane fouling increases, the TMP required to produce enough permeate to meet the plant demand increases, and this has been demonstrated to increases the rate of fouling of the membranes. When the TMP reaches a critical level, there is insufficient driving force to maintain permeate production, which can have the consequence of lowering the water level in the air/water separator and result in the potential for air being drawn into the permeate lines. Previous guidance provided to the facility indicated that the plant should run vacuum pumps at the top of each air/water separator to maintain the water level, but this does not address the inadequate production capacity as a result of fouling. Further, operation of the vacuum pump can increase TMP across the membrane, which leads to both further increases in fouling potential as well as membrane damage. This requires more frequent membrane cleaning to maintain normal TMP, which both increases operating costs and reduces the useful life of the membrane fibers. The operation of the vacuum pumps has also been reported to be problematic, with numerous incidents of vacuum pump failure.

An addition operational challenge is associated with operating the membranes at low flow rates. The permeate pump have a minimum speeds, which forces shutting off membrane trains in order to maintain minimum permeate production as necessary to maintain the check valves in the open position. Thornton staff have begun to operate the membranes using gravity feed for permeate production only, which eliminates the need for the permeate pumps during low flow and allows for operating a higher number of membrane trains at a lower flux rate, which reduces fouling potential. However, there are no means to currently control flux by train when operating with gravity filtration, resulting in cleaner membranes having a much higher flux relative to older, more fouled membranes. Modification to add modulating actuators to the permeate isolation valves on each train would allow the valves to operate for flow control to manage individual train flux and production.

The treatment process evaluation to be conducted as part of this master plan is intended to include evaluation of means to remove taste and odor compounds at the facility. Options to be evaluated for post-membrane treatment are expected to include both ozone and granular activated carbon (GAC). While there are a variety of means to introduce ozone into the membrane permeate, GAC would require sufficient head to drive permeate through the media, and there is not anticipated to be sufficient head when operating the membranes in gravity flow. This will be evaluated further as part of the process evaluation.

Ultraviolet System

The ultraviolet (UV) disinfection system is currently offline. The plant staff has indicated the UV system is not required to meet disinfection requirements and the cost and maintenance for the UV bulbs was found to be too high for the purported value.

Clearwells

Sodium hypochlorite, caustic and ammonia are added to the permeate, upstream of the clearwell. Two static mixers provide chemical mixing. Chemical dosage is based on the flow rate, but since permeate flow is variable; alkalinity (pH) control is a challenge. Caustic addition also creates significant scaling in the permeate piping due to high mineral content of the water.

Thornton is in the process of completing a design to modify the first pass of the clearwell to be a chlorine contact chamber for CT. Ammonia feed will be moved downstream of the first pass.

Finished Water Pumps

The facility includes six vertical turbine pumps of 10 MGD each, which form the high service pump station. This pump station is used to send the water produced at the WBWTP to the distribution system. More information on these pumps is included in the Water and Wastewater Infrastructure Master Plan.

Lagoons

The lagoons currently receive the following streams:

- Membrane reject (including chemical cleans),
- Clarifier sludge,
- Thornton Water Treatment plant (TWTP) wastes, including clarifier sludge, backwash wastewater and filter to waste (filter to waste only occurs during plant start-up and involves setting up temporary piping, so it is a limited activity and a small contribution to the overall waste stream),
  - A coagulant aid polymer is used in TWTP. Recent zeta testing has indicated that dosing is optimized but residual aspects of the polymer addition may be introduced to WBWTP as a result of the recycling of the waste streams. This may be a contributing factor for membrane fouling and will be investigated further as part of the process evaluation.
- While not part of the current operation, the new TWTP will have the option for filter-to-waste, which will be sent to the lagoons. This will likely lead to an increase in the percentage of return flow that is processed at the WBWTP as part of the influent.

The lagoon sludge is removed periodically and utilized for agricultural land application. Lagoon decant is sent to the WGLs without any additional treatment. The sludge in the northern lagoon has recently been found to have elevated levels of radionuclides, which prevents the sludge in this basin from being able to be land applied. If the radionuclide problem continues, it will lead to the need to dispose of the sludge in a landfill which will provide further motivation to change from ferric to ACH. No dewatering equipment is currently in place but would be recommended for reducing operating costs associated with sludge disposal to meet requirements (paint filter test) for landfill disposal of sludge.

Chemicals Systems

There are multiple chemical systems at the WBWTP. Additional information specific to each system is summarized as follows:

- Potassium Permanganate: Potassium permanganate is fed to oxidize naturally occurring reduced manganese in the source water. The chemical system equipment includes makedown tanks and feed equipment for dosing at the influent pump stations. The plant is considering switching to sodium permanganate in the future for its ease of operation and to limit the potential for feed malfunctions from the use of potassium permanganate that have resulted in pink water color in the past.

- Powder Activated Carbon: PAC is used for taste and odor control. The chemical system equipment consists of a concrete bunker for maintaining the carbon slurry, which is delivered dry and wetted on site, and hose feed pumps. The plant relies heavily on PAC throughout the year, with peaks occurring during the summer. There is limited storage within the bunker, which can be deleted quickly during high taste and odor events. It is recognized that PAC is a large operating expense and also contributes to increased sludge volume. PAC slurry feed has led to clogging of the feed lines on a number of occasions, which is a burden on maintenance staff.

- Ferric Chloride: Ferric chloride is fed as the primary coagulant to promote the formation of floc that can be removed via sedimentation. The chemical system equipment consists of bulk storage tanks and feed pumps. No significant problems were reported with the ferric feed equipment other than poor mixing at the feed point, but it is believed that the use of iron as a coagulant contributes to membrane fouling as well as introduces additional reduced manganese to the system, which requires the use of hypochlorite as an oxidant. The ferric chloride bulk storage tanks have experienced repeated tank failures, generally attributed to cracking in the tank structure when the tank is filled to its maximum capacity. This is believed to be a result of the tank bases being manufactured out of plumb, which has created stress points due to inadequate support from the tank pad that is maximized when the tank is filled to its maximum volume.

- Sodium Hypochlorite: Sodium hypochlorite is used for disinfection and manganese control. The chemical system equipment consists of multiple FRP storage tanks and peristaltic feed pumps. The plant is concerned with degradation rate of the chemical in storage and with numerous leaks in the piping and would prefer a welded piping system like Asahi. Additionally, the plant control system does not currently include automation to activate the redundant pumps if the primary pump fails, which is a concern for the operations staff. For the new TWTP, the facility will import bulk hypochlorite but then dilute it using softened water to reduce the degradation. Dilution is not currently possible at WBWTP due to the lack of an appropriate dilution water system.

- Hydrochloric Acid: The feed equipment was initially installed for feeding an anti-scalant for a future reverse osmosis system. The system was repurposed for hydrochloric acid to lower pH to improve coagulation, but the system is not currently used. The chemical system equipment consists of a small bulk storage tank and feed pump. The storage room had evidence of failure of the chemical coating system.
- Caustic: Caustic is used at the plant for pH control to adjust alkalinity. The chemical system equipment consists of two bulk storage tanks and multiple feed pumps. The concentration of caustic supplied by the vendor varies from 30% to 50%. At higher concentrations dilution may be required to avoid freezing / crystallization issues. However, dilution is done with plant water, which causes significant scaling and requires higher levels of maintenance for the feed equipment. Addition of a softening system to be used in conjunction with this system would be preferred to reduce maintenance outages.

4. Considerations for the Future Thornton Water Treatment Plant

A site visit of the TWTP occurred on January 3rd, 2018 in order to review the treatment of Standley Lake water and the plans for the new TWTP. The following issues and planned changes were discussed for each treatment process.

Raw Water

Standley Lake water supply is considered the best current source in terms of raw water quality within the existing Thornton system, but it is limited in quantity based primarily on yield associated with water rights.

Pumps at the EGL#4 allow influent water to be sent to the TWTP, but the EGL water source taste and odor issues exceed the treatment capabilities at the existing TWTP. Furthermore, the TOC in EGL source water is higher than Standley Lake source water, and the treatment at TWTP is not able to meet the required removal. Conversely, raw water from Standley Lake can be sent by gravity to WBWTP, which helps WBWTP improve its raw water quality, but this is conservatively used because of the desire to maintain the higher water quality for distribution to Thornton residents and the limited yield available from the Standley Lake supply.

In the past, there have been limited events where Standley Lake water has experienced high turbidity, which exceeds the treatment capability at TWTP and results in the plant discontinuing treatment. This has been rare and is attributed more to inadequacy of the existing treatment systems.

Sludge

Wastewater (clarifier sludge and filter backwash) from the existing Thornton Treatment Plant is discharge to an outdoor open basin at the plant site, which then drains by gravity through an interconnect pipeline to the WBWTP lagoons. There is no treatment or flow control on the pipeline. This basin and pipeline will continue to function to receive wastewater from the new plant. However, wastewater from the new treatment plant will first be sent to an equalization tank at the new plant and then pumped to the existing basin for gravity drainage to the lagoons. The new plant will also include filter-to-waste as an additional contribution to the wastewater volume.

When multiple backwashes need to be completed in short order, the onsite storage volume is limited, and the pipeline to WBWTP for backwash waste becomes a bottleneck. There is concern that the current gravity drain may be insufficient for wastewater generation rate at the new plant. The drain size will be evaluated as part of the treatment master plan.

Appendix A - Data Review Summary Tables

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

Table A.1: Water Treatment Data Overview

Document Title	Type of Document	Details
2017 TTP Daily Lab	Excel	CT spreadsheet for the Thornton treatment plant, with data from May to November 2017. The file contains daily flow, pH, temperature, turbidity, odor, chlorine, and manganese data.
2017 WBTP Clarifier and Manganese Testing	Excel	Spreadsheet for the Wes Brown treatment plant, with data from March to November 2017. The file contains daily flow, EGL vs WGL contributions, manganese, iron, potassium permanganate, free chlorine, TOC, chemical dosages and associated costs.
2017 WBTP Daily Lab	Excel	CT spreadsheet for the Wes Brown treatment plant, with data from March to November 2017. The file contains daily flow, pH, temperature, turbidity, odor, chlorine, and manganese data.
2005 WBTP DWG – Zenon	PDF, AutoCAD and Excel	Design documents for the Wes Brown treatment plant membranes. The documents include the bill of materials, electrical drawings, fabrication drawings, field change notices, general arrangements and plot plans, hydraulic profiles, pipe drawings and index files.
2005 WBTP DWG – As-Built PDF	PDF	As-built drawings for the Wes Brown Treatment Plant expansion dated 2005 to 2007. The membrane design drawings are in a separate package from Zenon.
15-468 TWTP Replacement-Specification-DD-30 Percent Drawings	PDF	30% design specifications for the new Thornton treatment plant, dated September 2017. The document includes specifications for water and wastewater equipment. 80% Design documents are expected to be available in April 2018
15-468 TWTP Replacement-Drawing-DD-30 Percent Drawings	PDF	30% design drawings for the new Thornton treatment plant, dated September 2017. The document includes civil, structural, architectural, fire protection, plumbing, process, mechanical and electrical drawings. 80% Design documents are expected to be available in April 2018
Old TTP	PDF	Various As-built drawings for the existing Thornton treatment plant, dated from 1973 to 2004.
2017 WNTP PFD Cartoon	PDF	Schematic of the Wes Brown treatment plant process and connections to EGL/WGL.
WBWTP Study Summary	Excel	Summary of studies performed at WBWTP 2013, 2014, 2016, 2017
WBWTP Operations Study – Final Report 7-11-2014	PDF	CH2M HILL report on the Wes Brown treatment plant operations, dated July 2014. The document includes an evaluation of the raw water supply, the chemical pre-treatment and mixing, the clarification process, the membranes, the UV and chlorine disinfection and instrumentation.
ThorntonWBWTPAltCoagAmmInjStudy_Final	PDF	Carollo report presenting the alternative coagulant and ammonia injection study done at the Wes Brown treatment plant, dated May 2017. The report includes bench-scale jar testing, pilot testing and full-scale testing results, as well as alternative coagulant preliminary design and ammonia/chlorine injection relocation preliminary design.
2016 Avista Membrane Autopsy	PDF	Avista document presenting the autopsy reports for 3 samples of the

Document Title	Type of Document	Details
		GE Zeeweed 500D membrane filter, dated October 2016.
14-468 TWTP replacement-report-CD-Final Conceptual Design Report	PDF	Carollo report containing the conceptual design information for the new Thornton treatment plant, dated November 2016.
Ozone & GAC Pilot at WBWTP – 2017 permeate Pilot Protocol	Excel	City of Thornton document presenting the pilot goals, objective and schedule.
Ozone & GAC Pilot at WBWTP – All Data	Excel	City of Thornton document presenting the 2017 pilot testing results
122017 – Thornton 16-309A – npv Analysis – Tier 1 solids	Excel	City of Thornton document presenting the net present value for project 1 (Using ACH instead of ferric), Project 2 (chlorine/ammonia relocation), and Project 3 (combined project 1 and 2). In these calculations solids are sent to Tier 1 landfill.
122017 – Thornton 16-309A – NPV Analysis – Tier 2 solids	Excel	City of Thornton document presenting the net present value for project 1 (Using ACH instead of ferric), Project 2 (chlorine/ammonia relocation), and Project 3 (combined project 1 and 2). In these calculations solids are sent to Tier 2 landfill.
CO0101150 Thornton City of_DW Design Record of Approved Waterworks (RAW)_170131	PDF	Document summarizing the CDPHE approved waterworks for the City of Thornton from 2003 to 2017.
2014 LT2ESWTR for WBTP and TTP	PDF	Letter from the CDPHE to classify the Wes Brown treatment plant in Bin 1, as part of the Long Term 2 Enhanced Surface Water treatment Rule, dated April 2014.
2013 Membrane Requirements	PDF	Letter from the CDPHE to notify the City of Thornton of the membrane standards requirements at the Wes Brown treatment plant, dated December 2013.
Sludge Removal – 2016 Aug – Thornton WTP Residuals 2016 N Pond Approval	PDF	Letter from the CDPHE to notify the City of Thornton of the approval for land application of the Wes Brown treatment plant sludge from the north pond, dated August 2016.
Sludge Removal – City of Thornton WTP Sludge BUD - Denial 2016	PDF	Letter from the CDPHE to notify the City of Thornton of the denial for land application of the Wes Brown treatment plant sludge, dated June 2016. The denial is based on the elevated combined Radium 226 and 228 concentrations.
Sludge Removal – 2016 radionuclide content comparison	Excel	City of Thornton document recording March 2016 and May 2016 sampling data on the south, central and north lagoons.
Sludge Removal – 2016 Solids Disposal Issues Notes 6 12 16	Excel	City of Thornton document of notes from a June 13, 2016 meeting. The subject of the meeting was the 2016 solids disposal issues.
Sanitary Survey – 2014 Sanitary Survey Items of Concern	Word	CDPHE List of significant deficiencies and recommendations regarding the 2014 sanitary survey.
Sanitary Survey – CO0101150 $ San Survey $ 06-27-2017 $ A $ SS Letter	Word	Letter from the CDPHE notifying the City of Thornton of the findings during the June 2017 sanitary survey, dated June 2017.
Thornton Water Treatment Plant Master Plan Report	Paper document	Dewberry-Ingerra report to evaluate alternatives for short-term upgrades of the existing TWTP facility, dated July 2011.

Regulatory Compliance Evaluation

Chapter 3

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Utility Master Plan

Project No. 17-467

Water Treatment Facilities Master Plan

Regulatory Compliance Evaluation

The City of Thornton

Project number: 60560104

AECOM

May 17, 2018

FINAL

Quality information

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Tables

List of Acronyms

ACH – Aluminum Chlorohydrate
CCL – Critical Contaminants List
CDPHE – Colorado Department of Public Health and Environment
D/DBPR – Disinfectants and Disinfection Byproducts Rule
FBRR – Filter Backwash Recycling Rule
IESWTR – Interim Enhanced Surface Water Treatment Rule
HAA – Haloacetic Acids
LCR – Lead and Copper Rule CDPHE – Colorado Department of Public Health and Environment
LT1ESWTR – Long-Term 1 Enhanced Surface Water Treatment Rule
LT2ESWTR – Long-Term 2 Enhanced Surface Water Treatment Rule
MCLG – Maximum Contaminant Level Goal
MCL – Maximum Contaminant Level
MCLG – Maximum Contaminant Level Goals
NPDWR – National Primary Drinking Water Regulation
NSDWR – National Secondary Drinking Water Regulations
PBBs – Polybrominated Biphenyls
RTCR – Revised Total Coliform Rule
SDWA – Safe Drinking Water Act
SWTR – Surface Water Treatment Rule
TCR – Total Coliform Rule
TM – Technical Memorandum
TOC – Total Organic Carbon
TTHM – Total Trihalomethanes
TTP – Thornton Treatment Plant
TWTP – Thornton Water Treatment Plant
UCMR – Unregulated contaminant Monitoring Rule
US EPA – United States Environmental Protection Agency
WBWTP – Wes Brown Water Treatment Plant
WGL - West Gravel Lake(s)

1. Introduction

This technical memorandum (TM) summarizes the regulatory compliance evaluation completed for the Utility Master Plan project (Project) for the city of Thornton (Thornton) as part of the Water Treatment Facilities Master Plan. The following documents were provided by Thornton and reviewed as part of this evaluation:

- Water and Wastewater Systems Master Plan (May 2010), *The Engineering Company*;
- Thornton Water Treatment Plant Master Plan (July 2011), *Dewberry*;
- Water Treatment Plant Replacement Project CIP 15-468 Conceptual Design Report (November 2016), *Carollo*.

The evaluation completed a review of regulatory assessments previously completed for Thornton and identifies applicable updates to federal and state regulations for potable water production (treatment) facilities. Section 3.3 of the Water Treatment Plant Replacement Project CIP 15-468 Conceptual Design Report developed in November 2016 (Appendix A) identified the following applicable regulations for Thornton's water treatment facilities:

- Safe Drinking Water Act (SDWA) or National Primary Drinking Water Regulations (NPDWR);
- National Secondary Drinking Water Regulations (NSDWR);
- Lead and Copper Rule (LCR);
- Arsenic Rule;
- Radionuclides Rule;
- Total Coliform Rule (TCR);
- Revised Total Coliform Rule (RTCR);
- Surface Water Treatment Rule (SWTR);
- Interim Enhanced Surface Water Treatment Rule (IESWTR);
- Long-Term 1 Enhanced Surface Water Treatment Rule (LT1ESWTR);
- Long-Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR);
- Stage 1 Disinfectants and Disinfection Byproducts Rule (Stage 1 D/DBPR);
- Stage 2 Disinfectants and Disinfection Byproducts Rule (Stage 2 D/DBPR); and
- Filter Backwash Recycling Rule (FBRR).

A literature review was also conducted to identify updates to these regulations that may have occurred since the November 2016 Conceptual Design Report. Additionally, information was compiled relative to potential candidate pollutants that have prospective regulatory action. The purpose of this TM is to summarize revisions to the regulations since 2016 and the potential future regulations that may impact Thornton's treatment facilities and guide the development of planned treatment improvements and associated costs to be developed during the Project.

2. Regulation Updates since 2016

Based on evaluation of applicable regulations identified in Sec6tion 1, there have been very few changes since the 2016 Conceptual Design Report. No changes have been identified to the applicable regulations at a federal level.

In 2017, the Colorado Department of Public Health and Environment (CDPHE) updated the Design Criteria for Potable Water Systems (Safe Drinking Water Program Implementation Policy 5), which became effective on December 15, 2017. The associated regulatory changes are focused on three water treatment aspects as follows:

- Modifications to treatment standards to provide corrosion control to mitigate potential concerns for lead and copper;
- Increased monitoring requirements at surface water treatment facilities; and
- Additional requirements for disinfection and storage tank appurtenances.

Review of these CDPHE regulatory changes did not identify impacts to Thornton's water treatment facilities or treatment processes.

Potential Future Regulations Update

The 2016 Conceptual Design Report identified several water quality parameters that had potential for future revisions through either new or modified regulations. The following items provide a current status update on these parameters:

- Strontium: A regulatory action was noted in the 2016 report as a potential to be proposed as draft in the 2017-2018 timeframe. However, the United States Environmental Protection Agency (US EPA) announced in January 2016 a delay for the final regulatory determination on strontium, with a goal of providing more time to consider additional data. No federal regulation has been proposed as of May 2018.
- Perchlorate: A regulatory action was noted in the 2016 report as a potential to be proposed as draft in the 2016-2017 timeframe. A public peer review meeting was conducted on January 29 and 30, 2018 to discuss various approaches in regulating perchlorate in drinking water. However, no further action on the federal regulation has been proposed as of May 2018.
- Lead and Copper Rule Long-term Revisions: A regulatory action was noted in the 2016 report as a potential to be proposed as draft in the 2016-2017 timeframe. A white paper was developed in October 2016 that provided examples of regulatory options to improve the rule. US EPA is currently consulting with the sovereign Native American nations, as the rule may impact them. US EPA identified in early 2018 that addressing high level lead contamination is a high priority for 2018. However, no further action on the federal regulation has been proposed as of May 2018.
- Fluoride: The third six-year review of National Primary Drinking Water Regulations (NPDWR) for fluoride was completed in December 2016. As part of the review of the Lead and Copper Rules, US EPA made the determination on November 1, 2017 that a revision for fluoride was not appropriate. No further action federal regulation has been proposed as of May 2018.
- Pesticides: In January 2017, US EPA updated the developed human health benchmarks for pesticides. There are now human health benchmarks for 394 compounds. These are non-enforceable and non-regulatory but may be used by States to regulate particular chemicals. There is insufficient data available from prior Thornton water quality to determine if any of these compounds may be of possible concern, but since the benchmarks are non-enforceable, it is assumed no action is required by Thornton at this time.

None of the other potential future regulation listed in the 2016 Conceptual Design Report have had any activity or a change in status.

Other Contaminants of Concern

The regulatory review also included review of US EPA's published information regarding potential future regulations or constituents/contaminants of concern. The review identified the following contaminants of concern that are applicable to potable water treatment:

- Cyanotoxins: Algal blooms can result in the release of algal toxins, known as cyanotoxins. In 2015, the EPA published drinking water advisories for microcystins of 0.3 µg/L for infants and 1.6 µg/L for school aged children and adults. The EPA also published health advisories for cylindrospermopsin of 0.7 µg/L for infants and 3.0 µg/L for school aged children and adults. In 2016, Health Canada also proposed a maximum acceptable concentration of total microcystins of 1.5 µg/L.

- Tungsten: Tungsten is currently used to replace lead previously used in fishing weights and in ammunition for hunting and recreational shooting. Tungsten has been identified by US EPA as a pollutant of concern, with a higher potential for impact around tungsten polluted sites. While these activities are prevalent in Colorado and have the potential to impact the watersheds that are source water supplies for Thornton, no federal regulation is expected within the next 5 years, as it is not included in the Contaminant Candidate List (CCL) 4 or in the Unregulated Contaminant Monitoring Rule (UCMR) 4. It is recommended that Thornton consider adding this parameter to annual water quality monitoring in raw water supplies.
- Dioxane: Dioxane is used primarily as a solvent and has the potential to enter waterways through the discharge of untreated or partially treated wastewater effluent. The State of California has established a drinking water notification level of 0.001 mg/L and a response level for which removal is recommended of 0.035 mg/L. Dioxane was included in CCL3 but was not identified for regulatory action. It is currently part of CCL4. EPA may determine in 2021that this contaminant requires federal regulation, but no regulation is expected before the 2022-2023 timeframe. It is recommended that Thornton consider adding this parameter to annual water quality monitoring in raw water supplies.
- Polybrominated Biphenyls (PBBs): PBBs are flame retardants which are often added to plastics. Various States have adopted screening values of cleanup goals for PBBs in drinking water or groundwater, ranging from 0.0001 to 5 µg/L. No regulatory action was identified for this class of constituents. However, it is recommended that Thornton consider adding this parameter to annual water quality monitoring in raw water supplies.
- Nanomaterials: Nanomaterials are a class of contaminants of which a single unit is sized (in at least one dimension) between 1 to 100 nm. No federal regulation is expected within the next 5 years as it is not included in the CCL4 or in the UCMR4. No activity is recommended for Thornton at this time associated with this class of contaminant.

3. Contaminants Candidate List

The Critical Contaminants List (CCL) is a list of contaminants published by US EPA that are viewed as potential constituents of concern in water systems but are not currently subject to any proposed or promulgated NPDWR. Contaminants listed on the CCL are subject to further research and evaluation and may require future regulation under the SDWA. Prior to 2016, US EPA had published and provided regulatory determination on three sets of CCL (CCL1: July 2003; CCL2: July 2008; CCL3: January 4, 2016).

US EPA published a draft of constituents of concern for CCL4 on February 4, 2015 and announced the final on November 17, 2016. US EPA carried forward all contaminants listed on CCL3 to the draft CCL4 with the exception of the five CCL3 contaminants with regulatory determinations (dimethoate, 1,3-dinitrobenzene, terbufos and terbufos sulfone). US EPA delayed the regulatory determination on strontium, as well as perchlorate, to allow for more data collection. The Final CCL4 includes 97 chemicals or chemical groups and 12 microbial contaminants. The list includes, among others, chemicals used in commerce, pesticides, biological toxins, disinfection byproducts, pharmaceuticals and waterborne pathogens.

Publication of the CCL does not impose any requirements on public water systems. After the Final CCL4 is published, US EPA must determine whether or not to regulate at least five contaminants from the CCL4 in a separate process called Regulatory Determination 4, which must be completed within five years of the last regulatory determination.

As this time US EPA is compiling and evaluating additional data on the CCL4 contaminants. Once the data evaluation is complete, US EPA will make regulatory determinations for five CCL4 contaminants for which there is sufficient health effects and occurrence data and which present the greatest public health concern. US EPA will continue to collect information on other constituents on CCL4, including conducting and supporting research and/or filling data and information gaps for contaminants that lack sufficient information to make a regulatory determination. If US EPA decides to regulate a contaminant on the list, they will start a rulemaking process with opportunity for public comment.

The regulatory determination for CCL4 is scheduled to complete by 2021, so there is no further information at this time. However, based on evaluation of the list compared against the treatment processes employed or planned to be employed by Thornton, there is no specific identified regulatory risk that would serve as a basis for recommending process improvements at this time.

4. Potential Regulatory Impacts at Wes Brown Water Treatment Plant

While there have been limited changes in the regulatory framework that impacts treatment requirements, the operations of the Wes Brown Water Treatment Plant (WBWTP) have been modified based on process adjustments and other improvements. This section discusses the potential regulatory implications of the recent regulatory changes in operation of the WBWTP.

Sludge Disposal

The WBWTP treats all wastewater associated with Thornton's production of drinking water. This wastewater currently originates from WBWTP and the existing Thornton Treatment Plant (TTP) and is accumulated within three lagoons located at the WBWTP. In the future the new TTP will operate in a similar manner and the existing TTP will be decommissioned. The decant water is released to the West Gravel Lakes (WGL), and sludge is allowed to remain in the lagoon and thicken until sufficient volume has accumulated to warrant disposal. The existing practice has been to dispose of the sludge via land application as a soil amendment for agricultural activity. The beneficial land application of the WBWTP is authorized under the Beneficial Use of Water Treatment Sludges and Fees Applicable to the Beneficial use of Sludges Regulation 5 Colorado Code of Regulation 1003-7.

On June 2016, Thornton received notification that the CDPHE Hazardous Materials and Waste Management Division had denied land application of the treatment plant's sludge stored in the South Lagoon due to elevated radionuclide as reflected in sampling data from May 2016, which showed a concentration of combined radium 226 and 228 of 13.06 pCi/g above background concentrations in the North Lagoon, 3 pCi/g above background concentration allowed for land application. Table 1 shows the regulatory limits for radionuclides associated with various types of disposal.

Table 1: Sludge Regulatory Limits (in pCi/g above background unless otherwise noted)

Disposal Tier	Combined Radionuclides 226/228	Natural Uranium	Natural Thorium
Exempt (land application authorized)	<3	<30	<3
Municipal Solid Waste Landfill or Compost Feed	<10	<100	<10
Industrial Landfill	<50	<300	<50
RCRA C Hazardous Waste landfill	<400	0.05% By Weight	0.05% by Weight

At this time, the elevated radionuclide levels have only been detected in the South Lagoon, so there is no immediate requirement to modify the disposal practices. However, a study should also be completed to determine the cause of the accumulation. It is recommended that the radionuclide content of the raw water supply should be actively monitored to determine if there is an increasing concentration trend. In the event that there is positive indication of increasing radionuclide, a shift to disposal in an industrial landfill may be required. Given the higher cost with this type of disposal, it would be recommended that Thornton should begin to study means to minimize sludge generation and/or minimize sludge disposal volumes. These could be accomplished via either a process study to optimize sludge generation and/or evaluating the thickening and disposal processes, including considering the installation of mechanical dewatering systems. This information will be further studied as part of the Process Evaluations to be completed during the Project.

Planned Modifications

In the Initial Data Review TM for the Water Treatment Facilities Master Plan, a list of currently planned WBWTP modifications was identified. While there are no specific regulatory impacts identified with the recent regulatory changes, the applicable regulatory requirements are listed below and are inclusive of all current regulatory considerations for the WBWTP treatment processes:

- Moving the chlorine dosing for disinfection contact time to the clearwell. This change will reduce the sodium hypochlorite dosage at the influent but may modify the formation of disinfection by-products. The concentrations of these contaminants (bromate, chlorite, HAA5, TTHM, chloramines, chlorine and chlorine dioxide) should not exceed the maximum contaminant level goals (MCLGs) and maximum contaminant levels (MCLs) established by US EPA under the Stage 1/2 Disinfection / Disinfection Byproducts Rule (D/DBPR).
- Improving the ferric chloride mixing by replacing the current mixer with a flash mixing system. Modifying the coagulant systems corresponds to a Category 3 project as defined in the updated Safe Drinking Water Program Implementation Policy 5. Thornton will need to submit an evaluation of the project's impact to corrosivity that includes mitigation measures.
- Replacing the ferric chloride with aluminum chlorohydrate (ACH): this change is being evaluated as a means to reduce membrane fouling, although it may also have benefits for reducing manganese issues as well as reducing potential concerns with radionuclide in the plant residuals. However, ACH cannot be applied beneficially as a soil amendment, which will require changing disposal practices to use either a sanitary or industrial landfill. This will require sludge to meet free liquid disposal requirements (SW-846 Test Method 9095B), which may require additional dewatering/thickening of sludge. Additionally, ACH requires a higher dosage to achieve the required total organic carbon (TOC) removal, which may increase sludge volume. Lastly, an additional consideration is that changing coagulant also corresponds to a Category 3 project as explained in the updated Safe Drinking Water Program Implementation Policy 5, which will require that Thornton submit an evaluation of the project's impact to corrosivity that includes mitigation measures.
- Formation of cyanotoxins in the Gravel Lakes: Since the City of Thornton recognizes the potential for cyanotoxins development in its Gravel Lakes, the City developed an "Algal Toxin Strategy" in 2017.

5. Summary

Review of the regulatory framework and associated considerations that impact Thornton's water treatment facilities has not identified emerging contaminants or changes in regulations that would require modification to the treatment facilities or processes currently employed or planned by Thornton. In particular, Thornton's treatment goals listed in Section 3.3.3 of the 2016 Conceptual Design Report should remain the same.

The levels of radionuclide found in the sludge in the lagoons at the Wes Brown Water Treatment Plant may require changes in disposal practices if the radioactivity continues to be above the regulatory limits for land application. The changes could include changing to an alternative disposal method (industrial or hazardous waste landfill) or changes to the primary coagulant. In event that the coagulant is changed, the disposal method will also likely have to be altered. The impact of this change may require evaluation of improved dewatering practices and/or equipment to meet free liquid disposal requirements.

It is assumed that Thornton's design of the new TTP is consistent with these current regulatory findings.

Expansion of existing treatment facilities or development of new treatment facilities that will be developed during the Project will also be based on these current regulatory findings.

Appendix A – Section 3.3, Water Treatment Plant Replacement Project CIP 15-468 Conceptual Design Report (November 2016), *Carollo*

3.2.2 Basis of Design Criteria

Table 3.3 presents the raw water quality conditions for key Standley Lake and EGL4 source water parameters that the Design-Builder shall use as the basis of its design, in addition to the previously presented historical data. The raw water quality values shown in Table 3.3 provide a larger range of conditions than the available historical data to account for the limitations of the available sampling data set, diurnal variation, and future changes to water quality. The new TWTP must be able to achieve the treated water quality acceptance standards over the full range of raw water quality presented.

Table 3.3 Basis of Design Criteria - Raw Water Quality

Parameter	Unit	Standley Lake		East Gravel Lake 4	
		Minimum	Maximum	Minimum	Maximum
Turbidity	NTU	0.1	50	0.1	50
pH	-	6.0	9.5	6.5	10.0
Temperature	degrees C	0.5	27	0.5	27
Alkalinity	mg/L as $CaCO_3$	35	70	80	250
Total Organic Carbon	mg/L	0.5	4.0	3.0	9.0
Dissolved Organic Carbon	mg/L	0.5	4.0	3.0	9.0
Total Hardness	mg/L as $CaCO_3$	60	240	100	350
Total Dissolved Solids	mg/L	50	300	150	750
Iron (Dissolved)	mg/L	0	1.5	0	0.3
Manganese (Dissolved)	mg/L	0	1.0	0	0.8
Bromide	mg/L	0	0.4	0	0.5
Geosmin	ng/L	0	50	0	300
MIB	ng/L	0	50	0	300
Ortho-P	mg/L	0	0.6	0	3.0
Nitrate	mg/L	0	1.0	0	3.0

3.3 FINISHED WATER QUALITY REQUIREMENTS

The USEPA has promulgated rules and regulations governing the treatment of drinking water. In Colorado, these rules have been adopted and are codified along with state-specific requirements in the Colorado Primary Drinking Water Regulations (CPDWR).

These regulations are administered and enforced by the Colorado Department of Public Health and Environment (CDPHE), and the City is required to meet the applicable requirements of these regulations. The Design-Builder is required to review the impact of all applicable rules and regulations on the new TWTP including, but not limited to, the following:

1. Safe Drinking Water Act (National Primary Drinking Water Regulations),
2. National Secondary Drinking Water Regulations,
3. Lead and Copper Rule (LCR),
4. Arsenic Rule,
5. Radionuclides Rule,
6. Total Coliform Rule (TCR),
7. Revised Total Coliform Rule (RTCR),
8. Surface Water Treatment Rule (SWTR),
9. Interim Enhanced Surface Water Treatment Rule (IESWTR),
10. Long-Term 1 Enhanced Surface Water Treatment Rule (LT1ESWTR),
11. Long-Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR),
12. Stage 1 Disinfectants and Disinfection Byproducts Rule (Stage 1 D/DBPR),
13. Stage 2 Disinfectants and Disinfection Byproducts Rule (Stage 2 D/DBPR),
14. Filter Backwash Recycling Rule (FBRR), and
15. Anticipated Future Regulations.

The Design-Builder is responsible for delivering a new TWTP that provides treatment capable of continuously meeting all applicable and promulgated drinking water regulations over the full range of raw water quality conditions. A summary of promulgated regulations, which is current as of the third quarter of 2016, is provided below. The Design-Builder is responsible for verifying the regulatory requirements information herein.

3.3.1 Summary of Current Regulations

3.3.1.1 Safe Drinking Water Act (National Primary Drinking Water Regulations)

The primary statutes that govern drinking water quality are codified in the Safe Drinking Water Act (SDWA) of 1974. Substantial amendments to the SDWA passed in 1986 significantly altered the rate at which the USEPA was to set drinking water standards, resulting in a three-fold increase in the number of regulated constituents. Additional SDWA amendments promulgated in 1996 required the USEPA to develop rules to balance risks between microbial pathogens and disinfection byproducts (DBP).

The National Primary Drinking Water Regulations (NPDWR) are the enforceable standards set forth by the USEPA which govern drinking water quality. These are based on Maximum

Contaminant Levels (MCL) and Treatment Technique (TT) requirements. NPDWRs currently exist for more than 80 contaminants, including:

- MCLs for fecal coliform/*Escherichia coli* (*E. coli*) and TTs for six indicator microorganisms (including turbidity).
- MCLs for four radionuclides.
- MCLs for 14 and TTs for two inorganic contaminants.
- MCLs for 51 and TTs for two organic contaminants.
- Maximum Residual Disinfectant Levels (MRDL) for three disinfectants (chlorine, chlorine dioxide, and chloramines).
- MCLs for four disinfection byproducts/classes of disinfection byproducts.

Adoption of these regulations by the State of Colorado allows the CDPHE to assume responsibility for enforcing the standards established by the federal SDWA. In addition to enforceable MCLs for a majority of regulated contaminants, the USEPA has also established Maximum Contaminant Level Goals (MCLG) as non-enforceable public health goals for all regulated contaminants.

Table 3.4 lists specific treatment requirements of existing regulations that apply to the TWTP Replacement Project, including references to the specific rule. Additional information on applicable regulations is provided in subsequent sections.

Table 3.4 National Primary Drinking Water Regulations

	USEPA			
Contaminant	**MCLG (mg/L)**	**MCL or TT (mg/L)**	**Regulation**	**Notes**
Microorganisms				
Cryptosporidium	0	TT(1)	IESWTR	
Fecal Coliform / *E. coli*	0	MCL(2)	RTCR	
Giardia lamblia	0	TT(1)	SWTR	
Heterotrophic Plate Count (HPC)	-	TT(1)	SWTR	
Legionella	0	TT(1)	SWTR	
Total Coliforms	0	< 5.0%	TCR	
Turbidity	-	TT(1)	IESWTR	
Viruses (Enteric)	0	TT(1)	SWTR	

Table 3.4 National Primary Drinking Water Regulations				
	USEPA			
Contaminant	**MCLG (mg/L)**	**MCL or TT (mg/L)**	**Regulation**	**Notes**
Disinfectants and Disinfection Byproducts				
Bromate	0	0.10	Stage 1 D/DBPR	
Chlorite	0.8	1.0	Stage 1 D/DBPR	
Haloacetic Acids (HAA5)	-	0.060	Stage 2 D/DBPR	LRAA
Total Trihalomethanes (TTHM)	-	0.080	Stage 2 D/DBPR	LRAA
Chloramines (as Cl_2)	4	4.0	Stage 1 D/DBPR	
Chlorine (as Cl_2)	4	4.0	Stage 1 D/DBPR	
Chlorine Dioxide (as Cl_2)	0.8	0.8	Stage 1 D/DBPR	
Volatile Organic Compounds (VOC)				
Benzene	0	0.005	SDWA	
Carbon Tetrachloride	0	0.005	SDWA	
1,2-Dichloroethane	0	0.005	SDWA	
1,1-Dichloroethylene	0.007	0.007	SDWA	
cis-1,2-Dichloroethylene	0.07	0.07	SDWA	
trans-1,2-Dichloroethylene	0.1	0.1	SDWA	
Dichloromethane	0	0.005	SDWA	
1,2-Dichloropropane	0	0.005	SDWA	
Ethylbenzene	0.7	0.7	SDWA	
Monochlorobenzene	0.1	0.1	SDWA	
o-Dichlorobenzene	0.6	0.6	SDWA	
p-Dichlorobenzene	0.075	0.075	SDWA	
Styrene	0.1	0.1	SDWA	
Tetrachloroethylene (PCE)	0	0.005	SDWA	
Toluene	1	1	SDWA	
1,2,4-Trichlorobenzene	0.07	0.07	SDWA	

Table 3.4 National Primary Drinking Water Regulations				
	USEPA			
Contaminant	MCLG (mg/L)	MCL or TT (mg/L)	Regulation	Notes
1,1,2-Trichloroethane	0.003	0.005	SDWA	
1,1,1-Trichloroethane	0.2	0.2	SDWA	
Trichloroethylene (TCE)	0	0.005	SDWA	
Vinyl Chloride	0	0.002	SDWA	
Xylenes (Total)	10	10	SDWA	
Synthetic Organic Chemicals (SOC)				
2,3,7,8-TCDD (Dioxin)	0	3×10^{-8}	SDWA	
2,4,5-TP (Silvex)	0.05	0.05	SDWA	
2,4-D	0.07	0.07	SDWA	
Acrylamide	0	TT	SDWA	
Adipates	0.4	0.4	SDWA	
Alachlor (Lasso)	0	0.002	SDWA	
Atrazine (Atranex, Crisazina)	0.003	0.003	SDWA	
Benzo(a)pyrene	0	0.0002	SDWA	
Carbofuran (Furadan 4F)	0.04	0.04	SDWA	
Chlordane	0	0.002	SDWA	
Dalapon	0.2	0.2	SDWA	
Dibromochloropropane (DBCP)	0	0.0002	SDWA	
Diethylhexyl Phthalate (DEHP)	0	0.006	SDWA	
Dinoseb	0.007	0.007	SDWA	
Diquat	0.02	0.02	SDWA	
Endothall	0.1	0.1	SDWA	
Endrin	0.002	0.002	SDWA	
Epichlorohydrin	0	TT	SDWA	
Ethylene Dibromide	0	0.00005	SDWA	
Glyphosate	0.7	0.7	SDWA	
Heptachlor (H-34, Heptox)	0	0.0004	SDWA	
Heptachlor Epoxide	0	0.0002	SDWA	
Hexachlorobenzene	0	0.001	SDWA	
Hexachlorocyclopentadiene	0.05	0.05	SDWA	

Table 3.4 National Primary Drinking Water Regulations				
	USEPA			
Contaminant	**MCLG (mg/L)**	**MCL or TT (mg/L)**	**Regulation**	**Notes**
Lindane	0.0002	0.0002	SDWA	
Methoxychlor (Marlate)	0.04	0.04	SDWA	
Oxyamyl (Vydate)	0.2	0.2	SDWA	
Pentachlorophenol	0	0.001	SDWA	
Picloram	0.5	0.5	SDWA	
Polychlorinated Biphenyls	0	0.005	SDWA	
Simazine	0.004	0.004	SDWA	
Toxaphene	0	0.003	SDWA	
Inorganic Chemicals (IOC)				
Antimony	0.006	0.006	SDWA	
Arsenic	0	0.010	Arsenic Rule	
Asbestos (Fibers > 10 µm)	7 MFL	7 MFL	SDWA	
Barium	2	2	SDWA	
Beryllium	0.004	0.004	SDWA	
Cadmium	0.005	0.005	SDWA	
Chromium	0.1	0.1	SDWA	
Copper	1.3	TT, Action Level = 1.3	SDWA	Per LCR
Cyanide	0.2	0.2	SDWA	
Fluoride	4	4	SDWA	SMCL= 2.0 mg/L
Lead	0	TT, Action Level = 0.015	SDWA	Per LCR
Mercury	0.002	0.002	SDWA	
Nitrate (as N)	10	10	SDWA	
Nitrite (as N)	1	1	SDWA	
Selenium	0.05	0.05	SDWA	
Thallium	0.0005	0.002	SDWA	

Table 3.4 National Primary Drinking Water Regulations				
	USEPA			
Contaminant	MCLG (mg/L)	MCL or TT (mg/L)	Regulation	Notes
Radionuclides				
Combined Radium (226/228)	0	5 pCi/L	Radio-nuclides Rule	
Gross Alpha	0	15 pCi/L	Radio-nuclides Rule	Excludes radon and uranium
Beta Particles and Emitters	0	4 mrems/yr	Radio-nuclides Rule	
Uranium	0	0.030	Radio-nuclides Rule	
Filter Backwash Recycle		TT	Filter Backwash Recycle Rule(3)	

Notes:

(1) The USEPA SWTRs require systems using surface water to:

a. Disinfect their water, and

b. Filter water or meet criteria for avoiding filtration so that the following contaminants are controlled at the following levels:

Cryptosporidium: 2-log removal.

Giardia lamblia: 3-log removal/inactivation.

Viruses: 4-log removal/inactivation.

Legionella: No limit, but USEPA believes that if *Giardia* and viruses are removed/inactivated, *Legionella* will also be controlled.

Turbidity: ≤0.3 NTU 95 percent of the time, never to exceed 1 NTU.

HPC: No more than 500 bacterial colonies/mL.

(2) A routine sample that is fecal coliform-positive or *E. coli*-positive triggers repeat samples. If any repeat sample is total coliform-positive, the system has an acute MCL violation. A routine sample that is total coliform-positive and fecal coliform-negative or *E. coli*-negative triggers repeat samples. If any repeat sample is fecal coliform-positive or *E. coli*-positive, the system has an acute MCL violation.

(3) Includes self-assessment and monitoring of recycle returned to the head of the plant.

LRAA	locational running annual average	mrems/yr	millirems per year
MFL	million fibers per liter	pCi/L	picocuries per liter
MRDLG	Maximum Residual Disinfectant Level Goal	SMCL	Secondary Maximum Contaminant Level

3.3.1.2 National Secondary Drinking Water Regulations

In addition to the enforceable NPDWRs listed in Table 3.4, the USEPA has established non-enforceable secondary standards recommended for 15 constituents to ensure the aesthetic quality of drinking water. These SMCL are listed in Table 3.5.

Table 3.5 National Secondary Drinking Water Regulations

Contaminant	USEPA SMCL
Aluminum	0.05 to 0.2 mg/L
Chloride	250 mg/L
Color	15 color units (cu)
Copper	1.0 mg/L
Corrosivity	Non-corrosive
Fluoride	2.0 mg/L
Foaming Agents	0.5 mg/L
Iron	0.3 mg/L
Manganese	0.05 mg/L
Odor	3 threshold odor number (TON)
pH	6.5 - 8.5
Silver	0.1 mg/L
Sulfate	250 mg/L
Total Dissolved Solids	500 mg/L
Zinc	5 mg/L

The Design-Builder shall ensure the new TWTP is capable of meeting the secondary standards listed in Table 3.5, even though such standards may not be considered enforceable by CDPHE.

It should be noted that the new TWTP Indicative Design does not include a TDS removal process, as it presents high costs and process complication given the low occurrence of source water TDS above the SMCL. During periods of elevated TDS in EGL4 source water, raw water blending with Standley Lake source water may be used as a control strategy to reduce TDS below the SMCL.

3.3.1.3 Lead and Copper Rule

Although lead and copper are not commonly found at excessive levels in raw water sources, these contaminants can leach from distribution system piping and plumbing fixtures in homes or buildings. In 1991, the USEPA promulgated the LCR which established

MCLGs for lead and copper and Action Levels (AL) for the 90th percentile concentration of home tap samples of:

- Lead: 0.015 mg/L and
- Copper: 1.3 mg/L.

The USEPA published minor revisions to the LCR in 2000 and 2007 which did not alter these ALs, but did address elements such as corrosion control optimization, lead service line replacement, public education, monitoring, analysis, and reporting.

3.3.1.4 Arsenic Rule

In January of 2001, the USEPA proposed a reduction in the previously established arsenic MCL from 50 µg/L to 10 µg/L. This modification was finalized in February of 2002 and all public water systems had to reach compliance with the new standard by January 23, 2006.

3.3.1.5 Radionuclides Rule

In 2000, the USEPA announced revised MCLs and monitoring requirements for radionuclides as well as a new standard for uranium as mandated by the 1986 SDWA Amendments. This rule became effective on December 8, 2003. Initial compliance under the new monitoring requirements is determined using the average of four quarterly samples, or at state-direction, using appropriate grandfathered data.

3.3.1.6 Total Coliform Rule

The TCR, promulgated in 1989, established total and fecal coliform MCLGs of zero, based on the percentage of positive samples collected during a compliance period. The number of samples a water system is required to collect per month depends on the number of people it serves.

The TCR allows for no more than 5 percent positive samples per month. If a system has greater than 5 percent total coliform-positive (TC-positive) samples in a month, it is considered a monthly MCL violation, and must be reported to CDPHE and the public within a specific timeframe. All TC-positive samples must be analyzed for the presence of *E. coli* or fecal coliforms. If two consecutive samples are TC-positive and one is also fecal coliform or *E. coli* positive, it is considered an acute MCL violation and the system must collect repeat samples and notify CDPHE and the public using mandatory language developed by the USEPA.

The TCR also requires secondary disinfection in accordance with the following:

- Maintain a recommended minimum disinfectant residual of 0.2 mg/L of free chlorine or 0.5 mg/L of chloramines measured as total chlorine present through the distribution system continually (CDPHE requires a 0.2 mg/L disinfectant residual of chloramines measured as total chlorine).

- A sample with a heterotrophic plate count of less than 500 colony forming units (cfu)/100 mL is assumed to carry the required minimum residual.

3.3.1.7 Revised Total Coliform Rule

Since publication of the original TCR, increased attention has been focused on how water quality changes in distribution systems. The Federal Advisory Committee recommended that the USEPA revise the TCR which has since been republished in February of 2013 as the RTCR. The goal of the RTCR is to decrease potential introduction of fecal contamination into distribution systems. All public water systems were required to comply with the RTCR by April 1, 2016.

The RTCR eliminated the MCLG for total/fecal coliforms and the MCL for total coliforms. It also established an MCLG of zero and an MCL for *E. coli*. Under the RTCR, public water system is in compliance with the *E. coli* MCL unless any of the conditions shown in Table 3.6 occur.

Table 3.6 *E. coli* MCL Violation Sample Result Combinations

Routine	Repeat
EC+	TC+
EC+	Any missing sample
EC+	EC+
TC+	EC+
TC+	TC+ (but no *E. coli* analysis)

Notes:
EC = *E. coli*
TC = total coliform
+ = positive sample result

The RTCR also mandated public water systems to develop a sample site plan identifying sampling sites and schedules for routine and repeat monitoring by April 1, 2016. This plan is intended to ensure that sites where total coliform samples are collected are representative of water quality throughout the distribution system and that samples will be collected at regular intervals throughout the month.

3.3.1.8 Surface Water Treatment Rule

In June of 1989, the USEPA promulgated the SWTR which requires systems using surface water or groundwater under the direct influence of surface water (GWUDI) to provide treatment to reduce turbidity, *Giardia*, *Legionella*, viruses, and HPC bacteria. Under the SWTR, surface water or GWUDI systems must use treatment systems capable of providing minimum reductions of 99.9 percent (3-log) for *Giardia* cysts and 99.99 percent (4-log) reduction for viruses. These performance standards are to be achieved by a multi-barrier approach involving a combination of physical removal by pretreatment and filtration, and inactivation by disinfection.

The SWTR also stipulates the following requirements for turbidity and disinfection in conventional filtration plants:

- The turbidity of representative samples of a system's filtered water must be less than or equal to 0.5 NTU in at least 95 percent of the measurements taken each month.
- The turbidity level of representative samples of a system's filtered water must at no time exceed 5 NTU.

Conventional treatment plants which meet the 0.5 NTU effluent turbidity standard are credited 2.5-log removal of *Giardia* cysts and a 2-log removal of viruses. In addition to meeting the filtration requirements, conventional treatment systems must also meet the following SWTR conditions:

- This disinfection process must achieve at least 0.5 inactivation of *Giardia* cysts and at least a 2-log inactivation of viruses as demonstrated by meeting minimum "CT" requirements based on the residual disinfectant concentration and effective contact time of the disinfectant.
- The residual disinfectant concentration in water entering the distribution system cannot be less than 0.2 mg/L of free chlorine or 0.5 mg/L of chloramines for more than 4 hours.
- The residual disinfectant concentration in the distribution system cannot be undetectable in more than 5 percent of the samples taken each month for any 2 consecutive months. Water in the distribution system with an HPC concentration less than or equal to 500 cfu/100 mL is deemed to have a detectable disinfectant residual.

3.3.1.9 <u>Interim Enhanced Surface Water Treatment Rule</u>

Several waterborne outbreaks of Cryptosporidiosis following the promulgation of the SWTR prompted congress to issue a congressional mandate in 1998 requiring the USEPA to develop rules to address the risk of chlorine resistant pathogens such as *Cryptosporidium*. Because information obtained from the Information Collection Rule (ICR) to support rule development would not be available until mid-1999, the USEPA developed the IESWTR for large systems.

Finalized in December of 1998, the IESWTR became effective in December of 2001 and included the following treatment technique provisions:

- An MCLG of zero for the protozoan genus *Cryptosporidium*.
- Filtered surface water and GWUDI systems serving 10,000 or more people must achieve at least 99 percent (2-log) removal of *Cryptosporidium*.

- Combined filter effluent average turbidity as measured every four hours must be less than or equal to 0.3 NTU in 95 percent of the samples taken each month. The maximum allowable combined filter effluent turbidity is 1 NTU.
- Individual filter effluent turbidity monitoring is required every 15 minutes. If the combined filter effluent exceeds the turbidity requirements listed above, the following conditions are to be reported to the State:
  - Any individual filter with an effluent turbidity > 1.0 NTU based upon two consecutive measurements taken 15 minutes apart.
  - Any individual filter with an effluent turbidity > 0.5 NTU after 4 hours of ripening based on two measurements taken 15 minutes apart.
  - Self-assessment in conformance with USEPA published guidelines is required for any filter with an effluent turbidity > 1.0 NTU, based upon two measurements taken 15 minutes apart at any time in each of 3 consecutive months.
  - Comprehensive Performance Evaluation (CPE) in conformance with the USEPA published guidelines is required for any filter with an effluent turbidity > 2.0 NTU, based upon two measurements taken 15 minutes apart at any time in each of two consecutive months.
- Microbial benchmarking/profiling requirements by the Rule apply to systems which have, based on one year running annual average of representative systems taken in the distribution system, measured:
  - TTHM levels of at least 80 percent of the MCL (64 µg/L).
  - HAA5 levels of at least 80 percent of the MCL (48 µg/L).
- Surface water and GWUDI systems are required to cover all new treated water reservoirs, holding tanks, and other storage facilities.

3.3.1.10 Long-Term 1 Enhanced Surface Water Treatment Rule

Promulgated in January of 2002, the LT1ESWTR expanded the requirements of the IESWTR to systems serving less than 10,000 people.

3.3.1.11 Long-Term 2 Enhanced Surface Water Treatment Rule

Promulgated in December of 2005, the LT2SWTR expanded upon the requirements of the IESWTR and LT1SWTR to target additional *Cryptosporidium* treatment in higher risk systems. Included in this rule are specific requirements for source water monitoring and risk-based treatment requirements.

Filtered systems serving a population of 10,000 or greater, including the City, were required to conduct a 24-month monitoring survey of their source water for *Cryptosporidium* followed by an action bin assignment based on the results of this sampling. The TWTP is currently Bin Level 1 and all required *Cryptosporidium* removal/inactivation credit is provided by filtration.

As shown in Table 3.7, a filtered system's bin classification determines the extent of any additional *Cryptosporidium* treatment necessary beyond the requirements of current regulations. Those systems that comply with the IESWTR and are classified as Bins 2 through 4 will be required to provide from 1.0- to 2.5-log of additional *Cryptosporidium* removal.

Table 3.7 Bin Classifications and Additional Treatment Requirements for Filtered Systems Under LT2ESWTR

Bin Classification	Average *Cryptosporidium* Concentration (oocysts/L)	Additional Treatment Requirements[1]: Conventional Filtration Systems	Additional Treatment Requirements[1]: Direct Filtration Systems[2]
1	< 0.075	No additional treatment	No additional treatment
2	≥ 0.075 to < 1.0	1-log treatment[3]	1-log treatment[3]
3	≥ 1.0 to < 3.0	2-log treatment[4]	2-log treatment[4]
4	≥ 3.0	2.5-log treatment[4]	2.5-log treatment[4]

Notes:

(1) Additional treatment assumes full compliance with SWTR, IESWTR, and LT1ESWTR (as applicable). Conventional filtration (including lime softening) and direct filtration treatment in compliance with these rules will receive 3.0- and 2.5-log Cryptosporidium treatment, respectively, prior to additional treatment required by LT2SWTR.

(2) Direct filtration systems use coagulation, flocculation, and filtration processes similar to a conventional filtration system, but lack a sedimentation or equivalent clarification process.

(3) Any individual combination of technologies from the microbial toolbox may be used to achieve this treatment.

(4) At least 1-log treatment must be achieved using ozone, chlorine dioxide, ultraviolet (UV), membranes, bag filters, cartridge filters, or bank filtration.

