NORTHWEST WATER TREATMENT PLANT

BRUNSWICK COUNTY

FINAL REPORT

Advanced Treatment Options for the Northwest Water Treatment Plant

Prepared for:

Brunswick County Public Utilities
Brunswick County, NC

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CDM Smith

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NORTH CAROLINA PROFESSIONAL SEAL 15394 ENGINEER WILLIAM B. DOWBIGGIN

William B. Dowbiggin 4/12/18

NORTH CAROLINA PROFESSIONAL SEAL 039912 ENGINEER REED M. BARTON

Reed M. Barton 04-12-2018

CDM Smith, Inc.
5400 Glenwood Avenue, Suite 400
Raleigh, North Carolina 27612
Tel: (919) 325-3500 Fax: (919) 781-5730
NC License No. F-1255

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List of Abbreviations

ACT	Accelerated Column Test
AIX	Anionic Ion Exchange
ASTDR	Agency for Toxic Substances and Disease Registry
BAF	Biological Aerated Filtration
BV	Bed Volume
CAS	Chemical Abstracts Service
cm	Centimeter
DBP	Disinfection Byproducts
DEET	N,N-Diethyl-meta-toluamide
DWR	Division of Water Resources
EBCT	Empty Bed Contact Time
EDC	Endocrine Disruptive Compound
EPA	United States Environmental Protection Agency
ft^2	Square Feet
ft^3	Cubic Feet
GAC	Granular Activated Carbon
gfd	gallons per ft^2 per day = gpd/ft^2
gpm	Gallon per Minute
g/mol	grams per mole/mol
hp	horsepower
IRIS	EPA Integrated Risk Information System
IX	Ion Exchange
lbs	pounds
lbs/day	pounds per day

List of Abbreviations (continued)

LOX	Liquid Oxygen
LPRO	Low Pressure Reverse Osmosis
LR	Loading Rate
MCL	Maximum Contaminant Level
MIEX	Magnetic Ion Exchange Resin
mg/L	Milligrams per Liter
mgd	Million Gallons per Day
NCDEQ	North Carolina Department of Environmental Quality
NCSU	North Carolina State University
NDMA	N-Nitrosodimethylamine
NF	Nanofiltration
NPDES	National Pollutant Discharge Elimination System
ng/L	NanogramS per Liter
NTU	Nephelometric Turbidity Unit
PAC	Powdered Activated Carbon
PACL	polyaluminum chloride
PFAS	Per- and polyfluoroalkyl substances
PFBA	Perfluorobutanoic Acid
PFBS	Perfluorobutane Sulfonate
PFECA	Perfuoroalkyl Ether Carboxylic Acid
PFHxA	Perfluorohexanoic Acid
PFOA	Perflurooctanoic Acid
PFOS	Perfluoroooctane Sulfonate
PFPeA	Perfluoropentanoic Acid
PFPrOPrA	Perfluoro-2-Propoxypropanoic Acid

List of Abbreviations (continued)

PPCP	Pharmaceuticals and Personal Care Products
psi	Pounds per Square Inch
RO	Reverse Osmosis
RSSCT	Rapid Small-Scale Column Test
SDWA	Safe Drinking Water Act
TC	Target Contaminants
TCCP	tris (1-chloro-2-propyl) phosphate
TCEC	Target Contaminants of Emerging Concern
TCEP	tris(2-chloroethyl) phosphate
TDCPP	tris(1,3-dichloroisopropyl)phosphate
TFE	Tetrafluoroethylene
TDH	Total Dynamic Head
TOC	Total Organic Carbon
UCMR	Unregulated Contaminant Monitoring Rule
UV	Ultraviolet
VFD	Variable Frequency Drive
WTP	Water Treatment Plant

Executive Summary

As a result of what is believed to be decades of the release of high levels of manufacturing chemicals and by-products, organic chemicals including per- and polyfluoroalkyl substances (PFAS) have been detected in the Cape Fear River, which supplies the Northwest Water Treatment Plant (WTP). Research completed by Dr. Detlef Knappe and Dr. Mei Sun at North Carolina State University (NCSU) in 2016 and 2017 determined that conventional treatment is inadequate for the removal of newly identified emerging contaminants including the PFAS compounds GenX and Nafion by-products. Advanced water treatment methods will be required to remove the PFAS compounds.

