City of Thornton

Owner's Advisor Services

PFAS Treatment

Project No. 23-127

Treatment Technology Study

FINAL / June 2024

carollo®

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COLORADO LICENSED
WILLIAM VERNON SARCHET
54103
PROFESSIONAL ENGINEER

Digitally signed by William V. Sarchet
Contact Info: Carollo Engineers, Inc.
Date: 2024.06.10 15:13:34-06'00'

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Abbreviations

3D	three-dimensional
AACE	Association of Cost Engineering International
AEC	aqueous electrostatic concentrator
AFY	acre-feet per year
AIS	American Iron and Steel
BABA	Build America Buy America
BV	bed volume
°C	degrees Celsius
$CaCO_3$	calcium carbonate
Carollo	Carollo Engineers
CCPP	calcium carbonate precipitation potential
cf	cubic feet
City	City of Thornton
cm	centimeter
CMAR	construction manager at risk
CSMR	chloride to sulfate mass ratio
CT/mL	count per milliliter
CT/100 mL	count per 100 milliliters
DB	Davis-Bacon Act
D/DBPR	Disinfectants and Disinfection Byproducts Rule
DIW	deep injection well
EBCT	empty bed contact time
DBP	disinfection byproduct
EC	electro-coagulation
ECCV	East Cherry Creek Valley Water and Sanitation District
EGL	East Gravel Lakes
EPA	Environmental Protection Agency
FF	foam fractionation
FRICO	Farmers Reservoir and Irrigation Company
GAC	granular activated carbon
GenX	hexafluoropropylene oxide dimer acid
gpm	gallons per minute
gpm/sf	gallons per minute per square foot
HFPO-DA	hexafluoropropylene oxide dimer acid
HI	Hazard Index
IX	ion exchange
lb	pound
µg/L	micrograms per liter

MCL	maximum contaminant level
MCLG	maximum contaminant level goal
mgd	million gallons per day
mg/L	milligrams per liter
MIB	2-methylisoborneol
mm	millimeter
MRL	method reporting limit
mS/cm	milliSiemens per centimeter
N/A	Not Applicable
ND	Non-Detect
NF	nanofiltration
ng/L	nanograms per liter
NPDWR	National Primary Drinking Water Regulation
NPV	net present value
NSF	National Science Foundation
NTU	nephelometric turbidity unit
O&M	operation and maintenance
ortho-P	orthophosphate
ozofractionation	ozone-based fractionation
PAC	powdered activated carbon
PFAS	per- and polyfluoroalkyl substances
PFBS	perfluorobutane sulfonic acid
PFD	process flow diagram
PFHxS	perfluorohexane sulfonic acid
PFNA	perfluorononanoic acid
PFOA	perfluorooctanoic acid
PFOS	perfluorooctane sulfonic acid
PFSA	perfluorosulfonic acid
Project	Thornton PFAS Treatment Project
RFP	Request for Proposals
RFQ	Request for Qualifications
RO	reverse osmosis
SCADA	supervisory control and data acquisition
SMCL	secondary maximum contaminant level
Study	Treatment Technology Study
RSSCT	rapid small-scale column tests
TDS	total dissolved solids
T&O	taste and odor
TOC	total organic carbon
TWTP	Thornton Water Treatment Plant

UF	ultrafiltration
UV	ultraviolet
UV254	ultraviolet absorbance at 254 nanometers
VOC	volatile organic compound
Water ARC®	Carollo Engineers Water Applied Research Center®
WBWTP	Wes Brown Water Treatment Plant
WGL	West Gravel Lakes
WPF	water purification facility
WTP	water treatment plant
ZLD	zero liquid discharge

SECTION 1 INTRODUCTION

1.1 Introduction and Purpose

The City of Thornton (City) has begun the planning efforts for the implementation of the Thornton Per- and Polyfluoroalkyl Substances (PFAS) Treatment Project (Project), which consists of evaluating and implementing PFAS treatment at the City's two water treatment facilities. The Treatment Technology Study (Study) facilitates and documents the selection of the preferred treatment process that meets the City's operations and water quality objectives and can be designed and constructed within the City's established budget and schedule.

The purpose of the Study is to:

- Analyze historical raw water and finished water quality data and establish PFAS treatment goals.
- Identify treatment processes that meet the City's operational and water quality goals.
- Evaluate PFAS treatment performance of the short-listed treatment alternatives through rapid small-scale column tests (RSSCT).
- Compare the short-listed PFAS treatment alternatives based on both economic and non-economic factors to determine a preferred treatment process to be implemented to meet both the City's short- and long-term PFAS treatment goal.
- Define the next steps in the implementation of the selected treatment process during conceptual design.

The ultimate objective of the Study is to provide the information and analysis required for the City to make a justified decision on a PFAS treatment process that will meet the City's short- and long-term needs.

1.2 Background

1.2.1 Thornton Water Treatment Facilities

The City operates two water treatment plants (WTP), the Thornton Water Treatment Plant (TWTP) and the Wes Brown Water Treatment Plant (WBWTP). The rated treatment capacities of both plants are presented in Table 1.

Table 1 Treatment Capacity of Thornton Water Treatment Facilities

Description	Summer Treatment Capacity		Winter Treatment Capacity	
	Continuous	Peaking	Continuous	Peaking
TWTP	20 mgd	30 mgd	20 mgd	20 mgd
WBWTP	40 mgd	50 mgd	N/A(1)	N/A(1)

Notes:
mgd - million gallons per day; N/A - not applicable
(1) WBWTP is taken out of service during the winter for maintenance.

The TWTP treatment process consists of coagulation, flocculation, sedimentation, intermediate ozone, biological filtration, and free chlorine disinfection. The TWTP currently does not have a treatment process that removes PFAS. Depending on demand, the City can reduce PFAS levels by controlling the blend of source water supplies to TWTP. Filter backwash waste and sedimentation basin solids are conveyed via a gravity pipeline to three solids handling lagoons located at WBWTP.

The WBWTP treatment process consists of powdered activated carbon (PAC) contact, coagulation, solids contact clarification, membrane filtration, and free chlorine disinfection. PAC has been able to remove low levels of PFAS in WBWTP source waters. The WBWTP was originally constructed in 1974 as a softening treatment facility for treating groundwater and rehabilitated in 2005 to a membrane treatment facility for surface water treatment. During the winter months, the WBWTP is typically taken offline for maintenance. The TWTP is used to satisfy all of the City's demands during this time of the year.

To meet future system demands, additional chemical storage and ozone system redundancy are planned at the TWTP to bring continuous treatment capacity to 30 mgd, and an expansion is planned at the WBWTP to bring continuous treatment capacity to 55 mgd.

1.2.2 Thornton Water Sources

The TWTP is supplied by Standley Lake and East Gravel Lakes (EGL) source waters. The WBWTP is supplied by EGL and West Gravel Lakes (WGL) source waters. In the future, water supplies to WBWTP will be augmented by northern supply source waters originating from the Cache la Poudre River. Table 2 presents the raw water supply capacities for each WTP.

Table 2 Raw Water Supply Capacities

Description	Capacity	Units
TWTP Raw Water Supply		
Standley Lake (Gravity), Maximum Flow	20	mgd
EGL Pump Station, Maximum Flow	15	mgd
WBWTP Raw Water Supply		
EGL Pump Station, Maximum Flow	60	mgd
WGL Pump Station, Maximum Flow	40	mgd
Northern Supply, Maximum Flow (Future)	40	mgd

1.2.2.1 Standley Lake

Standley Lake is a manmade reservoir fed primarily by Upper Clear Creek. Standley Lake is also the supply source for the City of Westminster, the City of Northglenn, and Farmers Reservoir and Irrigation Company (FRICO). The water stored in Standley Lake flows via a 48-inch pipeline shared by the City of Northglenn and City of Thornton to Northglenn's WTP, and then via a 36-inch pipeline to the TWTP. The firm yield from Standley Lake is considered 6,000 acre-feet per year (AFY) (i.e., rights to water during the 3-year drought conditions used for water supply planning purposes). On average, approximately 9,000 AFY is delivered to the TWTP, and as much as 12,000 AFY has been delivered historically. The flow capacity of the 36-inch pipeline, in combination with the water surface elevation of Standley Lake and the amount of water utilized concurrently by other utilities, can limit the flow that can enter the TWTP. Historically, 15 to 17 mgd of Standley Lake water can typically be fed to the TWTP with a historical maximum flow of approximately 20 mgd.

1.2.2.2 East Gravel Lakes

EGL is the terminus downstream of the South Tani Reservoir and a series of reclaimed gravel pit reservoirs that are fed by the South Platte River via the Burlington Canal. The EGL supply is a more challenging source water to treat due to influence from upstream treated wastewater discharge into the South Platte River. A series of alluvial wells located along the South Platte River can augment EGL supplies. However, these wells are rarely used due to high PFAS levels. From EGL, water is pumped to the WBWTP (60 mgd pumping capacity) and to the TWTP (15 mgd pumping capacity).

1.2.2.3 West Gravel Lakes

Raw water from Lower Clear Creek Canal flows in series through the WGL complex, which consists of three lined raw water storage lakes. WBWTP lagoon decant water is recycled to WGL1, adjacent to the WGL pump station intake in WGL2, which can influence source water quality. Overall, WGL water quality is generally similar to that of EGL with the exception of lower PFAS and TDS concentrations. However, elevated taste and odor (T&O) and organics occurrence is independent between EGL and WGL, allowing the City to optimize source selection and blending for the WBWTP. WGL source water is pumped from WGL2 to the WBWTP (40 mgd pumping capacity).

1.2.2.4 Northern Supply

The City is implementing the Thornton Water Supply Project to deliver Cache La Poudre River (i.e., northern supply) water to the City for treatment at the WBWTP (42-inch direct pipeline feed) and the TWTP (indirectly fed through EGL). The Thornton Water Supply Project is projected to deliver up to an average of 14,000 AFY to the City. Future northern supply water will be available for 3 to 4 months per year during the summer at flows up to 40 mgd. It is anticipated that northern supply water will be withdrawn from Water Supply and Storage Company Reservoir 3, located in Larimer County. Northern supply water quality is similar to that of Standley Lake, with the exception of lower alkalinity and higher total organic carbon (TOC) levels.

1.2.3 PFAS

1.2.3.1 Background

PFAS constitute a large family of manufactured chemicals that have been extensively used in a wide range of industrial and domestic applications since the 1940s. Because of their unique physical and chemical properties, PFAS have been used in a variety of products, including nonstick cookware, waterproof clothing, and firefighting foams. PFAS are chemically, biologically, and thermally stable, and can accumulate in humans, animals, and the environment over time. Today, PFAS are ubiquitously present in every stage of the water cycle, soil, air, and food as well as in everyday consumer products at trace concentration levels (i.e., parts per trillion or nanograms per liter [ng/L]). Exposure to PFAS can result in adverse health risks, such as developmental effects, cancer, liver effects, immune effects, and thyroid effects among others.

1.2.3.2 Regulatory Overview

In April 2024, the Environmental Protection Agency (EPA) announced the National Primary Drinking Water Regulation (NPDWR) for six PFAS compounds in drinking water as listed in Table 3.

Table 3 NPDWR for PFAS

Compound	MCL (enforceable levels)	MCLG (health based, non-enforceable)
Perfluorooctanoic Acid (PFOA)	4 ng/L(1)	Zero
Perfluorooctane Sulfonic Acid (PFOS)	4 ng/L(1)	Zero
Perfluorohexane Sulfonic Acid (PFHxS)	10 ng/L(1)	10 ng/L
Perfluorononanoic Acid (PFNA)	10 ng/L(1)	10 ng/L
Hexafluoropropylene Oxide Dimer Acid (HFPO-DA) (commonly referred to as GenX chemicals)	10 ng/L(1)	10 ng/L
Mixtures containing two or more of PFHxS, PFNA, HFPO-DA, and PFBS	1.0 (unitless) HI(1)	1.0 (unitless) HI

Notes:
HI - Hazard Index; MCL - maximum contaminant level; MCLG - maximum contaminant level goal
(1) Running annual average from quarterly sampling.

The HI is calculated as a sum of fractions of the measured concentration of each of the four PFAS divided by its corresponding health reference value, as shown in the following equation.

$$\text{HI} = \frac{\text{GenX}}{10\text{ ng/L}} + \frac{\text{PFBS}}{2{,}000\text{ ng/L}} + \frac{\text{PFNA}}{10\text{ ng/L}} + \frac{\text{PFHxS}}{10\text{ ng/L}}$$

The rule requires compliance by June 25, 2029.

1.3 Project Attributes

1.3.1 Treatment Capacity

It is currently planned that the capacity of the PFAS improvements will be designed to treat the build-out treatment capacities of TWTP and WBWTP identified in the "Water Treatment Plant Capacity Evaluation" (Carollo Engineers [Carollo], 2024). For TWTP, the capacity of the new PFAS treatment facility will equal 30 mgd. For WBWTP, the capacity of the new PFAS treatment facility will equal 55 mgd. These capacities will be used as the basis of evaluation in this Study.

1.3.2 Budget

The City's projected budget for the Project is $90 million. This budget includes the costs for all project elements, including owner's advisor services, permitting, design, construction, and commissioning.

1.3.3 Schedule

The City's goal is to implement the project within the compliance timeline established in the NPDWR for PFAS, which requires compliance by June 25, 2029. The current project schedule estimates project substantial completion by the third quarter of 2027.

SECTION 2 WATER QUALITY ANALYSIS

2.1 Historical Raw Water Quality

Historical water quality for each of the City's source water supplies is presented below. A summary of the primary water quality parameters of concern for each source has been provided at the end of this section.

2.1.1 Standley Lake

Table 4 contains a summary of the characteristics of Standley Lake source water. A discussion of selected key water quality parameters follows.

Table 4 Characteristics of Standley Lake Source Water

Parameter	Units	No. of Samples	Minimum	5th Percentile	25th Percentile	50th Percentile	75th Percentile	95th Percentile	Maximum
PFOA	ng/L	14	ND	ND	ND	0.6	0.7	0.8	0.8
PFOS	ng/L	14	ND	ND	ND	0.6	0.6	0.9	1.3
PFBS	ng/L	14	ND	ND	ND	0.7	0.8	0.9	0.9
GenX	ng/L	14	ND	ND	ND	ND	ND	ND	ND
PFNA	ng/L	14	ND	ND	ND	ND	ND	ND	ND
PFHxS	ng/L	14	ND	ND	ND	ND	ND	ND	ND
PFAS HI	--	14	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Turbidity	NTU	128	0.06	0.32	0.90	1.9	3.9	10.6	17.4
pH	--	128	6.5	6.7	7.0	7.5	7.8	8.1	8.9
Alkalinity	mg/L as $CaCO_3$	126	49.0	50.0	53.0	54.7	56.0	57.0	67.0
TOC	mg/L	128	1.8	1.9	2.0	2.0	2.2	2.4	6.0
Total Hardness	mg/L as $CaCO_3$	128	100	112	124	136	148	199	220
Calcium Hardness	mg/L as $CaCO_3$	88	64.0	77.4	84.0	92.0	100	108	124
TDS	mg/L	9	174	180	200	209	218	240	241
Iron	mg/L	128	ND	ND	0.03	0.06	0.09	0.22	0.61
Manganese	mg/L	128	ND	0.02	0.03	0.05	0.12	0.21	0.78
Bromide	mg/L	128	ND	ND	ND	ND	ND	ND	0.12
Temperature	°C	128	5.4	5.9	7.5	12.0	15.9	18.7	19.5
Dissolved Oxygen	mg/L	128	1.4	2.4	4.3	8.1	10.0	10.8	10.9
Ortho-P	mg/L	128	ND	ND	ND	ND	ND	0.15	0.19
Nitrite	mg/L	127	ND	ND	ND	ND	ND	ND	ND
Nitrate	mg/L	128	ND	ND	ND	0.13	0.19	0.42	0.61
E. coli	CT/ 100 mL	128	ND	ND	ND	3.0	15.0	34.3	118
Algae	CT/mL	128	ND	4	15	32	85	555	2080

Parameter	Units	No. of Samples	Minimum	5th Percentile	25th Percentile	50th Percentile	75th Percentile	95th Percentile	Maximum
Chlorophyll-a	µg/L	128	ND	0.90	1.5	2.0	3.2	9.0	27.3
Geosmin	ng/L	11	ND	ND	ND	ND	ND	ND	ND
MIB	ng/L	11	ND	ND	ND	ND	ND	ND	ND
Chloride	mg/L	128	38.0	39.8	43.2	45.2	50.0	55.0	60.0
Fluoride	mg/L	128	0.49	0.51	0.54	0.56	0.60	0.78	0.95
Sulfate	mg/L	127	47.1	51.0	54.0	58.0	60.6	64.0	69.0
Ammonia	mg/L	128	ND	ND	ND	ND	ND	ND	0.07
Antimony	mg/L	1	ND	ND	ND	ND	ND	ND	ND
Arsenic	mg/L	1	ND	ND	ND	ND	ND	ND	ND
Barium	mg/L	1	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Beryllium	mg/L	1	ND	ND	ND	ND	ND	ND	ND
Cadmium	mg/L	1	ND	ND	ND	ND	ND	ND	ND
Chromium	mg/L	1	ND	ND	ND	ND	ND	ND	ND
Copper	mg/L	1	0.004	0.004	0.004	0.004	0.004	0.004	0.004
Mercury	mg/L	1	0.07	0.07	0.07	0.07	0.07	0.07	0.07
Nickel	mg/L	1	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Selenium	mg/L	1	ND	ND	ND	ND	ND	ND	ND
Silver	mg/L	1	ND	ND	ND	ND	ND	ND	ND
Sodium	mg/L	1	19	19	19	19	19	19	19
Thallium	mg/L	1	ND	ND	ND	ND	ND	ND	ND
Zinc	mg/L	1	0.02	0.02	0.02	0.02	0.02	0.02	0.02

Notes:
$CaCO_3$ - calcium carbonate; CT/mL - count per milliliter; CT/100 mL - count per 100 milliliters; °C - degrees Celsius;
µg/L - micrograms per liter; mg/L - milligrams per liter; MIB - 2-methylisoborneol; mS/cm - milliSiemens per centimeter;
ND - Non-Detect; NTU - nephelometric turbidity unit; ortho-P - orthophosphate; TDS - total dissolved solids
(1) Historical data collected from 2020 to 2023 from Standley Lake.

2.1.1.1 PFAS

Standley Lake is a low PFAS source. The maximum measured source water concentrations of PFOA, PFOS, PFHxS, PFNA, GenX, and the HI are all below the final MCLs.

2.1.1.2 Total Organic Carbon

TOC is a measure of organic carbon, both particulate and dissolved. TOC is a useful parameter in gauging the general level or organic constituents in a water supply. As a competing contaminant for both granular activated carbon (GAC) and ion exchange (IX) resin, elevated TOC levels can result in fouling of either adsorbent and thus impacting the performance of GAC and IX resin for PFAS treatment.

Standley Lake is a low TOC source. The 50th percentile TOC is 2.0 mg/L.

2.1.1.3 Chloride and Sulfate

The chloride to sulfate mass ratio (CSMR) is a parameter used to evaluate potential lead corrosion. Several studies (e.g., Nguyen et al., 2011) have indicated that higher CSMR values can correlate to increased lead solubility, particularly with alkalinity levels below 50 mg/L as $CaCO_3$. CSMR values below 0.5 represent a lower potential for corrosion.

Standley Lake has a 50th percentile CSMR of 0.8.

2.1.1.4 Total Dissolved Solids

TDS is a measurement of inorganic salts (such as calcium, magnesium, potassium, sodium, bicarbonates, chlorides, and sulfates) and trace amounts of organic matter that is dissolved in water. Elevated levels of TDS may be associated with aesthetic and cosmetic effects, such as staining, taste, or precipitation problems.

Standley Lake has a 50th percentile TDS of 209 mg/L, which is below the secondary maximum contaminant level (SMCL) of 500 mg/L.

2.1.1.5 Taste and Odor

T&O is an aesthetic measure of water quality by consumers. Consumers generally correlate T&O with the quality and safety of the water. Typical T&O compounds, geosmin and MIB, are associated with seasonal algal growth and are often objectionable at concentrations above 3 ng/L.

Geosmin and MIB have not been detected in Standley Lake source waters.

2.1.2 East Gravel Lakes

Table 5 contains a summary of the characteristics of EGL source water. A discussion of selected key water quality parameters follows.

Table 5 Characteristics of East Gravel Lakes Source Water

Parameter	Units	No. of Samples	Minimum	5th Percentile	25th Percentile	50th Percentile	75th Percentile	95th Percentile	Maximum
PFOA	ng/L	23	7.4	7.8	8.1	9.1	11.0	13.7	14.0
PFOS	ng/L	23	7.0	7.6	9.0	9.6	9.9	12.0	19.0
PFBS	ng/L	23	6.3	6.4	8.1	9.2	10.4	11.9	12.0
GenX	ng/L	23	ND	ND	ND	ND	ND	ND	ND
PFNA	ng/L	23	ND	ND	ND	1.5	1.7	2.0	2.1
PFHxS	ng/L	23	5.1	5.4	5.9	6.5	7.8	9.9	10.0
PFAS HI	--	23	0.6	0.6	0.7	0.8	0.8	1.2	1.2
Turbidity	NTU	439	ND	0.20	0.52	0.90	1.3	2.8	10.7
pH	--	439	7.7	8.0	8.3	8.5	8.7	9.1	9.3
Alkalinity	mg/L as $CaCO_3$	277	115	128	147	155	162	176	233
TOC	mg/L	277	4.2	4.9	5.4	5.9	6.3	6.8	8.1

Parameter	Units	No. of Samples	Minimum	5th Percentile	25th Percentile	50th Percentile	75th Percentile	95th Percentile	Maximum
Total Hardness	mg/L as $CaCO_3$	277	212	248	268	292	312	340	360
Calcium Hardness	mg/L as $CaCO_3$	107	104	161	192	212	226	251	288
TDS	mg/L	20	493	503	559	628	681	709	733
Iron	mg/L	277	ND	ND	ND	ND	0.03	0.07	0.25
Manganese	mg/L	277	0.03	0.05	0.11	0.17	0.24	0.34	0.46
Bromide	mg/L	274	ND	ND	0.16	0.23	0.29	0.33	0.67
Temperature	°C	439	2.4	3.6	9.2	16.5	22.2	24.3	30.0
Dissolved Oxygen	mg/L	439	2.5	5.5	6.8	8.1	10.4	12.1	15.5
Ortho-P	mg/L	274	0.29	0.47	0.70	0.84	1.09	1.34	1.58
Nitrite	mg/L	273	ND	ND	ND	ND	ND	0.06	0.20
Nitrate	mg/L	274	ND	ND	0.30	0.57	0.81	1.29	1.59
E. coli	CT/ 100 mL	273	ND	ND	ND	ND	2.0	8.8	238
Algae	CT/mL	277	ND	5	19	53	131	689	6266
Chlorophyll-a	µg/L	277	ND	1.2	2.6	4.4	8.4	19.2	76.6
Geosmin	ng/L	305	ND	ND	2.5	6.9	14.2	80.4	310
MIB	ng/L	305	ND	ND	1.6	8.5	17.8	52.0	137
Chloride	mg/L	274	109	114	125	162	180	196	237
Fluoride	mg/L	274	0.47	0.68	0.78	0.84	0.89	0.96	1.4
Sulfate	mg/L	274	101	114	133	146	160	170	197
Ammonia	mg/L	194	ND	ND	ND	0.12	0.19	0.28	0.38
Antimony	mg/L	3	ND	ND	ND	ND	ND	ND	ND
Arsenic	mg/L	3	0.001	0.001	0.001	0.002	0.002	0.002	0.002
Barium	mg/L	3	0.05	0.05	0.05	0.06	0.06	0.06	0.06
Beryllium	mg/L	3	ND	ND	ND	ND	ND	ND	ND
Cadmium	mg/L	3	ND	ND	ND	ND	ND	ND	ND
Chromium	mg/L	3	ND	ND	ND	ND	ND	0.001	0.002
Copper	mg/L	3	0.004	0.005	0.007	0.010	0.016	0.021	0.022
Mercury	mg/L	3	ND	ND	ND	ND	ND	ND	ND
Nickel	mg/L	3	ND	ND	ND	ND	0.001	0.003	0.003
Selenium	mg/L	3	ND	ND	ND	ND	ND	ND	ND
Silver	mg/L	3	ND	ND	ND	ND	ND	ND	ND
Sodium	mg/L	3	77	81	99	120	120	120	120
Thallium	mg/L	3	ND	ND	ND	ND	ND	ND	ND
Zinc	mg/L	3	ND	ND	ND	ND	ND	ND	ND

Notes:
(1) Historical data collected from 2018 to 2023 from EGL4@PS TOP.

2.1.2.1 PFAS

EGL has the highest PFAS levels of the City's source water supplies. All samples taken have exceeded the final MCLs for PFOA and PFOS. The 75th percentile source water concentrations of PFBS and the 95th percentile concentration of the HI also exceed the final MCL. The maximum measured source water concentrations of PFNA and GenX are below the final MCLs.

2.1.2.2 Total Organic Carbon

EGL is a high TOC source. The 50th percentile TOC is 5.9 mg/L.

2.1.2.3 Chloride and Sulfate

EGL has a 50th percentile CSMR of 1.1.

2.1.2.4 Total Dissolved Solids

EGL has a 50th percentile TDS of 628 mg/L, and TDS is present in EGL source water at concentrations above the SMCL 95 percent of the time.

2.1.2.5 Taste and Odor

EGL experiences elevated T&O compound occurrence. EGL has 50th percentile geosmin and MIB levels of 6.9 ng/L and 8.5 ng/L, respectively, and has experienced T&O events where over 300 ng/L of geosmin was present.

2.1.3 West Gravel Lakes

Table 6 contains a summary of the characteristics of WGL source water. A discussion of selected key water quality parameters follows.

Table 6 Characteristics of West Gravel Lakes Source Water

Parameter	Units	No. of Samples	Minimum	5th Percentile	25th Percentile	50th Percentile	75th Percentile	95th Percentile	Maximum
PFOA	ng/L	22	2.6	2.7	3.1	3.6	4.1	5.0	5.2
PFOS	ng/L	22	3.0	3.2	3.9	4.8	5.2	6.2	12.0
PFBS	ng/L	22	3.3	3.4	4.3	5.3	6.0	6.8	8.0
GenX	ng/L	22	ND	ND	ND	ND	ND	ND	ND
PFNA	ng/L	22	ND	ND	ND	0.5	0.6	0.7	0.9
PFHxS	ng/L	22	2.0	2.2	2.6	3.3	3.6	4.2	4.5
PFAS HI	--	22	0.2	0.3	0.3	0.3	0.4	0.5	0.5
Turbidity	NTU	437	ND	0.20	0.60	0.90	1.60	4.03	142
pH	--	437	7.1	7.6	8.1	8.4	8.6	8.9	9.7
Alkalinity	mg/L as $CaCO_3$	274	44	95	124	149	158	175	196
TOC	mg/L	273	3.8	4.3	4.8	5.7	6.0	6.5	8.7

Parameter	Units	No. of Samples	Minimum	5th Percentile	25th Percentile	50th Percentile	75th Percentile	95th Percentile	Maximum
Total Hardness	mg/L as $CaCO_3$	274	72	157	196	224	242	275	300
Calcium Hardness	mg/L as $CaCO_3$	106	96	104	124	140	156	172	212
TDS	mg/L	18	354	366	399	459	495	562	573
Iron	mg/L	274	ND	ND	ND	ND	0.04	0.07	0.42
Manganese	mg/L	274	0.02	0.05	0.11	0.15	0.19	0.25	0.47
Bromide	mg/L	271	ND	ND	0.15	0.26	0.31	0.36	0.59
Temperature	°C	437	2.4	3.9	9.1	16.7	21.9	24.2	25.9
Dissolved Oxygen	mg/L	437	2.2	5.5	7.3	8.8	10.4	12.0	17.2
Ortho-P	mg/L	271	0.10	0.10	0.21	0.35	0.53	0.71	4.9
Nitrite	mg/L	270	ND	ND	ND	ND	ND	ND	ND
Nitrate	mg/L	271	ND	ND	ND	0.14	0.24	0.77	1.19
E. coli	CT/ 100 mL	269	ND	ND	ND	ND	2.0	20.6	1120
Algae	CT/mL	274	2	14	38	88	203	553	2359
Chlorophyll-a	µg/L	274	0.3	2.3	4.4	8.0	14.4	27.7	521
Geosmin	ng/L	301	ND	ND	2.6	7.2	14.9	57.3	286
MIB	ng/L	301	ND	ND	ND	1.8	3.3	6.4	41.4
Chloride	mg/L	271	64	77	106	121	129	147	188
Fluoride	mg/L	271	0.38	0.55	0.63	0.70	0.77	0.83	1.3
Sulfate	mg/L	271	54	70	89	102	117	133	141
Ammonia	mg/L	193	ND	ND	ND	0.13	0.19	0.27	0.36
Antimony	mg/L	3	ND	ND	ND	ND	ND	ND	ND
Arsenic	mg/L	3	ND	ND	ND	ND	ND	ND	0.001
Barium	mg/L	3	0.04	0.04	0.04	0.04	0.05	0.06	0.06
Beryllium	mg/L	3	ND	ND	ND	ND	ND	ND	ND
Cadmium	mg/L	3	ND	ND	ND	ND	ND	ND	ND
Chromium	mg/L	3	ND	ND	ND	ND	ND	0.0009	0.001
Copper	mg/L	3	0.01	0.01	0.01	0.01	0.02	0.02	0.02
Mercury	mg/L	3	ND	ND	ND	ND	ND	ND	ND
Nickel	mg/L	3	ND	ND	ND	ND	0.001	0.002	0.003
Selenium	mg/L	3	ND	ND	ND	ND	ND	ND	ND
Silver	mg/L	3	ND	ND	ND	ND	ND	ND	ND
Sodium	mg/L	3	53.0	55.2	64.0	75.0	82.5	88.5	90.0
Thallium	mg/L	3	ND	ND	ND	ND	ND	ND	ND
Zinc	mg/L	3	ND	ND	ND	ND	0.01	0.02	0.02

Notes:
(1) Historical data collected from 2018 to 2023 from WGL2@PS TOP.

2.1.3.1 PFAS

WGL has lower PFAS levels than EGL, but sample data are still consistently above the MCL. The maximum measured concentrations of PFOA and PFOS are 5.2 ng/L and 12.0 ng/L, respectively.

2.1.3.2 Total Organic Carbon

WGL is a high TOC source. The 50th percentile TOC is 5.7 mg/L.

2.1.3.3 Chloride and Sulfate

EGL has a 50th percentile CSMR of 1.2.

2.1.3.4 Total Dissolved Solids

WGL has a 50th percentile TDS of 459 mg/L, and TDS is present in WGL source water at concentrations above the SMCL 25 percent of the time.

2.1.3.5 Taste and Odor

WGL experiences a similar frequency of T&O events to EGL. WGL has 50th percentile geosmin and MIB levels of 7.2 ng/L and 1.8 ng/L, respectively, and has experienced T&O events where over 280 ng/L of geosmin was present.

2.1.4 Northern Supply

Cache la Poudre River water quality is monitored by the City at the Larimer County Canal and the Water Supply and Storage Company reservoirs. It is anticipated that northern supply water will be withdrawn from Water Supply and Storage Company Reservoir 3. Water quality characteristics of Larimer County Canal at Water Supply and Storage Company Reservoir 3 are summarized in Table 7.

Table 7 Characteristics of Northern Supply Source Water

Parameter	Units	No. of Samples	Minimum	5th Percentile	25th Percentile	50th Percentile	75th Percentile	95th Percentile	Maximum
PFOA	ng/L	5	ND	ND	ND	ND	ND	ND	ND
PFOS	ng/L	5	ND	ND	ND	ND	ND	1.0	1.3
PFBS	ng/L	5	ND	ND	ND	ND	ND	ND	ND
GenX	ng/L	5	ND	ND	ND	ND	ND	ND	ND
PFNA	ng/L	5	ND	ND	ND	ND	ND	ND	ND
PFHxS	ng/L	5	ND	ND	ND	ND	ND	ND	ND
PFAS HI	--	5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Turbidity	NTU	29	1.2	1.4	4.1	8.0	12.3	18.3	25.5
pH	--	29	7.1	7.8	7.9	8.3	8.6	8.8	8.8
Alkalinity	mg/L as $CaCO_3$	26	21.0	23.4	29.8	37.0	49.8	121	223
TOC	mg/L	24	3.3	3.4	3.6	4.1	5.4	7.0	7.9

Parameter	Units	No. of Samples	Minimum	5th Percentile	25th Percentile	50th Percentile	75th Percentile	95th Percentile	Maximum
Total Hardness	mg/L as $CaCO_3$	26	28.0	37.0	61.0	78.0	152	604	1684
Calcium Hardness	mg/L as $CaCO_3$	16	24.0	24.0	34.0	44.0	51.5	69.0	72.0
TDS	mg/L	12	40.0	57.1	90.8	119	181	205	213
Iron	mg/L	12	0.05	0.07	0.10	0.13	0.26	0.52	0.73
Manganese	mg/L	12	0.02	0.03	0.04	0.05	0.07	0.12	0.17
Bromide	mg/L	27	ND	ND	ND	ND	ND	0.18	0.25
Temperature	°C	29	6.0	7.7	13.0	14.8	16.6	18.1	19.0
Dissolved Oxygen	mg/L	29	7.8	7.9	8.2	8.6	9.1	10.0	10.6
Ortho-P	mg/L	27	ND	ND	ND	ND	ND	ND	ND
Nitrite	mg/L	27	ND	ND	ND	ND	ND	ND	ND
Nitrate	mg/L	27	ND	ND	ND	ND	0.16	0.68	0.89
E. coli	CT/100 mL	28	ND	21.1	28.8	37.5	53.3	216	387
Chloride	mg/L	27	ND	ND	ND	ND	ND	12.4	31.0
Fluoride	mg/L	27	ND	ND	ND	0.22	0.27	0.48	0.57
Sulfate	mg/L	26	ND	ND	16.0	36.0	85.2	125	136
Ammonia	mg/L	10	ND	ND	ND	ND	ND	ND	ND
Antimony	mg/L	7	ND	ND	ND	ND	ND	ND	ND
Arsenic	mg/L	4	ND	ND	ND	ND	0.19	0.64	0.75
Barium	mg/L	4	0.02	0.02	0.02	0.03	6.4	21.8	25.7
Beryllium	mg/L	7	ND	ND	ND	ND	ND	ND	ND
Cadmium	mg/L	7	ND	ND	ND	ND	ND	ND	ND
Chromium	mg/L	7	ND	ND	ND	ND	ND	ND	ND
Copper	mg/L	4	ND	ND	ND	ND	ND	ND	ND
Mercury	mg/L	7	ND	ND	ND	ND	ND	ND	ND
Nickel	mg/L	7	ND	ND	ND	ND	ND	ND	ND
Selenium	mg/L	7	ND	ND	ND	ND	ND	ND	ND
Silver	mg/L	7	ND	ND	ND	ND	ND	ND	ND
Sodium	mg/L	4	6.9	7.1	8.1	89.3	835	2431	2830
Thallium	mg/L	7	ND	ND	ND	ND	ND	ND	ND
Zinc	mg/L	4	ND	ND	ND	ND	ND	ND	ND

Notes:
(1) Historical data collected from 2018 to 2023 from LRCC@RES3.

2.1.4.1 PFAS

The northern supply is a low PFAS source. The maximum measured source water concentrations of PFOA, PFOS, PFHxS, PFNA, GenX, and the HI are all below the final MCLs.

2.1.4.2 Total Organic Carbon

The northern supply has higher levels of TOC than Standley Lake but lower levels of TOC than EGL and WGL. The 50th percentile TOC is 4.1 mg/L.

2.1.4.3 Chloride and Sulfate

The northern supply has low levels of chlorides. The maximum CSMR is 0.2, which is the lowest of all sources.

2.1.4.4 Total Dissolved Solids

The northern supply has a 50th percentile TDS of 119 mg/L, which is below the SMCL of 500 mg/L.

2.1.4.5 Taste and Odor

Geosmin and MIB data are not available for northern supply sources. It is expected that levels of geosmin and MIB will be similar to those of Standley Lake.

2.1.5 Summary of Raw Water Characterization

Table 8 contains an overview of key raw water quality parameters and their respective impact on PFAS treatment alternatives.

Table 8 Overview of 50th Percentile Raw Water Quality Parameters and Impact on Treatment

Parameter	Units	Standley Lake	EGL	WGL	Northern Supply	Impact on PFAS Treatment
PFOA	ng/L	0.6	9.1	3.6	ND	A PFAS treatment process will be required to consistently meet the MCL and MCLG.
PFOS	ng/L	0.6	9.6	4.8	ND	A PFAS treatment process will be required to consistently meet the MCL and MCLG.
PFHxS	ng/L	ND	6.5	3.3	ND	Treatment technologies utilized for PFOA and PFOS will also reduce PFHxS levels.
PFNA	ng/L	ND	1.5	0.5	ND	Treatment technologies utilized for PFOA and PFOS will also reduce PFNA levels.
GenX	ng/L	ND	ND	ND	ND	GenX is non-detect in Thornton's source waters.
PFAS HI	--	0.0	0.7	0.3	0.0	Treatment technologies utilized for PFOA and PFOS will also reduce PFAS HI levels.
TOC	mg/L	2.0	5.9	5.7	4.1	TOC levels may impact the performance of GAC and IX resin for PFAS treatment.
CSMR	--	0.8	1.1	1.2	0.0	Future blending of northern supply will improve CSMR at WBWTP.
TDS	mg/L	209	628	459	119	Future blending of northern supply will improve TDS at WBWTP.
Geosmin	ng/L	ND	6.9	7.2	N/A	T&O is commonly present in EGL and WGL.
MIB	ng/L	ND	8.5	1.8	N/A	T&O is commonly present in EGL and WGL.

2.2 Historical Finished Water Quality

Finished water quality is representative of the typical water quality for post-filter PFAS treatment alternatives, such as GAC, IX, alternative adsorbents, and high-pressure membranes. Historical finished water quality for each of Thornton's WTPs is presented below. A summary of the primary water quality parameters of concern for both TWTP and WBWTP has been provided at the end of this section.

2.2.1 TWTP

Table 9 contains a summary of the characteristics of TWTP finished water. A discussion of selected key water quality parameters follows.

Table 9 Characteristics of TWTP Finished Water

Parameter	Units	No. of Samples	Minimum	5th Percentile	25th Percentile	50th Percentile	75th Percentile	95th Percentile	Maximum
PFOA	ng/L	25	1.2	1.6	3.0	3.9	5.1	7.1	8.6
PFOS	ng/L	25	ND	1.0	2.2	2.6	3.3	4.9	5.6
PFBS	ng/L	25	1.2	1.7	3.4	4.1	6.0	8.1	9.0
GenX	ng/L	25	ND	ND	ND	ND	ND	ND	ND
PFNA	ng/L	25	ND	ND	ND	ND	0.5	0.6	0.7
PFHxS	ng/L	25	ND	0.1	1.8	2.4	3.4	5.7	5.9
PFAS HI	--	25	0.0	0.0	0.2	0.3	0.4	0.6	0.6
pH	--	166	7.6	7.6	7.9	8.1	8.3	8.6	8.8
Alkalinity	mg/L as $CaCO_3$	166	50	56	83	99	112	144	155
TOC	mg/L	166	ND	1.0	1.6	2.1	2.4	3.2	3.7
Total Hardness	mg/L as $CaCO_3$	166	104	125	180	208	251	312	368
Calcium Hardness	mg/L as $CaCO_3$	166	78	91	124	148	176	235	280
TDS	mg/L	165	177	214	349	430	527	709	744
Iron	mg/L	166	ND	ND	ND	ND	ND	0.05	0.50
Manganese	mg/L	166	ND	ND	ND	0.02	0.02	0.04	0.06
Bromide	mg/L	146	ND	ND	0.14	0.27	0.40	0.64	0.95
Temperature	°C	166	4.6	8.7	11.2	15.0	18.5	21.0	23.7
Dissolved Oxygen	mg/L	161	4.9	7.3	8.6	11.1	12.4	13.3	13.9
Ortho-P	mg/L	166	ND	ND	ND	ND	ND	ND	0.23
Nitrite	mg/L	165	ND	ND	ND	ND	ND	ND	0.06
Nitrate	mg/L	166	ND	0.10	0.20	0.33	0.55	1.0	1.5
Geosmin	ng/L	148	ND	ND	ND	ND	ND	ND	3.9
MIB	ng/L	148	ND	ND	ND	ND	ND	ND	3.6
Chloride	mg/L	166	43	49	92	108	137	188	207

Parameter	Units	No. of Samples	Minimum	5th Percentile	25th Percentile	50th Percentile	75th Percentile	95th Percentile	Maximum
Fluoride	mg/L	165	0.44	0.54	0.60	0.67	0.72	0.86	1.18
Sulfate	mg/L	166	57	70	99	112	140	188	202
Ammonia	mg/L	166	ND	ND	0.06	0.08	0.11	0.16	0.21
Antimony	mg/L	10	ND	ND	ND	ND	ND	ND	ND
Arsenic	mg/L	10	ND	ND	ND	ND	ND	0.001	0.001
Barium	mg/L	10	0.04	0.04	0.04	0.04	0.05	0.05	0.05
Beryllium	mg/L	10	ND	ND	ND	ND	ND	ND	ND
Cadmium	mg/L	10	ND	ND	ND	ND	ND	ND	ND
Chromium	mg/L	10	ND	ND	ND	ND	ND	0.001	0.002
Copper	mg/L	10	ND	ND	0.001	0.002	0.003	0.004	0.004
Mercury	mg/L	10	ND	ND	ND	ND	ND	ND	ND
Nickel	mg/L	10	ND	ND	0.002	0.003	0.003	0.005	0.005
Selenium	mg/L	10	ND	ND	ND	ND	ND	ND	ND
Silver	mg/L	10	ND	ND	ND	ND	ND	ND	ND
Sodium	mg/L	10	26.0	28.9	64.3	105	120	133	135
Thallium	mg/L	10	ND	ND	ND	ND	ND	ND	ND
Zinc	mg/L	10	ND	ND	ND	ND	ND	0.01	0.02

Notes:
(1) Historical data collected from 2020 to 2023.

2.2.1.1 PFAS

The TWTP currently does not have a treatment process that removes PFAS. Depending on demand, the City can reduce PFAS levels by controlling the blend of source water supplies to TWTP. The 50th percentile values for PFOA, PFOS, PFHxS, PFNA, GenX, and the HI are all below the final MCLs. The maximum values for PFOA and PFOS exceed the final MCL at 8.6 ng/L and 5.6 ng/L, respectively.

2.2.1.2 Total Organic Carbon

TWTP finished water has moderate levels of TOC. The 50th percentile TOC is 2.1 mg/L.

2.2.1.3 Chloride and Sulfate

TWTP finished water has a 50th percentile CSMR of 1.0.

2.2.1.4 Total Dissolved Solids

TWTP finished water has a 50th percentile TDS of 430 mg/L and a maximum concentration of 744 mg/L, which exceeds the SMCL of 500 mg/L.

2.2.1.5 Taste and Odor

TWTP utilizes ozone and biofiltration to effectively control T&O compounds. TWTP finished water has 50th percentile geosmin and MIB levels of non-detect and maximum geosmin and MIB levels of 3.9 ng/L and 3.6 ng/L, respectively.

2.2.1.6 Summary of TWTP Finished Water Characterization

Table 10 contains an overview of key TWTP finished water quality parameters and their respective impact on PFAS treatment alternatives.

Table 10 Overview of TWTP Finished Water Quality Parameters and Impact on PFAS Treatment and Water Quality

Parameter	Applicable Value	Impact on PFAS Treatment and Water Quality
PFAS	50th percentile PFOA = 3.9 ng/L 50th percentile PFOS = 2.6 ng/L Maximum PFOA = 8.6 ng/L Maximum PFOS = 5.6 ng/L	A PFAS treatment process is required to consistently meet the MCL and MCLG.
TOC	50th percentile = 2.1 mg/L Maximum = 3.7 mg/L	TOC levels will impact the performance of GAC and IX resin for PFAS treatment. Treatment technologies that remove TOC also reduce disinfection byproducts and improve chlorine stability.
CSMR	50th percentile = 1.0 mg/L	Treatment technologies that selectively remove sulfate while adding chloride will negatively impact finished water corrosivity by increasing the CSMR.
TDS	50th percentile = 430 mg/L Maximum = 744 mg/L	Treatment technologies that add TDS to the finished water will negatively impact finished water quality.
T&O	Maximum geosmin = 3.9 ng/L Maximum MIB = 3.6 ng/L	TWTP utilizes ozone and biofiltration to effectively control T&O. Treatment technologies that also remove T&O will provide an additional barrier of T&O removal.

2.2.2 WBWTP

Table 11 contains a summary of the characteristics of WBWTP finished water. A discussion of selected key water quality parameters follows.

Table 11 Characteristics of WBWTP Finished Water

Parameter	Units	No. of Samples	Minimum	5th Percentile	25th Percentile	50th Percentile	75th Percentile	95th Percentile	Maximum
PFOA	ng/L	18	ND	ND	0.9	1.4	2.4	5.6	6.8
PFOS	ng/L	18	ND	ND	1.3	1.7	2.0	2.2	2.4
PFBS	ng/L	18	1.5	2.4	3.5	3.9	4.8	7.1	7.4
GenX	ng/L	18	ND	ND	ND	ND	ND	ND	ND
PFNA	ng/L	18	ND	ND	ND	ND	ND	0.1	0.9
PFHxS	ng/L	18	ND	ND	0.8	1.3	1.9	3.3	3.6
PFAS HI	--	18	0.0	0.0	0.1	0.1	0.2	0.4	0.5
pH	--	185	7.4	7.5	7.6	7.7	7.9	8.3	8.6

Parameter	Units	No. of Samples	Minimum	5th Percentile	25th Percentile	50th Percentile	75th Percentile	95th Percentile	Maximum
Alkalinity	mg/L as $CaCO_3$	185	58	106	120	129	139	157	178
TOC	mg/L	185	1.2	1.8	2.5	3.0	3.4	3.9	4.5
Total Hardness	mg/L as $CaCO_3$	185	160	188	212	244	264	288	368
Calcium Hardness	mg/L as $CaCO_3$	185	82	132	148	166	184	206	292
TDS	mg/L	185	263	402	461	504	577	643	732
Iron	mg/L	185	ND	ND	ND	ND	ND	0.04	0.17
Manganese	mg/L	185	ND	ND	ND	0.02	0.02	0.04	0.14
Temperature	°C	185	8.3	11.3	14.9	19.4	22.6	24.4	25.3
Dissolved Oxygen	mg/L	178	5.4	6.4	6.8	7.2	8.3	9.5	11.6
Ortho-P	mg/L	181	ND	ND	ND	ND	ND	0.12	0.70
Nitrite	mg/L	181	ND	ND	ND	ND	ND	ND	0.05
Nitrate	mg/L	181	ND	ND	0.25	0.45	0.64	1.02	1.61
Geosmin	ng/L	238	ND	ND	ND	ND	1.5	4.4	26.0
MIB	ng/L	238	ND	ND	ND	ND	1.8	8.6	23.0
Chloride	mg/L	181	86	106	131	146	163	184	203
Fluoride	mg/L	181	0.49	0.51	0.58	0.64	0.71	0.82	0.92
Sulfate	mg/L	181	77	92	101	115	130	157	188
Ammonia	mg/L	185	ND	ND	0.07	0.10	0.12	0.18	0.28
Antimony	mg/L	7	ND	ND	ND	ND	ND	ND	ND
Arsenic	mg/L	7	ND	ND	ND	ND	ND	ND	ND
Barium	mg/L	7	0.04	0.04	0.04	0.04	0.05	0.05	0.05
Beryllium	mg/L	7	ND	ND	ND	ND	ND	ND	ND
Cadmium	mg/L	7	ND	ND	ND	ND	ND	ND	ND
Chromium	mg/L	7	ND	ND	ND	ND	ND	0.001	0.001
Copper	mg/L	7	0.007	0.007	0.008	0.008	0.009	0.01	0.01
Mercury	mg/L	7	ND	ND	ND	ND	ND	ND	ND
Nickel	mg/L	7	ND	ND	0.001	0.002	0.003	0.003	0.004
Selenium	mg/L	7	ND	ND	ND	ND	ND	ND	ND
Silver	mg/L	7	ND	ND	ND	ND	ND	ND	ND
Sodium	mg/L	7	81.0	81.6	86.0	99.0	110	117	120
Thallium	mg/L	7	ND	ND	ND	ND	ND	ND	ND
Zinc	mg/L	7	ND	ND	ND	0.008	0.01	0.02	0.02

Notes:
(1) Historical data collected from 2018 to 2023.

2.2.2.1 PFAS

Currently, the WBWTP can meet the final PFAS MCL utilizing PAC. The 50th percentile values for PFOA, PFOS, PFHxS, PFNA, GenX, and the HI are all below the final MCLs. To meet the MCLG of zero for PFOA and PFOS, additional treatment would be required.

2.2.2.2 Total Organic Carbon

WBWTP finished water has moderate levels of TOC. The 50th percentile TOC is 3.0 mg/L.

2.2.2.3 Chloride and Sulfate

WBWTP finished water has a 50th percentile CSMR of 1.3.

2.2.2.4 Total Dissolved Solids

WBWTP finished water has a 50th percentile TDS of 504 mg/L and a maximum concentration of 732 mg/L, which exceeds the SMCL of 500 mg/L.

2.2.2.5 Taste and Odor

WBWTP utilizes PAC for T&O treatment. While 50th percentile geosmin and MIB levels are non-detect, PAC has challenges completely removing T&O during elevated events. WBWTP finished water has maximum geosmin and MIB levels of 26 ng/L and 23 ng/L, respectively. However, these measurements were taken prior to conversion of the first pass of the clear well into a free chlorine contact basin, which allowed for improved PAC pretreatment performance by lowering the pre-chlorination dose. After these improvements were completed, geosmin and MIB levels have not exceeded 10 ng/L.

2.2.2.6 Summary of WBWTP Finished Water Characterization

Table 12 contains an overview of key WBWTP finished water quality parameters and their respective impact on PFAS treatment alternatives.

Table 12 Overview of WBWTP Finished Water Quality Parameters and Impact on PFAS Treatment and Water Quality

Parameter	Applicable Value	Impact on PFAS Treatment and Water Quality
PFAS	50th percentile PFOA = 1.4 ng/L 50th percentile PFOS = 1.7 ng/L	Currently, the WBWTP can meet the final PFAS MCL utilizing PAC. To meet the MCLG, additional treatment would be required.
TOC	50th percentile = 3.0 mg/L Maximum = 4.5 mg/L	TOC levels will impact the performance of GAC and IX resin for PFAS treatment. Treatment technologies that remove TOC also reduce disinfection byproducts and improve chlorine stability.
CSMR	50th percentile = 1.3 mg/L	Treatment technologies that selectively remove sulfate while adding chloride will negatively impact finished water corrosivity by increasing the CSMR.
TDS	50th percentile = 504 mg/L Maximum = 732 mg/L	Treatment technologies that add TDS to the finished water will negatively impact finished water quality.
T&O	Maximum geosmin = 26 ng/L Maximum MIB = 23 ng/L	WBWTP utilizes PAC for T&O treatment, which has challenges completely removing T&O during elevated events. Treatment technologies that also remove T&O will provide an additional barrier of T&O removal and allow for a reduction of PAC addition.