The additional treatment requirements are based, in part, on the assumption that conventional filtration systems in compliance with the IESWTR achieve an average of 3-log removal of *Cryptosporidium*. Therefore, the total *Cryptosporidium* removal requirements for the action bins with 1-log, 2-log, and 2.5-log additional treatment correspond to total removals of 4-log, 5-log, and 5.5-log, respectively. Additional treatment requirements can be achieved using combinations of technologies listed in the "Microbial Toolbox" presented in Table 3.8.

Table 3.8 Microbial Toolbox Components for LT2ESWTR

Additional Treatment Approach	Potential Log Credit: 0.5	1	2	> 2.5
Watershed Control				
Watershed Control Program[1]	X			
Reduction in Oocyst Concentration[2]	As Measured			
Reduction in Viable Oocysts Concentration[2]	As Measured			

Table 3.8 Microbial Toolbox Components for LT2ESWTR				
	Potential Log Credit			
Additional Treatment Approach	**0.5**	**1**	**2**	**> 2.5**
Alternative Source				
Intake Relocation[(2)]	As Measured			
Change to Alternative Source of Supply[(2)]	As Measured			
Intake Management to Reduce Capture of Oocysts in Source Water[(2)]	As Measured			
Managing Timing of Withdrawal[(2)]	As Measured			
Managing Level of Withdrawal in Water Column[(2)]	As Measured			
Pretreatment				
Pre-Settling Basin w/ Coagulant	X			
Two-Stage Lime Softening[(1)]	X			
In-Bank Filtration[(1)]		X		
Improved Treatment				
Low Finished Water Turbidity (0.15 NTU 95 percentile Combined Filter Effluent (CFE)	X			
Low Finished Water Turbidity (0.15 NTU 95 percentile individual filter)	X			
Slow Sand Filters[(1)]				X
Membranes (MF, UF, NF, RO)[(1)]				X
Bag Filters or Cartridge Filters[(1)]			X	
Improved Disinfection				
Chlorine Dioxide[(3)]	X	X		
Ozone[(3)]	X	X	X	
UV[(3)]				X
Peer Review / Other Demonstration / Validation or System Performance				
Peer Review Program (ex. Partnership for Safe Water Phase IV)		X		
Performance studies demonstrating reliable specific log removals for technologies not listed above. This provision does not supersede other inactivation requirements.	As Demonstrated			

Notes:
(1) Criteria specified in guidance to determine allowed credit.
(2) Additional monitoring for *Cryptosporidium* after this action would determine new bin classification and whether additional treatment is required.
(3) Inactivation dependent on dose and source water characteristics.
(4) X indicates potential log credit based on proper design and implementation in accordance with USEPA guidance.

3.3.1.12 Stage 1 Disinfectants and Disinfection Byproducts Rule

The Stage 1 D/DBPR was finalized in December of 1998 and became effective on January 1, 2002. All public water systems serving populations greater than 500 and using a primary disinfectant other than UV light are subject to this rule. The Stage 1 D/DBPR reduced the TTHM MCL and established MCLs for HAA5, bromate, and chlorite. It also set MRDLs and MRDLGs for three disinfectants and placed several restrictions on disinfection practices. The Stage 1 D/DBPR requirements are summarized in Table 3.9.

Table 3.9 Stage 1 D/DBPR MCLs and MRDLs

Constituent	Concentration (mg/L)	
	MCL	MRDL/MRDLG
Total Trihalomethanes (TTHM)(1)(3)	0.080	--
Haloacetic Acids (HAA5)(1)(4)	0.060	--
Bromate	0.010	--
Chlorite	1.0	--
Free Chlorine(2)	--	4.0
Chloramines(2)	--	4.0
Chlorine Dioxide(2)	--	0.8

Notes:
(1) Running annual average (RAA) compliance basis.
(2) As total chlorine.
(3) Sum of chloroform, bromodichloromethane, dibromochloromethane, and bromoform.
(4) Sum of mono-, di-, tri-chloroacetic acids, and mono- and di-bromoacetic acids.

In addition to establishing MCLs and MRDLs, the Stage 1 D/DBPR required reduction of DBP precursors. The specified treatment techniques for this purpose are enhanced coagulation and enhanced precipitative softening. TOC is used as a surrogate for natural organic matter. Treatment plants with source water TOC greater than 2.0 mg/L are required to implement one of these treatment techniques. The percent of influent TOC that must be removed is based on raw water TOC and alkalinity, as shown in Table 3.10.

Table 3.10 Stage 1 D/DBPR Required Removal of TOC

Raw Water TOC (mg/L)	TOC Reduction Requirements (%) for Given Source Water Alkalinity (mg/L as $CaCO_3$)		
	0 to 60 mg/L	> 60 to 120 mg/L	> 120 mg/L
> 2.0 to 4.0	35%	25%	15%
> 4.0 to 8.0	45%	35%	25%
> 8.0	50%	40%	30%

3.3.1.13 Stage 2 Disinfectants and Disinfection Byproducts Rule

The Stage 2 D/DBPR was established in January of 2006 to strengthen the requirements of the Stage 1 D/DBPR by reducing occurrences of DBP concentration spikes in distribution systems. The MCLs for TTHM and HAA5 remained the same as those established in the Stage 1 D/DBPR (80 and 60 µg/L, respectively); however, the method used to calculate MCL compliance was altered.

Under Stage 2, TTHM and HAA5 MCLs must be met as LRAAs, the average concentration at each individual monitoring location, rather than RAAs of the system as a whole. Monitoring samples must be collected at distribution system locations with high DBP concentrations as determined by an initial distribution system evaluation during peak months of TTHM and HAA5 occurrence. LRAAs are calculated by collecting quarterly samples at each monitoring location and taking the average of the most recent sample and the three preceding samples.

3.3.1.14 Filter Backwash Recycling Rule

The USEPA established the FBRR in January of 2002 to minimize *Cryptosporidium* concentrations in treated water due to the recycling of sludge supernatant and filter backwash wastewater. The FBRR applies to surface water and GWUDI systems. The major requirements of this rule are as follows:

- Systems that recycle backwash waste must do so prior to the point of application of primary coagulant.
- Direct filtration plants may be required to provide detailed recycle treatment information to the State.
- Conventional treatment plants that practice direct recycle, employ 20 or fewer filters to meet production requirements during a selected month, and recycle spent filter backwash water thickener supernatant and/or liquids from dewatering processes must perform a one month, one-time recycle self-assessment. The self-assessment requires hydraulic flow monitoring and certain data to be reported to the State. Recycling practice modifications may be required to protect public health.

3.3.2 Future Regulations

There are a number of unregulated contaminants which could be the subject of new USEPA rulemaking actions in the near future. The Design-Builder is responsible for delivering a new TWTP that provides treatment capable of continuously meeting all drinking water regulations promulgated prior to the date the Guaranteed Maximum Price (GMP) Amendment is executed for the Project. Any additional treatment processes required to meet regulations that are promulgated subsequent to issuance of the GMP Amendment are not considered as part of the Project.

The primary tools the USEPA uses to determine which unregulated contaminants to regulate are the Contaminant Candidate List (CCL) and Unregulated Contaminant Monitoring Rule (UCMR). Data for the most recent finalized UCMR (UCMR3) are currently being compiled. Any regulatory determinations that results from this are expected to be published in 2017 or 2018. A draft of potential CCL4 contaminants and a proposal for UCMR4 were published by the USEPA in December of 2015. UCMR4 data collection will occur from 2018 through 2020. Any regulatory determinations from the results of that monitoring effort will likely be published in 2022 or 2023.

In addition to the potential regulation of CCL and UCMR contaminants, there are a number of existing regulations which may be changed in the coming years. Both the LT2SWTR and LCR are included in a USEPA plan to review existing regulations as mandated by Executive Order 13563. Other existing chemical regulations which could be altered as a result of the include fluoride, total chromium/hexavalent chromium, VOCs, and manganese.

A schedule of potential changes to drinking water regulations is shown in Table 3.11. Further discussion about each of these anticipated regulatory changes can be found in subsequent sections.

Table 3.11 Anticipated Future Regulatory Actions

Regulatory Action	Proposal Date[1]	Final Date[1]
Strontium	2017 or 2018	2018 or 2019
Perchlorate	2016 or 2017	2017 or 2018
Nitrosamines	2019 or 2020	2022 or 2023
Chlorate	2019 or 2020	2022 or 2023
PFOS/PFOA	2019 or 2020	2022 or 2023
Cyanotoxins	2019 or 2020	2022 or 2023
LCR Long-Term Revisions	2016 or 2017	2018 or 2019
Fluoride	-	-
Hexavalent Chromium	-	-
Carcinogenic VOCs (cVOC)	2016 or 2017	2018
Toxic Organic Chemicals	-	-
Emerging DBPs	-	-
Manganese	2019 or 2020	2022 or 2023

Notes:
(1) Dates based on currently available regulatory information and are subject to change

3.3.2.1 Strontium

Strontium is a naturally occurring metal which is used in various applications including pyrotechnics and fertilizers. It can enter waterways through the weathering of rocks and soils. Strontium has been shown to impair bone growth in rats and is used as a surrogate for calcium in osteoporosis patients. Exposure risks are expected to be greater for children than adults because strontium accumulates more aggressively in their bones due to higher calcium requirements during development. The established health reference level (HRL) for strontium was lowered from 4.2 mg/L to 1.5 mg/L in 2014.

UCMR3 monitoring results indicated that strontium is present at concentrations greater than the specified HRL in only 5.7 percent of public water systems. Accordingly, the USEPA decided to postpone the decision to regulate strontium so additional occurrence data can be collected and analyzed. If a regulation is proposed, publication is expected by early 2019.

3.3.2.2 Perchlorate

Perchlorate occurs both naturally and as a man-made chemical. It is used in the manufacture of fireworks, explosives, flares, and rocket propellant. When ingested, perchlorate blocks the uptake of iodine by the thyroid thereby inhibiting the production of hormones. The USEPA has issued an interim lifetime drinking water health advisory of 15 µg/L. State specific enforceable drinking water regulations for perchlorate have been established by Massachusetts (2 µg/L) and California (6 µg/L). No such regulation has been developed in Colorado.

The USEPA initially eliminated perchlorate from regulatory consideration in 2008 as part of the second CCL regulatory determination. This decision was reversed in 2011. The Science Advisory Board Perchlorate Advisory Panel has finalized its review of the basis for setting a perchlorate MCLG. In June of 2016, there was a request for nominations for peer review approaches for deriving the MCLG. Once an MCLG is established, a federal perchlorate regulation could be promulgated as soon as 2017.

3.3.2.3 Nitrosamines

Nitrosamines are a group of suspected carcinogens that form from reactions with nitrate and secondary amines. UCMR2 data collected from 2008 and 2010 shows that N-nitrosodimethylamine (NDMA) and other nitrosamines are prevalent in public water systems. There is still significant debate as to whether or not regulation of this suite of chemicals would provide a meaningful opportunity for risk reduction as mandated by the SDWA. Regulatory discussions have focused around regulating nitrosamines as a group. Any regulation would almost certainly include NDMA. More information on this topic is anticipated to emerge in the coming years as the fourth CCL regulatory determination moves forward.

3.3.2.4 Chlorate

Chlorate is a DBP that forms from the use of chlorine dioxide as a disinfectant. Ingestion of chlorate can cause methemoglobinemia and decreased thyroid function. It was included on CCL3 and is currently included on the Draft-CCL4. The American Water Works Association (AWWA) assessed in 2014 that a future regulation is likely for chlorate. No regulatory actions were included for chlorate the most recent CCL regulatory determination; however, it remains a likely candidate for future regulatory action.

3.3.2.5 PFOS/PFOA

Perflurooctane sulfonate (PFOS) and perfluoroctanoic acid (PFOA) are fluorinated organic chemicals used in the production of water/grease/stain resistant carpets, clothing, furniture fabrics, and food packaging as well as in industrial processes. The use of these chemicals has been largely phased out due to voluntary action by the primary PFOS manufacturer (3M) from 2000 to 2002. Nevertheless, drinking water contamination is possible in areas where industries continue to utilize the constituents.

Exposure to PFOS and PFOA can result in developmental effects, cancer, liver effects, immune effects, and thyroid effects among others. In 2016, the USEPA published a lifetime health advisory of 70 parts per trillion for PFOA and PFOS. Both chemicals are included in CCL4 and will be investigated to determine if regulation presents an opportunity to protect human health.

3.3.2.6 Cyanotoxins

Algal blooms can result in the release of algal toxins, known as cyanotoxins. The health effects from cyanotoxin exposure vary based on the type of toxin and range from gastrointestinal effects, rashes, liver damage, and kidney damage among others. In June of 2016, the USEPA published drinking water advisories for microcystins of 0.3 µg/L for pre-school children and younger and 1.6 µg/L for school aged children and adults. Ten cyanotoxins are included in UCMR4. Occurrence data will be collected for raw and finished water from 2018 through 2020. Any regulations that results from this effort could be expected as soon as 2022.

3.3.2.7 Lead and Copper Rule Long-Term Revisions

The USEPA is currently developing a proposal to modify the current LCR to address several long-term issues and new health research data from the Center for Disease Control. LCR changes under consideration include the modification of partial lead service line replacement requirements, optimization of corrosion control and water quality parameters, and changes in sampling protocol.

3.3.2.8 Fluoride

In 2015, the federal Department of Health (DOH) recommended optimal fluoride concentration in drinking water was changed to 0.7 mg/L from the previously recommended range of 0.7 mg/L to 1.2 mg/L. The USEPA is in the process of evaluating the current primary and secondary MCLs for fluoride of 4 mg/L and 2 mg/L respectively. Revisions to existing fluoride regulations may be proposed at the conclusion of the Third Six-Year Review of NPDWRs.

3.3.2.9 Hexavalent Chromium

In 1991, the USEPA established a total chromium MCL of 100 µg/L. Over the past several years the USEPA has developed a draft risk assessment for hexavalent chromium (Cr-6), however, the development of an MCL for Cr-6 is still in the early stages. UCMR3 monitoring results for total and Cr-6 indicate widespread occurrence of both of these contaminants with 74 percent of public water systems reporting chromium results greater than the minimum reporting level (MRL) of 0.2 µg/L and 89 percent reporting hexavalent chromium greater than the MRL of 0.03 µg/L. Only one public water system exceeded the existing total chromium MCL of 100 µg/L.

California has promulgated a Cr-6 MCL of 10 µg/L which became effective in July 2014. To date, this is the only established drinking water regulation for Cr-6 in the U.S. Once the final risk assessment is published, the USEPA will determine whether or not to establish a federal Cr-6 MCL.

3.3.2.10 Carcinogenic Volatile Organic Compounds

cVOCs will be the first group of constituents to be regulated as part of the USEPA's new Drinking Water Strategy, which focuses on addressing contaminants as groups rather than on individual bases. The USEPA has indicated that eight cVOCs, which are currently regulated will be included in this regulation and eight additional unregulated cVOCs could be included. The USEPA is still in the process of collecting occurrence and treatment data to determine which unregulated cVOCs will be included in the new regulatory standard. This decision will likely consider potential co-occurrence and common treatment.

This new group regulation is also associated with the USEPA's efforts to revise the existing TCE and PCE MCLs as part of the Second Six-Year Review cycle (74 FR 15500). The USEPA has analyzed the impact of reducing both of these MCLs from 5 ng/L to 1 ng/L and 0.5 ng/L, which should be considered as "targets" that the USEPA is seriously considering for incorporation into the cVOC regulation.

3.3.2.11 Toxic Organic Chemicals

Whether toxic organic chemicals (TOrC) like pharmaceutical and personal care products (PPCP) and endocrine-disrupting chemicals (EDC) in the environment pose a significant exposure risk to humans or wildlife is still not well understood and the subject of much investigation and debate. Research on these compounds began in the late 1990s and the magnitude of the issue is still not fully defined. The use and subsequent release of antibiotics and natural/synthetic steroids to the environment has generated controversy to date regarding pharmaceuticals as pollutants. However, several other drug classes, bioactive metabolites, and transformation products, as well as personal care products have yet to be examined. Certain physiologically active compounds (for example, caffeine, aspirin, and sex steroids) have been known for over 20 years to enter the environment by a variety of routes, primarily via treated and untreated sewage effluents.

The USEPA is studying the effect of PPCPs and has not proposed any regulations as of yet, but as more information emerges over the next 5 to 10 years, new regulations may be established. A significant portion of on-going research concerns where and how TOrCs should be treated. Options include drug take-back programs (to keep them out of the water), treatment at wastewater treatment plants, and treatment at drinking water plants. Research suggests that advanced oxidation processes are effective at removing many PPCPs.

3.3.2.12 Emerging Disinfection Byproducts

A number of potential significant disinfection byproducts continue to be the subject of on-going research. For example, both iodo-substituted HAAs and trihalomethanes (THM) have been shown to form under certain conditions when drinking water is chloraminated. Bromate has been the subject of scrutiny as well. No regulations have been proposed as of yet, but as more information emerges, the USEPA may regulate some of these emerging DBPs.

3.3.2.13 Manganese

Manganese is a naturally occurring metal which is commonly found in both surface and ground water sources as the result of soil and bedrock weathering. It is an essential nutrient at low doses but may pose health risks at chronic high doses. Manganese currently has a Secondary Drinking Water Standard of 0.05 mg/L which has been established for aesthetic issues with discoloration rather than health concerns. Although manganese was originally included on CCL1, the USEPA decided to eliminate it from further regulatory consideration. However, the Agency published a drinking water health advisory for manganese in 2004 advising water providers to achieve concentrations below the SMCL of 0.05 mg/L.

Because new information on the potential health impacts of manganese exposure has emerged, the USEPA has included it on the Draft-CCL4 and the proposed UCMR4. The primary health concerns associated with manganese in drinking water are negative neurological impacts that it can have on infants and young children. There are a number of regulatory agencies which are currently considering more stringent manganese regulation. In June 2016, Health Canada posted a proposed enforceable manganese standard of 0.1 mg/L for public consultation. The State of Ohio has proposed a regulation that would require all water systems making changes in source or treatment to achieve the secondary standard of 0.05 mg/L. Data will be collected for UCMR4 from 2018 through 2020 and a regulatory determination for manganese is possible as soon as 2022. At this time, it is unclear whether a NPDWR for manganese will result from this; however, if a positive regulatory determination is made it would likely establish an MCL equivalent to the existing secondary standard of 0.05 mg/L.

3.3.3 City Treatment Goals

The City produces water that meets or exceeds all federal and state drinking water regulations. To continue providing high quality water to its customers, the City has established the following specific treatment and monitoring goals for its facilities that are more stringent than federal and state requirements. The City's settled water goals are presented in Table 3.12.

Table 3.12 City Settled Water Treatment Goals for the TWTP[1]

Parameter	TWTP Goal
Particulate/Microbial	
Turbidity, Each Treatment Train	< 1.0 NTU 95% of the time
General Physical	
pH Tolerance, Each Treatment Train	± 0.1 of Setpoint
TOC	Removal per Stage 1 D/DBPR
Manganese	< 0.03 mg/L (60% of SMCL)

Notes:
(1) Settled water is defined as water downstream of the flocculation/sedimentation process and upstream of ozonation/filtration.

The City's finished water treatment goals are presented in Table 3.13.

Table 3.13 City Finished Water Treatment Goals for the TWTP

Parameter	TWTP Goal
Particulate/Microbial	
Turbidity	< 0.10 NTU 95% of the time
Disinfection Byproducts	
Total Trihalomethanes (TTHM)	< 40 µg/L (50% of LRAA MCL)
Haloacetic Acids (HAA5)	< 30 µg/L (50% of LRAA MCL)
Bromate	< 5 µg/L (50% of MCL)[1]
Chlorite	< 0.5 mg/L (50% of MCL)[2]
General Physical	
pH	> 7.2
pH Tolerance	± 0.1 of Setpoint
Iron	< 0.1 mg/L
Manganese	< 0.03 mg/L (60% of SMCL)
T&O	< 3 ng/L for Geosmin and MIB
Langelier Index	> 0
Calcium Carbonate Precipitation Potential	3 to 8 mg/L
Free Ammonia (as N)	0.01 to 0.05 mg/L
Alkalinity	> 44 mg/L as $CaCO_3$

Table 3.13 City Finished Water Treatment Goals for the TWTP	
Parameter	**TWTP Goal**
Other	
CT Inactivation Ratio	1.5 @ 0.5 degrees C
Residual Disinfectant	Chloramines
Chloramines Residual (as Cl_2)	0.5 to 4 mg/L
Chloramines Residual (as Cl_2) Tolerance	± 0.1 mg/L of Setpoint

Notes:
(1) May result from ozonation and/or use of sodium hypochlorite.
(2) May result from use of sodium hypochlorite or chlorine dioxide.

The City participates in the *Partnership for Safe Water*, a national volunteer initiative developed by the USEPA and other water organizations, whose members strive to provide their customers with drinking water quality that surpasses federal standards. The Design-Builder shall ensure the new TWTP is capable of meeting the City's settled water and finished water treatment goals, including *Partnership for Safe Water*, Phase IV.

3.4 PERFORMANCE REQUIREMENTS

The Design-Builder is required to demonstrate that the new TWTP is capable of meeting all applicable water quality regulations and other performance requirements as defined herein, as defined within Exhibit A1-C of the Design Build Agreement, or as further defined and agreed upon by the Design-Builder and City during the design phase and incorporated in the Design-Build Documents. The water quality performance requirements shall be conditional upon the following:

1. Raw water quality treated at the TWTP does not differ materially from the basis of design raw water quality parameters presented herein.
2. The Project facilities are operated in a manner consistent with the Design-Builder's documented intent and as agreed upon by the City.
3. The Project facilities are operated with the appropriate resources of labor, chemicals, and power recommended by the Design-Builder and agreed upon by the City.

Performance Compliance Evaluation

Chapter 4

Utility Master Plan

Project No. 17-467

Water Treatment Facilities Master Plan

Performance Evaluation of Wes Brown Water Treatment Plant

The City of Thornton

Project number: 60560104

AECOM

January 3, 2019

Quality Information

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List of Acronyms

°C – degree Celsius
CIP – clean-in-place
DADMAC – Diallyldimethylammonium Chloride
CT – Contact Time
EGL – East Gravel Lakes
°F – degree Fahrenheit
$FeCl_3$ – ferric chloride
ft – feet
FRP – fiberglass reinforced plastic
gpm – gallons per minute
in – inches
$KMnO_4$ – potassium permanganate
lb – pound
M – million gallons
MGD – million gallons per day
NaOCl – sodium hypochlorite
NaOH – sodium hydroxide
PAC – powdered activated carbon
pH - alkalinity
ppm – parts per million
Project – Utility Master Plan project
psi – pounds per square inch
SCADA – supervisory control data acquisition
Thornton – City of Thornton
TOC - total organic carbon
TM – Technical Memorandum
TMP – transmembrane pressure
TWTP – Thornton Water Treatment Plant
UF – ultrafiltration
UMP – Utility Master Plan
UV - Ultraviolet
WBWTP – Wes Brown Water Treatment Plant
WGL – West Gravel Lakes

1. Executive Summary

A process evaluation of the Wes Brown Water Treatment Plant (WBWTP) was completed as part of the Utility Master Plan (UMP) for the city of Thornton (Thornton) as part of the Water Treatment Facilities Master Plan. The intent of the evaluation was to assess the current processes at the WBWTP to identify the operational capacity of the individual unit processes as well as the overall production capability of the facility. Each individual process was analyzed and is included in Appendix A. The analysis includes capacity, delivery and overall process evaluations. The evaluation was expected to establish necessary planning coordination of the raw water supply and water distribution system requirements.

1.1 Approach

To facilitate analysis of the WBWTP, the evaluation divided the facility into process areas as follows:

1. **Inlet Works**: Processes, systems, and facility components between the West Gravel Lakes (WGL)/East Gravel Lakes (EGL) pump stations and the inlet to the WBWTP clarifiers
2. **Sedimentation:** Processes, systems and facility components from the inlet of the clarifiers through the solids contact clarifier and into the membrane system influent channel
3. **Membranes:** Processes, systems and facility components from the discharge from the membrane influent channel to the individual membrane basins and into the combined effluent pipeline but prior to the ultraviolet (UV) disinfection system
4. **Finished Water Management and Chloramination**: Processes, systems, and facility components from the UV disinfection system to the finished water storage systems and high service pump station[1], which represents the transition to distribution
5. **Solids Handling:** Processes, systems, and facility components from the outlet discharge of the sedimentation (clarifier blowdown) and membrane process areas (reject, clean-in-place waste) to the solids lagoons, including the facilities associated with the return of decant from the solids lagoons to WGL

The evaluation of each area was further subdivided into individual process systems and involved a summary review of the major system components, performance and capacity analysis, identification of known operational and maintenance challenges, and discussion of the impact of the process on the overall facility capacity for current needs.

1.2 Major Findings

Based on the results of the process evaluation, the following major findings were identified for each process area:

1. **Inlet Works:** The systems include manganese control, taste and odor control, disinfection, coagulation, and pH control. The equipment for these systems was generally found to be adequate, relative to the WBWTP design conditions for current production and regulatory requirements. However, several systems were found to have operational or maintenance challenges as follows:
    a. The manganese control system has inadequate contact time in the piping from WGL to the WBWTP.
    b. The taste and odor control system, which utilizes powdered activated carbon, has limited storage, has a tendency to plug the chemical feed lines, and has degraded effectiveness due to interaction with the disinfection system. When the WBWTP is feeding higher percentages of EGL water, which is higher in taste and odor compounds, the taste and odor control system is unable to feed sufficient quantity of powdered activated carbon to fully attenuate the aesthetic issues with the influent water quality. This is at least partially attributed to the loss of functionality of the powdered activated carbon due to interaction with the hypochlorite used in the disinfection system.

[1] The analysis of the high service pumps in this technical memorandum is limited to comparison of pumping capacity relative to production capacity. Analysis of adequacy of the pumps to meet peak day and peak hour demands will be in the Distribution TM.

c. The disinfection system interacts with the taste and odor system, which reduces the effectiveness of both systems and results in additional demand for both powdered activated carbon (PAC) and hypochlorite. While the disinfection feed equipment is able to deliver sufficient quantities of hypochlorite to meet required contact time (CT) and maintain a disinfectant residual necessary for membrane performance, the consumption rate of hypochlorite is higher than would be expected due to the competition with the PAC fed as part of the taste and odor system.

d. The coagulation system has inadequate mixing, and the storage tanks cannot be fully filled without risking creating cracks within the fiberglass reinforced plastic (FRP) storage tanks.

Improvements are currently planned that are likely to significantly improve the performance of :

- The taste and odor system, due to planned transition to post-filtration disinfection;
- The disinfection system, due to planned elimination of pre-chlorination for CT-based disinfection; and
- The coagulation system due to planned replacement of the mixing system.

Additional PAC storage (either dry or as a slurry) for the taste and odor system could further improve operational reliability. Additional contact time is also required to meet recommended operational conditions for permanganate control, which could be met by providing either additional pipeline length or a contact chamber. Either solution would provide additional hydraulic residence time.

2. **Sedimentation:** The systems include the solids-contact clarifiers. The equipment was found to be adequately sized relative to design conditions for current production and regulatory requirements. However, there have historically been a number of operational challenges including:

a. The clarifiers were formerly operated to discharge solids using the blanket control method. This mode of operation did not adequately monitor solids concentration and was also conducted in a manner that resulted in excessive discharge to the lagoons. This practice was eliminated in 2017, when the WBWTP changed to managing clarifier operation based on center cone solids and reduced wasting durations to 1 minute per cycle.

b. The data indicate that the clarifiers are receiving influent water with varying amounts of coagulant or coagulation. The more hydraulically remote clarifiers have a measurable difference in performance, which is attributed to more contact time for coagulation.

c. The data indicate that the clarifiers are receiving an uneven hydraulic split of influent flow. The more hydraulically remote clarifiers receive less flow when all clarifiers are in operation, which results in a higher loading rate and reduced performance for the clarifiers that are closer to the influent source.

There are no planned changes to the sedimentation process at this time. Planned improvements to the coagulation system to install a flash mix system are anticipated to improve mixing, which is expected to translate to improved performance in the sedimentation process. Additional study by Thornton is required to determine if modification to the influent facility components is required to address the uneven hydraulic split. The improvements to the coagulation and sedimentation systems are expected to have a positive impact on water quality sent to the membranes, which would be anticipated to reduce the rate of fouling and improve the sustainability of the membrane process.

3. **Membranes:** The systems include individual membrane trains (which include the basin and the membrane modules), permeate pumps, reject pumps, and the clean-in-place (CIP) system. The equipment for the systems within this area, with the exception of the membrane modules themselves, was found to meet production and regulatory requirements. The membranes modules were found to be inadequately sized to operate in a sustainable manner for current production requirements, largely as the result of a high degree of fouling of the membranes at the design flux. The issues that lead to the membrane modules being inadequately sized can be summarized as follows:

a. The design flux for the membrane modules is higher than would typically be recommended for this water source. As a result, the membranes are operating at a flow rate that leads to the accumulation of foulants at a rate that requires more frequent maintenance and shortens membrane life.

b. The data from membrane module autopsy indicate that there is iron fouling within the fibers. This is believed to be correlated to the poor mixing associated with the coagulation system, resulting in free iron that subsequently passes through the sedimentation process and is captured on the membrane fibers.

c. The membrane trains are not fully equipped with all modules, which results in a lower available surface area versus what could be available if all modules were in place. Having a higher available surface area offers the potential to operate at a lower flux during current operations, which may be an opportunity to reduce the rate of membrane fouling.

There are other elements that were identified as part of the membrane process evaluation that are not directly related to the ability of the system to meet regulatory requirements but should be considered as other operational concerns:

d. When the total plant production is low, the permeate pumps do not have adequate turndown to match low membrane flux due to fouling. Operating individual trains at low production rates when the membranes are fouled can result in cavitation of the pumps. In 2018 the plant began operating in siphon mode when plant productions are low, which allows the facility to meet production without the permeate pumps in operation while processing at reduced flux. This mode of operation may not be possible in the future if a downstream process is added that requires pumping or if winter demand exceeds the capacity of the membranes under siphon flux.

e. The CIP system reject is returned to the lagoons, which then is returned to the WGL. This is a cause for concern, as the foulants that are captured by the membranes are then remobilized during the cleaning, but then subsequently returned to the source supply water rather than being purged from the system, which increases the likelihood of re-fouling the membranes.

Multiple changes to the membrane process are currently planned, including initiating a program to replace one train of membranes per year, as well as using older membranes to fill empty modules spaces[2] on other trains, which will contribute additional surface area. While these improvements are anticipated to improve performance in this process area, there remains a concern with the high design flux rate relative to the long-term facility production capacity. Further study[3] is required to determine if additional modification to the other systems at the WBWTP can reduce the rate of fouling. The other alternative would be to increase the membrane surface area, through the construction of additional membrane trains, to allow for normal operations at a lower peak flux rate.

4. **Finished Water Management and Chloramination:** The systems include UV, hypochlorite feed, ammonia feed, and alkalinity (pH) control. The equipment for the systems within this process area was found to be adequately sized relative to design conditions for current production and regulatory requirements[4], but several systems were found to have operational or maintenance challenges as follows:

a. The UV system is not required for meeting disinfection requirements, and due to the high cost relative to the perceived value, the system was decommissioned in 2016.

b. The pH control associated with the sodium hydroxide uses normal plant water for carrier water, which causes significant scaling within the feed equipment and also within the pipeline system downstream of the application point.

There are planned changes to the finished water management and chloramination process, which include conversion of a portion of the finished water storage tank to serve as a chlorine contact chamber for post-filtration disinfection. These changes are anticipated to significantly reduce overall chlorine demand at the facility. Addition of a water softener for use in conjunction with the sodium hydroxide system would be recommended to reduce the scaling in the sodium hydroxide equipment and reduce the scaling potential within the finished water systems downstream of the application point, which will result in reduced maintenance requirements in both areas.

5. **Solids Handling:** The systems include the lagoons and return to WGL. The equipment for the systems within this process area was found to be adequately sized relative to design conditions for current production and

[2] It is understood that the older modules will likely have a portion of the flux lost due to irrevocable fouling, but it is anticipated that the increase in surface area will contribute to a reduced flux per train module.
[3] A study was completed by Carollo in 2017 to evaluated changes in coagulant to reduce fouling.
[4] Meeting disinfection requirements is dependent on approval by CDPHE of a revised baffling factor for the new chlorine contact chamber. If a lower baffling factor is approved, the facility may not meet disinfection requirements under certain extreme operating scenarios

regulatory requirements, but the solids management systems were found to have a number of operational or maintenance challenges as follows:

a. Both WBWTP and the existing (and future) Thornton Water Treatment Plant (TWTP) discharge process wastewaters to the lagoons. This can result in scenarios where the percentage of return water as a fraction of influent to WBWTP can be as high as 15 to 20 percent. While this does not violate the Filter Backwash Recycle Rule, it is not recommended according to the 10 State Standards.

b. There are limited process equipment and operational practices involved in management of the lagoon system. Sludge is allowed to settle and thicken without any additional mechanical or chemical processing, and the resulting sludge is removed and used as an amendment in agricultural activity. While the systems have sufficient capacity to allow this practice, the current practice likely has sludge with a higher water content/lower solids fraction than could be achieved. If future operations require solids disposal in a landfill or other facility as a result of changing coagulants or contamination of the lagoon sludge, maximizing the solids content to reduce the overall sludge mass would be financially advantageous.

c. The sludge within the South Lagoon was detected to have elevated levels of radionuclide. This appears to be an isolated event, but continued monitoring of the radionuclide levels in the raw water supply and also sludge is warranted to allow for setting action levels for plant operations.

d. Return of the Lagoon decant to WGL is uncontrolled, or free-flow. While this is not an atypical practice in the water treatment industry, the particular combination of influent sources to the lagoons is likely contributing a higher level of foulant loading to WGL, which is evident in operations when the blend ratio of EGL to WGL becomes higher from WGL.

There are no changes currently planned for the lagoons. When the new TWTP is commissioned, loading rates on the lagoons are anticipated to increase, since the new facility will include filter-to-waste compared to the current TWTP, which does not. Further, the new facility will use a flocculant, which may further increase membrane fouling if polymer residuals are carried in the return water. Further study of the lagoon system is warranted, both to optimize the solids cycle and to determine means to reduce the fouling potential in return water to WGL.

1.3 Conclusions and Recommendations

Conclusions of this process evaluation of WBWTP are that the majority of the systems at the WBWTP are adequately sized for the current operation and regulatory requirements and are appropriate for a design production rate of 50 MGD. However, the membrane system is a significant bottleneck in the production capacity, with a capacity that is closer to 30 MGD during winter operation to operate at a more sustainable flux. There are potential operational and equipment system changes that could increase reliable and sustainable capacity to closer to 35 MGD[5], but significant increase in additional capacity will either require more frequent membrane maintenance and replacement or the construction of additional membrane trains.

The following is a summary of the conclusions from this study:

1. The inlet works systems are adequately sized for the current production and regulatory requirements, but there is insufficient contact time for the potassium permanganate feed from the WGL Pump Station (PS).
2. The injection points of hypochlorite and PAC at the inlet works are too close, resulting in competition and reduced effectiveness of both systems.
3. The coagulant addition system in the inlet works is adequately sized for current production and regulatory requirements, but the mixing method is ineffective and results in maldistribution to the clarifiers.
4. The clarifiers are adequately sized for current production and regulatory requirements, but the previous operational approach relying on sludge blanket thickness for clarifier performance management was inefficient, resulting in higher wasting rates than would be recommended. The recent change to monitoring center cone solids and reducing wasting rates is expected to significantly improve performance. Challenges also exist with

[5] Task 5 of the Water Distribution Master Plan identified an initial target for production of 41 mgd; this was a preliminary value that is expected to evolve through the integration of the components of the Master Plan.

uneven flow distribution between the units, resulting in variable performance. Further study is required to determine how to best address the hydraulic inequities.

5. The membrane systems are adequately designed for regulatory requirements but are not configured for sustainable production for current operations. The units were designed with a higher-than-recommended flux, which results in rapid fouling and loss of permeability. Based on analysis of other facilities equipped with this membrane technology, the sustainable operating flux would likely result in a peak production capacity closer to 30 MGD. This value could likely be increased to 35-40 MGD with optimization of other related treatment systems. Significant increase in production capacity will either require more frequent membrane maintenance or the construction of additional membrane trains to provide more surface area. Additional membrane area is required to be able to meet the intended design capacity. More frequent cleaning and membrane replacement will be required to sustain the production.

6. The processes associated with finishing of the water prior to distribution are adequately sized for current production and regulatory requirements, but the carrier water associated with the sodium hydroxide system is leading to extra maintenance. Modification of the finished water storage to produce a chlorine contact basin will be adequate for regulatory requirements associated with disinfection as long as the 0.7 baffling factor is approved. Analysis of the high service pump station associated with the finished water storage tank is further discussed in the distribution section of the UMP.

7. The lagoon systems are adequately sized for current production and regulatory requirements, but the management of the lagoons would benefit significantly from increased monitoring and control. Additionally, the return of decant water from two separate treatment processes to WGL appears to be leading to the accumulation of significant fouling elements.

The recommended facility improvements include:

- **Improved mixing for coagulant**: A design project has already been completed to improve mixing; AECOM reviewed the design and provided suggestions for optimization. Construction should be scheduled once there is sufficient funding.
- **Switch to an alternative coagulant**. The use of ferric salts with membrane filtration has been demonstrated to lead to a higher potential for fouling if operations are not optimized, in particular due to iron and manganese accumulation on the membrane fibers. Membrane suppliers typically recommend aluminum chlorohydrate to avoid this situation.
- **Movement of disinfection to clarifier effluent and post filtration**: A project has already been completed to design modifications to the finished water systems, and construction is anticipated to be completed during the Winter 2018/9 shutdown. Based on previous testing already completed by Thornton, it is anticipated that the transition to post-filtration disinfection should reduce PAC dosage to manage taste and odor, but this will need to be validated after completion of the disinfection modification. The project also includes adding a disinfection dosing location for sodium hypochlorite (NaOCl) to the clarifier effluent, which is anticipated to eliminate issues of disinfection dosing impacting PAC performance at the influent.
- **Improved hydraulic spilt between the clarifiers**: We recommend Thornton collect elevation data to evaluate the clarifier influent hydraulics to identify opportunities for improving the flow distribution.
- **Clarifier Coating:** the coatings within the clarifier require replacement, while this is not anticipated to impact treatment performance, maintenance of the clarifiers is an important factor for reliability and redundancy goals. Construction should be scheduled once there is sufficient funding.
- **Add a water softener to the carrier water associated with the sodium hydroxide system**: This would reduce maintenance associated with the feed equipment. A design project has already been completed to include a softening system. Construction should be scheduled once there is sufficient funding.
- **Improve management of the lagoon operations**: Study the potential to eliminate the return of membrane CIP system reject to WGL (at other facilities, reject is discharged to sewer after neutralization) and to add treatment to the lagoon decant water to manage foulants. Alternatively, moving the WBWTP lagoon decant discharge to downstream of the gravel lakes could have a benefit to influent water quality, but release of this water represents a potential loss of resource to Thornton.

- **Monitor Radionuclide in water quality**: increase the frequency of radionuclide monitoring in both the raw water and sludge lagoons to establish a performance trend. If the radionuclide concentration trend shows an upward trajectory that may exceed 90% of the discharge limit within 3 years, begin a study to investigate potential mitigation avenues, including evaluating mechanical dewatering to minimize disposal volume.
- **CIP chemical neutralization outside the membrane tanks**: previous improvements studies have identified that there would be benefit to completing CIP neutralization outside of the membrane basin, which could reduce potential impacts to the basins or membranes. Construction should be scheduled once there is sufficient funding.
- **Full Tank Maintenance Cleans**: add a program for performing Maintenance Cleans in addition to CIP for the membrane systems. These maintenance cleans typically have a shorter duration and use less chemicals but can remove a portion of foulants, allowing for flux recovery.

2. Introduction

This technical memorandum (TM) summarizes the WBWTP evaluation completed for the UMP for Thornton as part of the Water Treatment Facilities Master Plan. Thornton also operates the TWTP as part of their water treatment facilities, but the site is scheduled to be decommissioned and replaced with a new treatment plant currently under construction. As such, analysis of the existing TWTP has been excluded from this evaluation.

The evaluation of WBWTP included review of previous studies, analysis of the treatment processes, operations, and SCADA system data provided by Thornton, and interviews with the plant operators and maintenance staff. The following documents were provided by Thornton for use in this evaluation:

- 2016[6] Monthly Operator Records
- 2016 SCADA System Data
- Public Water System Record of Approved Waterworks
- 2016-2017 Analytical Data, Consisting of SCADA System Output, Laboratory Analytical Samples, and Operator Process Control Testing
- WBWTP Design Drawings
- 2014 *Wes Brown WTP Operations Study* by CH2M Hill
- 2017 *Wes Brown Water Treatment Plant Alternative Coagulant and Ammonia Injection Study* by Carollo
- 2016 *Ultrafiltration Fiber Analysis Report* by Avista Technologies
- Thornton Water Treatment Plant Basis of Design Report and 80 Percent Drawings

As a result of the process analysis using the provided data, process improvements that should be considered as part of the long-term strategy for the WBWTP will be identified. Existing improvements have been identified in this TM and future processes will be the subject of a separate TM.

3. Wes Brown Water Treatment Plant Process Overview

The WBWTP is located at 3651 East 86th Avenue and was constructed in 1974 with a capacity of 30 MGD. The initial facility was called the Columbine Water Treatment Plant and used conventional treatment processes involving

6 2016 was selected as a model year for evaluation to best reflect consistent operations at the WBWTP over the course of a Calendar year. Data from 2017 included significant process changes that would have resulted in more significant data anomalies.

flocculation, sedimentation, gravity media filters and chlorine disinfection. The facility was retrofitted and expanded in 2005 to replace the conventional filters with ultrafiltration membrane filtration and other modifications including the addition of UV disinfection. The plant improvements were intended to bring the design capacity up to 50 MGD. In 2006 the plant was renamed the WBWTP.

The plant is fed by two raw water pump stations that pump water from raw water storage ponds, called WGL and EGL. WGL is fed by Clear Creek, and EGL is fed by the South Platte River. The WBWTP can also receive water from a higher quality source at Standley Lake, but this supply source also feeds the TWTP and is generally reserved for that facility. A process flow diagram of the current facility is shown on Figure 1.

Sludge from the treatment process including clarifiers and membrane reject are sent to three on-site lagoons at the WBWTP. These lagoons also receive sludge from the TWTP. The lagoons allow for solids accumulation while decant water is returned to the WGL. The lagoons are generally drained annually and the sludge is land applied for use in agriculture. High technologically enhanced naturally occurring radioactive material (TENORM) sludge is landfilled.

Treatment production is driven by water distribution system demand. The existing peak hour demand (PHD) within the distribution system is 77.6 MGD, which must be met by a combination of the production from the WBWTP and the TWTP.

For the purposes of this evaluation, it is assumed that the treatment plants should be able to produce finished water at a peak production rate equal to the design rated capacity of the treatment system. It is understood that the distribution system may experience PHD in excess of the production rate, and the treatment systems may be able to exceed the design rate for short periods of time. However, there is insufficient information on the impact of the operating the facility above the design rate to adequately assess a total production peaking rate. Therefore, for the purposes of this analysis, it is assumed that the treatment facilities would not produce water at a rate that exceeds the design rating on a daily basis. Management of PHD would be accomplished using distribution storage, and shortfalls in peak day demand will be reported as a production shortfall that must be addressed.

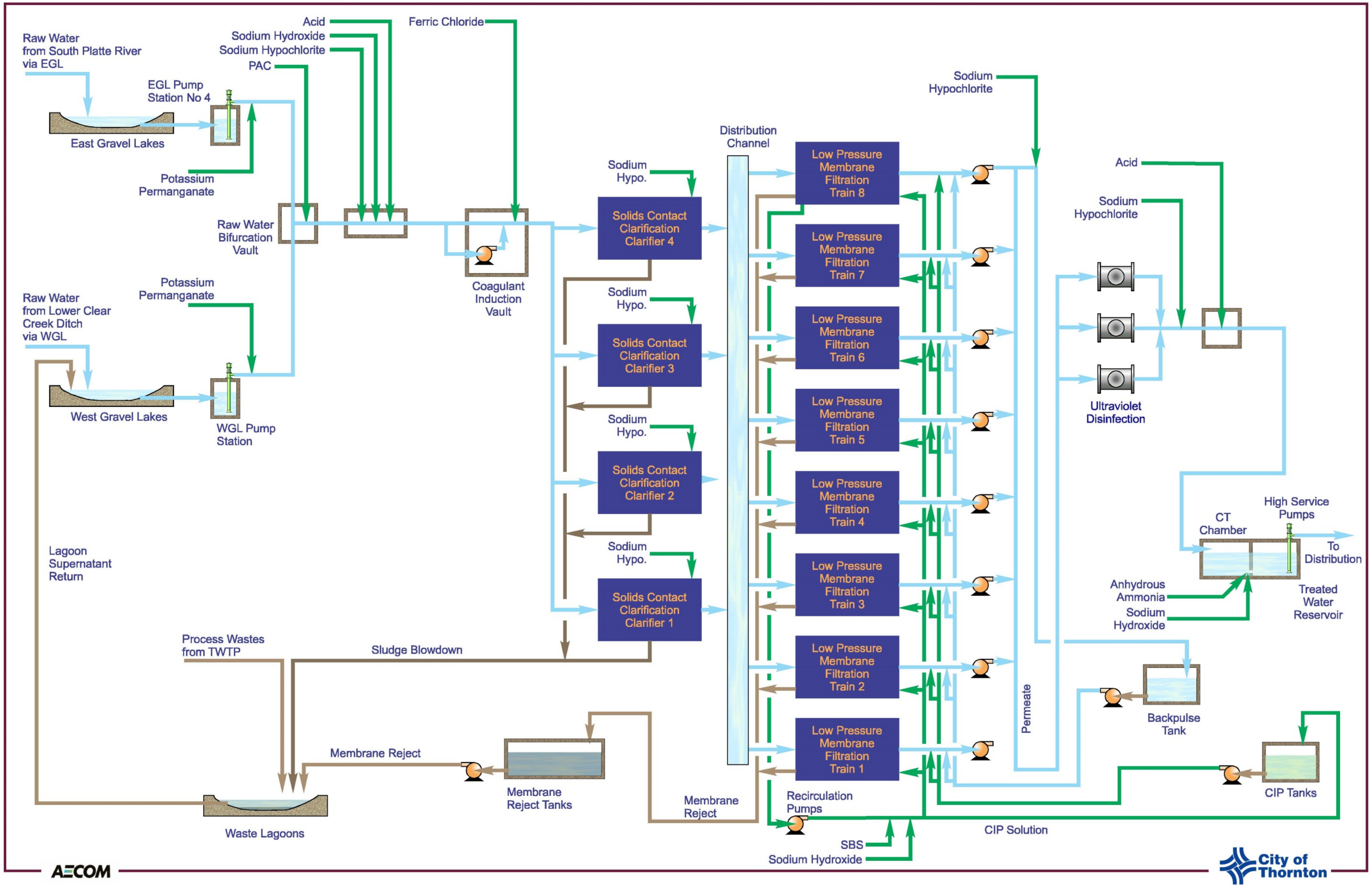

Figure 1. WBWTP Process Flow Diagram

4. Process Evaluation

This section provides a summary of the evaluation of the WBWTP performance including a process capacity analysis. Subsection 4.1 summarizes holistic evaluation of the facility as compared against the Tier 1/2/3 design criteria as defined in *Water Treatment Facilities Master Plan System Performance Criteria* for this UMP. The evaluation in general has used data from 2016 as a model for typical plant operations, but this has been supplemented with 2017 data where appropriate.

4.1 Performance Summary

4.1.1 Facility Production

The WBWTP produces water at a rate that is adjusted based on seasonal demand. The facility operates generally from late February through late November each year, after which time the facility is shut down to allow for maintenance. During this maintenance period, all water system demands are met by TWTP. Based on 2016 operating data, WBWTP averaged approximately 16 MGD of production during the operating period, with an even split of raw water supplied from WGL and EGL. While Standley Lake is an optional source, it is not typically used at WBWTP and was used briefly in 2016). The raw water supply to WBWTP by water source is shown on Figure 2.

As illustrated on Figure 2, the plant production and raw sources vary seasonally and can be summarized as follows:

- The facility is offline during the winter months (December-February). This will likely change once the new TWTP comes online.
- During the spring months (March-May), the facility averaged 10 MGD of production, with 63 percent of the source water from EGL and 37 percent from WGL.
- During the summer months (June-August), the facility averaged 24 MGD of production, with 55 percent of the source water from EGL and 45 percent from WGL
- During the fall months (September-November), the facility averaged approximately 15 MGD of production, with 19 percent of the source water from EGL and 81 percent from WGL

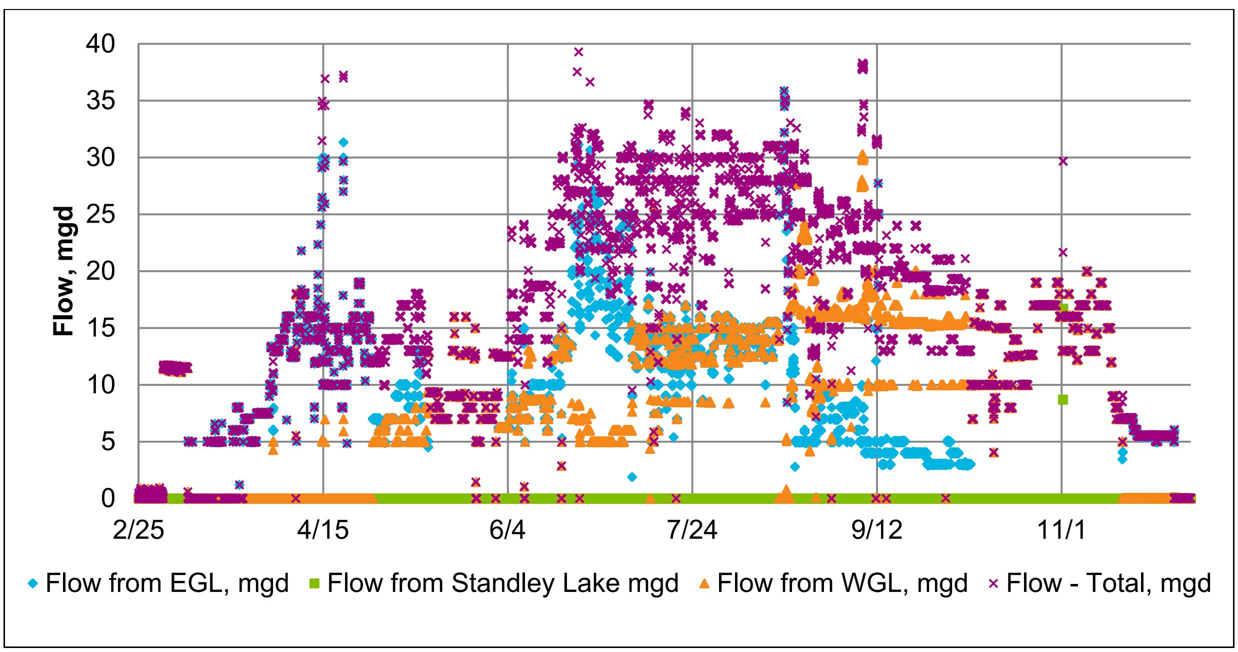

Figure 2. WBWTP 2016 Influent Raw Water Flow Data

The WBWTP water production met distribution requirements for finished water quality and production on a continuous basis, including meeting the majority of the Tier 1/2/3 performance criteria for redundancy and assumed production capacity for the new TWTP as defined in Water Treatment Facilities Master Plan System Performance Criteria. However, while the current distribution system PHD of 77.6 MGD is below the rated capacity of the two current treatment plants, analyses of the individual treatment unit processes at the WBWTP indicate that the facility would be unlikely to meet its obligation for the Tier 1 criteria for total treatment system production or unit process capacity, primarily due to performance challenges with the membrane system. This is discussed further in Appendix A.

There is an additional gap in production criteria associated with the Tier 2/3 requirement for standby power. At present the facility does has neither a permanent dual power supply nor an installed emergency power generator. The facility staff reported that they have been able to mobilize a portable generator in the past, such that there were no reported instances of loss of power leading to failure to meet distribution system demands, but the power supply remains a risk for the facility.

4.1.2 Water Quality

The WBWTP finished water quality continuously meets all federal, state, and local requirements. Additionally, the facility met the Tier 1 criteria for water quality based on the data evaluated as part of this study. However, operations staff has indicated performance issues related to taste and odor within the finished water, which denotes a failure of the facility to consistently meet the Tier 2 and Tier 3 criteria of less than 3 ng/L, with the majority of the issues occurring in late summer when there are a higher concentration of taste and odor compounds found in the raw water supply (particularly EGL). There were also indications of limited occurrence of aesthetic issues related to color, most frequently as a result of potassium permanganate overfeed, but there were no data to support an exceedance of the Tier 2 criteria for color or manganese. The plant was taken offline and drained when this occurrence took place.

While WGL has been shown to have lower concentrations of taste and odor compounds, use of this supply source has been shown to have a significant impact on production, most notably for an increased rate of fouling in the membrane systems. The sources of the fouling are not fully understood and are being further evaluated by Thornton and the membrane manufacturer.

4.2 Process Analysis

The intent of this section is to summarize the methodology and results of the process analysis performed for this Task. The evaluation has been performed based on performance data provided by Thornton for a model year, which was identified as 2016 as a typical year. The performance summary has been segmented to analyze the unit processes[7] at the WBWTP. For the purpose of organizing this evaluation into smaller segments to allow for analysis of the unit processes, the WBWTP process has been broken into five treatment areas, which include:

1. **Inlet Works**: Processes, systems, and facility components between the West Gravel Lakes (WGL)/East Gravel Lakes (EGL) pump stations and the inlet to the WBWTP clarifiers
2. **Sedimentation:** Processes, systems, and facility components from the inlet of the clarifiers through the solids contact clarifier and into the membrane system influent channel
3. **Membranes:** Processes, systems, and facility components from the discharge from the membrane influent channel to the individual membrane basins and into the combined effluent pipeline but prior to the UV
4. **Finished Water Management and Chloramination**: Processes, systems, and facility components from the UV disinfection system to the finished water storage systems and high service pump station[8], which represents the transition to distribution
5. **Solids Handling:** Processes, systems, and facility components from the outlet discharge of the sedimentation (clarifier blowdown) and membrane process areas (reject, clean-in-place waste) to the solids lagoons, including the facilities associated with the return of decant from the solids lagoons to WGL

[7] Analysis of the raw and finished water pumping system is presented in other sections of the UMP.

[8] The analysis of the high service pumps in this TM is limited to comparison of pumping capacity relative to production capacity. Analysis of adequacy of the pumps to meet peak day and peak hour demands will be in the Distribution TM.

The approach to the analysis included summarizing the major system components, calculating system capacity and performance, identifying known performance and maintenance challenges, and providing a summary of the adequacy of the treatment components. The details of the specific analysis are included in Appendix A. The summary of findings and recommendations is included in Section 6.

5. Water Quality Performance Analysis

5.1 TOC Removal

Removal of total organic carbon (TOC) at the WBWTP is primarily accomplished through conversion of dissolved organic species to a particulate solid via coagulation, which is then removed in the clarification and membrane process. While not the intended functionality, the PAC fed for taste and odor control also likely has a significant impact on TOC removal.

TOC removal averages between 30 and 40 percent, with the clarification process typically accounting for 70 percent of the TOC reduction as shown on Figure 3.