Neither the Environmental Protection Agency (EPA) nor the North Carolina Department of Environmental Quality (NC DEQ) have set enforceable maximum contaminant levels (MCLs) for GenX or other PFAS. Due to the concern over potential health effects associated with these compounds in drinking water, Brunswick County is proactively considering the feasibility and effectiveness of advanced water treatment methods to address these emerging contaminants of concern.

To meet the projected water demands, Brunswick County is planning to expand the Northwest WTP capacity from 24 to 36 mgd. In response to the increased concern over water quality in the Cape Fear River, the County contracted CDM Smith to create a plan to improve treatment and removal of contaminants of concern during the planned capacity expansion.

This report presents a conceptual design of the major facilities and components required for the plant expansion, identification of several target contaminants associated with water from the lower Cape Fear River, establishment of preliminary treatment goals, and evaluation of water treatment technologies that have been proposed for the removal of these target contaminants. The evaluation of treatment alternatives is based on a desktop analysis. The analysis is based on experience at similar facilities plus assumptions and extrapolations that could be confirmed by bench-scale and/or pilot-scale testing before full-scale implementation. The desktop analysis results indicate:

- Implementation of Ultraviolet-Advanced Oxidation Process (UV-AOP), ozone (O_3), and biologically active filtration (BAF or biofiltration), alternatives as single methods for advanced treatment at the Northwest WTP are ineffective as a treatment barrier for removing PFAS including GenX and Nafion by-products.

- Granular activated carbon adsorption (GAC), ion exchange (IX), and reverse osmosis are the primary advanced water treatment technologies that remove PFAS. GAC and IX are not very effective for certain other target compounds, particularly 1,4-dioxane, which has had high concentrations in the Cape Fear River. Advanced oxidation process (AOP) can remove 1,4-dioxane; therefore AOP has been included in the evaluation of GAC and IX options. AOP can be achieved using UV-AOP or using ozone with peroxide.

- The evaluation has highlighted three alternatives for advanced treatment at the Northwest WTP for the County's consideration, including:
  - Option 1 - Reverse Osmosis (RO)
  - Option 2 – Ozone with Biofiltration and Post-Filter GAC (Ozone/BAF-GAC)
  - Option 3 – Post-Filter GAC with IX and UV-AOP (GAC/IX/UV-AOP)

A summary of the planning-level opinion of capital cost and annual operation and maintenance costs for these advanced treatment alternatives is presented in Table E-1. Table E-1 also includes the calculated Net Present Worth (NPW) cost for the three major treatment options. The planning-level capital cost for the capacity expansion is assumed to be the same for all three alternatives as shown in Table E-2, which presents the total project capital cost for the combination of adding advanced treatment for PFAS and for expanding the Northwest WTP to 36 mgd capacity. Costs are preliminary, budgetary estimates and include 30 percent contingencies.

Table E-1. Planning-Level Opinion of Capital Cost, Annual O&M Cost and Net Present Worth (NPW) for Advanced Treatment Options

Planning-Level Cost Description	Reverse Osmosis	Ozone/BAF-GAC	GAC/IX/UV-AOP
Capital Cost	$ 99 Million	$ 99 Million	$ 84 Million
Annual O&M Cost	$ 2.9 Million/Year	$ 4.7 Million/Year	$ 4.7 Million/Year
25-yr NPW of Capital and Annual Costs	$ 158 Million	$ 193 Million	$ 178 Million

Table E-2. Total Project Capital Cost (Advanced Treatment + Capacity Expansion)

Opinion of Capital Cost (Advanced Treatment + Capacity Expansion)			
	Reverse Osmosis	**Ozone/BAF – GAC**	**IX/GAC/UV-AOP**
Total Advanced Treatment Cost	$ 99 M	$ 99 M	$ 84 M
Capacity Expansion Project Cost	$ 38 M	$ 38 M	$ 38 M
Opinion of Total Capital Cost	**$ 137 M**	**$ 137 M**	**$ 122 M**

Based on the evaluation of the alternatives, RO treatment provides the removal of the highest number of target contaminants and is recommended for the Northwest WTP expansion. To demonstrate the effectiveness of RO treatment, a pilot test at the Northwest WTP has been initiated. The RO pilot testing is expected to be completed in Summer 2018.