2.3 Finished Water Quality Goals

Combined with source water quality characteristics, finished water goals determine the level of PFAS treatment required for each WTP. 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 goals for its facilities, presented in Table 13. PFAS treatment technologies will be evaluated in their ability to continue to or improve the City's capacity to meet these goals.

Table 13 Finished Water Treatment Goals

Parameter	Goal
PFAS Short-Term Goals	
PFOA	< 4.0 ng/L (MCL)
PFOS	< 4.0 ng/L (MCL)
PFHxS	< 10 ng/L (MCL)
PFNA	< 10 ng/L (MCL)
GenX	< 10 ng/L (MCL)
PFAS HI	< 1.0 (MCL)
PFAS Long-Term Goals	
PFOA	Zero[(1)] (MCLG)
PFOS	Zero[(1)] (MCLG)
PFHxS	< 10 ng/L (MCLG)
PFNA	< 10 ng/L (MCLG)
GenX	< 10 ng/L (MCLG)
PFAS HI	< 1.0 (MCLG)
Particulate/Microbial	
Combined Filter Effluent Turbidity	< 0.10 NTU 95% of the time[(2)]
Disinfection By-Products	
Total Trihalomethanes	< 40 µg/L (50% of MCL)
Haloacetic Acids	< 30 µg/L (50% of MCL)
Bromate	< 5 µg/L (50% of MCL)
Chlorite	< 0.5 mg/L (50% of MCL)

Parameter	Goal
General Physical	
pH Tolerance	± 0.1 of Setpoint to meet CCPP
Iron	< 0.1 mg/L
Manganese	< 0.03 mg/L (60% of SMCL)
TDS	< 500 mg/L
T&O	< 3 ng/L for Geosmin and MIB
Langelier Index	> 0
CCPP	3 to 8 mg/L
Free Ammonia (as N)	0.01 to 0.05 mg/L
Alkalinity	> 44 mg/L as $CaCO_3$
TOC	Compliance with Stage 1 D/DBPR
Disinfection	
Disinfection Inactivation Ratio	1.5 at 0.5°C

Notes:
CCPP - calcium carbonate precipitation potential; D/DBPR - EPA Disinfectants and Disinfection Byproducts Rule
(1) Assumes a method reporting limit of 1.7 ng/L or greater.
(2) Partnership for Safe Water Phase IV Performance Goals include settled water turbidity less than 1.0 NTU 95% of the time.

SECTION 3 TREATMENT PROCESS ALTERNATIVES

PFAS treatment technologies are rapidly evolving, and a variety of treatment technologies have been evaluated for PFAS removal with considerations to both cost and efficacy. The treatment processes commonly used for drinking water treatment, such as filtration and chlorination, are unable to remove PFAS. Currently, only a few treatment alternatives are mature and applicable for full-scale drinking water treatment. Advanced treatment processes that can effectively remove PFAS from drinking water include:

- PAC.
- GAC.
- IX.
- High-pressure membranes.
- Novel adsorbents.

Each of these technologies has its own unique advantages and challenges for application at the City's WTPs, which are discussed in the following sections. It should be noted that currently, the EPA has designated only GAC, IX, and high-pressure membranes as best available technologies for PFAS removal from drinking water based on its review of treatment and cost literature.

3.1 Powdered Activated Carbon

PAC is a black, non-odorous powder used for adsorption of contaminants. After addition and adsorption, PAC is removed in the treatment process by either settling or filtration. PAC performance is impacted by dose, contact time, and other competing water quality parameters, such as TOC. Under favorable conditions, PAC has been shown to be moderately effective at removing long-chain PFAS and ineffective in short-chain PFAS removal.

The use of PAC for PFAS removal at TWTP and WBWTP are discussed below.

3.1.1 TWTP

PAC is likely capable of meeting the City's short-term PFAS treatment goals at TWTP. However, PAC by itself is not capable of meeting the City's long-term goals, so investment in this technology would need to become part of a multi-barrier long-term approach. Additionally, there are site-specific challenges associated with the increased solids from PAC addition and an uncertain regulatory framework around long-term disposal of PAC with adsorbed PFAS.

Solids removed from the TWTP treatment process are transferred to WBWTP for handling via a 2.5-mile sludge pipeline. The pipeline includes a 600-foot section of pipe that is 5 feet lower than the pipe outlet into the WBWTP lagoons. As a low point, this section of pipe may collect settled PAC solids over time, reducing pipeline capacity. Additionally, the increased solids loading at WBWTP would further exceed the capacity of the existing lagoons, necessitating consideration of new mechanical dewatering facilities at WBWTP to provide the required solids handling capacity. The "Water Treatment Plant Capacity Evaluation" (Carollo, 2024) estimated total construction costs of $70 million for mechanical dewatering at WBWTP.

As an alternative, solids could be handled and dewatered on site with new solids handling facilities at TWTP. The annual average unit solid production rate for TWTP with PAC addition (20 mg/L average dose) is estimated to be 410 dry pounds per million gallons. Based on current demand projections, maximum day demand for 2065 buildout is estimated between 73 and 78 mgd with a yearly average day demand of 20 mgd at TWTP. Table 14 summarizes the total dry solids produced under the plant finished water production scenarios noted.

Table 14 Estimated TWTP Total Dry Solids Produced

Scenario (Average Day)	Total Dry Solids Per Year (pounds)
Yearly Average Plant Production of 14 mgd without PAC (Current)	1,200,000
Yearly Average Plant Production of 14 mgd with PAC (Current)	2,000,000
Yearly Average Plant Production of 20 mgd with PAC (Buildout)	2,900,000

To effectively dry solids, passive drying alternatives such as sand drying beds have an annual drying capacity of 16 pounds per square foot. This would require 180,000 square feet of drying area, which exceeds the available room on the west side of the TWTP site, as shown in Figure 1.

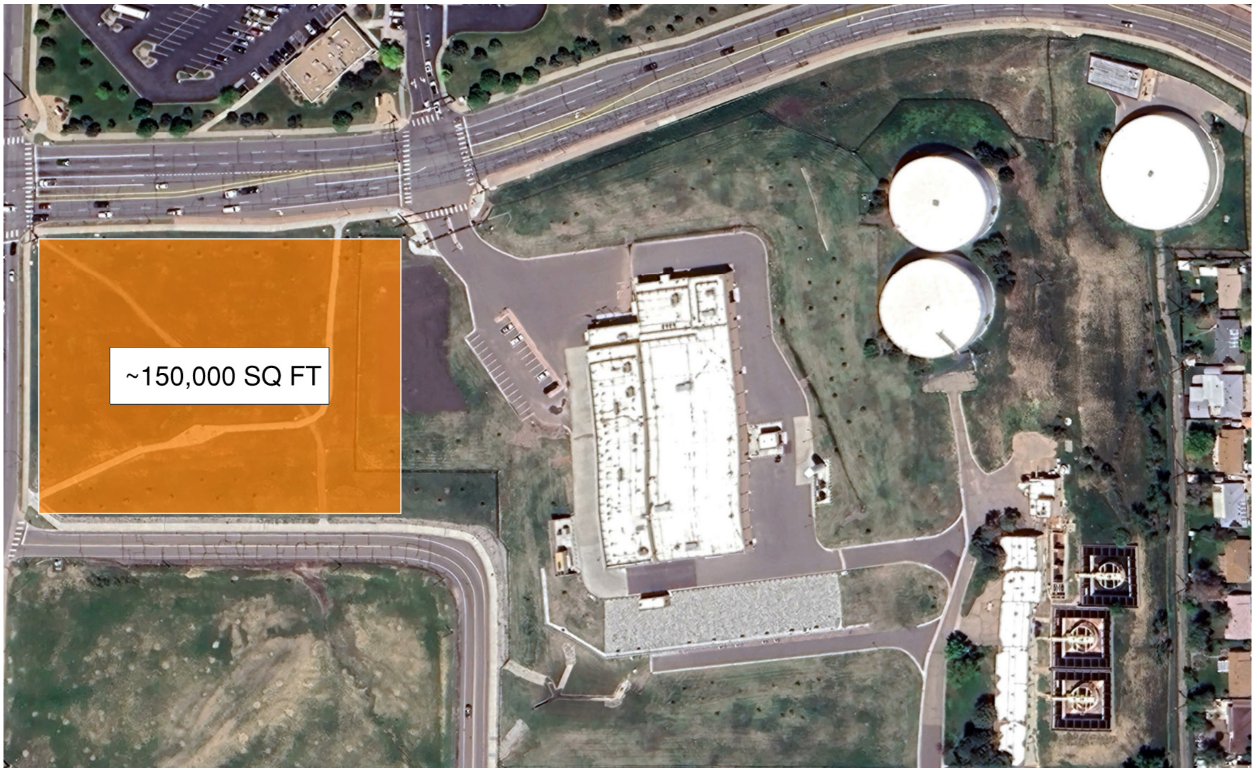


Figure 1 TWTP Area Available for Solids Handling

Mechanical dewatering would likely be the only alternative that would fit within the available site footprint. Total construction costs for mechanical dewatering at TWTP for buildout capacity are estimated at $50 million.

3.1.2 WBWTP

The existing PAC storage and feed system has proven reliable in meeting Thornton's short-term PFAS goals under current water quality conditions at WBWTP. Paired data from 2021 to present are shown in Table 15.

Table 15 PFAS Removal at WBWTP by PAC

Date	Source Water Concentration			Finished Water Concentration			PAC Dose (mg/L)	% Removal		
	PFOA (ng/L)	PFOS (ng/L)	HI	PFOA (ng/L)	PFOS (ng/L)	HI		PFOA (ng/L)	PFOS (ng/L)	HI
4/27/2021	4.9	6.2	0.5	4.0	2.4	0.4	11.5	18%	61%	20%
8/15/2022	6.8	6.0	0.5	3.8	2.2	0.3	8.5	44%	63%	42%
8/22/2022	5.6	6.3	0.5	0.0	2.0	0.0	31.4	100%	68%	100%
9/15/2022	6.1	11.3	0.7	1.0	1.6	0.1	27.6	84%	86%	85%
4/17/2023	4.1	5.9	0.5	0.0	0.0	0.0	24.0	100%	100%	100%
6/15/2023	5.6	7.3	0.6	1.8	1.4	0.1	20.0	68%	81%	82%
6/27/2023	5.6	7.7	0.6	2.0	1.8	0.2	15.0	64%	77%	67%

Date	Source Water Concentration			Finished Water Concentration			PAC Dose (mg/L)	% Removal		
	PFOA (ng/L)	PFOS (ng/L)	HI	PFOA (ng/L)	PFOS (ng/L)	HI		PFOA (ng/L)	PFOS (ng/L)	HI
7/18/2023	5.5	7.3	0.6	1.6	1.8	0.2	20.0	71%	75%	67%
8/14/2023	5.8	7.3	0.6	1.4	1.7	0.1	20.0	76%	77%	83%
8/29/2023	6.1	6.7	0.6	1.3	1.7	0.1	24.0	79%	75%	83%
9/7/2023	5.8	6.2	0.6	1.2	1.4	0.1	24.0	79%	78%	83%
9/26/2023	5.1	5.2	0.5	0.0	1.1	0.1	40.0	100%	79%	78%
10/10/2023	5.7	6.7	0.6	1.1	1.3	0.1	25.0	81%	80%	83%

Individual graphs for PFOA, PFOS, and HI paired data are presented in Figures 2, 3, and 4, respectively.

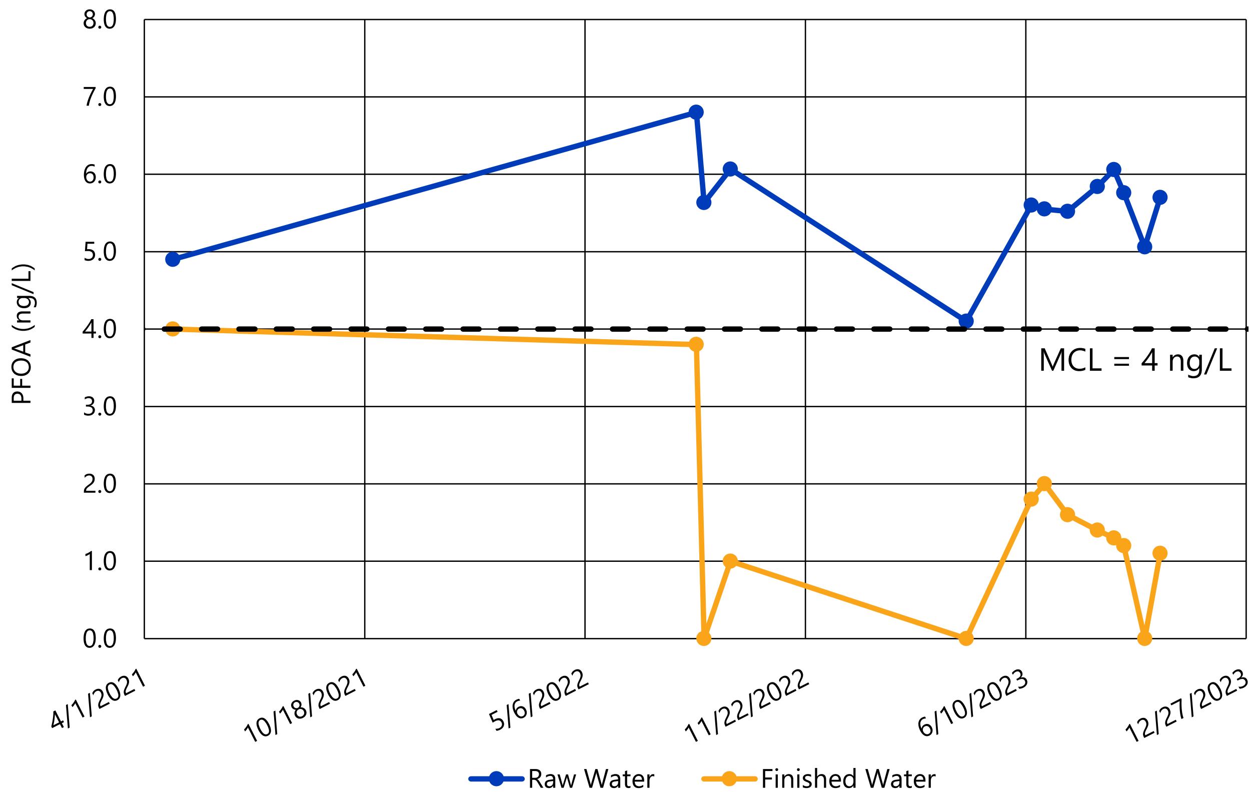


Figure 2 Influent and Effluent PFOA at WBWTP

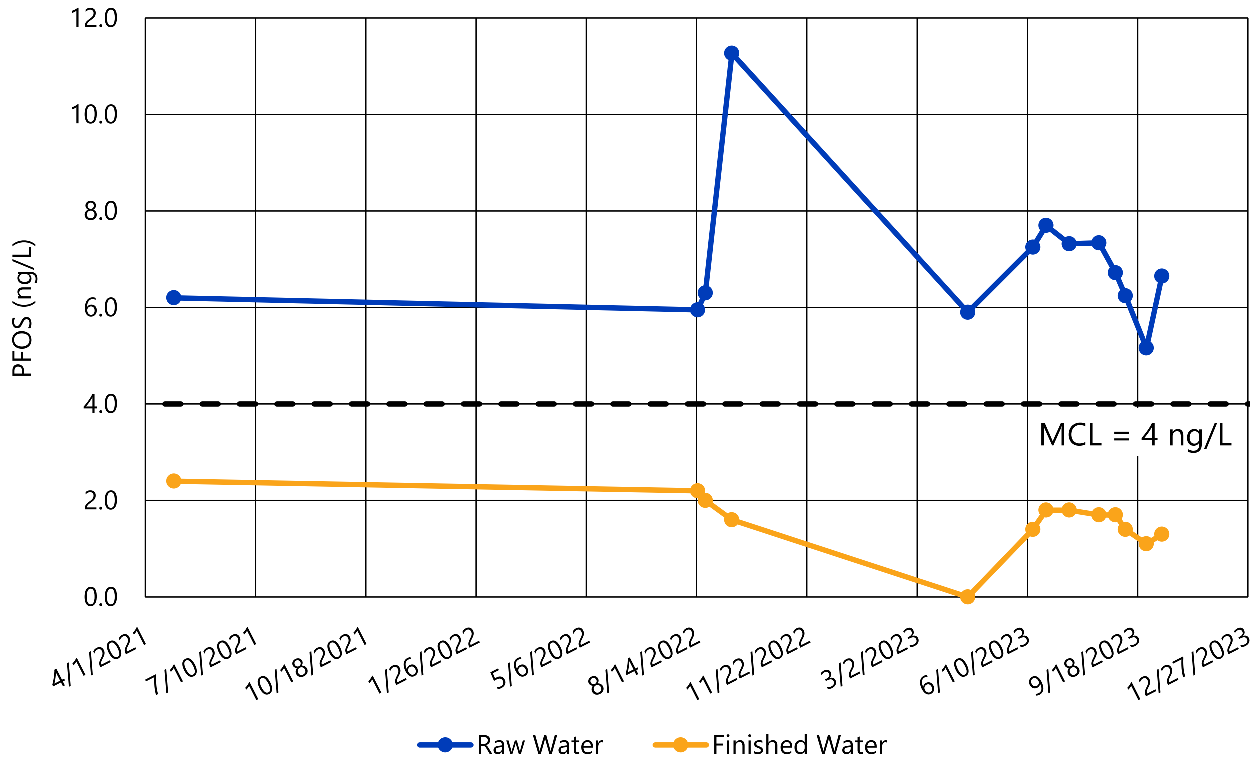


Figure 3 Influent and Effluent PFOS at WBWTP

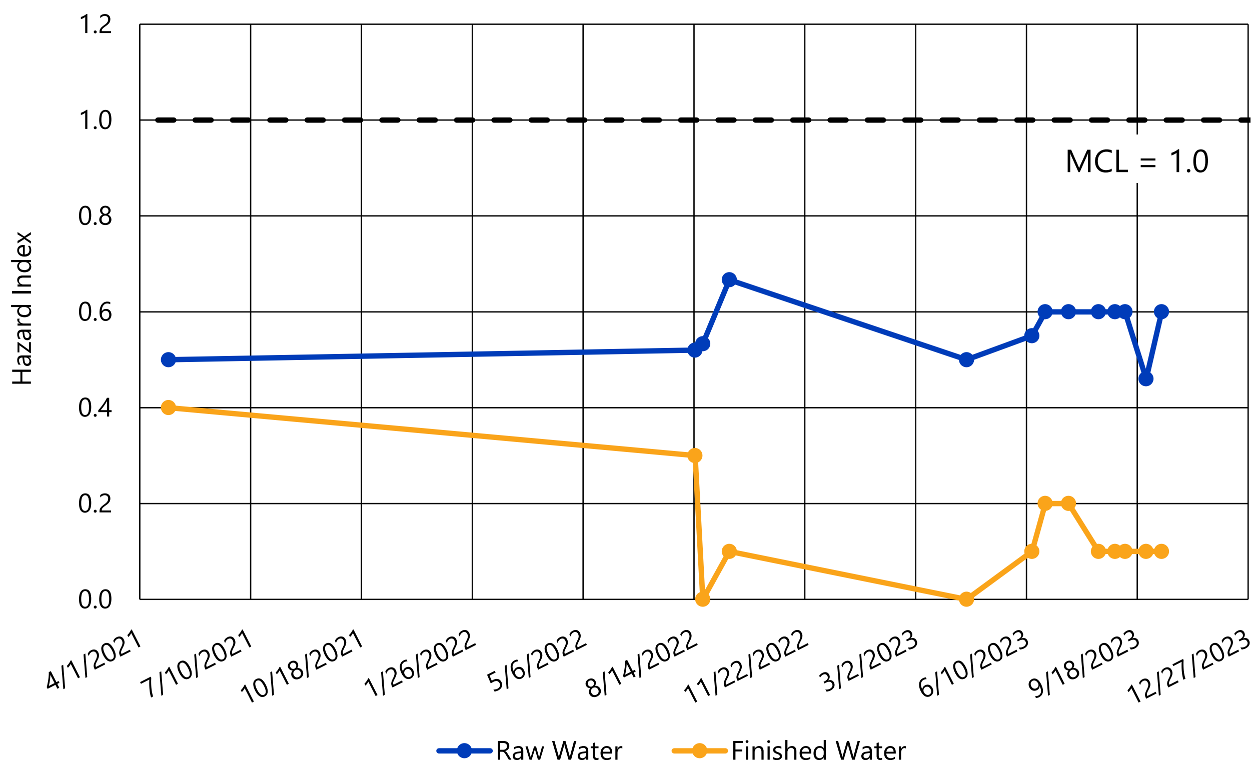


Figure 4 Influent and Effluent HI at WBWTP

After PAC was consistently fed at doses 20 mg/L and greater, the City was able to achieve sufficient PFOA, PFOS, and HI removal to achieve finished water levels less than half of the final MCLs. Percent PFAS removal as a function of PAC dose is presented in Figure 5.

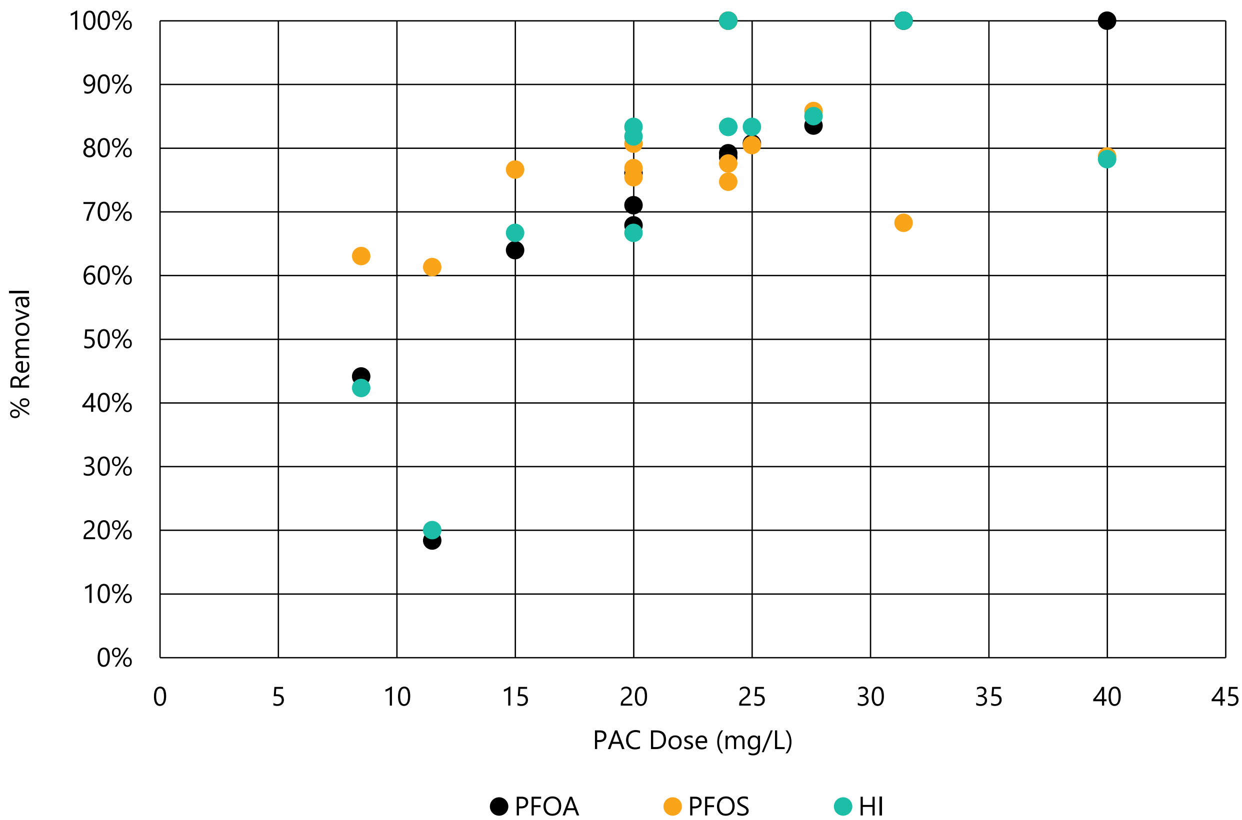


Figure 5 WBWTP PFAS Removal Utilizing PAC

While PAC has consistently been able to meet the final MCL at WBWTP, PAC by itself is not capable of meeting the City's long-term goals and requires higher doses than needed otherwise to achieve PFAS removal, resulting in increased chemical costs and solids. Further, PAC containing PFAS may increase solids handling costs if it is deemed hazardous in the future and solids are no longer suitable for composting. Additional PFAS treatment, such as the other treatment process alternatives highlighted in this section, would need to either replace PAC or become part of a multi-barrier approach to meet MCLG levels consistently.

In the interim, the City plans to increase the PAC storage available at WBWTP as currently there are challenges keeping up with deliveries at higher plant flow rates.

3.2 Granular Activated Carbon

GAC is a porous material with a very high specific surface area that is effective for adsorption of many dissolved contaminants. Studies and full-scale installations have shown GAC to be effective at removing PFAS from drinking water. In general, GAC adsorbs PFOA, PFOS, and other long-chain PFAS better than shorter-chain PFAS. GAC also provides secondary benefits as a treatment barrier for other contaminants, such as disinfection byproduct precursors, T&O compounds, and volatile organic compounds. For this reason, GAC provides a distinct advantage for the WBWTP as it would not only treat PFAS but would also address longstanding T&O challenges and other contaminants of emerging concern. GAC performance for PFAS removal can vary widely depending on carbon type, treatment target, design empty bed contact time (EBCT), adsorber configuration (lead-lag vs. staged parallel), influent PFAS concentration and speciation, and the presence of competing adsorbate such as TOC in the influent.

GAC can be used in gravity contactors or pressure vessels, often installed at the end of a treatment train before disinfection and distribution. Gravity contactors are better suited to large-scale systems and when large pressure drops are undesirable because of their effect on existing plant hydraulics and operation costs. Pressure vessels enclose the GAC and can be operated over a wide range of flow rates. Pressure vessels are more suited to small-scale systems, particularly for wellhead treatment. Table 16 presents a comparison between gravity contactor and pressure vessel designs for GAC treatment.

Table 16 Comparison of GAC Gravity Contactors and Pressure Vessels

Parameter	Gravity Contactor	Pressure Vessel
Cost	▪ Typically, more cost effective than pressure vessels for facilities with greater than 10 mgd of treatment capacity.	▪ Typically, more cost effective than gravity contactors for facilities with less than 10 mgd of treatment capacity.
Space Requirements	▪ For systems greater than 10 mgd, gravity contactors are typically more compact.	▪ For systems greater than 10 mgd, larger space requirements are needed for additional vessels and appurtenances.
Sizing	▪ Optimized basin sizing.	▪ Restricted by manufacturer vessel sizing.
Pumping Requirements	▪ Hydraulic gradient established by contactor level. ▪ May require pumping to provide sufficient EBCT and maintain plant production capacity within the existing plant hydraulic profile.	▪ Typically require pumping of influent to feed at the top of the vessel.
Media Changeout	▪ Changeouts often require multiple days due to the larger size of the contactor boxes.	▪ Changeout is simpler utilizing direct pumping of media into vessels from trucks. ▪ GAC vendors have indicated a half-day for media changeout for standard 12-foot diameter vessel size.
Lead-Lag Conversion Capabilities	▪ Conversion from staged parallel to lead-lag operation requires careful forethought through design.	▪ Lead-lag or staged parallel configuration is readily achievable.
Constructability	▪ Water bearing concrete design and construction is more complicated.	▪ Water bearing concrete is not required, simplifying construction on site. ▪ Vessels are fabricated in a controlled factory environment.

Operating GAC adsorption systems in lead-lag configuration increases media utilization by replacing media in lead vessels first and switching lag vessels to lead service. A noted increase in media utilization is observed when breakthrough curves of the targeted contaminants are steep, and the treatment objective requires a high level of removal. While GAC media is four to five times less expensive than IX resins on a unit volume basis, longer empty bed contact time is typically required (10 to 15 minutes is common).

Backwashing is important in the period following media changeout to remove fines from the new carbon. Additionally, arsenic can leach from bituminous carbon during start-up, which can be addressed by sufficient backwashing and providing the ability to waste initial adsorber effluent. Spent GAC can be potentially regenerated, reactivated, and sold to non-potable water sectors to lower media costs, which is most frequently handled by the GAC media supplier and included in the cost of media changeout.

Locally, GAC has been utilized by multiple utilities for TOC, T&O, and PFAS removal, with installations up to 50 mgd of capacity. Figure 6 presents an example of gravity GAC contactors at the 50-mgd Binney Water Purification Facility (WPF) in Aurora, CO, and Figure 7 presents an example of GAC pressure vessels at the 6-mgd Plum Creek WPF in Castle Rock, CO.

Figure 6 Gravity GAC Contactors at Binney WPF, Aurora, CO

Figure 7 GAC Pressure Vessels at Plum Creek WPF, Castle Rock, CO

Due to the larger size requirements of individual treatment units, both gravity contactors and pressure vessels can be easily designed to be compatible with GAC, IX resin, and novel adsorbents to allow media conversion from one to the other in response to changing water quality or treatment goals in the future.

3.3 Ion Exchange

IX treatment typically consists of pressurized vessels filled with polymeric IX resin that removes contaminants as water passes through the resin bed. Strong base anion exchange resin in chloride form is commonly used for PFAS treatment. Contaminant removal occurs when the anionic contaminant, such as PFAS, exchanges with the chloride counter ion. PFAS removal by IX occurs through classic "exchange" mechanisms, but also via PFAS adsorption to the resin beads. Depending on the presence of co-contaminants (e.g., TOC, sulfate, bromate, nitrate, etc.), significant competition for adsorption sites can be observed, lowering the PFAS removal efficiency. A visualization of the ion exchange mechanism is presented in Figure 8.

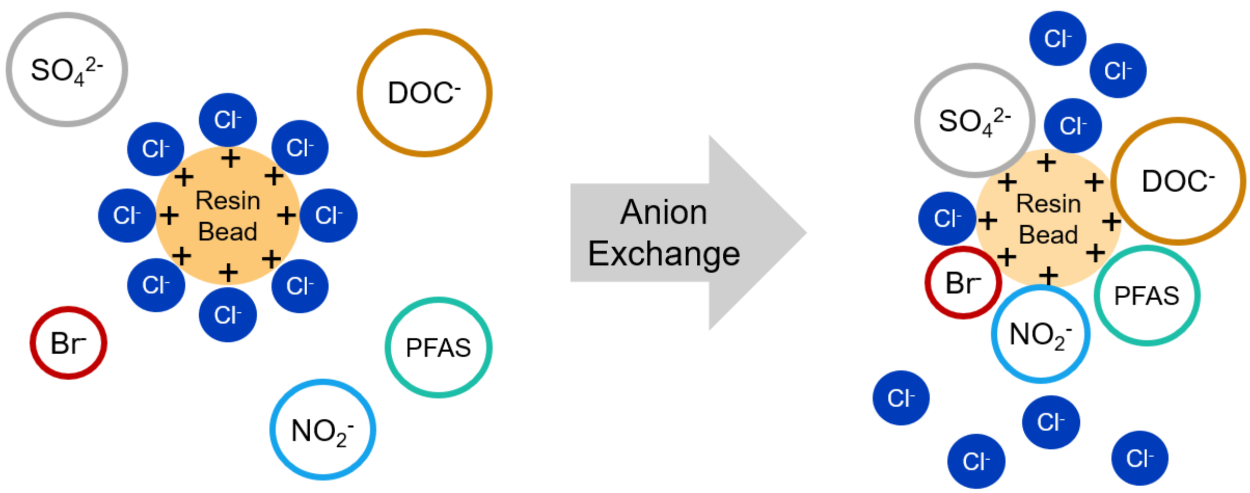


Figure 8 Ion Exchange Mechanism

As strong base anion exchange resins generally have a high affinity for sulfate due to its divalent charge, the exchange reaction between sulfate and chloride can result in increasing CSMR levels in treated water, particularly during initial system start-up. The extent and duration of the CSMR increase can be quantified utilizing bench-scale RSSCTs to better understand the potential implications on treated water corrosivity.

IX resin is sensitive to chlorine and other oxidants, which can cause resin degradation over time. IX is also susceptible to solids fouling, whereas backwashing is not recommended for IX systems because resin beds are shallow and backwashing would disturb the contaminant mass transfer zone, leading to early breakthrough. Following exhaustion, the single-use IX resin would be removed and incinerated.

Locally, IX has been utilized for PFAS removal on low-organic groundwaters from Widefield Aquifer near Colorado Springs and is currently in design for South Adams County Water and Sanitation District's Klein Water Treatment Facility. All current installations are 9 mgd or less.

Figure 9 presents an example of IX vessels at the 1-mgd Stratmoor Hills Water District, CO, groundwater facility.

Figure 9 IX Vessels at Stratmoor Hills Water District, CO

While IX resins are four to five times the cost of GAC on a unit volume basis, shorter EBCT is typically required (three minutes is common). However, IX does not remove other contaminants of concern for the City, such as T&O compounds, and there are less options for spent resin disposal. Currently, most of the spent resin in the Western United States is incinerated by Clean Harbors in Utah or by Desotec in Arizona, which is most frequently handled by the IX resin supplier and included in the cost of resin changeout.

Due to the smaller footprint requirements of individual treatment units, IX pressure vessels can be designed to be compatible with novel adsorbents to allow media conversion from one to the other in response to changing water quality or treatment goals in the future. However, since GAC requires a longer EBCT, it cannot be easily accommodated within IX vessels.

3.4 High-Pressure Membranes

High-pressure membranes, such as nanofiltration (NF) and reverse osmosis (RO), broadly remove both long- and short-chain PFAS, in addition to other dissolved constituents, including TOC, salts, and pathogens. RO systems are currently used in some communities in Colorado that have particularly challenging source waters, such as Brighton (soon to be decommissioned), Clifton, and East Cherry Creek Valley Water and Sanitation District (ECCV). Figure 10 presents an example of installed high-pressure membranes at the 7.7-mgd Zone 7 Water Agency Mocho Groundwater Demineralization Plant in California.

Figure 10 RO Membranes at Mocho Groundwater Demineralization Plant, Zone 7 Water Agency, CA

High-pressure membrane systems typically carry high capital and operating costs relative to other treatment technologies, but also provide benefits and levels of treatment unattainable by other technologies. For example, TDS reduction can be accomplished with high-pressure membranes, but not with the other technologies evaluated. The high-pressure pumping requirements for NF/RO systems can drive high energy costs. Energy recovery and more energy efficient membrane material designs have contributed to moderately lowering the overall net energy use in previous years.

Management of reject streams (or "brine") can drive significant capital and operating costs. Water recovery of two- to three-stage RO systems ranges from 70 to 85 percent, with brine compromising the remaining 15 to 30 percent of total treatment flow. Innovative RO technologies, such as closed-circuit RO with multiple stages, can bring overall water recovery rates upwards of 90 to 95 percent. However, this still leaves approximately 5 to 10 percent of the total treatment flow as brine, which is particularly challenging to dispose of or manage in Colorado. Stream discharge permitting has proven extremely challenging for at least two Colorado Front Range RO facilities in recent years. For example, more stringent Colorado Department of Public Health and Environment regulations on brine disposal placed Brighton's RO WTP at risk of noncompliance by 2022, leading to the design and construction of a new treatment facility including denitrification, pellet softening, greensand filtration, GAC adsorption, and free chlorine disinfection. Due to these challenges, deep injection wells (DIW) and zero liquid discharge (ZLD) facilities have remained as the two most potentially viable brine management strategies.

DIW, while driving significant capital and operation and maintenance (O&M) costs, have previously proven to be a viable option in the Colorado Front Range for disposal of brine streams at a limited number of facilities. ECCV operates a 10-mgd RO water treatment facility in the northeast Denver/ Brighton metro areas with high recovery rates generally exceeding 93 percent (with generation of correspondingly low brine flow rates). The plant's DIW system includes two DIWs on site of the WTP grounds, high-pressure pumping equipment, and high-pressure lines conveying the brine to the deep well. The well is 10,000 feet deep, and the pumping system has a design pressure of 1,400 pounds per square inch. While a successful example, there are increasing concerns of seismic activity resulting from DIW activities, putting future approval and feasibility of DIWs in jeopardy. Additionally, DIWs would result in waste of large volumes of the City's limited source water supplies.

As a result, identifying the most cost-effective and least energy intensive brine minimization and ZLD approaches are of increasing importance. There are several alternatives within the industry for ZLD that may be applicable to TWTP and WBWTP, including:

- Conventional lime/soda ash softening followed by secondary desalting treatment using RO or electrodialysis reversal.
- Seeded RO (or slurry precipitation and batch RO process) for treatment of first and second stage RO brine.
- Brine concentrators and/or crystallizers to process desalting concentrate to form a salt that can be disposed as solid waste, while recovering additional water.
- Recovering salts using the SAL-PROC process by Geo-Processors for beneficial use in chemical processing industry or WTPs.

Modular ZLD systems are available from suppliers, such as Veolia's Bulldozer Brine Crystallization System, shown in Figure 11. However, these systems, similar to non-modular options, are both footprint and cost intensive. The Veolia Bulldozer system has a maximum capacity of 70 gallons per minute (gpm) and is quoted at $11 million (for reference, TWTP waste streams would be 1,500 gpm assuming 93 percent recovery at 30 mgd).

Adoption of high-pressure membranes followed by either DIW or ZLD would lead to a significant financial burden to the City. Due to high membrane fouling potential downstream of biofiltration, ultrafiltration (UF) membranes would be required for pretreatment at TWTP in addition to NF/RO. Costs are estimated at $150 million and $400 million for high-pressure membranes followed by DIW or ZLD at TWTP, respectively, and $150 million and $500 million at WBWTP. These costs are the most expensive of all treatment alternatives and exceed project budget, eliminating high-pressure membranes from further consideration.

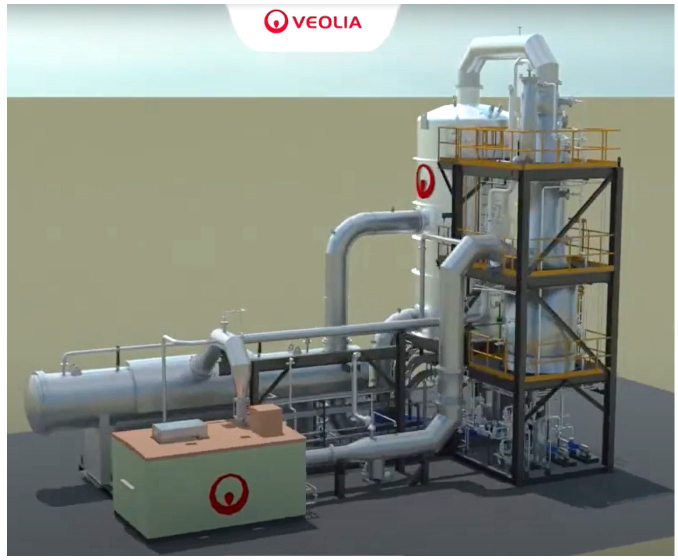


Figure 11 Veolia Bulldozer ZLD System

3.5 Novel Adsorbents

In addition to activated carbon and IX resin, novel adsorbents, such as CETCO FLUORO-SORB® 200 and Cyclopure DEXSORB+® are under development for drinking water treatment.

FLUORO-SORB® 200 is a National Science Foundation (NSF) certified, proprietary, surface-modified bentonite clay material. FLUORO-SORB® 200 has shown to have promise in removing both long- and short-chain PFAS from groundwater in pilot-scale treatment studies, and there are approximately 20 ongoing pilot studies in the Northeast United States and locally by Aurora Water and ECCV. FLUORO-SORB® 200 also has claimed to be less impacted by chlorine and higher TOC source waters than IX or GAC. However, currently, there is only one full-scale drinking water treatment installation of FLUORO-SORB® 200 at the New Jersey American Water's 1.2-mgd Beckett Station groundwater well facility in Swedesboro, New Jersey (installation in 2023). FLUORO-SORB® 200 was selected over IX and GAC at this facility because it is more chlorine tolerant and avoids a dechlorination step between the existing greensand filters and PFAS treatment. Due to the single installation, there is limited understanding of the design and operation requirements for FLUORO-SORB® 200 and its long-term, life-cycle cost for PFAS treatment.

Cyclopure DEXSORB+® is a renewable cyclodextrin-based material derived from corn. Cyclodextrin are cage-shaped molecules that have an inner hydrophobic pocket for capture of micropollutants such as PFAS. DEXSORB+® is in the process of pursuing NSF certification and is not yet applicable for full-scale drinking water treatment.

While novel adsorbents have limited records in full-scale drinking water applications, both IX vessels and GAC contactors can be designed to accept alternative adsorbents in the future if they prove to be advantageous as the technology matures.

3.6 Additional Technologies

In addition to the treatment processes presented, additional technologies were considered. However, these processes were eliminated from further consideration for the following reasons:

- **Foam Fractionation (FF):** FF is similar to dissolved air flotation. Bubbles are released into water that flow upward through the water column. PFAS molecules attach themselves at the air/water interface of the bubbles due to their surfactant nature and collect at the surface where the PFAS-concentrated foam layer is then removed. FF has been shown to be effective in removing long-chain PFAS and is under evaluation for groundwater remediation applications or landfill leachate treatment. The scale of the FF process is currently not large enough to allow for municipal drinking water treatment.
- **Ozone-Based Fractionation (Ozofractionation):** Ozofractionation is a type of FF that uses ozone instead of air to create the bubbles. It was designed by Evocra for groundwater remediation to treat PFAS while addressing complex background water matrices. The resulting waste stream requires further treatment, often by GAC, IX, or RO. Currently, there are no full-scale applications of this technology at drinking water facilities.
- **Aqueous Electrostatic Concentrator (AEC):** AEC was developed by BioLargo as a technology that separates PFAS compounds in an electrostatic field and concentrates PFAS by a proprietary membrane. When the membrane has reached its capacity, the module is removed and sent to a centralized facility for destruction. In December 2023, BioLargo announced it received its first purchase order for AEC to be installed at Lake Stockholm Water Systems, New Jersey, which supplies water to approximately 100 customers. AEC has not been implemented at the scale of TWTP or WBWTP and its long-term viability and life-cycle cost remain unknown.
- **Electro-Coagulation (EC):** The EC process involves destabilization of contaminants in solution to create a floc of pollutants that can be collected for further treatment, often by GAC, IX, or RO. EC studies have focused on waters that are more favorable to treatment for proof of concept (e.g., high initial PFAS concentration and absence of oxidant scavengers). EC has not been implemented at the scale of TWTP or WBWTP for PFAS removal.
- **Destructive Technologies:** Multiple destructive technologies are currently under development, including thermal treatment, hydrothermal, electrochemical oxidation, advanced reduction processes, and sonolysis technologies. Many of these technologies are currently being tested at either bench- or pilot-scale and are limited in treatment capacity (less than 10 gpm) due to the requirements for intensive energy supply or extended long reaction times to break the carbon-fluorine bond for PFAS destruction. There are currently no full-scale applications of PFAS destructive treatment technologies for drinking water treatment.

3.7 Summary of Treatment Process Alternatives

Table 17 presents an overview of PFAS treatment process alternatives and their respective advantages and disadvantages.

Table 17 Comparison of Available Drinking Water Treatment Technologies for PFAS

Technology	Advantages	Disadvantages
PAC	▪ PAC has been shown to be moderately effective at removing long-chain PFAS. ▪ PAC is already in use at WBWTP and has proven effective in reducing PFAS levels below the final MCLs under current water quality conditions. No capital improvements would be required at WBWTP to meet the City's short-term goals.	▪ PAC by itself is not capable of meeting the City's long-term PFAS treatment goals, so investment in this technology would need to become part of a multi-barrier long-term approach. ▪ PAC use results in increased solids production, resulting in higher solids disposal costs. Additionally, implementing PAC at TWTP would require significant investment in improved solids handling, likely costing between $50 million and $70 million in capital costs for build-out capacity. ▪ Uncertain regulatory framework around long-term disposal of PAC with adsorbed PFAS. ▪ Less effective in short-chain PFAS removal.
GAC	▪ Effective in removing PFOA, PFOS, and other long-chain PFAS. ▪ Proven advanced water treatment technology for many utilities for PFAS removal. ▪ Provides a treatment barrier for other contaminants (e.g., disinfection byproduct precursors, T&O compounds, etc.). ▪ Proven technology downstream of ozone/biofiltration treatment process utilized at TWTP. ▪ Lower head loss than IX, which reduces energy use from pumping and standby generation power requirements. ▪ Process upsets and water quality changes that result in particulates to accumulate in the GAC can be easily backwashed out. ▪ Spent GAC can be returned to the vendor for regeneration, reactivation, and re-sale to non-potable water sectors to lower media costs. ▪ Treatment units can be readily retrofit with either IX resin or novel adsorbents, maximizing flexibility for changing water quality, treatment goals, or treatment technology improvements in the future.	▪ Longer EBCT is required, resulting in a larger system footprint. ▪ Less effective in short-chain PFAS removal. ▪ GAC fouling by competing contaminants (e.g., TOC) present in TWTP and WBWTP waters. ▪ Non-steady state treatment process, requiring attentive monitoring of contaminant breakthrough to maximize GAC service life.

Technology	Advantages	Disadvantages
IX	▪ Effective in removing both long- and short-chain PFAS. ▪ Proven advanced water treatment technology for many utilities for PFAS removal. ▪ Faster adsorption kinetics, shorter EBCT, and smaller system footprint. ▪ Treatment units can be readily retrofit with novel adsorbents (but not GAC due to shorter EBCT), providing flexibility for changing water quality, treatment goals, or treatment technology improvements in the future.	▪ Resin fouling by TOC and inorganic ions (e.g., sulfate, nitrate, bicarbonate, etc.) that are present in TWTP and WBWTP waters. ▪ Potential for increase in CSMR and TDS of treated effluent. ▪ Greater head loss than GAC, which increases energy use from pumping and standby generation power requirements. ▪ Requires pretreatment (e.g., cartridge filtration) for turbidity control. ▪ Process upsets and water quality changes that result in particulates to accumulate in the IX resin require removal of the top layer of resin, which is maintenance intensive. ▪ Less proven technology downstream of ozone/biofiltration treatment process utilized at TWTP. ▪ Non-steady state treatment process, requiring attentive monitoring of contaminant breakthrough to maximize IX service life. ▪ Does not remove T&O compounds or as many emerging contaminants of concern as other alternatives. ▪ PFAS-specific IX resins are non-regenerable. Disposal of spent resin through high-temperature incineration is recommended.
High-Pressure Membranes	▪ Broadly removes both long- and short-chain PFAS. ▪ Removes other constituents, including TOC, salts, and pathogens. ▪ Produces excellent treated water quality. ▪ Steady-state treatment process.	▪ Most expensive of all alternatives, exceeding project budget. Cost estimates for TWTP and WBWTP are $400 million and $500 million utilizing ZLD for brine management. ▪ Produces a large volume of concentrate that is challenging to permit and requires further treatment or disposal. ▪ Energy intensive. ▪ Requires post-membrane treatment to ensure stable finished water quality.
Novel Adsorbents	▪ Pilot studies have shown effectiveness in removing both long- and short-chain PFAS in groundwater. ▪ Less impacted by chlorine and higher TOC source waters than IX or GAC. ▪ Faster adsorption kinetics and shorter EBCT, which is comparable to that of IX systems (typically 3 minutes).	▪ Limited full-scale installations for PFAS in drinking water (one installation at a 1.2-mgd groundwater well facility in 2023). ▪ Performance in surface water treatment has not been thoroughly investigated or demonstrated. ▪ Limited understanding of O&M, spent adsorbent disposal, and life-cycle costs due to limited number of full-scale installations.

3.7.1 Short-Listed Alternatives

Utilizing the above analysis of both economic and non-economic factors, the following treatment alternatives at TWTP and WBWTP were shortlisted for further evaluation:

- **TWTP:** GAC and IX will be evaluated for ability to meet the City's short- and long-term PFAS treatment goals.
- **WBWTP:** The existing PAC storage and feed system has proven reliable in meeting Thornton's short-term PFAS treatment goals under current water quality conditions. GAC and IX will be evaluated for ability to meet the City's long-term PFAS treatment goals. In the interim, the City plans to increase the PAC storage available at WBWTP as currently there are challenges keeping up with deliveries at higher plant flow rates.

While novel adsorbents have limited experience in full-scale drinking water applications, they have shown promising results in limited pilot testing. Both IX vessels and GAC contactors can be designed to accept alternative adsorbents in the future if they prove to be advantageous as the technology matures.

SECTION 4 RAPID SMALL-SCALE COLUMN TESTING

RSSCTs were performed to provide an expedited evaluation of the GAC and IX technologies being considered as alternatives for meeting the City's PFAS treatment goals at TWTP. The key objectives of bench-scale RSSCTs were to:

1. Inform PFAS treatment technology selection.
2. Determine critical design criteria.
3. Evaluate media use rate to estimate O&M costs associated with media changeout.

Appendix A includes a project memorandum detailing RSSCT column design, feed water characterization, system setup, sampling procedures, results, and conclusions. A summary is provided herein.

4.1 Column Design

RSSCTs utilize mini-columns and the principle of similitude using dimensionless parameters from the pore surface diffusion model to test the performance of GAC and IX adsorbers. By grinding GAC or IX resin into smaller particle sizes, RSSCTs can assess PFAS breakthrough behavior from a full-scale GAC or IX adsorber in a fraction of the time required for a pilot study.

Three GAC products and two IX resin products were evaluated and compared for PFAS treatment performance, including:

- Calgon Carbon Filtrasorb 400 (F400) GAC.
- Carbon Activated Corporation (CAC) ACOL-L100 GAC.
- Evoqua AquaCarb 1230CX GAC.
- Purolite PFA694E IX resin.
- Lanxess TP108 DW IX resin.

The RSSCT column designs are summarized in Table 18.

Table 18 RSSCT Column Designs

Parameter	Units	Column 1	Column 2	Column 3	Column 4	Column 5
Media	--	Calgon Filtrasorb 400	CAC ACOL-L100	Evoqua Aquacarb 1230CX	Purolite PFA694E	Lanxess TP108 DW
Media Type	--	GAC	GAC	GAC	IX	IX
Upper Sieve Size	mesh	12	12	12	20	20
Lower Sieve Size	mesh	40	40	30	30	30
RSSCT Design	--	Hybrid	CD			
Diffusivity Factor, X	--	0.25	0.25	0.25	0	0
Full-Scale GAC or IX Adsorber Design						
EBCT	minutes	15	15	15	3	3
Hydraulic Loading Rate	gpm/sf	6	6	6	10	10
RSSCT Column Design						
Upper Sieve Size	mesh	100	100	100	100	100
Lower Sieve Size	mesh	200	200	200	200	200
Column Internal Diameter	in	3/16	3/16	3/16	3/16	3/16
Column Internal Diameter	mm	4.76	4.76	4.76	4.76	4.76
Hydraulic Loading Rate	gpm/sf	6	6	6	10	10
Volumetric Flow Rate	mL/min	4.4	4.4	4.4	7.3	7.3
Aspect Ratio	--	44	44	44	44	44
Scaling Factor	--	8.32	8.32	9.75	6.63	6.63
Empty Bed Contact Time	minutes	0.37	0.37	0.28	0.07	0.07
Duration	BV	50,000	50,000	50,000	250,000	250,000
Duration	days	13	13	10	12	12

Notes:
BV - bed volume; gpm/sf - gallons per minute per square foot; mm - millimeter

4.2 Feed Water Quality Characterization

RSSCT feed water was collected at the Thornton WTP downstream of the biofiltration process on February 5, 2024, while the plant was operating at a 50:50 blend of Standley Lake and EGL source waters. The collected sample was shipped to Carollo's Water Applied Research Center® (Water ARC®) in Boise, Idaho. The feed water was filtered using 0.45-micron cartridge filter upon receiving and background water quality was characterized before and after cartridge filtration. Cartridge filtration was performed to prevent particle fouling of the high-pressure liquid chromatography pumps used for feeding water through the RSSCT columns and not necessarily for turbidity removal from the collected sample. Table 19 summarizes the feed water quality and PFAS characterization results.