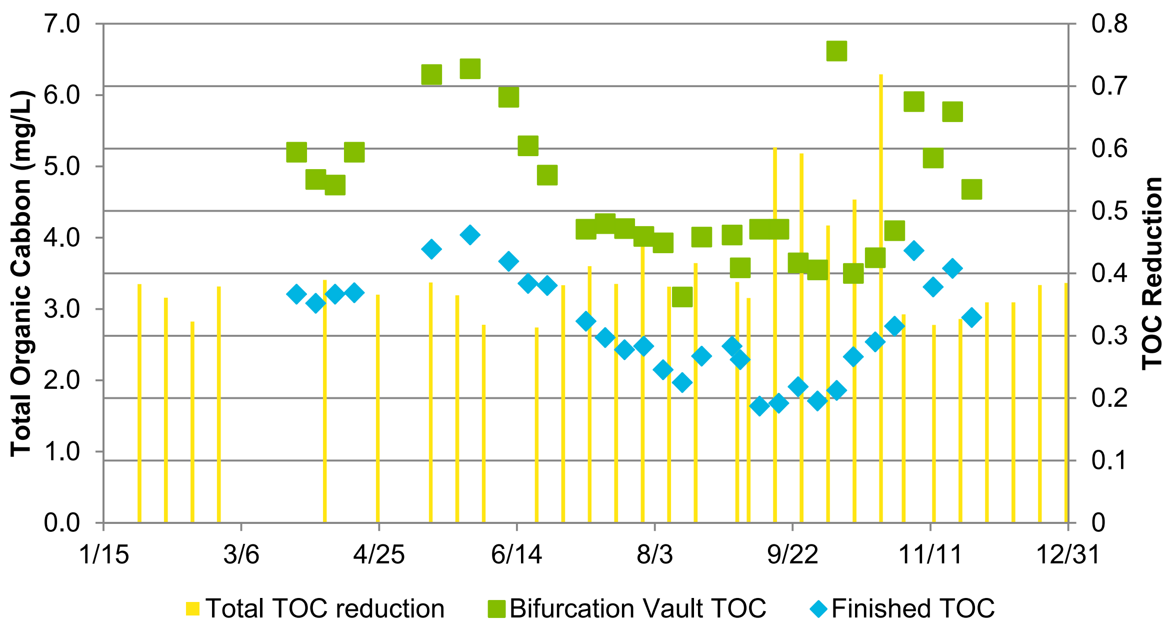

Figure 3. WBWTP Measured TOC Values

5.2 Manganese

Manganese is found in both EGL and WGL, but the concentrations tend to be higher in EGL. Inlet concentrations vary primarily by season, with minor variations associated with depth from the surface in either lake. The measured water manganese values are shown on Figure 4 and Figure 5. The data in Figure 4 was determined using a HACH method and considered more reliable.

The current manganese control approach using potassium permanganate is effective at reducing the concentration to less than 0.03 in 95% of the recorded sampling events. The data suggests that the current manganese control methodology is effective in meeting finished water targets, but additional evaluation should be conducted if there is a change in coagulant or when the revised disinfection procedure is implemented.

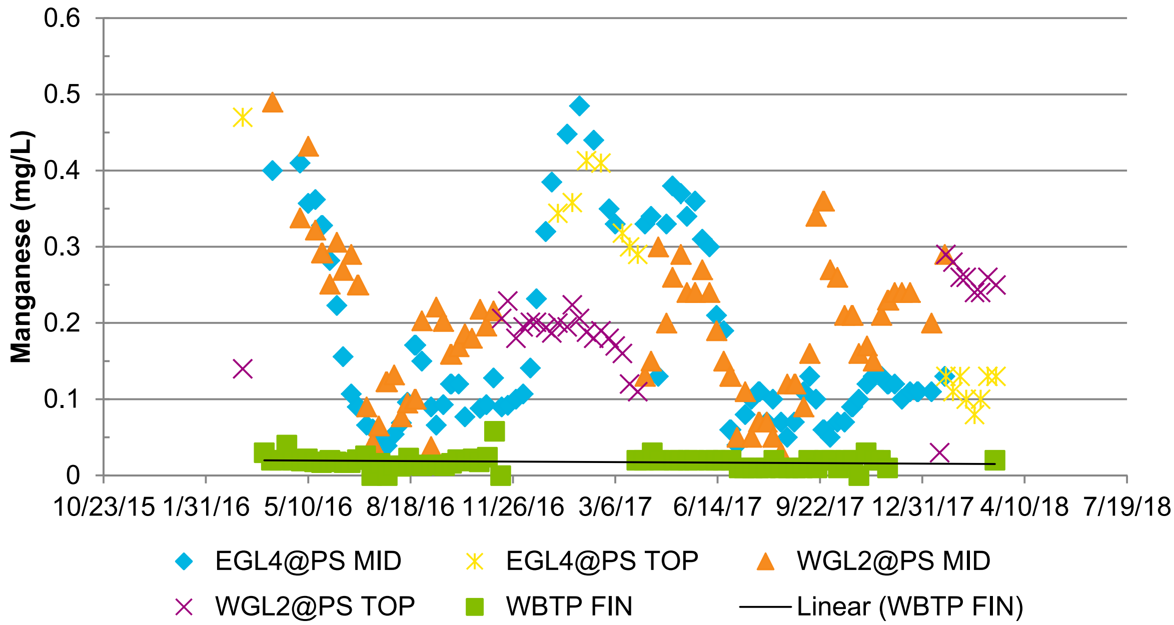

Figure 4. Manganese Measured Values (HACH Method)

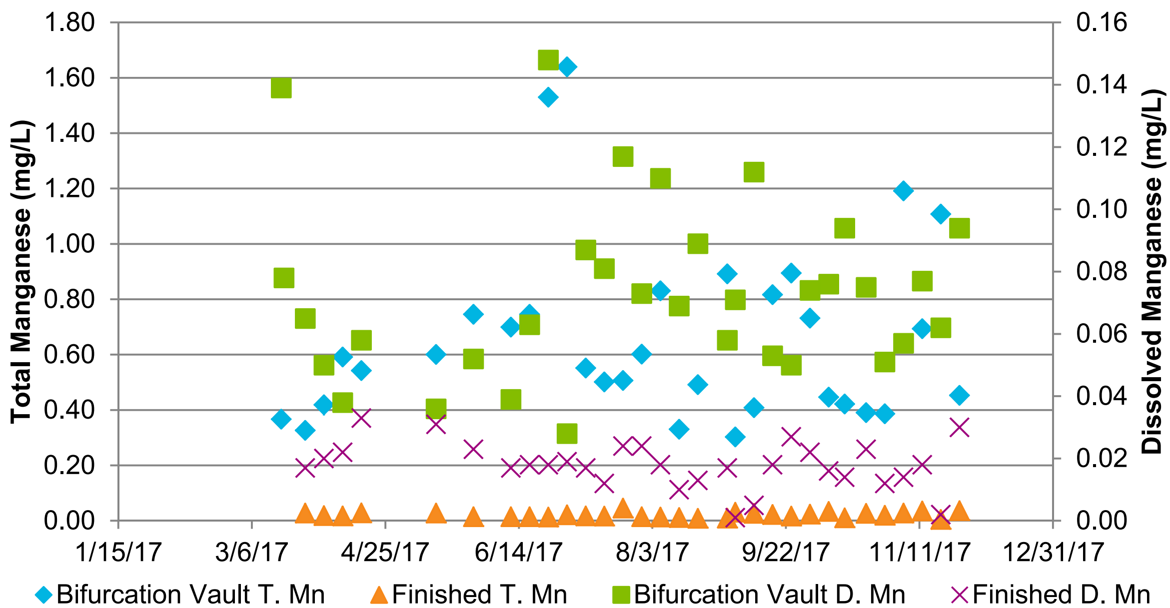

Figure 5. WBWTP Measured Manganese Values (Sunday Labs)

5.3 Iron

While there is iron is present in the raw water sources, the introduction of iron as part of the coagulant dosing is the primary source of iron within the system. The coagulant dose does not vary significantly and is typically around 19 mg/L. Total iron levels in the Clarifier effluent varied from approximately 0.2-1.0 mg/L, which are relatively high values and may suggest incomplete coagulation. Permeate iron levels closely mimic finished water iron levels, with typical levels around 0.03 mg/L, with a peak value of 0.061 mg/L from 3/2016 to 3/2018. There is little to no reported issues with excessive dissolved or reduced iron creating aesthetic issues in the distribution. The measured iron values are shown in Figure 6.

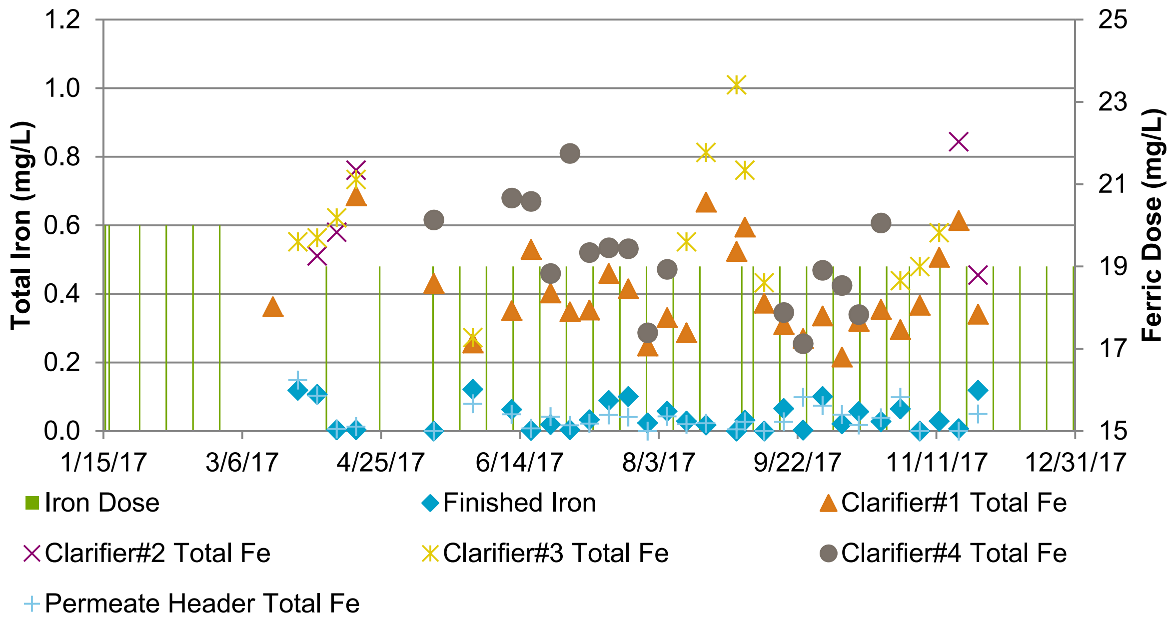

Figure 6. WBWTP Measured Iron Values and Ferric Dose

6. WBWTP Evaluation Summary

6.1 Conclusions

The evaluation of the WBWTP has been completed to consider the ability of the treatment processes at the facility to meet various production and water quality criteria as defined in the *Water Treatment Facilities Master Plan System Performance Criteria.* The findings from the treatment evaluation are intended to integrate with the other aspects of the UMP to confirm the capability of the WBWTP as part of the comprehensive water cycle for Thornton. The following are summary conclusions from the evaluation of the WBWTP.

1. While not directly related to treatment at the WBWTP, the raw water pump stations do not have reliable sources of backup power, which could directly impact treatment operations. More discussion on raw water pump station backup power expectation as it relates to overall system reliability and redundancy is presented as part of the Raw Water Supply Master Plan.
2. The inlet works systems are adequately sized for the current production and regulatory requirements, but there is insufficient contact time for the potassium permanganate feed from the WGL PS.
3. The injection points of hypochlorite and PAC at the inlet works are too close, resulting in competition and reduced effectiveness of both systems.
4. The coagulant addition system in the inlet works are adequately sized for current production and regulatory requirements, but the mixing method is ineffective and results in maldistribution to the clarifiers.
5. The clarifiers are adequately sized for current production and regulatory requirements, but the previous operational approach relying on sludge blanket thickness for clarifier performance management was inefficient, resulting in higher wasting rates than would be recommended. The recent change to monitoring center cones solids and reducing wasting rates is expected to significantly improve performance. There are also challenges

with uneven flow distribution between the units, resulting in variable performance. Further study is required to determine how to best address the hydraulic inequities.

6. The membrane systems are adequately designed for regulatory requirements but are not configured for sustainable production for current operations. The units were designed with a higher-than-recommended flux, which results in rapid fouling and loss of permeability. Based on analysis of other facilities equipped with this membrane technology, the sustainable operating flux would likely result in a peak production capacity closer to 30 MGD. Significant increase in production capacity will either require more frequent membrane maintenance or the construction of additional membrane trains to provide more surface area. Additional membrane area is required to be able to meet the intended design capacity. More frequent cleaning and membrane replacement will be required to sustain the production.
7. The processes associated with finishing of the water prior to distribution are adequately sized for current production and regulatory requirements, but the carrier water associated with the sodium hydroxide system is leading to extra maintenance. Modification of the finished water storage to produce a chlorine contact basin will be adequate for regulatory requirements associated with disinfection as the 0.7 baffling factor was approved by CDPHE. Analysis of the high service pump station associated with the finished water storage tank is further discussed in the Distribution section of the UMP.
8. The lagoon systems are adequately sized for current production and regulatory requirements, but the management of the lagoons would benefit significantly from increased monitoring and control. Additionally, the return of decant water from two separate treatment processes to WGL appears to be leading to the accumulation of significant fouling elements.

6.2 Recommendations

The following are recommendations for WBWTP equipment and process data to improve system performance; further technical and financial analysis of these recommendations will be included in a future TM:

1. Thornton should continue to monitor manganese removal performance as it implements other treatment process improvements and assess if there is a need to increase the contact time for the potassium permanganate feed from the WGL PS as defined in previous studies. This may require completing additional study to determine the impact of other process changes on the recommended means and cost of providing additional residence time between WGL PS and WBWTP.
2. While the CT-based disinfection is planned to be moved to the finished water systems, it is assumed that oxidation of manganese, in particular for manganese introduced with the ferric coagulant. While there is existing infrastructure to feed NaOCl, to oxidize manganese, the kinetics of manganese oxidation by $KMnO_4$ are more favorable, and it would be recommended to evaluate the opportunity to add a secondary KMnO4 feed point or re-purpose the NaOCl feed point for $KMnO_4$. The planned addition of a feed point for NaOCl at the membrane channel to help control membrane fouling would be a better location to minimize impacts to the feed. Use of other oxidants to control biofouling on the membranes should be thoroughly studied, as other oxidants such as ozone and hydrogen peroxide are much more aggressive and could significantly damage the membrane fibers.
3. The coagulant mixing system is planned to be replaced with a new flash mix system, which is anticipated to improve mixing. Appendix A contains a summary of a review of the new flash mix system including options to further optimize the design of the new system.
4. Continue to operate the clarification systems according to the current method of monitoring center cone solids. Complete a study to identify the causes of the hydraulic maldistribution between clarifiers, including identifying potential options for improvements.
5. Equip all membrane basins with the maximum number of membrane cassettes in order to operate the systems at a lower flux. Evaluate capacity and utilization of support systems such as blowers and backpulse pumps to determine if additional redundancy is required. Conduct further facility planning studies to investigate means to add additional membrane area in order to allow the plant to operate at a sustainable flux to meet a production flow rate of 50 MGD.

6. A softening system is intended to be added to the carrier water associated with the sodium hydroxide system to reduce maintenance. Continue to monitor conditions in the finished water pipelines to determine the impacts to scaling in those facilities.
7. Conduct a study on the lagoon systems to identify methods to improve process control.
8. In order to minimize potential for fouling, further investigate redirecting decant water downstream of WGL. If decant water cannot be fully redirected due to the lost water resource, it would be recommended to further study means to separate the wastewater sent to the lagoons from the TWTP and to determine if this stream can be isolated to either allow treatment or for this portion of the return flow to be sent downstream of the WGL.
9. Take steps to immediately cease discharge of membrane CIP to the residuals lagoons. This waste should be neutralized and disposed of offsite.

Appendix A:
WBWTP Process
Analysis Evaluation

Table of Contents

Tables

Figures

List of Acronyms

ACH – aluminum chlorohydrate
AOP – advanced oxidation process
°C – degree Celsius
CIP – clean-in-place
DADMAC – diallyldimethylammonium chloride
CT – contact time
EGL – East Gravel Lakes
°F – degree Fahrenheit
$FeCl_3$ – ferric chloride
ft – feet
FRP – fiberglass reinforced plastic
GAC – granular activated carbon
gpm – gallons per minute
in – inches
$KMnO_4$ – potassium permanganate
lb – pound
M – million gallons
MGD – million gallons per day
MIB – 2-Methylisoborneol
NaOCl – sodium hypochlorite
NaOH – sodium hydroxide
NTU – nephelometric turbidity unit
PAC – powdered activated carbon
PHD – peak hour demand
ppm – parts per million
Project – Utility Master Plan project
psi – pounds per square inch
TC – temperature corrected
Thornton – City of Thornton
TOC – total organic carbon
TM – Technical Memorandum
TMP – transmembrane pressure
TWTP – Thornton Water Treatment Plant
UF – ultrafiltration
UMP – Utility Master Plan
UV – ultraviolet
WBWTP – Wes Brown Water Treatment Plant
WGL – West Gravel Lakes

1. Inlet Works

Raw water is delivered to the WBWTP from the EGL and WGL via the EGL Pump Station and WGL Pump Station, respectively. For the purposes of this report, the boundary of the Inlet Works processes are from the EGL and WGL pump stations through the discharge to the upflow clarifiers. In the process of being conveyed to WBWTP, the raw water is subject to multiple treatment processes, which are shown in Table 1 and discussed in subsequent sections.

Table 1. Inlet Works Treatment Processes

Treatment Processes	Treatment Approach	Dose Location	Operational Considerations
Manganese Control	Potassium Permanganate ($KMnO_4$) is injected to oxidize reduced manganese from the raw water supply. This also promotes oxidation of reduced iron and some taste and odor compounds.	The pipeline diffuser is in the discharge line at WGL Pump Station. The pipeline diffuser is in the suction line at EGL Pump Station. No other mixing is provided.	Excessive dosage can impart color to the water. The membranes have a measurable capacity to oxidants. If a residual is carried onto the membranes, this could impact membrane integrity over time.
Taste and Odor Control	Powder activated carbon (PAC) is injected to adsorb taste and odor compounds and allow for subsequent removal as a solid.	The pipeline diffuser is in the inlet piping downstream of the pump stations and upstream of other chemicals and clarifiers. No other mixing provided.	Excess dosage leads to higher solids loading on the sedimentation process. PAC can be abrasive to equipment and piping, including membranes.
Disinfection	Sodium hypochlorite (NaOCl) is injected to provide disinfection contact time in the inlet piping. Sodium hypochlorite is also used for secondary manganese oxidation and mitigation of biofouling on the membranes. A small residual is carried onto the membranes from the clarification process.	The pipeline diffuser is on inlet piping, downstream of PAC addition, upstream of coagulant addition and clarifiers. No other mixing provided.	Hypochlorite can react with organic material in raw water to generate disinfection byproducts. The membranes have a measurable capacity to oxidants. If a residual is carried onto the membranes, this could impact membrane integrity over time.
Coagulation	Ferric chloride ($FeCl_3$) is injected to promote dispersion and charge destabilization.	Pipeline injection is conducted with an in-pipe induction mixer, downstream of other chemicals, and upstream of the clarifiers. The induction mixer is being replaced with a flash-mix system.	Excessive dosage can impart color to the water. Improper coagulation can lead to iron carryover that can contribute to fouling in membranes.

After discharge from the raw water pumping systems, the EGL and WGL have approximately 19.5 and 1.6 minutes, respectively, of contact time within the inlet piping at average flow rates of 12 mgd each before reaching the WBWTP treatment systems. The following subsections provide additional details on the treatment process systems, including system components, capacity analysis, and identification of known operational or maintenance challenges.

1.1 Manganese Control

Manganese is present in the WGL and the EGL storage systems at concentrations above the concentration limit of 0.05 mg/L recommended for membrane operations. Oxidation is required to control and remove manganese, which both protects against membrane fouling and prevents potential aesthetic issues in the WBWTP finished water. The current control methodology is via the introduction of potassium permanganate to oxidize reduced species.

1.1.1 System Components

Potassium permanganate is received at the facility as a dry powder in a cycle bin, which is loaded onto a hopper system that uses a volumetric feeder (auger) to add powder to a mix tank, where it is combined with water to produce a solution of approximately 0.055 percent by weight. The mix tank also serves the liquid reservoir for the chemical feed, which occurs via eduction into a 15 gpm carrier water supply for injection into the inlet works piping. Key aspects of the potassium permanganate system are summarized in Table 2.

Table 2. Potassium Permanganate System Summary

Parameter	Value
Tanks	
Number	2 (1 per pump station)
Storage (lbs)	6600 lbs per pump station
Dosing Solution Preparation System	Cycle-bin, loss-in-weight screw feeder and mix tank (1 per pump station)
Feeder Type	Volumetric Screw
Feed Rate (lb/day)	525
Mixer Number	2 (1 per pump station)
Mixer Motor Horsepower (hp)	0.5
Liquid Storage Volume	140 gallons (per pump station)
Liquid Solution Strength[1]	<0.055 wt%
Dosing Location	EGL and WGL Pump Stations
Metering Pumps	
Type	Eductor
Number	2 (1 per pump station)
Capacity (gph)	900

[1]Concentration may vary based EGL/WGL pump setpoint, which adjusts the feed rate

The permanganate feed is set by the Operator at a 2:1 ratio of dose to dissolved manganese concentration based on water quality in the WGL and EGL storage systems. Once set, the system adjusts automatically based on the flow rate to the WBWTP to deliver the required dose. At the time of this evaluation, the permanganate solution is educted and injected directly into the pipeline at each pump station without any supplemental mixing. Specifically at EGL, the feeder mix tank is educted to a 2nd tank with flow splitting baffles and injected into each of the operating pump intakes. A design is being completed to provide a batch system at EGL for dosing from a day tank to the pump intakes.

Figure 1 shows raw water manganese concentration as monitored at the Bifurcation Vault. Total manganese ranges from 0.3-0.8 mg/L, with an average concentration greater than 0.6 mg/L. However, dissolved manganese averages less than 0.1 mg/L, resulting in the plant operating at a typical dose of between 0.4-0.5 mg/L of potassium permanganate.

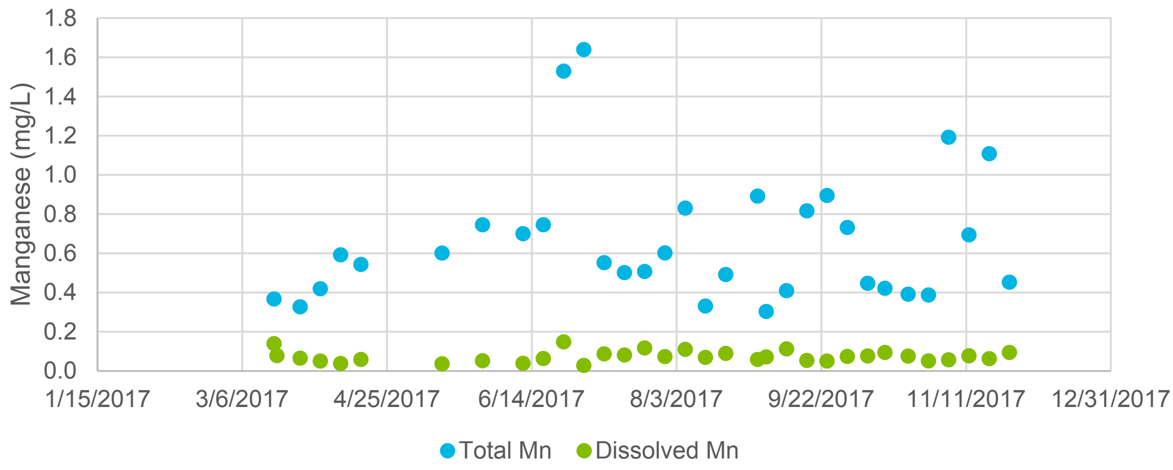

Figure 1. WBWTP Inlet Works 2017 Manganese Concentration

1.1.2 Performance and Capacity Analysis

Table 3 summarizes the capacity analysis conducted on the potassium permanganate system:

Table 3. Potassium Permanganate System Capacity Analysis

Parameter	Value
Dosing Location	WGL + EGL Pump Stations
Design Dosage	EGL: 0.6-1.0 mg/L WGL: 0.5-1.34 mg/L
Target Dosage	1.92 mg/L KMnO4 per 1.0 mg/L Mn 0.94 mg/L KMnO4 per 1.0 mg/L Fe
Max Dosage in 2016 (mg/L)	EGL:1.0 WGL: 0.90
Average Dosage in 2016 (mg/L)	EGL:0.63 WGL: 0.55
Treated Flow Capacity at Metering System Capacity and Design Dose (MGD)	EGL:63.0 WGL: 47.0
Treated Flow Capacity at Metering System Capacity at Average Dosage (MGD)	EGL:100 WGL: 114
Total Storage at Design Dose and Plant Capacity (days)	EGL:11.8 WGL: 15.8

The calculation demonstrates that one potassium permanganate system is adequate to deliver 9920 grams to the inlet works if the other is not in operation, demonstrating that the facilities are suitable to treat up to 50 MGD at a dosage of up to 1.26 mg/L. Lower dosage rates would be achieved by reducing the strength of the solution, with a lower dosage boundary of 0.06 mg/L when fed on a continuous basis. The facility maintains adequate dry storage for 11 to 15 days of operation at peak flow.

1.1.3 Known Operational or Maintenance Challenges

1.1.3.1 Contact Time

The 2014 Wes Brown WTP Operations Study by CH2M Hill of the WBWTP demonstrated that seven minutes of reaction time are required for adequate oxidation. The transit time from the EGL pump station to the next process downstream (introduction of powdered activated carbon) is 10.6 minutes of contact time at peak flow, which is more than the minimum time required. However the transit time between the WGL pump station and the PAC addition is only 1.0 minutes of contact time at 20 mgd and 1.9 min minutes at 10 mgd flow, which does not provide the target reaction time. This may result in interference from the powdered activated carbon, which may reduce its effectiveness and lead to higher demand for permanganate to compensate for the oxidant consumption by the carbon.

1.1.4 Process Demonstrated Capacity

Based on the analysis in Subsection 4.1.1, the manganese control equipment associated with the inlet works at the WBWTP was found to be appropriately sized for the current production and regulatory requirements and is consistent with industry standards. However, the system would benefit from additional contact time for oxidation for the discharge from the WGL Pump Station prior to the introduction of powdered activated carbon. It is recommended to increase hydraulic residence time for the WGL raw water by adding approximately 200,000 gallons of volume to provide the necessary contact time.

1.2 Taste and Odor Control

Compounds such as 2-methylisoborneol (MIB) and geosmin are byproducts of cyanobacteria proliferation in the raw water supplies for the WBWTP, in particular in the EGL storage systems. While the concentrations of the compounds peak in the summer, they are present year round, requiring continuous PAC dosing to maintain aesthetic taste and odor qualities of the finished water. PAC is the only taste and odor control system at the WBWTP and is more effective on geosmin than MIB. This approach generally is effective for control of taste and odor issues, but PAC systems can be costly to operate and can generate operational and maintenance challenges.

1.2.1 System Components

PAC is received at the facility as a dry powder, which is combined with water in the slurry vault to produce a dosing solution. The dosing pumps are diaphragm metering units that discharge to the influent pipeline and are controlled based on an operator-selectable dose and the plant flow rate. Key aspects of the powdered activated carbon system are summarized in

Table 4.

Table 4. PAC System Summary

Parameter	Value
Tanks	
Number	1
Slurry Preparation	Wetting chamber with mixer
Mixer Type	Turbine
Mixer Motor Horsepower (hp)	30
Bulk Storage Volume (gal)	74,000
Slurry Concentration	1 lb PAC / gallon water
Metering Pumps	
Type	Diaphragm
Number	2
Capacity per pump (gph)[1]	330

[1]Pumps are designed to operate in a lead/lag configuration, allowing a 660-gph feed.

Due to the lack of available online instrumentation to quantify taste and odor compounds combined with the high cost and time required to complete analysis, dosage for PAC is set by the Operator based on quantitative geosmin/MIB results. Once the dosage is set, the pump speed is automatically adjusted to deliver the required dose based on the pump station flow rate. The slurry is injected into the inlet pipeline near the treatment plant. Figure 2 presents the dosing rate for PAC in 2016; changes in PAC dose are calculated based on plant treatment flow rates PAC feed rate. PAC doses in excess of the maximum design are achieved by operating both PAC pumps while the total plant production is less than the design rate.

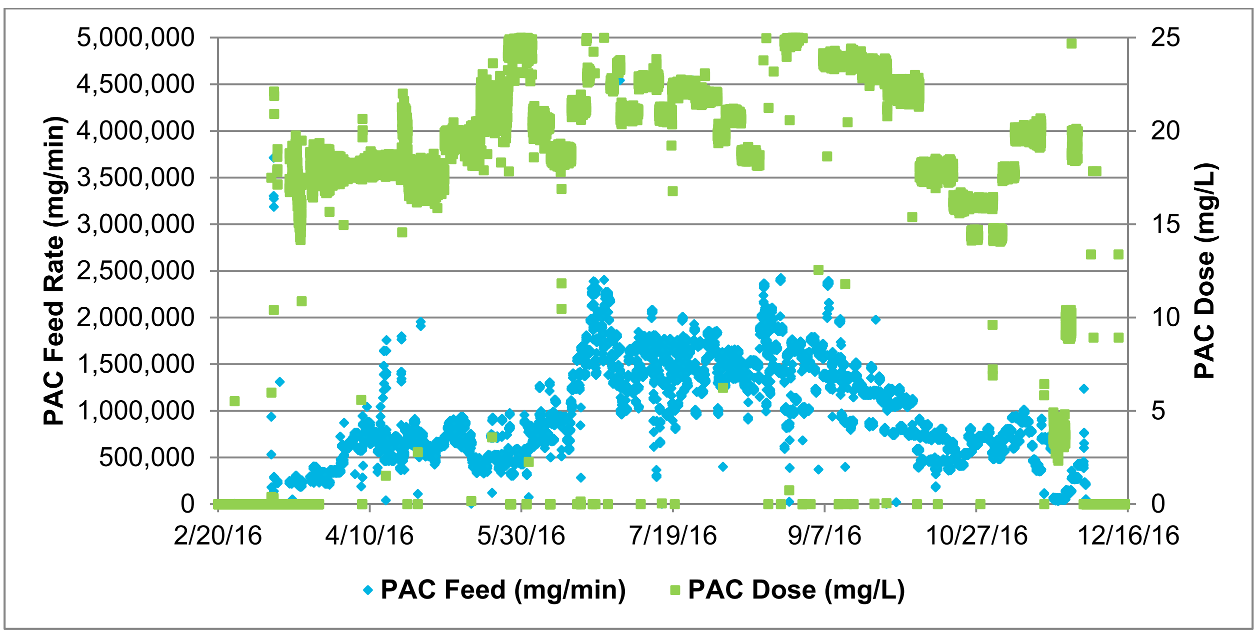

Figure 2. PAC Feed Rate and Dose

1.2.2 Performance and Capacity Analysis

Table 5 summarizes the capacity analysis conducted on the PAC system. The calculation demonstrates that the PAC system is adequate to deliver the design dosage to meet the plant PAC dosage demand with both pumps in operation. The system is capable of delivering 19 mg/L of PAC on a continuous basis at plant capacity with a single pump. However, the empirical data indicate that the design dosage is inadequate to meet the aesthetic quality goals for the finished water, and a more typical dosage rate of 20 to 40 mg/L is required. The slurry vault only provides approximately 4.8 days of storage at peak flow and maximum dosage, which leads to a requirement for frequent chemical delivery, as there is no option for additional dry storage of PAC at the WBWTP facility.

Table 5. PAC System Capacity Analysis

Parameter	Value
Dosing Location	Inlet Works
Design Dosage	12
Maximum Dose at Plant Capacity (mg/L)	38.0
95th Percentile Dosage in 2016 (mg/L)	129
Median Dosage in 2016 (mg/L)	29
Treatment Flow Capacity at Metering Pump Capacity and Design Dose (mgd)	158.5
Tank Storage Capacity (days) at Max Dose and Plant Capacity	4.76

1.2.3 Known Operational or Maintenance Challenges

1.2.3.1 Efficiency at Taste and Odor Control

During peak taste and odor events, the design dosage for the WBWTP is not adequate to fully attenuate all of the aesthetic concerns with the water. As such, the plant frequently feeds PAC at a rate that is significantly higher than the design dosage to remove taste and odor compounds.

Based on analysis conducted by Thornton, PAC efficiency has been found to be impacted by the current operational configuration. As noted in the previous section, permanganate from the WGL pump station does not have sufficient contact time in the inlet works, which may result in interaction with the PAC. More critically, sodium hypochlorite is added to the inlet pipeline shortly after the addition of the PAC, which depletes the adsorptive capacity of the activated carbon for taste and odor compounds. As a result, the design dosage has been demonstrated to be inadequate during peak taste and odor events, resulting in breakthrough of compounds into the finished water. The plant has compensated for this by using both pumps in a lead/lag configuration, which allows for much higher dosage, but these results in significant solids loading on the clarifiers and greatly reduces the number of days of available storage.

The 2017 Alternative Coagulant Study has shown that PAC could be approximately 75 percent more efficient at removing taste and odors without the impact of chlorine, which may result in reduced PAC dosage. Thornton has plans to complete modifications to the facility by adding a new chlorine contact pass into the clearwell, which will allow moving the chlorine dosing for disinfection CT away from inlet piping. The modifications are scheduled to be completed during the 2018/2019 shutdown beginning in December 2018.

The following are recommendations for evaluation of improvements to the taste and odor control system:

- Consider evaluation of alternative means for taste and odor management. While PAC is a relatively low capital cost system, it has been shown to be most cost-effective for transient, short-term events. Continuous feed of PAC has been demonstrated to have a high life cycle cost and creates additional operational issues including significant contribution to solids accumulation in the lagoons. Use of alternative taste and odor strategies, such as granular activated carbon (GAC) contactor, with or without advanced oxidative processes (AOPs), could provide an effective means to manage both taste and odor compounds. Additionally, AOPs could offer additional benefits for reducing foulants that may be entering the WBWTP from the return flow.

- If PAC is to remain the primary method of taste and odor management, increase on-site storage (dry or wet) to minimize risk of potential treatment disruption due to PAC supply interruption.

1.2.3.2 Equipment Maintenance

WBWTP staff reported that the PAC system has been one of the largest maintenance issues at the plant, with a significant number of instances of clogging for the PAC feed lines (particularly at locations where there are 90 degree bends in the pipe) and impact to the online instruments. There has also been evidence of material abrasion on the 90-degree bends.

We recommend that modification to the slurry feed system to reduce plugging potential and improve the ability to perform maintenance be evaluated. This could include use of tubing instead of piping to eliminate bends or installation of long radius, 45-degree bends to replace short radius, 90-degree bends, which will reduce low velocity points and should minimize plugging potential. Reduced PAC dosage may also reduce maintenance issues.

1.2.4 Process Demonstrated Capacity

Based on this analysis, the taste and odor control system at the WBWTP has the potential to meet the Tier 2 criteria goal as defined in Water Treatment Facilities Master Plan System Performance Criteria TM and is generally consistent with industry standards, but the effectiveness of the system is impacted due to negative interaction with other systems, and quantity of on-site storage is low, relative to the usage rate and therefore could represent a risk to the WBWTP's ability to meet the finished water aesthetic goals.

Further, the current application strategy is competing with other chemicals (hypochlorite, permanganate), which reduces effectiveness and efficiency. Changes in the chemical feed strategy to separate the oxidants from the PAC is expected to have a significant benefit for the effectiveness of the PAC in removing taste and odor compounds, which is expected to translate into reduced dosage, increased available storage, and reduced solids generation.

Given the need for oxidation associated with manganese control within the inlet works, there is an opportunity for implementation of alternative means for taste and odor management; while PAC is a relatively low capital cost system, it has been demonstrated to have a high life cycle cost. Use of alternative taste and odor strategies, such as those being implemented at the new TWTP, could provide an effective means to manage both taste and odor compounds and may offer additional benefits for reducing foulants that may be entering the WBWTP from the return flow.

1.3 Disinfection

As required by the Safe Drinking Water Act, the WBWTP must achieve 4-log virus, 3-log *Giardia*, and 2-log *Cryptosporidium* removal/inactivation. The WBWTP receives 3-log removal credits for *Giardia* and 2-log credits for *Cryptosporidium* removal based on maintaining membrane systems as verified by integrity testing, which meets the full requirements for these two constituents. The remainder of the disinfection for viruses can be met with multiple disinfectant systems available at the WBWTP, which is primarily achieved via sodium hypochlorite for chlorine-based contact time disinfection. The UV system can provide additional disinfection credits but is currently offline.

Sodium hypochlorite is used primarily as a disinfectant and can be fed at multiple locations within the facility. The primary feed point is currently the inlet works, but sodium hypochlorite is also fed at the membrane effluent for providing the appropriate chlorine residual prior to the introduction of ammonia (for chloramination). A final feed point is included in the finished water vault to be used to adjust chlorine residual prior to discharge to distribution. There are plans to move the primary disinfection point to post filtration, including modification of a clearwell. However, hypochlorite has also been employed as an oxidant to control manganese introduced to the system as part of the ferric chloride addition, so an oxidant feed location at the inlet works will likely be required.

1.3.1 System Components

Sodium hypochlorite is injected into the inlet works pipeline to achieve contact time disinfection prior to the treatment systems. The system is designed to inject up to 5 mg/L at peak plant flow, with the piping serving as a contactor, but the actual peak recorded dosage in 2017 was 29.5 mg/L at 17.5 mgd. As discussed in previous sections, this approach has operational challenges due to competition for the oxidant, so the disinfection strategy is being modified to conduct post-treatment disinfection in a clearwell. The modification construction is planned for the winter shutdown of the WBWTP starting in November of 2018; and the new facilities will begin starting operations in March 2019. The current sodium hypochlorite injection point at the inlet works will be maintained as a backup. Use of hypochlorite may continue to help control manganese, but the dosage will be significantly reduced. Additionally, potassium permanganate would be more effective for controlling the manganese introduced as a result of the coagulant addition, so modification or addition of a second $KMnO_4$ feed location could allow for improved interaction with the permanganate dose.

Sodium hypochlorite is received at the facility as a bulk liquid at 12.5 percent solution strength. The dosing pumps are diaphragm units that discharge directly to the various dosing locations based on an operator-selectable dose and the plant flow rate. Key aspects of the sodium hypochlorite system are summarized in Table 6.

Table 6. Sodium Hypochlorite System Summary

Parameter	Value
Tanks	
Number	3
Bulk Storage Volume (gal)	78,000
Bulk Chemical Strength	12.5%
Metering Pumps	
Type	Peristaltic
Number	5
Capacity (gph)	412

1.3.2 Performance and Capacity Analysis

The system design is based on up to 5 mg/L of sodium hypochlorite can be fed at any of the dosing locations at peak plant production, but the feed equipment provides additional capacity above the design, and higher doses are possible at lower production rates and are common current operating practices at WBWTP. For example, the 2017 maximum dosage at the inlet works was 29.5 mg/L, and the 2017 maximum dosage for post-membrane chlorine was 4.4 mg/L.

The chlorine residual from the inlet work is fed to be able to maintain a residual in the membrane influent channel to control membrane fouling, which results in a higher dose than would be required for disinfection credits.

Table 7 summarizes the disinfection system design criteria for facilities that will be on site in March 2019.

Table 7. Disinfection Process Summary

Parameter	Value
Inlet Works	
Volume (gal)	35,689
Baffle Factor	1.0
Design Dose (mg/L)	5
Contact Time at Peak Day Flow (estimated)	6
CT Required for Virus (min*mg/L) [1]	12
Chlorine Residual to Meet Disinfection Requirements	2.0
2016 Average Chlorine Residual (mg/L)	4.9
2016 1st Percentile Chlorine Residual (mg/L)	4.0
Average CT Observed	29.4
Minimum CT Observed	24.0
Maximum Potential Chlorine Dose per Location at Plant Capacity with a Single Pump (mg/L)	29.7
Calculated CT at Peak Flow and 90% Residual of Max Dose (min*mg/L)	160.4
Storage at Design Dose at 3 Locations and Plant Capacity (days)	15.5

[1] CT based on maximum anticipated raw water pH (9.0) and minimum temperature (0.5° C).

Figure 3 shows the chlorine residual as reported by online instrumentation at the primary disinfection point at the inlet works. This data includes drop-outs due to maintenance and other sample disruptions. The data suggest that the dosage exceeded the upper boundary of the instrumentation measurement range but indicate the concentration exceeded the residual requirements for disinfection CT. The high dosage provides sufficient hypochlorite through the clarifiers to maintain a residual in the membrane feed.

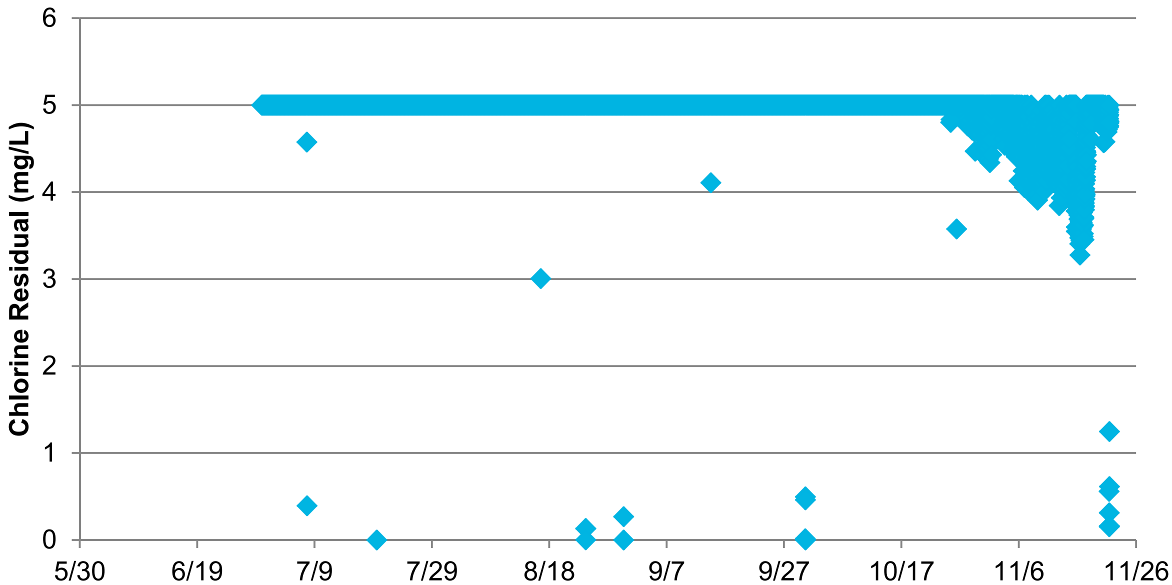

Figure 3. Measured Chlorine Residual at Inlet Works

1.3.3 Known Operational or Maintenance Challenges

1.3.3.1 Interaction with PAC

No significant problems were reported with the sodium hypochlorite feed equipment. However, the current application point at the raw water has been demonstrated to be problematic due to the interactions with PAC, which reduces the effectiveness of both chemicals and requires higher feed rates than would otherwise be needed. Providing separation between the application point at the inlet works between the introduction of PAC and the disinfectant is recommended to maximize effectiveness. However, given the planned change to post-filtration disinfection, no changes should be completed until the adjusted disinfection strategy is implemented.

1.3.4 Process Demonstrated Capacity

Based on this analysis, the disinfection systems associated with the inlet works at the WBWTP were found to be adequately sized for the current applications and are consistent with industry standards. All disinfection requirements are being met through the combination of the membrane system performance (for *Giardia* and *Cryptosporidium*) and virus (chlorine contact). Future operations involve a design modification to the finished water storage tank, which will move primary disinfection to downstream of the membranes. This modification is expected to improve disinfection effectiveness and reduce overall chlorine demand, so the existing equipment is expected to be adequate.

While disinfection will move to a downstream process, hypochlorite may be required to the inlet works for continued prevention of accelerated membrane fouling. This is expected to continue to be counter-productive to the taste and odor systems, so providing more separation between the introduction of the PAC and the hypochlorite could improve effectiveness of both systems. A new feed point is being added at the clarifier effluent troughs to allow for improved flexibility in hypochlorite dosing.

Additional discussion on post-filtration hypochlorite feed (as used as part of chloramination) is discussed in Section 4 of this report.

1.4 Coagulation

Ferric chloride is used as the primarily coagulant and is fed in a vault on the inlet piping shortly before the flow split for the clarifiers. There is an inline induction mixer associated with the ferric chloride system, which has had performance issues due to design problems and does not appear to provide sufficient energy transfer for dispersion, which significantly reduces the mixing effectiveness. The mixer has experienced numerous maintenance problems.

1.4.1 System Components

Ferric chloride is received at the facility as a bulk liquid at approximately 38 to 42 percent solution strength. Key aspects of the current ferric chloride system are summarized in Table 8.

Table 8. Ferric Chloride System Summary

Parameter	Value
Chemical Tanks	
Number	3
Bulk Storage Volume (gal)	78,000
Bulk Chemical Strength	38-42%
Metering Pumps	
Type	Diaphragm
Number of Pumps	3
Capacity (gph)	194
Mixer	
Number of Mixers	1
Mixer Number	IntrudRRR, In-line
Mixer Motor Horsepower (hp)	10

1.4.2 Performance and Capacity Analysis

Table 9 summarizes the capacity analysis conducted on the ferric chloride system.

Table 9. Ferric System Capacity Analysis

Parameter	Value
Dosing Location	Coagulant Induction Mixing Vault
Design Dosage	17.5
Maximum Potential Dose at Plant Capacity (mg/L)	52.9
Max Dosage in 2016 (mg/L)	36
Average Dosage in 2016 (mg/L)	20
Treated Flow Capacity at Metering Pump Capacity and Design Dose (mgd)	93
Treated Flow Capacity at Metering Pump Capacity at Average Dosage (mgd)	163
Tank Storage Capacity at Peak Day Flow at 2016 Average Dose (days)	118

Ferric chloride dosage at the facility typically operates at an average dose of 19 mg/L but can range from 9 to 25 mg/L. The plant has previously borrowed and plans to acquire a Zeta-Meter System to measure the Zeta potential (potential difference between the surface of the particles immersed in the water and the water itself) to optimize the coagulant dose. However, studies of the Zeta-Meter indicate higher ferric chloride dosages (up to 70 mg/L, which has never been fed at WBWTP) would be required for optimized coagulation and TOC removal, but this has been shown to have a significantly detrimental effect on both pH and membrane fouling due to poor mixing and dispersion. Previous attempts to increase the dosage to 30 mg/L resulted in rapid and significant drops in membrane permeability. High dosages would also likely result in the need for caustic addition to restore the finished water pH and may require additional chemicals to manage corrosivity in the water due to the high chloride content. Higher doses of ferric may also increase the quantity of manganese that is introduced into the system, which would create an additional water quality challenge.

1.4.3 Known Operational or Maintenance Challenges

1.4.3.1 Poor Mixing

Multiple studies conducted at the facility have indicated that the induction mixer is inadequate for achieving equal distribution of the chemical within the inlet piping, which results in differential performance within the individual clarifiers. Thornton has completed a design for a new flash mix system to replace the current induction mixer, which is scheduled to be installed during a future winter shutdown. AECOM reviewed the design for the new flash mix system and recommended the following modifications:

- The design document reviewed by AECOM indicates the introduction of coagulant approximately 30 inches upstream of the nozzle used to introduce the high energy flow nozzle. We recommend that this distance be significantly reduced, so that the coagulant is dosed directly at the throat of the nozzle to maximize the utilization of the mixing energy. Thornton staff indicate that more recent documents have reduced the distance to between 9-12”, depending on fittings.
- We recommend that careful structural analysis be undertaken to ensure that the turning moment introduced by the jet does not causing buckling in the pipe. Bracing is often needed to provide additional support due to the high lateral forces created by the kinetic energy being introduced by the flash mix sidestream pump. Thornton staff indicates that more recent documents have flanges on both side of the piping to provide additional structural stability.
- We recommend a victaulic coupling be included in the design of the interface for the injection of the high energy flow to facilitate disconnecting the pipe for maintenance. Thornton staff indicates that the more recent documents include a grooved victaulic coupling and a 24" flange for the pump mix line which will allow for removal of the assembly once the nozzle is removed. Access is provided via a 30" blind flange with hinge.

1.4.3.2 Coagulant Effectiveness

In 2017 the Wes Brown Water Treatment Plant Alternative Coagulant and Ammonia Injection Study completed by Carollo determined there would be benefit to replacing the ferric chloride with aluminum chlorohydrate (ACH) for reducing fouling. Additional studies conducted by the WBWTP staff identified that a dosage of 28 mg/L achieved positive results, but the achieving TOC reduction goals could require a dosage of 45 up to mg/L ACH. This represents a significant increase in operating costs for this chemical system compared to current operations, but should be compared to the optimized Zeta dose of 70 mg/L for ferric chloride. Another benefit of using a highly pre-hydrolyzed coagulant such as ACH is that it consumes very little alkalinity with very little impact to pH, which could reduce the usage of sodium hydroxide and reduce maintenance costs associated with that system.

One additional consequence of a change to the ACH coagulant would be the loss of the option to use land application for sludge disposal, which may be able to be composted but otherwise would need to be sent to a landfill. In 2018, Thornton submitted a permit application to start using ACH as coagulant and is expecting approval in early spring 2019.

1.4.3.3 Storage Tanks

The ferric chloride fiberglass reinforced plastic (FRP) bulk storage tanks have experienced multiple tank failures, generally associated with filling the storage tanks to capacity, which has led to cracking in the tank base structure.

This may be a result of the tank bases being manufactured out of plumb, which may have created stress points due to inadequate support of the tank base in localized areas of the pad, which then makes the tank base susceptible to stress cracking due to weight when the tank is filled to its maximum volume.

1.4.4 Process Demonstrated Capacity

Based on this analysis, the coagulation systems associated with the inlet works at the WBWTP were found to be capable of delivering sufficient coagulant for the current production and regulatory requirements. However, the current mixing system appears to provide inadequate rapid dispersion of coagulant into the raw water flow and should be improved to allow for better clarification performance and reduce the potential for iron carryover to the membranes. A design has been completed for a new flash mix system that is anticipated to resolve the mixing challenges, which should be implemented as soon as is practical.

2. Clarification

The clarification processes begin downstream of ferric chloride injection and continues through the clarification equipment to the membrane influent channel. The clarification processes have approximately 26 minutes of contact and settling time.

2.1 System Components

Major design factors associated with the clarification processes are reflected in Table 10 and discussed below.

Table 10. Clarification Processes Summary

Clarification Processes	Purpose
Number	4
Diameter (ft)	65
Surface Area (sq ft)	2699
Influent Pipe Diameter (in.)	30
Effluent Pipe Diameter (in.)	36
Capacity (each, mgd)	18.35
Flocculation Well	
Center Well Diameter	14
Center Volume (gal)	6910
Hydraulic Residence Time @18.25 mgd (min)	12.23
Target Solids Concentration (center cone, Vol%)	15-25% high flow 11-15% low flow 3-8’ blanket thickness
Solids Recirculation Capacity (gpm)	55,000
Target Recirculation Ratio	4:1
Upflow Solids Contact Clarifier with Tube Settler	
Weir Length (ft)	1,007 ft
Tube Length (ft)	4

Clarification Processes	Purpose
Design Surface Loading Rate (gpd/sf)	6,800
Surface Loading (gpm/sf) @18.35 mgd[2]	4.72
Hydraulics Residence Time Settling Zone @18.25 mgd (min)	12

2.2 Performance and Capacity Analysis

Table 11 summarizes the design capacity analysis of the clarification system against operational conditions in the model year 2016.

Table 11. Clarification Process Summary

Parameter	Value
Plant Rated Flow Based on Clarifier Capacity with One Unit Out of Service (mgd)	55.1
Max Plant Flow at Clarifier Capacity (mgd)	73.4
2016 Average Flow (mgd)	17.4
2016 Max Flow (mgd)	47
2016 Surface Loading Rate at Average Flow (gpd/sf)	1,614 (24% of design rate)
2016 Surface Loading Rate at Maximum Flow (gpd/sf)	4,353 (64% of design rate)
Average Combined Turbidity (NTU)	0.40
95th Percentile Combined Turbidity (NTU)	0.90
Maximum Combined Settle Water Turbidity (NTU)	5

The hydraulic capacity of the clarification system exceeds the overall rated capacity of the WBWTP, indicating there is sufficient capacity within the clarification process to consistently meet the rated design flow for the WBWTP.

In 2016, the turbidity of the WBWTP raw water was constantly low, with an average of 1.2 NTU and 95th percentile below 2.2 NTU. The combined clarifier performance in comparison to the raw water turbidity experienced in 2016 is presented on Figure 4. Figure 5 presents settled water turbidity as a function of raw water turbidity.

[2] Observed performance at this loading rate has exceeded 5 NTU in the clarifier effluent, which exceeds the guidelines from the Partnership for Safe Water.

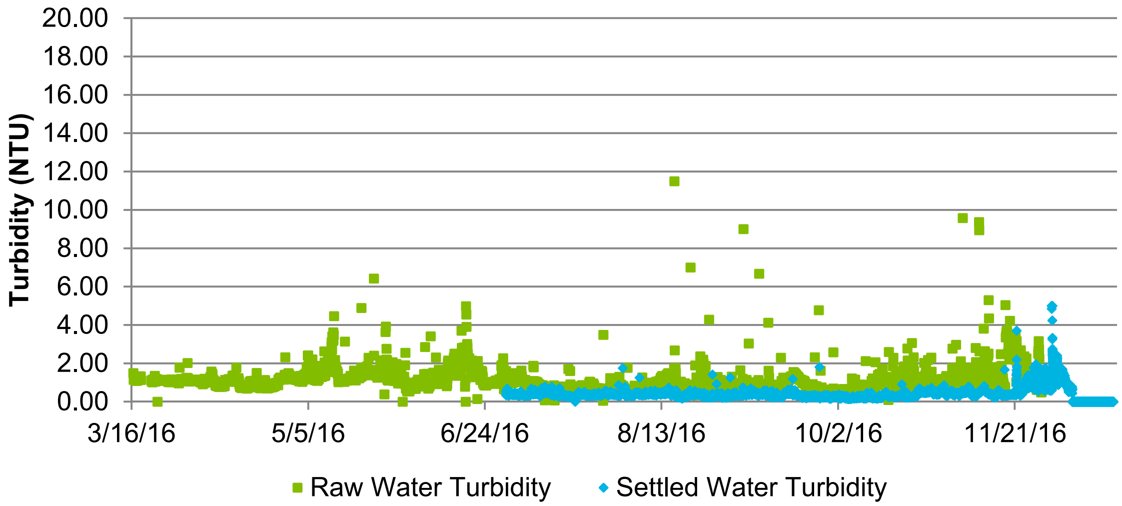

Figure 4. 2016 Raw Water Turbidity and Settled Water Turbidity[3]

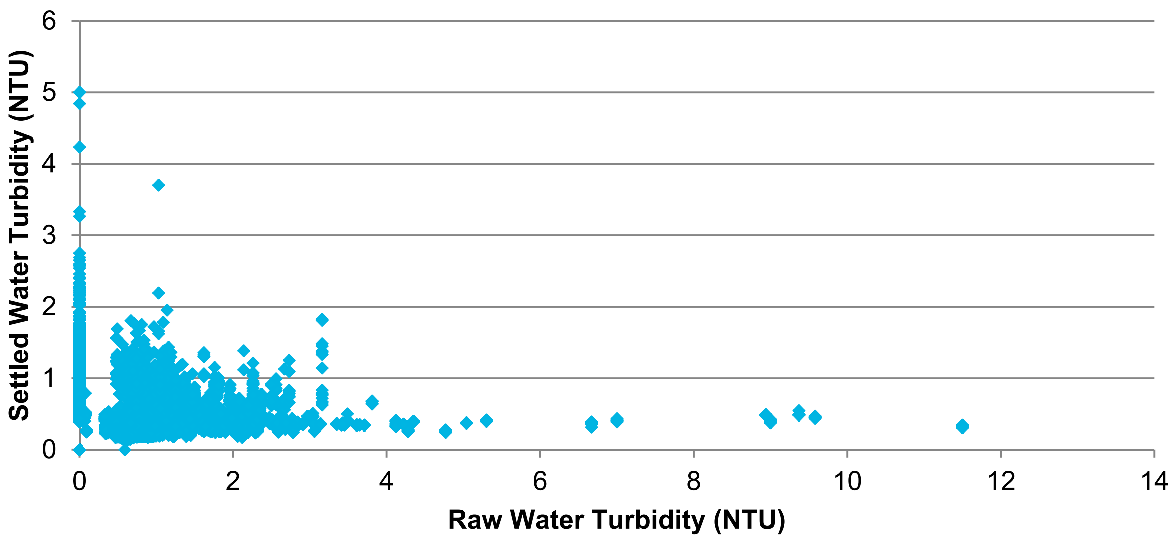

Figure 5. 2016 Raw Water Turbidity versus Settled Water Turbidity[4]

Figure 6 presents clarification performance as a function of flow. At higher flows, the turbidity of the combined clarifier effluent was consistently low (below 1 NTU), but the system performance degrades at lower flow rates, which may be attributed to temperature.