RO is recommended over the other options for the following reasons:

- RO is the Best Technology for Removal of PFAS. Some PFAS, such as GenX, PFMOAA and PFO2HxA would require very frequent change-out of GAC and IX for removal.
- GAC and IX would likely result in higher finished water concentrations of GenX, PFMOAA, and PFO2HxA than RO (technologies are not equal).
- RO has the lowest net present worth costs for removing 90% or more of the Target Contaminants.
- RO is the most robust technology for protecting against unidentified contaminants.
- RO treated water concentrations will not vary as much with influent concentrations as with GAC and IX. RO treated water quality does not rely on frequent media change-out to protect from the spills and contaminants in the Cape Fear River.
- RO does not release elevated concentrations after bed life is spent as can happen with GAC and IX if feed concentration drops.

The overall recommended project includes expansion of the existing facilities and the addition of RO advanced treatment.

Section 1

Background and Scope of Work

1.1 Project Background

1.1.1 Existing Water Supply and Treatment

Brunswick County Public Utilities provides drinking water to a population of nearly 100,000 people annually and 200,000 seasonally. The County obtains its supply from two main water sources:

- 211 Water Treatment Plant (WTP) which is a groundwater plant located near the Town of Southport in the southeastern portion of Brunswick County
- Northwest WTP which is a surface water plant located near the Towns of Northwest and Leland

The Cape Fear River is the water source for the Northwest WTP and which serves the majority of the Brunswick County's customers. Raw water is pumped from the Cape Fear River using the Kings Bluff Pump Station, located north of Lock and Dam No. 1 to the Northwest WTP in the Town of Northwest (**Figure 1-1**). The Kings Bluff Pump Station, owned by the Lower Cape Fear Water and Sewer Authority, also provides raw water to the Cape Fear Public Utility Authority's (CFPUA) Sweeney WTP in Wilmington and the Pender County WTP. The Lower Cape Fear Water and Sewer Authority's Bladen Bluffs WTP has its own intake and pump station further upstream on the Cape Fear River.

Figure 1-1
Lock and Dam No. 1 on the Cape Fear River

The Northwest WTP has a rated capacity of 24 million gallons per day and uses conventional treatment to provide safe drinking water to its residential, commercial, industrial, and wholesale customers. Raw water is treated with chlorine dioxide (pre-oxidant), powdered activated carbon (PAC) for taste and odor control, polyaluminum chloride (PAX) as a coagulant, and caustic. Pulsator® clarifiers and Greenleaf® filters, modified for a pumped backwash, provide solids and particulate removal from the treated water. Filtered water is treated with sodium fluorosilicate for fluoridation, orthophosphate for corrosion inhibition, caustic for pH adjustment, chlorine as primary disinfectant, and ammonia to form chloramines for distribution system residual. An aerial view of the existing plant site is shown on **Figure 1-2**.

Figure 1-2
Aerial View of Northwest WTP

Since 2009, the County has been implementing a phased approach for the design and construction of the WTP expansion from 24 to 36 mgd. Phases 1 and 2 have been completed. Phase 3 of the expansion involves an increase in capacity of the core water treatment processes. In addition to the capacity expansion, it was determined in 2017 that advanced treatment will be required to remove emerging contaminants that have been recently identified, including GenX, per- and polyfluoroalkyl substances (PFASs), 1,4-dioxane, Nafion byproducts, and other potentially harmful contaminants found in the Cape Fear River.

Conventional treatment as with the existing plant does not effectively remove perfluorinated compounds such as GenX. Granular activated carbon adsorption (GAC), ion exchange (IX), and reverse osmosis are the technologies that remove per- and polyfluorinated alkyl substances and are hence studied in this report. GAC and IX are not very effective for certain other target compounds, particularly 1,4-dioxane, which has had high concentrations in the Cape Fear

River. Advanced oxidation process (AOP) can remove 1,4-dioxane, so AOP is included in GAC and IX options. AOP can be achieved using UV-AOP or using ozone with peroxide.