Table 19 RSSCT Feed Water Quality Characterization

Parameter	Units	Raw Sample	Filtrate(1)
pH	-	7.32 - 7.72	7.37 - 7.74
UV254	cm^{-1}	0.015 - 0.017	0.015 - 0.017
Turbidity	NTU	0.58 - 0.81	0.37 - 0.51
Alkalinity	mg/L as $CaCO_3$	84 - 86	82 - 86
TOC	mg/L	1.81 - 1.91	1.82 - 1.84
Chloride	mg/L	72.2 - 78.5	73.3 - 80.3
Sulfate	mg/L	110 - 113	111 - 112
TDS(2)	mg/L	410 - 420	410 - 420
PFOA(3)	ng/L	-	4.2 - 4.7
PFOS(3)	ng/L	-	1.8 - 2.5

Notes:
cm - centimeter; UV254 - ultraviolet (UV) absorbance at 254 nanometers
(1) RSSCT feed water was filtered with 0.45-micron cartridge filter.
(2) TDS was analyzed on samples from two of five drums.
(3) PFOA and PFOS were measured on filtered samples only.

4.3 Results

Of the six PFAS compounds with final MCLs, only PFOA was present in the RSSCT feed water at concentrations above its final MCL. PFOA breakthrough as a function of system throughput (i.e., number of days GAC and IX single adsorbers in service) is shown in Figure 12.

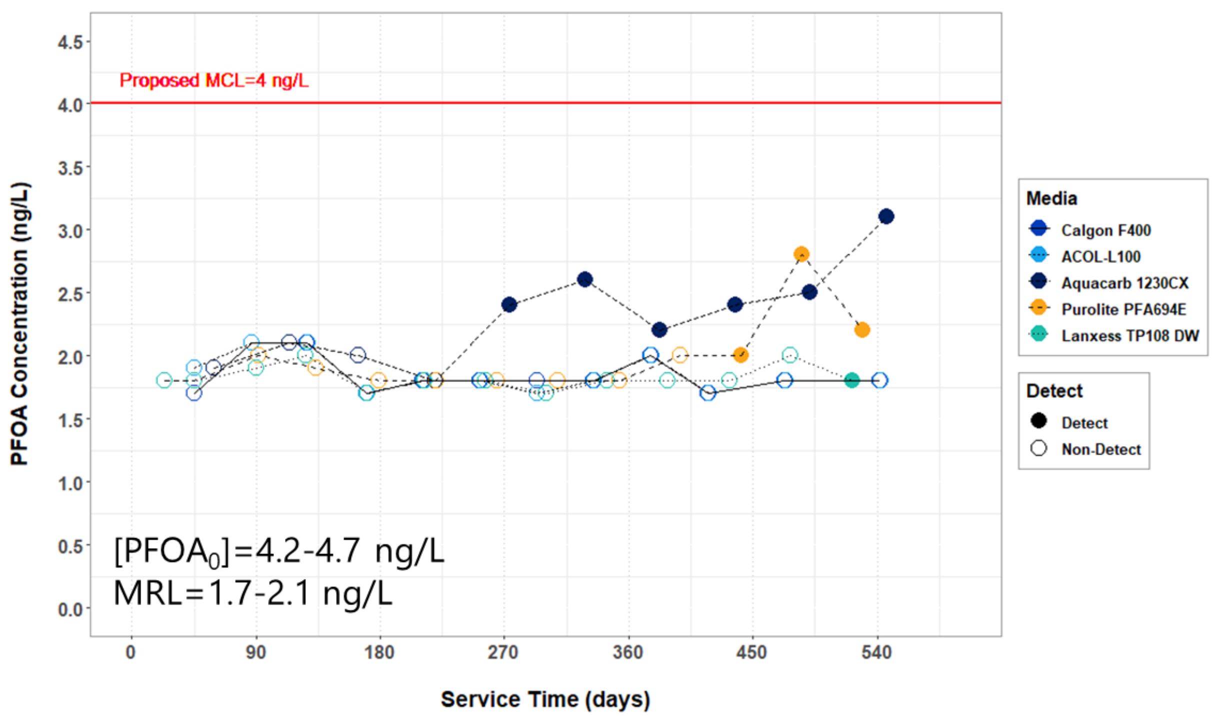


Figure 12 PFOA Breakthrough

Results indicated that effluent PFOA concentration did not exceed its final MCL of 4 ng/L for any of the medias tested and the breakthrough curves observed were flat, indicating that breakthrough is a gradual process. PFOA concentration remained below the method reporting limits (MRL) (1.7 to 2.1 ng/L) for up to 540 days in the two 12x40 GAC column effluents (i.e., Calgon F400 and CAC ACOL-L100). Earlier PFOA breakthrough was observed in the 12x30 GAC column effluent (i.e., Aquacarb 1230CX), exceeding the MRL after 270 days. PFOA breakthrough was only observed near the end of the RSSCT operation from the two IX columns. PFOA concentration exceeded the MRL after 440 days for Purolite PFA694E resin and 520 days for Lanxess TP108 DW resin.

PFOS remained non-detectable in all five column effluents throughout the entire RSSCT duration. Both PFNA and GenX were not detected in the RSSCT feed water. PFHxS concentrations ranged between 2.5 and 3.0 ng/L, which is below the final MCL of 10 ng/L. PFBS concentration in the RSSCT feed water ranged between 4.6 and 5.3 ng/L, which is well below its health-based water concentration (HBWC) of 2,000 ng/L. None of the HI compounds will drive media changeout for either GAC or IX resin.

4.4 RSSCT Conclusions

Conclusions from the RSSCTs performed include the following:

- PFOA will drive GAC media and IX resin use rate.
- PFOA breakthrough curves were flat in nature, indicating that breakthrough is a gradual process. This allows for single pass alternatives utilizing blending to meet the City's PFAS treatment goals.
- In general, GAC and IX performed similarly in terms of system throughput (i.e., media changeout frequency). 12x40 GAC outperformed 12x30 GAC in removing PFOA. Additionally, Lanxess TP108 DW resin outperformed Purolite PFA694E resin in removing all detected PFAS compounds.
- PFOS remained non-detectable in all column effluents throughout the entire RSSCT duration.

SECTION 5 TWTP ALTERNATIVES ANALYSIS

5.1 Treatment Process Alternatives

Alternatives were developed for the following PFAS treatment processes at TWTP:

- GAC Contactors (gravity):
  - Lead/lag.
  - Single pass (stage parallel).
- GAC Pressure Vessels:
  - Lead/lag.
  - Single pass (stage parallel).
- IX Pressure Vessels:
  - Lead/lag.
  - Single pass (stage parallel).

The following sections include proposed design criteria, conceptual three-dimensional (3D) model, site layouts, operational considerations, capital cost estimates, and life-cycle costs as a basis for comparing alternatives.

5.1.1 GAC Contactors

5.1.1.1 Overview

New GAC contactors would be located downstream of the existing biological filtration process. Filtered water would be conveyed from the combined filter effluent pipe in the yard (or at the entry to the chlorine contact chamber) and conveyed to the new intermediate pump station. The intermediate pump station would boost water pressure through the GAC contactors, and treated water would then be returned to the chlorine contact chamber.

Lead/Lag

The process flow diagram (PFD) for lead/lag GAC contactors at TWTP is presented in Figure 13.

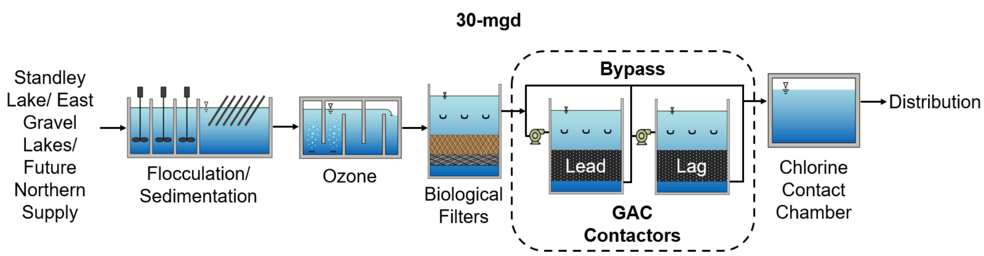


Figure 13 TWTP Lead/Lag GAC Contactors PFD

Lead/lag treatment increases the amount of GAC inventory available and provides additional redundancy if the City's goals are to maintain non-detect in individual GAC contactor effluent as opposed to the blended effluent. However, lead/lag treatment results in additional capital costs and required footprint.

Single Pass

The PFD for single pass GAC contactors at TWTP is presented in Figure 14.

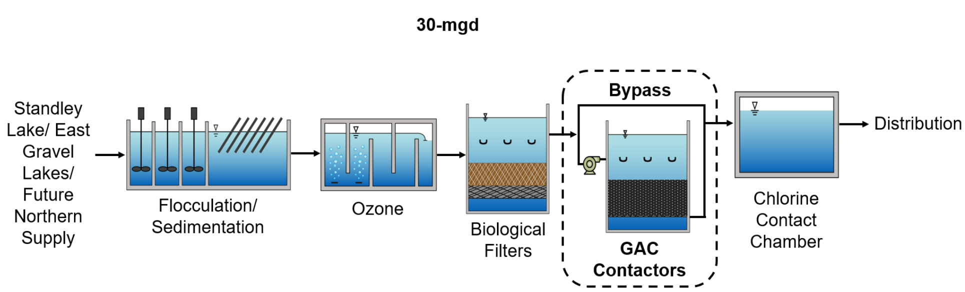


Figure 14 TWTP Single Pass GAC Contactors PFD

Given the longer duration and flat shape of the PFOA breakthrough curves observed during RSSCT testing, single pass treatment is a lower capital cost alternative that can maintain the City's goals for PFAS combined effluent concentrations utilizing blending.

5.1.1.2 Design Criteria

Table 20 outlines the proposed design criteria for lead/lag and single pass GAC contactor alternatives at TWTP.

Table 20 TWTP GAC Contactors Design Criteria

Description	Units	Criteria	
		Lead/Lag	Single Pass
GAC Contactors			
Contactor Type: Gravity, Concrete Box			
Process Capacity	mgd	30	
Number of Contactors, Total	No.	10	6
Number of Lead Contactors	No.	5	5
Number of Lag/Standby Contactors	No.	5	1
Contactor Dimensions (Width x Length)	feet x feet	16.5 x 62	
Contactor Area			
Each Contactor	sf	1,000	
Total	sf	10,000	6,000
Surface Loading Rate (at 30 mgd)	gpm/sf	4.0	
Empty Bed Contact, Per Contactor (at 30 mgd)	minutes	15	
Empty Bed Contact Time, Total (at 30 mgd)	minutes	30	15
GAC Media			
Depth	inch	96	
Bed Volume			
Each Contactor	cf	8,000	
GAC Influent/Intermediate Pump Station			
Type: Submersible Pumps, Variable Speed			
Number of Pumps	No.	10 (8 + 2)	5 (4 + 1)
Capacity, Each	mgd	7.5	

Notes:
cf - cubic feet

5.1.1.3 Conceptual 3D Model

Lead/Lag

A conceptual 3D model for lead/lag GAC contactors at TWTP is presented in Figures 15 and 16.

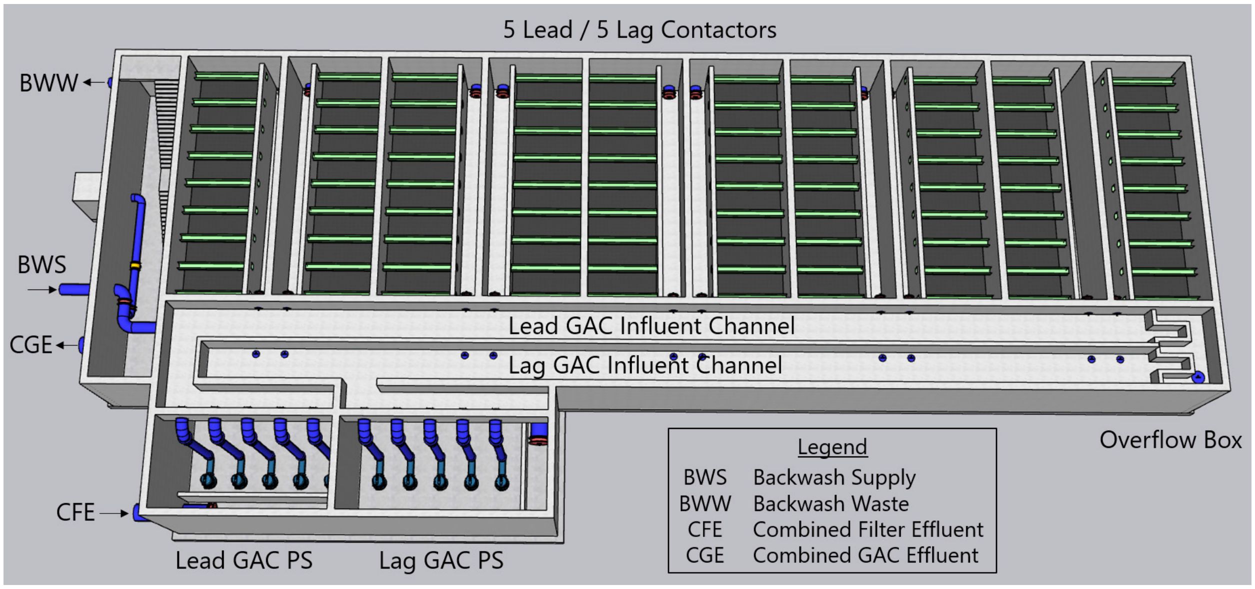


Figure 15 TWTP Lead/Lag GAC Contactors 3D Model Perspective 1

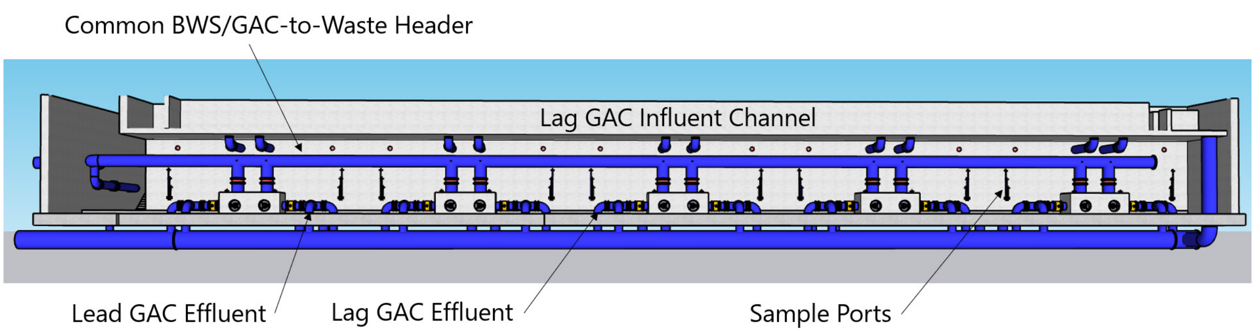


Figure 16 TWTP Lead/Lag GAC Contactors 3D Model Perspective 2

The conceptual design allows for each individual GAC contactor to serve as a lead or lag GAC contactor. Lead contactor effluent is returned to the lag GAC pump station, and then pumped to the lag GAC influent channel, where all lead contactor effluent is blended before treatment in the lag contactor. Flexibility is provided to operate in either single pass or lead/lag. However, since water is blended in the lag GAC influent channel, individual lead contactors cannot be coupled with a specific lag contactor. Treated water is collected in the effluent header and conveyed to the existing Chlorine Contact Chamber.

Backwash supply water is provided by the existing backwash supply pumps for removal of fines after media installation and for intermittent backwash during operation. Filter-to-waste is provided through the common backwash supply header for wasting of effluent when a contactor is first placed into service. An overflow weir is provided in the influent channel that directs process overflow water to the treated water effluent header pipe.

The operating deck, building, and roof of the structure is not shown for clarity.

Single Pass

A conceptual 3D model for single pass GAC contactors at TWTP is presented in Figures 17 and 18.

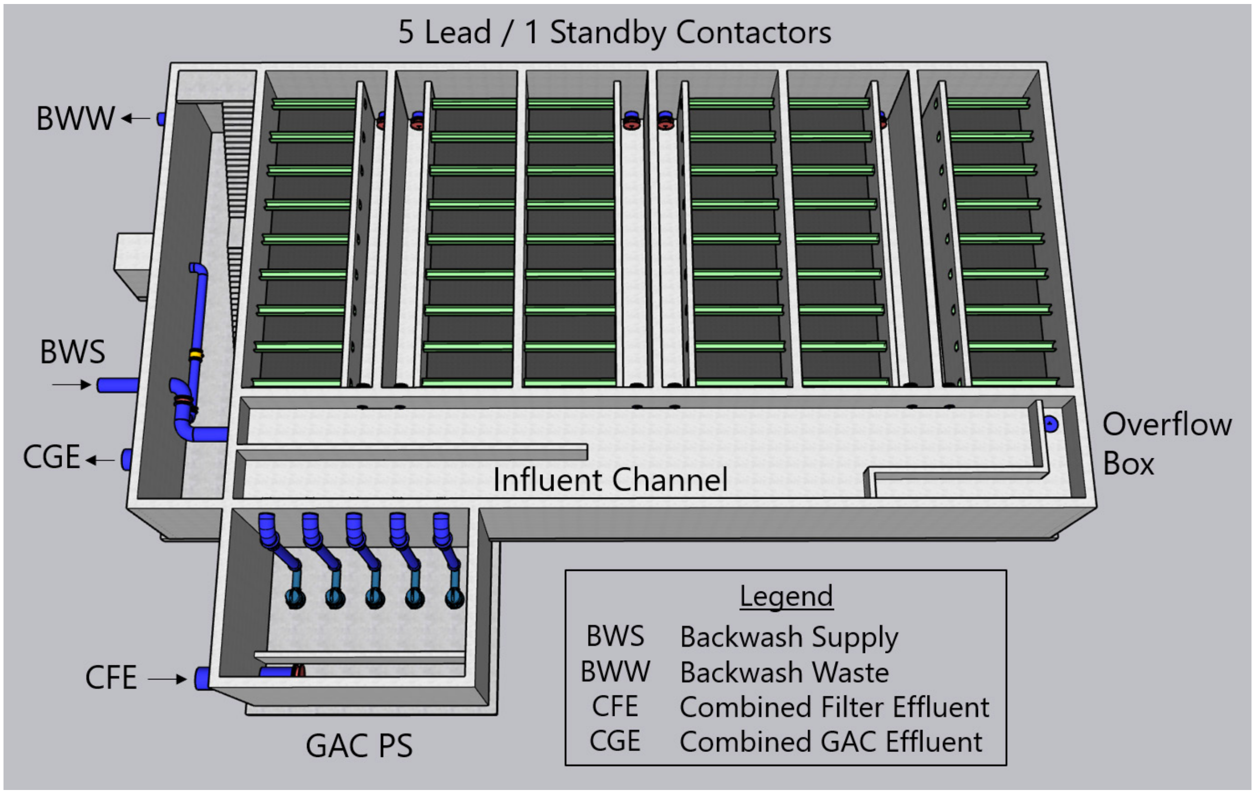


Figure 17 TWTP Single Pass GAC Contactors 3D Model Perspective 1

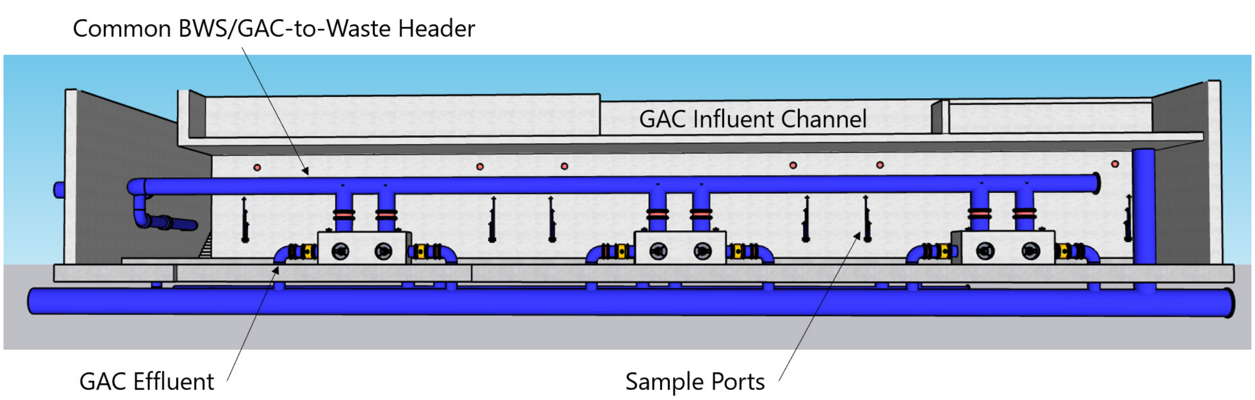


Figure 18 TWTP Single Pass GAC Contactors 3D Model Perspective 2

The conceptual design presented offers stage parallel treatment, where the effluent from each GAC contactor is blended. Valving is provided for operations to select in-service contactors, and treated water is collected in the effluent header and conveyed to the existing Chlorine Contact Chamber.

Backwash supply water is provided by the existing backwash supply pumps for removal of fines after media installation and for intermittent backwash during operation. Filter-to-waste is provided through the common backwash supply header for wasting of effluent when a contactor is first placed into service. An overflow weir is provided in the influent channel that directs process overflow water to the treated water effluent header pipe.

The operating deck, building, and roof of the structure is not shown for clarity.

5.1.1.4 Site Layout

Lead/Lag

A preliminary site layout for lead/lag gravity contactors is presented in Figure 19.

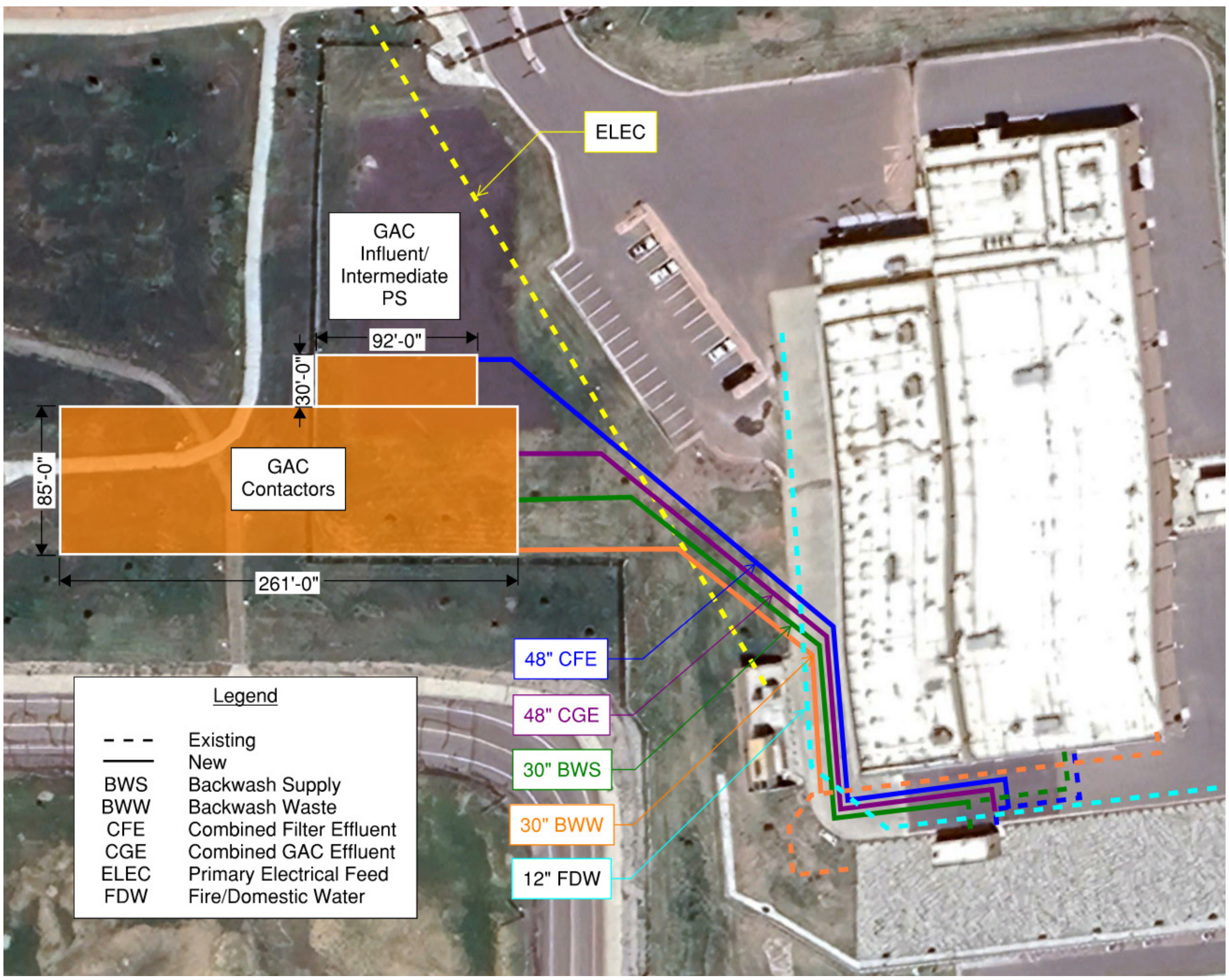


Figure 19 TWTP Lead/Lag GAC Contactors Site Layout

The proposed site layout utilizes the open area to the west of the existing TWTP. Unique challenges presented with this layout include deep yard piping adjacent to the existing chemical building, resulting in the need for temporary chemical off-loading for caustic soda, sodium hypochlorite, and liquid ammonium sulfate. The larger footprint required for this alternative eliminated options for siting the facilities to the south or immediately east of the TWTP process building. The old TWTP site to the east was eliminated from consideration due to the costs associated with demolition of the existing facility and the potential presence of asbestos-containing materials in the soil.

Single Pass

A preliminary site layout for single pass gravity contactors is presented in Figure 20.

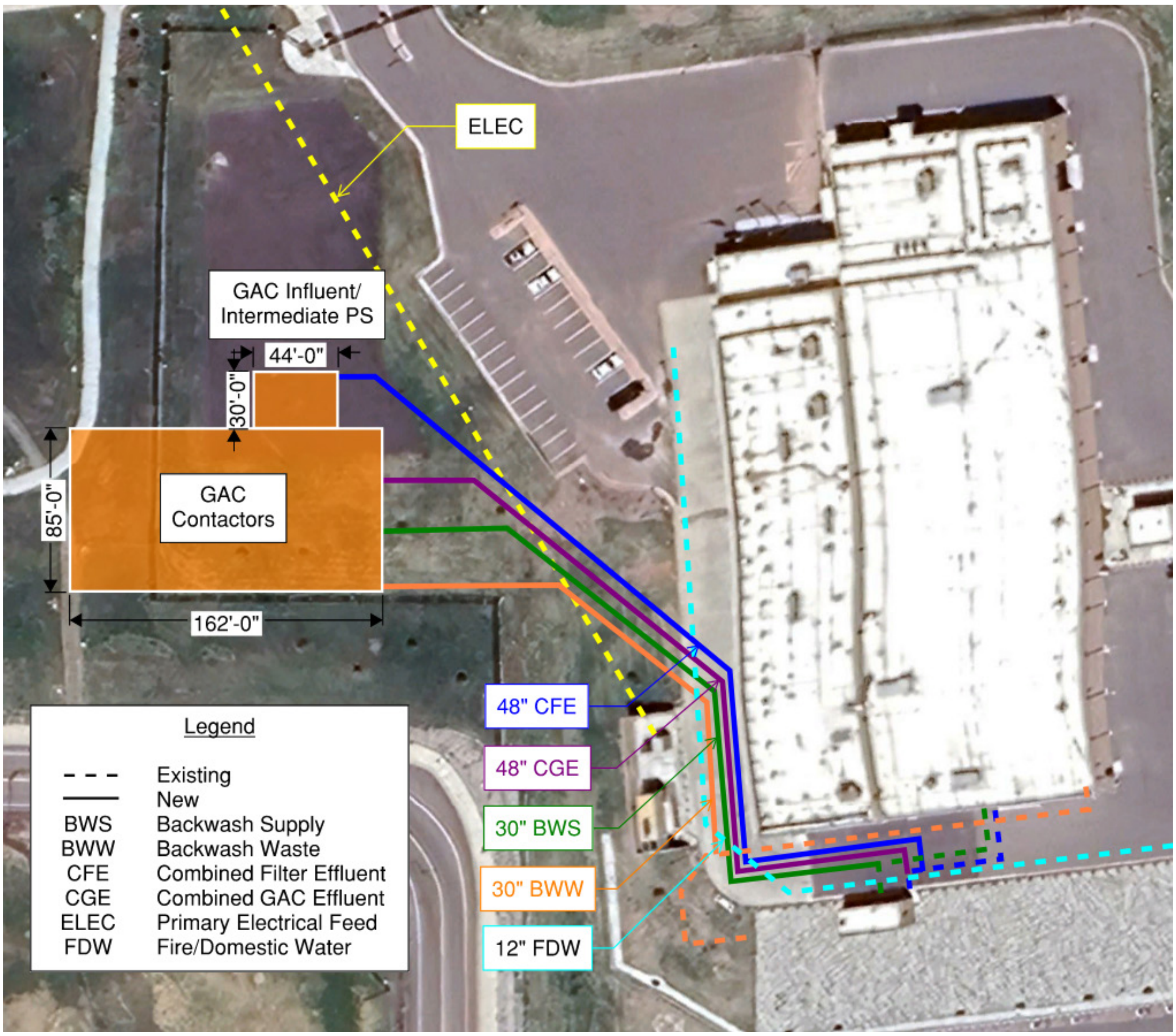


Figure 20 TWTP Single Pass GAC Contactors Site Layout

The proposed site layout utilizes the open area to the west of the existing TWTP and presents similar challenges as with the lead/lag alternative.

5.1.1.5 Operational Considerations

The advantages and disadvantages of this alternative are presented in Table 21.

Table 21 Operational Considerations for GAC Contactors at TWTP

Advantages	Disadvantages
▪ GAC provides a treatment barrier for other contaminants such as disinfectants and disinfection byproduct (DBP) precursors, T&O compounds, and volatile organic compounds (VOC). ▪ GAC is a proven technology for installation downstream of ozone/biofiltration. ▪ GAC contactors require fewer valves and instrumentation than pressure vessels due to the lower number of treatment units required. ▪ GAC contactors provide fewer sample locations that would be required for monitoring GAC media life due to the lower number of treatment units required. ▪ The footprint for GAC contactors is smaller than the footprint for GAC pressure vessels. ▪ GAC contactor backwash can utilize the existing TWTP backwash supply system. ▪ Spent GAC can be returned to the vendor for regeneration, reactivation, and re-sale to non-potable water sectors, which reduces media disposal costs compared to IX resin. ▪ GAC gravity contactors can be designed to be compatible with novel adsorbents to allow for media conversion in the future. ▪ The GAC market has historically observed more price stability than the IX market.	▪ The time required for GAC replacement in gravity contactors is longer and replacement is a more complicated process than for pressure vessels. ▪ GAC contactors provide less modularity and redundancy than pressure vessels. ▪ GAC contactors require more complicated construction (water-bearing concrete structures) compared to pressure vessels. ▪ GAC requires longer EBCT than IX, resulting in a larger system footprint. ▪ Less effective in short-chain perfluorosulfonic acids (PFSA) removal than IX. ▪ Non-steady state treatment process, requiring attentive monitoring of contaminant breakthrough to maximize GAC service life. ▪ GAC alternatives require more frequent backwashing (start-up and operation) than IX alternatives.

5.1.2 GAC Pressure Vessels

5.1.2.1 Overview

New GAC pressure vessels would be located downstream of the existing biological filtration process. Filtered water would be conveyed from the combined filter effluent pipe in the yard (or at the entry to the chlorine contact chamber) and conveyed to the new intermediate pump station. The intermediate pump station would boost water pressure through the GAC pressure vessels, and treated water would then be returned to the chlorine contact chamber.

Lead/Lag

The PFD for lead/lag GAC pressure vessels at TWTP is presented in Figure 21.

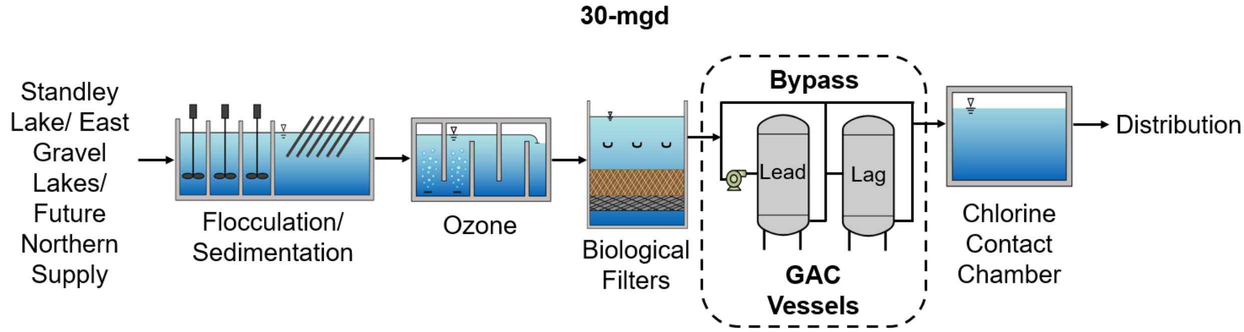


Figure 21 TWTP Lead/Lag GAC Pressure Vessels PFD

Lead/lag treatment increases the amount of GAC inventory available and provides additional redundancy if the City's goals are to maintain non-detect in individual GAC pressure vessel effluent as opposed to the blended effluent. However, lead/lag treatment results in additional capital costs and required footprint.

Single Pass

The PFD for single pass GAC pressure vessels at TWTP is presented in Figure 22.

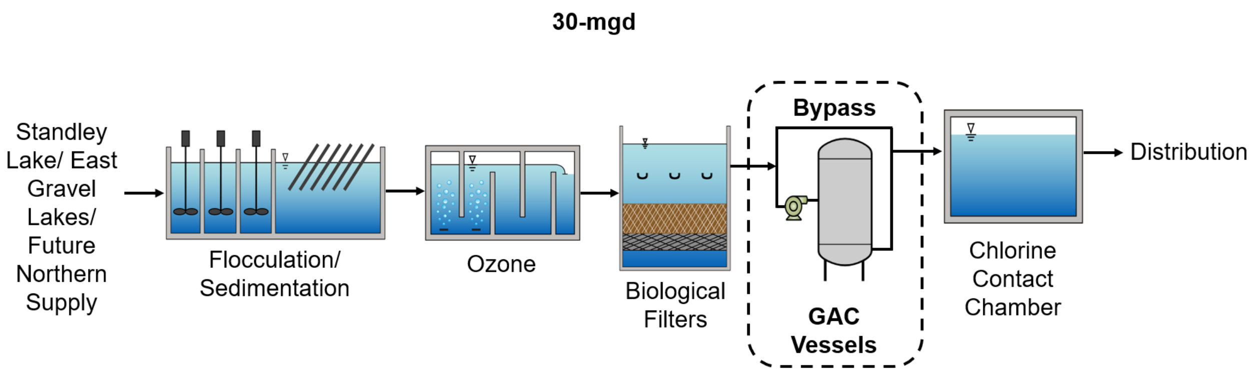


Figure 22 TWTP Single Pass GAC Pressure Vessels PFD

Given the longer duration and flat shape of the PFOA breakthrough curves observed during RSSCT testing, single pass treatment is a lower capital cost alternative that can maintain the City's goals for PFAS combined effluent concentrations utilizing blending. For pressure vessel alternatives, flexibility is provided for lead/lag treatment at flow rates equal to or less than half the design flow rate (i.e., 15 mgd or less).

5.1.2.2 Design Criteria

Table 22 outlines the proposed design criteria for lead/lag and single pass GAC pressure vessel alternatives at TWTP.

Table 22 TWTP GAC Pressure Vessels Design Criteria

Description	Units	Criteria	
		Lead/Lag	Single Pass
GAC Pressures Vessels			
Vessel Type: Carbon Steel			
Process Capacity	mgd	30	
Number of Vessels, Total	No.	42	24
Number of Lead Vessels	No.	21	21
Number of Lag/Standby Vessels	No.	21	3
Vessel Dimensions			
Diameter	feet	14	
Height	feet	27	
Vessel Surface Area	sf	154	
Carbon Per Vessel	lbs	60,000	
Flow Rate Per Vessel	gpm	1,000	
Hydraulic Loading Rate	gpm/sf	6.5	
Empty Bed Contact Time, Per Vessel (at 30 mgd)	minutes	15	
Empty Bed Contact Time, Total (at 30 mgd)	minutes	30	15
Total Headloss per Train	psi	18	9
Intermediate Pump Station			
Type: Vertical Turbine Pumps, Variable Speed			
Number of Pumps	No.	5 (4 + 1)	
Capacity, Each	mgd	7.5	

Notes:
lb - pound; psi - pounds per square inch

5.1.2.3 Conceptual 3D Model

Lead/Lag

A conceptual 3D model for lead/lag GAC pressure vessels at TWTP is presented in Figures 23 and 24.

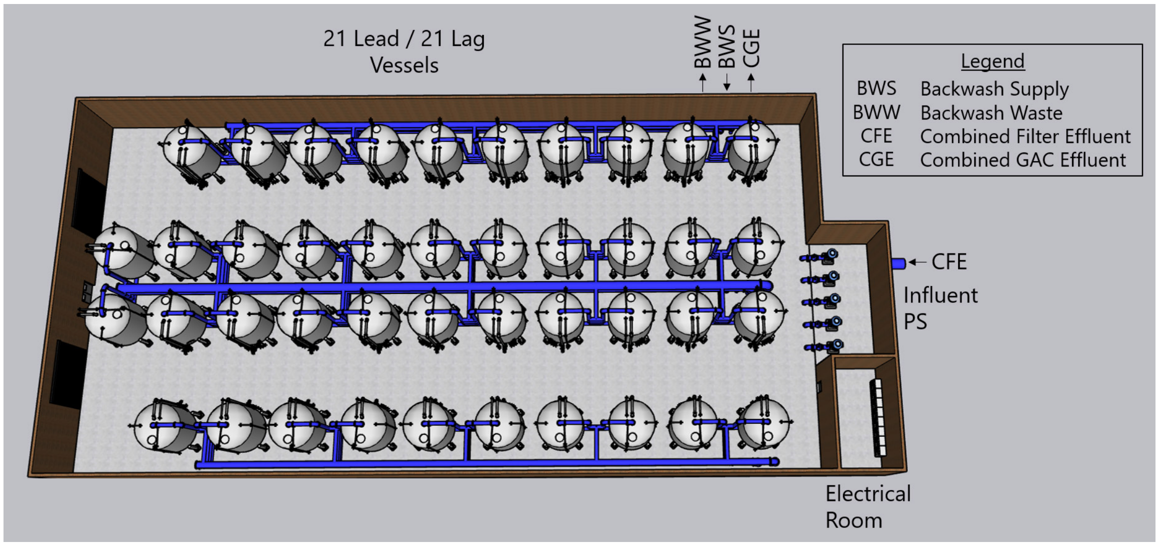


Figure 23 TWTP Lead/Lag GAC Pressure Vessels 3D Model Perspective 1

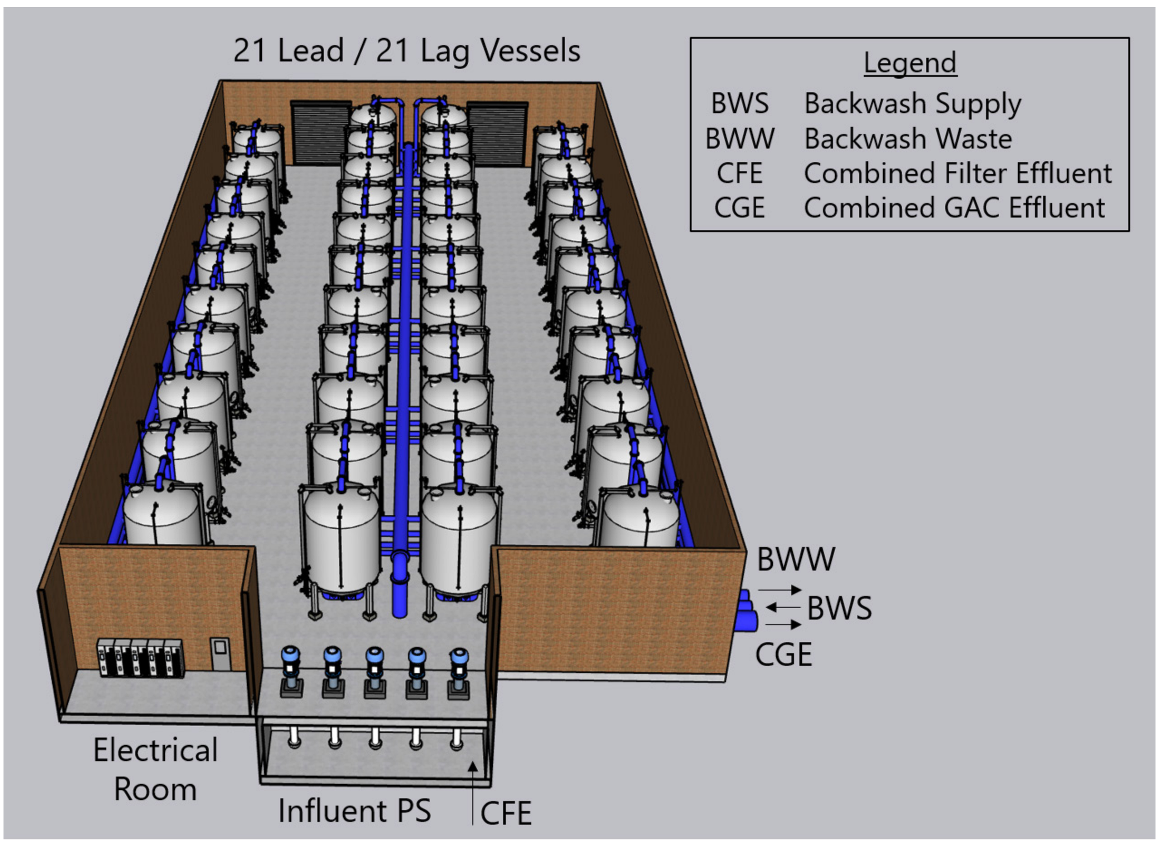


Figure 24 TWTP Lead/Lag GAC Pressure Vessels 3D Model Perspective 2

The conceptual design allows for each individual paired GAC pressure vessel to serve as the lead or lag pressure vessel. However, the large number of vessels required results in a large footprint and significant operational and maintenance complexity. Treated water is collected in the effluent header and conveyed to the existing Chlorine Contact Chamber.

Backwash supply water is provided by the existing backwash supply pumps for removal of fines after media installation and for intermittent backwash during operation. Filter-to-waste is provided for wasting of effluent when a pressure vessel is first placed into service. Two roll-up doors are provided for access for GAC replacement and maintenance activities.

The roof of the structure is not shown for clarity.

Single Pass

A conceptual 3D model for single pass GAC pressure vessels at TWTP is presented in Figures 25 and 26.

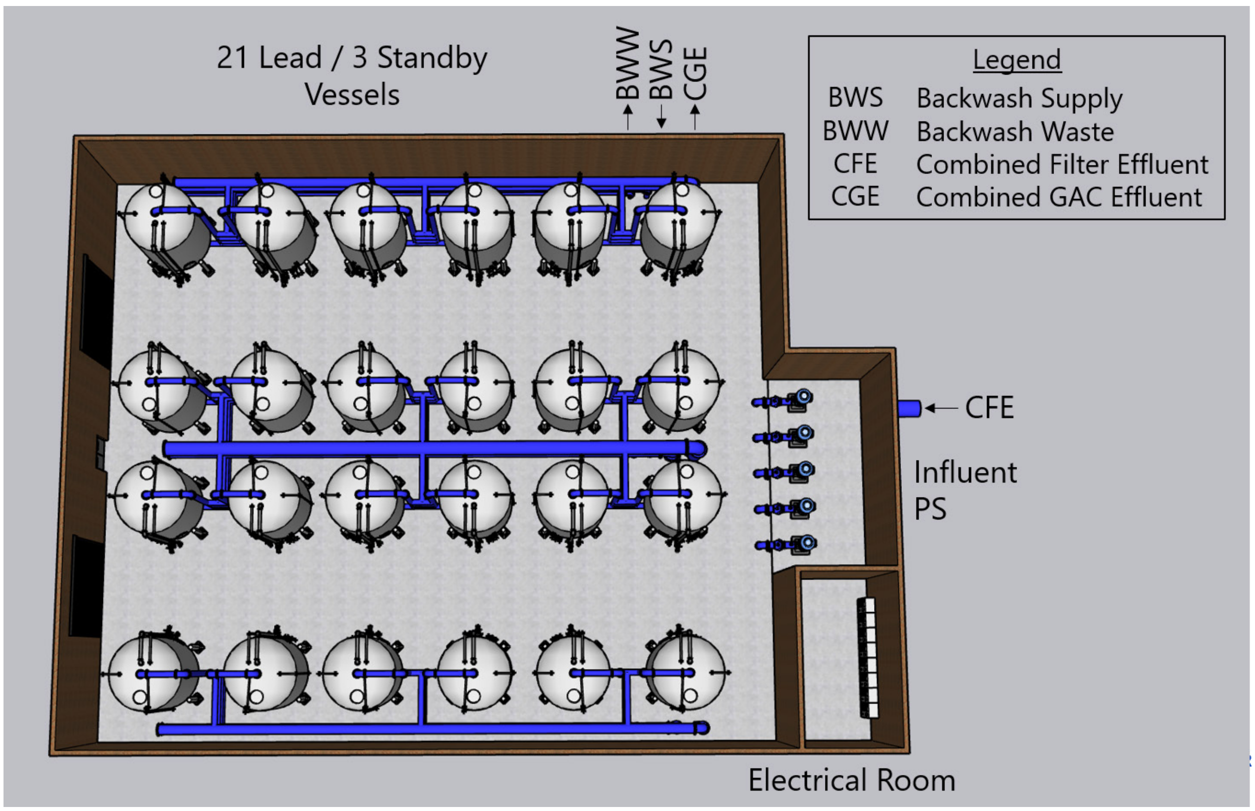


Figure 25 TWTP Single Pass GAC Pressure Vessels 3D Model Perspective 1

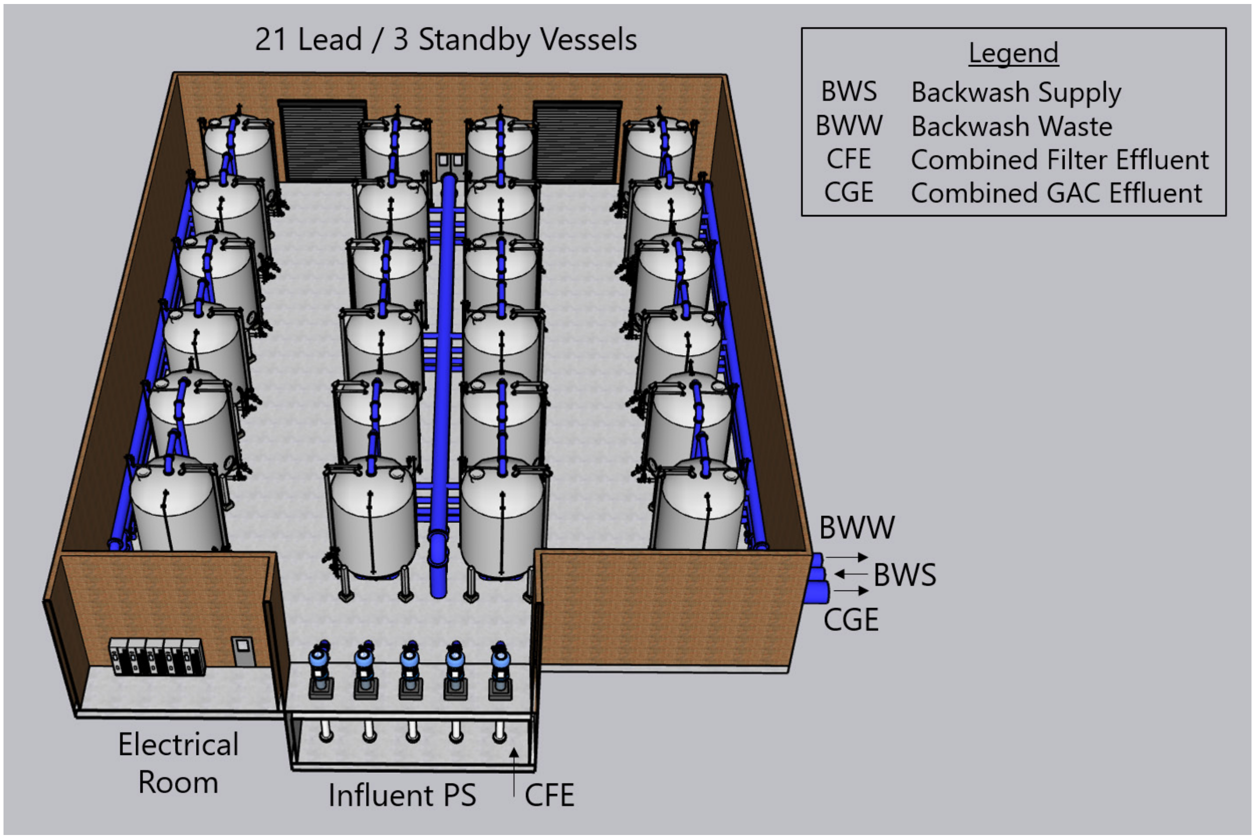


Figure 26 TWTP Single Pass GAC Pressure Vessels 3D Model Perspective 2

Similar to the lead/lag conceptual design, this alternative includes paired GAC pressure vessels. At the design flow rate of 30 mgd, each individual GAC pressure vessel is operated, with three standby vessels available. At lower flow rates, paired vessels can operate in a lead/lag arrangement, providing operational flexibility.

Backwash supply water is provided by the existing backwash supply pumps for removal of fines after media installation and for intermittent backwash during operation. Filter-to-waste is provided for wasting of effluent when a pressure vessel is first placed into service. Two roll-up doors are provided for access for GAC replacement and maintenance activities.

The roof of the structure is not shown for clarity.

5.1.2.4 Site Layout

Lead/Lag

A preliminary site layout for lead/lag GAC pressure vessels is presented in Figure 27.