[3] 3/16 to 6/24 settled turbidity was not included in the data set
[4] Reported values for raw turbidity less than 0.1 NTU and settled turbidity greater than 1.0 are considered artificial anomalies likely attributed to disruption due to activities associated with maintenance or sampling.

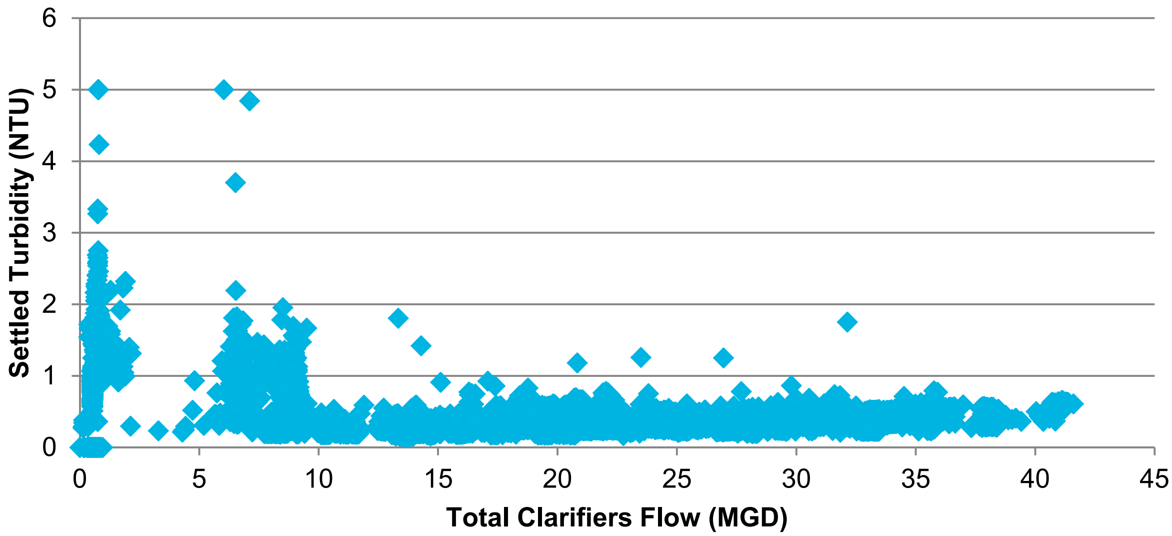

Figure 6. 2016 Settled Water Turbidity versus Total Clarifier Flow

Analysis of the charts indicates that clarifier performance degrades at lower flow rates and lower influent turbidity. Circular clarifiers can often have hydraulic instabilities as a result of the radial flow patterns, which can create upflow velocities that destabilize the solids blanket and result in solids carryover. At low turbidity, the solids blanket can have lower solids mass, which can contribute to solids release. It is important to closely monitor center cone solids to maintain solids density and also monitor clarifier operations regularly to identify potential zones of escaping solids.

In 2016, the clarifier units were operated using the blanket level control for determination of sludge wasting. However, this mode of operation did not account for low sludge blanket density, which could negatively impact clarifier performance. In 2017, operators modified operations of the clarifiers to monitor the center cone solids concentration, and sludge blowdown time was adjusted to a one-minute limit. These modifications have resulted in improved clarifier stability due to better preservation of the solids blanket and less water being discharged to the lagoon.

2.3 Known Operational or Maintenance Challenges

Clarifier effluent directly correlates with membrane performance, and clarifier performance is believed to be a contributing factor in the fouling rate for the membranes. The following subsection discusses operational and maintenance challenges at the facility that are believed to have a direct impact on clarifier performance

2.3.1 Variable Flow

Circular clarifiers perform best when flow conditions are stable. However, the WBWTP plant is a peaking plant, with peak requirements usually in the evenings as a result of system demand and limited storage in the distribution system. This leads to more frequent changes in the influent flow rate as shown in Figure 7, which can create additional hydraulic instability in the clarifiers.

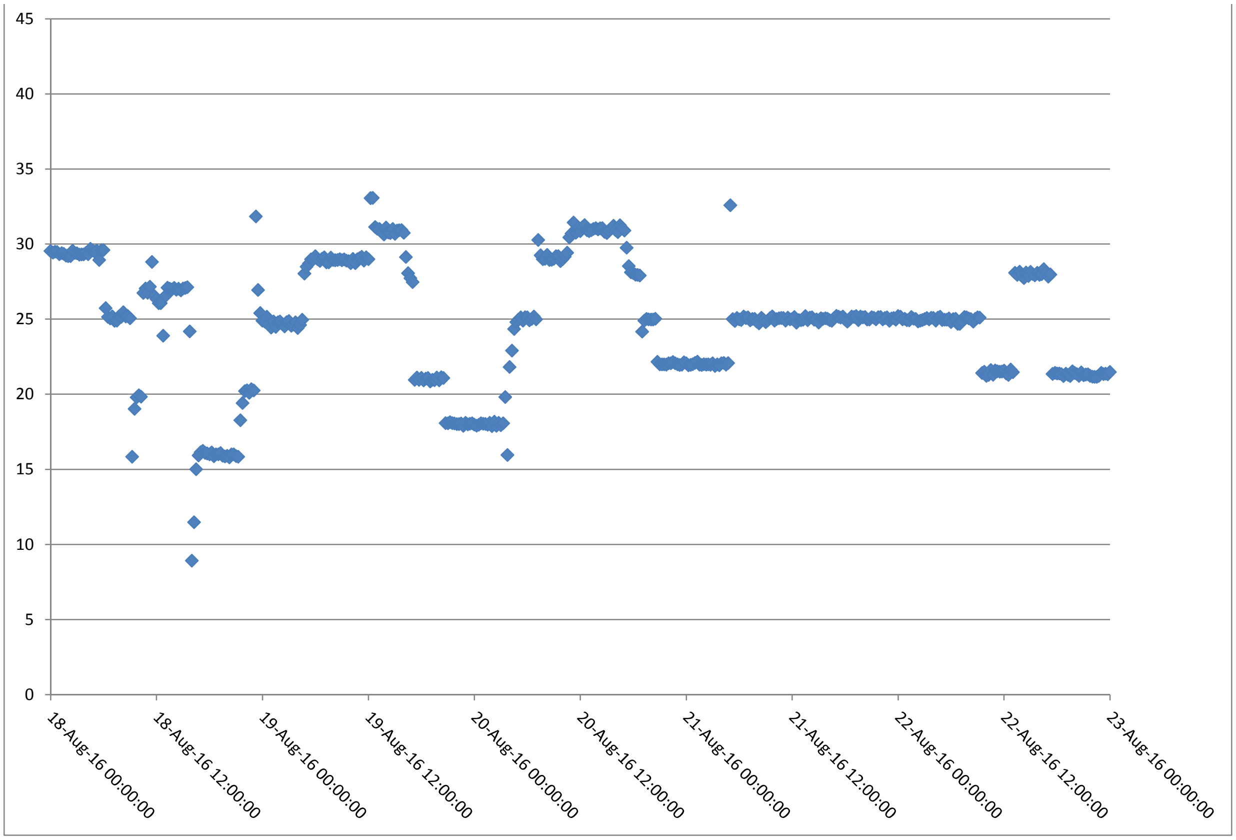

Figure 7. 2016 Plant Influent Flow Changes To Meet Distribution Demand

It is recommended that flow changes should, to the extent possible, be made in a stepwise manner over a period of time rather than all at once to avoid significant changes in the clarifiers' operating conditions.

2.3.2 Inadequate Mixing and Hydraulic Distribution

Analysis of individual clarifier performance indicates a differential between the individual units, which is shown in Figure 7, Figure 8, and Figure 9. Summary data are presented in Table 12. When all clarifiers are operating, the flow to Clarifier 1 and Clarifier 2 average approximately 8 to 13 percent more than the flow to Clarifier 3 and Clarifier 4. The original control scheme for the clarifiers included control valves control to balance the flow. However, this was bypassed because discrepancies in the flow meter readings between the plant influent flow meters (from the gravel lakes) and the flow meters feeding each clarifier caused instability in the control system, which led to the control valves restricting flow too much, causing increased line pressures and disrupting the chemical feed systems.

Since each of the clarifier units is intended to have identical construction and is assumed to be fed by the same influent water quality, the expectation should be that the performance of each unit should be similar. The figures demonstrate that the more hydraulically remote clarifiers tend to have better and more consistent performance but also are receiving less flow. The performance of Clarifier 1 and Clarifier 2 is more significantly impacted by raw water turbidity and tends to degrade as the turbidity increases. Additionally, Clarifier 1 and Clarifier 2 produce settled water with a higher average turbidity and tend to be more likely to experience variable performance when compared to Clarifier 3 and Clarifier 4. This trend is likely a reflection of inadequate mixing for the coagulant prior to introduction to the individual clarifier units as well as uneven hydraulic loading, which is likely causing maldistribution of the ferric coagulant and may also be causing post-precipitation issues.

A study was completed by AmWest in December 2005 to review flows through each clarifier. The findings from that study indicated that flow distribution is "remarkably close".

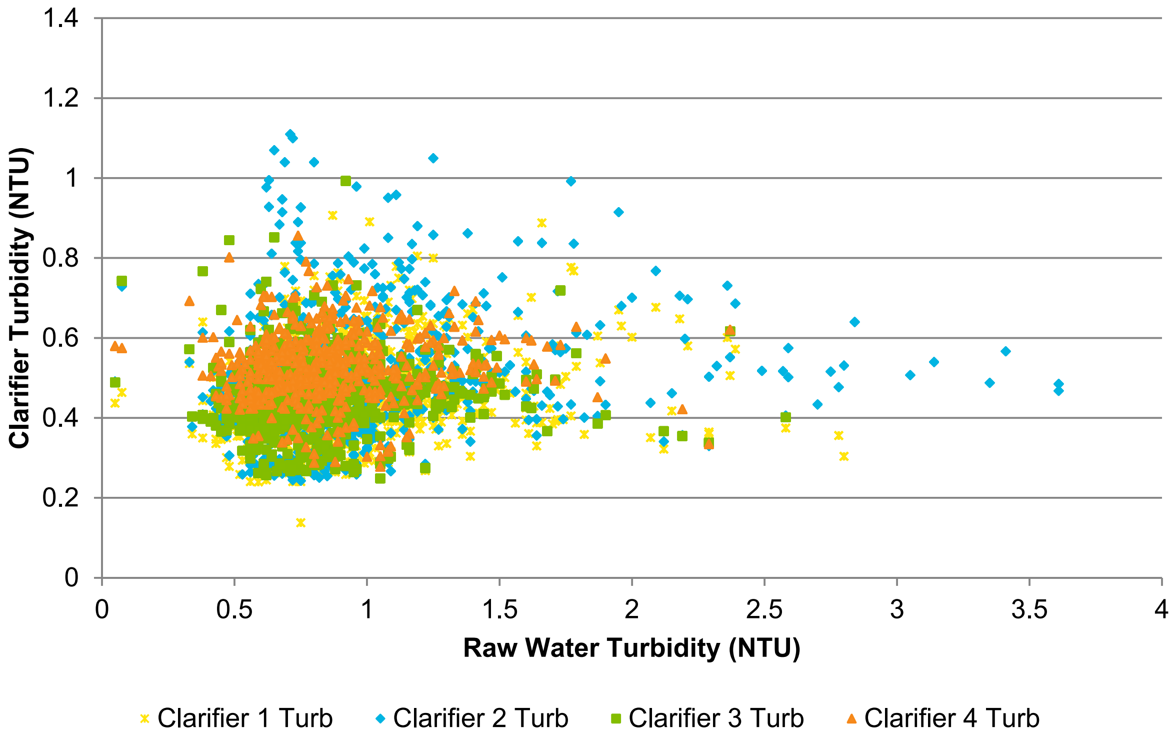

Figure 7. 2016 Settled Water Turbidity versus Raw Water Turbidity

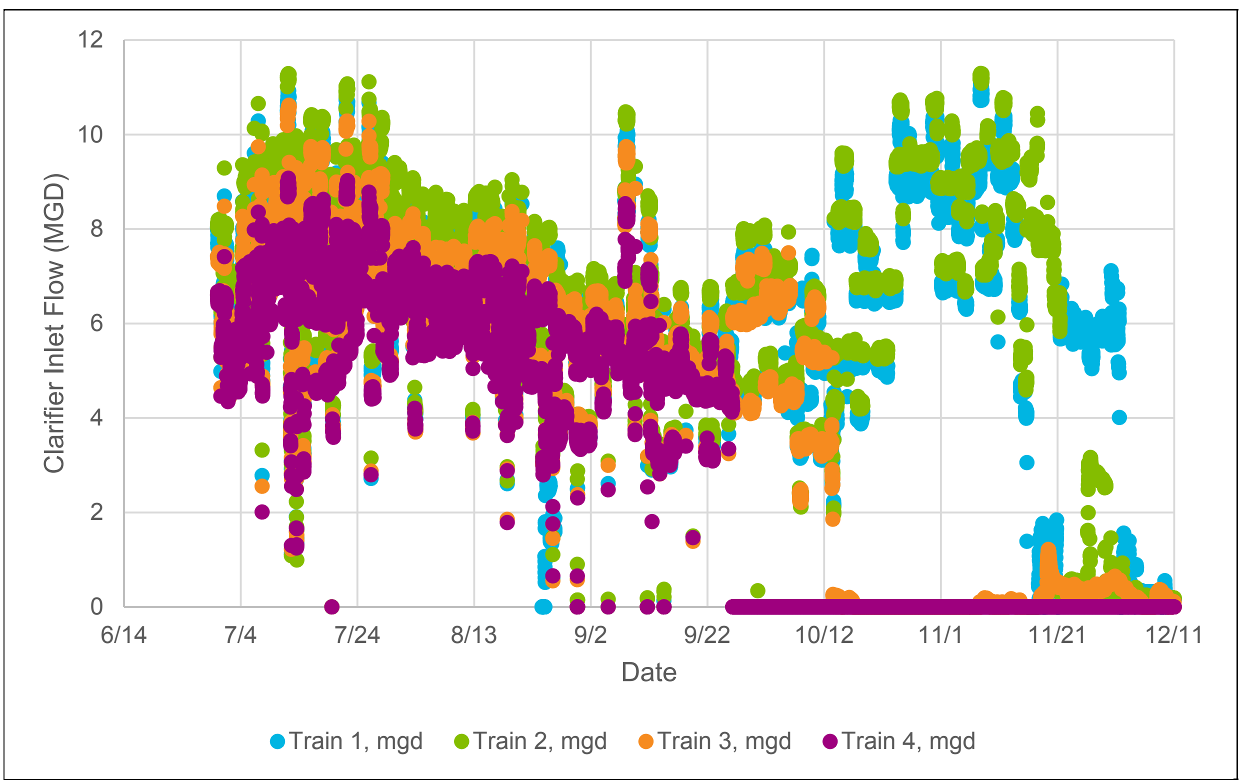

Figure 8. 2016 Inlet Flow by Clarifier

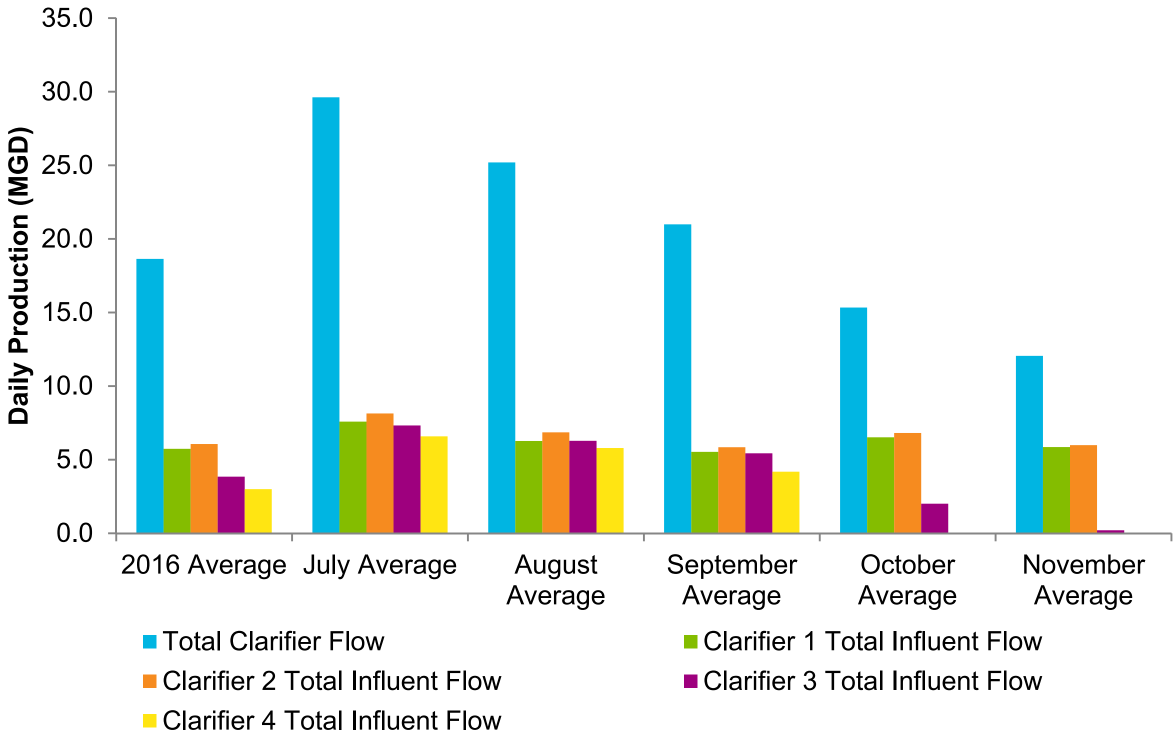

Figure 9. Clarifier Flow Averages by Month

Table 12. Clarification Flow Summary

Flow Value	All Clarifiers (MGD)	Clarifier 1 (MGD)	Clarifier 2 (MGD)	Clarifier 3 (MGD)	Clarifier 4 (MGD)
July Average	29.6	7.6	8.1	7.3	6.6
August Average	25.2	6.3	6.9	6.3	5.8
September Average	21.0	5.5	5.9	5.4	4.2
October Average	15.3	6.5	6.8	2.0	0.0
November Average	12.1	5.9	6.0	0.2	0.0
2016 Maximum	41.6	11.1	11.3	10.6	9.1
2016 Average	18.6	5.7	6.1	3.8	3.0
Total Year Volume (MG)	3166.3	973.2	1031.3	652.9	509.2

2.3.3 Impact of PAC Dosage

PAC dosage varies significantly throughout the year based on MIB and geosmin levels. The addition of PAC increases the quantity of solids in the flow stream, which increases the solids loading on the clarification process. This can have a negative impact on clarifier performance and increase effluent turbidity. Clarifier performance as a function of PAC dose is presented in Figure 10. The chart indicates that clarifier performance varies largely, independent of PAC dose.

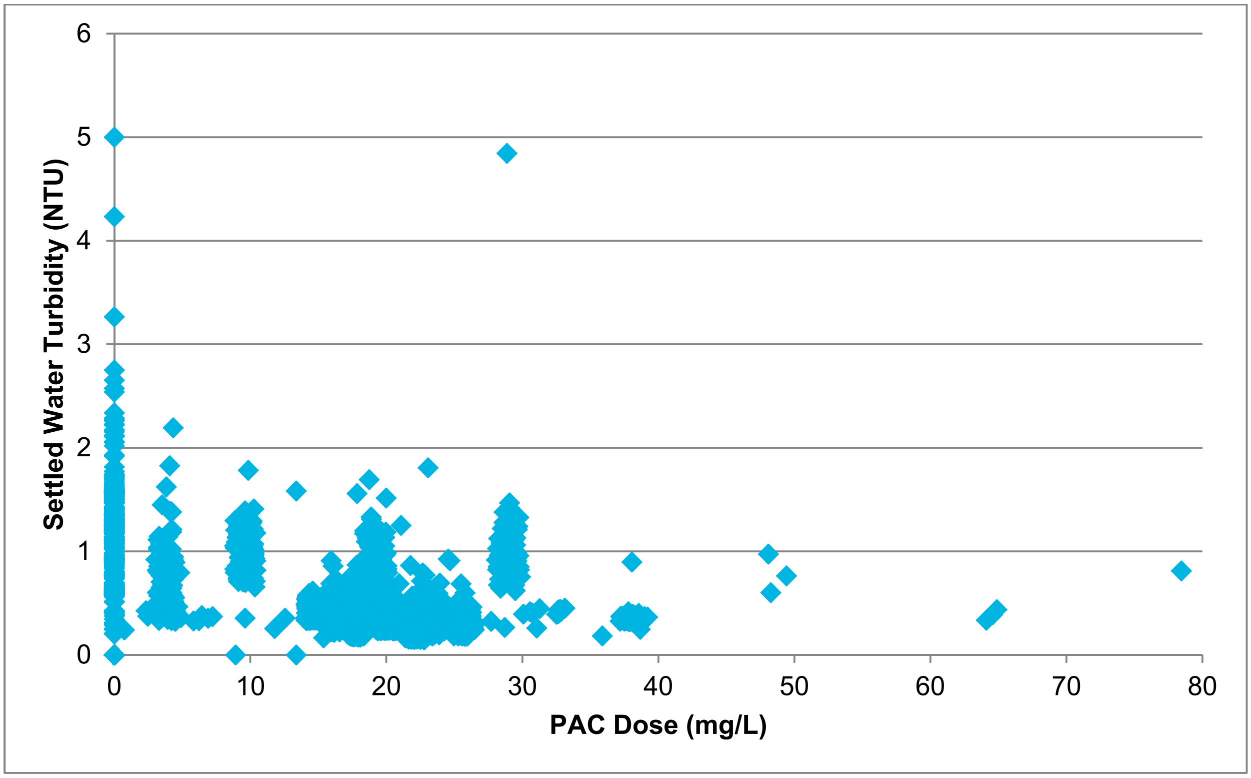

Figure 10. 2016 Clarifier Performance versus PAC Usage

2.4 Clarification Process Demonstrated Capacity

Based on this analysis, the clarification system works at the WBWTP were found to be appropriately sized for the current production and regulatory requirements, and are consistent with industry standards. While there are operational challenges with the current configuration of the clarification process, there are planned changes at the WBWTP that are anticipated to improve the performance of the clarification process.

3. Membranes

The membrane filtration system includes eight immersed membrane filtration tanks, designed to provide filtration of the clarified water. The original system design allowed for seven of the eight membrane trains to operate as primary (or first stage) membrane filtration, designed to directly filter clarified water to produce permeate. The remaining train was intended in the original design to be a secondary (second stage) membrane filtration system, designed to handle the reject stream from the seven primary trains to further concentrate the waste prior to lagoon discharge.

It is understood that early in the operating life of the plant, productivity issues were experienced with the membrane filtration systems, such that Thornton struggled to meet production demands with the seven primary trains, and eventually the secondary train was re-configured to operate as a primary train.

3.1 System Components

The membrane system as a whole comprises a number of sub-systems, including the membrane tanks themselves, but also a number of ancillary systems including vacuum pumps, facilities for backpulsing of the membranes, blowers for assisting in the membrane cleaning, CIP systems for periodic chemical cleans of the membranes, and chemical storage and dosing systems specific to the membranes. Table 13 and Table 14 describe the key design criteria for each of these systems.

Table 13. Process Summary – Membrane Filtration Trains

Parameter	Value
Membrane Filters	
Type	Immersed, Hollow Fibers Ultrafiltration
Number	8 total: • 7 primary trains • 1 secondary train as originally designed, then subsequently modified to operate as a primary train
Manufacturer	Suez[1]
Membrane Module Type	Suez ZW-500D PVDF Hollow Fiber Ultrafiltration
Rated Capacity, each train	8.01 mgd at 1ºC
Capacity (mgd total)	Firm capacity of 48.1 mgd firm capacity as permeate with one train out of service (N+1 design)[5]
Minimum Recovery[6]	<95%
Modules per Cassette	Train #1: 60 x ZW-500D-340 Trains #2-7: 50 x ZW-500D-440 Train #8: 50 x ZW-500D-440
Cassettes per Train:	Train #1: 10 Trains #2-7: 10 Train #8: 5
Modules per Train	Train #1: 600 Trains #2-7: 500 Train #8: 250
Membrane Area per Train	Train #1: 204,000 ft^2 Trains #2-7: 220,000 ft^2 Train #8: 110,000 ft^2
Design Flux (gfd)	34 gfd at 1ºC 60 gfd at 20 ºC
Maximum Transmembrane Pressure (TMP) (psi)	10
Absolute Pore Size (um)	0.1
Nominal Pore Size (um)	0.04
Log removal credits	Giardia Lamblia cysts: 3-log (99.9%) Cryptosporidium oocysts: 3-log (99.9%)
Surface Properties	Non-Ionic and Hydrophilic
Fiber Diameter (mm)	1.9 OD / 0.8 ID
Flow Path	Outside – In

[1]The firm capacity is somewhat unclear, as re-purposing of the secondary train as a primary train likely was not intended to raise capacity but to allow the system as a whole to operate at a lower flux.

[6] The original design recovery was set at 95.7% based on using Train 8 as a secondary treatment. With Train 8 converted to Primary train, recovery would be anticipated to be less. Thornton has reported recovery at approximately 92%.

Parameter	Value
TMP Range (psi)	-13 to 13
Maximum Operating Temperature (F)	104
Operating pH Range	5.0 – 9.5
Maximum Cleaning Temperature (F)	104
Cleaning pH Range	2.0 – 10.5
Recommended CIP Frequency (days between cycles)	30
Maximum Cl_2 Concentration (ppm)	1000
Certification	NSF 61

[1]Membranes were originally by Zenon, who was subsequently acquired by General Electric, then Suez.

Table 14. Process Summary – Membrane Filtration Ancillaries

Parameter	Primary Stage	Secondary Stage
Permeate Pumps		
Type	Horizontal End Suction Centrifugal	
Number	7 (1 per Train 1-7)	1 (Train 8)
Capacity (gpm each)	5,660	1,785
Total Dynamic Head (ft)	31.5	31.5
Motor Horsepower (hp)	30	10
Blowers		
Type	Multistage Centrifugal	
Number	3	2
Capacity	1984	945
Backpulse Tank		
Volume (gal)	34,000	
Reject Pumps		
Type	Horizontal End Suction Centrifugal	
Number	2	
Capacity (gpm each)	2740	
Total Dynamic Head (ft)	31	
CIP Pump		
Type	Horizontal End Suction Centrifugal	
Number	2	
Capacity (gpm)	310	
Pressure (ft)	52	
Motor Horsepower (hp)	15	

Parameter	Primary Stage	Secondary Stage
CIP System		
Number	2	
Storage, each (gal)	8000	
Chemical System	• Citric acid • Sodium bisulfite • Sodium hypochlorite • Sodium hydroxide	

3.2 Performance and Capacity Analysis

The membrane systems have been subjected to a number of studies over the years to assess, troubleshoot, and identify solutions to the known fouling issues with the membranes. The following documents paid particular attention to membrane performance and fouling issues:

- Wes Brown WTP Operations Study – Final Report, CH2-Hill, July 11th, 2014
- Ultrafiltration Fiber Analysis Report, Avista Technologies, October 7th, 2016

These issues are understood to have persisted from the first days of plant operation and continue to the present day. Specific findings of the studies were as follows:

- Surging issues were experienced with the membrane permeate pumps during cold weather conditions. It is believed that this surging was a result of increased levels of dissolved air in the cold water causing higher TMP. It was suspected that other issues also contributed to this issue, notably suspected piping leaks, which may have allowed the ingress of air, as well as insufficient air venting at the air separation tanks during permeate pump priming.
- Membrane autopsy studies conducted by Avista appear to indicate that the fouling on the membranes was predominantly iron based. The CH2M-Hill work also asserted that recycling of the cleaning wastes to the head of the plant may contribute to organic fouling, although the specific testing conducted by Avista did not indicate this to be the case, as minimal organic foulants were observed on the membranes.

Various adjustments have been made over the years to address these fouling issues through changes in the approach to membrane cleaning. These changes include:

- Modification to the use of air for membrane cleaning/scouring from continuous to intermittent operation. This change was quite common along ZeeWeed membrane plants, notably to reduce the energy cost of continual aeration of the tanks during operation.
- Reduction in the frequency of maintenance cleans from daily to 3-4 times per week. There has been discussion to eventually eliminate MC, notably due to an observation that they showed limited effectiveness in restoring TMP during operation.
- A change in recovery cleans (or CIP cycles) to increase the concentration of chemicals used. It is understood that CIPs were previous conducted without heating the CIP cleaning solutions, and that at times, only a partial CIP was done (acid only), to reduce CIP cycle times. Delivery water and chemical are now heated for cleans, but if the tank is topped off following the introduction of chemical, the additional water is not heated. In 2018, Thornton began to separate acid and hypochlorite recovery cleans and switched the order to perform acid cleaning first followed by hypochlorite cleaning. Thornton also tried an acid clean only for one month on one train and saw similar permeability to recovery to trains with both cleans done.

SCADA data at 15-minute intervals for the period July 2016 through November 2016 was provided on the operation of the membranes to allow an assessment of present day performance. Figure 11 summarizes the temperature corrected (TC) permeability data for the trains:

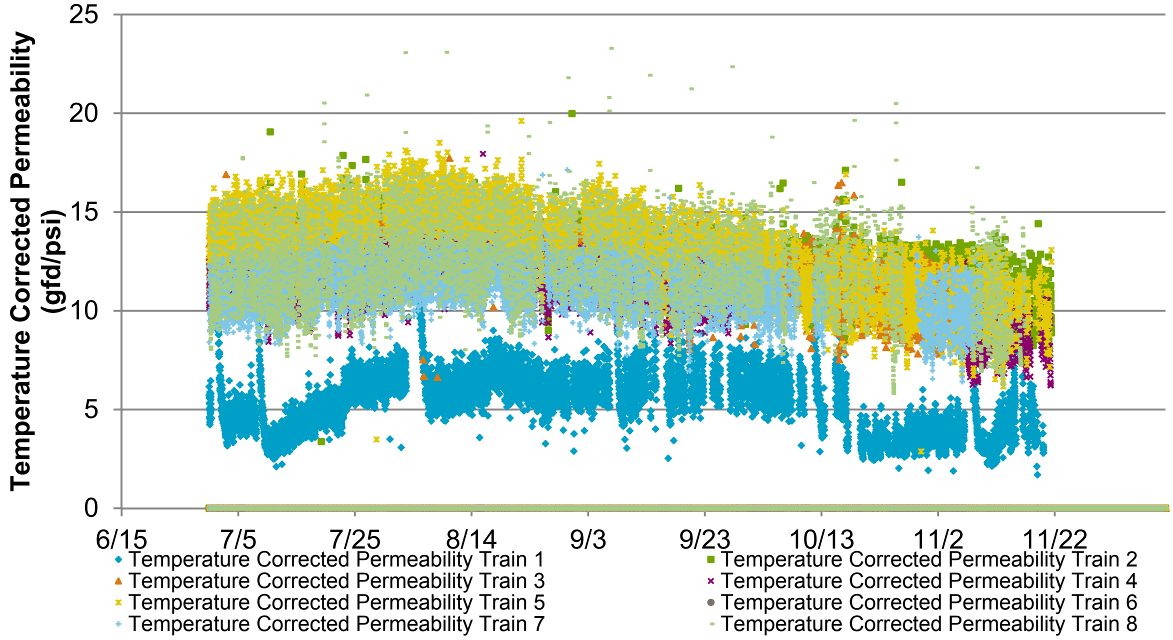

Figure 11. Temperature Corrected Permeability versus Time

Given the volume of data, the data is presented as individual graphs for each membrane train, as follows:

- Figure 12 through Figure 19 present transmembrane pressure data for Trains 1 through 8, respectively, for July through November 2016. Note that the graphs are configured to show only negative pressure data, such that only TMP data during production are shown (i.e., when the membranes are producing permeate under vacuum, and not when the membranes are under a positive TMP, during backpulsing. Train 1 shows the most significant TMP of all of the trains; the remaining basins have similar TMP performance values.
- Figure 20 through Figure 27 present TC permeability data for Trains 1 through 8 respectively for July through November 2016. Trains 1, 4, and 7 demonstrate the lowest permeability, indicating a higher degree of permanent fouling.

Table 15 summarizes the TC permeability data.

Table 15. Temperature Corrected Permeability Data (Trains 1 – 8) – July through November 2016

	Train 1	Train 2	Train 3	Train 4	Train 5	Train 6	Train 7	Train 8
Average	8.0	18.8	17.6	15.9	19.8	17.3	15.7	17.2
Max	12.8	20.0	17.7	18.0	19.6	18.6	17.1	23.3