1.1.2 North Carolina State University Study of Emerging PFAS in Cape Fear Watershed

The first detections of perfluorinated compounds (PFAS) in the Cape Fear River were part of the Environmental Protection Agency's Third Unregulated Contaminant Monitoring Rule (UCMR-3) required monitoring from 2013 to 2015 administered by the United States Environmental Protection Agency (EPA). The results raised interest from researchers including Dr. Detlef Knappe at North Carolina State University (NCSU), who worked with students to assess the variety and distribution of PFAS throughout the Cape Fear River watershed as reported in multiple publications by Mei Sun, et al in 2016. As a result of research completed by Dr. Knappe and Dr. Mei Sun, it was discovered in 2016 that target contaminants found in the Cape Fear River were being found in high concentrations in the drinking water for the communities that withdrew raw water from the lower portion of the Cape Fear River at the Kings Bluff Pump Station, despite undergoing a treatment process.

The new PFAS contaminants including GenX were noted to be downstream of a Fluorochemical manufacturer (Mei Sun et al 2016) located upstream of the County's raw water intake. The wastewater discharge includes perfluorinated compounds (PFAS) and other industrial process waste streams, containing GenX, PFASs, Nafion byproducts, and other potentially harmful contaminants. The Fayetteville Works Plant discharges this wastewater via a permitted outfall under the State's National Pollutant Discharge Elimination System (NPDES) program and it is believed that these chemicals may have been released into the river for nearly four decades.

While a Ph.D. student at NCSU, Dr. Sun published an important research paper that discussed how long-chain PFASs are being replaced by short-chain PFAS and fluorinated alternatives such as GenX. The paper indirectly spurred attention to the issue of GenX in the Cape Fear River, after being reported by multiple news outlets. Relevant technical findings by Mei Sun et al., 2016, include:

1. For 10 legacy PFAS and seven recently discovered perfluoroalkyl ether carboxylic acids (PFECAs):
    a. Confirming the presence and concentrations of these contaminants in the Cape Fear River watershed
    b. The effectiveness of conventional and some advanced treatment processes on removing these contaminants
    c. The effectiveness of treating these contaminants with PAC
2. In the headwater region of the Cape Fear River basin, PFECAs were not detected in the raw water where sampled, but concentrations of legacy PFAS were high.
3. In raw water drawn by the Sweeney WTP, the mean concentration of GenX was reported to be 631 nanograms per liter (ng/L) (n = 37). Six other PFECAs were detected, with three exhibiting chromatographic peak areas up to 15 times that of GenX.

4. At the Sweeney WTP, where advanced ozone treatment is utilized, PFECA removal by coagulation, ozonation, biofltration, and disinfection was negligible.
5. The absorbability of PFAS by PAC increased with increasing chain length.

1.1.3 North Carolina House Bill 56 Study of GenX

North Carolina House Bill 56 (HB56) issued a mandate and funding for the current study being conducted by Cape Fear Public Utility Authority (CFPUA) to evaluate water treatment technology to remove GenX at the Sweeney WTP. Per HB56, CPFUA is to perform this work in coordination with Brunswick County Public Utilities and Pender County Utilities. The data from this study has been made public and a final report on this HB 56 pilot testing study is required by April 1, 2018.

HB56 also funded the University of North Carolina at Wilmington to identify and quantify GenX, the extent to which it biodegrades or bioaccumulates, and the risk the contaminant poses to human health; this study is ongoing.

It is important to note that the HB 56 pilot testing study is limited primarily to PFAS (some data on pharmaceuticals and personal care products (PPCPs) and endocrine disruptive compounds (EDCs) is available). The study includes pilot-plant evaluations of two treatment technologies for removal of PFAS: GAC and ion exchange (IX). Interim results from the HB 56 study are presented in the GAC and IX sections of this report.