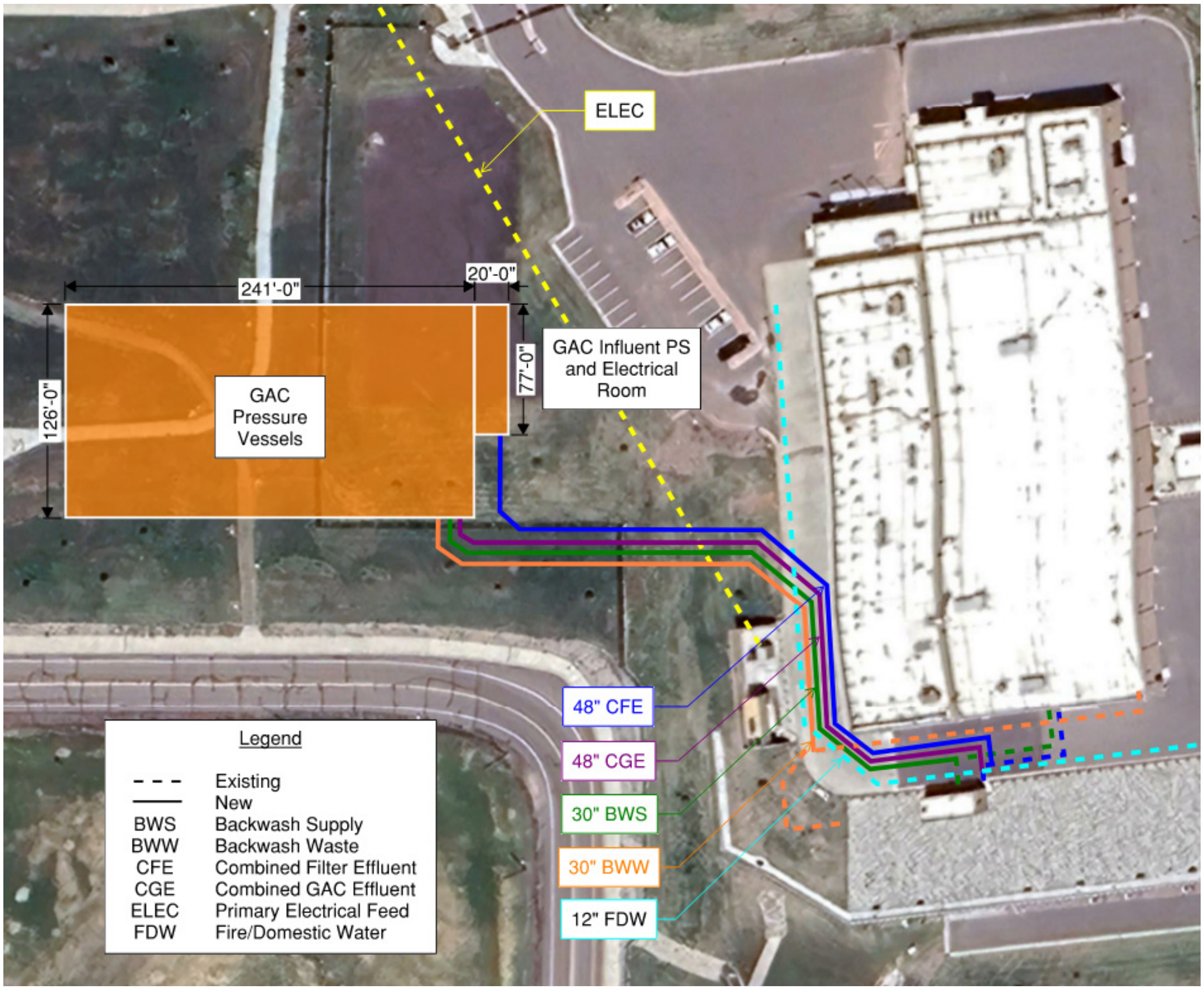


Figure 27 TWTP Lead/Lag GAC Pressure Vessels Site Layout

The proposed site layout utilizes the open area to the west of the existing TWTP. Unique challenges presented with this layout include deep yard piping adjacent to the existing chemical building, resulting in the need for temporary chemical off-loading for caustic soda, sodium hypochlorite, and liquid ammonium sulfate. The larger footprint required for this alternative eliminated options of siting the facilities to the south or immediately east of the TWTP process building. The old TWTP site to the east was eliminated from consideration due to the costs associated with demolition of the existing facility and the potential presence of asbestos-containing materials in the soil.

Single Pass

A preliminary site layout for single pass GAC pressure vessels is presented in Figure 28.

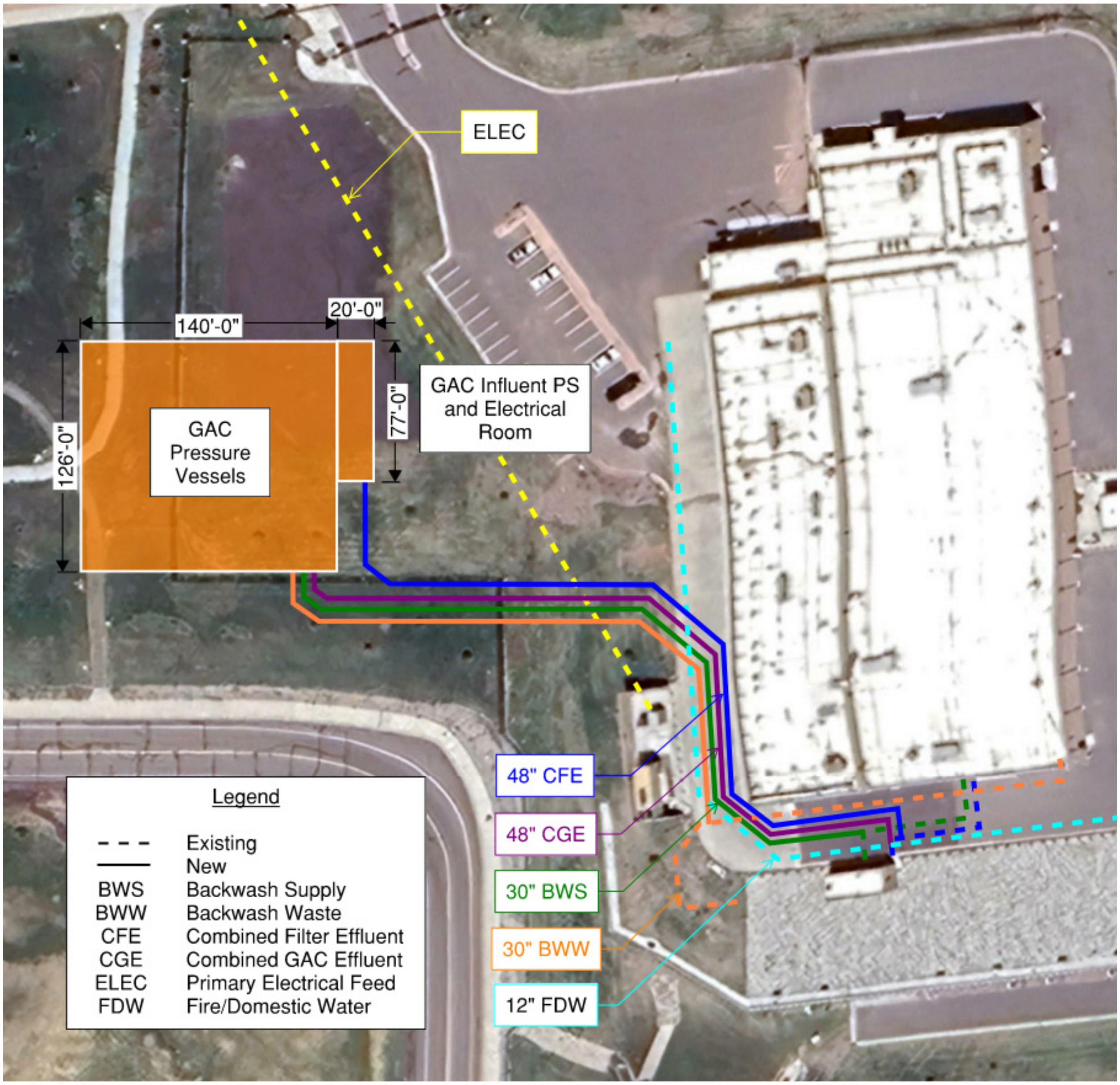


Figure 28 TWTP Single Pass GAC Pressure Vessels Site Layout

The proposed site layout utilizes the open area to the west of the existing TWTP and presents similar challenges as with the lead/lag alternative.

5.1.2.5 Operational Considerations

The advantages and disadvantages of this alternative are presented in Table 23.

Table 23 Operational Considerations for GAC Pressure Vessels at TWTP

Advantages	Disadvantages
▪ GAC provides a treatment barrier for other contaminants such as DBP precursors, T&O compounds, and VOCs. ▪ GAC is a proven technology for installation downstream of ozone/biofiltration. ▪ GAC replacement is a shorter and more simple process (about 4 hours) for pressure vessels as opposed to gravity contactors. ▪ Pressure vessels provide more modularity and redundancy than gravity GAC contactors. ▪ A pressure vessel facility is simpler to construct than GAC contactors (slab on grade with building as compared to water-bearing concrete structures). ▪ GAC pressure vessel backwash can utilize the existing TWTP backwash supply system. ▪ Spent GAC can be returned to the vendor for regeneration, reactivation, and re-sale to non-potable water sectors, which reduces media disposal costs compared to IX resin. ▪ GAC pressure vessels are compatible with IX resin and novel adsorbents to allow for media conversion in the future. ▪ The GAC market has historically observed more price stability than the IX market.	▪ Pressure vessels require more valves and instrumentation than gravity GAC contactors due to the greater number of vessels. ▪ Utilizing pressure vessels results in a greater number of sample locations that would be required for monitoring GAC media life due to the greater number of vessels required. ▪ GAC requires longer EBCT than IX, resulting in a larger system footprint. ▪ The footprint for GAC pressure vessels is greater than the footprint for gravity GAC contactors. ▪ Less effective in short-chain PFSAs removal than IX. ▪ Non-steady state treatment process, requiring attentive monitoring of contaminant breakthrough to maximize GAC service life. ▪ GAC alternatives require more frequent backwashing (start-up and operation) than IX alternatives.

5.1.3 IX Pressure Vessels

5.1.3.1 Overview

New IX pressure vessels would be located downstream of the existing biological filtration process. Filtered water would be conveyed from the combined filter effluent pipe in the yard (or at the entry to the chlorine contact chamber) and conveyed to the new intermediate pump station. The intermediate pump station would boost water pressure through the IX pressure vessels, and treated water would then be returned to the chlorine contact chamber.

Lead/Lag

The PFD for lead/lag IX pressure vessels at TWTP is presented in Figure 29.

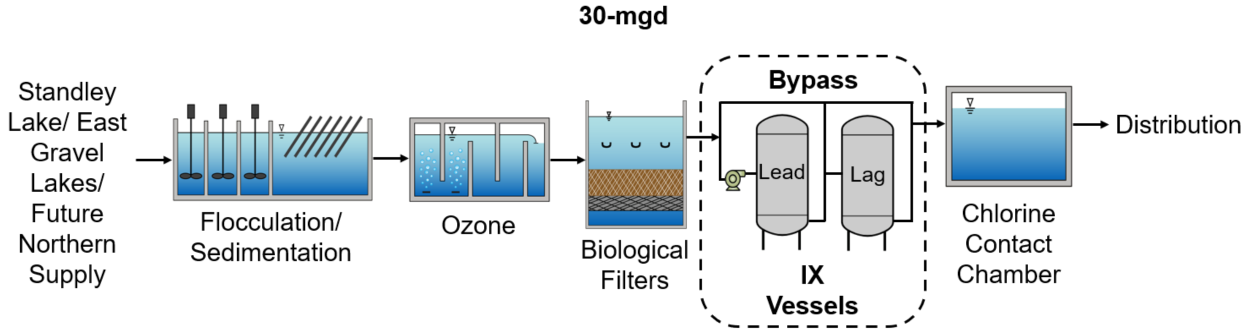


Figure 29 TWTP IX Lead/Lag Pressure Vessels PFD

Lead/lag treatment increases the amount of IX resin inventory available and provides additional redundancy if Thornton's goals are to maintain non-detect in individual IX pressure vessel effluent as opposed to the blended effluent. However, lead/lag treatment results in additional capital costs and required footprint.

Single Pass

The PFD for single pass IX pressure vessels at TWTP is presented in Figure 30.

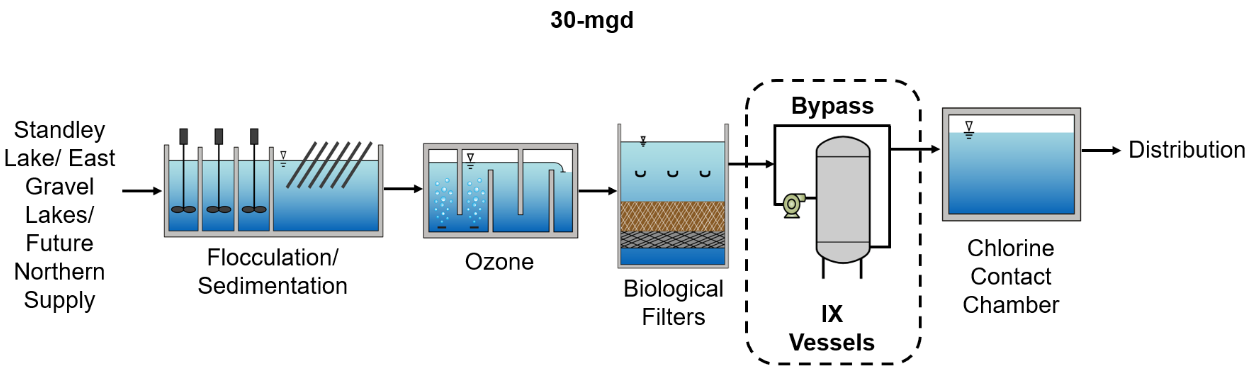


Figure 30 TWTP Single Pass IX Pressure Vessels PFD

Given the longer duration and flat shape of the PFOA breakthrough curves observed during RSSCT testing, single pass treatment is a lower capital cost alternative that can maintain the City's goals for PFAS combined effluent concentrations utilizing blending. For pressure vessel alternatives, flexibility is provided for lead/lag treatment at flow rates equal to or less than half the design flow rate (i.e., 15 mgd or less).

5.1.3.2 Design Criteria

Table 24 outlines the proposed design criteria for lead/lag and single pass IX pressure vessel alternatives at TWTP.

Table 24 TWTP IX Pressure Vessels Design Criteria

Description	Units	Criteria	
		Lead/Lag	Single Pass
IX Pressures Vessels			
Vessel Type: Carbon Steel			
Process Capacity	mgd	30	
Number of Vessels, Total	No.	20	12
Number of Lead Vessels	No.	10	10
Number of Lag Vessels	No.	10	2
Vessel Dimensions			
Diameter	feet	14	
Height	feet	17	
Vessel Surface Area	sf	154	
IX Resin Per Vessel	cf	840	
Flow Rate Per Vessel	gpm	2,100	
Hydraulic Loading Rate	gpm/sf	13.5	
Empty Bed Contact Time, Per Vessel (at 30 mgd)	min	3	
Empty Bed Contact Time, Total (at 30 mgd)	min	6	3
Total Headloss per Train	psi	30	15
Intermediate Pump Station			
Type: Vertical Turbine Pumps, Variable Speed			
Number of Pumps	No.	5 (4 + 1)	
Capacity, ach	mgd	7.5	

5.1.3.3 Conceptual 3D Model

Lead/Lag

A conceptual 3D model for lead/lag IX pressure vessels at TWTP is presented in Figures 31 and 32.

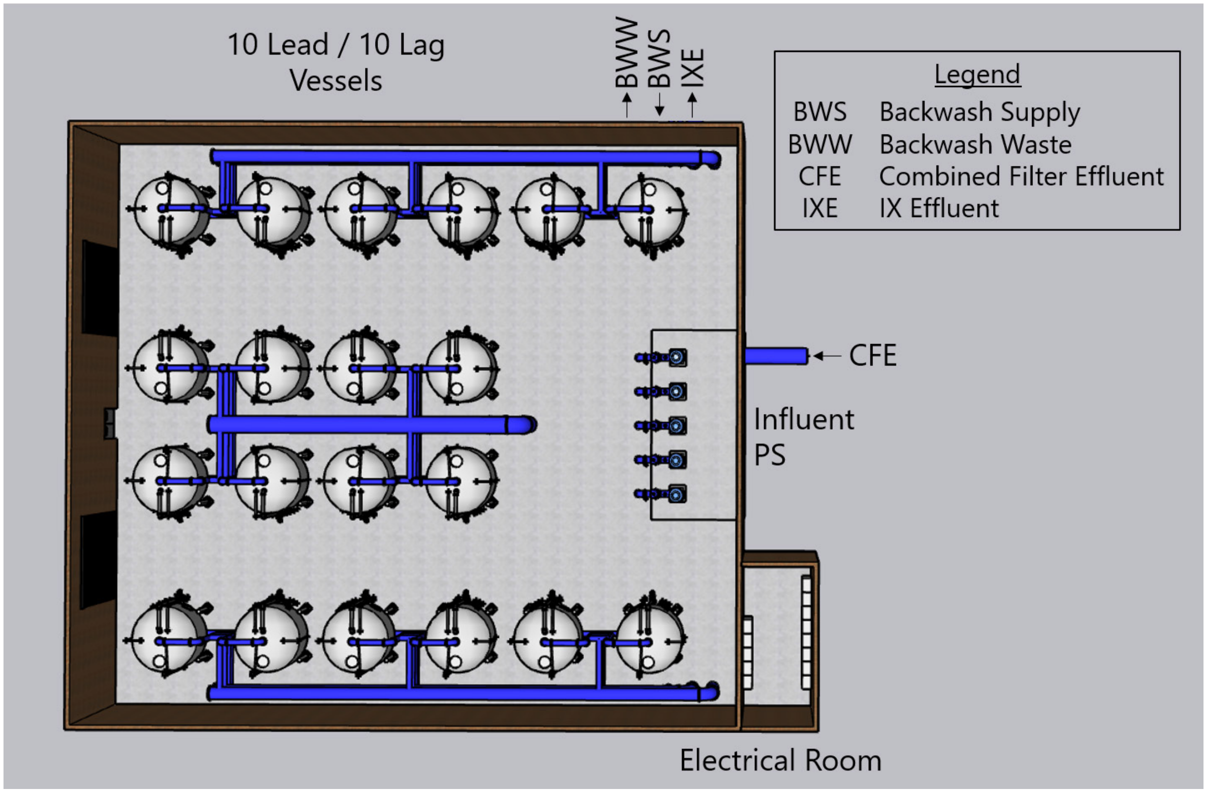


Figure 31 TWTP Lead/Lag IX Pressure Vessels 3D Model Perspective 1

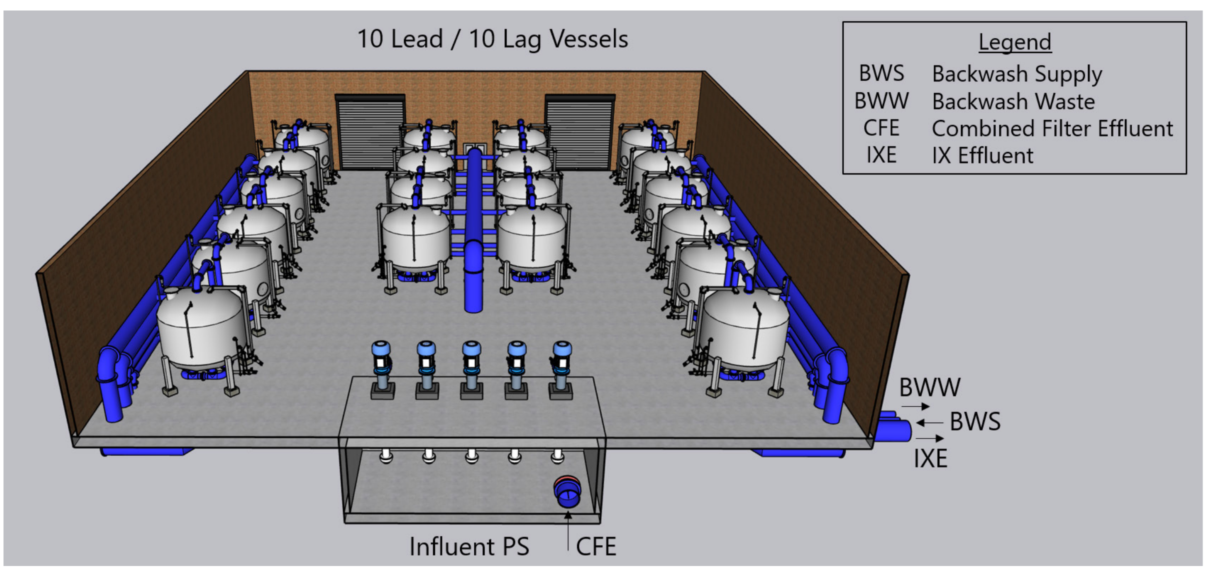


Figure 32 TWTP Lead/Lag IX Pressure Vessels 3D Model Perspective 2

The conceptual design allows for each individual paired IX pressure vessel to serve as the lead or lag pressure vessel. Due to the smaller EBCT and higher loading rates required by IX, the total number of IX vessels required for lead/lag operation is fewer than the number of vessels required for both lead/lag and single pass GAC pressure vessels. Treated water is collected in the effluent header and conveyed to the existing Chlorine Contact Chamber.

Backwash supply water is provided by the existing backwash supply pumps for removal of fines after resin installation. Filter-to-waste is provided for wasting of effluent when a pressure vessel is first placed into service. Two roll-up doors are provided for access for IX replacement and maintenance activities.

The roof of the structure is not shown for clarity.

Single Pass

A conceptual 3D model for single pass IX pressure vessels at TWTP is presented in Figures 33 and 34.

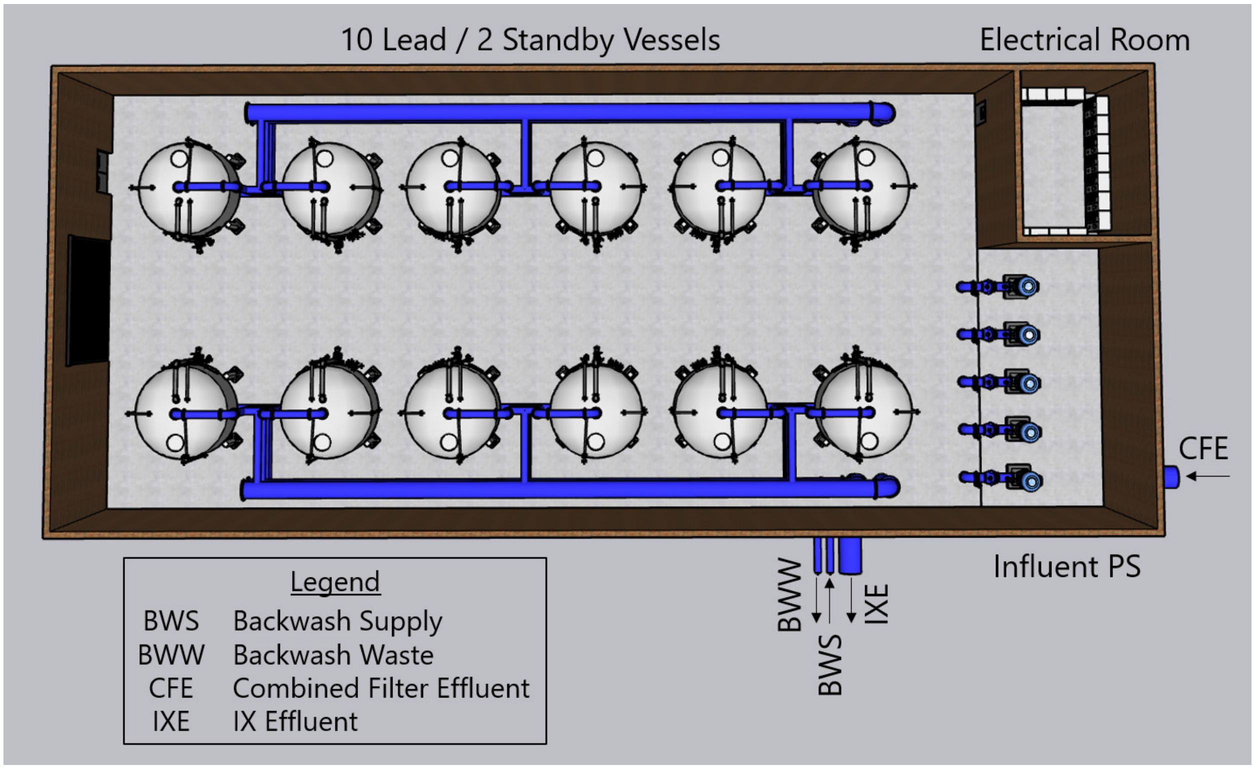


Figure 33 TWTP Single Pass IX Pressure Vessels 3D Model Perspective 1

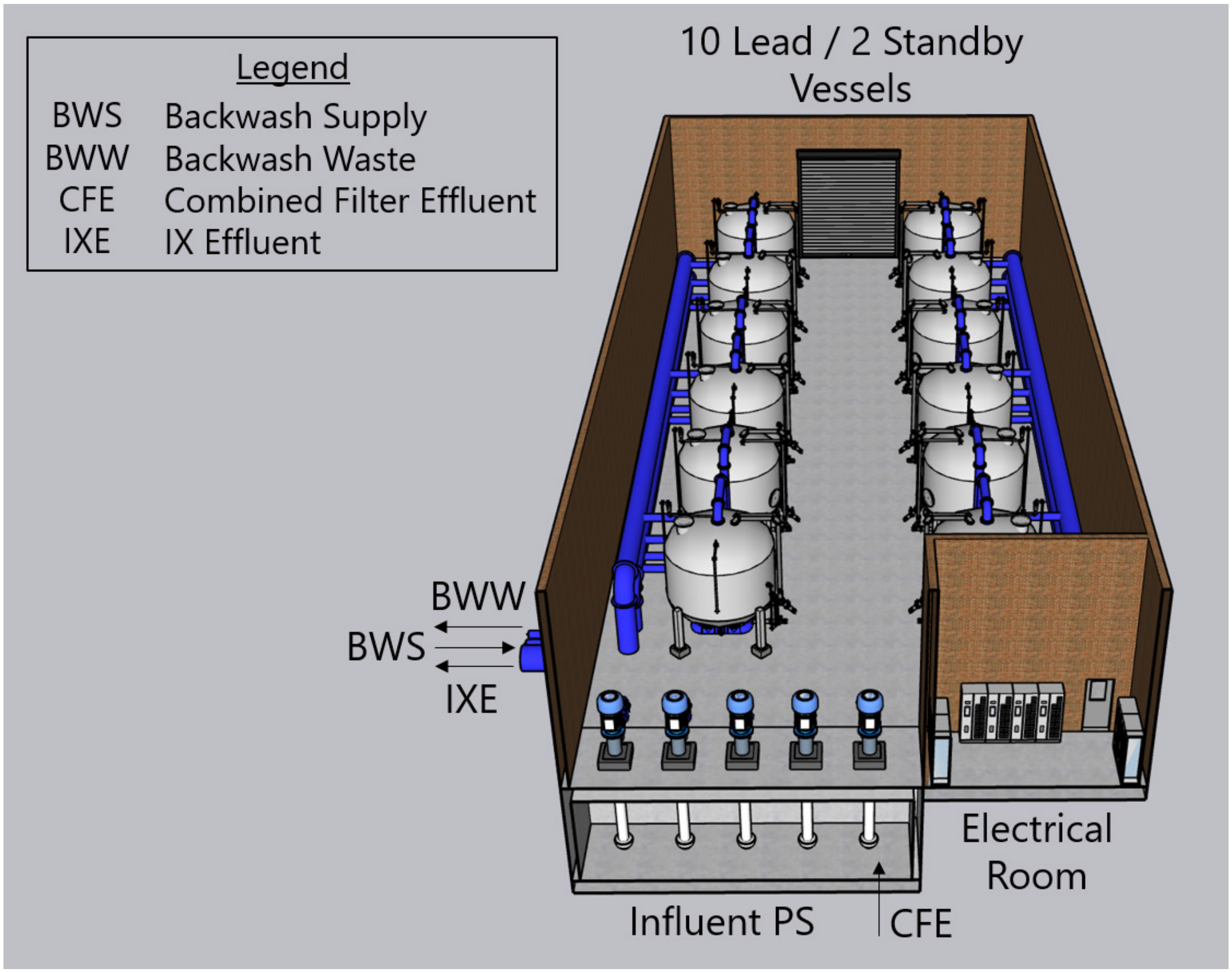


Figure 34 TWTP Single Pass IX Pressure Vessels 3D Model Perspective 2

Similar to the lead/lag conceptual design, this alternative includes paired IX pressure vessels. At the design flow rate of 30 mgd, each individual GAC pressure vessel is operated, with two standby vessels available. At lower flow rates, paired vessels can operate in a lead/lag arrangement, providing operational flexibility.

Backwash supply water is provided by the existing backwash supply pumps for removal of fines after resin installation. Filter-to-waste is provided for wasting of effluent when a pressure vessel is first placed into service. A roll-up door is provided for access for IX replacement and maintenance activities.

The roof of the structure is not shown for clarity.

5.1.3.4 Site Layout

Lead/Lag

Two preliminary site layouts for lead/lag IX pressure vessels are presented in Figures 35 and 36. Figure 35 presents a site layout for the pressure vessels located on the west side of the site, while Figure 36 includes a site layout for the pressure vessels located on the east side of the existing Treatment Process Building.

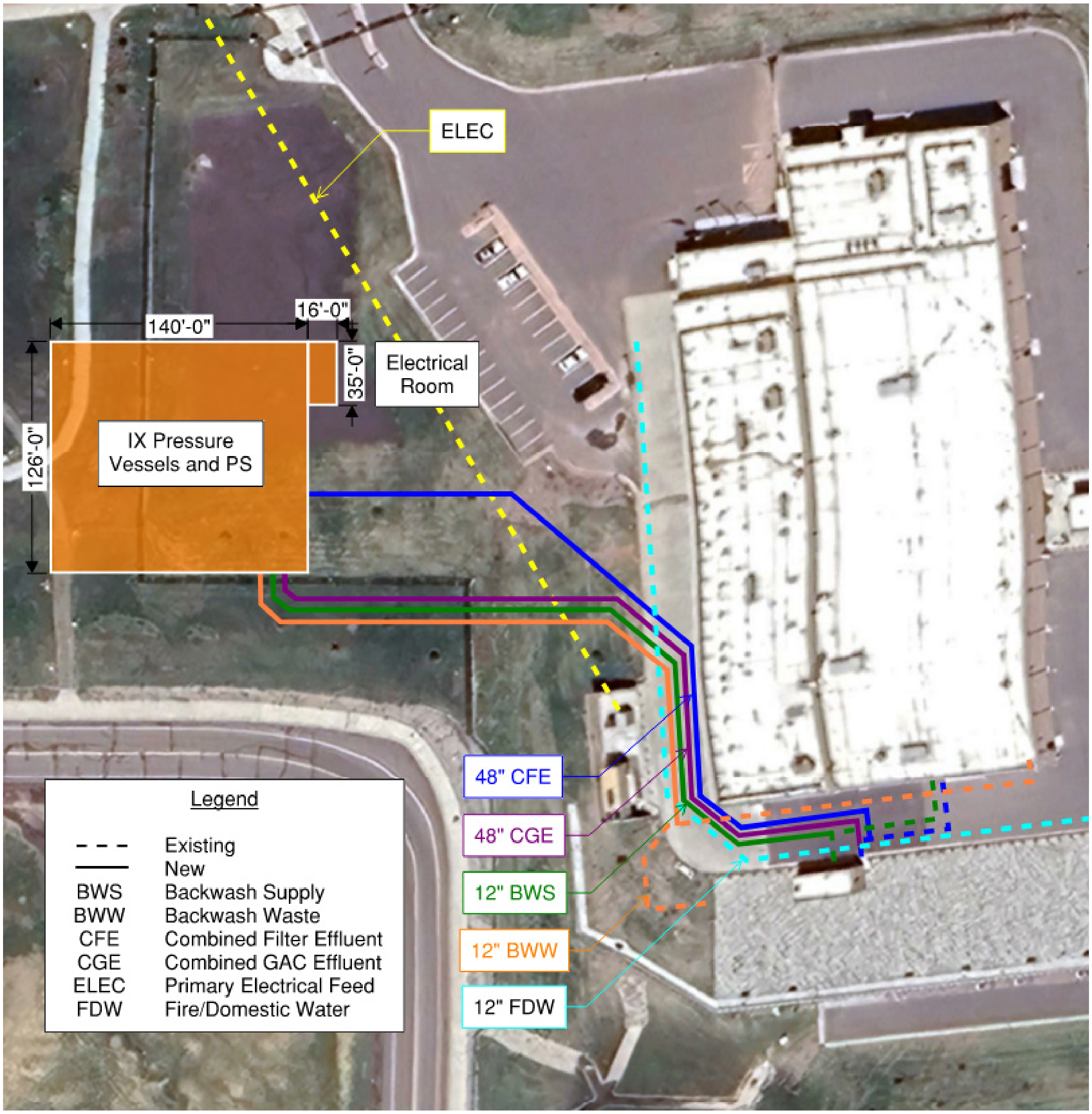


Figure 35 TWTP Lead/Lag IX Pressure Vessels Site Layout – Option 1

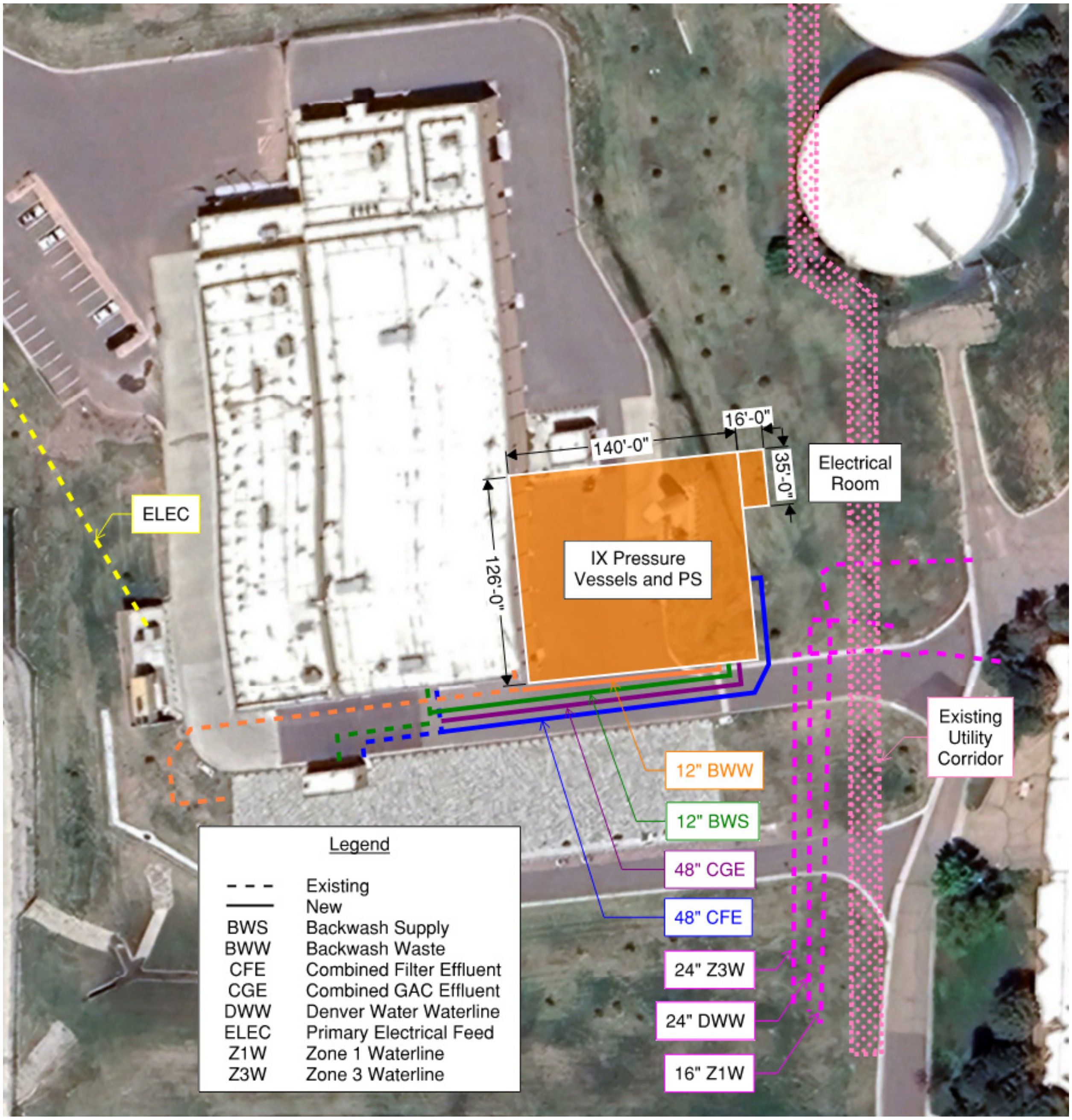


Figure 36 TWTP Lead/Lag IX Pressure Vessels Site Layout – Option 2

Option 1 presents challenges with deep yard piping adjacent to the existing chemical building, resulting in the need for temporary chemical off-loading for caustic soda, sodium hypochlorite, and liquid ammonium sulfate. Option 2 simplifies the yard piping connections but results in challenges with relocation of the existing LOX equipment for the ozone system, pretreatment overflow pipe, large retaining walls due to the grade to the east, and construction adjacent to the existing utility corridor, which includes finished water mains. For cost estimating purposes, Option 1 was utilized due to the lower capital costs. The old TWTP site to the east was eliminated from consideration for siting of the facility due to the costs associated with demolition of the existing facility and the potential presence of asbestos-containing materials in the soil.

Single Pass

Three preliminary site layouts for single pass IX pressure vessels are presented in Figures 37, 38, and 39. Figure 37 presents a site layout for the pressure vessels located on the west side of the site, while Figure 38 includes a site layout for the pressure vessels located immediately adjacent to the east side of the existing Treatment Process Building. Figure 39 presents a site layout for the pressure vessels located to the south of the existing Chlorine Contact Chamber.

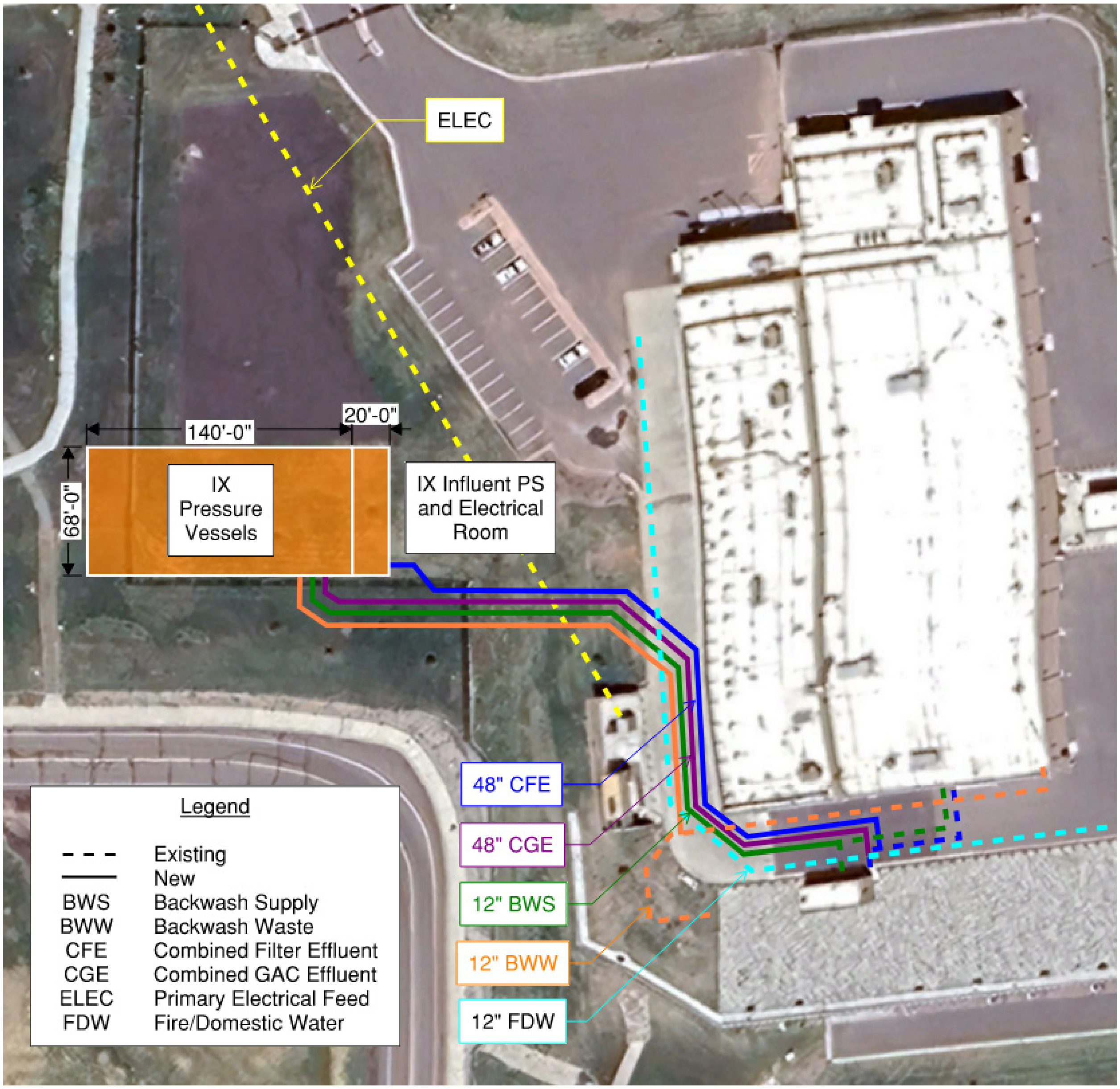


Figure 37 TWTP Single Pass IX Pressure Vessels Site Layout – Option 1

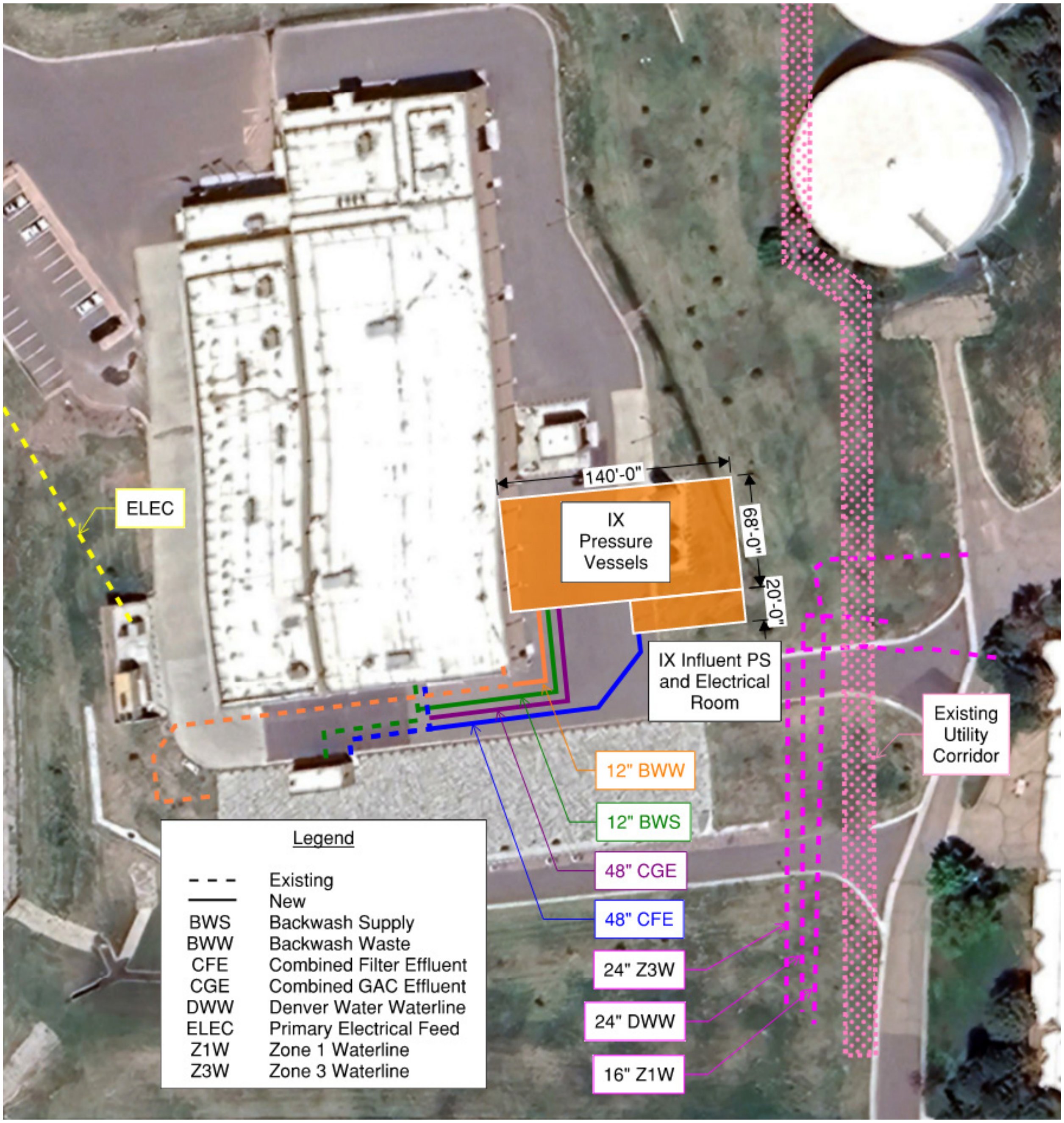


Figure 38 TWTP Single Pass IX Pressure Vessels Site Layout – Option 2

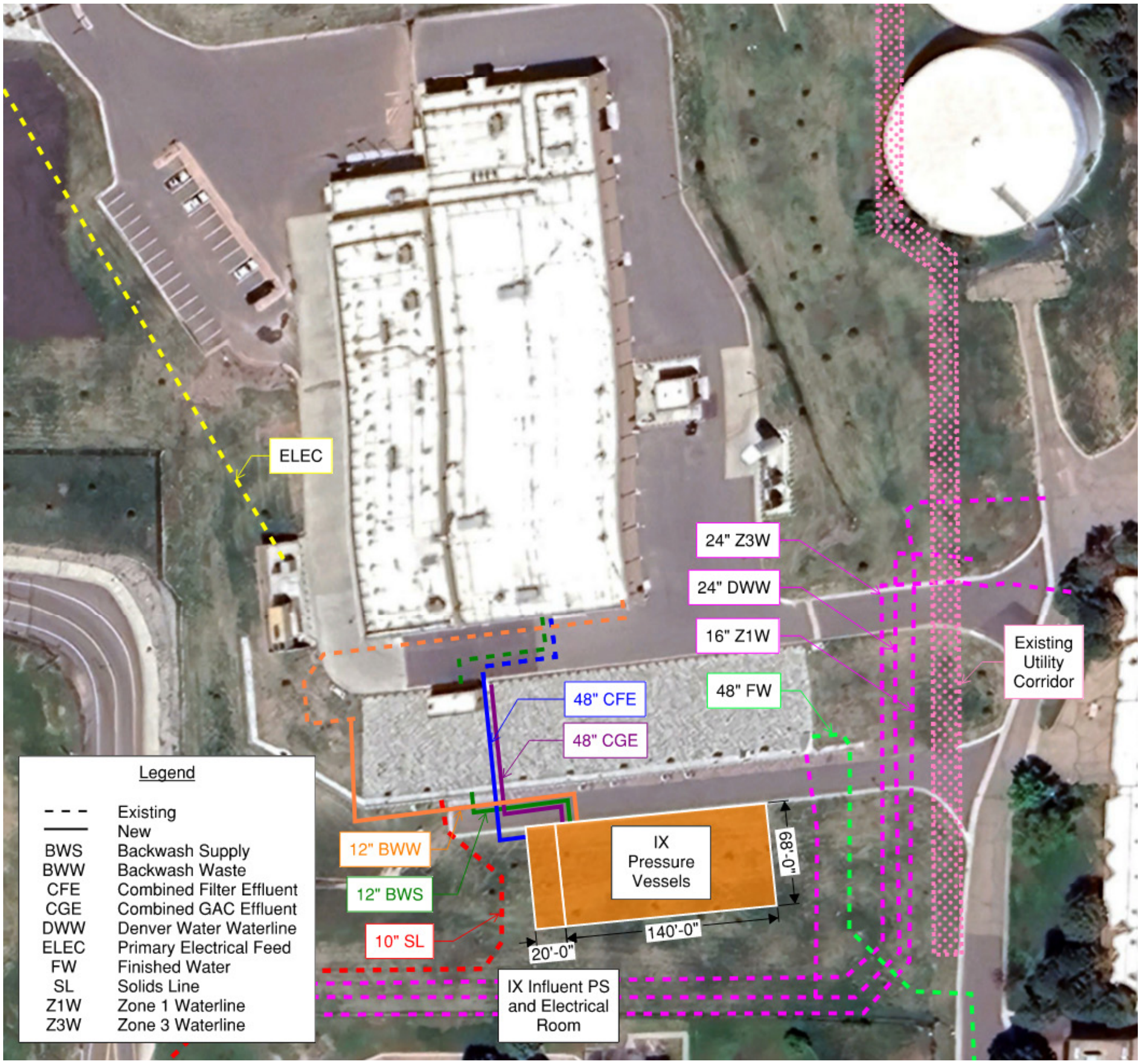


Figure 39 TWTP Single Pass IX Pressure Vessels Site Layout – Option 3

Options 1 and 2 present similar challenges as with the lead/lag alternative; however, the smaller footprint provides more space between the construction for Option 2 and the utility corridor. Option 3 eliminates the need for either temporary chemical off-loading or LOX relocation but results in challenges with construction adjacent to existing utilities that need to be protected, construction within the backwash supply chamber, and a sloped grade that will require retaining walls. For cost estimating purposes, Option 1 was utilized. The old TWTP site to the east was eliminated from consideration due to the costs associated with demolition of the existing facility and the potential presence of asbestos-containing materials in the soil.

5.1.3.5 Operational Considerations

The advantages and disadvantages of this alternative are presented in Table 25.

Table 25 Operational Considerations for IX Pressure Vessels at TWTP

Advantages	Disadvantages
▪ IX is effective in removing both long-chain PFAS and short-chain PFSAs. ▪ Faster adsorption kinetics results in a shorter EBCT and a smaller footprint than GAC pressure vessels. The smaller footprint provides considerable flexibility in siting the facility on the existing site. ▪ IX pressure vessels represent the most simple and shortest construction schedule. ▪ IX alternatives have the most simple media replacement of all alternatives. ▪ IX alternatives require limited backwashing (only during start-up for removal of fines). ▪ IX resin backwash can utilize the existing TWTP backwash supply system. ▪ IX pressure vessels are compatible with novel adsorbents to allow for media conversion in the future.	▪ Does not remove T&O compounds or as many emerging contaminants of concern as GAC removes. ▪ IX is a less proven technology for installation downstream of ozone/biofiltration compared to GAC. ▪ Greater head loss than GAC, which results in higher pumping costs. ▪ Non-steady state treatment process, requiring attentive monitoring of contaminant breakthrough to maximize IX service life. ▪ PFAS-specific IX resins are non-regenerable. Disposal of spent resin through high-temperature incineration is recommended. ▪ The IX resin market is tied to the petroleum industry, leading to less price stability for replacement when compared to GAC.