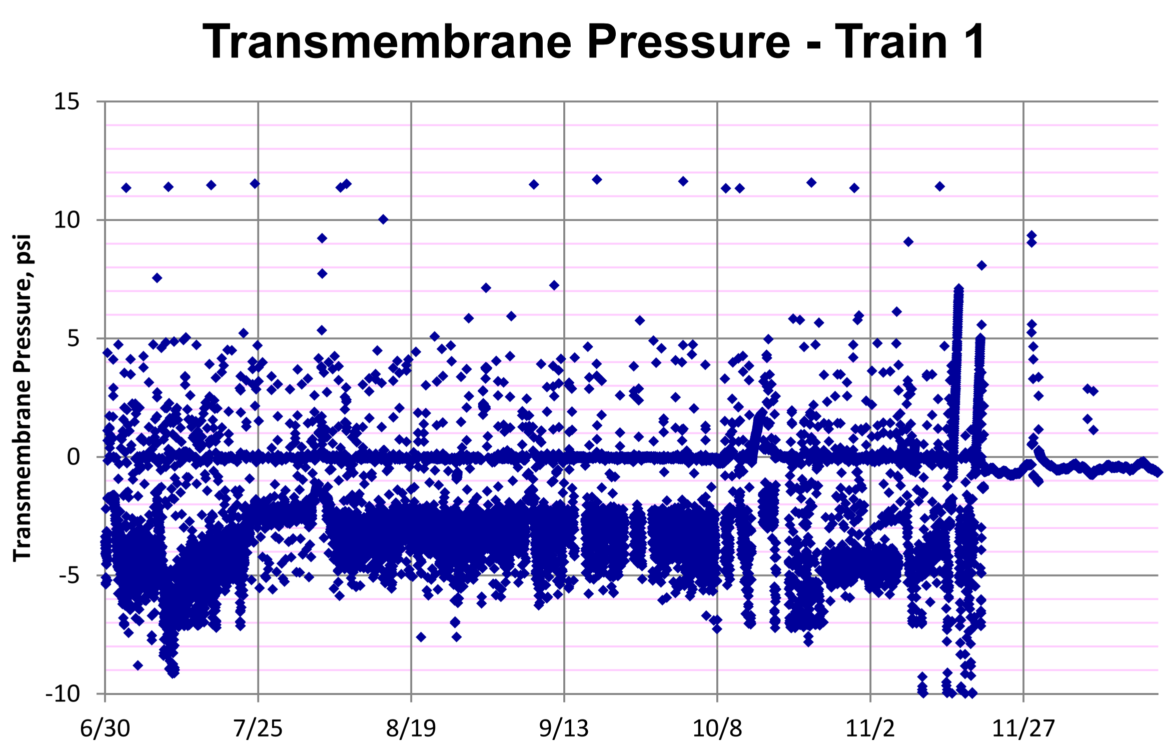

Figure 12. Train 1 Transmembrane Pressure

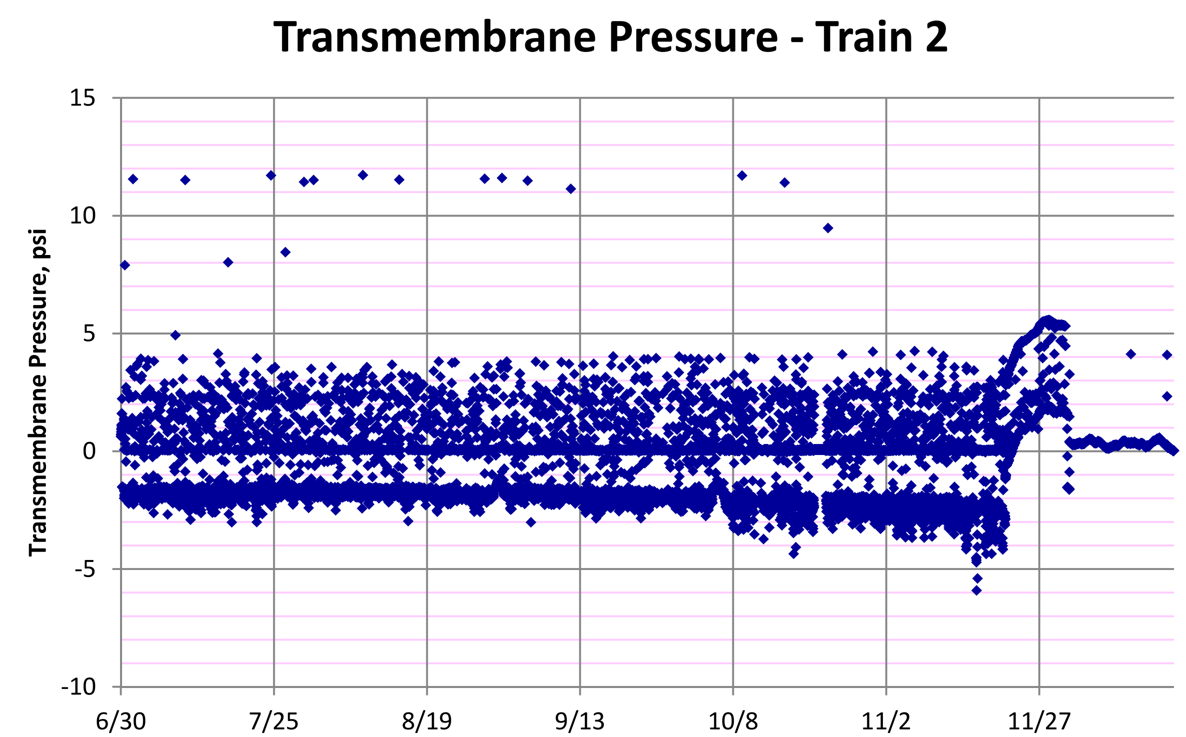

Figure 13. Train 2 Transmembrane Pressure

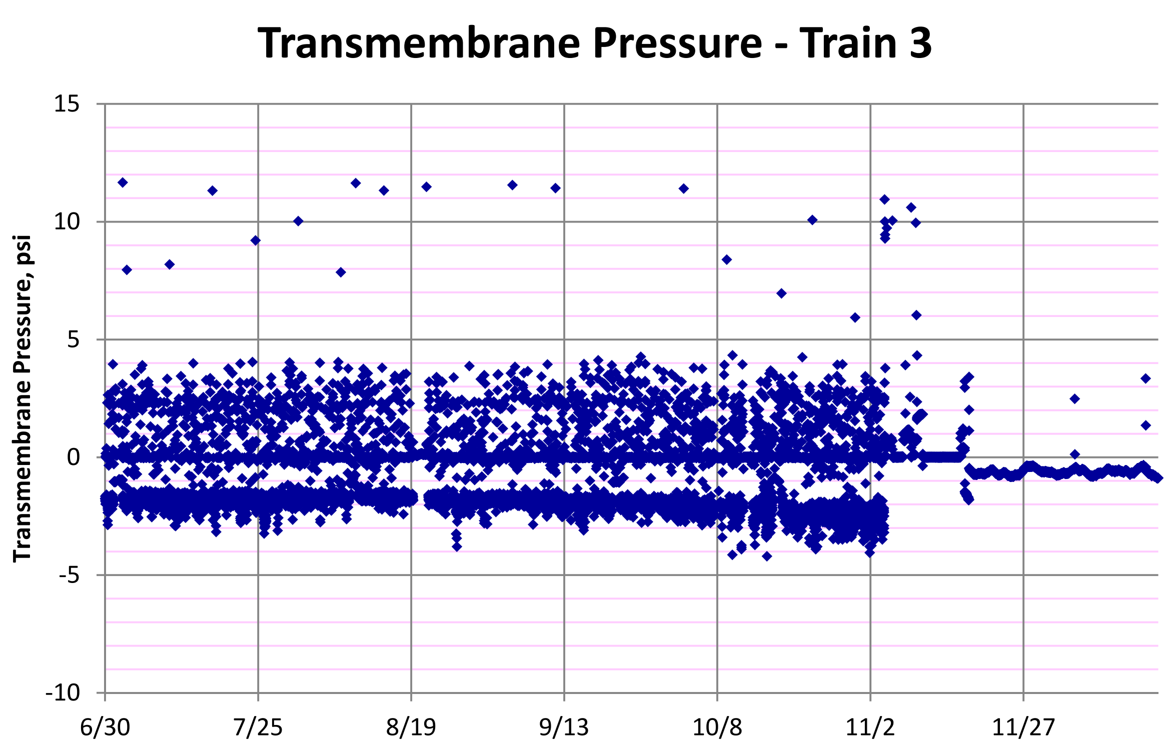

Figure 14. Train 3 Transmembrane Pressure

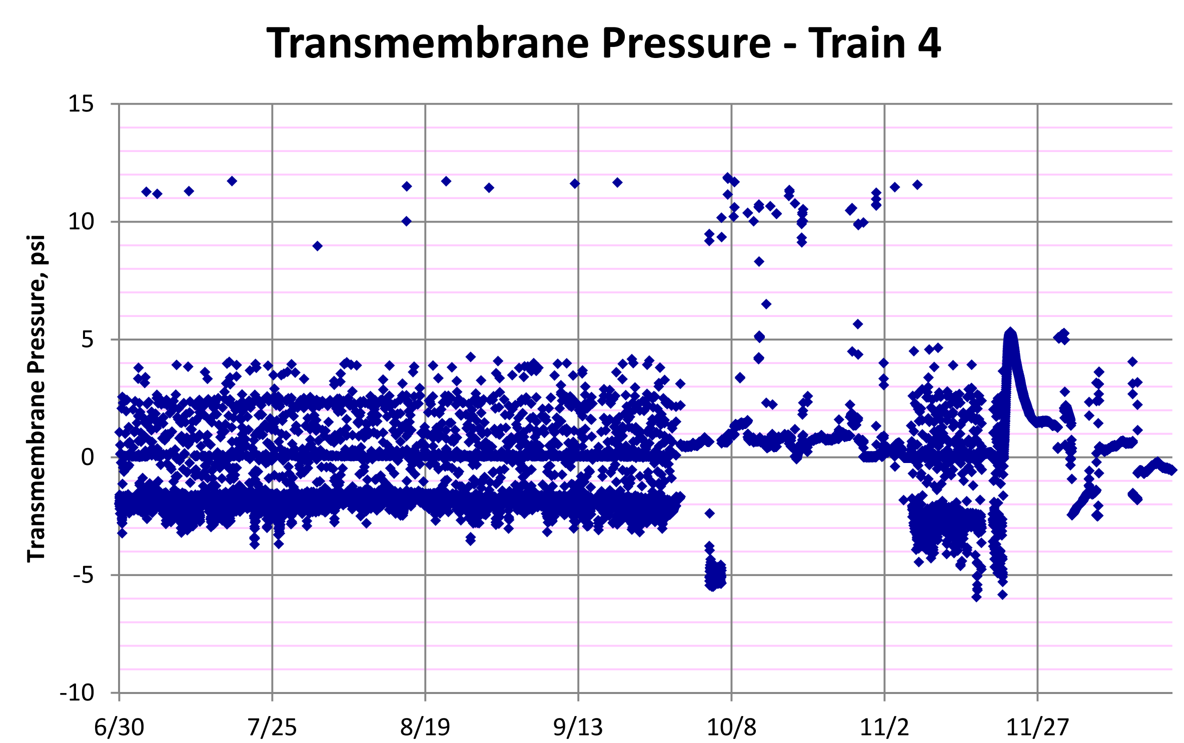

Figure 15. Train 4 Transmembrane Pressure

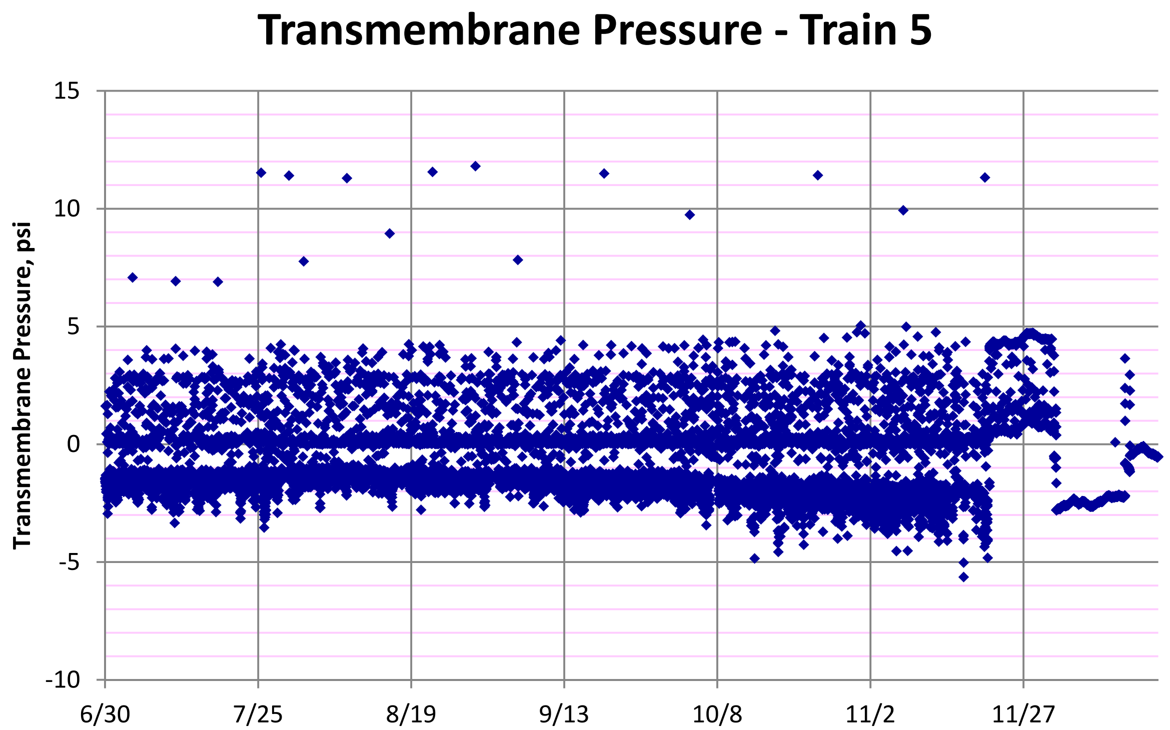

Figure 16. Train 5 Transmembrane Pressure

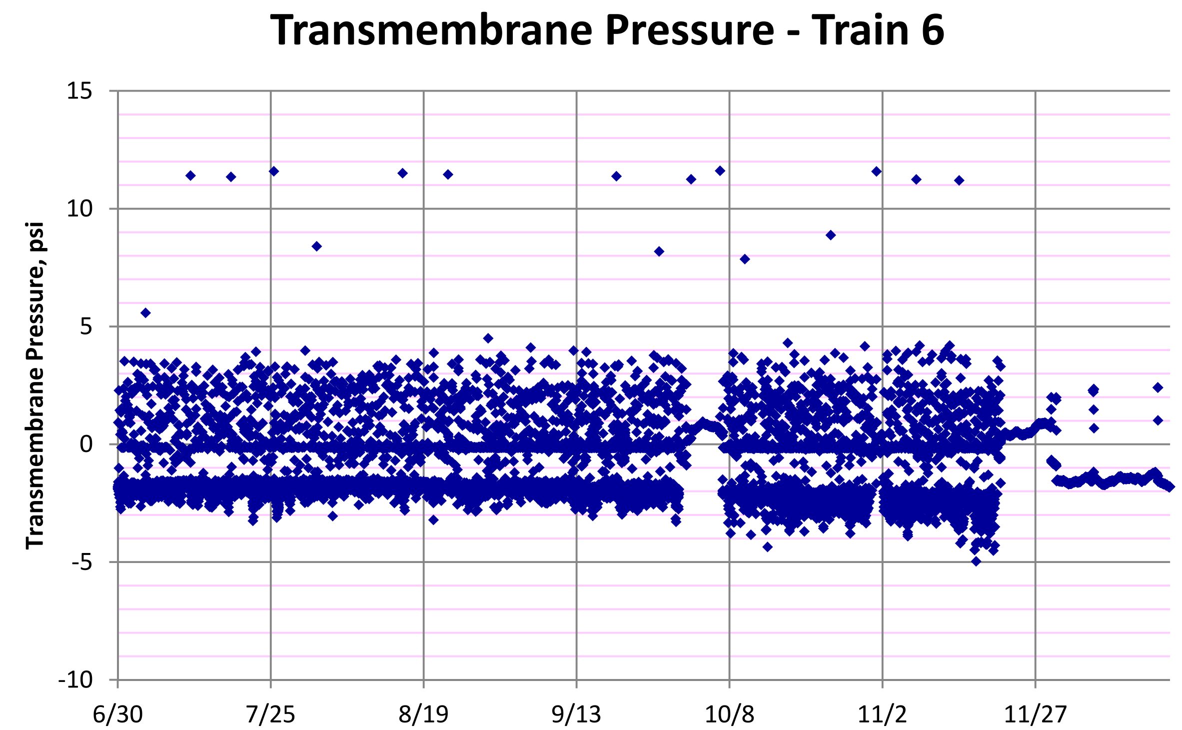

Figure 17. Train 6 Transmembrane Pressure

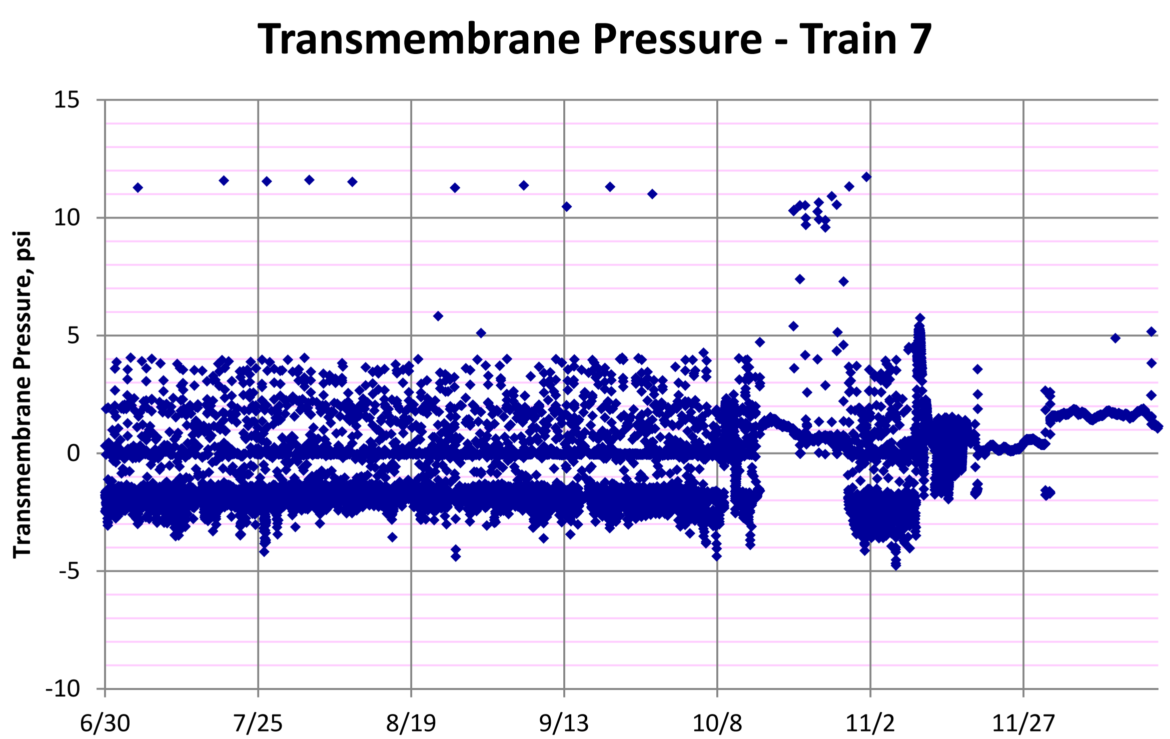

Figure 18. Train 7 Transmembrane Pressure

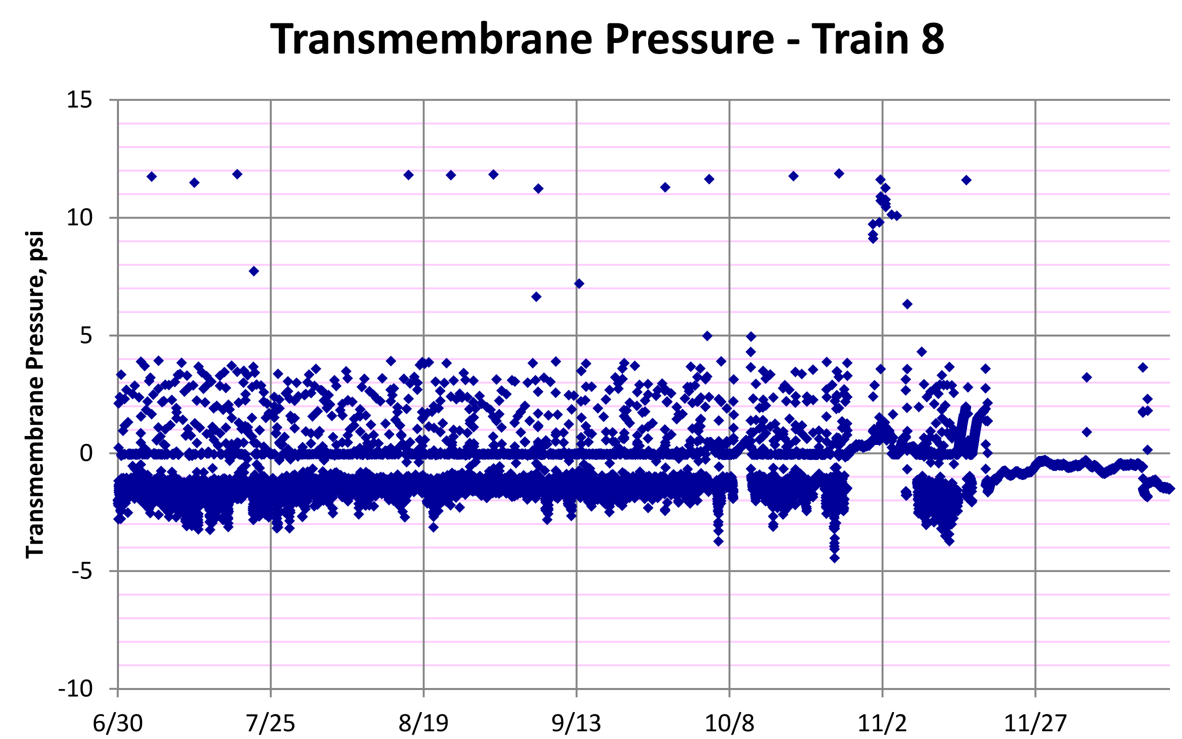

Figure 19. Train 8 Transmembrane Pressure

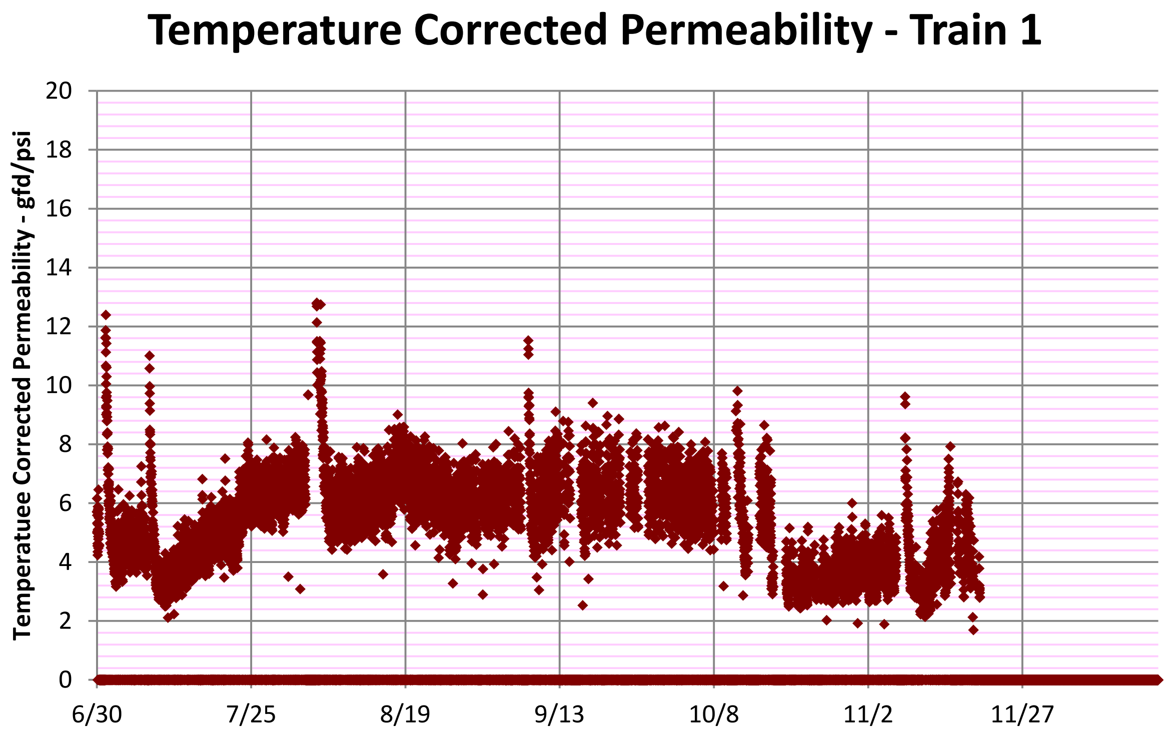

Figure 20. Train 1 Temperature Corrected Permeability

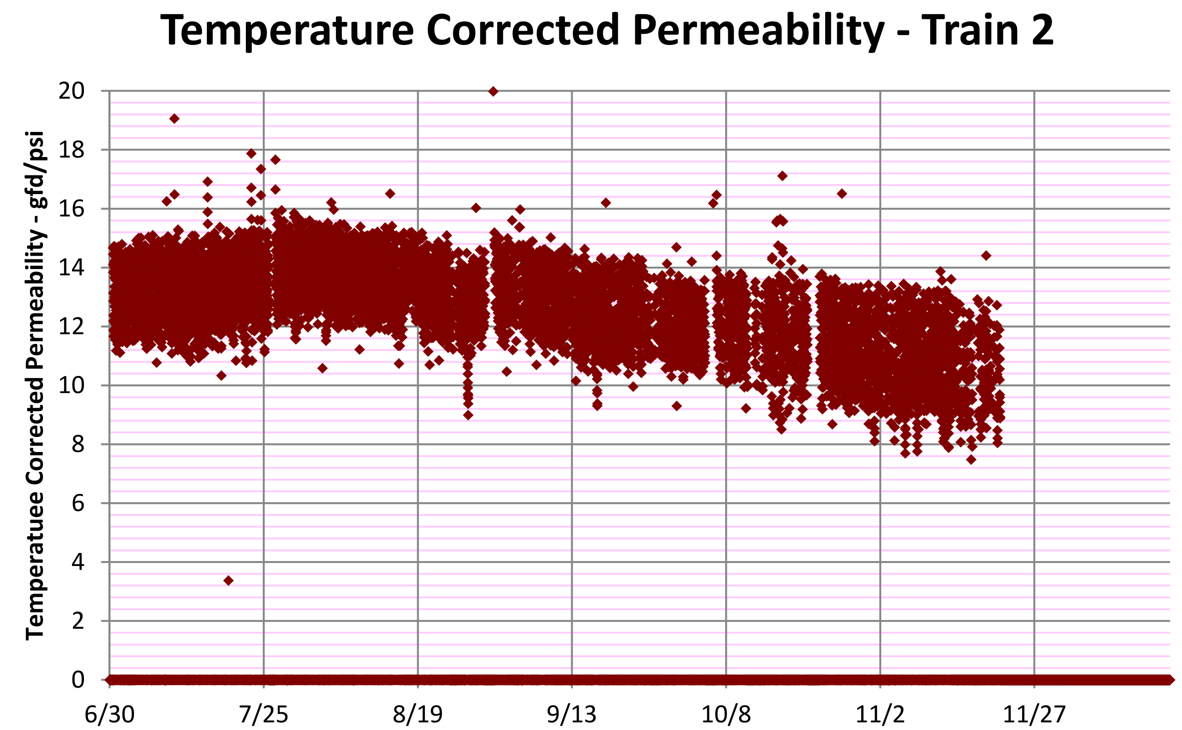

Figure 21. Train 2 Temperature Corrected Permeability

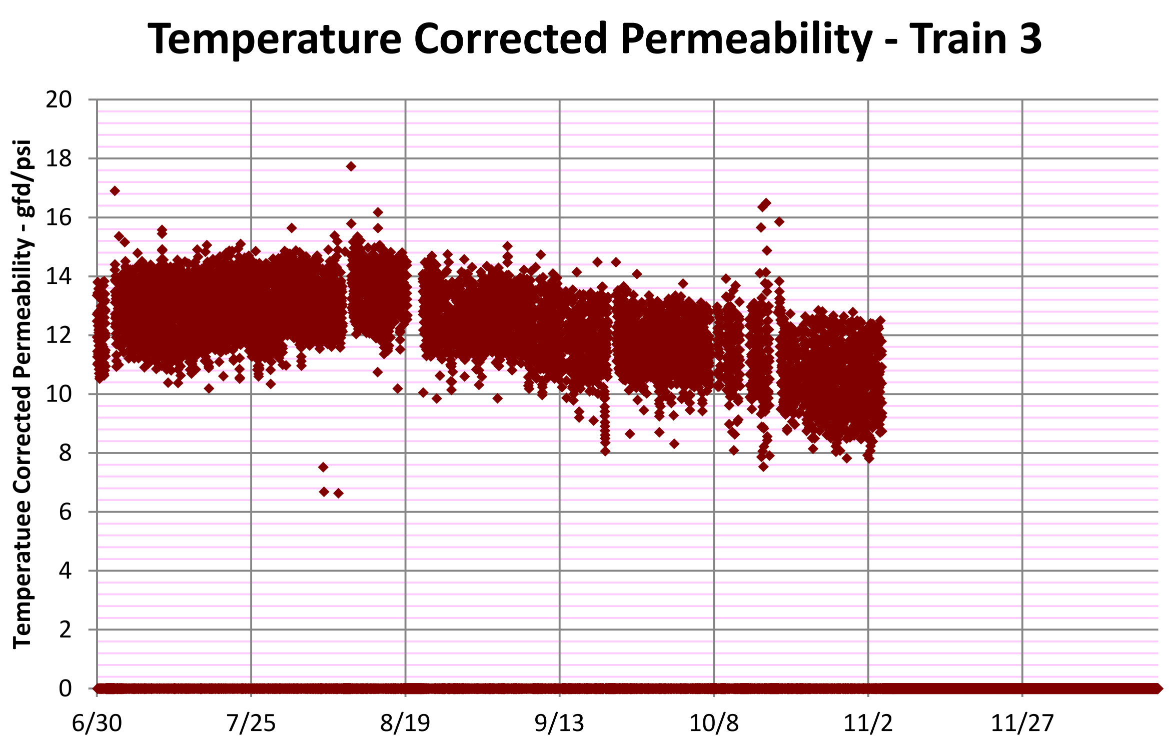

Figure 22. Train 3 Temperature Corrected Permeability

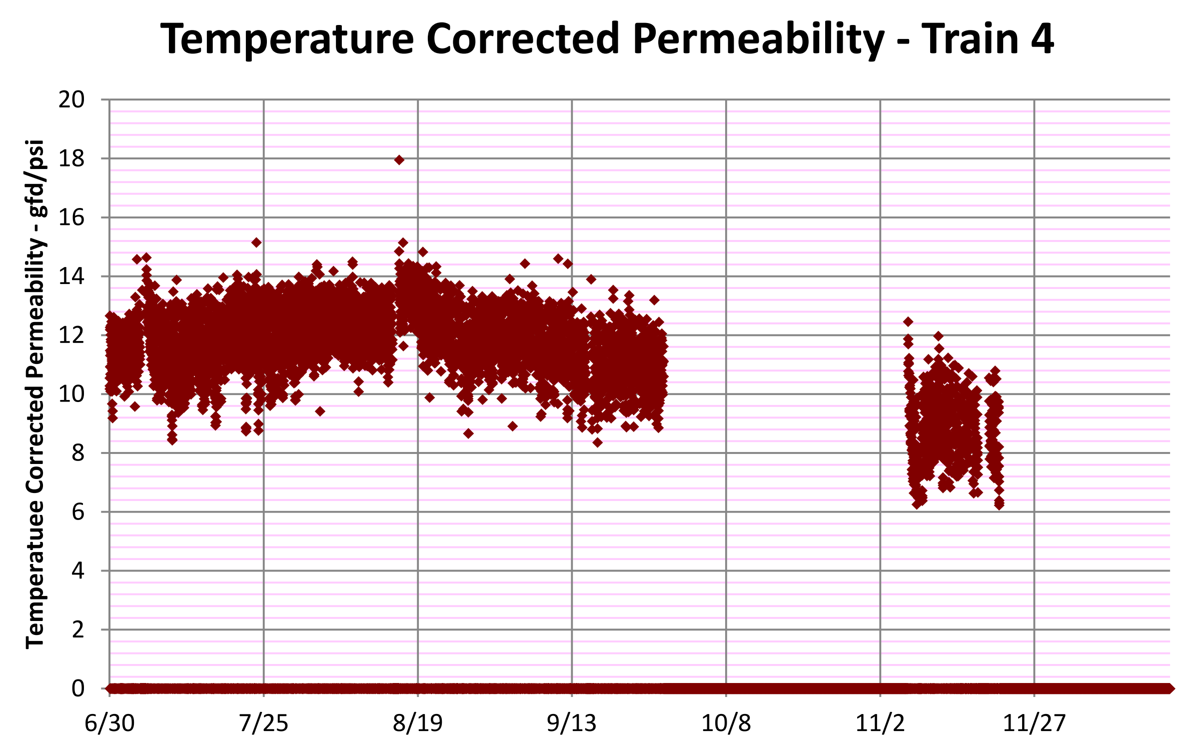

Figure 23. Train 4 Temperature Corrected Permeability

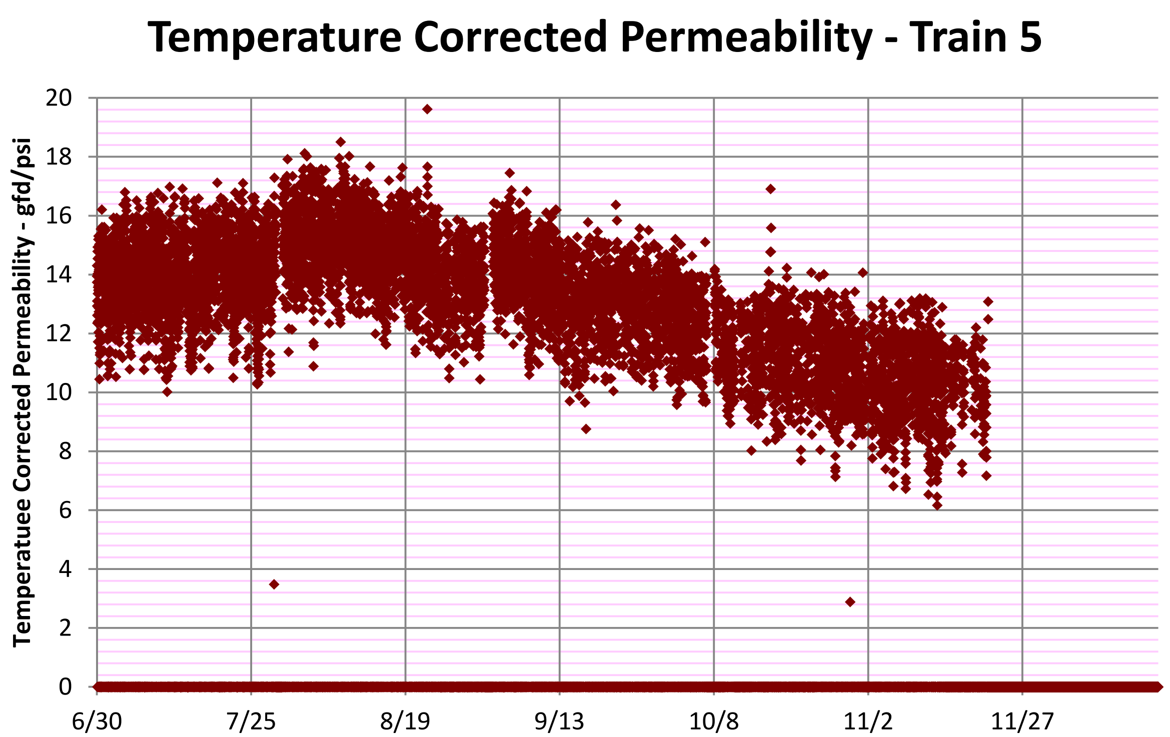

Figure 24. Train 5 Temperature Corrected Permeability

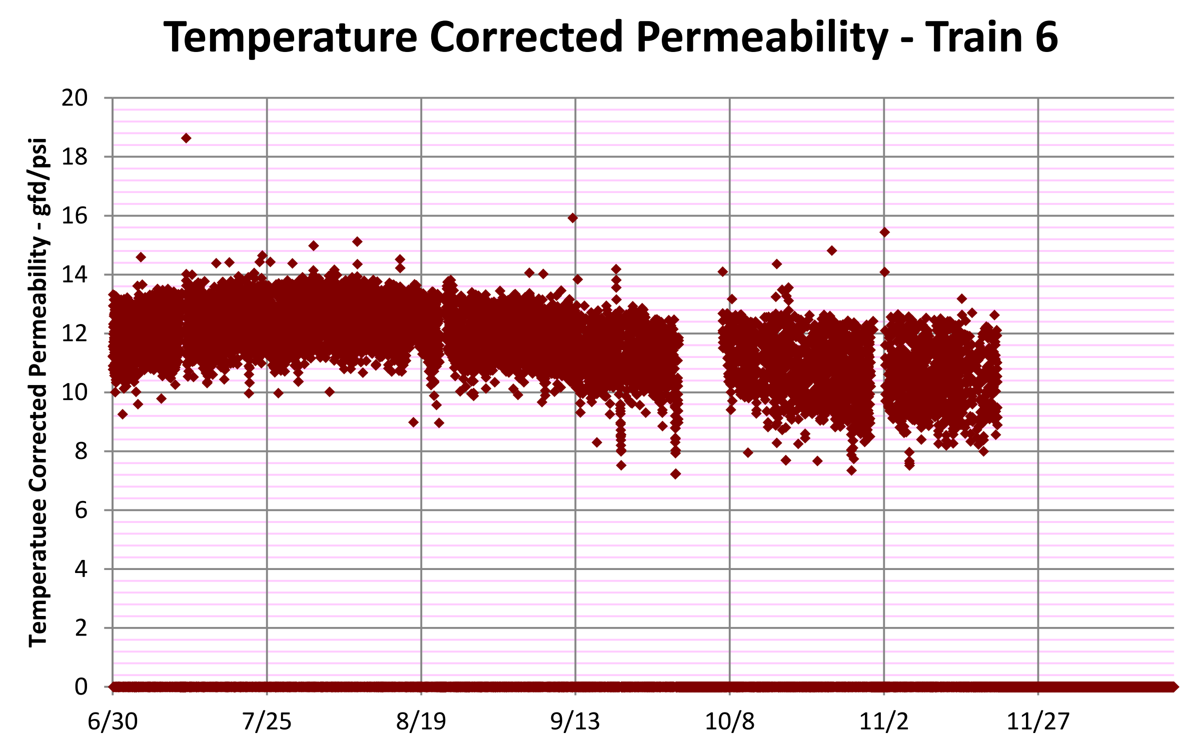

Figure 25. Train 6 Temperature Corrected Permeability

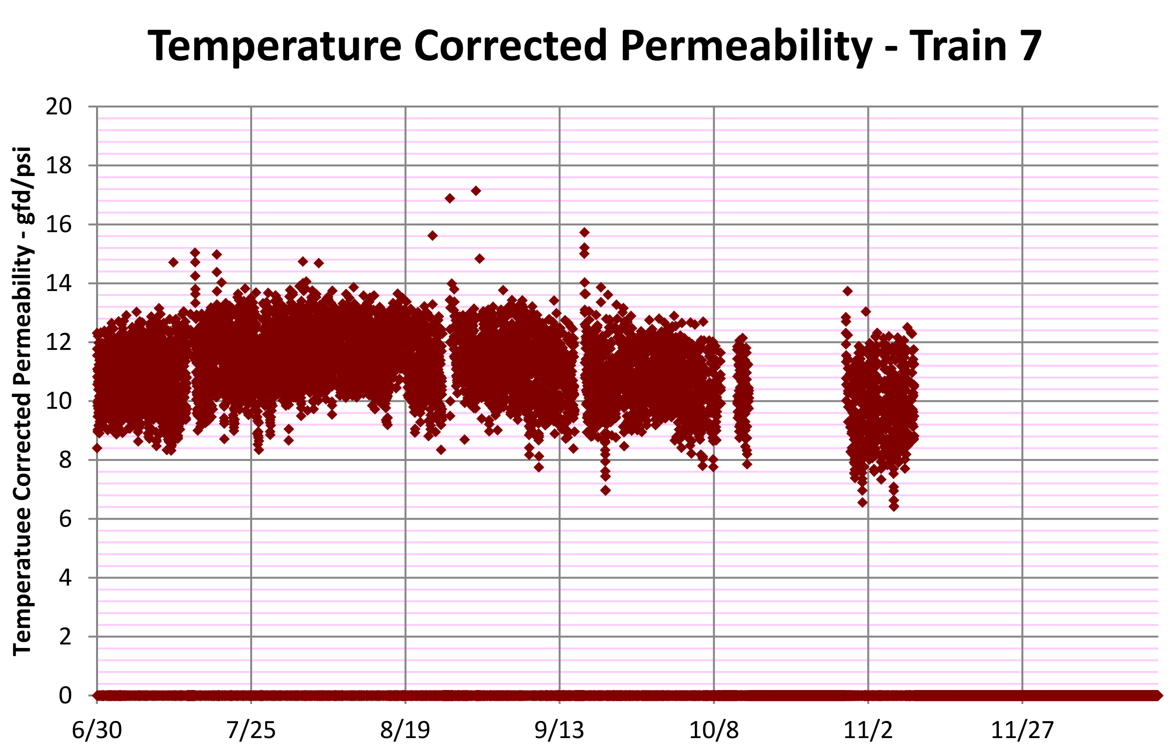

Figure 26. Train 7 Temperature Corrected Permeability

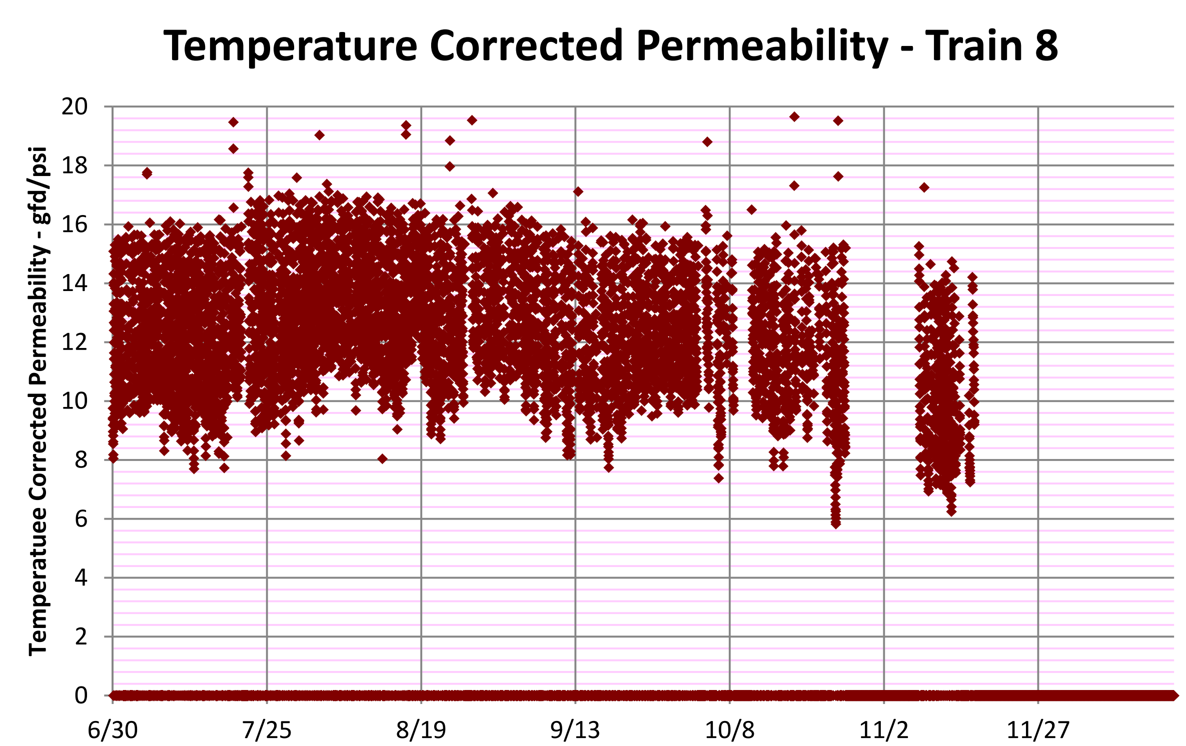

Figure 27. Train 8 Temperature Corrected Permeability

Several important observations can be drawn from these graphs, relevant to the evaluation:

- TMP on Train 1 (see Figure 12) was highly variable over the study period, ranging approximately across the range -2 to -10 psi. TMP typically was approximately -2 psi after a backpulse, or maintenance clean, and typically increased to -6 to -7 psi prior to the next backpulse/maintenance clean. TC permeability for Train 1 was also markedly lower than other trains, indicating that the membranes in Train 1 are in a particularly fouled state;
- Trains 2 through 8 all show a gradual increase in maximum TMP across the study period, indicating that the membranes are becoming progressively more fouled over the 6-month period;
- Trains 2 through 8 all show a markedly higher TC permeability than Train 1, but all exhibit permeabilities that would still be considered indicative of fouling on the membranes. In all cases, a gradual decline in TC permeability occurred during August through November, also indicating fouling on the membranes. Avista undertook single fiber cleaning experiments during their membrane autopsy work, testing membranes from Trains 1, 5, and 7. TC permeability for fibers from Train 1 were increased from 11.5 to 16.4 gfd/psi, while Trains 5 and 7 fibers showed increases from 18.1 to 22.2 and from 17.7 to 21.1 gfd/psi, respectively. The average TC permeabilities in 2016 were consistently markedly less than the values seen during the Avista trials, implying that the permeability decline is steady over time.
- The fibers used in the Avista trials for Train 1 exhibited significantly lower TC permeability than the fibers from Trains 5 and 7, again implying that fouling is particularly pronounced on Train 1.[7]

When these operational data are taken against a broader backdrop of how the plant is designed and operated as a whole, a number of plausible factors that may contribute to the overall fouling effect on the membranes become evident. Although the Avista work appears to have suggested that iron was the predominant foulant, it does not preclude other foulants being a factor in the overall fouling of the membranes. These plausible factors are presented and discussed below.

3.3 Known Operational or Maintenance Challenges

3.3.1 Membrane Design Flux

The ZW500D membranes were designed for a design flux of 34 gfd at 1 °C, and 60 gfd at 20 °C. Since the membrane plant is only part of an overall plant rated for approximately 50 MGD, including pre-treatment, it is impractical to operate the membranes at 60 gfd during warm weather conditions, as this would require operation of the pre-treatment process well beyond its design capacity. For all intents and purposes, the controlling design parameter is the winter design flux of 34 gfd at 1°C. This design flux was established to allow the production of 48.1 MGD of permeate with six of the seven original primary trains (Trains 1 through 7) in service to allow the plant to operate at its full rated capacity during the winter.

This is not to imply that the membranes will always operate at this flux; rather, that the membranes would need to operate at 34 gfd only when the plant is operating at full capacity when the water is at its coldest. During normal operation, membrane flux would vary routinely, as plant production levels vary, and if one or more trains are removed from service for backpulsing or maintenance.

Factors typically considered in the selection of the design flux for a particular design, include:

- Raw water quality. Notably, the seasonal variability in source water quality, and particularly the presence of possible foulants, including natural organic matter, algae, iron and manganese, and silica.
- Extent and type of pre-treatment. Since the pre-treatment process will attenuate variability in source water quality, this will generally improve the water quality actually fed to the membranes. Ideally, pre-treatment processes will particularly target the removal of potential foulants.

[7] The membranes in Train 1, 5, and 7 have been in service for different operational periods (Train 1: 6.5 years; Train 5: 4 years; Train 7: 4.5 years), which also contributes to the higher fouling observed in Train 1

- Chemicals used in pre-treatment. Chemicals used upstream of the membranes may have either a beneficial or a detrimental effect.
- Raw water temperature and its relation to seasonal demand. Since water is more dense and viscose under cold conditions, cold water membrane operations are generally more challenging and energy intensive. However, many plants typically experience lower demands during the winter months, and often this allows a lower design flux to be adopted in the winter months, as it is not necessary for the plant to run at full capacity.
- The use of pilot testing during design to prove sustainable design flux. In the absence of such data, or if the pilot testing period is short due to project or budget constraints, a conservative design flux is often employed.

Taking these considerations into account for the WBWTP, it is our opinion that the design flux adopted for the plant is abnormally high for a source of this nature. To substantiate this assertion, Table 16 documents known design flux for a number of ZeeWeed membrane plants.

Table 16. Design Flux for a Number of ZeeWeed Membrane Plants[8]

Plant	Client	Membrane Type	Instantaneous Flux	Notes
Lorne Park WTP	Mississauga	ZW1000V3	35.3 gfd @ 2°C	Direct membrane filtration of a high quality source (no coagulation)
David St WTP	Sudbury	ZW1000 V2 (primary treatment)	16 gfd @ 10°C @ 40 ML/D & 14.3 gfd @0.5°C	Good quality lake source with some iron and manganese. Direct membrane filtration with pre-oxidation
Tony Agnello WTP	Parry Sound	ZW500b	40 – 45 gfd @ 20°C	Direct membrane filtration of a high quality lake source
Long Sault & Ingleside Regional Water Plant	Township of South Stormont	ZW1000V2	30 gfd	Direct membrane filtration of the St. Lawrence River
Fairfield WTP	Loyalist Township	ZW500a	40 gfd at 20°C	Direct membrane filtration of Lake Ontario (high quality source)
Raymond A. Barker Ultrafiltration WTP	Town of Collingwood	ZW500a	20 to 24 gfd @ 2°C	Direct membrane filtration of a high quality source (no coagulation)
		ZW500b	27 gfd @ 2°C	Direct membrane filtration of a high quality source (no coagulation)
		ZW1000V1	13 gfd @2°C	Direct membrane filtration of a high quality source (no coagulation)
Port Hope WTP	Municipality of Port Hope	ZW1000V2	24.4 gfd @ 0.5°C	
Taunton River Desalination Plant	Taunton, MA	ZW500D	22 gfd, design temperature unknown	Coagulation-membrane filtration of a tidal estuary source
Carroll County WTP	Carroll County, MD	ZW1000	28 gfd at 5°C	Cranberry Reservoir
South Norwalk Electric & Water	Wilton, CT	ZW500D	30 gfd at 15°C, 20 gfd at 5°C	Unknown

[8] While the data presented in this table is for direct filtration plants, the information is applicable to plants using clarification processes, assuming the settled water meets the membrane supplier's influent standards.

All of these plants, with the exception of the Lorne Park Water Treatment Plant, have a design flux markedly lower than that used for the WBWTP, despite the fact that many of them draw on high quality sources, with low turbidity and raw water organics.

The high flux used in the design of the WBWTP may be a contributing factor in the longstanding performance and fouling issues with the plant, particularly due to the nature of the source water supplied to the WBWTP. Ongoing operation at higher flux, particularly when the source water contains known foulants, will generally increase the stress placed on the membranes over their lives, and will generally accelerate fouling and increase cleaning requirements. Analysis of a sustainable flux value and the associated implications to the WBWTP capacity will be included as part of the future alternatives analysis.

3.3.2 Pre-Treatment Process

The conventional pre-treatment process used at the WBWTP is relatively unorthodox for a membrane filtration plant, in that ferric chloride is used as the coagulant. While ferric coagulants generally perform well for organics removal, it is highly unusual for iron based coagulants to be used for membrane plants, largely due to fouling considerations. This may be particularly significant as many commercially available ferric coagulants have comparatively high concentrations of manganese as a contaminant, which can further exacerbate fouling if it reaches the membranes. ACH is generally the coagulant preferred for ZeeWeed membrane plants.

While effective coagulation and flocculation would normally be expected to result in the precipitation of the bulk of the iron as ferric hydroxide precipitate, which should then be physically removed in the sedimentation basins, there are some key characteristics of the design of the pre-treatment systems at WBWTP that may result in iron carryover to the membranes:

- The flash mixing system uses an induction mixer, with coagulant dosed upstream of the mixer, but this arrangement has not been observed to be effective for mixing of the coagulant. Since coagulation reactions are extremely rapid, it is critical that dispersion of coagulant into the water be completed as quickly as practically possible. If mixing is ineffective, this can result in precipitation of other by-products of coagulation, which can either result in post-precipitation or dissolved iron being carried onto the membranes.
- The flash mixing system is located close to the diversion tee that feeds coagulated water to Clarifier No. 4. This likely further exacerbates this issue, and may result in maldistribution of coagulant between clarifier trains.
- Data from the plant suggest that flow distribution between the clarifiers is unequal, with Trains 1 and 2 receiving the highest flow. This can lead to overloading of one or more of the clarifiers, potentially resulting in iron floc carryover.
- The sedimentation basins are circular, center fed solids contact style clarifiers. It has been our experience that this type of clarifier can be prone to occasional hydraulic instability, again potentially resulting in floc carryover.

3.3.3 Residuals Management

It is understood that supernatant from the residual lagoons is recycled to WGL No. 1, and thereby indirectly to the head of the plant. The CH2M-Hill report has suggested that fouling rates appeared to be worse when WGL was used as the source water to the plant. The residuals management lagoons receive a variety of waste streams, including both membrane backpulse waste and clarifier sludge blowdown from the plant, but also sludge from the TWTP, as well as the membrane recovery cleaning wastes from the WBWTP. This may have important impacts on membrane fouling for a number of reasons:

- Membrane recovery cleans are specifically designed to dissolve and remove foulants from the membranes. The waste stream from these recovery cleans will predominantly contain soluble foulants known to have fouled the membranes previously. It is unlikely that significant reduction in the concentration of the foulants will occur in the lagoons, since they would not be particulate bound. As such, recycle of lagoon supernatant to the head of the plant will in effect recycle the majority of the foulants into the plant.

This not only would be expected to raise fouling potential, but over time could worsen it by increasing the overall concentration of foulants in the cycle.

- It is understood that polymers are used in the sedimentation process at TWTP. While these polymers would be expected to be largely particulate bound, some polymers can carry over in the liquid phase with the supernatant. Use of polymers upstream of membrane filtration is a common cause of membrane fouling.
- Recycling of supernatant with elevated organics to the WGL may increase the likelihood of algae proliferation. While the pre-treatment process should remove a significant portion of the algae load in the raw water, algae also have the potential to be fouling to the membranes, as algae produce natural biopolymers.

A thorough evaluation of the approach to residuals management at the plant is highly recommended to better understand potential impacts on the membranes.

3.4 Membrane Process Demonstrated Capacity

Since membranes produce water by the application of transmembrane pressure, it often is possible to meet the design capacity of a membrane plant even under fouling conditions by applying a higher TMP. However, this approach is not sustainable, as operation at ever increasing TMP results in high energy costs, increased rates of fouling, and reduced membrane life.

As such, the reliable capacity of a membrane filtration system should be measured by its ability to operate at a sustainable flux which causes fouling at a manageable rate. All membranes foul as part of their normal operation, but a sustainable operation would be one that allows cost-effective production of drinking water over at least a 10-year period without undue fouling of the membranes, or membrane replacement.

It is our opinion that the original design flux of the membrane filtration was too high and unsustainable for a raw water source with appreciable fouling potential. While it is impossible to definitively determine that “ideal” flux without more testing, we note that the examples listed in Table 16 use design fluxes in the 20 to 24 gfd range at low temperatures, which are significantly lower design fluxes than those used for the WBWTP, despite the fact that raw water quality is higher in most cases.

Using these design fluxes as a benchmark for estimating reliable capacity of the membrane filtration system, and assuming an N+1 design with one of the larger trains out of service (Trains 1 through 7), this would equate to a reliable capacity in the range of 28 to 34 MGD. This capacity would be increased to 30.5 to 36.6 MGD if Train 8 were fully populated with membranes.

4. Finished Water Management

Filtered water from membrane process is combined in a common permeate header, which is then subjected to UV disinfection, hypochlorite and ammonia addition as part of chloramination, and final pH adjustment.

Table 17 summarizes the finished water management processes. The finished water is then stored in an on-site reservoir prior to being discharged to various pressure zones as dictated by distribution requirements. Analysis of finished water pumping is covered in the distribution segment of the UMP.

Table 17. Finished Water Management Processes

Treatment Processes	Treatment Approach	Dose Location
UV	Exposure of the water to ultraviolet light to effect disinfection	Inline reactors on the membrane permeate; the system is currently offline
Chlorine Feed	Addition of sodium hypochlorite to achieve a chlorine residual for distribution	In the piping downstream of the UV reactors prior to the contact chamber
Chloramination via Ammonia Feed	Addition of aqueous ammonia to reactor with hypochlorite to produce monochloramine	Contact chamber immediately upstream of the finished water reservoir
pH Adjustment	Adjustment of pH to meet target distribution system conditions	Downstream of the UV reactors and upstream of the on-site treated water reservoir

4.1 UV

The UV system is not required for disinfection and is currently decommissioned. Due to the lack of performance data, it has been excluded from this analysis.

4.2 Chlorine Feed

4.2.1 System Components

The WBWTP has a five pumps associated with the chlorine feed system (two pumps each for pre- and post-filtration chlorination points plus one pump for the membrane cleans), which can discharge to multiple locations. Details for the chlorine feed equipment were presented in Section 1.3.

4.2.2 Performance and Capacity Analysis

Figure 28 summarizes chlorine residual as reported by online instrumentation at the finished water.

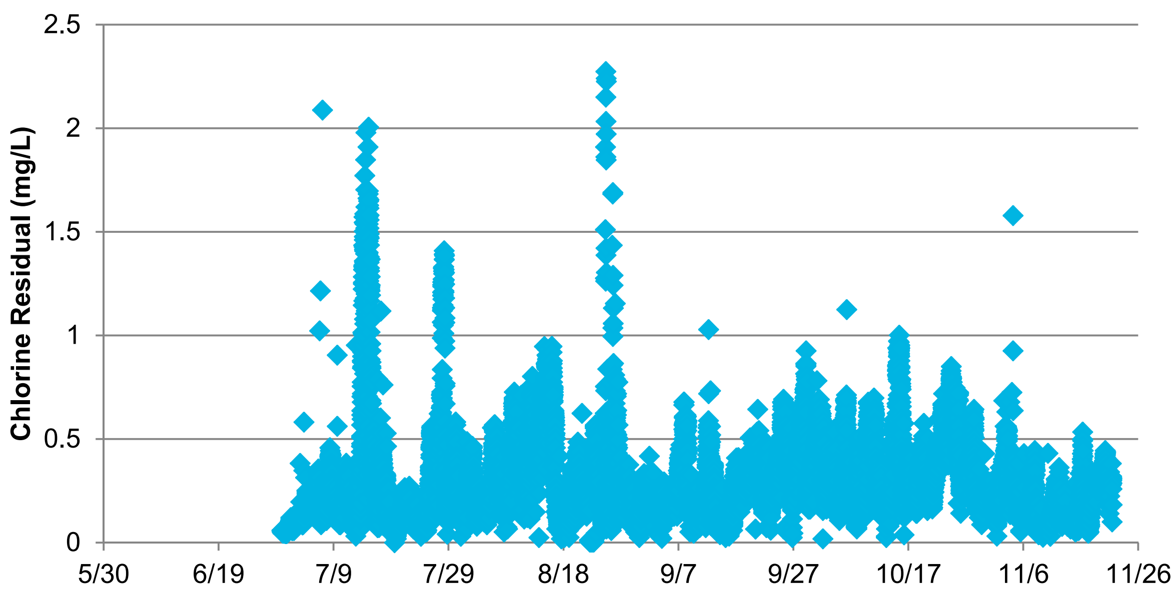

Figure 28. Finished Water Chlorine Residual

The assumption is that the primary chlorine demand is consumed as part of the inlet works disinfection, so chlorine dosing at the finished water location is primarily for chloramination. Equal molar ratios of hypochlorite and ammonia are required to produce monochloramine, which translates to approximately 3 mg/L of free chlorine per mg/L of ammonia on a mass basis to result in an equivalent mass of chloramine. Therefore, for a target distribution chloramine residual of 0.5-1.0 mg/L, finished water chlorine residual should be within a similar range. The data from the residual monitor indicate that concentrations are consistent with levels that would be expected to provide the necessary chlorine residual to produce monochloramine.

Since there is a design in progress to complete disinfection contact time using the finished water system, an analysis has been completed on the systems strategy to be implemented in 2019. The following assumptions were made for performance evaluation:

- The peak flow rate through the plant is equivalent to the firm capacity flow rate, which is 48.1 MGD as defined by the membrane system.
- The pH (9.0 s.u.) and temperature (0.5 °C) value used in the evaluation represent the worst case operating scenario under which the WBWTP would receive raw water or continue to release finished water to the distribution system.
- A baffle factor of 0.7 is approved by CDPHE for the modified clearwell.
- Approximately 30 percent of the chlorine injected into the clearwell is consumed prior to the residual monitoring point.

The required CT for Virus is 12 min*mg/L. Based on the assumptions outlined above, the equipment at WBWTP is adequately sized to meet the CT requirements for 4-log virus removal. However, if the 0.7 baffle factor is not approved by CDPHE, the required residual will increase. For example, if a baffle factor of 0.3 is approved, a chlorine residual of 4.46 mg/L will be required to achieve the 12 min*mg/L CT requirement. The disinfection CT is summarized in Table 18.

Table 18. Ammonia Dose vs. Time

Parameter	Value
Chlorine Disinfection – Clearwell	
CT Required for Worst Case (min*mg/L)	12
Contact Time in Clearwell (min), Adjusted to Baffle Factor	6.29
Required Chlorine Residual	1.91
Maximum Potential Chlorine Dose at Peak Day Flow (mg/L)	29.7
Target Chlorine Dose Entering the Clearwell (mg/L)	2.7

4.2.3 Known Operational or Maintenance Challenges

There were no reported operational or maintenance challenge associated with the chlorine feed as part of the finished water management.

4.2.4 Demonstrated Capacity

Based on this analysis, the finished water management systems at the WBWTP were found to be appropriately sized for the current applications and are consistent with industry standards. The modifications for application of post-filtration disinfection appears to be adequate as CDPHE has approved a 0.7 baffle factor

4.3 Ammonia Feed

4.3.1 System Components

Ammonia is received at the facility as a bulk liquid at approximately 19 to 29 percent solution strength. Key aspects of the current ammonia system are summarized in Table 19.

Table 19. Aqueous Ammonia System Summary

Parameter	Value
Chemical Tanks	
Number	1
Bulk Storage Volume (gal)	9000
Bulk Chemical Strength	19-29%
Metering Pumps	
Type	Peristaltic
Number	4
Capacity (gph)	24

4.3.2 Performance and Capacity Analysis

Table 20 summarizes the capacity analysis conducted on the aqueous ammonia system, and the ammonia dose verse time is shown in Figure 29.

Table 20. Ammonia Capacity Analysis

Parameter	Value
Dosing Location	Clearwell
Design Dosage (mg/L)	0.9
Maximum Dose at Plant Capacity (mg/L)	2.5
95th Percentile Dosage in 2016 (mg/L)	0.56
Average Dosage in 2016 (mg/L)	0.27
Treated Flow Capacity at Metering Pump Capacity and Design Dose (mgd)	138
Tank Storage Capacity at Plant Capacity at 2016 Average Dose (days)	43.2

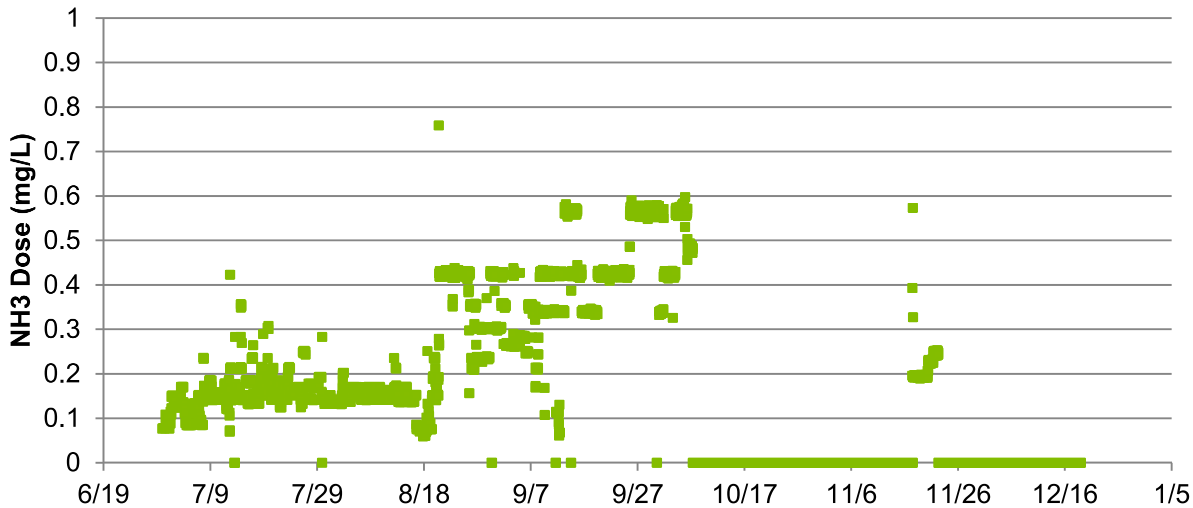

Figure 29. Ammonia Dose vs. Time

4.3.3 Known Operational or Maintenance Challenges

There were no reported operational or maintenance challenge associated with the ammonia feed as part of the finished water management.

4.3.4 Demonstrated Capacity

Based on this analysis, the ammonia feed systems as part of finished water management systems at the WBWTP were found to be appropriately sized for the current production and regulatory requirements and are consistent with industry standards.

4.4 pH Control

Sodium hydroxide and acid are available for use as required for pH control in the finished water management. Both chemicals can also be fed at the inlet works, but this is not commonly required. Sodium hydroxide is typically the only chemical used as part of the finished water management.

4.4.1 System Components

Sodium hydroxide is received at the facility as a bulk liquid, ranging from 25 to 50 percent strength. Many municipalities prefers to purchase the chemical at the higher concentration (to minimize cost), but there is potential for crystallization with high concentration sodium hydroxide at 50 °F or below.

The sodium hydroxide dosing pumps are diaphragm units that discharge to a secondary carrier water system that routes the solution to the influent pipeline. The pumps are controlled based on an operator-selectable pH and the plant flow rate. Key aspects of the sodium hydroxide system are summarized in Table 21.

Acid can be received as a bulk liquid, but it is not used at the plant for pH control. The acid dosing pumps are diaphragm units that discharge to the membrane CIP system, chemical injection manhole at the inlet works, or the finished water vault. Due to the pH depression associated with the coagulant, adding acid is not typically required; however, switching to an alternative coagulant could increase acid demand.

Key aspects of the pH control systems are summarized in Table 21.

Table 21. Sodium Hydroxide System Summary

Parameter	Value
Sodium Hydroxide Tanks	
Number	2
Bulk Storage Volume (gal)	24,000
Bulk Chemical Strength	25-50% (facility has the ability to dilute in storage tank)
Sodium Hydroxide Metering Pumps	
Type	Diaphragm
Number	3
Capacity (gph)	108
Acid Tank	
Number	2
Bulk Storage Volume (gal)	6,000
Bulk Chemical Strength	50%
Acid Metering Pumps	
Type	Diaphragm
Number	5
Capacity (gph)	632

4.4.2 Performance and Capacity analysis

Table 22 summarizes the capacity analysis conducted on the sodium hydroxide system. There was no significant recorded usage of the acid system as part of normal water production, and as such there is no performance data to identify.

Table 22. Sodium Hydroxide System Capacity Analysis

Parameter	Sodium Hydroxide Value	HCl Acid System Value
Dosing Location	Inlet Works Pipeline[1] Finished Water Vault	Inlet Works Pipeline[2] Finished Water Vault[2]
Design Dosage	14	5
Maximum Dose at Plant Capacity (mg/L)	79	188
Average Dosage in 2016 (mg/L)	8	N/A
Treated Flow Capacity at Metering Pump Capacity and Design Dose (mgd)	80	N/A (pump size is significantly larger than required for treatment)
Treated Flow Capacity at Metering Pump Capacity at Average Dosage (mgd)	248	N/A (pump size is significantly larger than required for treatment)
Tank Storage Capacity (50% NaOH) at Peak Day Flow at 2016 Average Dose (days)	12	N/A (tank size is significantly larger than required for treatment)

[1]Sodium hydroxide is rarely used at the inlet.

[2]Acid is rarely used at the inlet or finished water vault.

The capacity demonstrated that the sodium hydroxide systems are adequate to deliver the required dosage without the largest feed pump in operation, demonstrating that the facilities are suitable to treat up to the plant rated capacity of 50 MGD. The tanks will provide approximately 12 days of storage at peak flow.

Evaluation of the acid systems indicates that the system is suitable to provide sufficient treatment in excess of the rated capacity of the plant.

4.4.3 Known Operational or Maintenance Challenges

4.4.3.1 Interaction with Plant Water

The sodium hydroxide system uses plant water for a carrier water system. As the plant water is high in calcium, it interacts with the high pH chemical to result in significant scaling in valves and piping. This has resulted in significant maintenance on this system. Attempts to feed neat sodium hydroxide at the application point experience significant scaling. Freezing of the solution has occurred in the past.

Additionally, the plant staff has indicated that there is a tendency for the pipeline between the membrane effluent and the clearwell to develop scale, which can negatively impact plant hydraulics. The primary cause of scaling is the use of unsoftened carrier water with the introduction of sodium hydroxide, which causes calcium carbonate scaling. Use of softened water for carrier water would be anticipated to significantly reduce the scaling potential.

4.4.4 Demonstrated Capacity

Based on this analysis, the pH management systems at the WBWTP were found to be appropriately sized for the current production and regulatory requirements and are consistent with industry standards.

We recommend that the carrier water system should be modified to include a water softener within the design to reduce maintenance. Otherwise the designs of the storage and feed pumps are consistent with industry standards and are appropriate for the application at the WBWTP.

5. Solids Management

The WBWTP manages residuals in a set of lagoons located immediately to east of the main process building. The lagoons currently receive the following streams:

- Sludge blowdown from the clarifiers
- Reject from the membranes
- Membrane maintenance and recovery cleans
- Waste sludge from the existing TWTP, which includes clarifier sludge and backwash wastes

The lagoons function to allow solids to settle and accumulate within the bottom of the lagoon, and the supernatant water is returned to WGL. Once solids reach a certain level within the lagoons, the thickened sludge is removed and sent for land application as an agricultural amendment or to landfill if high in radionuclides.

5.1 System Components

The lagoons design criteria is summarized in Table 23.

Table 23. Solids Management Summary

Residuals Processes	Value
Solids Management Process	*Lagoon*
Number	3
Length (ft)	65
Width (ft)	2699
Depth (ft)	30
Storage Volume (gal)	3,000,000 (1,000,000 per pond)
Decant Structure	Fixed Weir
Decant Discharge	West Gravel Lake

5.2 Performance and Capacity Analysis

Residuals management at WBWTP uses lagoons to promote settling and thickening of solids. All lagoons are in service normally except when completing maintenance activities. Normal operations involve decanting of free water and periodic removal of the accumulated sludge.

There is no instrumentation or regular sampling of the lagoon process, so there is limited information by which to assess performance or the rate of accumulation of solids. In 2016 the return flow from the lagoons typically represented about 20 percent of the influent to WBWTP, which is higher than the typical guidance that recycled flow should be less than 10 percent of the influent flow to a treatment plant. The capacity analysis has been performed based on data obtained from operations staff, which is summarized in Table 24.

Table 24. Lagoon Mass and Flow Balance

Parameter	Value
WBWTP Clarifiers	
2016 Blowdown (mgd)[1]	0.27
Estimated Average Solids fraction (%wt)	0.5%
WBWTP Membrane	

Parameter	Value
2016 Estimated Average Membrane Reject (mgd)[2]	2.4
Estimated Average Solids Fraction (%wt)	0.01%
WBWTP Membrane Maintenance	
Estimated CIP Return (gal/month)	128,000
Estimated Average Solids Fraction (%wt)	0.05%
TWTP Wastewater	
Estimated 2016 Blowdown (mgd)	0.5-0.8
Estimated Average Solids Fraction (%wt)	0.3%
Lagoon Decant to WGL	
Estimated Average Decant Rate (mgd)	0.7
Estimated Average Solids Fraction (%wt)	0.005%
Sludge Accumulation	
Calculated Solids Accumulation (# dry/day)	43,400
Sludge Blanket Solids (est wt%)	20%
Thickened Solids Rise Rate (in/day)	0.07

[1]Clarifier blowdown is not recorded in SCADA. Operators indicated that blowdown would occur for 3-5 minutes per cycle, with an estimated daily volume of 150,000-390,000 gallons.

[2]Membrane reject rate indicated to be 12-15% of influent, which results in a range of vary from 1.5 to 3.4 MGD.

In 2016 the WBWTP operated clarifier blowdowns based on the depth of the sludge blanket within the clarifier, which would typically increase as a function of influent turbidity and coagulant dose. Operators typically wasted solids for a 5-minute period. However, this methodology did not evaluate the conditions or actual sludge mass within the blanket, and as such there was more variability in the solids concentration and typically a lower solids weight fraction, resulting in a higher load on the clarifiers. This methodology was changed in 2017 to monitor blanket solids concentration, and blowdown was reduced to 1 minute per cycle. Both changes have resulted in significant reductions in return flow to the lagoons from the clarifiers while still capturing a similar amount of solids.

Membrane reject rates are adjusted by the WBWTP staff to manage flux rate and reduce the rate of fouling. Information from Thornton indicates that the membrane reject rate was typically 12 to 15 percent of influent flow. This is noteworthy because guidance materials from EPA's *2011 Residuals Management Technical Report* recommends that membrane reject rates should typically range between 2 and 15 percent, and WBWTP was designed for 95 percent recovery. Running at 92 percent is contributing to difficulty in meeting production in a sustainable way, as the membranes have to be operated at a higher flux to overcome the return rate.

Membrane CIP operations are based on the permeability within the individual membranes, and as such the frequency of cleaning is dependent on the amount of fouling within each train. Typically older membranes have higher permanent loss of membrane permeability. Operating older membranes at the same flux rate as newer membranes will increase the rate of fouling and have a corresponding loss of permeability. The cleaning cycle typically involves isolating a membrane train, completely draining the basin to allow for introduction of the cleaning solutions, which are circulated through the membranes for a period of time to remove foulants. The spent cleaning solutions are neutralized in the basin[9] and discharged to the lagoons.

Residuals from the TWTP include clarifier sludge blowdown, backwash wastewater, and filter to waste (filter to waste for the existing TWTP only occurs during plant start-up and involves setting up temporary piping, so it is a limited

[9] Neutralization of the cleaning fluid within the basin is not typically recommended, as it allows the foulants an opportunity to re-adhere to membrane surfaces. Neutralization of the cleaning solution would be best performed outside of the basin, with the waste fluid then sent for disposal.

activity and a small contribution to the overall waste stream). The WBWTP lagoons receive residual flow from the existing TWTP via a gravity pipeline, but there is no monitoring or flow data available.

While not part of the current lagoon loading, the new TWTP will have the same residual discharge streams as the existing TWTP and will continue to discharge to the WBWTP lagoons. Additionally, the new TWTP will be expected to operate closer to 20 mgd on a regular basis (the existing TWTP was resource limited and typically operated much below 20 mgd) and include filter-to-waste as part of normal operations. This will increase the residual flow that is processed at the WBWTP and may also contribute more solids due to the biological activity in the filters.

5.3 Known Operational or Maintenance Challenges

5.3.1 Passive Solids Management

The lagoon process is a semi-passive process that does not depend on chemical or mechanical means. As such, there are no means to encourage solids consolidation and maximize solids thickening before discharge. While there is no evidence at this time to identify a significant concern in the current operation since solids are sent for land application, the lack of solids conditioning could represent a significant higher cost if solids are forced to be sent to a landfill. Further, decant water quality to the WGL is potentially at risk due to potential disruption of the sludge layer.

Improved monitoring and active management of the solids could result in improved decant water quality and a higher weight fraction within the sludge blanket, which would result in less water being sent with solids for disposal.

5.3.2 High Fraction of Return Water in WGL

Given the contribution of wastewater from WBWTP and TWTP, the rate of return of supernatant to WGL can represent a significant fraction of the influent water to WBWTP. It has been demonstrated in multiple process studies that a high percentage of WGL water in the WBWTP influent results in a significant increase in the rate of membrane fouling.

5.3.3 Polymer Residuals

While the WBWTP does not use polymers (which is typically recommended due to the potential for fouling of membranes), the existing TWTP does use a diallyldimethylammonium chloride (DADMAC) as a coagulant aid and flocculant aid polymer. Since both of these systems discharge their wastewaters to the lagoons, it is reasonable to assume that polymer residuals are entering the influent stream to WBWTP.

5.3.4 Cycling of Treatment Byproducts

While lagoons can be effective for settable solids, other dissolved or colloidal species would be expected to return to WGL, which then would be immediately available to return to the WBWTP. This is particularly concerning for return of the membrane cleaning solution, which typically re-mobilizes foulants that have accumulated on the membranes. Return of this material to the influent source represents a direct pathway for the membranes to be re-exposed to those same foulants that were removed in the cleaning cycle.

5.3.5 Radionuclide

Sludge in the southern lagoon was found in 2016 to have levels of radionuclides above the levels that allow for land application. The WBWTP staff have investigated the issue and made the determination that the radionuclides are from naturally-occurring sources in the raw water, which can accumulate in the lagoons at a mass fraction directly proportional to the concentration in the source water. If the radionuclide in the source water continues to increase, the sludge will need to be disposed of the sludge in a landfill.

While the radionuclide issue has not been found in other lagoons as yet, it is recommended that the WBWTP actively and regularly monitor the levels within the lagoons. In the event that levels approach a critical threshold, the sludge should be evacuated to mitigate the potential for a large mass of solids becoming hazardous. In the event that a basin becomes fouled with radionuclide, temporary dewatering equipment should be used to reduce the volume of sludge that would be required to be disposed of in a landfill.