5.2 Alternatives Evaluation

5.2.1 Capital Costs

Capital costs were developed for each treatment process alternative utilizing quantity take-offs from the conceptual 3D models presented. Key assumptions for capital cost development include the following:

- Deep foundations similar to existing TWTP structures were assumed.
- Architectural features shall match the existing TWTP facilities.
- The existing backwash supply and backwash waste systems are re-used for backwashing activities.
- Remediation of regulated asbestos contaminated soils will not be required due to previous remediation activities on site.
- The existing electrical service feed and switchgear do not require upsizing. The existing transformer will require upsizing for pressure vessel alternatives.
- Additional back-up generator capacity will be provided for the new facilities.
- Costs were escalated to the midpoint of construction, which was assumed to be summer 2026.
- Any additional Owner's costs in addition to Owner's Advisor, Design Engineer, Services During Construction, and Contractor costs are not included (such as City project management).

A contingency of 20 percent was assumed. This accounts for unforeseeable elements of cost within the project scope, as well as known elements that are undefined at this stage of design progress. Items such as variations in process configuration, unforeseen site conditions, and reasonable project changes that are determined during the detailed design phase are included in the contingency.

The level of accuracy for capital cost estimates varies depending upon the level of detail to which the project has been defined. The Association of Cost Engineering (AACE) International publishes guidelines that define the class of estimate and the expected accuracy range. Based on these guidelines, the capital cost estimate presented herein is a Class 4 estimate, which should be considered a conceptual design level estimate. The expected range of accuracy for this type of estimate is +50 percent to -30 percent.

Budgetary estimates of the total project costs for each of the alternatives are summarized in Table 26. These estimates include all costs directly related to the project, including owner's advisor services, permitting, design, construction, and commissioning, but do not include any Owner costs such as City project management.

Table 26 Construction Cost Estimate for TWTP Alternatives

Description	GAC Contactors		GAC Pressure Vessels		IX Pressure Vessels		Notes
	Lead/Lag	Single Pass	Lead/Lag	Single Pass	Lead/Lag	Single Pass	
Direct Costs							
GAC Contactors/GAC Vessels/IX Vessels	$36,700,000	$23,900,000	$49,000,000	$31,900,000	$26,800,000	$18,200,000	
Influent/Intermediate Pump Station	$6,700,000	$4,700,000	$4,200,000	$4,200,000	$5,100,000	$5,100,000	
Site Civil	$7,000,000	$7,000,000	$6,500,000	$6,500,000	$5,500,000	$5,000,000	Site concrete, retaining walls, yard piping, site electrical, landscaping, fencing, and paving.
Electrical and Backup Power Generation	$9,900,000	$6,900,000	$9,400,000	$6,600,000	$10,700,000	$8,000,000	
Escalation to Project Midpoint	*$4,500,000*	*$3,200,000*	*$5,200,000*	*$3,700,000*	*$3,600,000*	*$2,600,000*	7.5% of Direct Costs (5% per year)
Subtotal Direct Costs	*$64,800,000*	*$45,700,000*	*$74,300,000*	*$52,900,000*	*$51,700,000*	*$39,000,000*	
Indirect Costs							
General Conditions	$9,700,000	$6,900,000	$11,100,000	$7,900,000	$7,800,000	$5,900,000	15% of Subtotal Direct Costs
Bonds and Insurance	$1,900,000	$1,400,000	$2,200,000	$1,600,000	$1,600,000	$1,200,000	3% of Subtotal Direct Costs
Contractor Fee (Overhead and Profit) and Risk	$13,000,000	$9,100,000	$14,900,000	$10,600,000	$10,300,000	$7,800,000	20% of Subtotal Direct Costs
Subtotal Indirect Costs	*$24,600,000*	*$17,400,000*	*$28,200,000*	*$20,100,000*	*$19,700,000*	*$14,900,000*	
TOTAL CONSTRUCTION COSTS	**$89,400,000**	**$63,100,000**	**$102,500,000**	**$73,000,000**	**$71,400,000**	**$53,900,000**	
Owner's Contingency	$17,900,000	$12,600,000	$20,500,000	$14,600,000	$14,300,000	$10,800,000	20% of Subtotal Construction Costs
TOTAL CONSTRUCTION COSTS WITH CONTINGENCY	**$107,300,000**	**$75,700,000**	**$123,000,000**	**$87,600,000**	**$85,700,000**	**$64,700,000**	
Engineering Costs							
Design Engineer – Design Services	$8,600,000	$6,100,000	$9,800,000	$7,000,000	$6,900,000	$5,200,000	8% of Total Construction Cost
Design Engineer – Services During Construction	$6,400,000	$4,500,000	$7,400,000	$5,300,000	$5,100,000	$3,900,000	6% of Total Construction Cost
Owner's Advisor Services	$3,200,000	$2,300,000	$3,700,000	$2,600,000	$2,600,000	$1,900,000	3% of Total Construction Cost
Total Engineering Costs	*$18,200,000*	*$12,900,000*	*$20,900,000*	*$14,900,000*	*$14,600,000*	*$11,000,000*	
TOTAL PROJECT COSTS	**$125,500,000**	**$88,600,000**	**$143,900,000**	**$102,500,000**	**$100,300,000**	**$75,700,000**	
Federal Funding Requirements (AIS, BABA, DB, etc.)	$16,100,000	$11,400,000	$18,500,000	$13,100,000	$12,900,000	$9,700,000	15% of Total Project Costs
TOTAL PROJECT COSTS WITH FEDERAL FUNDING REQUIREMENTS	**$141,600,000**	**$100,000,000**	**$162,400,000**	**$115,600,000**	**$112,200,000**	**$85,400,000**	

Notes:
AIS - American Iron and Steel; BABA - Build America Buy America; DB - Davis-Bacon Act

5.2.2 Net Present Value Analysis

A net present value (NPV) analysis is a useful tool for evaluating alternatives on a life-cycle cost basis. The NPV of a given alternative is a summation of present and future costs converted to present day dollar value. This allows for an equivalent comparison of alternatives on an economic basis. The NPV figures calculated herein represent the estimated amount of funds presently required to pay for future expenditures (including capital, operations, maintenance, and replacement costs) over the examined time period. Therefore, the higher the NPV, the more costly the alternative is on a life cycle basis. However, it is important to note that the NPV costs were determined for the purpose of analyzing the cost differential between alternatives. Thus, the values presented should be limited to assisting in alternative selection and not used as a basis for setting future capital and operations budgets, as it is not a complete accounting of all recurring costs. The following assumptions and guidelines were used in the development of NPV costs:

- Construction and annual costs are based on 2026 estimated values, as it is the assumed project midpoint.
- A 4.0 percent interest rate, a 4.0 percent discount rate, a 5.0 escalation rate, and a 20-year operations period were used to calculate the NPV of the annual costs.
- Operations and maintenance costs were based on a plant flow rate of yearly flow rate of 13.3 mgd, which is the average of the currently yearly average flow rate and the build-out design average yearly flow rate.
- Power costs were based on an average value of $0.15/kilowatt-hour.
- GAC carbon replacement costs were estimated at $2.60/pound, which was the cost provided for replacement and disposal of Calgon F400 media escalated to the year 2026.
- GAC replacement is based on a 2.2-year media life. This is 150 percent of the breakthrough point observed during the RSSCT, which is the expected lifespan of the media to maintain a combined effluent PFAS levels below Thornton's long-term goals.
- IX resin replacement costs were estimated as $435/cf for IX resin and $85/cf for incineration/disposal, which are the costs provided by IX resin suppliers in replacement bids escalated to the year 2026.
- IX resin replacement schedule is based on a 2-year media life. This is 150 percent of the breakthrough point observed during the RSSCT, which is the expected lifespan of the resin to maintain a combined effluent PFAS levels below Thornton's long-term goals.
- Labor and equipment preventative maintenance costs are presented as cost differentials between alternatives, not as a complete accounting of all labor and equipment preventative maintenance costs. Equipment replacement, unless specifically noted, is assumed to be negligible within the time period of the NPV analysis.

The calculated NPV for each alternative is presented in Table 27. A detailed NPV analysis of each treatment process alternative is presented in Appendix B.

Table 27 NPV for TWTP Alternatives

Alternative	20 Year NPV	
	Lead/Lag	Single Pass
GAC Contactors	$145,390,000	$107,650,000
GAC Pressure Vessels	$166,500,000	$123,050,000
IX Pressure Vessels	$130,640,000	$103,590,000

5.2.3 Non-Monetary Evaluation Criteria

In addition to cost criteria, alternatives were evaluated based on the additional non-monetary criteria presented in Table 28.

Table 28 Treatment Process Non-Economic Evaluation Criteria

Objective/Criteria	Description
Process Reliability	Treatment processes that have lead/lag treatment capabilities, the ability to utilize lead/lag treatment at lower flow rates of more challenging source water (i.e., 100% EGL flow), or longer service time between media changeouts were given preference.
Simple Operation	Ability of each alternative to achieve finished water quality goals using simple equipment with low operational intensity.
Treatment Barrier for Other Contaminants	Preference was given to treatment processes that meet finished water quality goals and remove other contaminants of concern, including T&O, TOC, DBP precursors, algal toxins, and VOCs.
Media/Resin Replacement Frequency and Effort	Alternatives with less frequent media/resin replacement and a simpler replacement effort (i.e., shorter replacement duration) were given preference.
Lower Hydraulic Requirements	Treatment alternatives with less pressure loss across the process train were given preference.
Compatibility With Other Media Types	Preference was given to alternatives that are easily compatible with other media types (i.e., GAC, IX, and alternative adsorbents such as FLUORO-SORB® 200).
Compact Footprint	Alternatives with smaller site footprints that leave more space for future expansion and treatment processes were given preference.
Ease of Construction/Impacts to Operation	Preference was given to alternatives with simpler construction that requires less water-bearing concrete structures, fewer concrete pours, fewer plant shut-downs and interference to plant operations, fewer under-slab piping runs, and less confined spaces.

Table 29 presents the results of the treatment facility alternatives evaluation.

Table 29 TWTP Alternatives Evaluation

Alternative	Total Project Cost (without Federal Funding Requirements)	20-Year Net Present Value	Process Reliability	Simple Operation	Treatment Barrier for Other Contaminants	Media/Resin Replacement Frequency and Effort	Lower Hydraulic Requirements	Compatibility With Other Media Types	Compact Footprint	Ease of Construction/Impacts to Operation
GAC Contactors Lead/Lag	$126 M	$146 M	Excellent	Poor	Excellent	Fair	Excellent	Fair	Poor	Fair
GAC Contactors Single Pass	$89 M	$108 M	Excellent	Excellent	Excellent	Fair	Excellent	Fair	Fair	Fair
GAC Pressure Vessels Lead/Lag	$144 M	$167 M	Excellent	Poor	Excellent	Fair	Fair	Excellent	Poor	Fair
GAC Pressure Vessels Single Pass	$103 M	$123 M	Excellent	Fair	Excellent	Fair	Excellent	Excellent	Fair	Fair
IX Pressure Vessels Lead/Lag	$100 M	$131 M	Excellent	Fair	Poor	Excellent	Poor	Fair	Fair	Fair
IX Pressure Vessels Single Pass	$76 M	$104 M	Excellent	Excellent	Poor	Excellent	Fair	Fair	Excellent	Excellent

Legend:
Excellent Fair Poor

5.2.4 Preferred Treatment Process

As a result of this evaluation, the preferred treatment process for PFAS treatment at TWTP is single pass GAC contactors. Although this alternative has a higher capital cost compared to single pass IX pressure vessels, the 20-year NPV is similar between the alternatives and GAC contactors provide the greatest value to the City in achieving the Project's treatment, operations, and maintenance goals.

SECTION 6 WBWTP ALTERNATIVES ANALYSIS

6.1 Treatment Process Alternatives

The existing PAC storage and feed system has proven reliable in meeting Thornton's short-term PFAS treatment goals under current water quality conditions. Alternatives were developed for the following potential PFAS treatment processes at WBWTP, which are capable of meeting the City's long-term PFAS treatment goals.

- GAC Contactors (gravity):
  - Lead/lag.
  - Single pass (staged parallel).
- GAC Pressure Vessels:
  - Lead/lag.
  - Single pass (staged parallel).
- IX Pressure Vessels:
  - Lead/lag.
  - Single pass (staged parallel).

The following sections include proposed design criteria, conceptual 3D model, site layouts, operational considerations, capital cost estimates, and life-cycle costs as a basis for comparing alternatives. All alternatives are based on the planned expansion at WBWTP to bring continuous treatment capacity to 55 mgd, which includes a 15-mgd flocculation/sedimentation and filtration train parallel to the existing solids contact clarification/UF membrane filtration train.

6.1.1 GAC Contactors

6.1.1.1 Overview

New GAC contactors would be located downstream of the combined filter effluent from the existing UF membranes/future biological filters. Filtered water would be conveyed from the combined filter effluent pipe in the yard and conveyed to the new intermediate pump station. The intermediate pump station would boost water pressure through the GAC contactors, and treated water would then be conveyed to the clear well.

Lead/Lag

The PFD for lead/lag GAC contactors at WBWTP is presented in Figure 40.

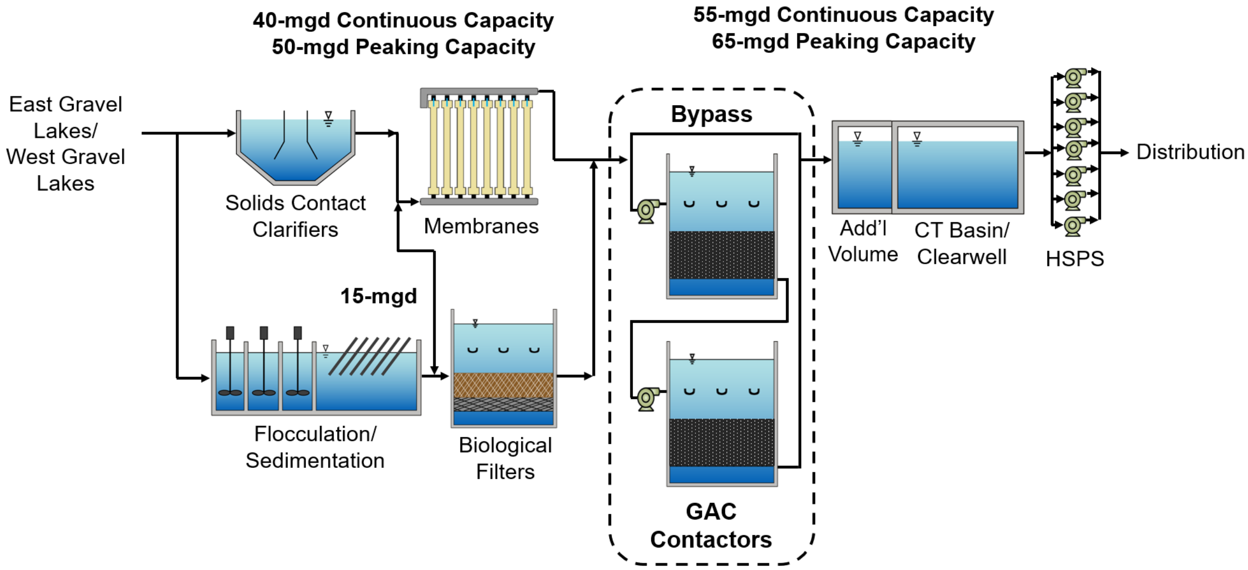


Figure 40 WBWTP Lead/Lag GAC Contactors PFD

Lead/lag treatment increases the amount of GAC inventory available and provides additional redundancy if Thornton's goals are to maintain non-detect in individual GAC contactor effluent as opposed to the blended effluent. However, lead/lag treatment results in additional capital costs and required footprint.

Single Pass

The PFD for single pass GAC contactors at WBWTP is presented in Figure 41.

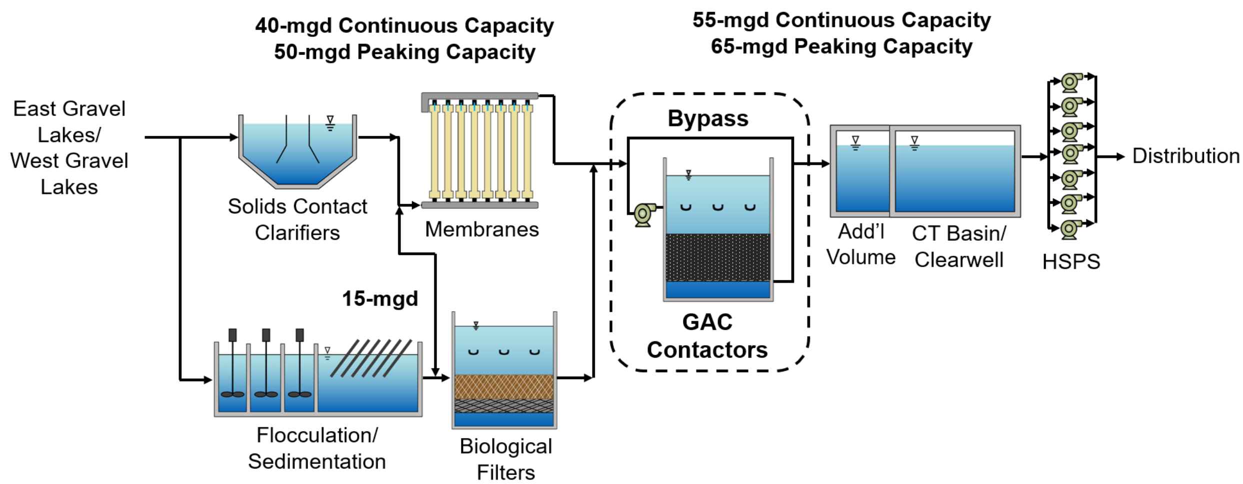


Figure 41 WBWTP Single Pass GAC Contactors PFD

Single pass treatment is a lower capital cost alternative that can maintain the City's goals for PFAS combined effluent concentrations utilizing blending.

6.1.1.2 Design Criteria

Table 30 outlines the proposed design criteria for lead/lag and single pass GAC contactor alternatives at WBWTP.

Table 30 WBWTP GAC Contactors Design Criteria

Description	Units	Criteria	
		Lead/Lag	Single Pass
GAC Contactors, New			
Contactor Type: Gravity, Concrete Box			
Process Capacity	mgd	55	
Number of Contactors, Total	No.	18	10
Number of Lead Contactors	No.	9	9
Number of Lag/Standby Contactors	No.	9	1
Contactor Dimensions (Width x Length)	feet x feet	18 x 60	
Contactor Area			
Each Contactor	sf	1,080	
Total	sf	19,400	10,800
Surface Loading Rate (at 30 mgd)	gpm/sf	3.9	
Empty Bed Contact Time of GAC, Per Contactor (at 30 mgd)	minute	15	
Empty Bed Contact Time of GAC, Total (at 30 mgd)	minute	30	15
GAC Contactor Media			
Depth	inch	96	
Bed Volume			
Each Contactor	cf	8,600	
GAC Influent/Intermediate Pump Station			
Type: Vertical Turbine Pumps			
Number of Pumps	No.	10 (8 + 2)	5 (4 + 1)
Capacity, Each	mgd	14	

6.1.1.3 Conceptual 3D Model

Lead/Lag

A conceptual 3D model for lead/lag GAC contactors at WBWTP is presented in Figure 42.

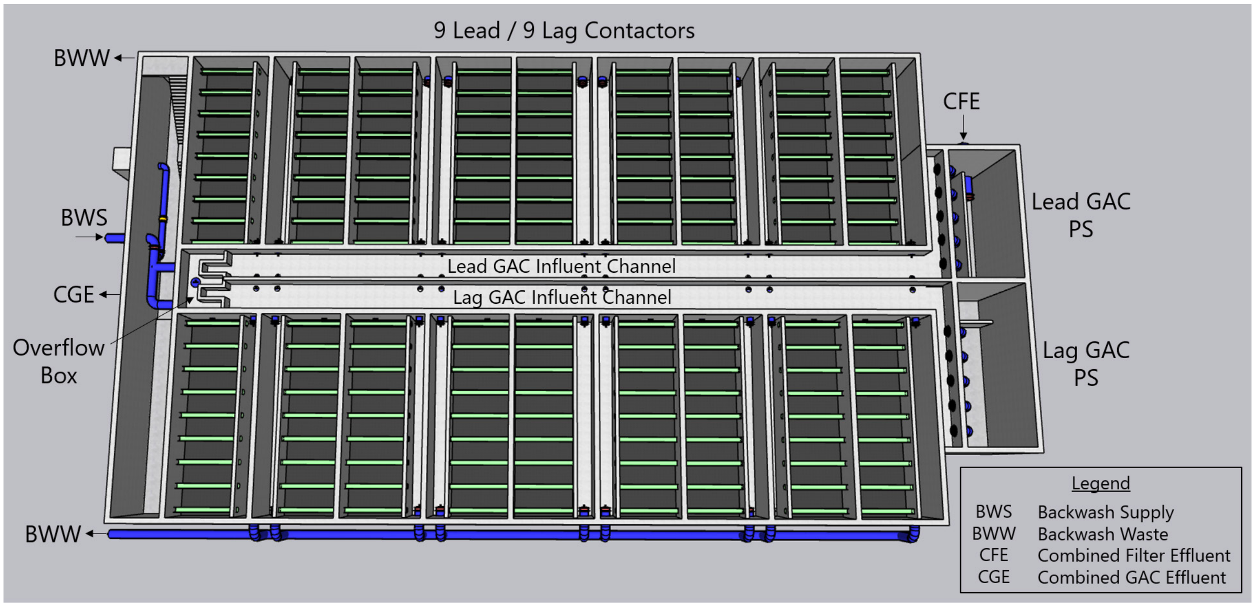


Figure 42 WBWTP Lead/Lag GAC Contactors 3D Model Layout 2

The conceptual design allows for each individual GAC contactor to serve as a lead or lag GAC contactor. Lead contactor effluent is returned to the lag GAC pump station, and then pumped to the lag GAC influent channel, where all lead contactor effluent is blended before treatment in the lag contactor. Flexibility is provided to operate in either single pass or lead/lag. However, since water is blended in the lag GAC influent channel, individual lead contactors cannot be coupled with a specific lag contactor. Treated water is collected in the effluent header and conveyed to the existing clear well.

Backwash supply water is provided by the backwash supply pumps associated with the 15-mgd gravity filter expansion and is utilized for removal of fines after media installation and for intermittent backwash during operation. Filter-to-waste is provided through the common backwash supply header for wasting of effluent when a contactor is first placed into service. An overflow weir is provided in the influent channel that directs process overflow water to the treated water effluent header pipe.

The operating deck, building, and roof of the structure is not shown for clarity.

Single Pass

A conceptual 3D model for single pass GAC contactors at WBWTP is presented in Figure 43.

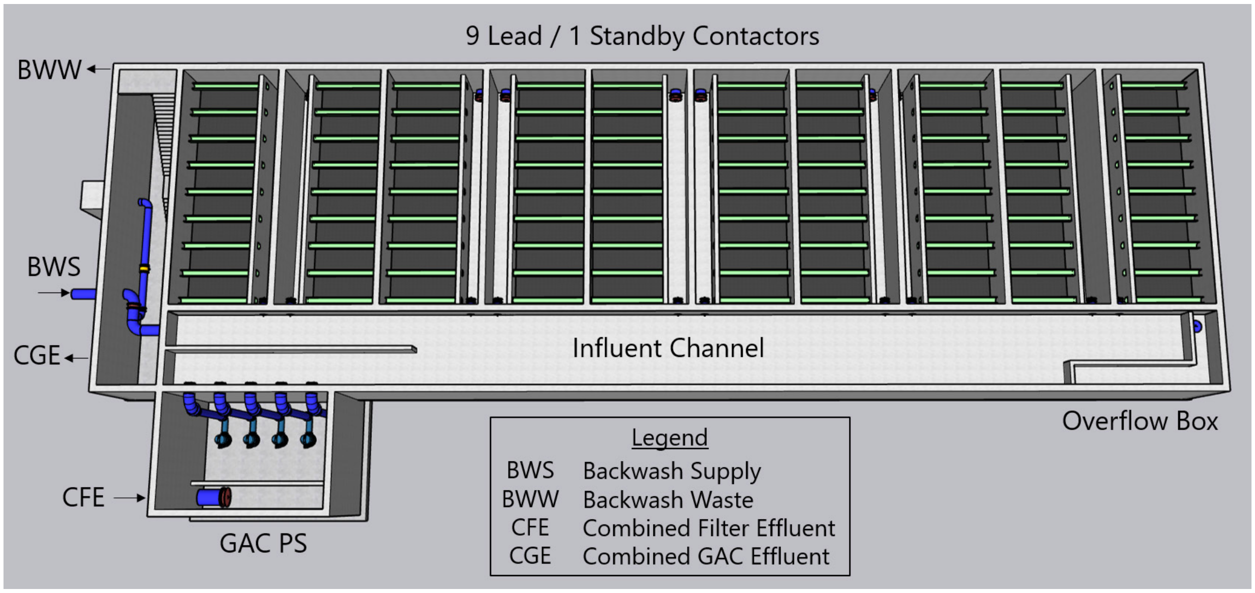


Figure 43 WBWTP Single Pass GAC Contactors 3D Model

The conceptual design presented offers stage parallel treatment, where the effluent from each GAC contactor is blended. Valving is provided for operations to select in-service contactors, and treated water is collected in the effluent header and conveyed to the existing clear well.

Backwash supply water is provided by the backwash supply pumps associated with the 15-mgd gravity filter expansion and is utilized for removal of fines after media installation and for intermittent backwash during operation. Filter-to-waste is provided through the common backwash supply header for wasting of effluent when a contactor is first placed into service. An overflow weir is provided in the influent channel that directs process overflow water to the treated water effluent header pipe.

The operating deck, building, and roof of the structure is not shown for clarity.

6.1.1.4 Site Layout

For facility planning purposes, the site layouts presented include facilities for the planned expansion at WBWTP to bring continuous treatment capacity to 55 mgd.

Lead/Lag

A preliminary site layout for lead/lag gravity contactors is presented in Figure 44.

Single Pass

A preliminary site layout for single pass gravity contactors is presented in Figure 45.

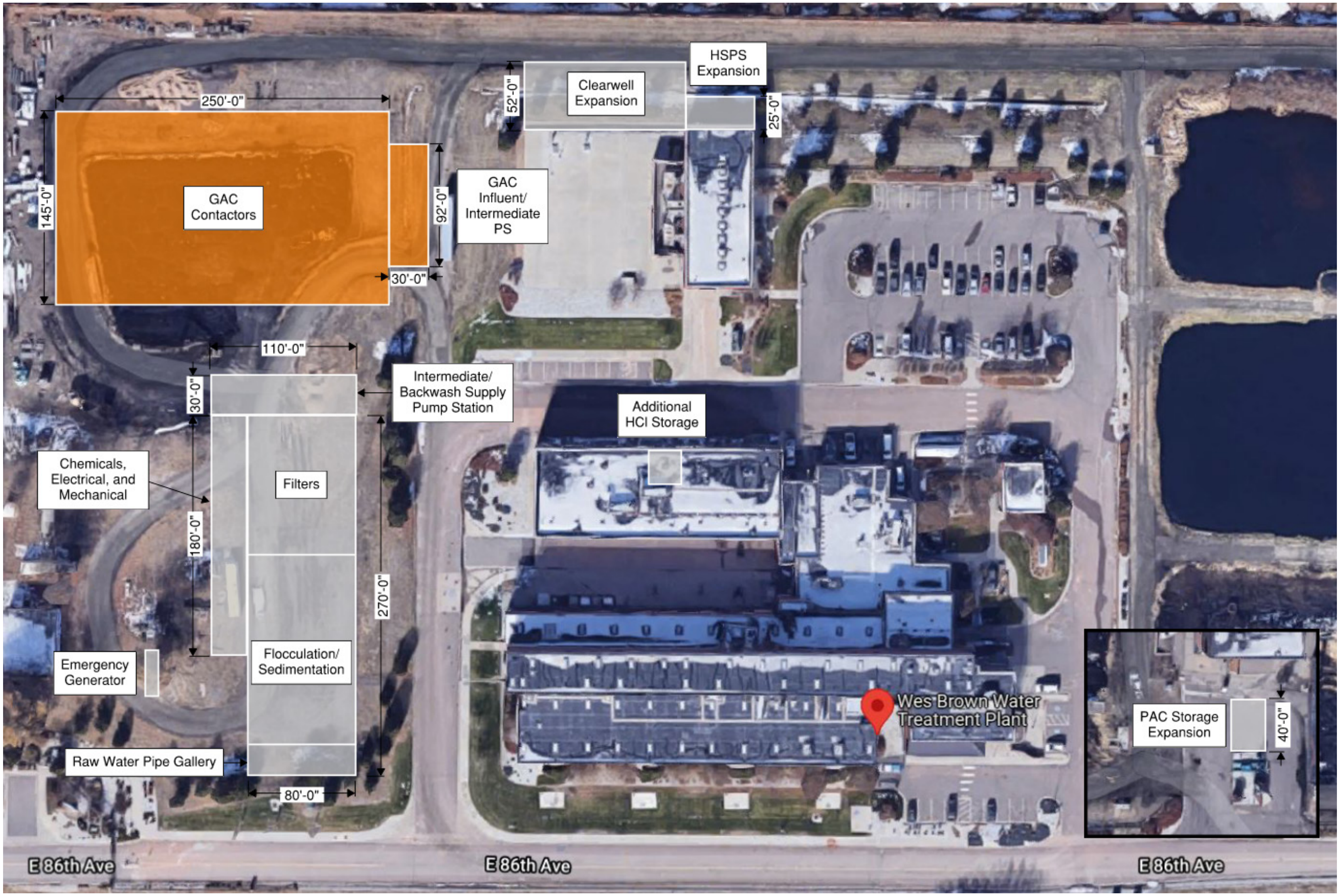


Figure 44 WBWTP Lead/Lag GAC Contactors Site Layout

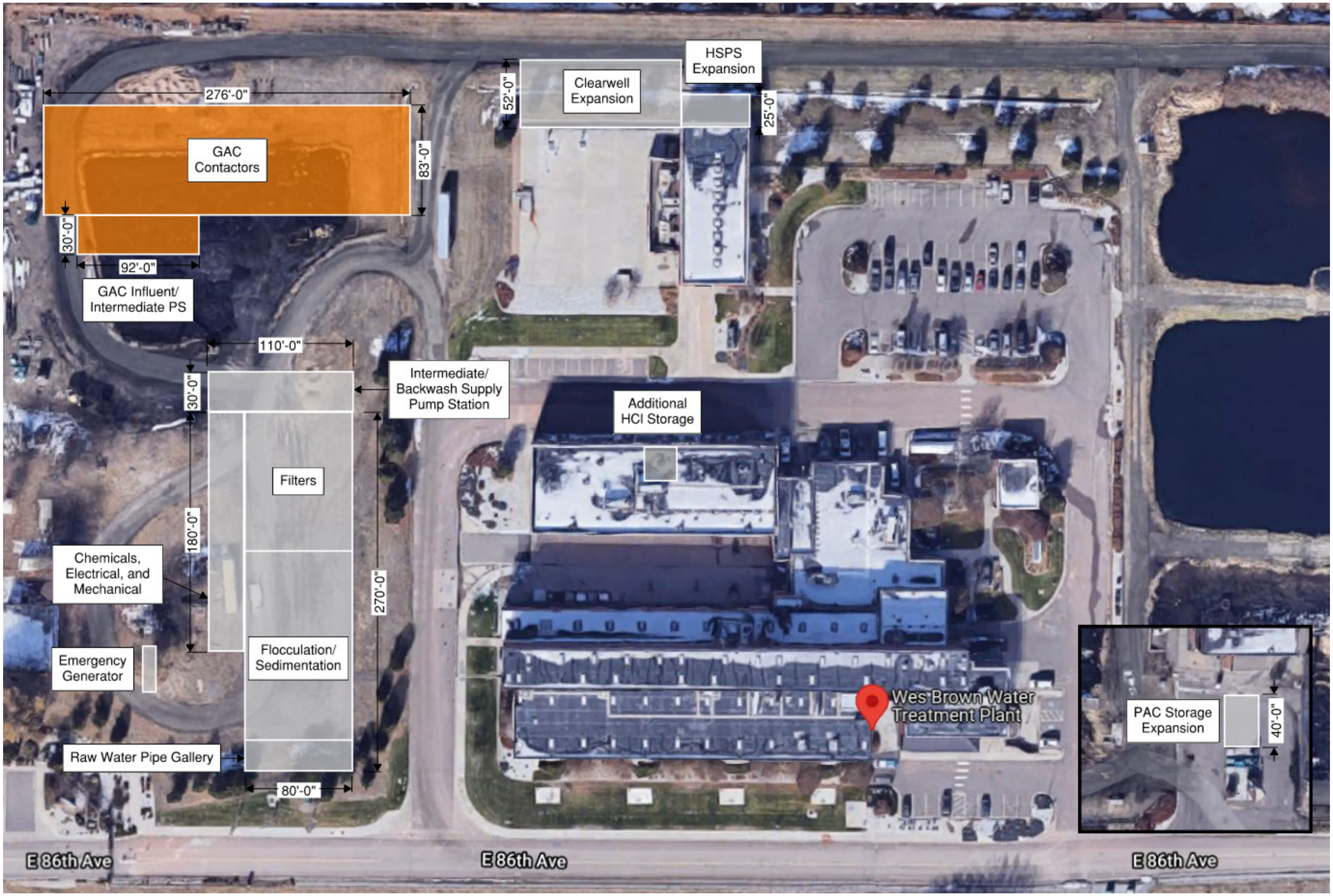


Figure 45 WBWTP Single Pass GAC Contactors Site Layout

6.1.1.5 Operational Considerations

The advantages and disadvantages of this alternative are presented in Table 31.

Table 31 Operational Considerations for GAC Contactors at WBWTP

Advantages	Disadvantages
▪ GAC provides a treatment barrier for other contaminants such as DBP precursors, T&O compounds, and VOCs. T&O is of considerable importance at WBWTP, as the facility currently cannot meet the City's T&O goals under all expected water quality conditions. ▪ GAC contactors require fewer valves and instrumentation than pressure vessels due to the lower number of treatment units required. ▪ GAC contactors provide fewer sample locations that would be required for monitoring GAC media life due to the lower number of treatment units required. ▪ The footprint for GAC contactors is smaller than the footprint for GAC pressure vessels. ▪ GAC contactor backwash can utilize the backwash supply system for the planned biofiltration expansion. ▪ Spent GAC can be returned to the vendor for regeneration, reactivation, and re-sale to non-potable water sectors, which reduces media disposal costs compared to IX resin. ▪ GAC gravity contactors can be designed to be compatible with novel adsorbents to allow for media conversion in the future. ▪ The GAC market has historically observed more price stability than the IX market.	▪ The time required for GAC replacement in gravity contactors is longer and replacement is a more complicated process than for pressure vessels. ▪ GAC contactors provide less modularity and redundancy than pressure vessels. ▪ GAC contactors require more complicated construction (water-bearing concrete structures) compared to pressure vessels. ▪ GAC requires longer EBCT than IX, resulting in a larger system footprint. ▪ Less effective in short-chain PFSAs removal than IX. ▪ Non-steady state treatment process, requiring attentive monitoring of contaminant breakthrough to maximize GAC service life. ▪ GAC alternatives require more frequent backwashing (start-up and operation) than IX alternatives.

6.1.2 GAC Pressure Vessels

6.1.2.1 Overview

New GAC pressure vessels would be located downstream of the combined filter effluent from the existing UF membranes/future biological filters. Filtered water would be conveyed from the combined filter effluent pipe in the yard and conveyed to the new intermediate pump station. The intermediate pump station would boost water pressure through the GAC pressure vessels, and treated water would then be conveyed to the clear well.

Lead/Lag

The PFD for lead/lag GAC pressure vessels at WBWTP is presented in Figure 46.

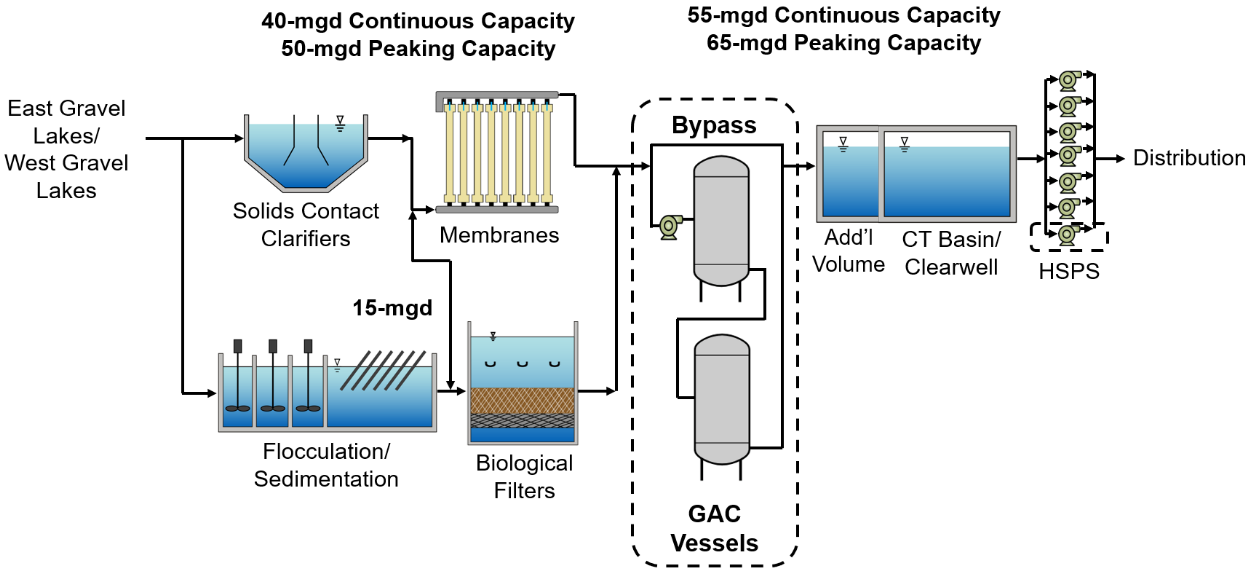


Figure 46 WBWTP Lead/Lag GAC Pressure Vessels PFD

Lead/lag treatment increases the amount of GAC inventory available and provides additional redundancy if Thornton's goals are to maintain non-detect in individual GAC pressure vessel effluent as opposed to the blended effluent. However, lead/lag treatment results in additional capital costs and required footprint.

Single Pass

The PFD for single pass GAC pressure vessels at WBWTP is presented in Figure 47.

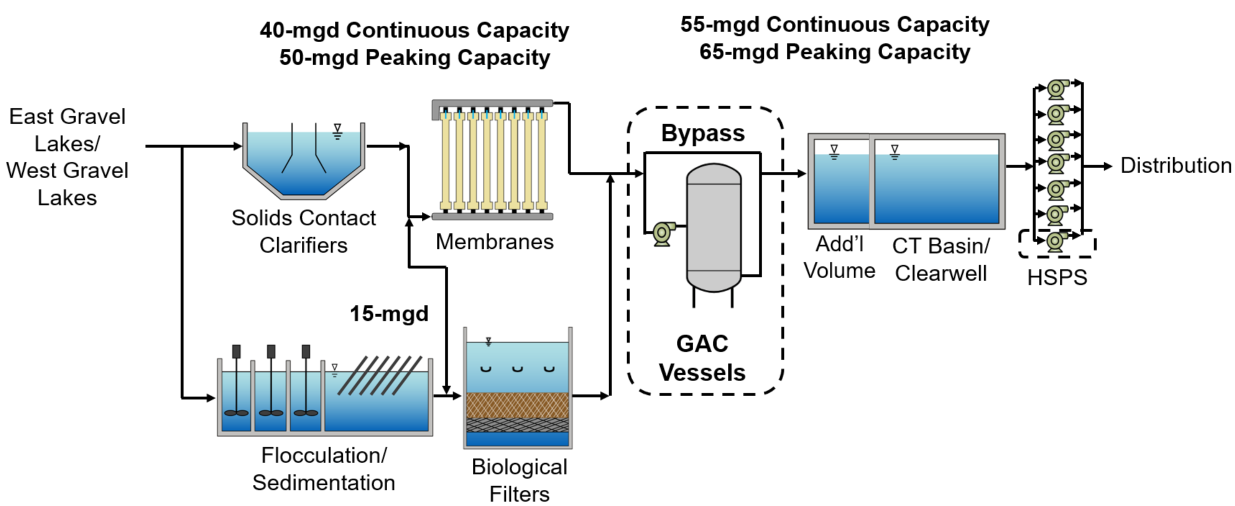


Figure 47 WBWTP Single Pass GAC Pressure Vessels PFD

Single pass treatment is a lower capital cost alternative that can maintain the City's goals for PFAS combined effluent concentrations utilizing blending.

6.1.2.2 Design Criteria

Table 32 outlines the proposed design criteria for lead/lag and single pass GAC pressure vessel alternatives at WBWTP.

Table 32 WBWTP GAC Pressure Vessels Design Criteria

Description	Units	Criteria	
		Lead/Lag	Single Pass
GAC Pressures Vessels, New			
Vessel Type: Carbon Steel			
Process Capacity	mgd	55	
Number of Vessels, Total	No.	80	44
Number of Lead Vessels	No.	40	40
Number of Lag/Standby Vessels	No.	40	4
Vessel Dimensions			
Diameter	feet	14	
Height	feet	27	
Vessel Surface Area	sf	154	
Carbon Per Vessel	lbs	60,000	
Flow Rate Per Vessel	gpm	1,000	
Hydraulic Loading Rate	gpm/sf	6.5	
Empty Bed Contact Time, Per Vessel (at 30 mgd)	min	15	
Empty Bed Contact Time, Total (at 30 mgd)	min	30	15
Total Headloss per Train	psi	18	9
Intermediate Pump Station			
Type: Vertical Turbine Pumps			
Number of Pumps	No.	5 (4 + 1)	
Capacity, Each	mgd	14	

6.1.2.3 Conceptual 3D Model

Lead/Lag

A conceptual 3D model for lead/lag GAC pressure vessels at WBWTP is presented in Figure 48.

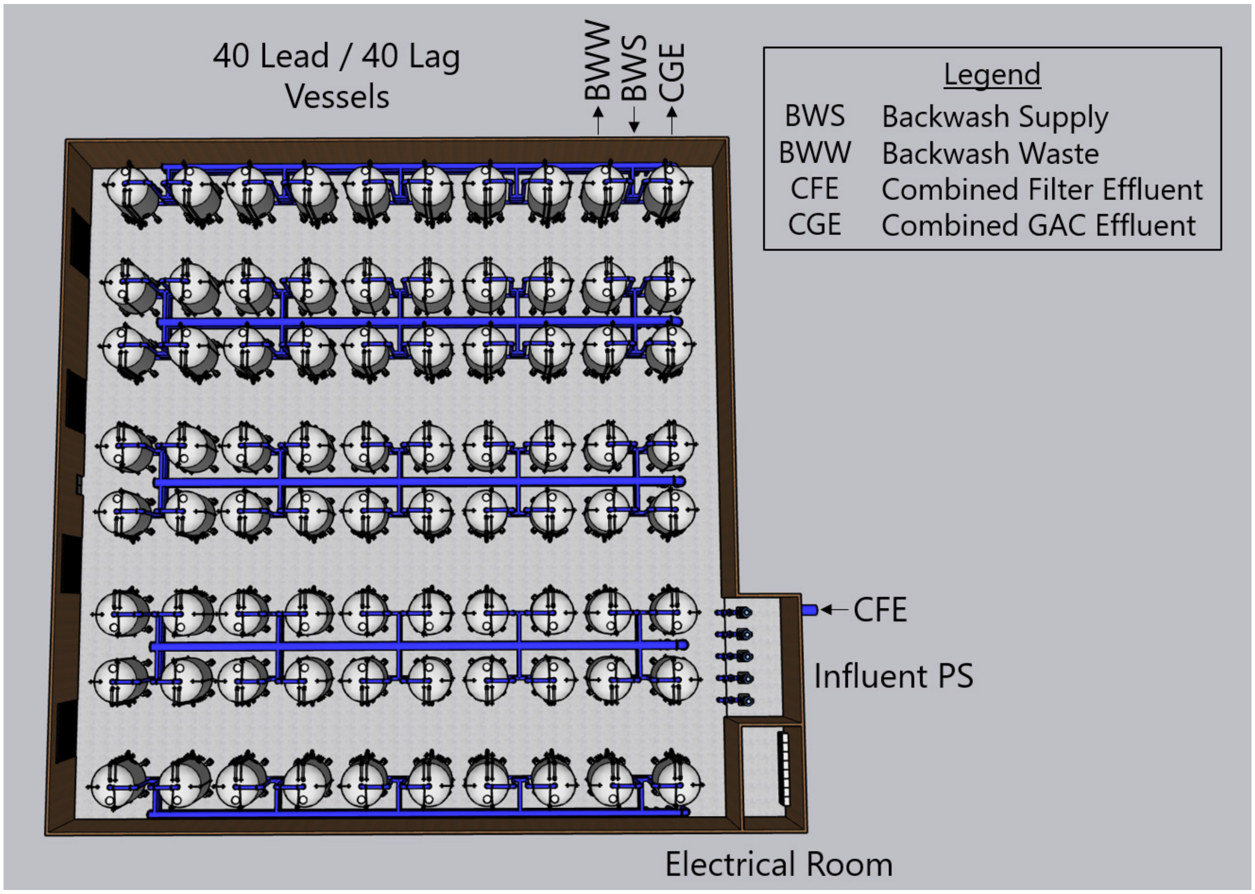


Figure 48 WBWTP Lead/Lag GAC Pressure Vessels 3D Model

The conceptual design allows for each individual paired GAC pressure vessel to serve as the lead or lag pressure vessel. However, the large number of vessels required results in a large footprint and significant operational and maintenance complexity. Treated water is collected in the effluent header and conveyed to the existing clear well.

Backwash supply water is provided by the backwash supply pumps associated with the 15-mgd gravity filter expansion and is utilized for removal of fines after media installation and for intermittent backwash during operation. Filter-to-waste is provided for wasting of effluent when a pressure vessel is first placed into service. Four roll-up doors are provided for access for GAC replacement and maintenance activities.

The roof of the structure is not shown for clarity.

Single Pass

A conceptual 3D model for single pass GAC pressure vessels at WBWTP is presented in Figure 49.

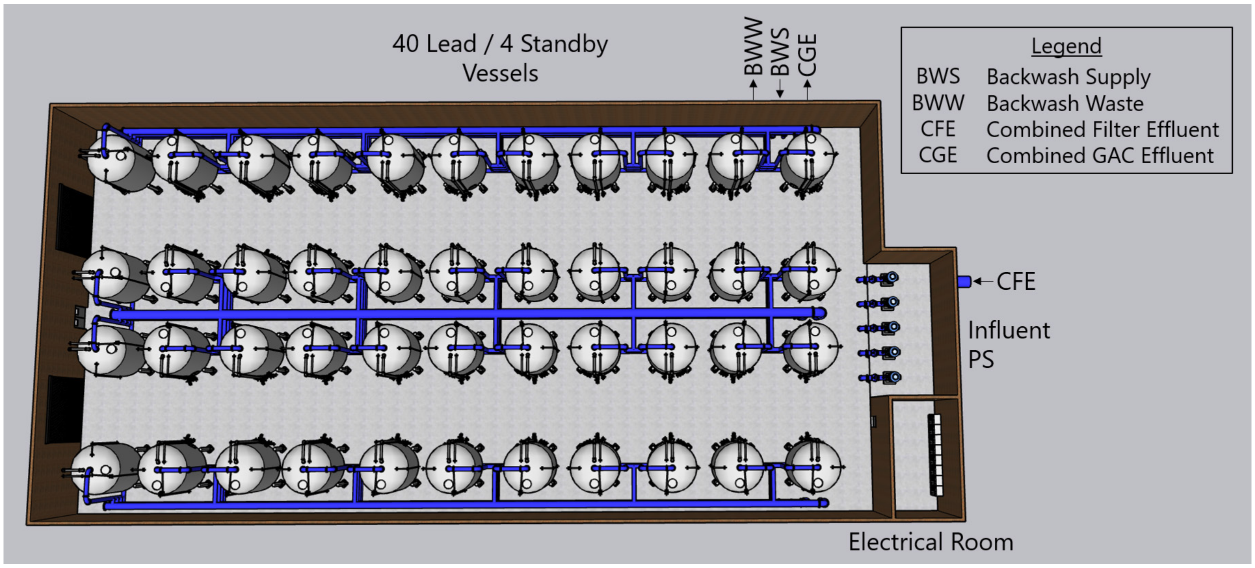


Figure 49 WBWTP Single Pass GAC Pressure Vessels 3D Model

Similar to the lead/lag conceptual design, this alternative includes paired GAC pressure vessels. At the design flow rate of 55 mgd, each individual GAC pressure vessel is operated, with four standby vessels available. At lower flow rates, paired vessels can operate in a lead/lag arrangement, providing additional flexibility.

Backwash supply water is provided by the backwash supply pumps associated with the 15-mgd gravity filter expansion and is utilized for removal of fines after media installation and for intermittent backwash during operation. Filter-to-waste is provided for wasting of effluent when a pressure vessel is first placed into service. Two roll-up doors are provided for access for GAC replacement and maintenance activities.

The roof of the structure is not shown for clarity.

6.1.2.4 Site Layout

For facility planning purposes, the site layouts presented include facilities for the planned expansion at WBWTP to bring continuous treatment capacity to 55 mgd.

Lead Lag

A preliminary site layout for lead/lag GAC pressure vessels is presented in Figure 50.

Single Pass

A preliminary site layout for single pass GAC pressure vessels is presented in Figure 51.

Figure 50 WBWTP Lead/Lag GAC Pressure Vessels Site Layout

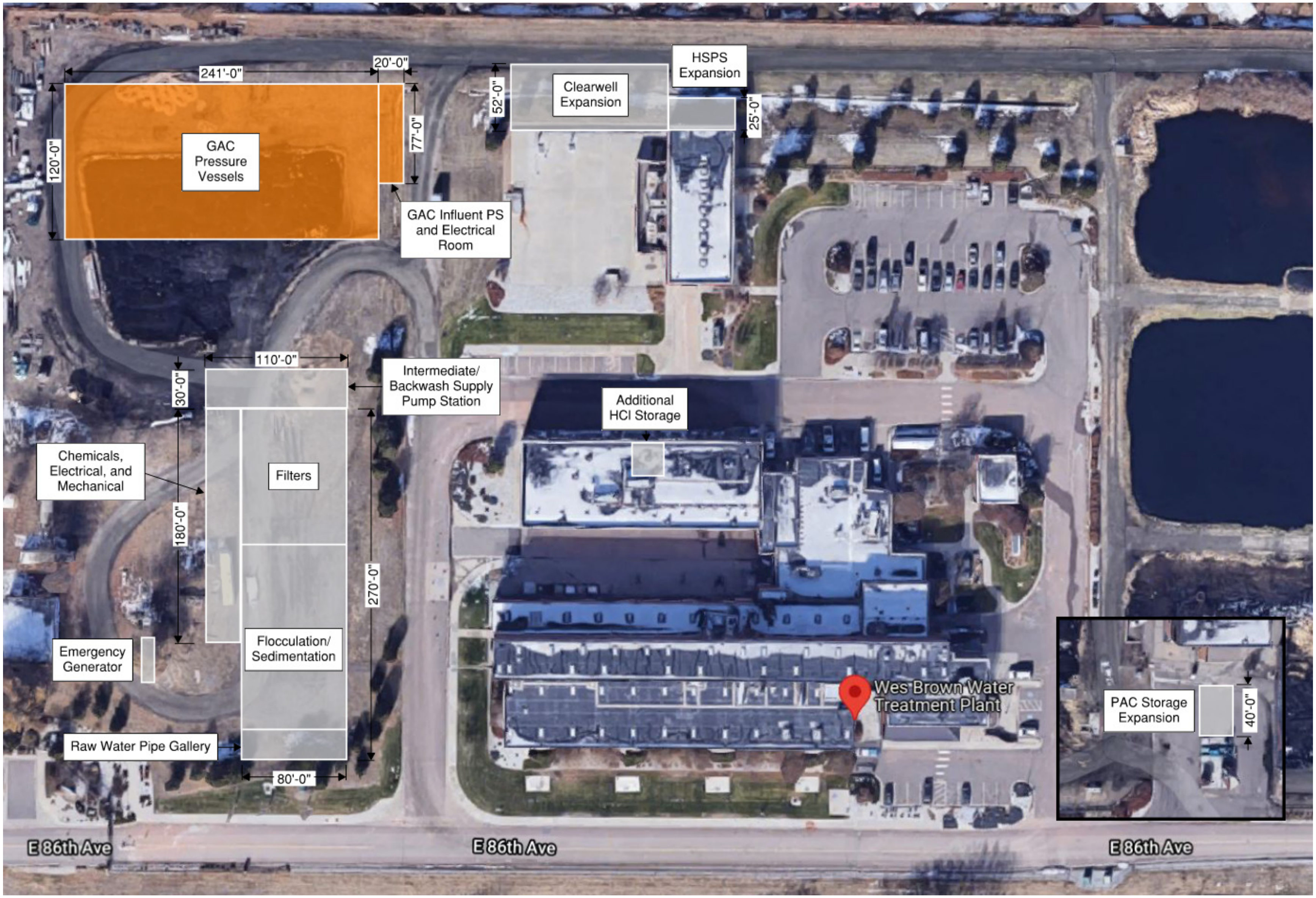


Figure 51 WBWTP Single Pass GAC Pressure Vessels Site Layout

6.1.2.5 Operational Considerations

The advantages and disadvantages of this alternative are presented in Table 33.

Table 33 Operational Considerations for GAC Pressure Vessels at WBWTP

Advantages	Disadvantages
▪ GAC provides a treatment barrier for other contaminants such as DBP precursors, T&O compounds, and VOCs. T&O is of considerable importance at WBWTP, as the facility currently cannot meet the City's T&O goals under all expected water quality conditions. ▪ GAC replacement is a shorter and more simple process (about 4 hours) for pressure vessels as opposed to gravity contactors. ▪ Pressure vessels provide more modularity and redundancy than gravity GAC contactors. ▪ A pressure vessel facility is simpler to construct than GAC contactors (slab on grade with building as compared to water-bearing concrete structures). ▪ GAC contactor backwash can utilize the backwash supply system for the planned biofiltration expansion. ▪ Spent GAC can be returned to the vendor for regeneration, reactivation, and re-sale to non-potable water sectors, which reduces media disposal costs compared to IX resin. ▪ GAC pressure vessels are compatible with IX resin and novel adsorbents to allow for media conversion in the future. ▪ The GAC market has historically observed more price stability than the IX market.	▪ Pressure vessels require more valves and instrumentation than gravity GAC contactors due to the greater number of vessels. ▪ Utilizing pressure vessels results in a greater number of sample locations that would be required for monitoring GAC media life due to the greater number of vessels required. ▪ GAC requires longer EBCT than IX, resulting in a larger system footprint. ▪ The footprint for GAC pressure vessels is greater than the footprint for gravity GAC contactors. ▪ Less effective in short-chain PFSAs removal than IX. ▪ Non-steady state treatment process, requiring attentive monitoring of contaminant breakthrough to maximize GAC service life. ▪ GAC alternatives require more frequent backwashing (start-up and operation) than IX alternatives.

6.1.3 IX Pressure Vessels

6.1.3.1 Overview

New IX pressure vessels would be located downstream of the combined filter effluent from the existing UF membranes/future biological filters. Filtered water would be conveyed from the combined filter effluent pipe in the yard and conveyed to the new intermediate pump station. The intermediate pump station would boost water pressure through the IX pressure vessels, and treated water would then be conveyed to the clear well.

Lead/Lag

The PFD for lead/lag IX pressure vessels at WBWTP is presented in Figure 52.

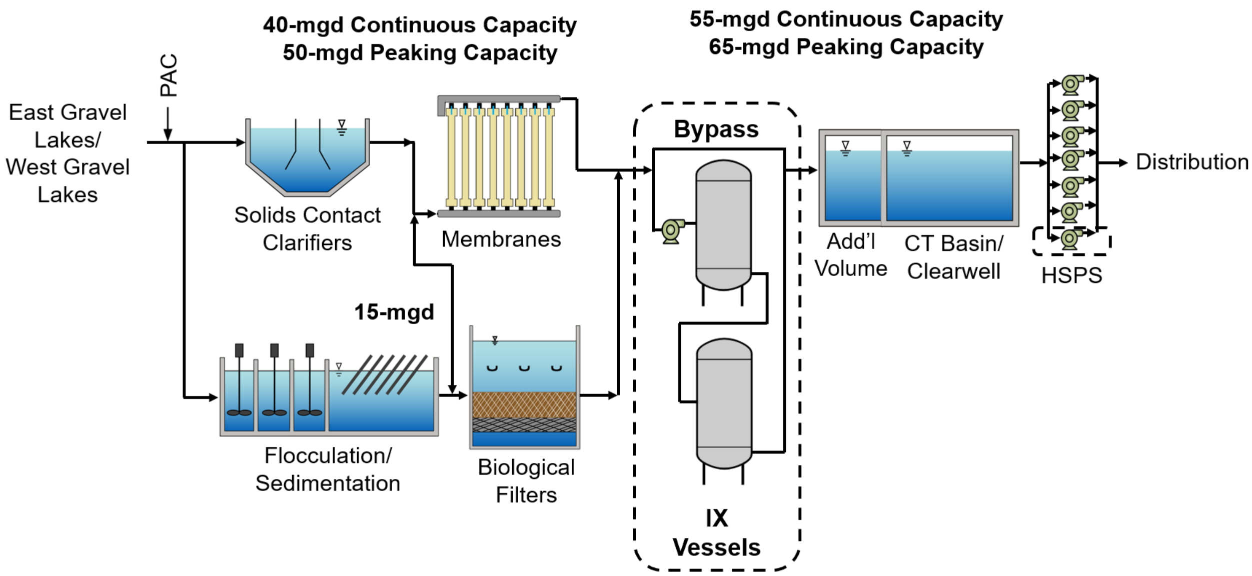


Figure 52 WBWTP Lead/Lag IX Pressure Vessels PFD

Lead/lag treatment increases the amount of IX resin inventory available and provides additional redundancy if Thornton's goals are to maintain non-detect in individual IX vessel effluent as opposed to the blended effluent. However, lead/lag treatment results in additional capital costs and required footprint.

Single Pass

The PFD for single pass IX pressure vessels at WBWTP is presented in Figure 53.

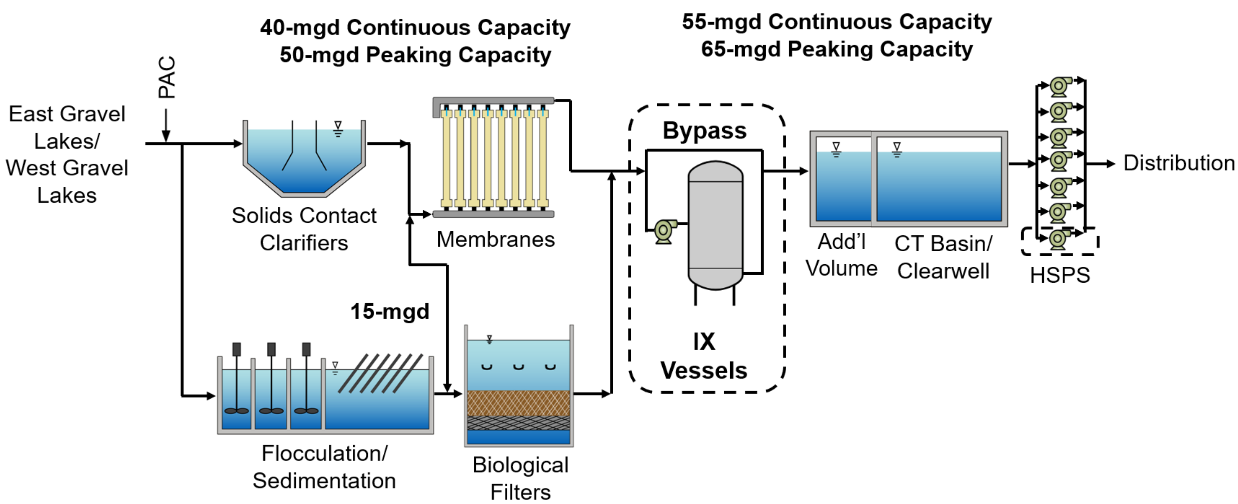


Figure 53 WBWTP Single Pass IX Pressure Vessels PFD

Single pass treatment is a lower capital cost alternative that can maintain the City's goals for PFAS combined effluent concentrations utilizing blending.

6.1.3.2 Design Criteria

Table 34 outlines the proposed design criteria for lead/lag and single pass IX pressure vessel alternatives at WBWTP.

Table 34 WBWTP IX Pressure Vessels Design Criteria

Description	Units	Criteria	
		Lead/Lag	Single Pass
IX Pressures Vessels, New			
Vessel Type: Carbon Steel			
Process Capacity	mgd	55	
Number of Vessels, Total	No.	38	22
Number of Lead Vessels	No.	19	19
Number of Lag Vessels	No.	19	3
Vessel Dimensions			
Diameter	feet	14	
Height	feet	17	
Vessel Surface Area	sf	154	
IX Resin Per Vessel	cf	840	
Flow Rate Per Vessel	gpm	2,100	
Hydraulic Loading Rate	gpm/sf	13.5	
Empty Bed Contact Time, Per Vessel (at 30 mgd)	min	3	
Empty Bed Contact Time, Total (at 30 mgd)	min	6	3
Total Headloss per Train	psi	30	15
Intermediate Pump Station			
Type: Vertical Turbine Pumps, Variable Speed			
Number of Pumps	No.	5 (4 + 1)	
Capacity, Each	mgd	14	

6.1.3.3 Conceptual 3D Model

Lead/Lag

A conceptual 3D model for lead/lag IX pressure vessels at WBWTP is presented in Figure 54.

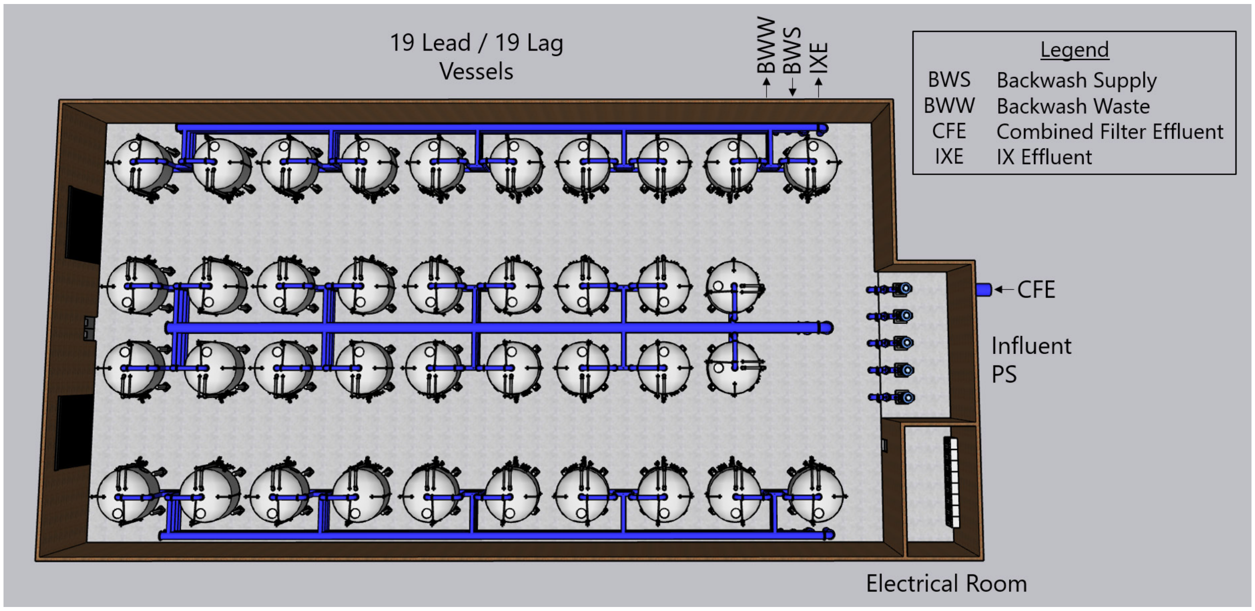


Figure 54 WBWTP Lead/Lag IX Pressure Vessels 3D Model

The conceptual design allows for each individual paired IX pressure vessel to serve as the lead or lag pressure vessel. Due to the smaller EBCT and higher loading rates required by IX, the total number of IX vessels required for lead/lag operation is fewer than the number of vessels required for both lead/lag and single pass GAC pressure vessels. Treated water is collected in the effluent header and conveyed to the existing clear well.

Backwash supply water is provided by the backwash supply pumps associated with the 15-mgd gravity filter expansion and is utilized for removal of fines after resin installation. Filter-to-waste is provided for wasting of effluent when a pressure vessel is first placed into service. Two roll-up doors are provided for access for IX replacement and maintenance activities.

The roof of the structure is not shown for clarity.

Single Pass

A conceptual 3D model for single pass IX pressure vessels at WBWTP is presented in Figure 55.

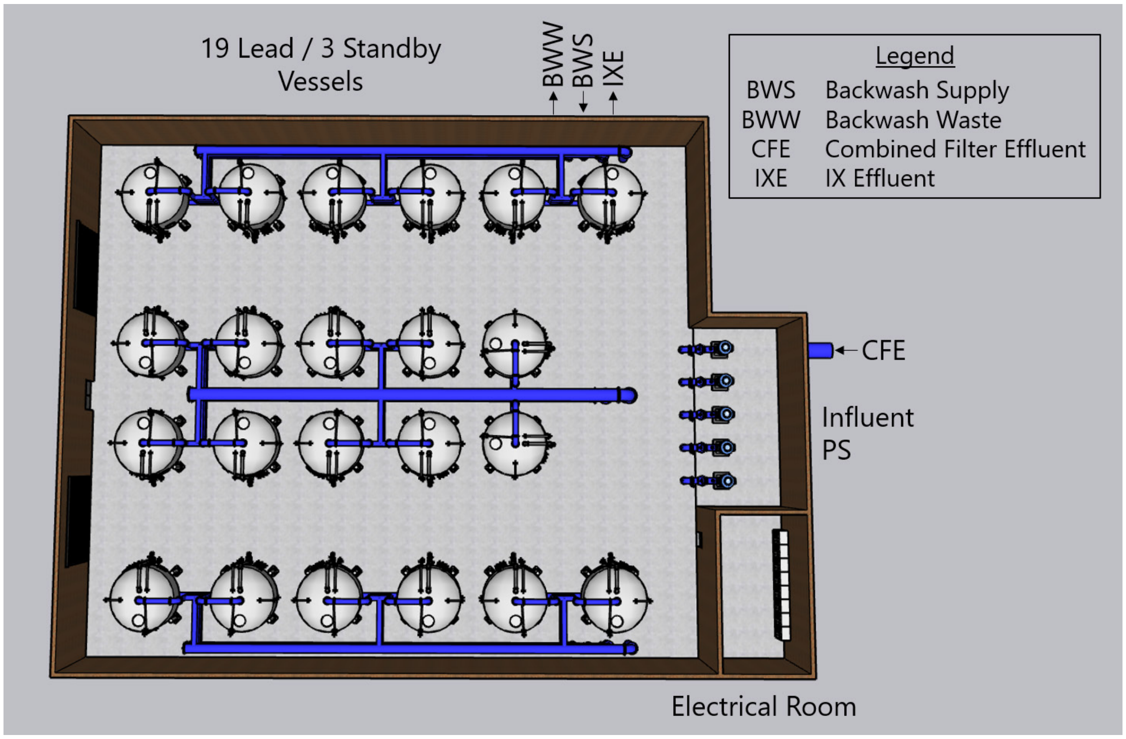


Figure 55 WBWTP Single Pass IX Pressure Vessels 3D Model

Similar to the lead/lag conceptual design, this alternative includes paired IX pressure vessels. At the design flow rate of 55 mgd, each individual GAC pressure vessel is operated, with two standby vessels available. At lower flow rates, paired vessels can operate in a lead/lag arrangement, providing additional flexibility.

Backwash supply water is provided by the backwash supply pumps associated with the 15-mgd gravity filter expansion and is utilized for removal of fines after resin installation. Filter-to-waste is provided for wasting of effluent when a pressure vessel is first placed into service. Two roll-up doors are provided for access for IX replacement and maintenance activities.

The roof of the structure is not shown for clarity.

6.1.3.4 Site Layout

For facility planning purposes, the site layouts presented include facilities for the planned expansion at WBWTP to bring continuous treatment capacity to 55 mgd.

Lead/Lag

A preliminary site layout for lead/lag IX pressure vessels is presented in Figure 56.

Single Pass

A preliminary site layout for single pass IX pressure vessels is presented in Figure 57.

Figure 56 WBWTP Lead/Lag IX Pressure Vessels Site Layout

Figure 57 WBWTP Single Pass IX Pressure Vessels Site Layout

6.1.3.5 Operational Considerations

The advantages and disadvantages of this alternative are presented in Table 35.

Table 35 Operational Considerations for IX Pressure Vessels at WBWTP

Advantages	Disadvantages
▪ IX is effective in removing both long-chain PFAS and short-chain PFSAs. ▪ Faster adsorption kinetics results in a shorter EBCT and a smaller footprint than GAC pressure vessels. The smaller footprint provides considerable flexibility in siting the facility on the existing site. ▪ IX pressure vessels represent the most simple and shortest construction schedule. ▪ IX alternatives have the most simple media replacement of all alternatives. ▪ IX alternatives require limited backwashing (only during start-up for removal of fines). ▪ IX pressure vessel backwash can utilize the backwash supply system for the planned biofiltration expansion. ▪ IX pressure vessels are compatible with novel adsorbents to allow for media conversion in the future.	▪ Does not remove T&O compounds or as many emerging contaminants of concern as GAC removes. ▪ Greater head loss than GAC, which results in higher pumping costs. ▪ Non-steady state treatment process, requiring attentive monitoring of contaminant breakthrough to maximize IX service life. ▪ PFAS-specific IX resins are non-regenerable. Disposal of spent resin through high-temperature incineration is recommended. ▪ The IX resin market is tied to the petroleum industry, leading to less price stability for replacement when compared to GAC.

6.2 Alternatives Evaluation

6.2.1 Capital Costs

Capital costs were developed for each treatment process alternative utilizing quantity take-offs from the conceptual 3D models presented. Key assumptions for capital cost development include the following:

- Deep foundations similar to existing WBWTP structures were assumed.
- Architectural features shall match the existing WBWTP facilities.
- The backwash supply and backwash waste systems associated with the 15-mgd gravity filter expansion are re-used for backwashing activities.
- The existing electrical service feed, switchgear, and transformer do not require upsizing.
- Additional back-up generator capacity will be provided for the new facilities.
- Costs were escalated to the midpoint of construction, which was assumed to be 2030.
- Any additional Owner's costs in addition to Owner's Advisor, Design Engineer, Services During Construction, and Contractor costs are not included (such as City project management).

A contingency of 20 percent was assumed. This accounts for unforeseeable elements of cost within the project scope, as well as known elements that are undefined at this stage of design progress. Items such as variations in process configuration, unforeseen site conditions, and reasonable project changes that are determined during the detailed design phase are included in the contingency.

The level of accuracy for capital cost estimates varies depending upon the level of detail to which the project has been defined. AACE International publishes guidelines that define the class of estimate and the expected accuracy range. Based on these guidelines, the capital cost estimate presented herein is a Class 4 estimate, which should be considered a conceptual design level estimate. The expected range of accuracy for this type of estimate is +50 percent to -30 percent.

Budgetary estimates of the total project costs for each of the alternatives are summarized in Table 36. These estimates include all costs directly related to the project, including owner's advisor services, permitting, design, construction, and commissioning, but do not include any Owner costs such as City project management.

Table 36 Construction Cost Estimate for WBWTP Alternatives (Base Year 2030)

Description	GAC Contactors		GAC Pressure Vessels		IX Pressure Vessels		Notes
	Lead/Lag	Single Pass	Lead/Lag	Single Pass	Lead/Lag	Single Pass	
Direct Costs							
GAC Contactors/GAC Vessels/IX Vessels	$58,700,000	$38,200,000	$78,400,000	$51,000,000	$42,900,000	$27,900,000	
Influent/Intermediate Pump Station	$10,700,000	$6,700,000	$6,700,000	$6,700,000	$8,200,000	$8,200,000	
Site Civil	$8,400,000	$8,400,000	$7,800,000	$7,800,000	$6,600,000	$6,600,000	Site concrete, retaining walls, yard piping, site electrical, landscaping, fencing, and paving.
Electrical and Backup Power Generation	$15,800,000	$11,100,000	$15,000,000	$10,500,000	$17,100,000	$12,000,000	
Escalation to Project Midpoint	*$32,800,000*	*$22,500,000*	*$37,800,000*	*$26,600,000*	*$26,200,000*	*$19,100,000*	35% of Direct Costs (5% per year)
Subtotal Direct Costs	*$126,400,000*	*$86,900,000*	*$145,700,000*	*$102,600,000*	*$101,000,000*	*$73,800,000*	
Indirect Costs							
General Conditions	$19,000,000	$13,000,000	$21,900,000	$15,400,000	$15,200,000	$11,100,000	15% of Subtotal Direct Costs
Bonds and Insurance	$3,800,000	$2,600,000	$4,400,000	$3,100,000	$3,000,000	$2,200,000	3% of Subtotal Direct Costs
Contractor Fee (Overhead and Profit) and Risk	$25,300,000	$17,400,000	$29,100,000	$20,500,000	$20,200,000	$14,800,000	20% of Subtotal Direct Costs
Subtotal Indirect Costs	*$48,100,000*	*$33,000,000*	*$55,400,000*	*$39,000,000*	*$38,400,000*	*$28,100,000*	
TOTAL CONSTRUCTION COSTS	**$174,500,000**	**$119,900,000**	**$201,100,000**	**$141,600,000**	**$139,400,000**	**$101,900,000**	
Owner's Contingency	$34,900,000	$24,000,000	$40,200,000	$28,300,000	$27,900,000	$20,400,000	20% of Subtotal Construction Costs
TOTAL CONSTRUCTION COSTS WITH CONTINGENCY	**$209,400,000**	**$143,900,000**	**$241,300,000**	**$169,900,000**	**$167,300,000**	**$122,300,000**	
Engineering Costs							
Design Engineer – Design Services	$16,800,000	$11,500,000	$19,300,000	$13,600,000	$13,400,000	$9,800,000	8% of Total Construction Cost
Design Engineer – Services During Construction	$12,600,000	$8,600,000	$14,500,000	$10,200,000	$10,000,000	$7,300,000	6% of Total Construction Cost
Owner's Advisor Services	$6,300,000	$4,300,000	$7,200,000	$5,100,000	$5,000,000	$3,700,000	3% of Total Construction Cost
Total Engineering Costs	*$35,700,000*	*$24,400,000*	*$41,000,000*	*$28,900,000*	*$28,400,000*	*$20,800,000*	
TOTAL PROJECT COSTS	**$245,100,000**	**$168,300,000**	**$282,300,000**	**$198,800,000**	**$195,700,000**	**$143,100,000**	
Federal Funding Requirements (AIS, BABA, DB, etc.)	$31,400,000	$21,600,000	$36,200,000	$25,500,000	$25,100,000	$18,300,000	15% of Total Project Costs
TOTAL PROJECT COSTS WITH FEDERAL FUNDING REQUIREMENTS	**$276,500,000**	**$189,900,000**	**$318,500,000**	**$224,300,000**	**$220,800,000**	**$161,400,000**	

6.2.2 Net Present Value Analysis

A NPV analysis is a useful tool for evaluating alternatives on a life-cycle cost basis. The NPV of a given alternative is a summation of present and future costs converted to present day dollar value. This allows for an equivalent comparison of alternatives on an economic basis. The NPV figures calculated herein represent the estimated amount of funds presently required to pay for future expenditures (including capital, operations, maintenance, and replacement costs) over the examined time period. Therefore, the higher the NPV, the more costly the alternative is on a life cycle basis. However, it is important to note that the NPV costs were determined for the purpose of analyzing the cost differential between alternatives. Thus, the values presented should be limited to assisting in alternative selection and not used as a basis for setting future capital and operations budgets, as it is not a complete accounting of all recurring costs. The following assumptions and guidelines were used in the development of NPV costs:

- Construction and annual costs are based on 2030 estimated values, as it is the assumed project midpoint.
- A 4.0 percent interest rate, a 4.0 percent discount rate, a 5.0 escalation rate, and a 20-year operations period were used to calculate the NPV of the annual costs.
- Operations and maintenance costs were based on a plant flow rate of yearly flow rate of 20.7 mgd, which is the average of the currently yearly average flow rate and the build-out design average yearly flow rate.
- Power costs were based on an average value of $0.20/kilowatt-hour.
- GAC carbon replacement costs were estimated at $3.30/pound, which was the cost provided for replacement and disposal of Calgon F400 media escalated to the year 2026.
- GAC replacement is based on a 1.5-year media life. This is 67 percent of the expected lifespan of the TWTP media, which was reduced due to higher TOC and PFAS levels in the water to be treated.
- IX resin replacement costs were estimated as $560/cf for IX resin and $110/cf for incineration/ disposal, which are the costs provided by IX resin suppliers in replacement bids escalated to the year 2030.
- IX resin replacement schedule is based on a 1.4-year media life. This is 67 percent of the expected lifespan of the TWTP media, which was reduced due to higher TOC and PFAS levels in the water to be treated.
- Labor and equipment preventative maintenance costs are presented as cost differentials between alternatives, not as a complete accounting of all labor and equipment preventative maintenance costs. Equipment replacement, unless specifically noted, is assumed to be negligible within the time period of the NPV analysis.

The calculated NPV for each alternative is presented in Table 37. A detailed NPV analysis of each treatment process alternative is presented in Appendix B.

Table 37 NPV for WBWTP Alternatives (Base Year 2030)

Alternative	20-Year NPV	
	Lead/Lag	Single Pass
GAC Contactors	$291,540,000	$213,000,000
GAC Pressure Vessels	$334,500,000	$246,880,000
IX Pressure Vessels	$270,110,000	$212,650,000

6.2.3 Non-Monetary Evaluation Criteria

In addition to cost criteria, alternatives were evaluated based on the additional non-monetary criteria presented in Table 38.

Table 38 Treatment Process Non-Economic Evaluation Criteria

Objective/Criteria	Description
Process Reliability	Treatment processes that have lead/lag treatment capabilities, ability to utilize lead/lag treatment at lower flow, or longer service time between media changeouts were given preference.
Simple Operation	Ability of each alternative to achieve finished water quality goals using simple equipment with low operational intensity.
Treatment Barrier for Other Contaminants	Preference was given to treatment processes that meet finished water quality goals and remove other contaminants of concern, including T&O, TOC, DBP precursors, algal toxins, and VOCs.
Media/Resin Replacement Frequency and Effort	Alternatives with less frequent media/resin replacement and a simpler replacement effort (i.e., shorter replacement duration) were given preference.
Lower Hydraulic Requirements	Treatment alternatives with less pressure loss across the process train were given preference.
Compatibility With Other Media Types	Preference was given to alternatives that are easily compatible with other media types (i.e., GAC, IX, and alternative adsorbents such as FLUORO-SORB® 200).
Compact Footprint	Alternatives with smaller site footprints that leave more space for future expansion and treatment processes were given preference.
Ease of Construction/Impacts to Operation	Preference was given to alternatives with simpler construction that requires less water-bearing concrete structures, fewer concrete pours, fewer plant shut-downs and interference to plant operations, fewer under-slab piping runs, and less confined spaces.

Table 39 presents the results of the treatment facility alternatives evaluation.

Table 39 WBWTP Alternatives Evaluation

Alternative	Total Project Cost (Base Year 2030) (without Federal Funding Requirements)	20-Year Net Present Value (Base Year 2030)	Process Reliability	Simple Operation	Treatment Barrier for Other Contaminants	Media/Resin Replacement Frequency and Effort	Lower Hydraulic Requirements	Compatibility With Other Media Types	Compact Footprint	Ease of Construction/Impacts to Operation
GAC Contactors Lead/Lag	$245 M	$291 M	Excellent	Poor	Excellent	Fair	Excellent	Fair	Poor	Fair
GAC Contactors Single Pass	$168 M	$213 M	Excellent	Excellent	Excellent	Fair	Excellent	Fair	Fair	Fair
GAC Pressure Vessels Lead/Lag	$282 M	$335 M	Excellent	Poor	Excellent	Fair	Fair	Excellent	Poor	Fair
GAC Pressure Vessels Single Pass	$199 M	$247 M	Excellent	Fair	Excellent	Fair	Excellent	Excellent	Fair	Fair
IX Pressure Vessels Lead/Lag	$196 M	$270 M	Excellent	Fair	Poor	Excellent	Poor	Fair	Fair	Fair
IX Pressure Vessels Single Pass	$143 M	$213 M	Excellent	Excellent	Poor	Excellent	Fair	Fair	Excellent	Excellent

Legend:
● Excellent ◒ Fair ○ Poor

6.2.4 Preferred Treatment Process

As a result of this evaluation, the preferred treatment process for PFAS treatment at WBWTP is single pass GAC Contactors. Although this alternative has a higher capital cost compared to single pass IX pressure vessels, the 20-year NPV is similar between the alternatives and GAC contactors provide the greatest value to the City in achieving the Project's treatment, operations, and maintenance goals as well as addressing longstanding T&O challenges at WBWTP.

SECTION 7 APPROACH TO CONCEPTUAL DESIGN

7.1 Purpose and Objectives

The purpose of the Conceptual Design is to provide sufficient information to convey the technical intent, goals, criteria, and objectives of the Project. The Conceptual Design is supplemental to the Request for Proposals (RFP) to procure the design engineer and the contractor (construction manager at risk [CMAR] is the contracting method the City selected for the project). It serves as the baseline information utilized by prospective design engineer and contractor teams in preparing and submitting proposals in response to the RFP and establishes the minimum technical requirements that shall be utilized in completing the project design and for implementing the project.

The primary objectives of the Conceptual Design are to:

- Define the project requirements that are critical to the City, which the design engineer and contractor must satisfy.
- Provide an indicative design concept that demonstrates technical feasibility of the design that is estimated to be within the project budget and for the design engineer to consider in developing the design.
- Identify specific technical evaluations that the designer shall perform as its design scope of services.
- Allow for more targeted technical proposals by prospective design engineer and contractor teams.
- Provide the design engineer and contractor with existing conditions information and documentation.
- Allow for the design engineer to expedite their design development efforts (reducing project schedule).

The Conceptual Design for a CMAR contract, in essence, establishes the minimum requirements for the technical aspects of the project to be used as the basis for the design.

7.2 Content of the Conceptual Design

The proposed content of the Conceptual Design consists of the following main sections:

- Project Overview.
- Project Site.
- Water Quality and Performance Requirements.
- Codes, Standards, and Guidelines.
- Design Criteria.

A brief description of each section is provided below.

7.2.1 Project Overview

The project overview section includes project background information, an overview of the Conceptual Design, a description of the project purpose and objectives, a summary of the project elements (i.e., scope of the project), and project budget and schedule.

7.2.2 Project Site

The project site section includes the following existing conditions information:

- Project site description.
- Existing project facilities, utilities and easements, and site restrictions.
- Reference information such as geotechnical, environmental, and survey/topography documentation.

Reference information/documentation is provided for background information only. The design engineer and/or the contractor shall verify the background information in accordance with the requirements stipulated in the respective agreements. An existing site plan figure will be provided.

7.2.3 Water Quality and Performance Requirements

A summary of the historical water quality data available from the City will be provided in this section. The historical raw water and finished water quality summary consists of summary tables and notable water quality considerations as it relates to treatment.

A description of all finished water quality requirements is included, which consist of regulatory requirements for PFAS and City-specific finished water goals (such as corrosivity and secondary treatment benefits). Also, other performance goals are summarized here that may include maximum power and/or chemical usage requirements. The combination of finished water requirements and other performance requirements constitute the minimum technical requirements that the design engineer shall utilize in its completion of the design.

7.2.4 Codes, Standards, and Guidelines

This section lists the minimum City codes, standards, and guidelines that the design engineer and contractor shall follow in completing its design, including:

- State and local reference codes (City's building code, fire code, etc.).
- Building system standards (heating, ventilation, and air conditioning, security, etc.).
- Equipment standards.
- Applicable standard details and/or specifications.
- Electrical, instrumentation, and controls standards.

The list provided in the Conceptual Design summarizes key reference codes, standards, and guidelines for the project. It provides a general summary only, with the expectation that it will be further refined by the design engineer and contractor. Compliance with local, state, and federal codes and laws is the sole responsibility of the design engineer and contractor.

7.2.5 Design Criteria

7.2.5.1 Baseline Design Criteria

The baseline design criteria are developed based on the preferred treatment process selected via the Study and provide a baseline approach and design criteria for achieving the finished water quality requirements. The design engineer may propose changes to the baseline design criteria in developing its design of the new PFAS treatment facilities but is required to provide factual justification for any such deviations.

Figures used to illustrate the baseline design approach and criteria include a process flow diagram, hydraulic profile, proposed site plan, and layouts of key facilities (e.g., GAC contactor layout). Design criteria tables are included to summarize the key design parameters.

7.2.5.2 Other Requirements

Other requirements included with the Conceptual Design that describes the City's preferences and design requirements include:

- Architectural requirements.
- Landscaping requirements.
- Site development requirements.
- Civil/stormwater management requirements.
- Subsurface water management requirements.
- Supervisory control and data acquisition (SCADA) system and instrumentation and control requirements.
- Electrical requirements (including backup power).
- Naming and tagging conventions.
- Equipment preferences.
- Operations preferences.

APPENDIX A

PROJECT MEMORANDUM: RAPID SMALL-SCALE COLUMN TEST RESULTS

PROJECT MEMORANDUM

CITY OF THORNTON

Owner's Advisor Services PFAS Treatment

Project No.:	23-127 (202719)
Date:	June 10, 2024
Prepared By:	Juliana Levi, PhD
Reviewed By:	Rosa Yu, PhD, PE
Subject:	Rapid Small-Scale Column Test Results

1.0 EXECUTIVE SUMMARY

This project memorandum summarizes the results of per- and polyfluoroalkyl substances (PFAS) rapid small-scale column tests (RSSCT) as part of the City of Thornton (City) Owner's Advisor Services PFAS Treatment project. All bench-scale RSSCTs were performed at Carollo Engineers' (Carollo) Water Applied Research Center (Water ARC®) in Boise, Idaho, from February 2024 to March 2024.

Three granular activated carbon (GAC) products and two ion exchange resin (IX) products were evaluated and compared for PFAS treatment performance, including:

- Calgon Carbon Filtrasorb 400 (F400) GAC.
- Carbon Activated Corporation (CAC) ACOL-L100 GAC.
- Evoqua AquaCarb 1230CX GAC.
- Purolite PFA694E IX resin.
- Lanxess TP108 DW IX resin.

All three bench-scale GAC RSSCT columns were designed to simulate a design empty bed contact time (EBCT) of 15 minutes. Both bench-scale IX RSSCT columns were designed to simulate a design EBCT of 3 minutes. Feed water for the bench-scale RSSCTs was collected from the Thornton Water Treatment Plant (TWTP) after the biological filters and before free chlorine addition while the plant was operating at a 50:50 blend of Standley Lake and East Gravel Lakes source waters.

Results of the PFAS RSSCTs indicated that GAC and IX resin performed comparably the same in terms of system throughput (i.e., media life in number of days before effluent treatment target was exceeded). Both GAC and IX resin performance was driven by perfluorooctanoic acid (PFOA) breakthrough exceeding the method reporting limits (MRL), which were specific to the laboratory used and the individual sample matrices. PFOA breakthrough curves were flat in nature, indicating that breakthrough is a gradual process. This allows for single pass alternatives utilizing blending to meet the City's PFAS treatment goals. Bituminous GAC with a 12x40 mesh size outperformed enhanced coconut-based GAC with a mesh size of 12x30. In addition, Lanxess TP108 DW resin outperformed Purolite PFA694E resin in PFOA removal.

2.0 OBJECTIVES

Carollo conducted RSSCTs and evaluated PFAS treatment performance of three GAC products and two IX products. The key objectives of bench-scale RSSCTs were to:

1. Inform PFAS treatment technology selection.
2. Determine critical design criteria.
3. Evaluate media use rate to estimate operation and maintenance (O&M) costs associated with media changeout.

3.0 RSSCT COLUMN DESIGN

RSSCTs utilize mini-columns and the principle of similitude using dimensionless parameters from the pore surface diffusion model to test the performance of GAC and IX adsorbers. By grinding GAC or IX resin into smaller particle sizes, RSSCTs can assess PFAS breakthrough behavior from a full-scale GAC or IX adsorber in a fraction of the time required for a pilot study. RSSCTs have been widely employed in PFAS treatment studies and provide unique advantages over pilot columns for making informed decisions about treatment technology, media product, critical design criteria, and for predicting O&M costs associated with GAC or IX resin changeout.

Carollo has adopted the newly validated RSSCT designs for PFAS. For GAC adsorber performance evaluation, the "hybrid" RSSCT column design was used (Hopkins and Knappe, 2024). In the hybrid-RSSCT design, the diffusivity factor, X, is equal to 0.25 (i.e., intraparticle diffusivity of PFAS partially depends on GAC particle size). This intraparticle diffusivity factor has been shown to be the most accurate predictor when GAC RSSCT throughput (i.e., bed volumes) were compared with pilot-scale GAC throughput.

For IX resin performance evaluation, the constant diffusivity (CD) design was used. In the CD-RSSCT design, the diffusivity factor, X, is equal to zero (i.e., intraparticle diffusivity of PFAS is independent of IX resin particle size). The CD-RSSCT design has been the default bench-scale approach for target contaminants such as volatile organic compounds at high concentrations (i.e., milligram per liter concentration range). However, research has indicated that CD-RSSCT design could result in a more conservative estimation of PFAS treatment performance than full-scale IX adsorber (Cheng et al., 2024), therefore validating its use for IX performance evaluation.

The RSSCT column designs are summarized in Table 1.

Table 1 RSSCT Column Designs

Parameter	Unit	Column 1	Column 2	Column 3	Column 4	Column 5
Media	--	Calgon Filtrasorb 400	CAC ACOL-L100	Evoqua Aquacarb 1230CX	Purolite PFA694E	Lanxess TP108 DW
Media Type	--	GAC	GAC	GAC	IX	IX
Upper Sieve Size	mesh	12	12	12	20	20
Lower Sieve Size	mesh	40	40	30	30	30
RSSCT Design	--	Hybrid			CD	
Diffusivity Factor, X	--	0.25	0.25	0.25	0	0

Parameter	Unit	Column 1	Column 2	Column 3	Column 4	Column 5
Full-Scale GAC or IX Adsorber Design						
EBCT	minute	15	15	15	3	3
Hydraulic Loading Rate	gpm/sq ft	6	6	6	10	10
RSSCT Column Design						
Upper Sieve Size	mesh	100	100	100	100	100
Lower Sieve Size	mesh	200	200	200	200	200
Column Internal Diameter	inch	3/16	3/16	3/16	3/16	3/16
Column Internal Diameter	mm	4.76	4.76	4.76	4.76	4.76
Hydraulic Loading Rate	gpm/sq ft	6	6	6	10	10
Volumetric Flow Rate	mL/min	4.4	4.4	4.4	7.3	7.3
Aspect Ratio	---	44	44	44	44	44
Scaling Factor	---	8.32	8.32	9.75	6.63	6.63
Empty Bed Contact Time	min	0.37	0.37	0.28	0.07	0.07
Duration	BV	50,000	50,000	50,000	250,000	250,000
	days	13	13	10	12	12

Notes:
BV - bed volume; gpm/sq ft - gallons per minute per square foot; mL/min - milliliter per minute; min - minute; mm - millimeter

4.0 FEED WATER QUALITY CHARACTERIZATION

RSSCT feed water was collected at the TWTP downstream of the biofiltration process on February 5, 2024, while the plant was operating at a 50:50 blend of Standley Lake and East Gravel Lakes source waters. The collected sample was shipped to Carollo's Water ARC® in Boise, Idaho. The feed water was filtered using 0.45-micron (µm) cartridge filter upon receiving and background water quality was characterized before and after cartridge filtration. Cartridge filtration was performed to prevent particle fouling of the high-pressure liquid chromatography pumps used for feeding water through the RSSCT columns and not necessarily for turbidity removal from the collected sample. Tables 2 and 3 summarize the feed water quality and PFAS characterization results.

Table 2 RSSCT Feed Water Quality Characterization

Parameter	Units	Raw Sample	Filtrate [1]
pH	-	7.32 - 7.72	7.37 - 7.74
UVA254	cm^{-1}	0.015 - 0.017	0.015 - 0.017
Turbidity	NTU	0.58 - 0.81	0.37 - 0.51
Alkalinity	mg/L as $CaCO_3$	84 - 86	82 - 86
Total Organic Carbon	mg/L	1.81 - 1.91	1.82 - 1.84
Chloride	mg/L	72.2 - 78.5	73.3 - 80.3
Sulfate	mg/L	110 - 113	111 - 112
TDS[(2)]	mg/L	410 - 420	410 - 420

Notes:
$CaCO_3$ - calcium carbonate; cm - centimeter; mg/L - milligrams per liter; nm - nanometer; NTU - nephelometric turbidity unit; UV254 - ultraviolet (UV) absorbance at 254 nanometers
(1) RSSCT feed water was filtered with 0.45- µm cartridge filter.
(2) TDS was analyzed on samples from two of five drums.

Table 3 RSSCT Feed Water PFAS Concentrations

PFAS(1)	Units	Column 1 Feed	Column 2 Feed	Column 3 Feed	Column 4 Feed[1]	Column 5 Feed	Final MCL/HBWC
Perfluoroalkyl Carboxylic Acids (PFCA)							
PFBA (C4)	ng/L	10	10	9.9	7.7[2]	7.7	NA
PFPeA (C5)	ng/L	7.3	7.5	7.4	6.4	6.4	NA
PFHxA (C6)	ng/L	7.4	7.4	6.9	6.5	6.5	NA
PFHpA (C7)	ng/L	2.2	2.4	2.3	2.1	2.1	NA
PFOA (C8)	ng/L	4.7	4.6	4.2	4.4	4.4	4
PFNA (C9)	ng/L	<1.8	<1.7	<1.7	<1.7	<1.7	10
PFDA (C10)	ng/L	<1.8	<1.7	<1.7	<1.7	<1.7	NA
Perfluoroalkyl Sulfonic Acids (PFSA)							
PFBS (C4)	ng/L	4.9	5.3	4.8	4.6	4.6	2,000
PFPeS (C5)	ng/L	<1.8	<1.7	<1.7	<1.7	<1.7	NA
PFHxS (C6)	ng/L	2.8	3.0	2.6	2.5	2.5	10
PFHpS (C7)	ng/L	<1.8	<1.7	<1.7	<1.7	<1.7	NA
PFOS (C8)	ng/L	2.4	2.5	2.4	1.8	1.8	4

Notes:
HBWC - health-based water concentration; MCL - maximum contaminant level; ng/L - nanograms per liter;
PFOS - perfluorooctanesulfonic acid
(1) All PFAS samples were analyzed using Environmental Protection Agency (EPA) Method 533 for a total of 29 PFAS compounds. No other PFAS compounds were detected other than PFCAs and PFSAs.
(2) Column 5 Feed PFAS measurements were used in place of Column 4 Feed measurements. Column 4 feed water sample was diluted by the external analytical laboratory for EPA Method 533 analysis. As a result, the Column 4 feed water PFAS measurements were all below the minimum reporting level.

5.0 RSSCT SYSTEM SETUP

All GAC and IX products were ground to 100×200 mesh sizes and packed into 4.8-mm diameter columns. The GAC columns were designed to simulate a full-scale design EBCT of 15 minutes and the IX columns were designed to simulate a full-scale design EBCT of 3 minutes. The five column tests were conducted concurrently.

All RSSCT components including tubing, valves, pressure gauges, sealant, etc. were carefully selected to avoid the use of any PFAS-containing materials. As part of the quality control protocols, prior to executing RSSCTs, approximately 5 gallons of ultra-pure PFAS-free water was passed through the RSSCT columns to establish the media bed. Rinse water was collected from each column and analyzed for PFAS to confirm the absence of PFAS contamination before RSSCTs commenced.

A schematic of the RSSCT columns is presented in Figure 1.

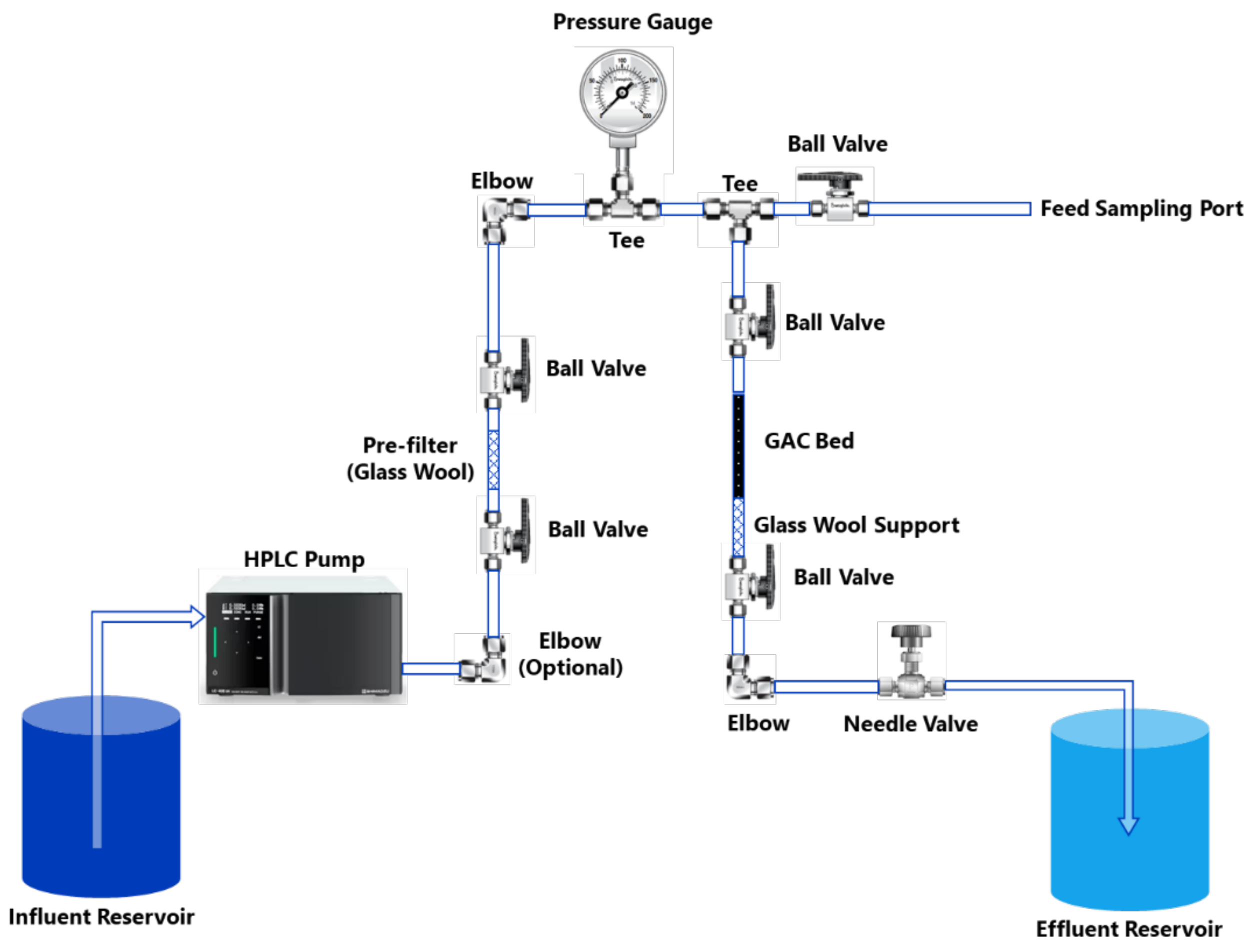


Figure 1 Bench-Scale RSSCT Column Schematic

Figure 2 presents the RSSCT test columns at Carollo's Water ARC® laboratory. GAC RSSCT columns are shown on the left, and IX RSSCT columns are shown on the right.

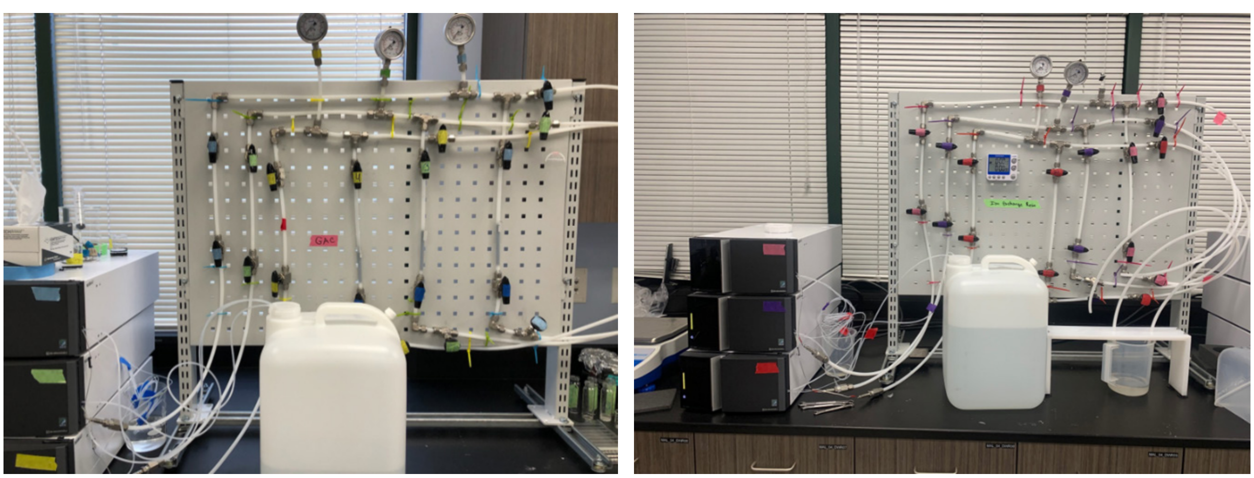


Figure 2 RSSCT Test Columns

6.0 RSSCT SAMPLING PROCEDURES

Effluent from each GAC column was sampled every 4,000 to 7,000 BVs for PFAS, dissolved organic carbon (DOC), and UV254 analysis. Effluent from each IX column was sampled every 10,000 to 25,000 BVs for the same analyses. DOC and UV254 breakthrough were monitored in the column effluent to determine if they could be used as a performance indicator for PFAS. A summary of the number of samples analyzed for each column and total BVs is provided in Table 4.