5.4 Solids Management Demonstrated Capacity

The solids management systems associated with the WBWTP were found to have sufficient hydraulic and solids storage capacity for both current and future applications and are consistent with industry standards. However, there are significant concerns regarding impacts that return water may be having on the water quality in WGL, and the current solids management practices have opportunities to be optimized. In the event that Thornton elects to change coagulants (which will eliminate the opportunity for land application), it is anticipated that there are significant opportunities for improved efficiency through modification to operational practices and through installation of additional process equipment.

To address the impacts on WGL water quality, Thornton should consider an alternative means of returning the decant water from the lagoons, potentially to a location downstream of the inlets to the WGL. A second alternative would be recommended to isolate the discharge of the TWTP wastes to a single lagoon at WBWTP, and the decant water from that lagoon could be returned downstream of the WGL. A final alternative could be to investigate a treatment system on the decant return to capture or inactivate fouling species, but there is insufficient information available at this time to identify the type of treatment that would be required.

There needs to be increased monitoring of the lagoons with respect to radionuclides, as there is limited understanding as to the causation and control of these elements. If this problem continues to worsen, waste solids may no longer be allowed to be land-applied. This would create a similar situation as would occur if there was a change in coagulant, as solids would be required to be disposed of in a landfill. Optimization of the solids management process could reduce the financial impacts of this change.

We recommend capture of the following information to better monitor the residual loading to the solids management system:

- TSS or turbidity data for the lagoons influent and effluent. It is recommended that either an influent and effluent turbidimeter should be installed for these streams, or TSS samples should be collected on a weekly basis.
- Improved flow data for decant from the lagoon to WGL. The 2016 lagoons' supernatant flow to WGL has regularly exceeded the maximum value that can be measured by the flow meter (limited to 4.6 MGD), which impacts the ability to compile an accurate flow and mass balance.
- Flow and solids data for the sludge produced at the new TWTP. If not already included in the design, we recommend that a flow meter be included for monitoring waste discharges to the WBWTP lagoons.

Water Treatment Future Alternatives Evaluation

Chapter 5

Utility Master Plan

Project No. 17-467

Water Treatment Facilities Master Plan

Water Treatment Future Alternatives Evaluation

The City of Thornton

Project number: 60560104

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List of Acronyms

°C	degree Celsius
µg/l	micrograms per liter
%	percent
ADD	average daily demand
AOP	advanced oxidation processes
CDPHE	Colorado Department of Public Health and Environment
CIP	Capital Improvement Program
EGL	East Gravel Lakes
GAC	granular activated carbon
gfd	gallons per square foot per day
gpm	gallons per minute
$KMnO_4$	potassium permanganate
Master Plan	Water Treatment Facilities Master Plan
MDD	maximum daily demand
mgd	million gallons per day
mg/l	milligram per liter
mJ/cm^2	millijoule per square centimeter
MWRD	Metropolitan Wastewater Reclamation District
NaOCl	sodium hypochlorite
NaOH	sodium hydroxide
ng/l	nanogram per liter
NTU	Nephelometric Turbidity Unit
NWTP	Northern Water Treatment Plant
O&M	operation and maintenance
PAC	powdered activated carbon
pH	alkalinity
Thornton	City of Thornton
TM	Technical Memorandum
TTP	Thornton Treatment Plant
TWTP	Thornton Water Treatment Plant
UV	Ultraviolet
WBWTP	Wes Brown Water Treatment Plant
WGL	West Gravel Lakes

1. Introduction

The intent of the Future Alternatives section of the Water Treatment Facilities Master Plan (Master Plan) is to identify and evaluate alternatives that should be considered by City of Thornton (Thornton) for improving existing treatment processes[1] with regards to water quality performance and for increasing production capacity for meeting buildout water demand requirements.

As part of the Master Plan, a Process Evaluation was previously completed to identify areas for improvements and enhancements in the current treatment facilities and operations in order to meet the System Performance Criteria identified in the June 2018 Water Treatment Facilities Master Plan Design Criteria. The Process Evaluation identified modifications to existing infrastructure necessary to address known issues that negatively impact the production capacity and water quality. The modifications have been segmented into the following primary categories:

- Process Enhancements, which identifies modifications to the Wes Brown Water Treatment Plant (WBWTP) in order to achieve improvements in water quality performance to meet the System Performance Criteria.
- Future Production Requirements, which identifies the modifications to the facility production capacity to address existing process deficiencies in order to achieve a more sustainable operation.
- Other Miscellaneous Improvements, which include work that may not directly impact production quality or quantity but have been identified as an opportunity to improvement the service life of equipment, improve operational efficiency, or reduce maintenance activities.

With regards to increasing production to meet future (buildout) water demand requirements, three alternatives were identified in conjunction with the Raw Water and Water Distribution Master Plans for evaluation, which are summarized as follows:

- Alternative 1 – Construct a new Northern Water Treatment Plant (NWTP) located in the northern portions of Thornton 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

Table 1 summarizes the production requirements for the three alternatives during maximum day demand (MDD) events. The information in the table is derived from values originally published in the Water and Wastewater Growth Master Plan developed as part of the Master Plan project. The values have been updated to reflect additional evolution of the project understanding and refinement of the quantities based on collaboration between the various segments of the Master Plan.

Table 1. Summary of Future Alternative Production Requirements

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

[1] The new Thornton Water Treatment Plant (TWTP) is currently under construction; therefore, no performance improvements were available to be evaluated. For the purposes of the Water Treatment Master Plan, it is assumed that the new TWTP is operational and capable of producing finished water consistent with the design criteria. The Process Evaluation was limited to performance of the Wes Brown Water Treatment Plant.

[2] TWTP has 30 mgd capacity during summer but this is reserved for emergency situations.

The purpose of this Technical Memorandum (TM) is to present the evaluation of the identified existing improvements to improve operations at WBWTP to meet current design conditions and future improvements necessary to meet buildout system demands. The TM is organized into five main sections:

- Section 2: Existing Facility Improvements
- Section 3: Future Treatment Requirements
- Section 4: Alternatives Development
- Section 5: Alternatives Evaluation
- Section 6: Capital Improvement Program (To Be Developed after Workshop)

2. Existing Facility Improvements

The intent of this section is to identify improvements to existing facilities to address deficiencies in treatment capabilities relative to water quality and production shortfalls (Section 2.1), interconnecting infrastructure (Section 2.2), or other miscellaneous activities (Sections 2.3 and 2.4). These elements are intended to adjust treatment capabilities to allow for full utilization of the existing production capacity meeting the performance criteria established by Thornton. Therefore these elements need to be included in capital planning as foundation elements prior to expanding production capacity.

As the existing Thornton Treatment Plant (TTP) is scheduled to be decommissioned, the improvements are focused on the WBWTP. The Performance Evaluation of WBWTP that was developed as part of the Master Plan, assessed the current processes and operations at the WBWTP in order to identify the functionality of the individual unit processes, as well as the impacts of any deficiencies on the overall production capability of the facility. This information was also used in order to establish necessary planning coordination to the raw water supply and water distribution system requirements.

Table 2 provides a summary of each unit process at the WBWTP and identifies if each meets the intended functionality to produce the targeted water quality at the associated production requirements identified for both existing conditions as well as the future Alternatives[3]. Appendix A provides a detailed discussion of each unit process which expands upon the previously completed WBWTP process evaluation.

Table 2. WBWTP Unit Process Evaluation of Existing and Future Capacity against Design Criteria

Process	Installed Capacity[1] (mgd)	Comments	Meets Revised Summer Capacity (54.8 mgd)	Meets Future Summer Capacity (76.3 mgd for Alternative 3)
Influent Hydraulic Capacity	62 to 82	54-inch line operating between 6 and 8 feet per second will provide approximately 62 to 82 mgd of capacity	✓	✓
Manganese Removal	63 47	At East Gravel Lakes (EGL) at metering system capacity and design dosage At West Gravel Lakes (WGL) at metering system capacity and design dosage	✓	X
Powdered Activated Carbon (PAC) Feed	158.5	At metering pump capacity and design dosage	✓	✓
Coagulant	93	Treated flow capacity at metering pump capacity and design dose	✓	✓

[3] The requirements for future Alternatives are further defined and discussed in Section 3.

Table 2. WBWTP Unit Process Evaluation of Existing and Future Capacity against Design Criteria

Process	Installed Capacity[1] (mgd)	Comments	Meets Revised Summer Capacity (54.8 mgd)	Meets Future Summer Capacity (76.3 mgd for Alternative 3)
Disinfection (hypochlorite)	Variable	Existing infrastructure is suitable for existing and future capacities by adjusting hypochlorite and contact times	✓	✓
Clarifier	55.1	Plant rated flow based on clarifier capacity with one unit out of service	✓[3]	X
Membranes[2]	31.1 54.8	Winter flux (adjusted) 22 gallons per square foot per day (gfd) Summer flux (adjusted) 38.8 gfd	✓[4]	X
Ammonia	138	Treated flow capacity at metering pump capacity and design dose	✓	✓
pH	80	Treated flow capacity at metering pump capacity and design dose	✓	✓
Solids	NA	NA	✓	X

[1]Design capacity values have been identified from previous engineering and regulatory documents for the WBWTP and may not correspond to actual operating conditions. Further study of the capacity of the system is warranted after completion of planned inlet works improvements to confirm if the design capacity is adequate.

[2]See Section 2.1.1.1 for further explanation of the reduction in production capacity for the membrane processes.

[3]Clarifier capacity is based on design value of 13.7 mgd per unit. However, there has been evidence that the systems have suffered performance degradation at flows above 10 mgd. Further study of the capacity of the system is warranted after completion of planned inlet works improvements to confirm if the design capacity is adequate.

[4]The membrane flux is a system average across all active trains. Trains with older membranes would be anticipated to have fouling and thereby operate below the average value. The lost flux is assumed to be offset by trains equipped with newer membranes that would exceed the average flux value. The system average will be maintained by replacing one train's worth of membranes per year,

2.1 WBWTP Process Enhancements

The focus of this section is to identify process enhancement to address shortfalls in treatment systems with regards to meeting water quality targets. Where deficiencies have been identified, process enhancements were recommended as necessary to improve the operational performance and achieve the current baseline production target summer[4] treatment capacity of 54.8 million gallons per day (mgd) for the WBWTP. Table 3 summarizes the recommended existing improvements for the existing unit processes to achieve the Design Criteria for quality and production at the WBWTP. These elements should be included as engineering development project and CIP planning.

Table 3. WBWTP Improvements to Existing Process to Meet Design Criteria

Process	Recommended Improvement	Comments
Manganese Removal	Reduce and/or eliminate the hypochlorite feed for manganese control	This recommendation is based on improved manganese control anticipated to be achieved by relocating disinfection, lowered PAC doses, and potential elimination of secondary manganese with a change to aluminum-based coagulants. Further monitoring of the performance of manganese removal is recommended after the relocation of disinfection.
Manganese Reduction	Convert to aluminum-based coagulation	This recommendation is made to reduce the introduction of secondary manganese that is common with iron coagulants. The

[4] The flux associated membrane process at WBWTP is impacted by temperature and therefore varies by season. In order to align with peak distribution demand, the analysis has focused on warmer water / summer conditions.

Table 3. WBWTP Improvements to Existing Process to Meet Design Criteria

Process	Recommended Improvement	Comments
		existing feed equipment is adequate for the aluminum coagulant, so the change is primarily an operational cost change.
Taste and Odor	Relocate the hypochlorite feed and monitor system improvements	This recommendation is based on switching to post-filtration disinfection, which is already planned, which is anticipated to curtail the competition between hypochlorite and powder activated carbon, increasing the removal efficiency. Work is also being completed as part of the Raw Water Master Plan to better manage raw water supplies, which is focused on reducing the formation of taste and odor compounds. Powder activated carbon is anticipated to be able to achieve 1-log reduction (90%), which will meet the Tier 1 criteria if the influent can be maintained below 50 ng/L. Further monitoring of the impact to taste and odor management is recommended after implementing the relocation of disinfection and raw water management strategies. If the Tier 1 criteria cannot be met, further evaluation of the installation of granular activated carbon with or without advanced oxidation processes would be necessary.
Coagulant Mixing	Replace the existing inline mixer with a new flash mix system	This recommendation is already planned. Further monitoring of clarifier performance after implementation is recommended to confirm that differential performance issues have been adequately addressed.
Clarifier	Convert to aluminum-based coagulation	This recommendation is made to reduce the risk associated with iron fouling of membranes. The existing feed equipment is adequate for the aluminum coagulant, so the change is primarily an operational cost change.
Membranes	Implement operational changes to achieve more sustainable flux	Fully populate empty cassettes within the existing membranes trains. Elimination or treatment of return or reject waste to remove foulants. If required to meet a target production, increase membrane area to coincide with the reduction in flux.
Finished Water	Relocate the hypochlorite feed	This recommendation is already planned as part of other operational improvements.
Residuals Management	Evaluate solids management practices at WBWTP to identify and size improvements	Based on information in the Alternative Coagulant Study, WBWTP is estimated to produce 3,000,000 dry lbs of solids per year and TWTP is estimated to produce 600,000 dry lbs per year at full production capacity. Standard design criteria for engineered lagoons on the Front Range is a net annual drying capacity of 8 lbs per square foot of drying area. WBWTP currently has three lagoons total drying area of ~135,000 SF (based on 300 ft long by 150 ft wide). This results in a net annual drying capacity of ~1,100,000 lbs of dry solids, which is a significant shortfall and could limit production at the treatment facilities. There are additional considerations for residuals management at WBWTP, such as solids layering, cycling lagoons, and considerations for potential TENORM. These issues require further study to identify the most appropriate means to provide increase residuals management capacity for the Thornton treatment facilities.

It is important to note that the analysis of the alternative buildout scenarios in Sections 3 through 5 of this TM are predicated on the recommendations in Table 3 being implemented to address deficiencies in the existing process. It is critical that the operation at WBWTP meet the Design Criteria for Water Quality and Production prior to analyzing means to expand production treatment capacity.

2.1.1 WBWTP Production Capacity

Table 2 provided a summary of the production capacity of the existing infrastructure at WBWTP. The majority of the equipment identified is based on the original design capacity as established by the Colorado Department of Public Health and Environment (CDPHE), which included identifying the firm capacity of the WBWTP as 48.1 mgd at 1 degree Celsius (°C).

Operationally, the membrane systems at WBWTP have experienced a number of challenges since installation due to accelerated flux loss, leading to production limitations. These have been attributed to a number of factors, including an aggressive design flux compounded by performance deficiencies in several critical upstream treatment processes. The combination of these factors has impacted the operations at WBWTP, manifesting as accelerated decline in flux capacity within the membranes and shortened lifetime for the membrane elements. The conclusion reached during the WBWTP Process Evaluation was that operation at the original design flux will likely result in a reduction in membrane service life by approximately 20-30 percent (%). Alternatively, the membrane life can be extended to meet the original design target, but this will require operation at a lower flux rate and other performance improvements to limit the potential for membrane fouling.

Section 2.1.1.1 provides a discussion of the original design rating of the membranes and a suggested revision to the operating limit for flux to reduce the rate of fouling that has been witnessed with the system.

2.1.1.1 Adjustment to Membrane Design Flux

The WBWTP production capacity is significantly impacted based on the achievable flux in the membranes. The firm rated capacity design of the WBWTP as defined by CDPHE is 48.0 mgd based on the membrane flux value[5] of 34 gfd at 1°C with the largest single unit of each process out of service. As discussed in Section 3.3.1 of the Process Evaluation, this value is at the higher end of the range for other membrane facilities, and many of those facilities have very high quality raw water source. The operational history of membrane fouling at WBWTP supports the argument that this value is not appropriate or sustainable by typical industry standards for membrane life and performance.

While WBWTP has the supporting infrastructure to operate the other unit processes as required to support membrane operations at this flux value, continuous production at the original design flux will likely require a more robust maintenance program for the membranes to address the rapid rate of fouling. Further, membrane life will likely be significantly curtailed. A conservative estimate is that membrane life would be reduced by approximately 20-30%, corresponding to the difference volume process at WBWTP as compared to other similar facilities with lower flux values. Replacement would need to be completed every 6 to 8 years in lieu of the target of 8 to 10 years that is the industry target for membrane life.

In order to provide for a more sustainable operation, it is recommended that a conservative operational limit be established based on using a winter flux of 22 gfd at 1°C. Based on the manufacturer original recommended design flux (60 gfd at 20°C / 39.9 gfd at 1°C), maintaining the ratio would equate to a summer flux of 38.8 gfd at 20°C. The treatment capacity at WBWTP based on the estimated sustainable flux with the proposed improvements and the manufacturer design flux is identified in Table 4. These revised flux values would be used as operational limits and are not intended to be submitted to CDPHE for a revised design basis, but rather these values will result in greater longevity and reduced maintenance for the membranes. The revised flux values have been used to establish production capacity to serve as the planning basis for development of the future alternatives in Sections 4 and Section 5 of this TM.

Table 4. Existing WBWTP Treatment Capacity with Proposed Improvements

Parameter	Recommended		Original Design	
	Winter (0°C)	Summer (20°C)	Winter (0°C)	Summer (20°C)
Estimated Potential Flux (gfd)[1]	22[2]	38.8[3]	34[3]	60[3]

[5] Due to the membrane processes, the production capacity at WBWTP is impacted by temperature. Suez membrane design indicated operation at a membrane flux of 39.9 gfd at 1°C and 60 gfd at 20°C. The Design Criteria for Production at WBWTP is therefore 48.0 mgd production during winter conditions (1 °C) and 84.8 mgd during summer conditions (20 °C) with one unit of service.

Membrane Area with One Train Out (10^6 ft^2)[4]	1.41		1.41	
Total Membrane Area (10^6 ft^2)	1.63		1.63	
Flow with One Train Out (mgd)[4]	31.1	54.8	48.0	84.8
Flow with All Train In Service (mgd)	35.9	63.4	55.5	97.9

[1]To achieve this flux, Thornton will need to implement proposed process modifications.
[2]Based on a literature review of achieved flux from other facilities with same membranes.
[3]Based on Summer and Winter design flux of 60 at 20°C and 34 at 1°C provided by membrane manufacturer.
[4]Based on largest train out of service.

The determination of the flux value for sustainable operations is based on multiple factors, including the current raw water quality as well as existing performance trends. The Process Evaluation identified multiple operational issues with the existing treatment operations that impact the membrane flux, therefore reducing the achievable treatment capacity at the plant. In order to better support the original design flux, operational changes would need to be made to improve the life and flux of the membranes at WBWTP increasing the treatment capacity as outlined in Table 3.

These changes are largely geared at improving the pre-treatment prior to the membranes so that higher quality influent water is passed to the membranes providing a higher and more sustainable membrane flux.

Conversely, if the desire is to combine both sustainable operation while also meeting the original design rating of the WBWTP, a similar reduced design flux value can be used, but the consequence of this choice would be that higher production would require more membrane surface area, which would exceed the capacity of the current infrastructure at the facility and would therefore require an expansion.

It is important to note that the firm capacity of the WBWTP is based on the lowest production capacity with one unit out of service. However, the peak demand analysis as part of the Distribution Master Plan occurs during summer conditions. So applying the winter flux values for WBWTP to the MDD during the summer Distribution Analysis results in a significantly conservative analysis of the production capability of the facility. As noted in Table 4 based on the recommended adjustments to flux values, the peak production for the WBWTP on the current configuration during summer conditions with one train out of service would be 54.8 mgd. This value has been used as the current baseline for maximum firm production capacity of the WBWTP during MDD during summer conditions. As discussed above, increasing production beyond this level during summer conditions would require operating at higher flux values (which may not be sustainable) or adding additional membrane surface area.

2.2 TWTP Sludge Line

Under current operations, all sludge generated at the TWTP is collected and conveyed to the WBWTP lagoons via the TWTP sludge line. The hydraulic capacity of the existing TTP sludge line was reviewed to determine the existing capacity and the available capacity to accommodate additional sludge production if the treatment capacity of TWTP is increased.

Sludge is conveyed by gravity from TWTP to the WBWTP lagoons; therefore, the hydraulic capacity is driven by the elevation difference between the facilities and any hydraulic losses that occur through the pipeline. A simple capacity analysis was completed using Manning’s equation and compared against Hazen-Williams, since portions or the line may surcharge in normal operations. The existing diameter, alignment and elevations for the sludge line were provided by Thornton to perform the calculation and are identified in Table 5. The existing sludge line is 16 inches with a length of 14,600 feet. The discharge elevation at TWTP is 5365.5 feet and the intake elevation at the WBWTP lagoon, based on embankment elevation, is 5102.2 feet. The maximum estimated sludge flow that can be conveyed from TWTP to WBWTP in the existing sludge line is 5,000 gallons per minute (gpm).

Sludge generation rate as a result of water treatment activities is assumed to be 10% of influent flow in accordance with 10 States Standards. Based on the simple capacity analysis, the existing sludge line could have capacity for up to approximately 70 mgd of treatment at TWTP.

Table 5. TWTP Sludge Line Hydraulic Capacity

Parameter	Value
Diameter (inch)	16
Length (feet)	14,600
TWTP Sludge Pond Bottom Elevation	5365.5
WBWTP Pond Embankment Elevation	5102.0
Available Head (feet)	263.5
Maximum Flow (gpm)	5,000
Velocity at Maximum Flow (feet per second)	8.3

However, previous testing completed for Thornton has demonstrated that the hydraulic capacity of the line is limited to between 1.5 to 2.1 mgd, which is attributed to piping dynamics, sludge blockages, and additional factors that are not captured in the hydraulic calculations. Based on the field observations, the existing sludge line does not provide sufficient capacity to allow for reliable operations of the new TWTP and requires replacement.

As an adjunct to the sizing of the residuals management line, it should be noted that the source of the TENORM issues at WBWTP are not necessarily isolated to the source waters for that treatment facility. Further, since the long-term strategy for raw water management could involve treating gravel lakes water at the new TWTP, further study should be conducted to determine if solids management at TWTP, either by lagoons or mechanical dewatering, may reduce the risk for potential transfer of TENORM between facilities that may lead to contamination of dewatered sludge.

2.3 TWTP Demolition

The existing TTP was originally constructed in 1953 and was purchased by Thornton in 1955. The treatment processes have been upgraded multiple times, but the overall facility has reached the end of its useful life and is scheduled to be decommissioned in 2019. A new TWTP is in the process of being designed and constructed on property adjacent to the existing treatment plant. City of Thornton intends to demolish the majority of the existing treatment works once the new facilities are online and when budget is available.

A conceptual plan for the demolition of the existing TTP facilities is reflected in Figure 1. Thornton's intent is to maintain the existing clearwells and pumping station as part of distribution infrastructure, although much of the equipment is nearing the end of its useful life and may be added to demolition scope. The existing Sludge Pond will be maintained for use in conjunction with the new TWTP until a new sludge line is created that provide sufficient hydraulic capacity to preclude the need for equalization storage, at which point the sludge pond would be removed from service. The Ultraviolet (UV) Building would be maintained for potential future usage. All other structures are anticipated to be demolished.

During initial discussions for developing a demolition strategy, Thornton was preparing to retain the services of an environmental contractor to perform an evaluation of the buildings to investigate extent of asbestos and contaminations and then develop costs to remove. In addition, there was a need to discuss with operations and evaluated asbestos pipelines (in use and abandoned all around the plant) to determine steps to mitigate those materials.

While no formal costs estimates were developed, the preliminary information for abatement and demolition indicated that the cost would be an excess burden on the capital budgets when compared to other more critical activities. As such the planned demolition for the existing TTP infrastructure has been deferred to a later date.

In evaluation of future production requirements, implementation of Alternative 2 would likely require additional space that is currently occupied by the existing TTP infrastructure. Therefore the evaluation of that alternative would need to consider the cost of demolition and abatement activities. More discussion on the impacts of expanding the new TWTP is included in Section 4.

As an additional consideration, there is a need to determine if the expansion of the TWTP in Alternative 2 should include provisions for onsite treatment of treatment residuals. Given the challenges observed at WBWTP with the management of residuals from two water treatment facilities, the expansion of TWTP would increase the loading and further impact WBWTP. Treatment of residuals at the TWTP would be more consistent with 10 States Standards for return water and could also potentially eliminate the need for the sludge line that is currently used to transfer residuals to WBWTP. The consequence for adding residuals treatment at the expanded TWTP would be the increased land area required for the additional solids management infrastructure plus the capital expenditure for additional solids management infrastructure.

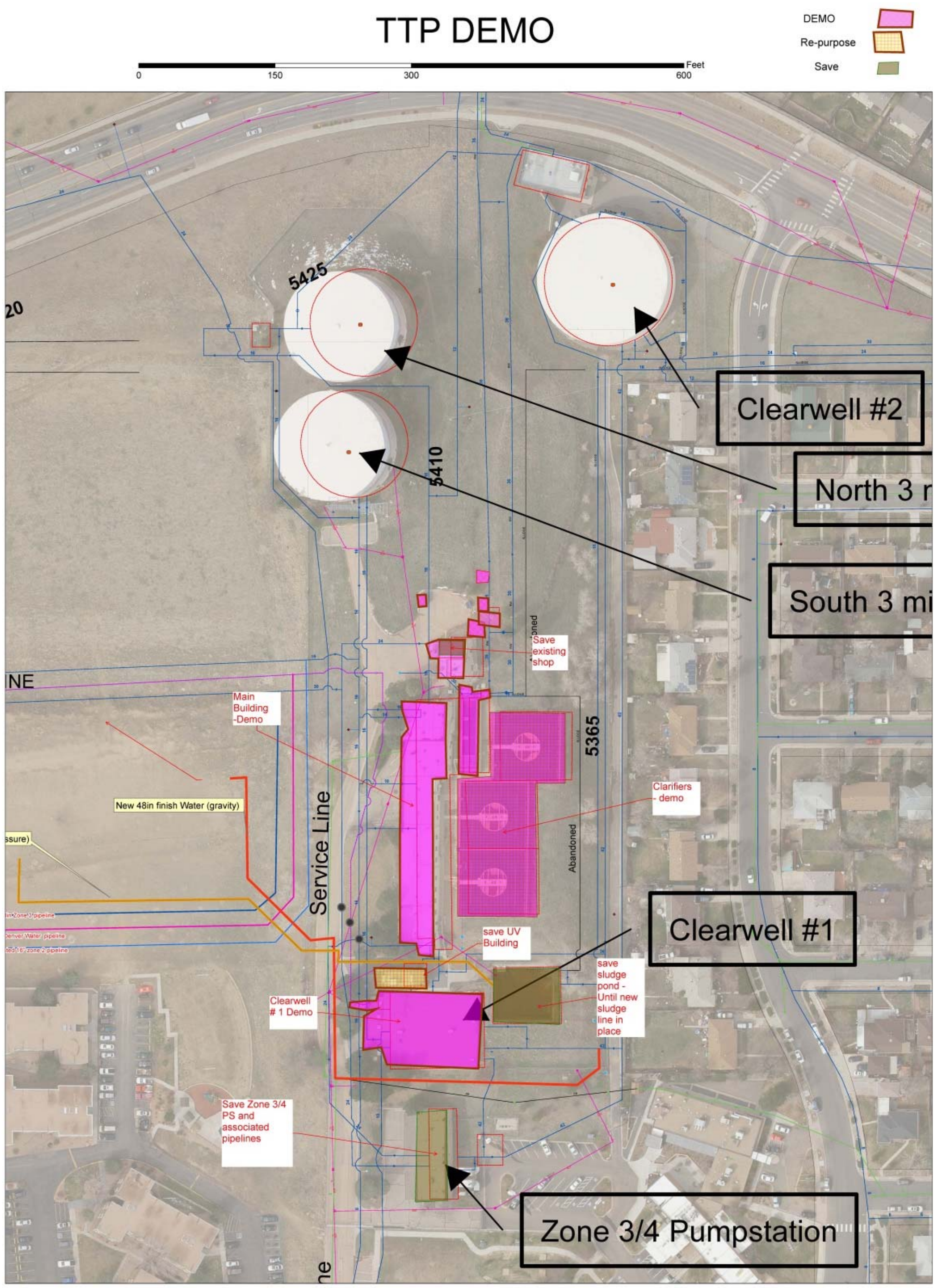


Figure 1. Existing Thornton Treatment Plant Conceptual Demolition Plan

2.4 Other Miscellaneous Planning Elements

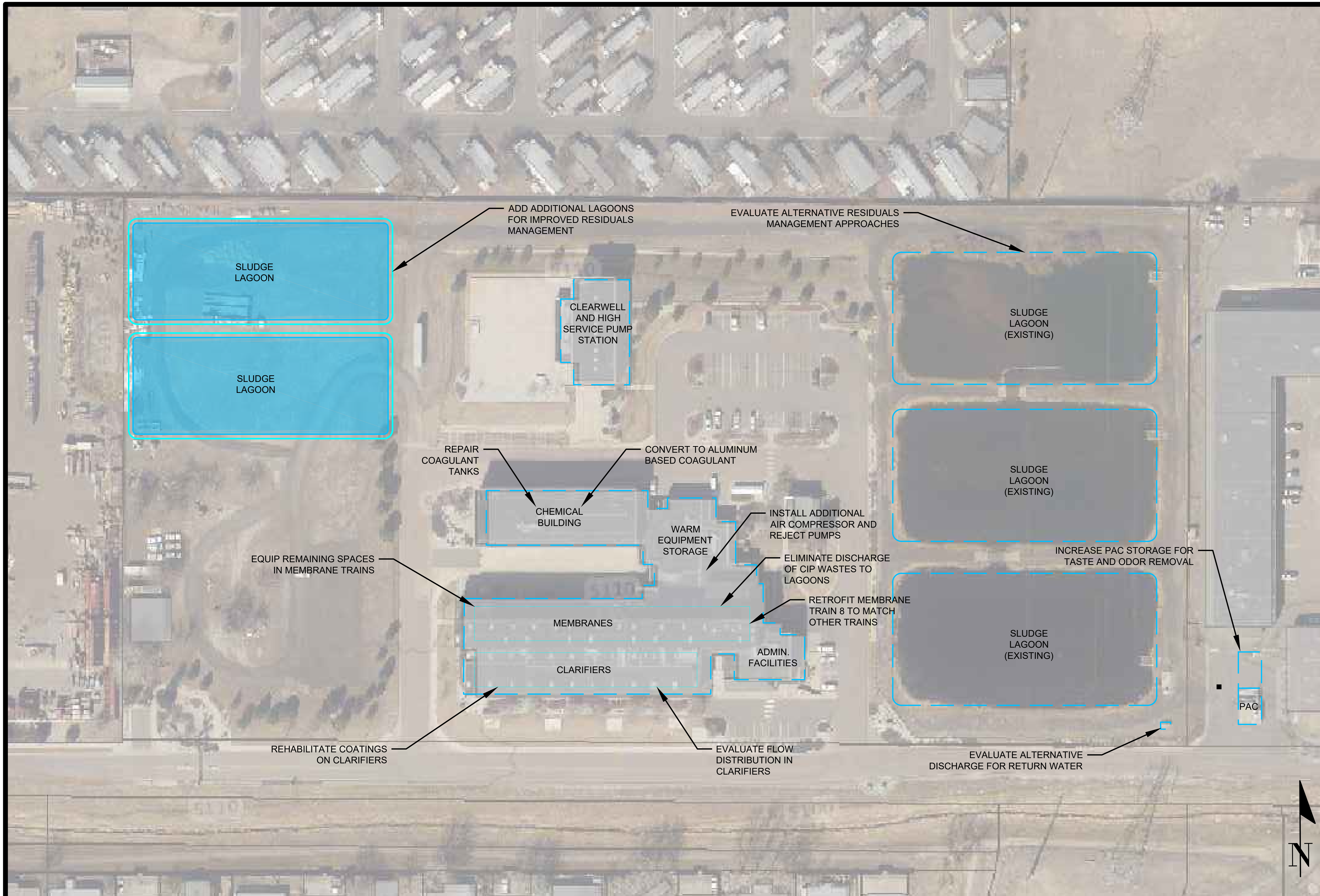
The focus of Sections 2.1 and 2.2 is to identify improvements to existing facilities, specifically to address deficiencies in treatment capabilities relative to water quality and production shortfalls. However, there are other factors that should be considered by Thornton that may directly impact budgetary planning processes which include additional studies and other improvements to address redundancy and maintenance activities. Table 6 provides a summary of the additional elements that should be incorporated into capital planning as a result of the Master Plan.

Table 6. Miscellaneous Treatment Plant Improvements, Maintenance Projects, and Studies

Process	Recommended Improvement	Comments
Chemical Feed	Coagulant tank modifications	Maintenance project to address risk of cracking when the tank is filled to capacity. See Appendix A for additional details.
Taste and Odor	PAC line improvements	Maintenance project to reduce the potential for plugging of PAC lines. See Appendix A for additional details.
Taste and Odor	PAC storage improvements	Operational enhancement project to increase onsite storage of PAC to avoid supply disruption. See Appendix A for additional details.
Taste and Odor	WBWTP alternatives analysis for granular activated carbon or advanced oxidation process	Alternatives study regarding taste and odor mitigation if the improvements recommended in Section 2.1 do not resolve the taste and odor issues satisfactorily.
Clarifiers	Complete recoating of the clarifiers	Maintenance project identified by Thornton in order to maintain the service life of clarification equipment.
Clarifier	Flow distribution study	Study to evaluate impact of improving flow balance between clarifiers to improve performance.
Membranes	Air compressor	Capital project to add additional air compressors to improve redundancy.
Membranes	Membrane replacement	Operational cost associated with replacement of membranes due to age and lost functionality.
Finished Water	Clearwell lining	Capital project to add lining system to clearwell to reduce leakage and increase longevity of the system.
Solids Management	Study of relocation of return water downstream of gravel lakes	Study of the impacts of sending lagoon return water to a point on the system that is downstream of the source supplies for West and East Gravel Lakes, which would eliminate the potential for recycling of fouling compounds. This approach could be considered after implementing other improvements in the event that the rate of fouling has not been adequately addressed.
Solids Management	Study application of treatment approaches to the return water	Introduction of an oxidant (sodium hypochlorite or ozone) to address fouling compounds including polymers. OR Introduction of a coagulant or settling agent to convert colloidal material to convert to a settable solid.
Solids Management	Evaluate opportunity to install solids management infrastructure into the new TWTP	Study to determine if enhancement to the new TWTP would improve overall treatment operations by reducing loading to the WBWTP lagoons.
Safe Drinking Water Act Amendment	Risk & resilience assessment	Community water system serving a population of greater than 3,300 persons shall conduct an assessment of the risks to, and resilience of, its system as part of Section 2013 of the America's Water Infrastructure Act.

A conceptual plan for the improvement of the existing WBWTP facilities is reflected in Figure 1.

Figure 2. Wes Brown Water Treatment Plant Conceptual Improvements



WBWTP EXISTING PROCESS IMPROVEMENTS
WATER TREATMENT FACILITIES MASTER PLAN
THE CITY OF THORNTON
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3. Future Treatment Requirements

The focus of Section 2 was to identify projects that were targeted to improve the existing facilities in order to meet water quality and production targets based on the existing design capacity. While these improvements are targeted towards maximizing the utilization of the current installed treatment works, they are not sufficient to meet the full requirements for the buildout scenarios for Thornton. Section 3 is intended to outline the buildout treatment system production requirements (Section 3.1), provide an overview of the monthly demand patterns that will be anticipated for future operations (Section 3.2), summarize the production capacity of the existing infrastructure as determined by the process analyses conducted for this study (Section 3.3), and provide an overview of timeline as to when additional treatment capacity will be required to match the projected growth rate for Thornton citizenry (Section 3.4).

3.1 Future Production Requirements

The existing and future system demands, distribution losses, and production losses were reviewed and developed in the Future Growth and Planning TM. The TM identified the future system demands, future production requirements, and future raw water requirements that serve as the basis for the integrated master planning efforts. The future system requirements were developed for typical and planning conditions where typical conditions reflect non-drought conditions represent anticipated flow requirements under typical climatic conditions and planning conditions reflect drought conditions where an increase in flow requirements has historically occurred largely resulting from increase in outdoor potable use due to dry climatic conditions. The future system requirements are summarized below in Table 7.

Losses through the WBWTP and TWTP are based on historical data. 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 relative raw water supply rates to WBWTP are higher than TWTP due to higher production losses associated with membrane filtration.

Table 7. Buildout Production Requirements

Parameter	Non-Drought	Drought
Distribution System Demands (mgd)[1]		
Minimum Month	18.6	18.6
ADD	32.9	39.1
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
Flow 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 neglecting 1.8 mgd for Brighton Interconnect.
[3]Based on supply versus production data from 4/1/2017-6/30/2017.

3.2 Monthly Demand Patterns

To consider the seasonal impacts on production requirements, the annual Average Daily Demand (ADD) and Maximum Daily Demand (MDD) were estimated as part of the Water and Wastewater Master Plan Planning Area and Future Growth Analysis TM in order to identify the required water treatment capacity. The estimated ADD and MDD were translated into ADD and MDD by months 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 based on the estimated maximum month MDD/ADD

The evaluated monthly ADD and monthly MDD values are identified in 3.

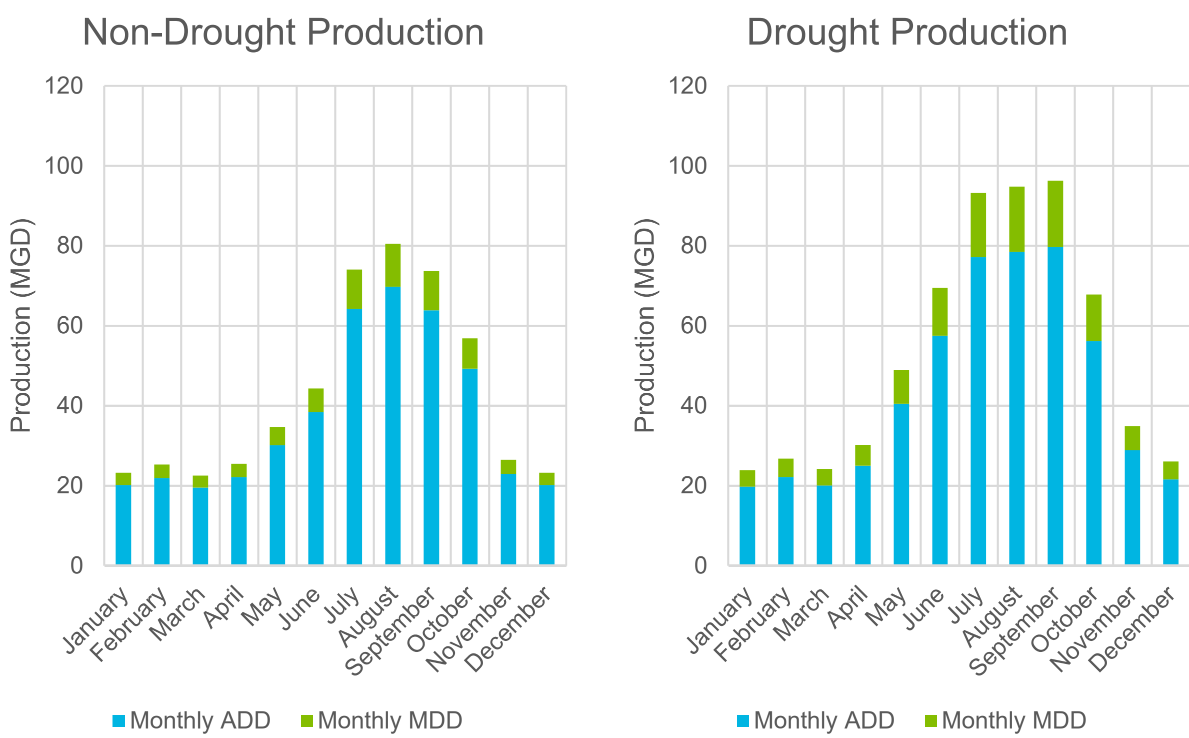


Figure 3. Anticipated Buildout Production Monthly ADD and Monthly MDD for Non-Drought and Drought Conditions

The planned production reflected in Figure 3 indicates that peak demand will occur during the summer months, with a peak value of 96.3 mgd for MDD. This value has been used as basis for determining enhancements to production to meet this firm required capacity. Section 3.3 provides additional information as to the difference between the current Typical Production and the required Planned Production as well as providing discussion on the impacts of seasons on production capacity.

3.3 Existing Production Capacity

As discussed in previous sections, the WBWTP has a permitted capacity of 48.1 mgd in the winter and has a theoretical production capacity 84.8 mgd in the summer[6]; however, this is based on an operational flux that has resulted in significant fouling and is not currently considered sustainable at WBWTP. Proposed existing improvements at WBWTP would be expected to improve the operational capacity, but a conservative value of 31.1 mgd in the winter and 54.8 mgd in the summer has been established to support sustainable operations. Operating the WBWTP at higher production capacities in its current configuration would be anticipated to require frequent maintenance, including higher occurrences of clean-in-place operations and membrane replacement. Alternatively, an additional membrane area could be installed to meet the original design capacity while operating at the reduced operating flux.

[6] 84.8 mgd is based on design flux values for the membrane system and represents an instantaneous maximum value. Production at this flow rate would not be anticipated to be sustainable or recommended. Thornton operational practice includes normally leaving one train in standby as an operational reserve to be available to support maintenance activities.

The old TTP will be decommissioned and replaced by the new TWTP. The TWTP is set to be commissioned and online in 2019, with an operational capacity of 20 mgd based on the TWTP design documents. The new plant utilizes conventional filtration and therefore is not expected to experience season changes in production capacity or otherwise suffer from treatment limitations observed at WBWTP.

The assumed production capacities by facility are summarized in Table 8. These values serve as the basis for the buildout alternatives evaluation.

Table 8. Existing Production Capacity

Parameter	WBWTP	TWTP[2]	Total
Permitted	48.1	20	68.1
Firm (One Train Out)			
Summer (mgd)	54.8[1]	20	74.8
Winter (mgd)	31.1[1]	20	51.1
Maximum (All Trains in Service)			
Summer (mgd)	63.4	24	87.4
Winter (mgd)	35.9	24	59.9

[1]Recommended value for capacity planning based on implementing identified existing improvements and adjusting operational limits for sustainable operations.
[2]Permitted Capacity of 20 mgd based on new TWTP design documents, equates to a capacity of 4 mgd per train. The facility is permitted to operate at 30 mgd during the summer during emergencies, but this cannot be included as part of normal capacity analysis.

3.4 Future Capacity Timing

The existing production capacity was analyzed against the future seasonal demand requirements to identify the trigger to require increased production capacity. The analysis indicates additional production requirements will be driven by the MDD demand experienced in the summer. The analysis is adjusted to utilize the summer operating capacity for WBWTP, which is higher than the firm capacity due to reduced capacity based on influent water temperatures.

Historically, Thornton has taken the WBWTP offline in the winter to allow for maintenance activities. In the future it is assumed that this will not be a limitation, and that WBWTP and TWTP can be operated continuously, year[7] round, to meet future system demands. This assumption has been made to limit potential significant gaps in production capacity, which would cause costly system improvements to add extra capacity to meet future production requirements if a facility is regularly maintained as offline.

As development occurs, additional treatment capacity will be required when the total firm capacity from the WBWTP and TWTP is not able to supply the MDD. Based on Thornton's current projections for future growth and development, the permitted capacity is anticipated to be exceeded in 2027, and the installed capacity is anticipated to be exceeded in 2032, as indicated in Figure 4. Design and permitting for treatment facilities can take anywhere from 3 to 7 years, depending on the complexity and land approvals, which indicates that Thornton should anticipate beginning planning activities for expansion of treatment capacity starting in 2020.

[7] It is understood that future operations would likely still require periodic shutdowns for maintenance activities, but it is assumed that these can be coordinated to occur in shorter shutdown periods when demand can be met by other installed capacity.

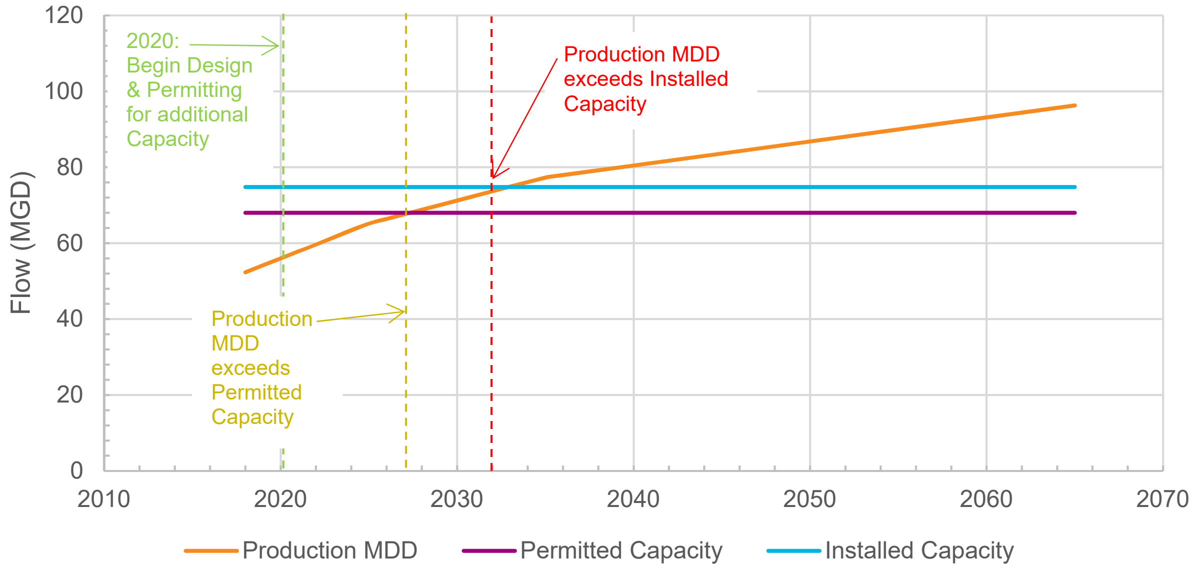


Figure 4. Timing of Future Capacity Requirement

4. Alternatives Development

Three alternatives have been identified for meeting 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 analysis performed for the Distribution 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 availability in the Thornton treatment system capacity. The analysis of infrastructure modifications has been based on the requirement to meet the capacities outlined in Table 9.

This section describes the major aspects of each Alternative, including a conceptual site and process description of each. The proposed modifications for all three alternatives are predicated on implementing the existing improvements outlined in Table 3.

Table 9. Alternative Production Requirements

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

4.1 Alternative 1 – Construct a new NWTP

Alternative 1 includes construction of a new water treatment plant to better serve the northern portion of the system (NWTP). 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 Avenue located between Colorado Boulevard and Holly Street, was identified as the preferred location for construction of the NWTP. The proposed site would be approximately 14.5 acres and is currently privately owned and part of unincorporated Adams County. Thornton would have to acquire these lands and complete zoning activities to permit construction and operation of a treatment facility at this location.

In terms of treatment configuration, a conventional filtration plant configuration similar to the new TWTP was assumed consistent with the preferred treatment method being employed by Thornton based on the existing and anticipated future raw water quality. This design has been reviewed and determined to provide the appropriate processes, flexibility, and resiliency to address future water quality and production capacity.

A raw water pipeline would need to be constructed to supply the NWTP. The alignment and approach for accomplishing this is documented in the Raw Water Future Alternative Evaluation TM[8]. The finished water from the plant would be pumped from the treatment plant clearwell to a nearby existing tank and a future planned tank, where the finished water can then function with the distribution system.

Due to the location of the NWTP being significantly remote from WBWTP and also in keeping with 10 States Standards, the water treatment plant should include residuals management processes. It has been assumed that the preferred residuals management process may be a lagoon system similar to the existing WBWTP residuals management handling process; however, further is needed to determine if there is potential TENORM concerns in the Poudre River, which may lead to a need for other residuals management strategies.

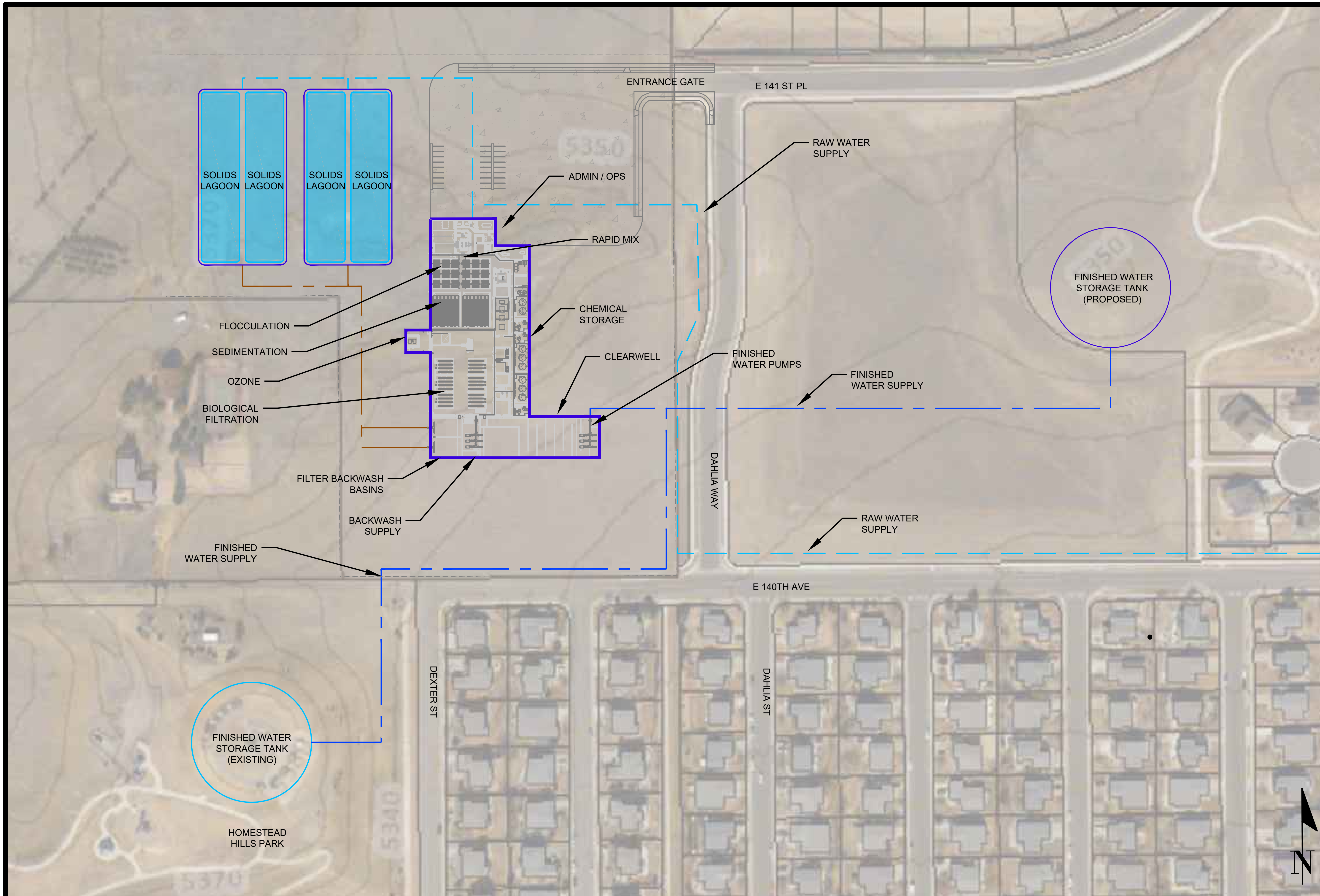
The NWTP conceptual design elements are summarized in Table 10. A conceptual layout is shown in Figure 5.

Table 10. NWTP Concept Development

Area	Approach
Conventional Treatment Process	• Raw water pipeline • Pretreatment: Flash mixing, inline with raw water • Flocculation: 2 trains at 100% capacity each. Each train will include 3 stages of flocculation. • Sedimentation: 2 trains at 100% capacity each. Each train will include 3 zones of sedimentation. • Ozone: 2 ozone generators with companion feed and destruct systems, oxygen storage and feed equipment, 2 parallel contact basins • Biological Filtration: 6 filters loaded granular activated carbon (GAC). Each filter will be sized for 20% of the plant rated capacity • Clearwell: 0.7 Baffle Factor, 1.5 Safety Factor, designed to work with 12.5% NaOCl to achieve 0.5 Log Giardia and 2.0 Log Virus disinfection contact time • Filter Backwash: supply tank, pumps (1 operational, 1 standby), backwash waste tank
Finished Water Supply	• Finished Water Pumps: 2 operational, 1 standby • Finished Water Pipeline: Existing tank, proposed tank
Solids Handling	• Return Water pumps: 2 operational, 1 standby • Lagoons: 2 lagoons, configured for external sludge removal
Site Work	• Site Acquisition: Private property in unincorporated Adams County • Site Area: 14.5 acres northwest of east 140th Avenue and Dahlia Way • Access: Dahlia Way

[8] The Raw Water Master Plan (as part of the Integrated Master Plan) will identify the necessary infrastructure to balance efficiency with equitability for distribution of water resources to the treatment facilities.

Figure 5. Alternative 1 – NWTP Concept Layout



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ALTERNATIVE 1 - NWTP CONCEPT LAYOUT
WATER TREATMENT FACILITIES MASTER PLAN
THE CITY OF THORNTON
Project No.: 60560104

4.2 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. At buildout for Alternative 2, the TWTP would be expanded by 21.5 mgd to a permitted production capacity of 41.5 mgd.

The existing TWTP location is approximately 12.5 acres in the southwestern portion of the distribution system and does not include solids handling facilities. Thornton currently owns sufficient property at the site to allow for the expansion. Depending on the layout, some facilities from the decommissioned TWTP may be required to be demolished to provide space for construction.

To produce an additional 21.5 mgd at the new TWTP, the conventional plant would need to go through an expansion to approximately double the production capacity. The existing raw water intake and pretreatment process would have adequate capacity (the capacity and improvements necessary for the raw water pipelines to TWTP are evaluated in the Raw Water Future Alternative Evaluation TM) but would be reconfigured to accommodate the increased firm capacity. The existing treatment expansion would be constructed to accommodate two additional treatment trains including flocculation, sedimentation, ozone contact basin, and biological filtration. The expanded TWTP have a total of four treatment trains and 12 biological filters. A second clearwell facility (Clearwell No. 2) would be constructed to meet the contact time requirements and house filter backwash pumps and tanks. The chemical storage at the TWTP would be anticipated to expand to provide adequate storage.

From the second clearwell, a gravity pipeline would be installed to the existing Clearwell No. 2, which provides storage before entering the distribution system. Improvements from the existing Clearwell No. 2 into the distribution system are evaluated as part of the Water Distribution Future Alternative Evaluation TM.