Table 4 RSSCT Sampling and Duration

Column No.	Media	No. of Samples	RSSCT Duration (No. of BVs)
1	Calgon F400	13	52,000
2	CAC ACOL-L100	13	52,000
3	Evoqua AquaCarb 1230CX	11	53,000
4	Purolite PFA694E	14	254,000
5	Lanxess TP108 DW	14	251,000

7.0 RSSCT RESULTS

7.1.1 PFOA and PFOS

Of the six PFAS compounds with final MCLs, only PFOA was present in the RSSCT feed water at concentrations above its final MCL. PFOA breakthrough as a function of system throughput (i.e., number of days GAC and IX single adsorbers in service) is shown in Figure 3.

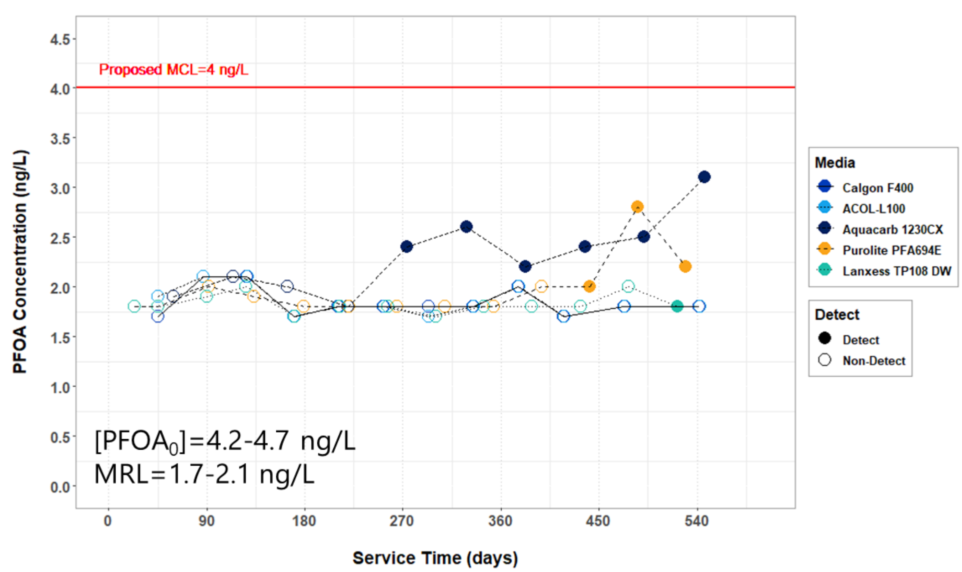


Figure 3 PFOA Breakthrough

It is noteworthy that system service time (throughput) was expressed in days in service rather than bed volumes to account for the different design EBCTs for GAC and IX.

$$Throughput\ (days) = \frac{No.of\ Bed\ Volumes \times Design\ EBCT}{24\frac{hours}{day} \times 60\frac{minutes}{hour}}$$

Results indicated that effluent PFOA concentration did not exceed its final MCL of 4 ng/L for any of the medias tested and the breakthrough curves observed were flat, indicating that breakthrough is a gradual process. PFOA concentration remained below the MRL (1.7 to 2.1 ng/L) for up to 540 days in the two 12x40 GAC column effluents (i.e., Calgon F400 and CAC ACOL-L100). Earlier PFOA breakthrough was observed in the 12x30 GAC column effluent (e.g., Aquacarb 1230CX), exceeding the MRL after 270 days. PFOA breakthrough was only observed near the end of the RSSCT operation from the two IX columns. PFOA concentration exceeded the MRL after 440 days for Purolite PFA694E resin and 520 days for Lanxess TP108 DW resin.

Table 5 compares the media changeout frequency based on a treatment target of MRL for PFOA for a single GAC or IX adsorber.

Table 5 Media Changeout Frequency

Supplier	Calgon	Carbon Activated Corporation	Evoqua	Purolite	Lanxess
Product	F400	ACOL-L100	Aquacarb 1230CX	PFA694E	TP108 DW
No. of BV	52,000+	52,000+	26,300	211,000	250,000
EBCT	15 min	15 min	15 min	3 min	3 min
No. of Days	540	540	270	440	520

As shown in Figure 4, PFOS remained non-detectable in all five column effluents throughout the entire RSSCT duration. Generally, PFSAs tend to adsorb more strongly to GAC and IX resin than PFCAs of equivalent perfluoroalkyl chain length due to their higher hydrophobicity. For this reason, PFOA rather than PFOS will drive GAC and IX resin use rate (i.e., changeout frequency).

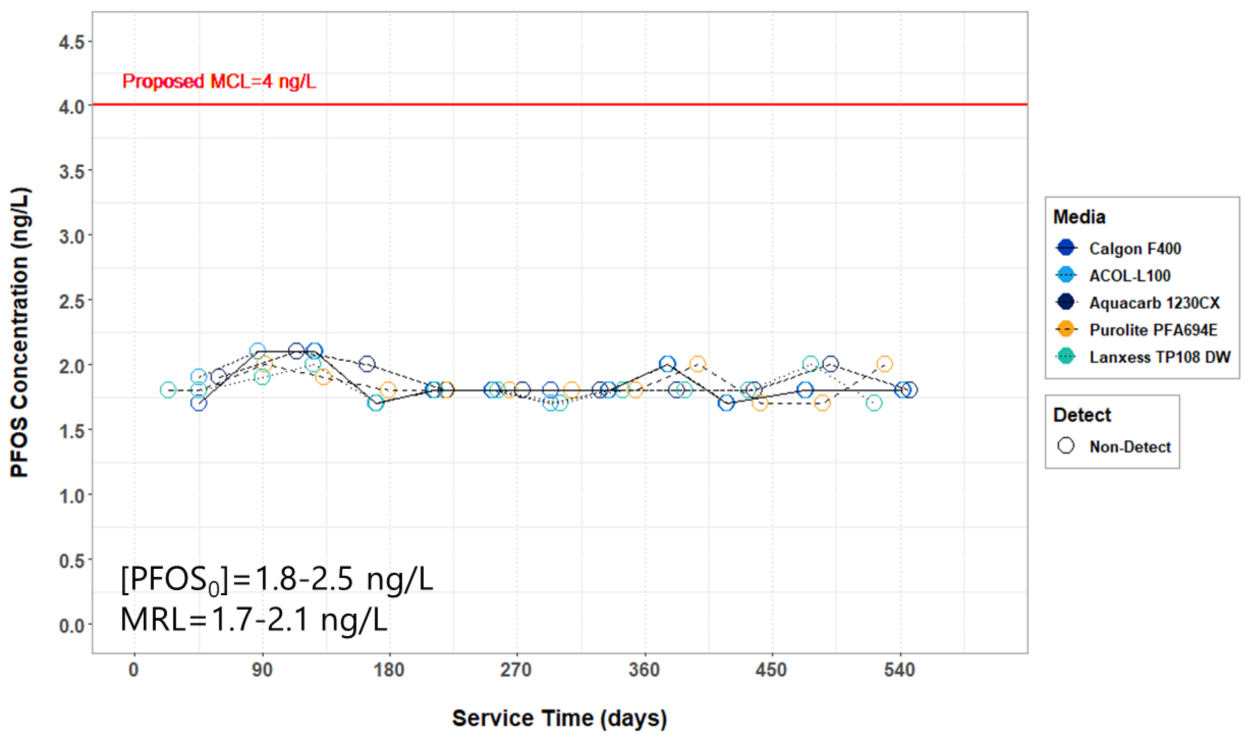


Figure 4 PFOS Breakthrough

7.2 PFBS, PFHxS, PFNA, and GenX

Both PFNA and GenX were not detected in the RSSCT feed water. PFBS concentration in the RSSCT feed water ranged between 4.6 and 5.3 ng/L, which is well below its final HBWC of 2,000 ng/L. Influent PFHxS concentration ranged between 2.5 and 3.0 ng/L, which is also below its final MCL of 10 ng/L. As presented in Figure 5, PFHxS remained non-detectable in all column effluents throughout the entire RSSCT duration other than one detection at the MRL in the Aquacarb 1230CX GAC column after a system throughput equivalent to 540 days.

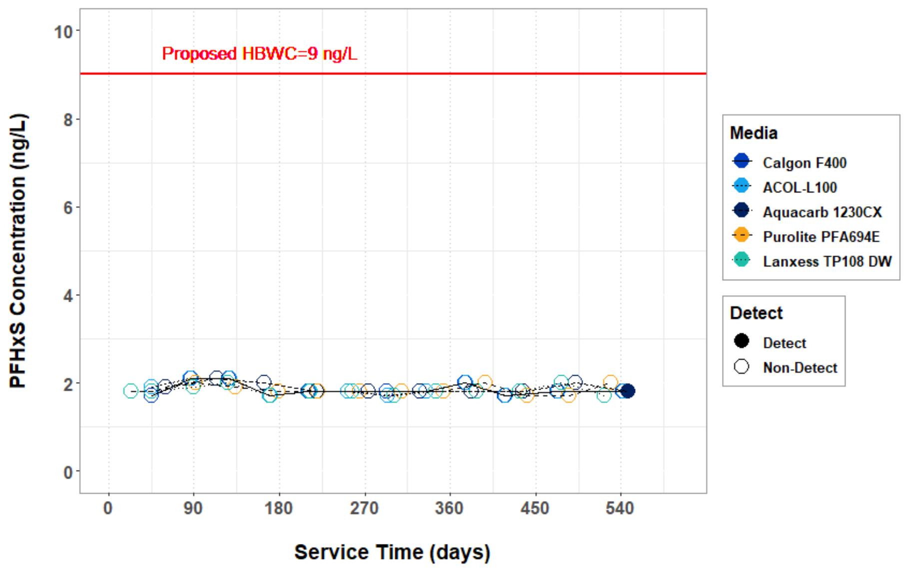


Figure 5 PFHxS Breakthrough

PFBS was only removed by IX resin and not by GAC, as shown in Figure 6. It is important to note that IX resin was shown to be effective in removing only short-chain PFSAs and not short-chain PFCAs (e.g., PFBA), as PFBA breakthrough was instantaneous from all media products tested (Figure 6).

Overall, all four compounds were below the final MCL and/or HBWCs in the RSSCT feed water with a 50:50 blending ratio between EGL and Standley Lake sources. None of these compounds will drive media changeout for either GAC or IX resin.

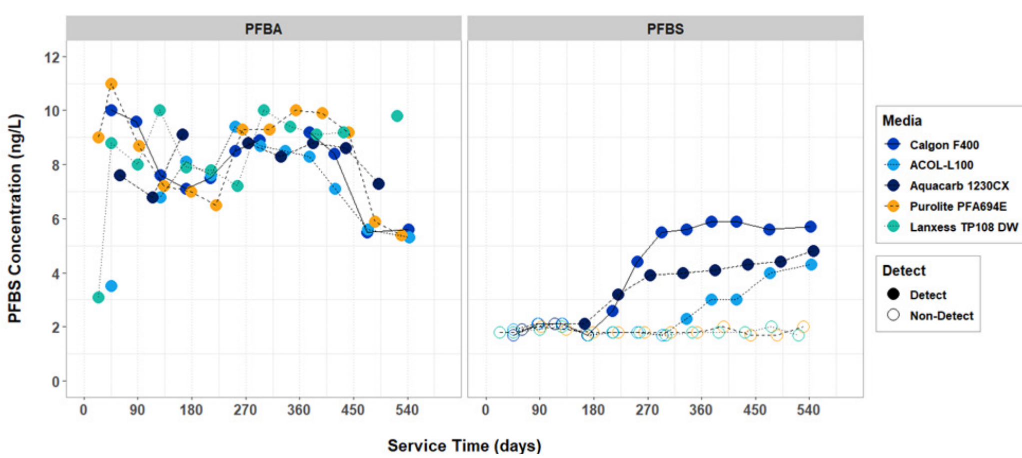


Figure 6 PFBA and PFBS Breakthrough

7.3 Other Non-Regulated PFCAs

Breakthrough and normalized breakthrough (i.e., C/C_0) curves of all detected PFCAs (with four to either perfluoroalkyl carbons) from each column are presented in Figures 7 and 8.

Generally, PFCA breakthrough follows the order of PFBA (C4) > PFPeA (C5) > PFHxA (C6) > PFHpA (C7) > PFOA (C8). This order is in alignment with the prevailing understanding of the impact of perfluoroalkyl chain length on adsorption performance, with efficacy decreasing with decreasing chain length.

PFPeA (C5) exhibited chromatographic peaking above the influent concentration across all media tested. The spikes in PFPeA concentrations were due to replacement adsorption of longer-chain, more adsorbable PFCAs (i.e., PFPeA was gradually replaced by PFHxA, PFHxA replaced by PFHpA, PFHpA by PFOA, and so on). Perhaps most importantly, the PFPeA normalized breakthrough curves (i.e., C/C_0) converged at 100 percent, indicating that the chromatographic peaking PFPeA was not due to analytical artifacts but a result of stronger adsorption of longer-chain PFCAs in the mixture.

7.4 DOC and UVA254 Breakthrough

Parallel to PFAS, DOC and UVA254 breakthroughs were monitored in all column effluents, as presented in Figure 9. The order of breakthrough was DOC > UVA254 > PFOA. Because PFOA broke through much later than both DOC and UVA254, neither parameter can serve as a good indicator to inform GAC or IX changeout for PFOA. It is noteworthy that neither hybrid nor CD RSSCT design was established for GAC and IX resin adsorption of DOC. For both approaches, the resulting DOC and UVA254 breakthrough curves may not necessarily reflect full-scale GAC and IX resin adsorption capacity for DOC.

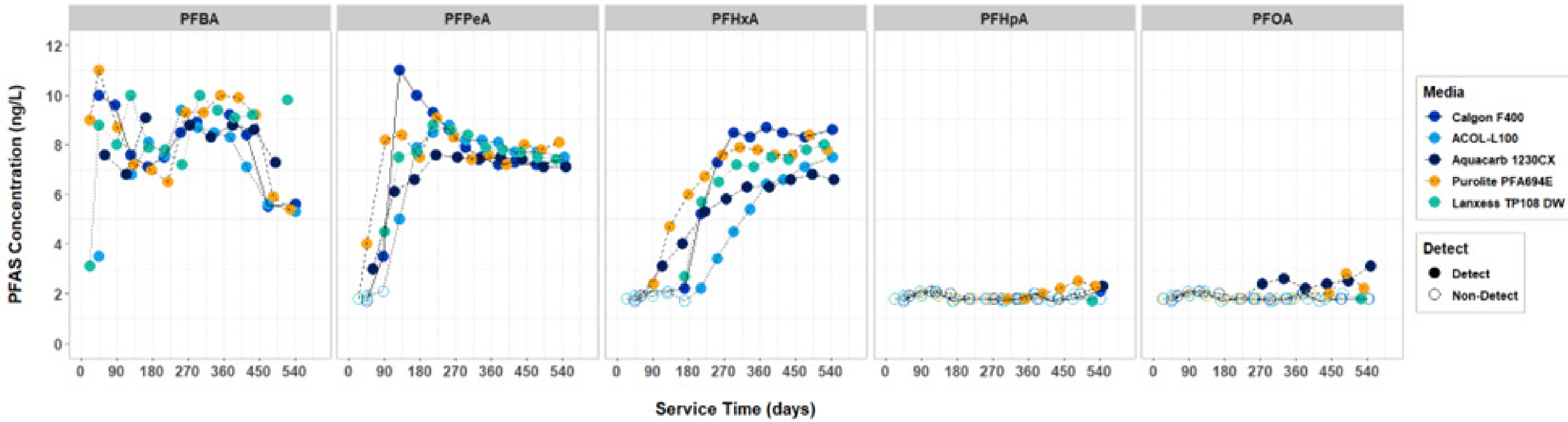


Figure 7 PFCA (C4-C8) Breakthrough

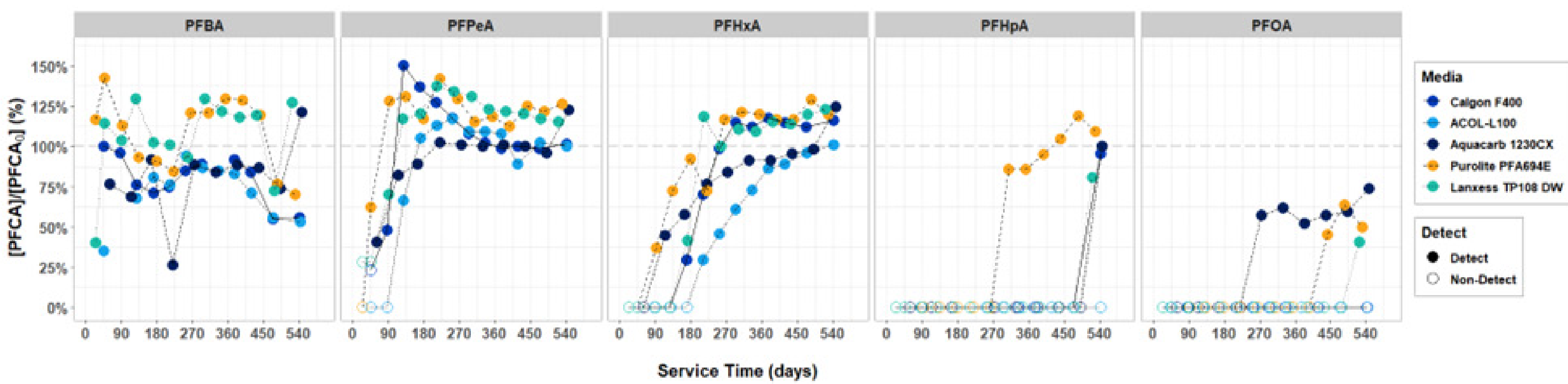


Figure 8 Normalized (C/C0) PFCA (C4-C8) Breakthrough

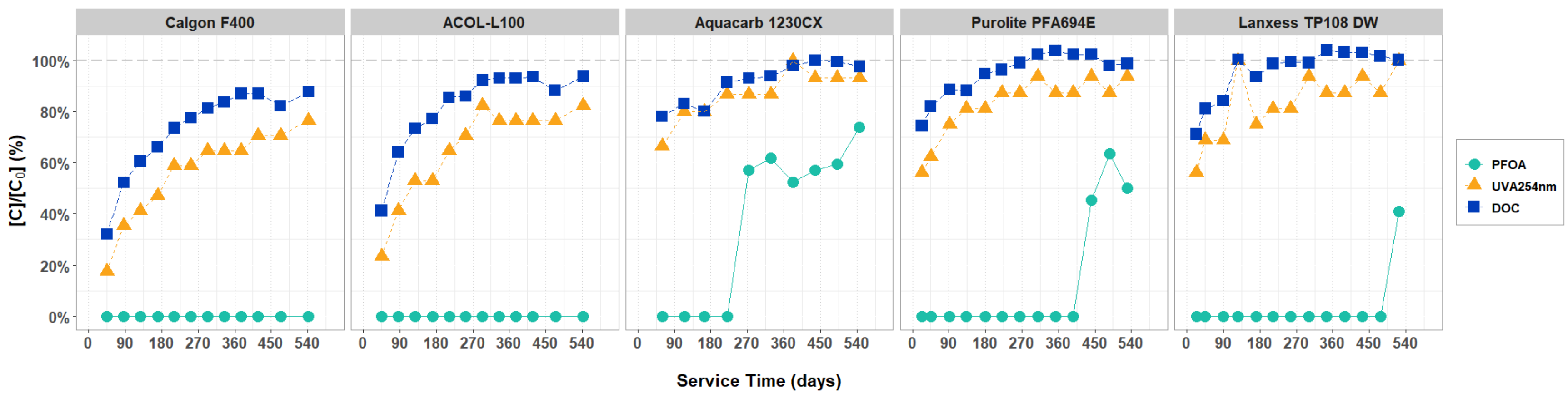


Figure 9 Normalized (C/C0) PFOA, UV254, and DOC Breakthrough

7.5 Chloride and Sulfate

One additional consideration of PFAS treatment by an IX adsorption process is the potential increase in treated water chloride to sulfate mass ratio (CSMR). Over the course of the IX-RSSCT experiment, no significant change was observed in chloride and sulfate concentrations from the two IX columns, as shown in Figure 10. However, each resin product was extensively rinsed with ultrapure PFAS-free water during resin preparation, before and after grinding. Additionally, each IX-RSSCT column was rinsed with 63,000 bed volumes of ultrapure PFAS-free water (equivalent to a system throughput of 130 days) to establish a uniform resin bed before RSSCT operation commenced. The extensive resin rinsing during RSSCT preparation and startup addressed initial chloride release and sulfate removal and therefore stabilized the chloride and sulfate output from the RSSCT columns.

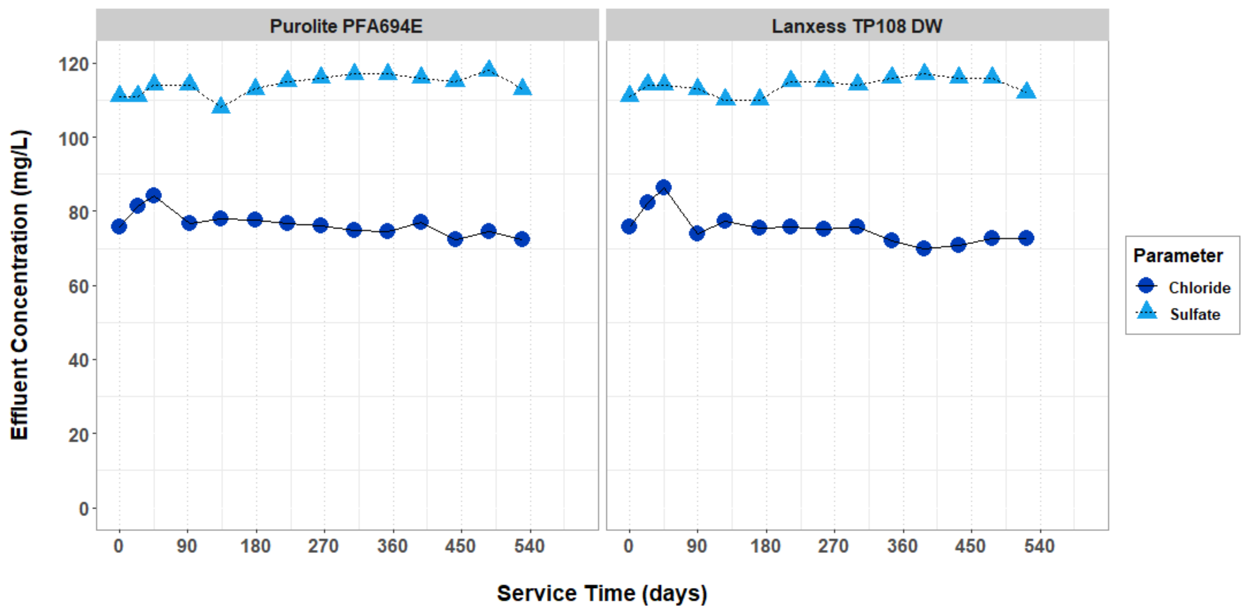
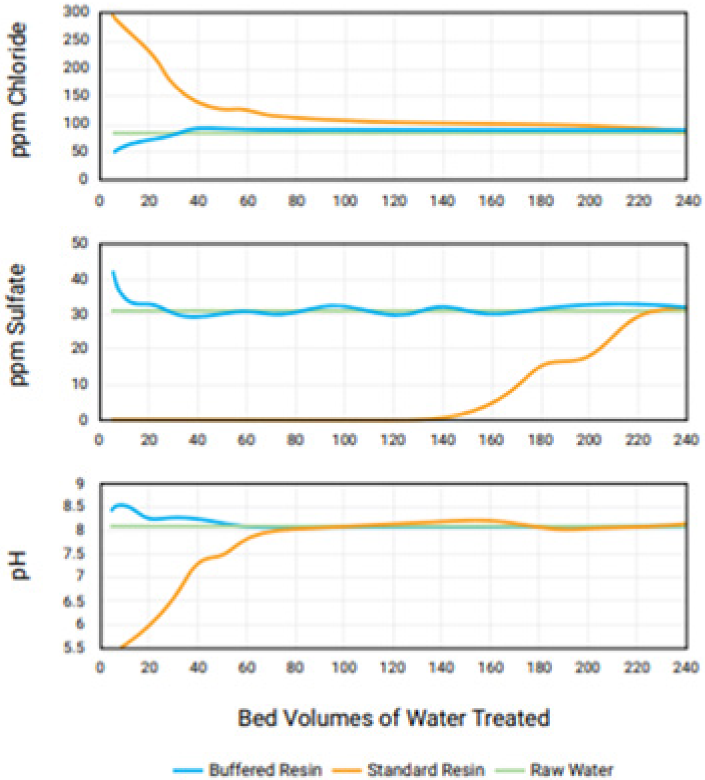


Figure 10 Chloride and Sulfate Breakthrough

The initial increase in CSMR during IX startup could be potentially addressed by using a buffered resin, such as Purolite PFA694EBF. Compared to non-buffered resin, PFA694EBF comes into equilibrium with background chloride and sulfate concentrations much more quickly as shown in Figure 11, and therefore alleviates the potential shift in treated water CSMR. It is important to note that the startup time required for the IX resin to reach equilibrium with background chloride and sulfate concentrations is site-specific. Typically, an increase in CSMR is only anticipated during IX startup and could be addressed by wasting initial start-up effluent before the vessel of IX resin is placed into service.



Source: Purolite

Figure 11 Chloride, Sulfate, and pH Elution Profile Example

8.0 CONCLUSIONS

Conclusions from the RSSCTs performed include the following:

- PFOA will drive GAC and IX resin use rate.
- PFOA breakthrough curves were flat in nature, indicating that breakthrough is a gradual process. This allows for single pass alternatives utilizing blending to meet the City's PFAS treatment goals.
- In general, GAC and IX performed similarly in terms of system throughput (i.e., media changeout frequency). 12x40 GAC outperformed 12x30 GAC in removing PFOA. Additionally, Lanxess TP108 DW resin outperformed Purolite PFA694E resin in removing all detected PFAS compounds.
- PFOS remained non-detectable in all column effluents throughout the entire RSSCT duration.
- Of the four PFAS HI compounds, PFNA and GenX were not detected in the RSSCT feed water. None of the HI compounds will drive media changeout for either GAC or IX resin.
- PFCA breakthrough follows the order of PFBA (C4) > PFPeA (C5) > PFHxA (C6) > PFHpA (C7) > PFOA (C8). Shorter-chain PFCAs break through earlier than longer-chain PFCAs.
- Chromatographic peaking of short-chain PFPeA was observed. The spike in PFPeA concentrations was due to replacement adsorption of longer-chain, more adsorbable PFAS compounds.
- Neither DOC nor UV254 can serve as a good indicator for PFOA breakthrough to inform timing for media changeout.

APPENDIX B

NPV ANALYSIS

Thornton WTP - GAC Contactors
(Lead/Lag)

Item Description	Costs	Escalation / Interest (%)	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Capital Costs	**$125,500,000**	-										
Initial Construction - Bond Repayment	**$184,600,000**	4.0%	$9,230,000	$9,230,000	$9,230,000	$9,230,000	$9,230,000	$9,230,000	$9,230,000	$9,230,000	$9,230,000	$9,230,000
TWTP O&M Costs												
Electrical Usage ($/yr)												
Intermediate Pumping	$60,000		$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000
Electrical Cost ($/year)			**$60,000**	**$60,000**	**$60,000**	**$60,000**	**$60,000**	**$60,000**	**$60,000**	**$60,000**	**$60,000**	**$60,000**
Operations and Maintenance ($/yr)												
GAC Replacement and Disposal	$800,000		$800,000	$800,000	$800,000	$800,000	$800,000	$800,000	$800,000	$800,000	$800,000	$800,000
Sampling, Labor, and Preventative Maintenance	$40,000		$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000
Maintenance Operations Cost ($/year)			**$840,000**	**$840,000**	**$840,000**	**$840,000**	**$840,000**	**$840,000**	**$840,000**	**$840,000**	**$840,000**	**$840,000**
Cost Summary												
Capital Cost Bond Repayment for Year	-	-	$9,230,000	$9,230,000	$9,230,000	$9,230,000	$9,230,000	$9,230,000	$9,230,000	$9,230,000	$9,230,000	$9,230,000
O&M Cost for Year	-	-	$900,000	$900,000	$900,000	$900,000	$900,000	$900,000	$900,000	$900,000	$900,000	$900,000
Total for Year	-	-	$10,130,000	$10,130,000	$10,130,000	$10,130,000	$10,130,000	$10,130,000	$10,130,000	$10,130,000	$10,130,000	$10,130,000
Net Present Value												
Discount Rate =	**4.0%**											
Escalation Rate =	**5.0%**											
Net Present Value Capital Cost =	**$125,450,000**		**$8,880,000**	**$8,530,000**	**$8,210,000**	**$7,890,000**	**$7,590,000**	**$7,290,000**	**$7,010,000**	**$6,740,000**	**$6,480,000**	**$6,240,000**
Net Present Value for O&M =	**$19,940,000**		**$910,000**	**$920,000**	**$930,000**	**$940,000**	**$940,000**	**$950,000**	**$960,000**	**$970,000**	**$980,000**	**$990,000**
Total Net Present Value for Alternative =	**$145,390,000**		**$9,790,000**	**$9,450,000**	**$9,140,000**	**$8,830,000**	**$8,530,000**	**$8,240,000**	**$7,970,000**	**$7,710,000**	**$7,460,000**	**$7,230,000**

Thornton WTP - GAC Contactors
(Lead/Lag)

Item Description	Costs	Escalation / Interest (%)	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16	Year 17	Year 18	Year 19	Year 20
Capital Costs	**$125,500,000**	-										
Initial Construction - Bond Repayment	**$184,600,000**	4.0%	$9,230,000	$9,230,000	$9,230,000	$9,230,000	$9,230,000	$9,230,000	$9,230,000	$9,230,000	$9,230,000	$9,230,000
TWTP O&M Costs												
Electrical Usage ($/yr)												
Intermediate Pumping	$60,000		$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000
Electrical Cost ($/year)			**$60,000**	**$60,000**	**$60,000**	**$60,000**	**$60,000**	**$60,000**	**$60,000**	**$60,000**	**$60,000**	**$60,000**
Operations and Maintenance ($/yr)												
GAC Replacement and Disposal	$800,000		$800,000	$800,000	$800,000	$800,000	$800,000	$800,000	$800,000	$800,000	$800,000	$800,000
Sampling, Labor, and Preventative Maintenance	$40,000		$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000
Maintenance Operations Cost ($/year)			**$840,000**	**$840,000**	**$840,000**	**$840,000**	**$840,000**	**$840,000**	**$840,000**	**$840,000**	**$840,000**	**$840,000**
Cost Summary												
Capital Cost Bond Repayment for Year	-	-	$9,230,000	$9,230,000	$9,230,000	$9,230,000	$9,230,000	$9,230,000	$9,230,000	$9,230,000	$9,230,000	$9,230,000
O&M Cost for Year	-	-	$900,000	$900,000	$900,000	$900,000	$900,000	$900,000	$900,000	$900,000	$900,000	$900,000
Total for Year	-	-	$10,130,000	$10,130,000	$10,130,000	$10,130,000	$10,130,000	$10,130,000	$10,130,000	$10,130,000	$10,130,000	$10,130,000
Net Present Value												
Discount Rate =	**4.0%**											
Escalation Rate =	**5.0%**											
Net Present Value Capital Cost =	**$125,450,000**		**$6,000,000**	**$5,770,000**	**$5,540,000**	**$5,330,000**	**$5,130,000**	**$4,930,000**	**$4,740,000**	**$4,560,000**	**$4,380,000**	**$4,210,000**
Net Present Value for O&M =	**$19,940,000**		**$1,000,000**	**$1,010,000**	**$1,020,000**	**$1,030,000**	**$1,040,000**	**$1,050,000**	**$1,060,000**	**$1,070,000**	**$1,080,000**	**$1,090,000**
Total Net Present Value for Alternative =	**$145,390,000**		**$7,000,000**	**$6,780,000**	**$6,560,000**	**$6,360,000**	**$6,170,000**	**$5,980,000**	**$5,800,000**	**$5,630,000**	**$5,460,000**	**$5,300,000**

Thornton WTP - GAC Contactors
(Single Pass)

Item Description	Costs	Escalation / Interest (%)	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Capital Costs	**$88,600,000**	-										
Initial Construction - Bond Repayment	**$130,400,000**	4.0%	$6,520,000	$6,520,000	$6,520,000	$6,520,000	$6,520,000	$6,520,000	$6,520,000	$6,520,000	$6,520,000	$6,520,000
TWTP O&M Costs												
Electrical Usage ($/yr)												
Intermediate Pumping	$40,000		$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000
Electrical Cost ($/year)			**$40,000**	**$40,000**	**$40,000**	**$40,000**	**$40,000**	**$40,000**	**$40,000**	**$40,000**	**$40,000**	**$40,000**
Operations and Maintenance ($/yr)												
GAC Replacement and Disposal	$800,000		$800,000	$800,000	$800,000	$800,000	$800,000	$800,000	$800,000	$800,000	$800,000	$800,000
Sampling, Labor, and Preventative Maintenance	$20,000		$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000
Maintenance Operations Cost ($/year)			**$820,000**	**$820,000**	**$820,000**	**$820,000**	**$820,000**	**$820,000**	**$820,000**	**$820,000**	**$820,000**	**$820,000**
Cost Summary												
Capital Cost Bond Repayment for Year	-	-	$6,520,000	$6,520,000	$6,520,000	$6,520,000	$6,520,000	$6,520,000	$6,520,000	$6,520,000	$6,520,000	$6,520,000
O&M Cost for Year	-	-	$860,000	$860,000	$860,000	$860,000	$860,000	$860,000	$860,000	$860,000	$860,000	$860,000
Total for Year	-	-	$7,380,000	$7,380,000	$7,380,000	$7,380,000	$7,380,000	$7,380,000	$7,380,000	$7,380,000	$7,380,000	$7,380,000
Net Present Value												
Discount Rate =	**4.0%**											
Escalation Rate =	**5.0%**											
Net Present Value Capital Cost =	**$88,610,000**		**$6,270,000**	**$6,030,000**	**$5,800,000**	**$5,570,000**	**$5,360,000**	**$5,150,000**	**$4,950,000**	**$4,760,000**	**$4,580,000**	**$4,400,000**
Net Present Value for O&M =	**$19,040,000**		**$870,000**	**$880,000**	**$890,000**	**$890,000**	**$900,000**	**$910,000**	**$920,000**	**$930,000**	**$940,000**	**$950,000**
Total Net Present Value for Alternative =	**$107,650,000**		**$7,140,000**	**$6,910,000**	**$6,690,000**	**$6,460,000**	**$6,260,000**	**$6,060,000**	**$5,870,000**	**$5,690,000**	**$5,520,000**	**$5,350,000**

Thornton WTP - GAC Contactors
(Single Pass)

Item Description	Costs	Escalation / Interest (%)	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16	Year 17	Year 18	Year 19	Year 20
Capital Costs	**$88,600,000**	-										
Initial Construction - Bond Repayment	**$130,400,000**	4.0%	$6,520,000	$6,520,000	$6,520,000	$6,520,000	$6,520,000	$6,520,000	$6,520,000	$6,520,000	$6,520,000	$6,520,000
TWTP O&M Costs												
Electrical Usage ($/yr)												
Intermediate Pumping	$40,000		$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000
Electrical Cost ($/year)			**$40,000**	**$40,000**	**$40,000**	**$40,000**	**$40,000**	**$40,000**	**$40,000**	**$40,000**	**$40,000**	**$40,000**
Operations and Maintenance ($/yr)												
GAC Replacement and Disposal	$800,000		$800,000	$800,000	$800,000	$800,000	$800,000	$800,000	$800,000	$800,000	$800,000	$800,000
Sampling, Labor, and Preventative Maintenance	$20,000		$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000
Maintenance Operations Cost ($/year)			**$820,000**	**$820,000**	**$820,000**	**$820,000**	**$820,000**	**$820,000**	**$820,000**	**$820,000**	**$820,000**	**$820,000**
Cost Summary												
Capital Cost Bond Repayment for Year	-	-	$6,520,000	$6,520,000	$6,520,000	$6,520,000	$6,520,000	$6,520,000	$6,520,000	$6,520,000	$6,520,000	$6,520,000
O&M Cost for Year	-	-	$860,000	$860,000	$860,000	$860,000	$860,000	$860,000	$860,000	$860,000	$860,000	$860,000
Total for Year	-	-	$7,380,000	$7,380,000	$7,380,000	$7,380,000	$7,380,000	$7,380,000	$7,380,000	$7,380,000	$7,380,000	$7,380,000
Net Present Value												
Discount Rate =	**4.0%**											
Escalation Rate =	**5.0%**											
Net Present Value Capital Cost =	**$88,610,000**		**$4,240,000**	**$4,070,000**	**$3,920,000**	**$3,770,000**	**$3,620,000**	**$3,480,000**	**$3,350,000**	**$3,220,000**	**$3,090,000**	**$2,980,000**
Net Present Value for O&M =	**$19,040,000**		**$960,000**	**$960,000**	**$970,000**	**$980,000**	**$990,000**	**$1,000,000**	**$1,010,000**	**$1,020,000**	**$1,030,000**	**$1,040,000**
Total Net Present Value for Alternative =	**$107,650,000**		**$5,200,000**	**$5,030,000**	**$4,890,000**	**$4,750,000**	**$4,610,000**	**$4,480,000**	**$4,360,000**	**$4,240,000**	**$4,120,000**	**$4,020,000**

Thornton WTP - GAC Pressure Vessels
(Lead/Lag)

Item Description	Costs	Escalation / Interest (%)	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Capital Costs	**$143,900,000**	-										
Initial Construction - Bond Repayment	**$211,800,000**	4.0%	$10,590,000	$10,590,000	$10,590,000	$10,590,000	$10,590,000	$10,590,000	$10,590,000	$10,590,000	$10,590,000	$10,590,000
TWTP O&M Costs												
Electrical Usage ($/yr)												
Intermediate Pumping	$140,000		$140,000	$140,000	$140,000	$140,000	$140,000	$140,000	$140,000	$140,000	$140,000	$140,000
Electrical Cost ($/year)			**$140,000**	**$140,000**	**$140,000**	**$140,000**	**$140,000**	**$140,000**	**$140,000**	**$140,000**	**$140,000**	**$140,000**
Operations and Maintenance ($/yr)												
GAC Replacement and Disposal	$800,000		$800,000	$800,000	$800,000	$800,000	$800,000	$800,000	$800,000	$800,000	$800,000	$800,000
Sampling, Labor, and Preventative Maintenance	$80,000		$80,000	$80,000	$80,000	$80,000	$80,000	$80,000	$80,000	$80,000	$80,000	$80,000
Maintenance Operations Cost ($/year)			**$880,000**	**$880,000**	**$880,000**	**$880,000**	**$880,000**	**$880,000**	**$880,000**	**$880,000**	**$880,000**	**$880,000**
Cost Summary												
Capital Cost Bond Repayment for Year	-	-	$10,590,000	$10,590,000	$10,590,000	$10,590,000	$10,590,000	$10,590,000	$10,590,000	$10,590,000	$10,590,000	$10,590,000
O&M Cost for Year	-	-	$1,020,000	$1,020,000	$1,020,000	$1,020,000	$1,020,000	$1,020,000	$1,020,000	$1,020,000	$1,020,000	$1,020,000
Total for Year	-	-	$11,610,000	$11,610,000	$11,610,000	$11,610,000	$11,610,000	$11,610,000	$11,610,000	$11,610,000	$11,610,000	$11,610,000
Net Present Value												
Discount Rate =	**4.0%**											
Escalation Rate =	**5.0%**											
Net Present Value Capital Cost =	**$143,910,000**		**$10,180,000**	**$9,790,000**	**$9,410,000**	**$9,050,000**	**$8,700,000**	**$8,370,000**	**$8,050,000**	**$7,740,000**	**$7,440,000**	**$7,150,000**
Net Present Value for O&M =	**$22,590,000**		**$1,030,000**	**$1,040,000**	**$1,050,000**	**$1,060,000**	**$1,070,000**	**$1,080,000**	**$1,090,000**	**$1,100,000**	**$1,110,000**	**$1,120,000**
Total Net Present Value for Alternative =	**$166,500,000**		**$11,210,000**	**$10,830,000**	**$10,460,000**	**$10,110,000**	**$9,770,000**	**$9,450,000**	**$9,140,000**	**$8,840,000**	**$8,550,000**	**$8,270,000**

Thornton WTP - GAC Pressure Vessels
(Lead/Lag)

Item Description	Costs	Escalation / Interest (%)	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16	Year 17	Year 18	Year 19	Year 20
Capital Costs	**$143,900,000**	-										
Initial Construction - Bond Repayment	**$211,800,000**	4.0%	$10,590,000	$10,590,000	$10,590,000	$10,590,000	$10,590,000	$10,590,000	$10,590,000	$10,590,000	$10,590,000	$10,590,000
TWTP O&M Costs												
Electrical Usage ($/yr)												
Intermediate Pumping	$140,000		$140,000	$140,000	$140,000	$140,000	$140,000	$140,000	$140,000	$140,000	$140,000	$140,000
Electrical Cost ($/year)			**$140,000**	**$140,000**	**$140,000**	**$140,000**	**$140,000**	**$140,000**	**$140,000**	**$140,000**	**$140,000**	**$140,000**
Operations and Maintenance ($/yr)												
GAC Replacement and Disposal	$800,000		$800,000	$800,000	$800,000	$800,000	$800,000	$800,000	$800,000	$800,000	$800,000	$800,000
Sampling, Labor, and Preventative Maintenance	$80,000		$80,000	$80,000	$80,000	$80,000	$80,000	$80,000	$80,000	$80,000	$80,000	$80,000
Maintenance Operations Cost ($/year)			**$880,000**	**$880,000**	**$880,000**	**$880,000**	**$880,000**	**$880,000**	**$880,000**	**$880,000**	**$880,000**	**$880,000**
Cost Summary												
Capital Cost Bond Repayment for Year	-	-	$10,590,000	$10,590,000	$10,590,000	$10,590,000	$10,590,000	$10,590,000	$10,590,000	$10,590,000	$10,590,000	$10,590,000
O&M Cost for Year	-	-	$1,020,000	$1,020,000	$1,020,000	$1,020,000	$1,020,000	$1,020,000	$1,020,000	$1,020,000	$1,020,000	$1,020,000
Total for Year	-	-	$11,610,000	$11,610,000	$11,610,000	$11,610,000	$11,610,000	$11,610,000	$11,610,000	$11,610,000	$11,610,000	$11,610,000
Net Present Value												
Discount Rate =	**4.0%**											
Escalation Rate =	**5.0%**											
Net Present Value Capital Cost =	**$143,910,000**		**$6,880,000**	**$6,610,000**	**$6,360,000**	**$6,120,000**	**$5,880,000**	**$5,650,000**	**$5,440,000**	**$5,230,000**	**$5,030,000**	**$4,830,000**
Net Present Value for O&M =	**$22,590,000**		**$1,130,000**	**$1,140,000**	**$1,160,000**	**$1,170,000**	**$1,180,000**	**$1,190,000**	**$1,200,000**	**$1,210,000**	**$1,220,000**	**$1,240,000**
Total Net Present Value for Alternative =	**$166,500,000**		**$8,010,000**	**$7,750,000**	**$7,520,000**	**$7,290,000**	**$7,060,000**	**$6,840,000**	**$6,640,000**	**$6,440,000**	**$6,250,000**	**$6,070,000**

Thornton WTP - GAC Pressure Vessels
(Single Pass)

Item Description	Costs	Escalation / Interest (%)	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Capital Costs	**$102,500,000**	-										
Initial Construction - Bond Repayment	**$150,800,000**	4.0%	$7,540,000	$7,540,000	$7,540,000	$7,540,000	$7,540,000	$7,540,000	$7,540,000	$7,540,000	$7,540,000	$7,540,000
TWTP O&M Costs												
Electrical Usage ($/yr)												
Intermediate Pumping	$90,000		$90,000	$90,000	$90,000	$90,000	$90,000	$90,000	$90,000	$90,000	$90,000	$90,000
Electrical Cost ($/year)			**$90,000**	**$90,000**	**$90,000**	**$90,000**	**$90,000**	**$90,000**	**$90,000**	**$90,000**	**$90,000**	**$90,000**
Operations and Maintenance ($/yr)												
GAC Replacement and Disposal	$800,000		$800,000	$800,000	$800,000	$800,000	$800,000	$800,000	$800,000	$800,000	$800,000	$800,000
Sampling, Labor, and Preventative Maintenance	$40,000		$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000
Maintenance Operations Cost ($/year)			**$840,000**	**$840,000**	**$840,000**	**$840,000**	**$840,000**	**$840,000**	**$840,000**	**$840,000**	**$840,000**	**$840,000**
Cost Summary												
Capital Cost Bond Repayment for Year	-	-	$7,540,000	$7,540,000	$7,540,000	$7,540,000	$7,540,000	$7,540,000	$7,540,000	$7,540,000	$7,540,000	$7,540,000
O&M Cost for Year	-	-	$930,000	$930,000	$930,000	$930,000	$930,000	$930,000	$930,000	$930,000	$930,000	$930,000
Total for Year	-	-	$8,470,000	$8,470,000	$8,470,000	$8,470,000	$8,470,000	$8,470,000	$8,470,000	$8,470,000	$8,470,000	$8,470,000
Net Present Value												
Discount Rate =	**4.0%**											
Escalation Rate =	**5.0%**											
Net Present Value Capital Cost =	**$102,480,000**		**$7,250,000**	**$6,970,000**	**$6,700,000**	**$6,450,000**	**$6,200,000**	**$5,960,000**	**$5,730,000**	**$5,510,000**	**$5,300,000**	**$5,090,000**
Net Present Value for O&M =	**$20,570,000**		**$940,000**	**$950,000**	**$960,000**	**$970,000**	**$980,000**	**$980,000**	**$990,000**	**$1,000,000**	**$1,010,000**	**$1,020,000**
Total Net Present Value for Alternative =	**$123,050,000**		**$8,190,000**	**$7,920,000**	**$7,660,000**	**$7,420,000**	**$7,180,000**	**$6,940,000**	**$6,720,000**	**$6,510,000**	**$6,310,000**	**$6,110,000**

Thornton WTP - GAC Pressure Vessels
(Single Pass)

Item Description	Costs	Escalation / Interest (%)	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16	Year 17	Year 18	Year 19	Year 20
Capital Costs	**$102,500,000**	-										
Initial Construction - Bond Repayment	**$150,800,000**	4.0%	$7,540,000	$7,540,000	$7,540,000	$7,540,000	$7,540,000	$7,540,000	$7,540,000	$7,540,000	$7,540,000	$7,540,000
TWTP O&M Costs												
Electrical Usage ($/yr)												
Intermediate Pumping	$90,000		$90,000	$90,000	$90,000	$90,000	$90,000	$90,000	$90,000	$90,000	$90,000	$90,000
Electrical Cost ($/year)			**$90,000**	**$90,000**	**$90,000**	**$90,000**	**$90,000**	**$90,000**	**$90,000**	**$90,000**	**$90,000**	**$90,000**
Operations and Maintenance ($/yr)												
GAC Replacement and Disposal	$800,000		$800,000	$800,000	$800,000	$800,000	$800,000	$800,000	$800,000	$800,000	$800,000	$800,000
Sampling, Labor, and Preventative Maintenance	$40,000		$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000
Maintenance Operations Cost ($/year)			**$840,000**	**$840,000**	**$840,000**	**$840,000**	**$840,000**	**$840,000**	**$840,000**	**$840,000**	**$840,000**	**$840,000**
Cost Summary												
Capital Cost Bond Repayment for Year	-	-	$7,540,000	$7,540,000	$7,540,000	$7,540,000	$7,540,000	$7,540,000	$7,540,000	$7,540,000	$7,540,000	$7,540,000
O&M Cost for Year	-	-	$930,000	$930,000	$930,000	$930,000	$930,000	$930,000	$930,000	$930,000	$930,000	$930,000
Total for Year	-	-	$8,470,000	$8,470,000	$8,470,000	$8,470,000	$8,470,000	$8,470,000	$8,470,000	$8,470,000	$8,470,000	$8,470,000
Net Present Value												
Discount Rate =	**4.0%**											
Escalation Rate =	**5.0%**											
Net Present Value Capital Cost =	**$102,480,000**		**$4,900,000**	**$4,710,000**	**$4,530,000**	**$4,350,000**	**$4,190,000**	**$4,030,000**	**$3,870,000**	**$3,720,000**	**$3,580,000**	**$3,440,000**
Net Present Value for O&M =	**$20,570,000**		**$1,030,000**	**$1,040,000**	**$1,050,000**	**$1,060,000**	**$1,070,000**	**$1,080,000**	**$1,090,000**	**$1,100,000**	**$1,120,000**	**$1,130,000**
Total Net Present Value for Alternative =	**$123,050,000**		**$5,930,000**	**$5,750,000**	**$5,580,000**	**$5,410,000**	**$5,260,000**	**$5,110,000**	**$4,960,000**	**$4,820,000**	**$4,700,000**	**$4,570,000**

Thornton WTP - IX Vessels
(Lead/Lag)

Item Description	Costs	Escalation / Interest (%)	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Capital Costs	**$100,300,000**	-										
Initial Construction - Bond Repayment	**$147,600,000**	4.0%	$7,380,000	$7,380,000	$7,380,000	$7,380,000	$7,380,000	$7,380,000	$7,380,000	$7,380,000	$7,380,000	$7,380,000
TWTP O&M Costs												
Electrical Usage ($/yr)												
Intermediate Pumping	$230,000		$230,000	$230,000	$230,000	$230,000	$230,000	$230,000	$230,000	$230,000	$230,000	$230,000
Electrical Cost ($/year)			**$230,000**	**$230,000**	**$230,000**	**$230,000**	**$230,000**	**$230,000**	**$230,000**	**$230,000**	**$230,000**	**$230,000**
Operations and Maintenance ($/yr)												
IX Resin Replacement and Disposal	$1,100,000		$1,100,000	$1,100,000	$1,100,000	$1,100,000	$1,100,000	$1,100,000	$1,100,000	$1,100,000	$1,100,000	$1,100,000
Sampling, Labor, and Preventative Maintenance	$40,000		$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000
Maintenance Operations Cost ($/year)			**$1,140,000**	**$1,140,000**	**$1,140,000**	**$1,140,000**	**$1,140,000**	**$1,140,000**	**$1,140,000**	**$1,140,000**	**$1,140,000**	**$1,140,000**
Cost Summary												
Capital Cost Bond Repayment for Year	-	-	$7,380,000	$7,380,000	$7,380,000	$7,380,000	$7,380,000	$7,380,000	$7,380,000	$7,380,000	$7,380,000	$7,380,000
O&M Cost for Year	-	-	$1,370,000	$1,370,000	$1,370,000	$1,370,000	$1,370,000	$1,370,000	$1,370,000	$1,370,000	$1,370,000	$1,370,000
Total for Year	-	-	$8,750,000	$8,750,000	$8,750,000	$8,750,000	$8,750,000	$8,750,000	$8,750,000	$8,750,000	$8,750,000	$8,750,000
Net Present Value												
Discount Rate =	**4.0%**											
Escalation Rate =	**5.0%**											
Net Present Value Capital Cost =	**$100,300,000**		**$7,100,000**	**$6,820,000**	**$6,560,000**	**$6,310,000**	**$6,070,000**	**$5,830,000**	**$5,610,000**	**$5,390,000**	**$5,190,000**	**$4,990,000**
Net Present Value for O&M =	**$30,340,000**		**$1,380,000**	**$1,400,000**	**$1,410,000**	**$1,420,000**	**$1,440,000**	**$1,450,000**	**$1,460,000**	**$1,480,000**	**$1,490,000**	**$1,510,000**
Total Net Present Value for Alternative =	**$130,640,000**		**$8,480,000**	**$8,220,000**	**$7,970,000**	**$7,730,000**	**$7,510,000**	**$7,280,000**	**$7,070,000**	**$6,870,000**	**$6,680,000**	**$6,500,000**

Thornton WTP - IX Vessels
(Lead/Lag)

Item Description	Costs	Escalation / Interest (%)	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16	Year 17	Year 18	Year 19	Year 20
Capital Costs	**$100,300,000**	-										
Initial Construction - Bond Repayment	**$147,600,000**	4.0%	$7,380,000	$7,380,000	$7,380,000	$7,380,000	$7,380,000	$7,380,000	$7,380,000	$7,380,000	$7,380,000	$7,380,000
TWTP O&M Costs												
Electrical Usage ($/yr)												
Intermediate Pumping	$230,000		$230,000	$230,000	$230,000	$230,000	$230,000	$230,000	$230,000	$230,000	$230,000	$230,000
Electrical Cost ($/year)			**$230,000**	**$230,000**	**$230,000**	**$230,000**	**$230,000**	**$230,000**	**$230,000**	**$230,000**	**$230,000**	**$230,000**
Operations and Maintenance ($/yr)												
IX Resin Replacement and Disposal	$1,100,000		$1,100,000	$1,100,000	$1,100,000	$1,100,000	$1,100,000	$1,100,000	$1,100,000	$1,100,000	$1,100,000	$1,100,000
Sampling, Labor, and Preventative Maintenance	$40,000		$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000
Maintenance Operations Cost ($/year)			**$1,140,000**	**$1,140,000**	**$1,140,000**	**$1,140,000**	**$1,140,000**	**$1,140,000**	**$1,140,000**	**$1,140,000**	**$1,140,000**	**$1,140,000**
Cost Summary												
Capital Cost Bond Repayment for Year	-	-	$7,380,000	$7,380,000	$7,380,000	$7,380,000	$7,380,000	$7,380,000	$7,380,000	$7,380,000	$7,380,000	$7,380,000
O&M Cost for Year	-	-	$1,370,000	$1,370,000	$1,370,000	$1,370,000	$1,370,000	$1,370,000	$1,370,000	$1,370,000	$1,370,000	$1,370,000
Total for Year	-	-	$8,750,000	$8,750,000	$8,750,000	$8,750,000	$8,750,000	$8,750,000	$8,750,000	$8,750,000	$8,750,000	$8,750,000
Net Present Value												
Discount Rate =	**4.0%**											
Escalation Rate =	**5.0%**											
Net Present Value Capital Cost =	**$100,300,000**		**$4,790,000**	**$4,610,000**	**$4,430,000**	**$4,260,000**	**$4,100,000**	**$3,940,000**	**$3,790,000**	**$3,640,000**	**$3,500,000**	**$3,370,000**
Net Present Value for O&M =	**$30,340,000**		**$1,520,000**	**$1,540,000**	**$1,550,000**	**$1,570,000**	**$1,580,000**	**$1,600,000**	**$1,610,000**	**$1,630,000**	**$1,640,000**	**$1,660,000**
Total Net Present Value for Alternative =	**$130,640,000**		**$6,310,000**	**$6,150,000**	**$5,980,000**	**$5,830,000**	**$5,680,000**	**$5,540,000**	**$5,400,000**	**$5,270,000**	**$5,140,000**	**$5,030,000**

Thornton WTP - IX Vessels
(Single Pass)

Item Description	Costs	Escalation / Interest (%)	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Capital Costs	**$75,700,000**	-										
Initial Construction - Bond Repayment	**$111,400,000**	4.0%	$5,570,000	$5,570,000	$5,570,000	$5,570,000	$5,570,000	$5,570,000	$5,570,000	$5,570,000	$5,570,000	$5,570,000
TWTP O&M Costs												
Electrical Usage ($/yr)												
Intermediate Pumping	$140,000		$140,000	$140,000	$140,000	$140,000	$140,000	$140,000	$140,000	$140,000	$140,000	$140,000
Electrical Cost ($/year)			**$140,000**	**$140,000**	**$140,000**	**$140,000**	**$140,000**	**$140,000**	**$140,000**	**$140,000**	**$140,000**	**$140,000**
Operations and Maintenance ($/yr)												
IX Resin Replacement and Disposal	$1,100,000		$1,100,000	$1,100,000	$1,100,000	$1,100,000	$1,100,000	$1,100,000	$1,100,000	$1,100,000	$1,100,000	$1,100,000
Sampling, Labor, and Preventative Maintenance	$20,000		$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000
Maintenance Operations Cost ($/year)			**$1,120,000**	**$1,120,000**	**$1,120,000**	**$1,120,000**	**$1,120,000**	**$1,120,000**	**$1,120,000**	**$1,120,000**	**$1,120,000**	**$1,120,000**
Cost Summary												
Capital Cost Bond Repayment for Year	-	-	$5,570,000	$5,570,000	$5,570,000	$5,570,000	$5,570,000	$5,570,000	$5,570,000	$5,570,000	$5,570,000	$5,570,000
O&M Cost for Year	-	-	$1,260,000	$1,260,000	$1,260,000	$1,260,000	$1,260,000	$1,260,000	$1,260,000	$1,260,000	$1,260,000	$1,260,000
Total for Year	-	-	$6,830,000	$6,830,000	$6,830,000	$6,830,000	$6,830,000	$6,830,000	$6,830,000	$6,830,000	$6,830,000	$6,830,000
Net Present Value												
Discount Rate =	**4.0%**											
Escalation Rate =	**5.0%**											
Net Present Value Capital Cost =	**$75,690,000**		**$5,360,000**	**$5,150,000**	**$4,950,000**	**$4,760,000**	**$4,580,000**	**$4,400,000**	**$4,230,000**	**$4,070,000**	**$3,910,000**	**$3,760,000**
Net Present Value for O&M =	**$27,900,000**		**$1,270,000**	**$1,280,000**	**$1,300,000**	**$1,310,000**	**$1,320,000**	**$1,330,000**	**$1,350,000**	**$1,360,000**	**$1,370,000**	**$1,390,000**
Total Net Present Value for Alternative =	**$103,590,000**		**$6,630,000**	**$6,430,000**	**$6,250,000**	**$6,070,000**	**$5,900,000**	**$5,730,000**	**$5,580,000**	**$5,430,000**	**$5,280,000**	**$5,150,000**

Thornton WTP - IX Vessels
(Single Pass)

Item Description	Costs	Escalation / Interest (%)	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16	Year 17	Year 18	Year 19	Year 20
Capital Costs	**$75,700,000**	-										
Initial Construction - Bond Repayment	**$111,400,000**	4.0%	$5,570,000	$5,570,000	$5,570,000	$5,570,000	$5,570,000	$5,570,000	$5,570,000	$5,570,000	$5,570,000	$5,570,000
TWTP O&M Costs												
Electrical Usage ($/yr)												
Intermediate Pumping	$140,000		$140,000	$140,000	$140,000	$140,000	$140,000	$140,000	$140,000	$140,000	$140,000	$140,000
Electrical Cost ($/year)			**$140,000**	**$140,000**	**$140,000**	**$140,000**	**$140,000**	**$140,000**	**$140,000**	**$140,000**	**$140,000**	**$140,000**
Operations and Maintenance ($/yr)												
IX Resin Replacement and Disposal	$1,100,000		$1,100,000	$1,100,000	$1,100,000	$1,100,000	$1,100,000	$1,100,000	$1,100,000	$1,100,000	$1,100,000	$1,100,000
Sampling, Labor, and Preventative Maintenance	$20,000		$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000
Maintenance Operations Cost ($/year)			**$1,120,000**	**$1,120,000**	**$1,120,000**	**$1,120,000**	**$1,120,000**	**$1,120,000**	**$1,120,000**	**$1,120,000**	**$1,120,000**	**$1,120,000**
Cost Summary												
Capital Cost Bond Repayment for Year	-	-	$5,570,000	$5,570,000	$5,570,000	$5,570,000	$5,570,000	$5,570,000	$5,570,000	$5,570,000	$5,570,000	$5,570,000
O&M Cost for Year	-	-	$1,260,000	$1,260,000	$1,260,000	$1,260,000	$1,260,000	$1,260,000	$1,260,000	$1,260,000	$1,260,000	$1,260,000
Total for Year	-	-	$6,830,000	$6,830,000	$6,830,000	$6,830,000	$6,830,000	$6,830,000	$6,830,000	$6,830,000	$6,830,000	$6,830,000
Net Present Value												
Discount Rate =	**4.0%**											
Escalation Rate =	**5.0%**											
Net Present Value Capital Cost =	**$75,690,000**		**$3,620,000**	**$3,480,000**	**$3,350,000**	**$3,220,000**	**$3,090,000**	**$2,970,000**	**$2,860,000**	**$2,750,000**	**$2,640,000**	**$2,540,000**
Net Present Value for O&M =	**$27,900,000**		**$1,400,000**	**$1,410,000**	**$1,430,000**	**$1,440,000**	**$1,450,000**	**$1,470,000**	**$1,480,000**	**$1,500,000**	**$1,510,000**	**$1,530,000**
Total Net Present Value for Alternative =	**$103,590,000**		**$5,020,000**	**$4,890,000**	**$4,780,000**	**$4,660,000**	**$4,540,000**	**$4,440,000**	**$4,340,000**	**$4,250,000**	**$4,150,000**	**$4,070,000**

Wes Brown WTP - GAC Contactors
(Lead/Lag)

Item Description	Costs	Escalation / Interest (%)	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Capital Costs	**$245,100,000**	-										
Initial Construction - Bond Repayment	**$360,600,000**	4.0%	$18,030,000	$18,030,000	$18,030,000	$18,030,000	$18,030,000	$18,030,000	$18,030,000	$18,030,000	$18,030,000	$18,030,000
TWTP O&M Costs												
Electrical Usage ($/yr)												
Intermediate Pumping	$120,000		$120,000	$120,000	$120,000	$120,000	$120,000	$120,000	$120,000	$120,000	$120,000	$120,000
Electrical Cost ($/year)			**$120,000**	**$120,000**	**$120,000**	**$120,000**	**$120,000**	**$120,000**	**$120,000**	**$120,000**	**$120,000**	**$120,000**
Chemcial Usage ($/yr)												
Powdered Activated Carbon	($300,000)		-$300,000	-$300,000	-$300,000	-$300,000	-$300,000	-$300,000	-$300,000	-$300,000	-$300,000	-$300,000
Chemical Cost ($/year)			**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**
Operations and Maintenance ($/yr)												
GAC Replacement and Disposal	$2,300,000		$2,300,000	$2,300,000	$2,300,000	$2,300,000	$2,300,000	$2,300,000	$2,300,000	$2,300,000	$2,300,000	$2,300,000
Solids Removal	($100,000)		-$100,000	-$100,000	-$100,000	-$100,000	-$100,000	-$100,000	-$100,000	-$100,000	-$100,000	-$100,000
Sampling, Labor, and Preventative Maintenance	$80,000		$80,000	$80,000	$80,000	$80,000	$80,000	$80,000	$80,000	$80,000	$80,000	$80,000
Maintenance Operations Cost ($/year)			**$2,280,000**	**$2,280,000**	**$2,280,000**	**$2,280,000**	**$2,280,000**	**$2,280,000**	**$2,280,000**	**$2,280,000**	**$2,280,000**	**$2,280,000**
Cost Summary												
Capital Cost Bond Repayment for Year	-	-	$18,030,000	$18,030,000	$18,030,000	$18,030,000	$18,030,000	$18,030,000	$18,030,000	$18,030,000	$18,030,000	$18,030,000
O&M Cost for Year	-	-	$2,100,000	$2,100,000	$2,100,000	$2,100,000	$2,100,000	$2,100,000	$2,100,000	$2,100,000	$2,100,000	$2,100,000
Total for Year	-	-	$20,130,000	$20,130,000	$20,130,000	$20,130,000	$20,130,000	$20,130,000	$20,130,000	$20,130,000	$20,130,000	$20,130,000
Net Present Value												
Discount Rate =	**4.0%**											
Escalation Rate =	**5.0%**											
Net Present Value Capital Cost =	**$245,040,000**		**$17,340,000**	**$16,670,000**	**$16,030,000**	**$15,410,000**	**$14,820,000**	**$14,250,000**	**$13,700,000**	**$13,170,000**	**$12,670,000**	**$12,180,000**
Net Present Value for O&M =	**$46,500,000**		**$2,120,000**	**$2,140,000**	**$2,160,000**	**$2,180,000**	**$2,200,000**	**$2,220,000**	**$2,250,000**	**$2,270,000**	**$2,290,000**	**$2,310,000**
Total Net Present Value for Alternative =	**$291,540,000**		**$19,460,000**	**$18,810,000**	**$18,190,000**	**$17,590,000**	**$17,020,000**	**$16,470,000**	**$15,950,000**	**$15,440,000**	**$14,960,000**	**$14,490,000**

Wes Brown WTP - GAC Contactors
(Lead/Lag)

Item Description	Costs	Escalation / Interest (%)	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16	Year 17	Year 18	Year 19	Year 20
Capital Costs	**$245,100,000**	-										
Initial Construction - Bond Repayment	**$360,600,000**	4.0%	$18,030,000	$18,030,000	$18,030,000	$18,030,000	$18,030,000	$18,030,000	$18,030,000	$18,030,000	$18,030,000	$18,030,000
TWTP O&M Costs												
Electrical Usage ($/yr)												
Intermediate Pumping	$120,000		$120,000	$120,000	$120,000	$120,000	$120,000	$120,000	$120,000	$120,000	$120,000	$120,000
Electrical Cost ($/year)			**$120,000**	**$120,000**	**$120,000**	**$120,000**	**$120,000**	**$120,000**	**$120,000**	**$120,000**	**$120,000**	**$120,000**
Chemcial Usage ($/yr)												
Powdered Activated Carbon	($300,000)		-$300,000	-$300,000	-$300,000	-$300,000	-$300,000	-$300,000	-$300,000	-$300,000	-$300,000	-$300,000
Chemical Cost ($/year)			**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**
Operations and Maintenance ($/yr)												
GAC Replacement and Disposal	$2,300,000		$2,300,000	$2,300,000	$2,300,000	$2,300,000	$2,300,000	$2,300,000	$2,300,000	$2,300,000	$2,300,000	$2,300,000
Solids Removal	($100,000)		-$100,000	-$100,000	-$100,000	-$100,000	-$100,000	-$100,000	-$100,000	-$100,000	-$100,000	-$100,000
Sampling, Labor, and Preventative Maintenance	$80,000		$80,000	$80,000	$80,000	$80,000	$80,000	$80,000	$80,000	$80,000	$80,000	$80,000
Maintenance Operations Cost ($/year)			**$2,280,000**	**$2,280,000**	**$2,280,000**	**$2,280,000**	**$2,280,000**	**$2,280,000**	**$2,280,000**	**$2,280,000**	**$2,280,000**	**$2,280,000**
Cost Summary												
Capital Cost Bond Repayment for Year	-	-	$18,030,000	$18,030,000	$18,030,000	$18,030,000	$18,030,000	$18,030,000	$18,030,000	$18,030,000	$18,030,000	$18,030,000
O&M Cost for Year	-	-	$2,100,000	$2,100,000	$2,100,000	$2,100,000	$2,100,000	$2,100,000	$2,100,000	$2,100,000	$2,100,000	$2,100,000
Total for Year	-	-	$20,130,000	$20,130,000	$20,130,000	$20,130,000	$20,130,000	$20,130,000	$20,130,000	$20,130,000	$20,130,000	$20,130,000
Net Present Value												
Discount Rate =	**4.0%**											
Escalation Rate =	**5.0%**											
Net Present Value Capital Cost =	**$245,040,000**		**$11,710,000**	**$11,260,000**	**$10,830,000**	**$10,410,000**	**$10,010,000**	**$9,630,000**	**$9,260,000**	**$8,900,000**	**$8,560,000**	**$8,230,000**
Net Present Value for O&M =	**$46,500,000**		**$2,330,000**	**$2,360,000**	**$2,380,000**	**$2,400,000**	**$2,420,000**	**$2,450,000**	**$2,470,000**	**$2,490,000**	**$2,520,000**	**$2,540,000**
Total Net Present Value for Alternative =	**$291,540,000**		**$14,040,000**	**$13,620,000**	**$13,210,000**	**$12,810,000**	**$12,430,000**	**$12,080,000**	**$11,730,000**	**$11,390,000**	**$11,080,000**	**$10,770,000**

Wes Brown WTP - GAC Contactors
(Single Pass)

Item Description	Costs	Escalation / Interest (%)	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Capital Costs	**$168,300,000**	-										
Initial Construction - Bond Repayment	**$247,600,000**	4.0%	$12,380,000	$12,380,000	$12,380,000	$12,380,000	$12,380,000	$12,380,000	$12,380,000	$12,380,000	$12,380,000	$12,380,000
TWTP O&M Costs												
Electrical Usage ($/yr)												
Intermediate Pumping	$80,000		$80,000	$80,000	$80,000	$80,000	$80,000	$80,000	$80,000	$80,000	$80,000	$80,000
Electrical Cost ($/year)			**$80,000**	**$80,000**	**$80,000**	**$80,000**	**$80,000**	**$80,000**	**$80,000**	**$80,000**	**$80,000**	**$80,000**
Chemcial Usage ($/yr)												
Powdered Activated Carbon	($300,000)		-$300,000	-$300,000	-$300,000	-$300,000	-$300,000	-$300,000	-$300,000	-$300,000	-$300,000	-$300,000
Chemical Cost ($/year)			**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**
Operations and Maintenance ($/yr)												
GAC Replacement and Disposal	$2,300,000		$2,300,000	$2,300,000	$2,300,000	$2,300,000	$2,300,000	$2,300,000	$2,300,000	$2,300,000	$2,300,000	$2,300,000
Solids Removal	($100,000)		-$100,000	-$100,000	-$100,000	-$100,000	-$100,000	-$100,000	-$100,000	-$100,000	-$100,000	-$100,000
Sampling, Labor, and Preventative Maintenance	$40,000		$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000
Maintenance Operations Cost ($/year)			**$2,240,000**	**$2,240,000**	**$2,240,000**	**$2,240,000**	**$2,240,000**	**$2,240,000**	**$2,240,000**	**$2,240,000**	**$2,240,000**	**$2,240,000**
Cost Summary												
Capital Cost Bond Repayment for Year	-	-	$12,380,000	$12,380,000	$12,380,000	$12,380,000	$12,380,000	$12,380,000	$12,380,000	$12,380,000	$12,380,000	$12,380,000
O&M Cost for Year	-	-	$2,020,000	$2,020,000	$2,020,000	$2,020,000	$2,020,000	$2,020,000	$2,020,000	$2,020,000	$2,020,000	$2,020,000
Total for Year	-	-	$14,400,000	$14,400,000	$14,400,000	$14,400,000	$14,400,000	$14,400,000	$14,400,000	$14,400,000	$14,400,000	$14,400,000
Net Present Value												
Discount Rate =	**4.0%**											
Escalation Rate =	**5.0%**											
Net Present Value Capital Cost =	**$168,260,000**		**$11,900,000**	**$11,450,000**	**$11,010,000**	**$10,580,000**	**$10,180,000**	**$9,780,000**	**$9,410,000**	**$9,050,000**	**$8,700,000**	**$8,360,000**
Net Present Value for O&M =	**$44,740,000**		**$2,040,000**	**$2,060,000**	**$2,080,000**	**$2,100,000**	**$2,120,000**	**$2,140,000**	**$2,160,000**	**$2,180,000**	**$2,200,000**	**$2,220,000**
Total Net Present Value for Alternative =	**$213,000,000**		**$13,940,000**	**$13,510,000**	**$13,090,000**	**$12,680,000**	**$12,300,000**	**$11,920,000**	**$11,570,000**	**$11,230,000**	**$10,900,000**	**$10,580,000**

Wes Brown WTP - GAC Contactors
(Single Pass)

Item Description	Costs	Escalation / Interest (%)	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16	Year 17	Year 18	Year 19	Year 20
Capital Costs	**$168,300,000**	-										
Initial Construction - Bond Repayment	**$247,600,000**	4.0%	$12,380,000	$12,380,000	$12,380,000	$12,380,000	$12,380,000	$12,380,000	$12,380,000	$12,380,000	$12,380,000	$12,380,000
TWTP O&M Costs												
Electrical Usage ($/yr)												
Intermediate Pumping	$80,000		$80,000	$80,000	$80,000	$80,000	$80,000	$80,000	$80,000	$80,000	$80,000	$80,000
Electrical Cost ($/year)			**$80,000**	**$80,000**	**$80,000**	**$80,000**	**$80,000**	**$80,000**	**$80,000**	**$80,000**	**$80,000**	**$80,000**
Chemcial Usage ($/yr)												
Powdered Activated Carbon	($300,000)		-$300,000	-$300,000	-$300,000	-$300,000	-$300,000	-$300,000	-$300,000	-$300,000	-$300,000	-$300,000
Chemical Cost ($/year)			**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**
Operations and Maintenance ($/yr)												
GAC Replacement and Disposal	$2,300,000		$2,300,000	$2,300,000	$2,300,000	$2,300,000	$2,300,000	$2,300,000	$2,300,000	$2,300,000	$2,300,000	$2,300,000
Solids Removal	($100,000)		-$100,000	-$100,000	-$100,000	-$100,000	-$100,000	-$100,000	-$100,000	-$100,000	-$100,000	-$100,000
Sampling, Labor, and Preventative Maintenance	$40,000		$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000
Maintenance Operations Cost ($/year)			**$2,240,000**	**$2,240,000**	**$2,240,000**	**$2,240,000**	**$2,240,000**	**$2,240,000**	**$2,240,000**	**$2,240,000**	**$2,240,000**	**$2,240,000**
Cost Summary												
Capital Cost Bond Repayment for Year	-	-	$12,380,000	$12,380,000	$12,380,000	$12,380,000	$12,380,000	$12,380,000	$12,380,000	$12,380,000	$12,380,000	$12,380,000
O&M Cost for Year	-	-	$2,020,000	$2,020,000	$2,020,000	$2,020,000	$2,020,000	$2,020,000	$2,020,000	$2,020,000	$2,020,000	$2,020,000
Total for Year	-	-	$14,400,000	$14,400,000	$14,400,000	$14,400,000	$14,400,000	$14,400,000	$14,400,000	$14,400,000	$14,400,000	$14,400,000
Net Present Value												
Discount Rate =	**4.0%**											
Escalation Rate =	**5.0%**											
Net Present Value Capital Cost =	**$168,260,000**		**$8,040,000**	**$7,730,000**	**$7,440,000**	**$7,150,000**	**$6,870,000**	**$6,610,000**	**$6,360,000**	**$6,110,000**	**$5,880,000**	**$5,650,000**
Net Present Value for O&M =	**$44,740,000**		**$2,240,000**	**$2,270,000**	**$2,290,000**	**$2,310,000**	**$2,330,000**	**$2,350,000**	**$2,380,000**	**$2,400,000**	**$2,420,000**	**$2,450,000**
Total Net Present Value for Alternative =	**$213,000,000**		**$10,280,000**	**$10,000,000**	**$9,730,000**	**$9,460,000**	**$9,200,000**	**$8,960,000**	**$8,740,000**	**$8,510,000**	**$8,300,000**	**$8,100,000**

Wes Brown WTP - GAC Pressure Vessels
(Lead/Lag)

Item Description	Costs	Escalation / Interest (%)	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Capital Costs	**$282,300,000**	-										
Initial Construction - Bond Repayment	**$415,400,000**	4.0%	$20,770,000	$20,770,000	$20,770,000	$20,770,000	$20,770,000	$20,770,000	$20,770,000	$20,770,000	$20,770,000	$20,770,000
TWTP O&M Costs												
Electrical Usage ($/yr)												
Intermediate Pumping	$300,000		$300,000	$300,000	$300,000	$300,000	$300,000	$300,000	$300,000	$300,000	$300,000	$300,000
Electrical Cost ($/year)			**$300,000**	**$300,000**	**$300,000**	**$300,000**	**$300,000**	**$300,000**	**$300,000**	**$300,000**	**$300,000**	**$300,000**
Chemcial Usage ($/yr)												
Powdered Activated Carbon	($300,000)		-$300,000	-$300,000	-$300,000	-$300,000	-$300,000	-$300,000	-$300,000	-$300,000	-$300,000	-$300,000
Chemical Cost ($/year)			**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**
Operations and Maintenance ($/yr)												
GAC Replacement and Disposal	$2,300,000		$2,300,000	$2,300,000	$2,300,000	$2,300,000	$2,300,000	$2,300,000	$2,300,000	$2,300,000	$2,300,000	$2,300,000
Solids Removal	($100,000)		-$100,000	-$100,000	-$100,000	-$100,000	-$100,000	-$100,000	-$100,000	-$100,000	-$100,000	-$100,000
Sampling, Labor, and Preventative Maintenance	$160,000		$160,000	$160,000	$160,000	$160,000	$160,000	$160,000	$160,000	$160,000	$160,000	$160,000
Maintenance Operations Cost ($/year)			**$2,360,000**	**$2,360,000**	**$2,360,000**	**$2,360,000**	**$2,360,000**	**$2,360,000**	**$2,360,000**	**$2,360,000**	**$2,360,000**	**$2,360,000**
Cost Summary												
Capital Cost Bond Repayment for Year	-	-	$20,770,000	$20,770,000	$20,770,000	$20,770,000	$20,770,000	$20,770,000	$20,770,000	$20,770,000	$20,770,000	$20,770,000
O&M Cost for Year	-	-	$2,360,000	$2,360,000	$2,360,000	$2,360,000	$2,360,000	$2,360,000	$2,360,000	$2,360,000	$2,360,000	$2,360,000
Total for Year	-	-	$23,130,000	$23,130,000	$23,130,000	$23,130,000	$23,130,000	$23,130,000	$23,130,000	$23,130,000	$23,130,000	$23,130,000
Net Present Value												
Discount Rate =	**4.0%**											
Escalation Rate =	**5.0%**											
Net Present Value Capital Cost =	**$282,230,000**		**$19,970,000**	**$19,200,000**	**$18,460,000**	**$17,750,000**	**$17,070,000**	**$16,410,000**	**$15,780,000**	**$15,180,000**	**$14,590,000**	**$14,030,000**
Net Present Value for O&M =	**$52,270,000**		**$2,380,000**	**$2,410,000**	**$2,430,000**	**$2,450,000**	**$2,480,000**	**$2,500,000**	**$2,520,000**	**$2,550,000**	**$2,570,000**	**$2,600,000**
Total Net Present Value for Alternative =	**$334,500,000**		**$22,350,000**	**$21,610,000**	**$20,890,000**	**$20,200,000**	**$19,550,000**	**$18,910,000**	**$18,300,000**	**$17,730,000**	**$17,160,000**	**$16,630,000**

Wes Brown WTP - GAC Pressure Vessels
(Lead/Lag)

Item Description	Costs	Escalation / Interest (%)	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16	Year 17	Year 18	Year 19	Year 20
Capital Costs	**$282,300,000**	-										
Initial Construction - Bond Repayment	**$415,400,000**	4.0%	$20,770,000	$20,770,000	$20,770,000	$20,770,000	$20,770,000	$20,770,000	$20,770,000	$20,770,000	$20,770,000	$20,770,000
TWTP O&M Costs												
Electrical Usage ($/yr)												
Intermediate Pumping	$300,000		$300,000	$300,000	$300,000	$300,000	$300,000	$300,000	$300,000	$300,000	$300,000	$300,000
Electrical Cost ($/year)			**$300,000**	**$300,000**	**$300,000**	**$300,000**	**$300,000**	**$300,000**	**$300,000**	**$300,000**	**$300,000**	**$300,000**
Chemcial Usage ($/yr)												
Powdered Activated Carbon	($300,000)		-$300,000	-$300,000	-$300,000	-$300,000	-$300,000	-$300,000	-$300,000	-$300,000	-$300,000	-$300,000
Chemical Cost ($/year)			**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**
Operations and Maintenance ($/yr)												
GAC Replacement and Disposal	$2,300,000		$2,300,000	$2,300,000	$2,300,000	$2,300,000	$2,300,000	$2,300,000	$2,300,000	$2,300,000	$2,300,000	$2,300,000
Solids Removal	($100,000)		-$100,000	-$100,000	-$100,000	-$100,000	-$100,000	-$100,000	-$100,000	-$100,000	-$100,000	-$100,000
Sampling, Labor, and Preventative Maintenance	$160,000		$160,000	$160,000	$160,000	$160,000	$160,000	$160,000	$160,000	$160,000	$160,000	$160,000
Maintenance Operations Cost ($/year)			**$2,360,000**	**$2,360,000**	**$2,360,000**	**$2,360,000**	**$2,360,000**	**$2,360,000**	**$2,360,000**	**$2,360,000**	**$2,360,000**	**$2,360,000**
Cost Summary												
Capital Cost Bond Repayment for Year	-	-	$20,770,000	$20,770,000	$20,770,000	$20,770,000	$20,770,000	$20,770,000	$20,770,000	$20,770,000	$20,770,000	$20,770,000
O&M Cost for Year	-	-	$2,360,000	$2,360,000	$2,360,000	$2,360,000	$2,360,000	$2,360,000	$2,360,000	$2,360,000	$2,360,000	$2,360,000
Total for Year	-	-	$23,130,000	$23,130,000	$23,130,000	$23,130,000	$23,130,000	$23,130,000	$23,130,000	$23,130,000	$23,130,000	$23,130,000
Net Present Value												
Discount Rate =	**4.0%**											
Escalation Rate =	**5.0%**											
Net Present Value Capital Cost =	**$282,230,000**		**$13,490,000**	**$12,970,000**	**$12,470,000**	**$11,990,000**	**$11,530,000**	**$11,090,000**	**$10,660,000**	**$10,250,000**	**$9,860,000**	**$9,480,000**
Net Present Value for O&M =	**$52,270,000**		**$2,620,000**	**$2,650,000**	**$2,670,000**	**$2,700,000**	**$2,720,000**	**$2,750,000**	**$2,780,000**	**$2,800,000**	**$2,830,000**	**$2,860,000**
Total Net Present Value for Alternative =	**$334,500,000**		**$16,110,000**	**$15,620,000**	**$15,140,000**	**$14,690,000**	**$14,250,000**	**$13,840,000**	**$13,440,000**	**$13,050,000**	**$12,690,000**	**$12,340,000**

Wes Brown WTP - GAC Pressure Vessels
(Single Pass)

Item Description	Costs	Escalation / Interest (%)	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Capital Costs	**$198,800,000**	-										
Initial Construction - Bond Repayment	**$292,600,000**	4.0%	$14,630,000	$14,630,000	$14,630,000	$14,630,000	$14,630,000	$14,630,000	$14,630,000	$14,630,000	$14,630,000	$14,630,000
TWTP O&M Costs												
Electrical Usage ($/yr)												
Intermediate Pumping	$190,000		$190,000	$190,000	$190,000	$190,000	$190,000	$190,000	$190,000	$190,000	$190,000	$190,000
Electrical Cost ($/year)			**$190,000**	**$190,000**	**$190,000**	**$190,000**	**$190,000**	**$190,000**	**$190,000**	**$190,000**	**$190,000**	**$190,000**
Chemcial Usage ($/yr)												
Powdered Activated Carbon	($300,000)		-$300,000	-$300,000	-$300,000	-$300,000	-$300,000	-$300,000	-$300,000	-$300,000	-$300,000	-$300,000
Chemical Cost ($/year)			**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**
Operations and Maintenance ($/yr)												
GAC Replacement and Disposal	$2,300,000		$2,300,000	$2,300,000	$2,300,000	$2,300,000	$2,300,000	$2,300,000	$2,300,000	$2,300,000	$2,300,000	$2,300,000
Solids Removal	($100,000)		-$100,000	-$100,000	-$100,000	-$100,000	-$100,000	-$100,000	-$100,000	-$100,000	-$100,000	-$100,000
Sampling, Labor, and Preventative Maintenance	$80,000		$80,000	$80,000	$80,000	$80,000	$80,000	$80,000	$80,000	$80,000	$80,000	$80,000
Maintenance Operations Cost ($/year)			**$2,280,000**	**$2,280,000**	**$2,280,000**	**$2,280,000**	**$2,280,000**	**$2,280,000**	**$2,280,000**	**$2,280,000**	**$2,280,000**	**$2,280,000**
Cost Summary												
Capital Cost Bond Repayment for Year	-	-	$14,630,000	$14,630,000	$14,630,000	$14,630,000	$14,630,000	$14,630,000	$14,630,000	$14,630,000	$14,630,000	$14,630,000
O&M Cost for Year	-	-	$2,170,000	$2,170,000	$2,170,000	$2,170,000	$2,170,000	$2,170,000	$2,170,000	$2,170,000	$2,170,000	$2,170,000
Total for Year	-	-	$16,800,000	$16,800,000	$16,800,000	$16,800,000	$16,800,000	$16,800,000	$16,800,000	$16,800,000	$16,800,000	$16,800,000
Net Present Value												
Discount Rate =	**4.0%**											
Escalation Rate =	**5.0%**											
Net Present Value Capital Cost =	**$198,830,000**		**$14,070,000**	**$13,530,000**	**$13,010,000**	**$12,510,000**	**$12,020,000**	**$11,560,000**	**$11,120,000**	**$10,690,000**	**$10,280,000**	**$9,880,000**
Net Present Value for O&M =	**$48,050,000**		**$2,190,000**	**$2,210,000**	**$2,230,000**	**$2,250,000**	**$2,280,000**	**$2,300,000**	**$2,320,000**	**$2,340,000**	**$2,370,000**	**$2,390,000**
Total Net Present Value for Alternative =	**$246,880,000**		**$16,260,000**	**$15,740,000**	**$15,240,000**	**$14,760,000**	**$14,300,000**	**$13,860,000**	**$13,440,000**	**$13,030,000**	**$12,650,000**	**$12,270,000**

Wes Brown WTP - GAC Pressure Vessels
(Single Pass)

Item Description	Costs	Escalation / Interest (%)	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16	Year 17	Year 18	Year 19	Year 20
Capital Costs	**$198,800,000**	-										
Initial Construction - Bond Repayment	**$292,600,000**	4.0%	$14,630,000	$14,630,000	$14,630,000	$14,630,000	$14,630,000	$14,630,000	$14,630,000	$14,630,000	$14,630,000	$14,630,000
TWTP O&M Costs												
Electrical Usage ($/yr)												
Intermediate Pumping	$190,000		$190,000	$190,000	$190,000	$190,000	$190,000	$190,000	$190,000	$190,000	$190,000	$190,000
Electrical Cost ($/year)			**$190,000**	**$190,000**	**$190,000**	**$190,000**	**$190,000**	**$190,000**	**$190,000**	**$190,000**	**$190,000**	**$190,000**
Chemcial Usage ($/yr)												
Powdered Activated Carbon	($300,000)		-$300,000	-$300,000	-$300,000	-$300,000	-$300,000	-$300,000	-$300,000	-$300,000	-$300,000	-$300,000
Chemical Cost ($/year)			**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**
Operations and Maintenance ($/yr)												
GAC Replacement and Disposal	$2,300,000		$2,300,000	$2,300,000	$2,300,000	$2,300,000	$2,300,000	$2,300,000	$2,300,000	$2,300,000	$2,300,000	$2,300,000
Solids Removal	($100,000)		-$100,000	-$100,000	-$100,000	-$100,000	-$100,000	-$100,000	-$100,000	-$100,000	-$100,000	-$100,000
Sampling, Labor, and Preventative Maintenance	$80,000		$80,000	$80,000	$80,000	$80,000	$80,000	$80,000	$80,000	$80,000	$80,000	$80,000
Maintenance Operations Cost ($/year)			**$2,280,000**	**$2,280,000**	**$2,280,000**	**$2,280,000**	**$2,280,000**	**$2,280,000**	**$2,280,000**	**$2,280,000**	**$2,280,000**	**$2,280,000**
Cost Summary												
Capital Cost Bond Repayment for Year	-	-	$14,630,000	$14,630,000	$14,630,000	$14,630,000	$14,630,000	$14,630,000	$14,630,000	$14,630,000	$14,630,000	$14,630,000
O&M Cost for Year	-	-	$2,170,000	$2,170,000	$2,170,000	$2,170,000	$2,170,000	$2,170,000	$2,170,000	$2,170,000	$2,170,000	$2,170,000
Total for Year	-	-	$16,800,000	$16,800,000	$16,800,000	$16,800,000	$16,800,000	$16,800,000	$16,800,000	$16,800,000	$16,800,000	$16,800,000
Net Present Value												
Discount Rate =	**4.0%**											
Escalation Rate =	**5.0%**											
Net Present Value Capital Cost =	**$198,830,000**		**$9,500,000**	**$9,140,000**	**$8,790,000**	**$8,450,000**	**$8,120,000**	**$7,810,000**	**$7,510,000**	**$7,220,000**	**$6,940,000**	**$6,680,000**
Net Present Value for O&M =	**$48,050,000**		**$2,410,000**	**$2,430,000**	**$2,460,000**	**$2,480,000**	**$2,500,000**	**$2,530,000**	**$2,550,000**	**$2,580,000**	**$2,600,000**	**$2,630,000**
Total Net Present Value for Alternative =	**$246,880,000**		**$11,910,000**	**$11,570,000**	**$11,250,000**	**$10,930,000**	**$10,620,000**	**$10,340,000**	**$10,060,000**	**$9,800,000**	**$9,540,000**	**$9,310,000**

Wes Brown WTP - IX Pressure Vessels
(Lead/Lag)

Item Description	Costs	Escalation / Interest (%)	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Capital Costs	**$195,700,000**	-										
Initial Construction - Bond Repayment	**$288,000,000**	4.0%	$14,400,000	$14,400,000	$14,400,000	$14,400,000	$14,400,000	$14,400,000	$14,400,000	$14,400,000	$14,400,000	$14,400,000
TWTP O&M Costs												
Electrical Usage ($/yr)												
Intermediate Pumping	$480,000		$480,000	$480,000	$480,000	$480,000	$480,000	$480,000	$480,000	$480,000	$480,000	$480,000
Electrical Cost ($/year)			**$480,000**	**$480,000**	**$480,000**	**$480,000**	**$480,000**	**$480,000**	**$480,000**	**$480,000**	**$480,000**	**$480,000**
Chemcial Usage ($/yr)												
Powdered Activated Carbon	($300,000)		-$300,000	-$300,000	-$300,000	-$300,000	-$300,000	-$300,000	-$300,000	-$300,000	-$300,000	-$300,000
Chemical Cost ($/year)			**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**
Operations and Maintenance ($/yr)												
IX Resin Replacement and Disposal	$3,200,000		$3,200,000	$3,200,000	$3,200,000	$3,200,000	$3,200,000	$3,200,000	$3,200,000	$3,200,000	$3,200,000	$3,200,000
Solids Removal	($100,000)		-$100,000	-$100,000	-$100,000	-$100,000	-$100,000	-$100,000	-$100,000	-$100,000	-$100,000	-$100,000
Sampling, Labor, and Preventative Maintenance	$80,000		$80,000	$80,000	$80,000	$80,000	$80,000	$80,000	$80,000	$80,000	$80,000	$80,000
Maintenance Operations Cost ($/year)			**$3,180,000**	**$3,180,000**	**$3,180,000**	**$3,180,000**	**$3,180,000**	**$3,180,000**	**$3,180,000**	**$3,180,000**	**$3,180,000**	**$3,180,000**
Cost Summary												
Capital Cost Bond Repayment for Year	-	-	$14,400,000	$14,400,000	$14,400,000	$14,400,000	$14,400,000	$14,400,000	$14,400,000	$14,400,000	$14,400,000	$14,400,000
O&M Cost for Year	-	-	$3,360,000	$3,360,000	$3,360,000	$3,360,000	$3,360,000	$3,360,000	$3,360,000	$3,360,000	$3,360,000	$3,360,000
Total for Year	-	-	$17,760,000	$17,760,000	$17,760,000	$17,760,000	$17,760,000	$17,760,000	$17,760,000	$17,760,000	$17,760,000	$17,760,000
Net Present Value												
Discount Rate =	**4.0%**											
Escalation Rate =	**5.0%**											
Net Present Value Capital Cost =	**$195,700,000**		**$13,850,000**	**$13,310,000**	**$12,800,000**	**$12,310,000**	**$11,840,000**	**$11,380,000**	**$10,940,000**	**$10,520,000**	**$10,120,000**	**$9,730,000**
Net Present Value for O&M =	**$74,410,000**		**$3,390,000**	**$3,420,000**	**$3,460,000**	**$3,490,000**	**$3,520,000**	**$3,560,000**	**$3,590,000**	**$3,630,000**	**$3,660,000**	**$3,700,000**
Total Net Present Value for Alternative =	**$270,110,000**		**$17,240,000**	**$16,730,000**	**$16,260,000**	**$15,800,000**	**$15,360,000**	**$14,940,000**	**$14,530,000**	**$14,150,000**	**$13,780,000**	**$13,430,000**

Wes Brown WTP - IX Pressure Vessels
(Lead/Lag)

Item Description	Costs	Escalation / Interest (%)	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16	Year 17	Year 18	Year 19	Year 20
Capital Costs	**$195,700,000**	-										
Initial Construction - Bond Repayment	**$288,000,000**	4.0%	$14,400,000	$14,400,000	$14,400,000	$14,400,000	$14,400,000	$14,400,000	$14,400,000	$14,400,000	$14,400,000	$14,400,000
TWTP O&M Costs												
Electrical Usage ($/yr)												
Intermediate Pumping	$480,000		$480,000	$480,000	$480,000	$480,000	$480,000	$480,000	$480,000	$480,000	$480,000	$480,000
Electrical Cost ($/year)			**$480,000**	**$480,000**	**$480,000**	**$480,000**	**$480,000**	**$480,000**	**$480,000**	**$480,000**	**$480,000**	**$480,000**
Chemcial Usage ($/yr)												
Powdered Activated Carbon	($300,000)		-$300,000	-$300,000	-$300,000	-$300,000	-$300,000	-$300,000	-$300,000	-$300,000	-$300,000	-$300,000
Chemical Cost ($/year)			**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**
Operations and Maintenance ($/yr)												
IX Resin Replacement and Disposal	$3,200,000		$3,200,000	$3,200,000	$3,200,000	$3,200,000	$3,200,000	$3,200,000	$3,200,000	$3,200,000	$3,200,000	$3,200,000
Solids Removal	($100,000)		-$100,000	-$100,000	-$100,000	-$100,000	-$100,000	-$100,000	-$100,000	-$100,000	-$100,000	-$100,000
Sampling, Labor, and Preventative Maintenance	$80,000		$80,000	$80,000	$80,000	$80,000	$80,000	$80,000	$80,000	$80,000	$80,000	$80,000
Maintenance Operations Cost ($/year)			**$3,180,000**	**$3,180,000**	**$3,180,000**	**$3,180,000**	**$3,180,000**	**$3,180,000**	**$3,180,000**	**$3,180,000**	**$3,180,000**	**$3,180,000**
Cost Summary												
Capital Cost Bond Repayment for Year	-	-	$14,400,000	$14,400,000	$14,400,000	$14,400,000	$14,400,000	$14,400,000	$14,400,000	$14,400,000	$14,400,000	$14,400,000
O&M Cost for Year	-	-	$3,360,000	$3,360,000	$3,360,000	$3,360,000	$3,360,000	$3,360,000	$3,360,000	$3,360,000	$3,360,000	$3,360,000
Total for Year	-	-	$17,760,000	$17,760,000	$17,760,000	$17,760,000	$17,760,000	$17,760,000	$17,760,000	$17,760,000	$17,760,000	$17,760,000
Net Present Value												
Discount Rate =	**4.0%**											
Escalation Rate =	**5.0%**											
Net Present Value Capital Cost =	**$195,700,000**		**$9,350,000**	**$8,990,000**	**$8,650,000**	**$8,320,000**	**$8,000,000**	**$7,690,000**	**$7,390,000**	**$7,110,000**	**$6,830,000**	**$6,570,000**
Net Present Value for O&M =	**$74,410,000**		**$3,730,000**	**$3,770,000**	**$3,810,000**	**$3,840,000**	**$3,880,000**	**$3,920,000**	**$3,950,000**	**$3,990,000**	**$4,030,000**	**$4,070,000**
Total Net Present Value for Alternative =	**$270,110,000**		**$13,080,000**	**$12,760,000**	**$12,460,000**	**$12,160,000**	**$11,880,000**	**$11,610,000**	**$11,340,000**	**$11,100,000**	**$10,860,000**	**$10,640,000**

Wes Brown WTP - IX Pressure Vessels
(Single Pass)

Item Description	Costs	Escalation / Interest (%)	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Capital Costs	**$143,100,000**	-										
Initial Construction - Bond Repayment	**$210,600,000**	4.0%	$10,530,000	$10,530,000	$10,530,000	$10,530,000	$10,530,000	$10,530,000	$10,530,000	$10,530,000	$10,530,000	$10,530,000
TWTP O&M Costs												
Electrical Usage ($/yr)												
Intermediate Pumping	$300,000		$300,000	$300,000	$300,000	$300,000	$300,000	$300,000	$300,000	$300,000	$300,000	$300,000
Electrical Cost ($/year)			**$300,000**	**$300,000**	**$300,000**	**$300,000**	**$300,000**	**$300,000**	**$300,000**	**$300,000**	**$300,000**	**$300,000**
Chemcial Usage ($/yr)												
Powdered Activated Carbon	($300,000)		-$300,000	-$300,000	-$300,000	-$300,000	-$300,000	-$300,000	-$300,000	-$300,000	-$300,000	-$300,000
Chemical Cost ($/year)			**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**
Operations and Maintenance ($/yr)												
IX Resin Replacement and Disposal	$3,200,000		$3,200,000	$3,200,000	$3,200,000	$3,200,000	$3,200,000	$3,200,000	$3,200,000	$3,200,000	$3,200,000	$3,200,000
Solids Removal	($100,000)		-$100,000	-$100,000	-$100,000	-$100,000	-$100,000	-$100,000	-$100,000	-$100,000	-$100,000	-$100,000
Sampling, Labor, and Preventative Maintenance	$40,000		$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000
Maintenance Operations Cost ($/year)			**$3,140,000**	**$3,140,000**	**$3,140,000**	**$3,140,000**	**$3,140,000**	**$3,140,000**	**$3,140,000**	**$3,140,000**	**$3,140,000**	**$3,140,000**
Cost Summary												
Capital Cost Bond Repayment for Year	-	-	$10,530,000	$10,530,000	$10,530,000	$10,530,000	$10,530,000	$10,530,000	$10,530,000	$10,530,000	$10,530,000	$10,530,000
O&M Cost for Year	-	-	$3,140,000	$3,140,000	$3,140,000	$3,140,000	$3,140,000	$3,140,000	$3,140,000	$3,140,000	$3,140,000	$3,140,000
Total for Year	-	-	$13,670,000	$13,670,000	$13,670,000	$13,670,000	$13,670,000	$13,670,000	$13,670,000	$13,670,000	$13,670,000	$13,670,000
Net Present Value												
Discount Rate =	**4.0%**											
Escalation Rate =	**5.0%**											
Net Present Value Capital Cost =	**$143,110,000**		**$10,130,000**	**$9,740,000**	**$9,360,000**	**$9,000,000**	**$8,650,000**	**$8,320,000**	**$8,000,000**	**$7,690,000**	**$7,400,000**	**$7,110,000**
Net Present Value for O&M =	**$69,540,000**		**$3,170,000**	**$3,200,000**	**$3,230,000**	**$3,260,000**	**$3,290,000**	**$3,330,000**	**$3,360,000**	**$3,390,000**	**$3,420,000**	**$3,460,000**
Total Net Present Value for Alternative =	**$212,650,000**		**$13,300,000**	**$12,940,000**	**$12,590,000**	**$12,260,000**	**$11,940,000**	**$11,650,000**	**$11,360,000**	**$11,080,000**	**$10,820,000**	**$10,570,000**

Wes Brown WTP - IX Pressure Vessels
(Single Pass)

Item Description	Costs	Escalation / Interest (%)	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16	Year 17	Year 18	Year 19	Year 20
Capital Costs	**$143,100,000**	-										
Initial Construction - Bond Repayment	**$210,600,000**	4.0%	$10,530,000	$10,530,000	$10,530,000	$10,530,000	$10,530,000	$10,530,000	$10,530,000	$10,530,000	$10,530,000	$10,530,000
TWTP O&M Costs												
Electrical Usage ($/yr)												
Intermediate Pumping	$300,000		$300,000	$300,000	$300,000	$300,000	$300,000	$300,000	$300,000	$300,000	$300,000	$300,000
Electrical Cost ($/year)			**$300,000**	**$300,000**	**$300,000**	**$300,000**	**$300,000**	**$300,000**	**$300,000**	**$300,000**	**$300,000**	**$300,000**
Chemcial Usage ($/yr)												
Powdered Activated Carbon	($300,000)		-$300,000	-$300,000	-$300,000	-$300,000	-$300,000	-$300,000	-$300,000	-$300,000	-$300,000	-$300,000
Chemical Cost ($/year)			**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**	**-$300,000**
Operations and Maintenance ($/yr)												
IX Resin Replacement and Disposal	$3,200,000		$3,200,000	$3,200,000	$3,200,000	$3,200,000	$3,200,000	$3,200,000	$3,200,000	$3,200,000	$3,200,000	$3,200,000
Solids Removal	($100,000)		-$100,000	-$100,000	-$100,000	-$100,000	-$100,000	-$100,000	-$100,000	-$100,000	-$100,000	-$100,000
Sampling, Labor, and Preventative Maintenance	$40,000		$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000
Maintenance Operations Cost ($/year)			**$3,140,000**	**$3,140,000**	**$3,140,000**	**$3,140,000**	**$3,140,000**	**$3,140,000**	**$3,140,000**	**$3,140,000**	**$3,140,000**	**$3,140,000**
Cost Summary												
Capital Cost Bond Repayment for Year	-	-	$10,530,000	$10,530,000	$10,530,000	$10,530,000	$10,530,000	$10,530,000	$10,530,000	$10,530,000	$10,530,000	$10,530,000
O&M Cost for Year	-	-	$3,140,000	$3,140,000	$3,140,000	$3,140,000	$3,140,000	$3,140,000	$3,140,000	$3,140,000	$3,140,000	$3,140,000
Total for Year	-	-	$13,670,000	$13,670,000	$13,670,000	$13,670,000	$13,670,000	$13,670,000	$13,670,000	$13,670,000	$13,670,000	$13,670,000
Net Present Value												
Discount Rate =	**4.0%**											
Escalation Rate =	**5.0%**											
Net Present Value Capital Cost =	**$143,110,000**		**$6,840,000**	**$6,580,000**	**$6,320,000**	**$6,080,000**	**$5,850,000**	**$5,620,000**	**$5,410,000**	**$5,200,000**	**$5,000,000**	**$4,810,000**
Net Present Value for O&M =	**$69,540,000**		**$3,490,000**	**$3,520,000**	**$3,560,000**	**$3,590,000**	**$3,620,000**	**$3,660,000**	**$3,690,000**	**$3,730,000**	**$3,770,000**	**$3,800,000**
Total Net Present Value for Alternative =	**$212,650,000**		**$10,330,000**	**$10,100,000**	**$9,880,000**	**$9,670,000**	**$9,470,000**	**$9,280,000**	**$9,100,000**	**$8,930,000**	**$8,770,000**	**$8,610,000**