The TWTP currently does not have solids handling on site. Expansion to 41.5 mgd would require implementation of one of two improvements options:

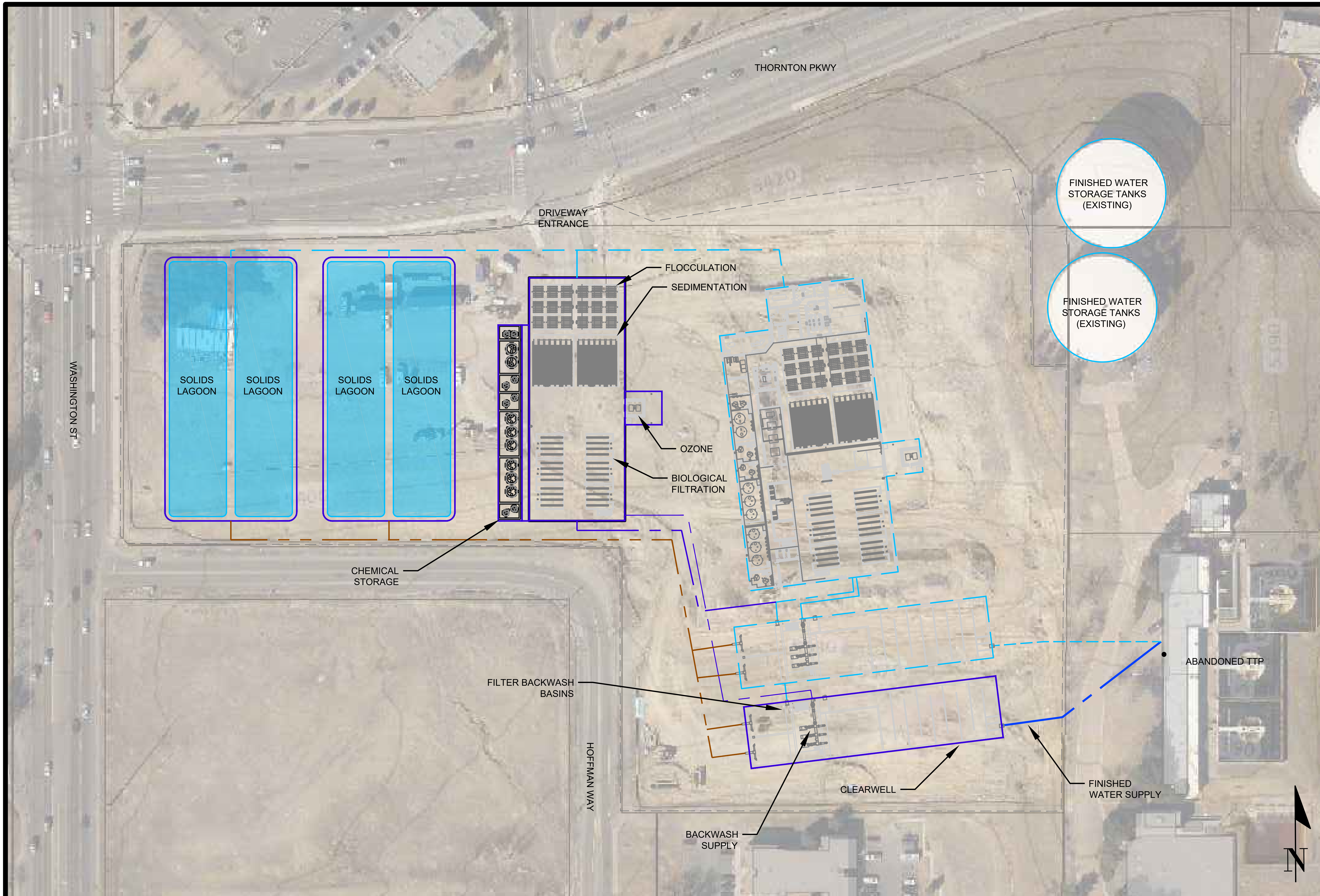
- Option 1 – Reconfigure TWTP for Onsite Solids Handling: An increase to 41.5 mgd would likely result in approximately 4 mgd of waste flows, which represent nearly 10% of the WBWTP rated capacity and would be a significant increase in loading that is not consistent with the 10 States Standards. Therefore, the TWTP should be enhanced to process solids on site. It is anticipated that this would be accomplished by constructing two lagoons onsite to accommodate solids handling on site like the approach implemented at WBWTP. Option 1 is the preferred option.
- Option 2 – Continue TWTP Solids Handling at WBWTP: This would maintain the current practice of sending solids to WBWTP for process. The existing residual detention basin at TWTP has a capacity of approximately 200,000 gallons, which is effectively the volume of a single filter. The expansion to 41.5 mgd would require the basin to drain within two hours (assuming one filter backwash per filter per day). Calculations show that the 16-inch sludge line has the capacity to manage 200,000 gallons in approximately 60 minutes, but it would be recommended to double the detention basin capacity to provide additional buffering and freeboard. Alternatively, the gravity sludge line to WBWTP would need to be replaced with a 24-inch diameter pipeline to convey the additional sludge to WBWTP within approximately 30 minutes. The lagoons were originally designed for processing solids for 97.9 mgd of treatment and therefore have sufficient hydraulic and solids capacity hydraulic capacity.

The TWTP expansion concept development is summarized in Table 11, and a proposed concept layout is shown in Figure 6. The expansion layout in Figure 5 is conceptual and intended to reflect that there is sufficient land space to meet the required footprint for the increased production. However, further site evaluation is required to identify potential interferences and determine the optimal configuration. This may include the use of the site area currently occupied by the existing TWTP for installation of new facilities and/or for use as a laydown area during construction.

Table 11. TWTP Expansion Concept Development

Area	Approach
Process Expansion	• Raw Water Pipeline: reconfigure for expansion • Pretreatment: Expand to meet enhanced capacity • Treatment: Construct 2 additional parallel trains east of current facilities • Flocculation: 2 trains at 100% capacity each. Each train will include 3 stages of flocculation • Sedimentation: 2 trains at 100% capacity each. Each train will include 3 zones of sedimentation • Ozone: 1 additional ozone generators with companion feed and destruct systems, oxygen storage and feed equipment, 2 additional parallel contact basins • Biological Filtration: 6 filters loaded with GAC. Each filter will be sized for 20% of the plant rated capacity • Clearwell: Construct second clearwell south of existing clearwell, matching 0.7 Baffle Factor, 1.5 Safety Factor, designed to work with 12.5% NaOCl to achieve 0.5 Log Giardia and 2.0 Log Virus disinfection contact time • Filter Backwash: Construct second backwash facility with second clearwell • Chemicals: Install additional storage equipment in expansion west of building
Finished Water Supply	• Finished Water Pipeline: Install gravity line from second clearwell to existing Clearwell No. 2
Solids Handling	• Return Water Pumps: 2 operational, 1 standby • Lagoons, configured for external sludge removal • Return Water Pumps: 2 operational, 1 standby • Solids Detention: Existing detention basin • Solids Pipeline: Replace existing sludge line with 24 inches to Wes Brown lagoons

Figure 6. Alternative 2 – TWTP Expansion Concept Layout



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ALTERNATIVE 2 - TWTP EXPANSION CONCEPT LAYOUT
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4.3 Alternative 3 – WBWTP Expansion

For Alternative 3, the WBWTP would be expanded from a firm capacity of 54.8 mgd to 76.3 mgd to meet buildout production requirements. The existing WBWTP location is approximately 17 acres located in the southeastern portion of the distribution system. Thornton currently owns sufficient property at the site to allow for the expansion. Depending on the layout, some systems may be required to be relocated, and the existing plant roadway system may be required to be modified.

As illustrated in Table 2, the production capacity at WBWTP is primarily limited by the influent mixing system[9], the clarifiers, and the membranes, but the other unit processes at the WBWTP have sufficient capacity to produce 76.3 mgd. The capacity of the manganese system may need to be increased to accommodate the future capacity requirement if the facility continues to operate with ferric coagulants and elects to use permanganate to manage all reduced manganese in the inlet works.

To accommodate the future equipment necessary to increase production, the WBWTP facility would require an expansion of the building of the existing WBWTP that currently houses the clarifiers and membranes or construction of a new building that would connect to the existing infrastructure. The expansion would include two additional clarifiers of similar size and capacity as the existing clarifiers. The expansion of the building would also house four new membrane trains[10] to increase the membrane surface area at WBWTP by 50% to provide additional production capacity and provide more sustainability in the membrane flux.

While the taste and odor removal process at WBWTP using powder activated carbon can be adjusted to meet the target production rate, this treatment strategy is generally assumed to be limited to 1-log removal as opposed to the advanced oxidation processes employed at the new TWTP, which are designed to produce 2-log removal. Inclusion of the advanced processes at WBWTP carries risks due to the membrane process; additionally, the Raw Water Master Plan is investigating changes in raw water management intended to maintain influent concentrations of taste and odor compounds to less than 50 ng/L, which would allow for meeting the Tier 1 criteria with 1-log removal. Further evaluation of taste and odor management strategies at WBWTP may require further evaluation if the planned improvements to treatment works and raw water management prove to be insufficient to meet the Tier 1 criteria.

Expansion to the west would require reconfiguring yard piping and roadways to adjust for the expanded building footprint. Other infrastructure at WBWTP was evaluated and determined to have sufficient capacity to meet the operating requirements for a production of 76.3 mgd. However, all processes at the WBWTP would need to be re-permitted with CDPHE as part of the WBWTP expansion.

The raw water pipeline to WBWTP is already in place. The capacity and improvements necessary for the raw water pipelines to WBWTP are evaluated in the Raw Water Future Alternative Evaluation TM.

The clearwell at WBWTP has sufficient contact time to meet disinfection requirements at the buildout capacity, but improvements may be necessary to conveyance infrastructure from the WBWTP clearwell to the distribution system. The improvements from the clearwell into the distribution system are evaluated as part of the Water Distribution Future Alternative Evaluation TM.

The expansion of the WBWTP will result in additional solids production. The existing solids handling equipment and lagoons were reviewed and would have adequate capacity at the buildout production capacity.

The WBWTP was constructed in 1974 and therefore will require additional improvements to address aging infrastructure to provide a fair comparison of WBWTP to construction of a new NWTP or doubling of capacity at TWTP based on the new TWTP design criteria. Examples of some improvements would be exterior upgrades such as roof, siding, door and window repairs or interior improvements including, flooring, paint, or furniture upgrades. Since those improvements have not yet been identified, a contingency cost will be added to Alternative 3.

[9] The new Flash Mix system being installed at WBWTP was designed for 50 mgd of production. The mixing system would require further expansion to meet a firm capacity of 76.3 mgd.

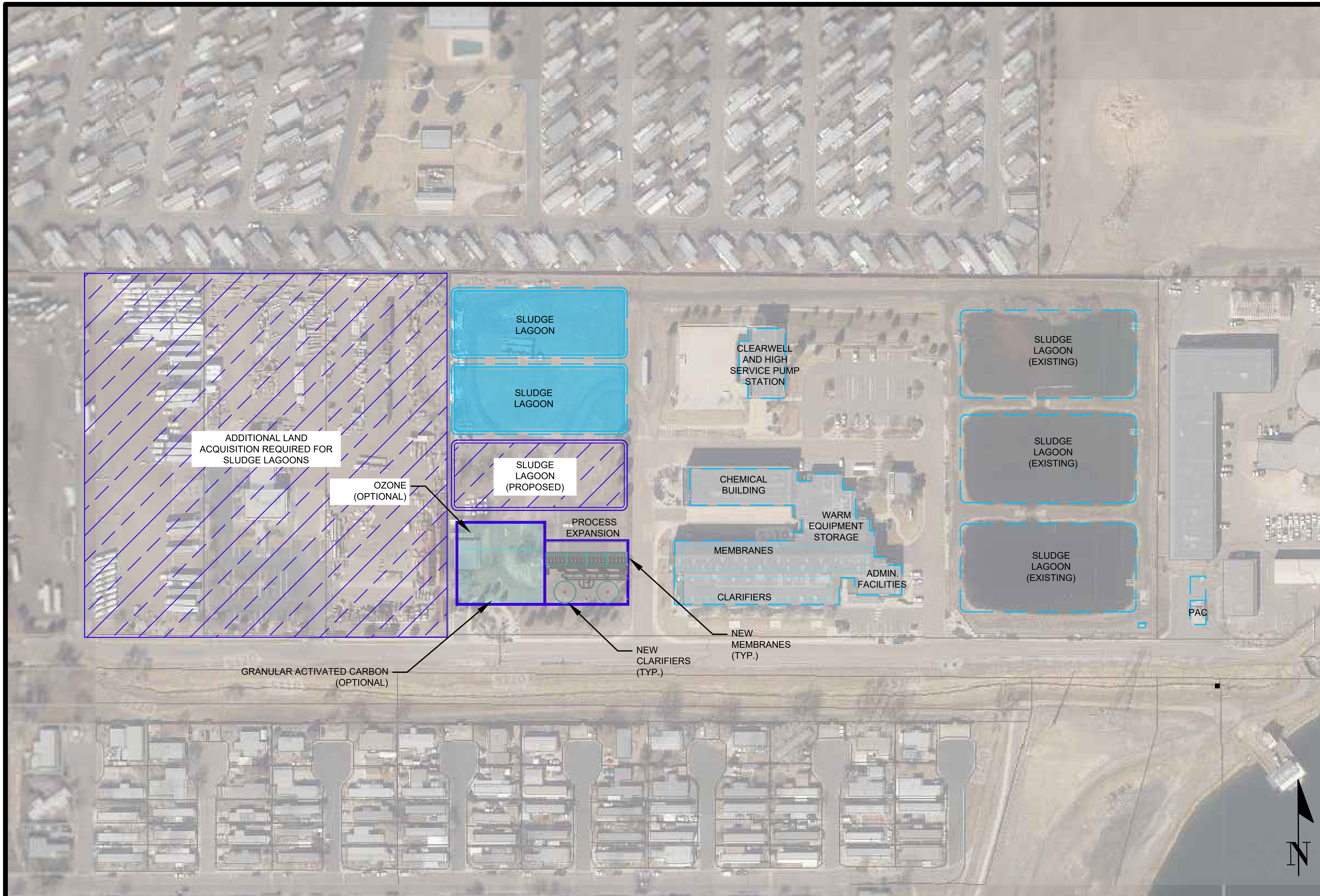
[10] A potential alternative could include the addition of multimedia filters in lieu of membranes; retrofit of the existing membrane systems back to multimedia filters is considered cost prohibitive and has not been evaluated as part of this master plan.

The WBWTP expansion concept development is summarized in Table 12. A conceptual layout is shown in Figure 7.

Table 12. Expanded WBWTP Conceptual Design

Area	Approach
Process Expansion	Clarifier: One additional, rerate 4 existing clarifiers Membrane: 4 additional trains
Site Work	Facility Improvements

Figure 7. Alternative 3 – WBWTP Expansion Concept Layout



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ALTERNATIVE 3 - WBWTP EXPANSION CONCEPT LAYOUT
WATER TREATMENT FACILITIES MASTER PLAN
THE CITY OF THORNTON
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5. Alternatives Evaluation

The purpose of this section is to evaluate the proposed improvements to treatment infrastructure relative to key performance indices (KPIs), which is intended to help differentiate between the various Alternatives and to identify improvement requirements that will be used to develop the CIP for each Alternative. The basis for evaluation is the performance criteria that were established in System Performance Criteria TM prepared as a portion of the Master Plan. The tables in the following sections provide the evaluation of KPIs for each alternative for overall system performance for production and water quality, including consideration for capacity, reliability, redundancy, resiliency, operations (chemical and energy usage), and maintenance.

The basis for establishing the components for each Alternative was the ability to meet the Performance Criteria. As such all alternatives are anticipated to meet the Tier 1/2/3 criteria. The evaluation therefore is intended to reflect instances where any particular alternative may meet the criteria in a manner that provides greater benefit to Thornton residents relative to the other alternatives.

5.1 Performance Evaluation

Table 13 summarizes the performance of each Alternative relative to the Tier 1 criteria for production, which are fundamental design requirements for the Thornton system. Each Alternative has been developed to meet all Tier 1 production requirements. Since the new NWTP has not been designed, it has been assumed to follow a similar design and process philosophy as applied to the new TWTP, so Alternative 1 and Alternative 2 are equivalent with regards to the Tier 1 criteria. As currently configured, there are no significant performance differentiators between any alternatives for Tier 1 criteria. Alternative 1 provides more total treatment capacity, but all Alternatives provide the 96.3 mgd needed.

Selection of a preferred Alternative will occur through a decision-making process in the Integrated Mater Plan and considering results from alternatives analysis 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 the most appropriate approach will be focused on determining the best lifecycle cost based on the capital and operating costs for each Alternative. Evaluation of reduction from Tier 1 criteria for adjusting lifecycle costs between any of the Alternatives has not been considered.

While the identification and evaluation of the Alternatives has been focused on meeting the required production and Tier 1 criteria, there are other factors that may influence the interpretation of meeting the Tier 1 criteria, such as overall allocation of production capacity across the system, ability of individual treatment processes to meet the critical flow, and sizing of infrastructure to meet power requirements. These factors provide an additional means to differentiate between Alternatives. The information in Table 13 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 an disadvantage relative to the other options.

Table 13. Tier 1 Water Treatment Facilities Performance Criteria

Performance Parameter	Criteria	Alternative 1 (mgd)	Alternative 2 (mgd)	Alternative 3 (mgd)
Total Treatment System Capacity	Total Production Capacity equal to System MDD during drought[1] period with a full treatment unit out of service at each treatment facility	WBWTP 63.4 TWTP 24.0 + NWTP 25.8 113.2 ±	WBWTP 63.4 + TWTP 45.5 108.9 ±	WBWTP 84.9 + TWTP 24.0 108.9 -
Unit Process Capacity	Firm installed capacity to meet production with one unit of each critical processes out of service	WBWTP 54.8 TWTP 20.0 + NWTP 21.5 96.3	WBWTP 54.8 + TWTP 41.5 96.3	WBWTP 76.3 + TWTP 20.0 96.3

Table 13. Tier 1 Water Treatment Facilities Performance Criteria

Performance Parameter	Criteria	Alternative 1 (mgd)	Alternative 2 (mgd)	Alternative 3 (mgd)
Critical treatment processes sized to meet capacity requirements	Various; established by previous approved design basis from various sources	+	+	±
Standby Power	Ability to activate sufficient backup power within 4 hours of loss of power in order to meet production requirements	±	±	±

[1]Maximum day drought condition is approximately 12.5% greater than the maximum day non-drought, which reflects a higher demand used for planning purposes.

Table 14 summarizes the performance of each Alternative relative to the Tier 2 criteria for production, which represent industry best practices but are not required by regulations or other system operational requirements. As a matter of establishing a baseline for equivalent comparison, each Alternative has been configured to meet all Tier 2 production criteria. The table has been populated to indicate if there are secondary differences in meeting the criteria that may identify one Alternative as preferential to the others for the same criteria.

One of the criteria for Tier 2 was the inclusion of separate, independent power sources to serve as a backup primary power supply in event of disruption of the normal power routing. The analysis used to develop Table 14 assumes that there are multiple primary power sources available in the vicinity of each treatment facility to allow for two independent primary power supplies. This assumption would need to be validated with the power supplier, as it may require construction of additional power infrastructure (substation). The new NWTP in Alternative 1 would require analysis to determine if there is sufficient grid isolation and capacity for two primary power supplies.

Assuming that there are multiple available power sources at each location, the selection of an Alternative should be based on determining the best lifecycle cost based on the capital and operating costs. It is anticipated that Alternative 1 would require more infrastructure due to the inclusion of a treatment plant at a third location.

As was the case for Table 13, the information in Table 14 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 an disadvantage relative to the other options.

Table 14. Tier 2 Water Treatment Facilities Performance Criteria

Performance Parameter	Criteria	Alternative 1	Alternative 2	Alternative 3
Redundancy for non-critical equipment (optional equipment excluded)	Reserved space to allow for installation of temporary systems to provide flexibility in operations and maintenance with one unit of each non-critical processes out of service	±	±	±
Standby Power	Dual power source available in order to meet production requirements without service interruption	- 3 facilities requiring secondary primary power supply	± 2 facilities requiring secondary primary power feed	± 2 facilities requiring secondary primary power feed

Table 15 summarizes the performance of each Alternative relative to the Tier 3 criteria for production, which represent features that are desirable to Thornton but are not considered Tier 2 criteria. The table has been populated to indicate if there are differences in meeting the criteria that may identify one Alternative as preferential to the others for the same criteria. For example, Alternative 3 cannot be configured to satisfy the ability to meet system capacity with the largest unit out of service.

The analysis used to develop Table 15 is based on the approach that each treatment facility would include sufficient emergency power for critical systems. It is assumed that, since all Alternatives provide the same overall production volume, the total emergency power requirement will be similar between options. However, because Alternative 1 includes more overall treatment locations, that Alternative would require the most generator equipment to meet the emergency power requirements due to the greater number of facilities, which is anticipated to reflect negatively on Alternative 1. Additionally, the WBWTP would be anticipated to have a larger overall power demand than the other two facilities when meeting production during peak demand due to the membrane processes and therefore would require more power infrastructure as compared with the other facilities, which would be expected to reflect negatively on Alternative 3.

Table 15. Tier 3 Water Treatment Facilities Performance Criteria

Performance Parameter	Criteria	Alternative 1 (mgd)	Alternative 2 (mgd)	Alternative 3 (mgd)
System Capacity when Largest Plant is Down	Production Capacity equal to System AADD during non-drought period (36.9 mgd) with a full treatment unit out of service at each treatment facility - assuming a mandatory outdoor water use restriction during this period	WBWTP 0.0 TWTP 20.0 + NWTP 21.5 41.5 +4.6 ±	WBWTP 0.0 + TWTP 41.5 41.5 +4.6 ±	WBWTP 0.0 + TWTP 20.0 20.0 -16.9 -
Redundancy for Optional Equipment	Firm installed capacity to allow for ease of operations and maintenance with one unit of each optional processes out of service	±	±	±
Emergency Power	A reliable power source meeting the requirements of the National Electrical Code for Emergency Power available for immediate use at each treatment plant.	±	+	-

5.2 Water Quality Evaluation

Table 16 summarizes the performance of each Alternative relative to the Tier 1 criteria for water quality, which are considered fundamental design requirements for the Thornton system. Each Alternative has been configured to meet all Tier 1 production requirements. Since the new NWTP has not been designed, it has been assumed to follow a similar design and process philosophy as applied to the new TWTP, so Alternative 1 and Alternative 2 are equivalent with regards to the Tier 1 criteria. There are no performance differentiators between Alternatives for Tier 1 criteria. Therefore selection of an Alternative should be based on determining the best lifecycle cost based on the capital and operating costs for each Alternative, as well as any implications of the Tier 2 and Tier 3 criteria. It is not anticipated that any Tier 1 criteria can be avoided to allow for adjusting lifecycle costs between any of the Alternatives.

Table 16. Tier 1 Water Treatment Facilities Water Quality Criteria

Performance Parameter	Criteria	Alternative 1	Alternative 2	Alternative 3
Finished Water	Turbidity < 0.30 Nephelometric Turbidity Unit (NTU) 95% of the time	±	±	+
	Chloramine 0.5 to 4 mg/L (as Cl2)	±	±	±
	Color ≤15 true color units	±	±	±
	Copper ≤1.0 mg/L	±	±	±
	Non-corrosive Langelier Saturation Index = 0.0 +/- 0.1	±	±	±
	Fluoride ≤2.0 mg/L	±	±	±
	Iron ≤0.3 mg/L	±	±	±
	Manganese ≤0.05 mg/L	±	±	±

Table 16. Tier 1 Water Treatment Facilities Water Quality Criteria

Performance Parameter	Criteria	Alternative 1	Alternative 2	Alternative 3
	MIB / Geosmin concentration < 5 nanogram per liter (ng/L)	+	+	-[11]
	pH 7.2 – 8.5	±	±	±
	Alkalinity > 44 mg/L as $CaCO_3$	±	±	±

Table 17 summarizes the performance of each Alternative relative to the Tier 2 criteria for water quality, which include industry best practices and secondary water quality standards but are not required by regulation or other system operational requirements. As a matter of establishing a baseline for equivalent comparison, each Alternative has been configured to meet all Tier 2 production requirements. However, the table has been populated to indicate if there are secondary differences in meeting the criteria that may identify one Alternative as preferential to the others for the same criteria. For example,

- Alternative 3 has the lowest potential risk for turbidity events in the finished water due to the positive barrier from the membrane process, which is reflected as a positive consideration.
- Alternative 1 and Alternative 2 increase the risk of chlorite or bromate formation due to the inclusion of ozone in the treatment process, which is reflected as a negative consideration. This risk would be equalized if ozone were to be included at WBWTP, but that would add an additional risk at WBWTP due to the potential for ozone to damage the membranes.
- Alternative 1 and Alternative 2 would be anticipated to have a higher removal rate for disinfection byproduct precursors due to the combination of ozone and biological filtration, which is reflected as a positive consideration. This configuration is also expected to be beneficial for addressing taste and odor issues that could impact these facilities if they include Gravel Lake water in their influent blend.
- Alternative 3 could be anticipated to have a higher risk for failure to meet the taste and odor criteria based on previous performance, but it is assumed for the purpose of this analysis that the performance issues will be resolved by the improvements discussed in Section 2.1.

Table 17. Tier 2 Water Treatment Facilities Water Quality Criteria

Performance Parameter	Criteria	Alternative 1	Alternative 2	Alternative 3
Settled Water - Total Organic Carbon	Removal per Stage 1 D/DBPR for conventional treatment plants	±	±	±
Settled Water - Manganese	< 0.03 mg/L (60% of SMCL)	±	±	±
Finished Water - Turbidity	< 0.10 NTU 95% of the time	±	±	+
Finished Water - Chlorite[12]	< 0.5 mg/L (50% of MCL)	-	-	±
Finished Water - Manganese	< 0.03 mg/L (60% of SMCL)	±	±	±
Finished Water - Taste and Odor	< 3 ng/L for Geosmin and MIB	+	+	±
Finished Water - Langelier Saturation Index	> 0	±	±	±
Finished Water - Chloramines Residual (as Cl2) Tolerance	± 0.1 mg/L of Setpoint	±	±	±
Finished Water – Aluminum[13]	0.05 - 0.2 mg/L	±	±	±
Finished Water - Chloride	≤250 mg/L	±	±	±
Finished Water - Foaming Agents	≤0.5 mg/L	±	±	±
Finished Water - Silver	≤0.1 mg/L	±	±	±

[11] WBWTP uses powder activated carbon for removal, which is generally assumed to have a maximum removal rate of 1-log for taste and odor compounds. Historical records have demonstrated that raw water concentrations of taste and odor compounds may exceed 50 ng/L, which would indicate that the treatment process is insufficient to meet the discharge criteria. However, the Raw Water Master Plan is exploring options to provide a maximum of 50 ng/L of taste and odor compounds in the influent.
[12] Chlorite is not considered a significant risk since it is most common associated with facilities that use chlorine dioxide and ozone; however, since TWTP and NWTP utilize ozone, they have a higher potential risk for this compound than WBWTP.
[13] Switching to aluminum-based coagulants could potentially increase the potential for challenges to this performance parameter, but the risk would be considered equal between alternatives.

Table 17. Tier 2 Water Treatment Facilities Water Quality Criteria

Performance Parameter	Criteria	Alternative 1	Alternative 2	Alternative 3
Finished Water - Sulfate[14]	≤250 mg/L	±	±	±
Finished Water - Zinc	≤5 mg/L	±	±	±
Finished Water - Total Trihalomethanes (TTHM)	< 40 micrograms per liter (µg/L) (50% of LRAA MCL)	+	+	±
Finished Water - Haloacetic Acids (HAA5)	< 30 µg/L (50% of LRAA MCL)	+	+	±
Finished Water - Bromate	< 5 µg/L (50% of MCL)	-	-	±
Finished Water - Cylindrospermopsin	< 0.7 µg/L	+	+	±
Finished Water - Microcystins	< 0.3 µg/L	+	+	±

Table 18 summarizes the performance of each Alternative relative to the Tier 3 criteria for water quality, which represent performance factors that are desirable to Thornton but are not considered Tier 2 criteria. The table has been populated to indicate if there are differences in meeting the criteria that may identify one alternative as preferential to the others for the same criteria. Alternative 3 was identified as having an increased risk of settled water turbidity exceeding the criteria value due to the radial configuration of the clarification equipment relative to the primarily linear flow pattern anticipated for Alternative 1 and Alternative 2.

Table 18: Tier 3 Water Treatment Facilities Water Quality Criteria

Performance Parameter	Criteria	Alternative 1	Alternative 2	Alternative 3
Settled Water - Turbidity, Each Treatment Train	< 1.0 NTU 95% of the time	±	±	-
Settled Water - pH Tolerance, Each Treatment Train	± 0.1 of Setpoint	±	±	±
Finished Water - Free Ammonia as N	0.01 to 0.05 mg/L	±	±	±
Finished Water - Calcium Carbonate Precipitation Potential	3 to 8 mg/L	±	±	±
Finished Water - pH Tolerance	± 0.1 of Setpoint	±	±	±
Finished Water - Iron	< 0.1 mg/L	±	±	±

5.3 Other Considerations

Table 19 reflects the performance of Alternative relative to key performance indices that are important considerations for Thornton but are not considered a production quantity or quality issue. The table has been populated to indicate if there are differences in meeting the criteria that may identify one alternative as preferential to the others for the same criteria.

It is assumed that infrastructure will be added to allow for homogeneity between all plants with regards to raw water sources, such that WBWTP should not be negatively impacted by being the only facility to treat Gravel Lakes water. The practicality of this assumption will be further evaluated as part of the integration of the Master Plan.

Table 19. Other Considerations

Performance Parameter	Criteria	Alternative 1	Alternative 2	Alternative 3
Number of Facilities	Number of facilities does not result in significant duplication of staffing, chemicals and spare parts	-	±	±

[14] Use of ferric sulfate as the primary coagulant would contribute to sulfate concentrations in finished water and could impact compliance with this performance parameter if there is a combination of elevated influent sulfate at the same time as dosing coagulant at higher levels than typically observed.

Table 19. Other Considerations

Performance Parameter	Criteria	Alternative 1	Alternative 2	Alternative 3
Waste Handling and Management	Solids conveyance, storage, operations, and disposal	WBWTP Lagoons and 2 new lagoons at NWTP -	2 new lagoons at TWTP and WBWTP lagoons +	Cycle existing lagoons at WBWTP more frequently ±
Owner / Operator Preference	Processes favors conventional versus membrane treatment	±	±	-
Resiliency	Overall treatment infrastructure designed to minimize impacts of outages or other operational disruptions	+	±	-
Land Acquisition	Approach provides necessary land with minimized negotiations, permit, public outreach	-	±	+
Age of Infrastructure	Equipment and infrastructure anticipated to provide >20 years of service life without significant maintenance	±	±	-
Water Blending	Approach maximizes the potential for raw and/or finished water blending for full benefit of majority of Thornton residents	-	±	-
Phasing	Ability to complete construction with minimized impact to existing operations	+	±	±

Table 20 presents the capital costs as well as operation and maintenance (O&M) costs for each Alternative.

Table 20. Capital and O&M Costs

Performance Parameter	Criteria	Alternative 1	Alternative 2	Alternative 3
Capital Cost	Construction, including land acquisition and supporting infrastructure	To be determined (TBD)	TBD	TBD
O&M Cost	Labor, utility consumption, and chemical estimates	TBD	TBD	TBD

6. Capital Improvement Program

The following sections summarize cost information assembled for the improvements identified in this TM. The information is intended to provide Thornton with the opportunity to establish budgetary elements as part of Capital Planning. Further details on methodology, cost estimates details, and assumptions are included in Appendix B.

6.1 Existing Improvements

Table 21 summarizes costs associated with improvements to existing infrastructure at WBWTP as identified in Section 2. Improvements that were identified in the Process Evaluation that have already been completed by Thornton have been omitted for brevity.

Table 21. Existing Improvements CIPs

Recommended Improvement	Budgetary Cost
Convert to Aluminum-based Coagulation[15]	$0
Taste & Odor Removal Improvements	$710,000
Membrane Surface Area Increase	$0
Residuals Management Improvements	$1,100,000
Clarifier Flow Distribution Study	$30,000
Study to Eliminate Recycling for Clean-in-Place Wastes	$30,000
Return Water Discharge Study	$50,000
Thornton Water Treatment Residuals Management Study	$110,000
Clarifier Coatings Rehabilitation	$500,000
Coagulant Tank Repairs	$40,000
Additional air compressor and reject pump	$500,000
Expansion of Train 8 by 5 cassettes along with vacuum pumps and blowers.	$1,840,000
TOTAL	**$4,900,000**

6.2 Future Improvements

Table 22, Table 23, and Table 24 presents the capital costs associated with each Alternative.

Table 22. Alternative 1 Capital Improvement Summary

Recommended Improvement	Budgetary Cost
Land Acquisition	$660,000
Improvements to WBWTP	$4,900,000
Raw Water Infrastructure	Cost in Raw Water MP
New NWTP (treatment plant only)	$63,070,000

[15] According on the original design dosage, the existing ferric coagulant systems were found to have adequate capacity and are assumed to be compatible with the aluminum-based chemistry. Based on input from testing with aluminum coagulants, the existing pumps appear to be adequate for the expected operational conditions. However, the testing indicated that higher coagulant doses may be required to achieve TOC removal. Further evaluation will be required at plant-scale to confirm the operational impacts of the change in chemistry, which could result in additional improvements if the existing pumping equipment is not sufficient for the required dosage.

Recommended Improvement	Budgetary Cost
Finished Water Infrastructure	Cost in Distribution MP
Residuals Management Infrastructure	$1,320,000
Power Supply to NWTP	$1,990,000
Standby Power (Tier 1 – Provide Standby Generator for Full Production)	$2,210,000
Standby Power (Tier 2 – Upgrade to Second Utility feed)	$1,330,000
Standby Power (Tier 3 – Upgrade to Emergency Generator meeting NEC)	$220,000
TOTAL	$75,700,000

Table 23. Alternative 2 Capital Improvement Summary

Recommended Improvement	Budgetary Cost
Demolition - existing TWTP	$2,050,000
Improvements to WBWTP	$4,900,000
Raw Water Infrastructure	Cost in Raw Water MP
TWTP Expansion	$59,830,000
Finished Water Infrastructure	Cost in Distribution MP
Residuals Management Infrastructure	$2,210,000
Standby Power (Tier 1 – Provide Standby Generator for Full Production)	$1,110,000
Standby Power (Tier 2 – Upgrade to Second Utility feed)	$1,330,000
Standby Power (Tier 3 – Upgrade to Emergency Generator meeting NEC)	$220,000
TOTAL	$71,650,000

Table 24. Alternative 3 CIPs

Recommended Improvement	Budgetary Cost
Land Acquisition	$240,000
Improvements to WBWTP	$4,900,000
Facility Building Renovations	$6,800,000
Raw Water Infrastructure	Cost in Raw Water MP
WBWTP Expansion	$47,860,000
Addition of Ozone to WBWTP	$11,790,000
Addition of GAC Contactors to WBWTP	$18,570,000
Finished Water Infrastructure	Cost in Distribution MP
Residuals Management Infrastructure	$6,150,000
Standby Power (Tier 1 – Provide Standby Generator for Full Production)	$3,320,000
Standby Power (Tier 2 – Upgrade to Second Utility feed)	$1,130,000
Standby Power (Tier 3 – Upgrade to Emergency Generator meeting NEC)	$200,000
TOTAL	$102,210,000

While there are specific differences between each Alternative, each result in the same net water production. There is insufficient additional data to accurately calculate a quantitative difference in Operating cost. Qualitative measurements for differences in Operations are presented in Section 5.

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.
- Thornton Water Project Hydraulic and Economic Analysis, CH2MHILL, 2017.
- Planning Area and Future Growth Analysis TM, AECOM, 2018.
- Regulatory Compliance Evaluation TM, AECOM, 2018.
- Public Water System Record of Approved Waterworks, CDPHE, 2017.
- Thornton Water Treatment Plant Replacement Project – Basis of Design Report, Burns and McDonnell, 2017.
- 10 States Standards, Recommended Standards for Water Works, 2012.

Appendix A – WBWTP Existing Improvements Evaluation

Existing improvements were identified for the Wes Brown Water Treatment Plant (WBWTP) based on the findings of the Performance Evaluation of the WBWTP. These improvements considered various approaches to improve known system deficiencies limiting production capacity or operational efficiencies. The proposed improvements in each operation area are discussed in detail below.

A.1 Improvements for Inlet Works Performance

The WBWTP Process Evaluation identified multiple areas for improved performance associated with the inlet facilities and initial raw water conditioning. In general, systems are appropriately sized but suffer from competition between sub-systems that negatively impact performance. The following sections identify changes by sub-system that could be implemented at WBWTP to improve inlet works performance as well as providing recommendation for elements to be carried forward for further study or capital planning.

A.2 Improvement for Manganese Removal Performance

Information reviewed as part of the WBWTP Process Evaluation indicated that there have been instances where the facility has exceeded the National Secondary Drinking Water Regulations of 0.05 milligrams per liter (mg/L) for total manganese. There are several factors that were identified that impact manganese removal at WBWTP, including limited contact time for the permanganate reactive solution, competition with powdered activated carbon (PAC), and addition of reduced manganese as part of the ferric coagulant introduction. The following paragraphs discuss potential system modifications to improve the effectiveness of the manganese removal process.

A.2.1 Add a secondary potassium permanganate feed point to address manganese introduced from ferric coagulant addition

Reduced manganese introduction as a result of coagulant addition is a common problem for facilities using iron salts. The current method employed at WBWTP to address the reduced manganese is to overfeed sodium hypochlorite at the inlet works to provide an oxidizing environment. However, the reaction kinetics for sodium hypochlorite with reduced manganese are considerably slower than potassium permanganate ($KMnO_4$). Given that there is adequate capacity within the $KMnO_4$ feed system, an alternative solution would be to add a secondary permanganate feed point further downstream of the current application point that would be specifically targeted to control of reduced manganese introduced with the ferric coagulant.

This alternative is not recommended for implementation at this time. The rationale is that the current permanganate feed point is believed to be impacted by the introduction of PAC as part of taste and odor control, and that the system has been operating at elevated levels due to the competition with oxidants introduced in the inlet works. There are already plans to relocate the hypochlorite feed associated with disinfection contact time to the finished water, which is anticipated to significantly reduce the competition within the inlet works. This is expected to cascade and improve the effectiveness of the PAC feed, which will then also reduce the competition for the permanganate feed.

Further monitoring of manganese removal performance is suggested after addressing the relocation of the disinfection step to determine if further modifications are required.

A.2.2 Improve effectiveness of the current potassium permanganate feed

The current permanganate feed has been identified as potentially being impacted due to insufficient contact time. Further, effectiveness is believed to be impacted by the introduction of PAC, which creates a demand for the permanganate residual. As identified above, the PAC dose is believed to be artificially high as a result of competition with both permanganate and hypochlorite feeds. It is anticipated that effectiveness will be improved when disinfection is relocated, which should improve PAC effectiveness, allowing for a lower mass dosage. It is believed that this will reduce consumption of the permanganate, allowing for deeper penetration into the inlet works systems and higher effectiveness.

Further monitoring of manganese removal performance is suggested after addressing the relocation of the disinfection step to determine if further modifications are required.

A.2.3 Change Coagulant Type

There have been multiple evaluations conducted by the City of Thornton (Thornton) on the efficacy of changing coagulant types at the WBWTP from the current ferric salt to an aluminum-based product. There has been previous resistance to this change because there was concern that the sludge produced from aluminum-based coagulation would not be suitable for land disposal, which would therefore require landfill disposal at a much higher cost to Thornton. Recent information from the sludge disposal company, however, has identified that they will be able to compost the aluminum sludge at a cost that is similar to the ferric sludge, thereby removing that obstacle.

Switching to the aluminum-based product would be expected to eliminate the secondary introduction of reduced manganese. Further, membrane manufacturers generally recommend the use of aluminum coagulant to avoid potential iron-based fouling. Based on these two factors, it is strongly recommended that Thornton convert to aluminum-based coagulation. The current feed systems are compatible with the either coagulant type, so there are no anticipated capital investments required for this change.

Based on previous studies completed by Thornton, the use of aluminum-based coagulants may require a higher coagulant dose; however, the specific differential in coagulant dose cannot be predicted with sufficient accuracy to allow for determination of the differential in operating cost. For the purposes of this analysis, the increase in operating cost has been assigned based on the difference in cost between the coagulant products plus an assumed 10 percent (%) increase in coagulant demand.

A.3 Improvements for Taste and Odor Removal Performance

Information reviewed as part of the WBWTP Process Evaluation indicated there have been instances where the facility has exceeded the National Secondary Drinking Water Regulations of 5 nanogram per liter (ng/L) for taste and odor compounds. There are several factors that were identified that impact taste and odor removal at WBWTP, including competition with oxidants and limitations on PAC feed capacity. The following paragraphs discuss potential system modifications to improve the effectiveness of the taste and odor removal process.

A.3.1 Relocate Disinfection away from PAC feed point

As discussed in the previous section, it is believed that the effectiveness of PAC is significantly diminished due to the impact of oxidants in the inlet works. The oxidants are believed to be reacting with the PAC, reducing the adsorptive capacity of the material for taste and odor compounds.

Relocating of the disinfection process to post-filtration is strongly encouraged for this facility. It is anticipated that the reduced competition will improve adsorptive capacity, which will result in higher unit efficiency per mass quantity of PAC fed. This will thereby result in greater removal effectiveness for taste and odor compounds and should allow the PAC dose to be reduced to closer to the original design value.

Further monitoring of taste and odor removal performance is suggested after addressing the relocation of the disinfection step to determine if further modifications are required.

A.3.2 Increase PAC Feed capability

Removal of taste and odor compounds is typically based on an adsorption isotherm, which indicates that higher doses are required to increase the removal effectiveness. While this logic is sound and would suggest that improving taste and odor removal can be accomplished via increased dosage, the removal for powder activated carbon has generally been demonstrated to be limited to 1-log reduction, which would require influent taste and odor compound concentration to be limited to less than 50 ng/L[16] in order to meet the Tier 1 criteria. Further, there are negative consequences with increasing the dosage of powder activated carbon as well, as the increased feed dose will result in higher solids loading on the clarification system, which may cascade into higher solids in the settled water and thereby requiring more frequently cleaning and maintenance for the membrane systems. Further, increasing PAC feed will result in a reduction in onsite storage availability, which will likely require installation of additional capacity.

Based on the belief that PAC feed effectiveness is impacted by the introduction of oxidants, increasing feed capabilities is not recommended at this time. Further monitoring of taste and odor removal performance is suggested after addressing the relocation of the disinfection step to determine if further modifications are required.

Post-Membrane Granular Activated Carbon Contactors

Granular activated carbon (GAC) is a different physical configuration of using carbon, but the material otherwise functions in a similar manner as PAC for the adsorption of organic compounds. Granular activated carbon is typically installed in fixed bed filters and sized based on a target empty-bed contact time of 5-10 minutes. Beds are operated in a downflow configuration, and the adsorptive surfaces are exhausted in a progressive pattern extending downward into the bed. Once the effluent reaches a preset breakthrough value (typically 70-80% of the target effluent concentration), the media is removed and replaced with fresh media, with the spent material either sent for regeneration or disposal.

Addition of GAC at WBWTP would need to be configured as post-membrane contactors; while use of GAC prior to the membranes is possible and may result in improved membrane life, the GAC would be exposed to higher levels of non-target organic compounds, which would result in more rapid exhaustion. Addition of post-membrane contactors can be configured in a variety of ways but would be suggested as a sidestream unit, with the capability of the unit to be bypassed except during peak taste and odor events. The equipment would be sized to allow for 100% of the membrane effluent to be directed to the post-contactors.

Installation of post-contactors would require the installation of new infrastructure at the WBWTP. This would be a new contactor building installed between the end of the membrane process and prior to the introduction of hypochlorite used as part of the disinfection clearwell.

Installation of post-membrane contactors is not recommended at this time. The installation of GAC would be a significant investment and would likely carry a significant operating cost, and it is believed that other improvements should be completed first to determine if taste and odor removal can be accomplished in a more cost effective manner.

In the event that the other system improvements do not sufficiently improve taste and odor compound removal, installation of GAC would be recommended for further evaluation.

A.3.3 Advanced Oxidation Process

There is a growing amount of research available on the use of advanced oxidation processes (AOP) for control of taste and odor compounds. While there are a variety of approaches that are being evaluated, the most common involve the use of ultraviolet (UV) reactors combined with an oxidative process (which could include ozone, hydrogen peroxide, or chlorine) to degrade taste and odor compounds[17]. The most effective approach has been combining UV light with hydrogen peroxide, which results in the formation of a hydroxyl radical that is highly effective in oxidizing taste and odor compounds. Research has shown that up to 60% reduction of taste and odor compounds (specifically 2-methylisoborneol and geosmin) could be achieved with AOP-based UV irradiation in ambient water quality conditions. Use of an UV-based AOP at WBWTP would most effectively be configured as part of a post-membrane treatment system, similar to the current UV reactors already installed at WBWTP.

However, the process requires significantly increasing the applied UV energy to several hundred millijoule per square centimeter (mJ/cm^2) MS2 reduction equivalent dose. The reactors at WBWTP are sized for disinfection dosage, which

[16] The Raw Water Master Plan is investigating system improvements to manage taste and odor concentrations to less than 50 ng/L.
[17] While AOPs are effective for oxidizing taste and odor compounds, the products from the process are often highly bio-available and could contribute to biofouling within downstream systems unless there is a companion organic removal process such as GAC or biologically-activate filtration.

is typically in the range of 40 mJ/cm^2. Therefore, pursing this approach would mostly likely require replacement of the existing UV equipment with much larger vessels and would have a significantly impact on annual operating costs due to the increased power and maintenance requirements.

While UV-AOP approach remains technically viable, the additional gains in taste and odor reduction do not justify the high capital and operating investment in this approach, in particular when contrasted against the potential opportunities to increase PAC effectiveness followed by exploring opportunities to increase dosage. It is recommended that Thornton continue to monitor the progression made within the water treatment industry on AOP to determine if this option becomes more cost effective in the future.

Ozone

The use of ozone for taste and odor compound control has been well documented in industry. Ozone is an effective oxidant, which reacts with most organic compounds (including taste and odor compounds) to allow for more effective removal. The introduction of ozone at the inlet works could be a powerful means to reduce the effectiveness of taste and odor compounds. When properly employed, ozone can support reduction of taste and odor compounds by greater than 90%.

However, ozone by itself does not remove organic compounds but instead tends to break molecular bonds in the organics species, which make them more assimilable in other process. This same process, however, makes the organic compounds more bio-available, and as such ozone typically requires an effective downstream organic removal step. This has been shown to be most effective with a biological process such biologically active filtration, which then consumes the organic species as part of respiration to remove it from the water stream.

The processes at WBWTP do not include an appropriate biological removal process. Introduction of ozone in the inlet work or other processes upstream of the membranes would likely lead to an increase in bio-available organic components, which would likely have a strong potential to be captured on the surface of the membrane fibers. These in turn could interact with other bacteria in the water source, leading to a biological reaction on the membrane surface that would result in significant biological fouling and reduction in membrane flux. While maintaining a quantity of residual oxidant in the water could prevent biological activity, this would also likely damage the membrane fibers, leading to loss of flux due to physical damage.

The processes downstream of the membranes at WBWTP do not include an organic removal step, so the introduction of ozone would likely result in partially degraded organic compounds being present in the finished water, which could result in negative impacts in the distribution system, including the potential for formation of disinfection byproducts and increased chloramine demand.

While ozone remains technically viable, this approach is not recommended due to the risks to membrane fouling, membrane damage, or degradation of finished water quality, in particular when contrasted against the potential opportunities to increase PAC effectiveness and/or opportunities to increase PAC dosage. Combination of ozone with GAC upstream of the membranes would represent a potential approach that manages the risks of ozone and biological fouling. However, this would represent the bulk of the treatment process being installed at TWTP and would mostly supplant the need for the membranes, which would result in additional capital and operational costs at WBWTP without significant benefit.

Improvements for Clarifier Performance

The WBWTP Process Evaluation has limited findings with regards to the clarifier performance. However, the operation of the clarifiers is both impacted by upstream systems and has direct impact on membrane performance. The following sections identify changes that should be implemented at WBWTP to improve clarifier performance.

A.4 Coagulant Mixing

The current format for mixing of the coagulant at the WBWTP (Intrudrr® system) involves introduction of coagulant in the inlet works piping using a pipe diffuser coupled with an in-line mixer to promote dispersion. Analysis of system performance at WBWTP provides indications that the mixing process has been inadequate, resulting in delayed flocculation and is also believed to potentially contribute to iron fouling in the membrane process.

Thornton has already identified and completed a design for a modified mixing approach to be employed at the inlet work using a flash mix system. This approach introduces the coagulant into a sidestream of the inlet water, which is then pressurized before being returned to the inlet work piping. The pressurized water adds significant energy to the mixing process and is anticipated to improve dispersion of the coagulant, which is thereby expected to result in improvements to coagulation and flocculation. AECOM has reviewed the design of the modifications to include the flash mix system and agrees with the approach that is targeted to be employed.

Thornton has previously advertised a bid for procurement and construction of the new flash mix system and is waiting on funding allocation. Given the potential impacts to improved water quality and reduced fouling potential, AECOM strongly endorses completing this work as soon as funding can be made available.

A.5 Flow Distribution

The original design of the clarifiers included flow meters and flow balancing valves, but this proved complicated to operate due to discrepancies between the individual flow signals as compared to overall flow signal, which would lead to loss of control. As such, WBWTP has been operating with the control valves in a fixed position and relying on hydraulics to achieve distribution. A study was conducted by AmWest in December 2005 indicated that the hydraulic split was "remarkably close."

Analysis of data for the clarifiers at WBWTP indicates there is a more significant concern with maldistribution of flow between the individual process units. Data indicates that Clarifier 1 and Clarifier 2 are receiving approximately 8 to 13% more flow than Clarifier 3 and Clarifier 4. This effect is observed in the quality of the clarified water, which is typically higher settled water turbidity for Clarifier 1 and Clarifier 2. Further, this effect is believed to contribute to membrane performance issues, as units closer to Clarifier 1 and Clarifier 2 hydraulically tend to require more maintenance.

While the overall performance differential is expected to be minor, there is sufficient evidence to indicate that further evaluation of the flow distribution is warranted to better define the consequence to the clarifier (and membrane) performance. In the event that a correlation can be established between flow and performance, it would be recommended to further improve the hydraulic distribution. This could be accomplished in means:

- The programming for the valves and flow signals should be further evaluated to determine if there is an opportunity to adjust the control values to allow for use of the automated features. Many treatment plants operate successfully with multiple control valves in parallel, albeit an investment must be made in tuning the system.
- In the event that the valves cannot be fully adjusted to a satisfactory level of control, a detailed evaluation of the inlet channel dynamics should be completed to determine appropriate modifications (weir plates or similar) to each clarifier to adjust the overall hydraulic to better balance the system.

A.6 Improvements for Membrane Performance

The WBWTP Process Evaluation identified the membrane process as being a significant constraint on the facility's production capacity. However, the design of the membrane system itself is appropriate based on similar facilities in other locations, and the majority of the constraint is be attributed to challenges associated with pretreatment systems and overall raw water quality. The following sections identify changes that should be implemented at WBWTP to improve membrane performance both in terms of productivity as well as longevity of the membranes themselves.

A.6.1 Change Coagulant Type

The WBWTP uses ferric as the primary coagulant. While this is a common chemical to be used in water treatment, studies have shown that membrane processes are more susceptible to fouling as a result of poor coagulation when the primary coagulant is an iron-based salt. WBWTP has completed multiple studies and has identified that use of aluminum chlorohydrate as a primary coagulant that produces similar water quality as the current coagulant and does not result in the same degree of fouling of membranes. The primary objection to the use of aluminum chlorohydrate has been that it was believed to have greater restrictions on disposal and would be required to be sent to a landfill, which would significantly increase the operating cost of using this chemical. However, more recent information from

Thornton's sludge management service has indicated that the sludge produced using aluminum chlorohydrate should be able to be composted, which would be competitive with the current land-application process employed with the ferric sludge.

A secondary concern for the use of aluminum chlorohydrate is associated with increased coagulant demand. A prior study by Thornton staff have identified that the coagulant demand may be higher than using ferric, which will result in an increase in annual operating cost. However, the use of aluminum chlorohydrate is also expected to have a positive impact on membrane life, which would be an offsetting cost. A conservative estimate would be that the membrane would be anticipated to have a minimum of 5% longer life as compared with operation with ferric.

A.6.2 Adjust Membrane Flux

The firm rated capacity design of the WBWTP as defined by the Colorado Department of Public Health and Environment (CDPHE) (which includes operation one the largest single unit of each process out of service) is 48.1 million gallons per day (mgd) based on the membrane flux value[18] of 34 gallons per square foot per day (gfd) at 1 degree Celsius (°C). As discussed in Section 3.3.1 of the Process Evaluation, this value is at the higher end of the range for other membrane facilities, and many of those facilities have a very high quality raw water source. The operational history of membrane fouling at WBWTP supports the argument that this value is not appropriate or sustainable by typical industry standards for membrane life and performance. While WBWTP has the facilities to operate at this flux value, it will likely require a more robust maintenance program to address the rapid rate of fouling. Further, membrane life will likely be significantly curtailed. A conservative estimate is that membrane life would be reduced by approximately 30% (corresponding to the difference volume process at WBWTP as compared to other similar facilities with lower flux values), replacement would need to be completed every 6-8 years in lieu of the target of 8-10 years that is the industry target for membrane life.

In order to provide for a more sustainable operation, it is recommended that a conservative winter flux of 22 gfd at 1°C be used. Based on the manufacturer recommended flux ratio (60 gfd at 20°C / 39.9 gfd at 1°C), this would equate to a summer flux of 38.8 gfd. The treatment capacity at WBWTP based on the estimated sustainable flux with the proposed improvements and the manufacturer design flux is identified in Table 25. The sustainable flux serves as the planning basis for development of the future alternatives.

Table 25. Existing WBWTP Treatment Capacity with Proposed Improvements

Parameter	Recommended		Original Design	
	Winter (0°C)	Summer (20°C)	Winter (0°C)	Summer (20°C)
Estimated potential flux (gfd)[1]	22[2]	38.8[3]	34[3]	60[3]
Membrane Area with One Train Out (10^6 ft^2)[4]	1.41		1.41	
Total Membrane Area (10^6 ft^2)	1.63		1.63	
Flow with One Train Out (mgd)[4]	31.1	54.8	48.0	84.8
Flow with All Train In Service (mgd)	35.9	63.4	55.5	97.9

[1]To achieve this flux, Thornton will need to implement proposed process modifications
[2]Based on a literature review of achieved flux from other facilities with same membranes
[3]Based on Summer and Winter design flux of 60 at 20°C and 39.9 at 0°C provided by membrane manufacturer
[4]Based on largest train out of service

Conversely, the Process Evaluation also identified operational issues with the existing treatment operations that impact the membrane flux, therefore reducing the achievable treatment capacity at the plant. In order to better support the original design flux, operational changes would need to be made to improve the life and flux of the membranes at WBWTP increasing the treatment capacity. These operational changes are as follows:

- Fully populate empty cassettes within the existing membranes trains
- Changing the location and procedure of Chlorine / PAC dosing

[18] Suez membrane design indicated operation at a membrane flux of 39.9 gfd at 1°C and 60 gfd at 20°C.

- Improving the mixing of coagulation/flocculation prior to the membranes
- Elimination or treatment of return of reject waste to remove foulants and residual polymers

These changes are largely geared at improving the pretreatment prior to the membranes so that higher quality influent water is passed to the membranes providing a higher and more sustainable membrane flux.

Another opportunity that could be explored would be to investigate means by which the influent water is heated, which would increase the membrane flux and result in a higher firm capacity at the winter conditions. One concept that could be explored is potential sewer heat recovery, which would be to take advantage the heat provided by the Metro Wastewater Reclamation District transmission line that runs through the WBWTP site, utilizing the potential of heat transfer to warm the raw water as it enters the WTP during cold water periods of the year. This concept has been employed at other locations and could potentially have synergistic value to MWRD, who has challenges during winter months with excess heat in their effluent. However, while sewer heat recovery has been implemented in the past, it is a low-quality heat and has generally been used to offset building heating. The efficacy of heat exchange between two water streams would require further exploration and would need to confirm that there is sufficient thermal gradient (typically 5 to 10 degree of temperature difference) to make the heat exchange viable. It should be noted that this approach would not be recommended to improve summer flux values, as increasing the water temperature in the summer would likely have significant consequences for biological fouling and disinfection byproduct formation.

A.7 Improvements for Finished Water

The WBWTP Process Evaluation generally identified that the Finished Water facilities are adequately sized for the intended services; however, the facility is adjusting the disinfection strategy, which will directly impact the Finished Water services. The following section summarizes the changes to the Finished Water infrastructure.

A.7.1 Creation of chlorine contact disinfection cell

As discussed in the Process Evaluation Technical Memorandum (TM), the WBWTP currently uses pre-chlorination in the Inlet Works to achieve the necessary disinfection. While this approach has been successful, it has suffered from competition with other Inlet Works systems, resulting in a significant reduction in efficiency.

Thornton has elected to modify the facility to move to post-membrane disinfection. A design has been completed that will convert a portion of the onsite storage reservoir to a chlorine contact cell. This will include modifying the interior baffling to provide a contact pass as well as modification to chemical feed locations.

The changes to the onsite reservoir will have a negligible impact on storage and is expected to significantly improve overall efficiency of facility operations. The current chemical feed equipment coupled with the revised configuration will allow for sufficient contact time to achieve disinfection up to a total treatment flow of 100 mgd.

The existing disinfection system is adequate for existing and future flows up to 100 mgd. Contact time of 6 (min*mg/L) is required based on 10°C and a pH range of 6-9. WBWTP has a minimum, maximum, and average water temperature of 11.46, 25.53, and 20.73°C respectively[19]. A baffle factor of 0.7 and 1.5 safety factor were used, consistent with the recent Thornton Water Treatment Plant (TWTP) Basis Of Design Report and the CDPHE Record of Approval.

A.8 Improvements for Solids Management

The WBWTP Process Evaluation had limited operational data by which to complete a quantitative analysis of the residuals management facilities. Evaluation of the systems based on qualitative input from operations staff indicated that the facilities are adequately for current productions, but calculations based on 10 States Standards indicate that the lagoons may become undersized at higher flow rates and could be a constraint on operations. Additional lagoon volume will be required to allow for adequate time for dewatering and maintenance activities.

[19] Temperature values represent current operational practices, which include shutting down WBWTP from late November until early March. If operations are modified to include winter production, the facility would be anticipated to see a minimum water temperature of approximately 4°C.

There are a number of operational practices associated with residuals management employed at the facility that have opportunities for improvements. In particular, the facility would benefit from adopting operational practices that focus on managing foulants in a manner to remove them from the system. The following section summarizes the changes to the Solids Management infrastructure.

A.8.1 Discharge of Capital Improvement Program (CIP) Waste to Sewer

Due to the tight porosity of membrane systems in combination with the chemical treatments applied to the raw water, there are a number of different compounds that can become attached to the surface of the fibers themselves. The majority of these compounds can be removed through cleaning regimes, which typically involve introduction of chemical cleaning solutions (using a clean-in-place system) to remove the compounds.

In the majority of typical membrane system designs, the process of cleaning the membranes simply remobilizes the compounds into the cleaning solution. This results in a concentrated solution of organic and inorganic fouling compounds that must be managed. The preferred approach for this waste product is to discharge the materials to a sewer system that has the capacity and capability to process the material. This has the benefit of both removing the foulants from the water circuit and allowing for appropriate processing of the compounds, typically to an inert state.

At WBWTP, the CIP wastes are currently chemically neutralized and returned to the West Gravel Lakes (WGL). While the stabilization typically manages the pH of the solution, the majority of the organic and inorganic species remain within the water column. Therefore the compounds are not removed from the water circuit and have the potential to re-foul the membranes. This may result in accumulation and increasing concentration of fouling species in the WGL over time.

In order to mitigate the potential for accumulation of foulants in WGL, it is strongly encouraged that Thornton begin to discharge CIP cleaning solutions to sewer instead of to WBL. This will require entering into discussion with the receiving wastewater authority (Metropolitan Wastewater Reclamation District [MWRD]) to amend the discharge permit. Discharges would need to be in accordance with the rules and regulations governing the operation, use and service for MWRD, but it is expected that the materials and quantities discharged from WBWTP should be within the accepted limits. The materials will likely still require chemical neutralization prior to discharge to sewer.

It is expected that adopting this approach will significantly reduce the mass of fouling species that are likely being contributed to WGL. This in turn is anticipated to improve (over time) the quality of the water within WGL, which has been shown to lead to higher rate of fouling when used as a significant portion of the influent water blend between West and East Gravel Lakes. There may also be a secondary benefit, in that WGL has been shown to have lower concentrations of taste and odor compounds. The ability to use high percentages of WGL water during peak taste and odor events will further reduce the need for treatment infrastructure for those compounds.

A.8.2 Discharge of Return Water Downstream of West Gravel Lakes

Another option for management of fouling compounds for the WBWTP facility would be to redirect return water from the system away from the raw water supplies altogether. In this approach, the return water from the lagoons would be redirected to a point on the system that is downstream of the source supplies for West and East Gravel Lakes. This approach would virtually eliminate the potential for recycling of fouling compounds in the return water from the treatment facilities, which would be anticipated to have a significant positive benefit to the system.

The consequence of this action is that there will be a significant loss in raw water resource to the WBWTP. Assuming both facilities are following 10 States Standards for recycling of return water[20], this could represent up to 8.34 mgd[21] of lost water resource. It has been indicated by Thornton staff that this water value may be “captured” elsewhere in the system as a credit, so there may not be an actual loss. Further analysis would be required to confirm if the raw water supply systems can provide the additional quantity of water to offset the loss of resource at this location as well as to confirm that the water value can be captured in the system.

[20] 10 States Standards indicates that recycled water should be at or below 10% of the influent water to a facility.
[21] Volume is based on 10% of the rated capacity of Thornton Water Treatment Plant (20 mgd) and summer maximum production rating of WBWTP (63.4 mgd) based the adjusted flux values indicated in Section 2.1.3.2.

This approach is not currently recommended for implementation by Thornton, as it is anticipated that water quality for the return water can be improved by implementing other changes, which will then allow for utilization of this resource at this location. But it is recommended that Thornton conduct further study of the raw water supply and return water systems to determine if there are effective means to capture water at downstream locations in the future if fouling continues to be a major challenge at WBWTP after making the other process improvements.

A.8.3 Treatment of Return Water

As an alternative to discharge of CIP waste to sewer or discharge of return water downstream, Thornton could choose to address the problem more directly by applying treatment approaches to the return water. The lagoons are believed to function appropriately as a sedimentation system to capture solids, so the focus for return water treatment would be to remove or inactivate colloidal or dissolved fouling compounds. The most probable approach to return water treatment would likely include:

- Introduction of an oxidant (sodium hypochlorite or ozone) to address dissolved organic compounds including polymers.
- Introduction of a coagulant after oxidation to form a settable solid that would allow colloidal material to convert to a settable solid.

Given the configuration of WBWTP, the current approach to introduction of a coagulant in the Inlet Works would likely be suitable for addressing colloidal materials. However, the oxidation step may be a challenge to implement. Specifically, the introduction of oxidants on the return water would be expected to have a high demand, which could require high dosages. This could represent a concern with the long-term impact of oxidant impact on the natural biological processes raw water impoundment, in particular if there is an excess residual that is carried into the ponds. Conversely, insufficient oxidant dosage could potentially be reversed within the raw water storage impoundments due to natural biological activity, which could re-activate the compounds as a fouling species.

While technically viable as a solution, treatment of return water is not recommended for implementation at this time at WBWTP due to the complexity of balancing treatment requirements with raw water supply environment. However, this option should be a target for future study for Thornton after implementation of other process improvements to determine if there is a potential opportunity for improved efficiency in the event that the rate of fouling at WBWTP does not improve to a point that allow for sustainable production at a membrane life that matches industry standards.

A.8.4 Solids Management at TWTP

The WBWTP is currently exceeding the 10 States Standards for use of return water as a fraction of influent water sources, primarily due to the fact that residuals treatment for two facilities is managed at a single facility. This situation is expected to be further impacted by the addition of filter-to-waste as part of the new Thornton Water Treatment Plant design, which will result in higher quantity of water discharged to the WBWTP lagoons.

The future operating strategy is that all treatment facilities will have the opportunity to blend raw water from all of the available Thornton resources, which could involve transfer of Gravel Lake water to the new Thornton Water Treatment Plant and transfer of the higher quality Standley Lake water to WBWTP[22]. This would have the benefit of both improving the influent quality at WBWTP and spreading the impacts of return water across more facilities. However, this would require a significant amount of pumping energy to move water resources from location to location, and therefore it is not likely an efficient practice.

As an alternative to this approach, Thornton could evaluate the opportunity to install solids management infrastructure into the new Thornton Water Treatment Plant. The advantage of this approach is that it would allow the new facility (which is already equipped with ozone) to manage the treatment residuals that are likely to contain polymers from flocculants, which are a significant area of concern for membrane treatment systems. Further, this would align better with 10 States Standards for the management of return water as a percentage of treatment. Lastly, this would likely

[22] Currently there is a pipeline between WBWTP and TWTP, which is used for transfer of Standley Lake and Gravel Lakes waters between facilities. However, there is only a single pipeline, which limits transfers to one direction at any given time. The Raw Water Master Plan is evaluating required improvements to infrastructure to allow for distribution of raw water supplies to all facilities simultaneously

eliminate the need for the gravity interconnect line from the TWTP to the WBWTP lagoons, which would eliminate the potential bottleneck in that operation.

It is recommended that Thornton conduct further evaluation and site planning for the eventual installation of solids management facilities at the new TWTP. This approach is anticipated to improve overall treatment quality, provide increased independence between facilities, and reduce the potential for fouling at WBWTP.

A.9 Other Miscellaneous Improvements

While the majority of the findings for the future alternatives are directly correlated to improvements in process functionality, there are other improvements that have been identified that are important but do not otherwise directly impact water quality. The following sections describe other system improvements that were identified in order to maximize the functional life of equipment and reduce system maintenance.

A.9.1 Carrier Water Softening

Sodium hydroxide (NaOH) is added to the finished water at WBWTP in order to adjust the pH and adjust alkalinity to desired conditions for the distribution. The system uses a carrier water system, and the water prior to the introduction of the NaOH has high hardness. The resulting reaction results in significant build-up of scaling material within the NaOH feed system.

In order to reduce scale formation, the carrier water should be softened. Thornton has previously evaluated this and has previously identified the necessary upgrades. This improvement has been employed at other facilities with similar hardness issues and would be expected to significantly curtail scaling within the system. It is recommended that the softening system should be prioritized in capital planning for the facility.

A.9.2 Clarifier Coating

Thornton has previously identified a project to complete recoating of the clarifiers. This is a typical maintenance process that is strongly encouraged to maximize the functional life of equipment. It is recommended that the coating of the clarifiers should be prioritized in the capital planning for this facility.

A.9.3 Coagulant Tank Repairs

The coagulant tanks at WBWTP have suffered from tank failures if filled to the full capacity of the tank. This likely is an indication of a lack of support within the tank base, and the level at which the failure occurs represents a critical loading point.

Tank point loading is not an uncommon problem and typically indicates that there is not a good interface between the tank and the support pad. There are multiple means that can be employed to address the situation:

- Operate below the critical tank level: Under this approach, the tank would continue to be used as is the current practice, with the tank level being maintained below the critical level. There is no cost with this approach and has a limited consequence to the storage capacity on site. This approach is recommended based on the ready availability of coagulant supplies.
- Retrofit the tank base / pad to improve the interface. In this scenario, the tank bottom and support pad would be carefully surveyed to identify gaps in interface points, and those locations would be reinforced with additional supporting material. This approach is not recommended, as the bottom of the tank typically deforms under loading, so it is unlikely that there will be the ability to properly map the interface to eliminate the potential for point loading failures.
- Add a tank liner system. Under this scenario, the tank interior would be lined with a polyethylene liner to provide protection against failures in the fiberglass reinforced plastic tank. While this approach is generally sound, there is no ability to inspect the liner system, which could degrade with time. As such the liner may offer limited protection against failure and may not represent a longer term solution.

Thornton has elected to move forward with the installation of a liner system in Ferric Tank 1. The performance of this system should be monitored over time to determine if further improvements are required.

A.9.4 Powdered Activated Carbon Line Improvements

The current PAC feed lines have experienced multiple instances of failure due to plugging. In order to reduce the maintenance requirements associated with addressing plugging, the following changes should be considered:

- Review the piping configuration and ensure that long radius elbows are used throughout the system to prevent low velocity zones.
- Install additional hose connection points to allow for regular line flushing.
- Install additional dismantling points to allow for system inspection and more robust cleaning activities such as pipe swabbing or rodding.

A.9.5 PAC Storage Improvements

As discussed in the Process Evaluation TM, the current PAC system has limited storage capacity, and there are concerns that the storage is inadequately under peak loading conditions. As previously discussed in this TM, the carbon effectiveness is believed to be significantly impacted by competition, but storage would still be limited under even the original design dosage conditions. It is recommended that Thornton further evaluate improvements for PAC storage, in particular for allowing for dry storage (anticipated to be supersacks). This would likely require the installation of a PAC wetting system to allow for making down the PAC into the slurry bunker as volumes are decreased. This option is preferred over the alternative of installing additional slurry storage capacity, as PAC is stable in dry storage, whereas installation of an additional slurry bunker would require a significant capital investment and would lead to an additional operational cost for the continuous motor load for the mixer to maintain the slurry suspension.

Appendix B – Cost Assumptions for Water Treatment Projects

AECOM was requested by the City of Thornton (Thornton) to develop project costs for identified Capital Improvement Programs (CIP) as part of the Water Treatment Facilities Master Plan. This section presents the summary of assumptions and 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 WBWTP to address existing performance issues as well as installation of new treatment infrastructure. The cost estimating has included:

- Cost of improvements or rehabilitation of older systems to allow legacy systems to meet the performance expectation and similar service life as newer infrastructure
- Installation of new facilities and/or expansion of existing facilities as required to meet the production requirements as dictated by the Distribution Master Plan.

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 reference information including:

- Quantities and sizing developed based on work performed by AECOM in the development of this Master Plan, including process analysis of existing infrastructure as well as conceptual improvements developed to meet the requirements to address system deficiencies for water quality or production;
- Scaled equipment costs developed from historic parametric data of construction and installation costs from similar AECOM and City of Thornton projects;
- Budgetary vendor quotations for materials and equipment, where available;

Where applicable, costs from prior to June 2019 have been adjusted based on Engineering News Record (ENR) construction indices.

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 of 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 developed based on direct equipment costs allowances for other direct costs as well as 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, or temporary facilities.

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

- Improvements at Wes Brown Water Treatment Plant (WBWTP)
- Capital Improvement Project Alternatives for future water treatment
  - Alternative 1: Construction of a new Water Treatment Plant

- Alternative 2: Expansion of the new Thornton Water Treatment Plant (TWTP)
- Alternative 3: Expansion of the WBWTP

2. Improvements at WBWTP

The following section summarizes the elements and basis of estimate for defined improvements to the WBWTP as identified in the Process Evaluation TM. The estimate is intended identify studies and improvements to stabilize and enhance treatment specific to the following elements:

- Improved manganese reduction and removal
- Improved taste and odor compound capture and removal
- Improved clarifier performance and system rehabilitation
- Improved membranes operational and maintenance practices and increased capacity
- Improved residuals management practices and facilities
- Other miscellaneous improvements

Table 1: Improvements at WBWTP Cost Basis

Recommended Improvement at WBWTP	Cost Information Source	Basis of Estimate
Convert to aluminum-based coagulants instead of iron-based	N/A	Existing feed equipment anticipated to be adequate for alternative chemistry; dosage for operations assumed to be similar to current conditions
Taste & Odor Removal Improvements	Parametric Estimate	Increased storage and improvements to existing feed infrastructure "$= -0.0142X^2 + 195.03X + 194823 - X=Carbon Feed - Lb/h. 76.3 mgd @20 mg/L = 530lbs/hr. Assume existing system provide ~210 lb/hr based on 50 mgd@12 mg/L PAC dose from Design Criteria. Additional 30% added to cost for existing system improvements
Membrane Surface Area Increase	City of Thornton	Intention is to replace and fully equip 1 membrane train per year and use older membranes to equip unused cassettes to add capacity
Lagoon Improvements	10 States Standards City of Thornton Parametric Estimate	Calculations based on 10 States Standard and using historic residual generation rates provided by City of Thornton, indicating a need for 70,000 square feet of additional lagoons. Parametric information for similar lagoons is $0.70/gallon. Lagoons assumed to be 3' deep.
Clarifier Flow distribution study	Previous similar AECOM projects	Evaluation of the flow dynamics to determine appropriate modifications to each clarifier to adjust the overall hydraulics to improve the system balance.
Study to Eliminate Recycling for Clean-in-Place Wastes	Previous similar AECOM projects	Evaluation of the flow dynamics to determine appropriate modifications to each clarifier to adjust the overall hydraulics to improve the system balance.
Return Water Discharge Study	Previous similar AECOM projects	Evaluate water quality data from CIP and assemble application for SIC discharges to sewer. Limited analytical work to characterize CIP waste

Recommended Improvement at WBWTP	Cost Information Source	Basis of Estimate
Thornton Water Treatment Residuals Management Study	Previous similar AECOM projects	Residuals Management Study to determine best management practices for Return Water Management. Study expected to include evaluation of impacts of discharge downstream of Gravel Lakes, which could be considered after implementing other improvements in the event that the rate of fouling has not been adequately addressed.
Clarifier Coating Rehabilitation	City of Thornton	Study to determine best practices to manage residuals as part of treatment plants. Study would include evaluation of existing lagoon operations as well as potential enhancement, such as adding residuals management to the new TWTP or inclusion of mechanical dewatering at one or multiple treatment facilities.
Coagulant Tank Repairs	City of Thornton	Cost information provided by City of Thornton; existing Maintenance project identified in order to maintain the service life of clarification equipment.
Additional air compressor and reject pump	City of Thornton	Maintenance project to address risk of cracking when the tank is filled to capacity.
Expansion of Train 8 by 5 cassettes along with vacuum pumps and blowers.	City of Thornton	Cost information provided by City of Thornton; project to improve redundancy of existing equipment at WBWTP

3. Future Improvements

The following section summarizes the elements and basis of estimate for improvements to the treatment infrastructure to meet the future capacity requirements as identified in the Future Alternatives TM. The estimate is configured to represent the following elements:

- Land Acquisition
- Expansion of existing facilities to increase production capacity
- Installation of new facilities to increase production capacity
- Modification to existing facilities to reclaim land area or address process deficiencies arising from expansion
- Improvements to Power infrastructure to increase reliability and redundancy.

Table 2 identifies the source and basis of estimate for the improvements associated with the Alternative 1 New Water Treatment Plant.

Table 2: CIP Alternative 1 Cost Basis

Capital Improvement Project	Cost Information Source	Basis of Estimate
Land Acquisition	Land parcel values from County Assessor	Identified value for report location: Parcel # 157119200002. Adjusted values ($/acre) to coincide with adjacent parcels #157119117036 & #157119117037. Space requirement is based on scaled value for new TWTP, adjusted to reflect the future flow requirement.
New NWTP (treatment plant only)	TWTP Bid Information	Assumed similar treatment process for new TWTP, used construction cost as basis for estimate. Adjusted price to future flow requirements.
Residuals Management Infrastructure	Similar AECOM projects	Calculated based on estimated solids loading from future TWTP as provided by Thornton.

Capital Improvement Project	Cost Information Source	Basis of Estimate
		Lagoon sized based on 8 lb solids handling per sf, 3 ft deep, results in 73,500 sf at NWTP; Previous project experience indicates an installed cost of $0.70/gal for lagoon
Power Supply to NWTP	Similar AECOM projects	Baseline power supply cost developed based on anticipated electrical load and previous project cost information. Pricing including permitting, offsite infrastructure, and power supply to transformer
Standby Power (Tier 1 – Provide Standby Generator for Full Production)	Similar AECOM projects	Generator sized based on anticipated full production load, requires of 800kW/1000kVA Generator. Cost provided based on similar recent costs for generators from similar projects.
Standby Power (Tier 2 – Upgrade to Second Utility feed)	Similar AECOM projects	Additive percentage of initial cost for secondary supply. Percentage based on professional experience; permitting handled with baseline power supply.
Standby Power (Tier 3 – Upgrade to Emergency Generator meeting NEC)	Similar AECOM projects	Incremental cost difference for upgrade of generator equipment from Tier 1 to meet NEC for Tier 3

Table 3 identifies the source and basis of estimate for the improvements associated with the Alternative 2 Thornton Water Treatment Plant Expansion.

Table 3: CIP Alternative 2 Cost Basis

Capital Improvement Project	Cost Information Source	Basis of Estimate
Demolition - old TWTP		71,750 SF TTP (not including clearwell #1) @ $10/SF for demolition, hauling, disposal, Clearwell = 9,600 SF @ $5/SF for demolition, hauling, disposal, $2/SF Restoration for total area.
TWTP Expansion	TWTP Bid Information	Used TWTP Construction cost as basis for estimate, adjusted to reflect flow and elimination of additional Admin Bldg, CCC, or BWPS
Residuals Management Infrastructure	Similar AECOM projects	Calculated based on estimated solids loading from future TWTP as provided by Thornton. 8 lb solids handling per sf, 3 ft deep, 141,500 sf at TWTP. Previous project experience indicates an installed cost of $0.70/gal for lagoon
Standby Power (Tier 1 – Provide Standby Generator for Full Production)	Similar AECOM projects	Generator sized based on anticipated full production load, requires of additional 400kW/500kVA Generator. Cost provided based on similar recent costs for generators from similar projects.
Standby Power (Tier 2 – Upgrade to Second Utility feed)	Similar AECOM projects	Additive percentage of initial cost for secondary supply. Percentage based on professional experience; permitting handled with baseline power supply.
Standby Power (Tier 3 – Upgrade to Emergency Generator meeting NEC)	Similar AECOM projects	Incremental cost difference for upgrade of generator equipment from Tier 1 to meet NEC for Tier 3

Table 4 identifies the source and basis of estimate for the improvements associated with the Alternative 3 Wes Brown Water Treatment Plant Expansion.

Table 4: CIP Alternative 3 Cost Basis

Capital Improvement Project	Cost Information Source	Basis of Estimate
Land Acquisition	Land parcel values from County Assessor	Used same value for $/acre as Alternative 1. Land Acquisition based on additional area required for facility expansion beyond available space.

Capital Improvement Project	Cost Information Source	Basis of Estimate
Facility Building Renovations	Parametric estimate	Take-off indicates 57,387 SF for renovation. Unit costs developed from similar project experience at other facilities
WBWTP Expansion	Similar AECOM projects	Parametric Cost Curves: • Membrane: $500,000/mgd per parametric cost curve • Clarifier: $ = 3470.6 * (5398 SF Basin Area)^0.6173 (Cost Equation $ = 3470.6 X^0.6173 - X=Basin Area - SF; 2 additional, 2699 sf each, 18.35 MGD each) • Chemical Feed ($= 20990 X^0.3190 X= Feed-Lb/d; assume 40% increase from 30 mg/L at 54.8 mgd) • Piping+Electrical+I&C: Factored as 50% of Process equipment Cost Building Expansion: 17050 sf, $150 unit cost per SF"
Addition of Ozone to WBWTP	Similar AECOM projects	Parametric Cost Curves: $ = 89.217 X^0.6442 - X=Contact Chamber Volume-GAL (500 Kgal Contact Chamber for 10 min CT) $ = 31,015 X^0.6475 - X=Ozone Gener.Cap.-Lb/d (2500 ppd generator for 4 mg/L at 74.8 mgd)
Addition of GAC Contactors to WBWTP	Similar AECOM projects	Parametric Cost Curves: Contactor Basin: $ = -0.0034X^2 + 575.85X + 665305 - X=Filter Area - SF (8700 sf 74.8 mgd @6 gpm/sf) Backwashing Pumping: $ = 292.44 X + 92497 - X=Filter Surface Area -SF (8700 sf 74.8 mgd @6 gpm/sf) Washwater Surge Basin: $ = 5.6602 X^0.8473 - X=Storage Volume-GAL (450Kgal, 20 min @ 15gpm/sf)
Residuals Management Infrastructure	Similar AECOM projects	Calculated based on estimated solids loading as provided by Thornton. 8 lb solids handling per sf, 3 ft deep, 393,000 sf additional at WBWTP. Previous project experience indicates an installed cost of $0.70/gal for lagoon
Standby Power (Tier 1 – Provide Standby Generator for Full Production)	Similar AECOM projects	Generator sized based on anticipated full production load, requires of 800kW/1000kVA Generator. Cost provided based on similar recent costs for generators from similar projects.
Standby Power (Tier 2 – Upgrade to Second Utility feed)	Similar AECOM projects	Additive percentage of initial cost for secondary supply. Percentage based on professional experience; permitting handled with baseline power supply.
Standby Power (Tier 3 – Upgrade to Emergency Generator meeting NEC)	Similar AECOM projects	Incremental cost difference for upgrade of generator equipment from Tier 1 to meet NEC for Tier 3

4. Additional Costs

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

Costs for improvements to increase or improve raw water supply or finished water distribution are being provided in the respective sections of the Master Plan.

Direct:

- Cost are inclusive of Equipment, Labor, Materials, and other Direct Construction Costs

Indirect:

- Mobilization and Site Setup 5%
- Engineering Design 15%
- Legal and Administrative 5%

- Freight / Shipping: 5%
- Construction Management 10%
- Taxes: 10%
- Bonding and Insurance: 10%
- Overhead and Profit: 10%

Contingency

- Contingencies 25% (AACE Class V)

ENR Index June 2019 = 7542.17

Recommended Improvement at WBWTP	Type of Cost (Study or Capital)	Direct Cost	Indirect Costs (70% of Direct Cost)	Contingency (25% of D+I)	Project Cost	Description
Convert to alumimun-based coagulants instead of iron-based	Capital	$0	$0	$0	$0	Existing feed equipment anticipated to be adequate for conversion in chemistry
Taste & Odor Removal Improvements	Capital	$332,512	$232,758	$141,318	$710,000	$= -0.0142X^2 + 195.03X + 194823 - X=Carbon Feed - Lb/h. 76.3 mgd @20 mg/L = 530lbs/hr. Assume existing system provide ~210 lb/hr based on 50 mgd@12 mg/L PAC dose from Design Criteria
Membrane Surface Area Increase	Capital	$0	$0	$0	$0	Intention is to replace and fully equip 1 membrane train per year and use older membranes to equip unused cassettes to add capacity
Residuals Management Improvements	Capital	N/A	N/A	N/A	$1,100,000	Calculations based on 10 States Standard and using historic residual generation rates provided by City of Thornton, indicating a need for 70,000 square feet of additional lagoons. Parametric information for similar lagoons is $0.70/gallon. Lagoons assumed to be 3' deep.
Clarifier Flow distribution study	Study	$15,000	$10,500	$6,375	$30,000	Evaluation of the flow dynamics to determine appropriate modifications to each clarifier to adjust the overall hydraulics to improve the system balance.
Study to Eliminate Recycling for Clean-in-Place Wastes	Study	$15,000	$10,500	$6,375	$30,000	Evaluate water quality data from CIP and assemble application for SIC discharges to sewer. Limited analytical work to characterize CIP waste
Return Water Discharge Study	Study	$25,000	$17,500	$10,625	$50,000	Residuals Management Study to determine best management practices for Return Water Management. Study expected to include evaluation of impacts of discharge downstream of Gravel Lakes, which could be considered after implementing other improvements in
Thornton Water Treatment Residuals Management Study	Study	$50,000	$35,000	$21,250	$110,000	Study to determine best practices to manage residuals as part of treatment plants. Study would include evaluatin of existing lagoon operations as well as potential enhancement, such as adding residuals management to the new TWTP or inclusion of mechanical dewatering at one or multiple treatment facilities.
Clarifier Coating Rehabilitation	Capital	N/A	N/A	N/A	$500,000	Cost informaton provided by City of Thornton; existing Maintenance project identified in order to maintain the service life of clarification equipment.
Coagulant Tank Repairs	Capital	$16,000	$11,200	$6,800	$30,000	Maintenance project to address risk of cracking when the tank is filled to capacity.
Additional air compressor and reject pump	Capital	N/A	N/A	N/A	$500,000	Cost informaton provided by City of Thornton; project to improve redundancy of existing equipment at WBWTP
Expansion of Train 8 by 5 cassettes along with vacuum pumps and blowers.	Capital	N/A	N/A	N/A	$1,840,000	Cost informaton provided by City of Thornton; project to increase capacity of Membrane Train 8 at WBWTP
				Total	$4,900,000	

ENR Index June 2019 = 7542.17

Capital Improvement Project	Qnty	Units	Unit Cost	Direct Cost (not rounded)	Indirect Costs (70% of Direct Cost)	Contingency (25% of D+I)	Project Cost	Info Source
Alt 1 New Water Treatment Plant								
Land Acquisition	15	Acres	$21,510	$311,889	$218,322	$132,553	$660,000	County Assessor, actual parcel has low reported value, used adjacent parcel actual value, not accessed value, Parcel is zoned A-3
Improvements to WBWTP							$4,900,000	From Existing CIP Estimate
Raw Water Infrastructure							Cost in Raw Water MP	
New NWTP (treatment plant only)							$63,070,000	TWTP Bid Info, Adj for Flow Diff & Time
Finished Water Infrastructure							Cost in Dist MP	
Residuals Management Infrastructure	1,895,590	gal	$0.32	$597,111	$417,978	$304,527	$1,320,000	8 lb solids handling per sf, 3 ft deep, 73,500 sf at NWTP; 315,000 sf at WBWTP. Previous project experience: $0.315/gal direct cost for lagoon ($0.70/gal installed cost)
Power Supply to NWTP	1	EA	$900,000	$900,000	$630,000	$459,000	$1,990,000	Baseline power supply cost, including offsite infrastructure and power supply to transformer
Standby Power (Tier 1 – Provide Standby Generator for Full Production)	1	EA	$1,000,000	$1,000,000	$700,000	$510,000	$2,210,000	800kW/1000kVA Generator
Standby Power (Tier 2 – Upgrade to Second Utility feed)	1	EA	$600,000	$600,000	$420,000	$306,000	$1,330,000	Additive cost for secondary supply; permitting handled with baseline power supply
Standby Power (Tier 3 – Upgrade to Emergency Generator meeting NEC)	1	EA	$100,000	$100,000	$70,000	$51,000	$220,000	Upgrade of equipment from Tier 1 to meet NEC
						Total	**$75,700,000**	
Alt 2 Expansion of Thornton Water Treatment Plant								
Demolition - existing TWTP	71750 sf 9600 sf	sf	$10 $7	$928,200	$649,740	$473,382	$2,050,000	Takeoff (Google Earth): 71,750 SF (not including clearwell) $10/SF demolition, hauling, disposal, Clearwell = 9600 SF @ $5/SF, $2/SF Restoration for total area.
Improvements to WBWTP							$4,900,000	From Existing CIP Estimate
Raw Water Infrastructure							Cost in Raw Water MP	
TWTP Expansion							$59,830,000	TWTP Bid Info, Adj for Flow Diff & Time, Deducts for TWTP Expansion (no Admin Bldg, 2/3 Floc/Sed, no new CCC/BWPS))
Finished Water Infrastructure							Cost in Dist MP	
Residuals Management Infrastructure	3,180,870	gal	$0.32	$1,001,974	$701,382	$511,007	$2,210,000	8 lb solids handling per sf, 3 ft deep, 141,500 sf for TWTP; no changes to WBWTP. Previous project experience: $0.315/gal direct cost for lagoon ($0.70/gal installed cost)
Standby Power (Tier 1 – Provide Standby Generator for Full Production)	1	EA	$500,000	$500,000	$350,000	$255,000	$1,110,000	Additional 400kW/500kVA Generator
Standby Power (Tier 2 – Upgrade to Second Utility feed)	1	EA	$600,000	$600,000	$420,000	$306,000	$1,330,000	Estimate from Electrical Engineer based on previous project experience
Standby Power (Tier 3 – Upgrade to Emergency Generator meeting NEC)	1	EA	$100,000	$100,000	$70,000	$51,000	$220,000	Upgrade of equipment from Tier 1 to meet NEC
						Total	**$71,650,000**	
Alt 3 Expansion of Wes Brown Water Treatment Plant								
Land Acquisition	5	Acres	$21,510	$107,548	$75,284	$54,849	$240,000	Land Value cost from Alternative 1, land acquisition adjusted to WBWTP requirements
Improvements to WBWTP							$4,900,000	From Existing CIP Estimate
Facility Building Renovations- roof, building, finishes	57,387	sf	$61.71	$3,541,570	$2,479,099	$1,806,201	$7,830,000	Calc'd unit costs of Div 7, 8, 9, 10 from TWTP bid for Main Bldg, Adj for time
Raw Water Infrastructure							Cost in Raw Water MP	
WBWTP Expansion	1	EA	$21,655,677	$21,655,677	$15,158,974	$11,044,395	$47,860,000	Membrane: $500,000/mgd per cost Curve, 21.5 mgd (treated as new since not planned expansion) Clarifier: $ = 3470.6 * (5398 SF Basin Area)^0.6173 (Cost Equation $ = 3470.6 X^0.6173 - X=Basin Area - SF; 2 additional, 2699 sf each, 18.35 MGD each) Chemical Feed ($= 20990 X^0.3190 X= Feed-Lb/d; assume 40% increase from 30 mg/L at 54.8 mgd) Piping+Electrical+I&C: Factored as 50% of Process equipment Cost Building Expansion: 17050 sf, $150 unit cost per SF
Addition of Ozone to WBWTP	1	EA	$5,335,955	$5,335,955	$3,735,168	$2,721,337	$11,790,000	$ = 89.217 X^0.6442 - X=Chamber Volume-GAL (500 Kgal Contact Chamber for 10 min CT) $ = 31,015 X^0.6475 - X=Ozone Gener.Cap.-Lb/d (2500 ppd generator for 4 mg/L at 74.8 mgd)
Addition of GAC Contactors to WBWTP	1	EA	$8,403,558	$8,403,558	$5,882,490	$4,285,814	$18,570,000	Contactor Basin: $ = -0.0034X^2 + 575.85X + 665305 - X=Filter Area - SF (8700 sf 74.8 mgd @6 gpm/sf) Backwashing Pumping: $ = 292.44 X + 92497 - X=Filter Surface Area -SF (8700 sf 74.8 mgd @6 gpm/sf) Washwater Surge Basin: $ = 5.6602 X^0.8473 - X=Storage Volume-GAL (450Kgal, 20 min @ 15gpm/sf)
Finished Water Infrastructure							Cost in Dist MP	
Residuals Management Infrastructure	8,831,823	gal	$0.32	$2,782,024	$1,947,417	$1,418,832	$6,150,000	8 lb solids handling per sf, 3 ft deep, 393,000 sf of additional lagoons to provide for expansion Previous project experience: $0.315/gal direct cost for lagoon ($0.70/gal installed cost)
Standby Power (Tier 1 – Provide Standby Generator for Full Production)	1	EA	$1,500,000	$1,500,000	$1,050,000	$765,000	$3,320,000	800kW/1000kVA Generator, Rework of utility service and electrical distribution equipment
Standby Power (Tier 2 – Upgrade to Second Utility feed)	1	EA	$600,000	$600,000	$420,000	$306,000	$1,330,000	Estimate from Electrical Engineer based on previous project experience
Standby Power (Tier 3 – Upgrade to Emergency Generator meeting NEC)	1	EA	$100,000	$100,000	$70,000	$51,000	$220,000	Upgrade of equipment from Tier 1 to meet NEC
						Total	**$102,210,000**	

Lagoon Sizing

engineered lagoon = 8 lb/sf

Use 60K solids/yr per mgd ADD for both TWTP and the NWTP, and use 122K solids/yr for WBWTP

WBWTP existing lagoons 150x300 = 45,000 SF = 1,000,000 MG volume

Facility	Capacity (mgd)	Solids (lb/yr)	Lagoon Area Needed (KSF)			
NWTP	9.8	588000	73500	75312		
TWTP	18.9	1134000	141750			
WBWTP Alt 3	34.8	4792600	599075	240750	358325	
WBWTP Current	54.8	1644000	205500	135000	70500	35250
			393575			

If intent of the evaluation is to masterplan the WBWTP site, the report may want to consider evaluating solids. We believe that the solids lagoons at WBWTP are currently undersized, and beyond not being able to dry the basins (without supplemental on-site mechanical dewatering by Veris when they remove the solids from the lagoons), there has been carryover of solids into the gravel lakes (in addition to the WQ issues mentioned in the report) . This is part of a larger discussion on Thornton's philosophy on solids management and source water quality management, but using existing operation as a guideline:

a. Current solids production at WBWTP (using flows from 2016) are approximately 1,500,000 dry lbs of solids per year (after the CT Chamber project and ACH transition, this should remain roughly the same). Solids from the TWTP represent another 600,000 dry lbs per year. See page 235-239 of 272 from the Alt Coag Study.

b. If this is scaled up to a future max capacity of 54.8 mgd at WBWTP, the amount of yearly solids will approximately double to 3,000,000 dry lbs per solids per year.

c. Standard design criteria for drying beds on the Front Range (to be able to dry solids on site) includes:

i. Engineered lagoons: Net annual drying capacity of 8 lbs/SF of drying area

ii. Sand drying beds: Net annual drying capacity of 16 lbs/SF of drying area

d. WBWTP currently has three lagoons, each are approximately 300 ft long by 150 ft wide. This gives a total drying area of ~135,000 SF.

i. Assuming a drying capacity of 8 lbs/SF, this leads to a net annual drying capacity of ~1,100,000 lbs of dry solids.

ii. This capacity is less than current sludge production, so you can see why there are current challenges with drying solids.

iii. There are additional considerations with solids, such as solids layering, cycling lagoons, and designing with the time it takes for TENORM in mind, etc., but these numbers give a decent big picture of current solids handling capacity.

e. The reason we bring this up is that increased solids handling capacity can be a significant capital cost and have a large site footprint. As stated before, this is part of a larger discussion on solids handling philosophy and source WQ management philosophy, but something that may be worth considering in the masterplan.

TWTP produced about 600K lbs solids/yr for an average daily flow of 10.2 mgd, and WBWTP produced 1500K solids/yr for an average daily flow of 12.3 mgd (this number drops to 1235K for the future PAC dose but increases to 1799K for the switch in coagulant, so the two effectively offset).

Alternative 1

21.5 mgd NWTP MDD (22.3% of total MDD, results in 9.8 mgd of ADD): produces 588K solids, has to be separate lagoons, will need 73,500 SF of lagoon

20 mgd TWTP MDD (20.8% of total MDD, results in 9.1 mgd of ADD): produces 547K solids, sent to WBWTP lagoons

54.8 mgd WBWTP MDD (56.9% of total MDD, results in 25.0 of ADD): produces 3050K solids. Adding 547K from TWTP, results in 449,625 SF of lagoons (NOTE: this is 330% of the lagoon area currently at WBWTP)

Alternative 2

41.5 mgd TWTP MDD (43.1% of total MDD, results in 18.9 mgd of ADD): produces 1135K solids. Assuming these solids remain at TWTP, will need 141,875 sf of lagoon

54.8 mgd WBWTP MDD (56.9% of total MDD, results in 25.0 of ADD): produces 3050K solids. Will need 381250 SF of lagoons (NOTE: this is 282% of the lagoon area currently at WBWTP)

Alternative 3

20 mgd TWTP MDD (20.8% of total MDD, results in 9.1 mgd of ADD): produces 547K solids, sent to WBWTP lagoons

74.3 mgd WBWTP MDD (79.2% of total MDD, results in 34.8 of ADD): produces 4246K solids. Adding 547K from TWTP, results in 599,075 SF of lagoons (NOTE: this is 444% of the lagoon area currently at WBWTP)

Notes

	w (ft)	l (ft)	area (sf)	unit cost	
General Area with clearwell #1	175	550	96250	$ 10.00	$ 962,500
without clearwell #1	175	410	71750	$ 10.00	$ 717,500
without clearwell#1 and without ancillary	175	300	52500	$ 10.00	$ 525,000

Cost Calculation

use area without clear well	175	410	71750	$ 10.00	$ 717,500
clearwell	80	120	9600	$ 5.00	$ 48,000
restoration			81350	$ 2.00	$ 162,700
Total					$ 928,200

ENR Indexes

Denver ENR Index	Date		General CCI	
7542.17	June-19	Current	11069	Jun-19
7484	March-19	AECOM W/WW Cost Est	9453	Feb-13
7474.95	June-18	Coag Tank Liner Est	9027	Apr-11
7388.09	July-17	TWTP Bid Garney		
7137.53	October-16			
7112.09	July-16	Garney/Carollo Cost Est		
7093.28	June-16	TWTP Budget Est by Garney		
7012.84	April-14	Date of Posting fo Report of Land Value with Adams Co Assessors		
6845	April-11	Date of ASCE WTP Cost Est Article		
5707.04	Jan-07	Date of Posting fo Report of Land Value with Adams Co Assessors		

Adams Co Assessors - Land Values

Site	Proposed Thornton NWTP Site	Property adjacent to NWTP	Next adjacent property to the East
Parcel Number	157119200002	157119117036	157119117037
Property Owner	Private	School District 12	City of Thornton
Report added	1/1/2007	4/7/2014	4/7/2014
Parcel Size (ares)	64.66	11.1469	18.9531
Account No	R0178577	R0183321	
Mill Levy	119.59	191.647	191.647
Adams County Zoning	A-3		
Land Valuation Actual Date of Report	$8,877	$222,938	$379,062
Land Value Actual ($/acre) Date of Report	$137	$20,000	$20,000
Land Value Actual ($/acre) June 2019	$181	$21,510	$21,510
Land Valuation Assessed Date of Report	$2,570	$64,650	$109,930
Land Valuation Assessed ($/acre) Date of Report	$40	$5,800	$5,800
Land Valuation Assessed ($/acre) June 2019	$53	$6,238	$6,238

ENR Indexes

Denver ENR Index	Date	
7542.17	June-19	Current
7484	March-19	AECOM W/WW Cost Est
7474.95	June-18	Coag Tank Liner Est
7388.09	July-17	TWTP Bid Garney
7137.53	October-16	
7112.09	July-16	Garney/Carollo Cost Est
7093.28	June-16	TWTP Budget Est by Garney
7012.84	April-14	Date of Posting fo Report of Land Value with Adams Co Assessors
6845	April-11	Date of ASCE WTP Cost Est Article
5707.04	Jan-07	Date of Posting fo Report of Land Value with Adams Co Assessors

Construction Costs

TWTP Construction Bid July 2017 (20 MGD)	$57,475,000	No Finished Water Pumps
Updated to June 2019 and adjusted for flow (20 mgd to 21.5 mgd)	$63,074,176	
cts for TWTP Expansion (no Admin Bldg, 2/3 Floc/Sed, no new CCC/BWPS))	$59,825,591	

Facility Improvements

TWTP Bid	Total Cost	Size(SF)	Unit Cost per SF
Roofing Division 7			
Main Bldg Cost	$974,722	62400	$15.62
Back wash PS	$9,465	384	$24.65
Doors and windows Division 8			
Main Building	$401,458	62400	$6.43
Painting Division 9			
Main Building	$843,442	62400	$13.52
Furnishings Division 10			
Main Building	$14,585	62400	$0.23
Total (adjusted for June 2019)			$61.71

TWTP Bid	Total Cost	Size(SF)	Unit Cost per SF
Rework Roadway			
Road Demo (adjusted for June 2019)	9687.00	900	$10.99
New Road (adjusted for June 2019)	2092.00	900	$2.37

TWTP Bid	Total Cost	Size(LF)	Unit Cost per LF
Rework Yard Piping (adjusted for June 2019)	$214,157.00	700	$312.32

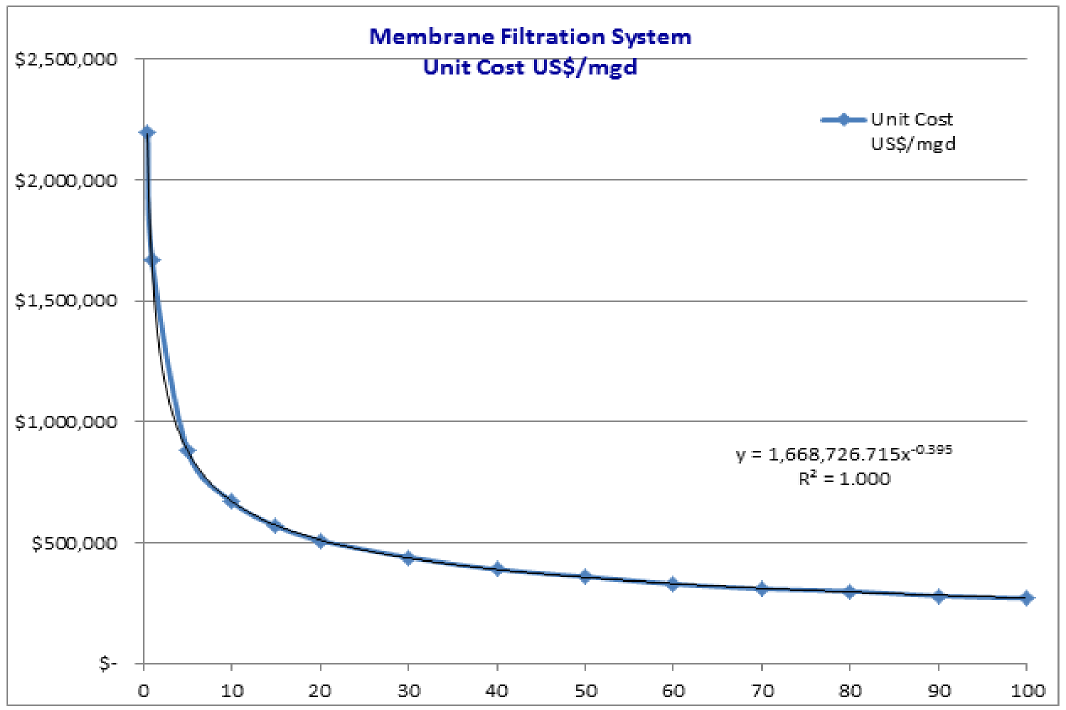
Div 8	Div 9	Div 10	Div 2 Replace Rd - Hoffman Wy Demo at Storm Tie-in	Div 2 Rmv Rd Hoffman Wy Demo at Storm Tie-in	Div 2 - Rmv Water Lines, Ld/Haul/Disp, Misc Rubble	Div 2 - Rmv Rmv C&Gtr, Asphalt, Ld/Haul/Disp	Yard Piping - "Reroute 30 inch City of Thornton Line" include demo	Yard Piping - "Reroute 16 inch City of Thornton Line" include demo
14,878	425,000	5334.00	450.00	658.00	8388.00	658.00	1794.00	1794.00
16,719	125,000	6250.00	135.00	540.00	2838.00	60.00	3069.00	2815.00
28,765	140,000	3001	246	394	530	6558	889	889
2,550	37,796	14585.00	909	500	11756.00	735	144380	65965
18,979	3,400		4000	2092.00		1676	289	154
21,469	35,280		750			9687.00	144	77
38,917	3,250		6490.00				13750	6654
2,700	8,633						3246	1024
2,334	2,420						3661	6199
4,734	22,875						1024	8685
6,768	12,288						6199	954
600	27,500						11941	10797
6,701	843,442						18081	13509
13,601							5690	3664
20,305							214157.00	123180.00
1,800								
15,036								
9,536								
20,172								
7,641								
60,000								
12,000								
20,003								
55,250								
401,458								

Garney Construction

Thornton Water Treatment Plant Replacement Project
Cost Model Summary - BODR Submittal

Date:	6/29/2016	7/19/2017	
	Budget Estimate	**BODR Estimate**	**Comments**
Design Phase Services			
Original Contract Value		$ 3,348,252.00	
Amendment 1 (including Bench/Pilot Testing)		$ 1,038,012.00	
Subtotal Design Phase Services - A		**$ 4,386,264.00**	
Design Services During Construction			
Final Design		$ 1,853,179.00	
Design Consultant Services		$ 2,186,038.00	*Cut 50% of $4,372,076 Assuming Potential Scope Reduction/Overlap
Subtotal Professional Services - B		**$ 4,039,217.00**	
Subtotal Design Services (A+B)		**$ 8,425,481.00**	
Construction Phase Services			
Cost of Work	$ 52,463,285.00	$ 51,164,000.00	
QC Testing		$ 368,000.00	
General Conditions	Inc In Above	$ 5,943,000.00	
Subtotal Construction Costs - C	$ 52,463,285.00	$ 57,475,000.00	
Construction Fee @ 8% - D	Inc In Above	$ 4,598,000.00	
Design-Builder Contingency			
Design-Builders Risks		$ 4,500,000.00	
Escalation	used 2016 $$	w/above	
Scope Gap/Exclusions	$ 7,869,493.00	w/above	
Subtotal Design-Builder Contingency - E	$ 7,869,493.00	$ 4,500,000.00	7% of Construction Phase
Subtotal Construction Phase (C+D+E)	**$ 60,332,778.00**	**$ 66,573,000.00**	Difference = 8% From 2016
Total (A+B+C+D+E)		**$ 74,998,481.00**	
Owner's Contingency (7%) - F		**$ 5,249,890.00**	Reduce from 10% to 7%
Other Owner Project Costs			
Turn Lane (Design)		$ 983,062.00	
Turn Lane (Construction)		Inc In Above	
Initial Site Restoration/Asbestos Survey		$ 1,000,000.00	
Asbestos Abatement		$ 3,646,000.00	

Capacity	Unit Cost $/mgd	Delta Unit Cost	Total Cost
54.8	$343,216		$18,808,210
76.3	$301,154		$22,978,018
		$42,062	
21.5			$904,331



No.	PROCESS	USABLE EQUATION	COST EQUATION	APPLICABLE RANGE MINIMUM	MAXIMUM	QUANTITY PER UNIT PROCESS	NUMBER OF PROCESS UNITS	PROCESS COST PER UNIT	TOTAL PROCESS COST
1a	Chlorine storage and feed 150# cylinder storage	0	$ = 1181.9 X^0.6711 - *X=Chlorine feed cap.-Lb/d*	10	200			$0	$0
1b	Chlorine storage and feed 1-ton cylinder storage	1076388.868	$ = 5207.41 X^0.6621 - *X=Chlorine feed cap.-Lb/d*	200	10,000	5000	2	$1,856,536	$3,713,072
2	On-site storage tank with rail delivery	0	$ = 63640 X^0.2600 - *X=Chlorine feed cap.-Lb/d*	1,980	10,000			$0	$0
3	Direct feed from rail car	0	$ = 69778 X^0.2245 - *X=Chlorine feed cap.-Lb/d*	1,980	10,000			$0	$0
4	Ozone Generation	0	$ = 31,015 X^0.6475 - *X=Ozone Gener.Cap.-Lb/d*	10	3,500			$0	$0
5	Ozone Contact Chamber	0	$ = 89.217 X^0.6442 - *X=Chamber Volume-GAL*	1,060	423,000			$0	$0
6	Liquid Alum Feed - 50% Solution	270786	$= 699.78X + 88526 - *X=Liquid Feed cap.- Gal/h*	2	1,000	400	2	$467,047	$934,094
7	Dry Alum Feed	116233	$ = 212.32x + 73225 - *X=Dry Alum. Feed- Lb/h*	10	5,070	400	2	$200,477	$400,953
8	Polymer Feed	2023532	$= 13662 X+20861 - *X=Polymer Feed-Lb/d*	1	220	200	2	$3,490,151	$6,980,303
9	Lime Feed	1274307.318	$ = 12985 X^0.5901 - *X=Lime Feed- Lb/d*	10	10,000	4000	2	$2,197,902	$4,395,804
10	Potassium Permanganate Feed	26778.2	$= 26.427 X + 25864 - *X=Dry KMNO4 Feed-Lb/d*	1	500	400	1	$46,187	$46,187
11	Sulfuric Acid Feed - 93% Solution	19339	$ = 32.606 X+26395 - *X=Sulfuric Acid (93%)Feed-Gal/d*	11	5,300			$0	$0
12	Sodium Hydroxide Feed - 50% Solution	38701	$ = 118.68 X+38701 - *X=Liquid Sodium Feed -gal/d*	1	1,600			$0	$0
13	Ferric Chloride Feed - 42% Solution	0	$= 20990 X^0.3190 - *X=Dry Ferric Sulf. Feed-Lb/d*	13	6,600			$0	$0
14	Anhydrous Ammonia Feed - 29% Solution	0	$= 7959 X^0.4235 - *X=Ammonia Feed - Lb/d*	240	5,080			$0	$0
15	Aqua Ammonia Feed	0	$ = 6699 X^0.4219 - *X=Ammonia Feed - Gal/d*	240	5,080			$0	$0
16	Powdered Activated Carbon	198948	$= -0.0142X^2 + 195.03X + 194823 - *X=Carbon Feed - Lb/h*	3	6,600	400	1	$343,142	$343,142
17	Rapid Mix G=300	22811	$= 3.2559 X+31023 - *X=Basin Volume - GAL*	800	145,000			$0	$0
18	Rapid Mix G=600	76325.22	$= 4.0668 X+33040 - *X=Basin Volume - GAL*	800	145,000	17400	1	$131,644	$131,644
19	Rapid Mix G=900	115062.06	$= 7.0814 X+33269 - *X=Basin Volume -GAL*	800	145,000	17400	2	$198,457	$396,914
20	Flocculator G=20	165254	$= 566045 X+224745 - *X=Basin Volume - MG*	0.015	7			$0	$0
21	Flocculator G=50	241481.15	$ = 673894 X+ 217222 - *X=Basin Volume - MG*	0.015	7	0.165	4	$416,502	$1,666,009
22	Flocculator G=80	246003.395	$ = 952902 X + 177335 - *X=Basin Volume - MG*	0.015	7	0.165	4	$424,302	$1,697,209
23	Circular Clarifier	0	$ = 3470.6 X^0.6173 - *X=Basin Area - SF*	650	32,300			$0	$0
24	Rectangular Clarifier	0	$ = 13572 X^0.3182 - *X=Basin Area - SF*	5,000	150,000			$0	$0
25	Gravity Filter Structure	1097897.75	$ = -0.0034X^2 + 575.85X + 665305 - *X=Filter Area - SF*	140	28,000	1450	12	$1,893,634	$22,723,610
26	Filtration Media - Stratified Sand	33421.06667	$ = 20.561 X +11185 - *X=Filter Media Area -SF*	140	28,000	1667		$57,644	$0
27	Filtration Media - Dual Media	48590	$ = 38.319 X +21377 - *X=Filter Media Area -SF*	140	28,000	1167	12	$83,807	$1,005,686
28	Filtration Media - Tri-Media	16058	$ = 62.844 X + 21838 - *X=Filter Media Area - SF*	140	28,000			$0	$0
29	Filter Backwash Pumping	197061	$ = 292.44 X + 92497 - *X=Filter Surface Area -SF*	90	1,500	600	2	$339,887	$679,774
30	Surface Wash System	76733	$ = 58.487 X + 69223 - *X=Filter area -SF*	140	27,000	600	2	$132,348	$264,695
31	Air Scour Wash	296270.2	$= 50.157X + 266176 - *X=Filter area -SF*	140	27,000	600	2	$511,001	$1,022,003
32	Wash Water Surge Basin - (Holding Tank)	958070.4821	$= 119.42X^0.7505 - *X=Basin Capacity -GAL*	9,250	476,000	240000	1	$1,652,463	$1,652,463
33	Wash Water Storage Tank - (Waste Wash Water)	155943.1169	$ = 5.6602 X^0.8473 - *X=Storage Volume-GAL*	19,800	925,000	250000	2	$268,968	$537,936
34	Clear Water Storage - Below Ground	3713761	$ = 604450 X + 215121 - *X=Capacity -MG*	0.011	8	8.000	2	$6,405,428	$12,810,855
35	Finished Water Pumping TDH =100ft	537519.25	$ = 18888x + 140743 - *X=Pump Capacity MGD*	1.45	300	31.25	4	$927,103	$3,708,414
36	Raw Water Pumping	313075	$ = 13889x + 103488 - *X=Pump Capacity MGD*	1	200	30	4	$539,986	$2,159,944
37	Gravity Sludge Thickener	56488.01942	$ = 2798.7 X ^1.305 - *X=Thickener Diameter-FT*	20	150	10	3	$97,430	$292,289
38	Sludge Dewatering lagoons	46171	$ = 62792 X^0.7137 - *X=Storage Volume -MG*	0.08	40	1.00	5	$79,635	$398,175
39	Sand Drying Beds	101707.9787	$ = 30.648 X^0.8751 - *X= Bed Area-SF*	4,800	400,000	15000	10	$175,424	$1,754,241
40	Filter Press	66744	$ = -0.0716X^2 + 1078.2X + 667445 - *X= Filter Press Vol. - GAL*	30	6,600			$0	$0
41	Belt Filter Press	313097	$ = 146.29 X + 433972 - *X=Machine Capacity - GAL/h*	800	53,000			$0	$0
42	Administration, Laboratory, and Maintenance Building	596620.2636	$ = 63568 X^0.553 - *X=Plant Capacity MGD*	1	200	100	1	$1,029,040	$1,029,040