1.1.4 North Carolina Department of Environmental Quality Division of Water Resources Studies on 1,4-Dioxane

As with PFAS, it was UCMR-3 that first required utilities to test for 1,4-dioxane from 2013 to 2015. Dr. Detlef Knappe further researched the UCMR-3 findings by testing and reporting on 1,4-dioxane concentrations across the Cape Fear River watershed. This attracted much public attention and “alerted”, the North Carolina Department of Environmental Quality (NCDEQ) to the issue in March 2014. As a result, NCDEQ Division of Water Resources (DWR) performed studies of 1,4-dioxane in the Cape Fear River (Ruhlman and Hill (2016), Wrenn and Hill (2017)). In advance of regulation for either water or wastewater, the State has been helping to identify sources and adding 1,4-dioxane monitoring to NPDES permits to indirectly lower concentrations by identifying and working with source contributors, many of which have reduced their 1,4-dioxane discharges.

1.2 Scope of Work

In response to the increased concern over water quality in the Cape Fear River, Brunswick County contracted CDM Smith to study and recommend a plan to improve treatment and removal of contaminants of concern during the planned capacity expansion. The following objectives were established for the project:

- Determine a subset of the target contaminants (TC) from the lower Cape Fear River that will be the focus of the project, including but not limited to the following contaminants:
  - Primary Target Contaminants: Per- and Polyfluoroalkyl substances (PFASs)

  - *GenX and other new PFAS from the Mei Sun 2016 Article on occurrence in the Cape Fear River (PFMOAA, PFMOPrA, PFMOBA, PFPrOPrA (GenX), PFO2HxA, PFO3OA, and PFO4DA)*
  - *Nafion by-products*
  - *Others PFAS.*
- Secondary Target Contaminants
  - *1,4-Dioxane*
  - *N-Nitrosodimethylamine (NDMA)*
  - *General background Pharmaceuticals and Personal Care Products (PPCPs) and Endocrine Disruptive Compounds (EDCs)*
  - *Hexavalent Chromium*
  - *Brominated compounds*

- Establish treatment goals for the TC.
- Evaluate feasible treatment alternatives for the removal of TC at the Northwest WTP.
- Recommend a plan to improve treatment and the removal of TC at the Northwest WTP, including a planning-level opinion of probable construction cost estimate for the recommendation.
- Provide the County with an updated planning-level opinion of probable construction costs to expand the Northwest WTP to 36 mgd.

To meet the project objectives, the project approach includes the following tasks:

- Desktop Treatment Alternative Analysis
- Pilot and Bench-Scale Testing
- Treatment Recommendation and Final Report
- Pre-Permit Application Services
- Concentrate Discharge Dilution Study, Toxicity Testing, and NPDES Permit

This report presents a conceptual design of the plant expansion, identification of several TC associated with water from the lower Cape Fear River, establishment of preliminary treatment goals, and evaluation of water treatment technologies that have been proposed for the removal of these TCs. The evaluation of treatment alternatives is based on a desktop analysis. The analysis is based on experience at similar facilities along with assumptions and extrapolations that could be confirmed by bench-scale and/or pilot-scale testing before full-scale implementation where not addressed by current pilot testing. To present the results, this report is divided into the following sections:

Section 2	Target Contaminants and Preliminary Treatment Goals
Section 3	Granular Activated Carbon
Section 4	Ion Exchange
Section 5	Reverse Osmosis
Section 6	Ozone with Biofiltration
Section 7	Ultraviolet Radiation/Advanced Oxidation Process
Section 8	Existing Facilities Expansion
Section 9	Preliminary Findings, Planning-Level Cost Estimates, and Recommendations
Section 10	Implementation Plan

Section 2

Target Contaminants and Preliminary Treatment Goals

2.1 Target Contaminants

For presentation and evaluation, target contaminants have been identified and have been separated into primary target contaminants and secondary target contaminants:

- Primary Target Contaminants: Per- and Polyfluoroalkyl substances (PFAS)
  - GenX and other PFAS from the Mei Sun 2016 Article on occurrence in the Cape Fear River (PFMOAA, PFMOPrA, PFMOBA, PFPrOPrA (GenX), PFO2HxA, PFO3OA, and PFO4DA)
  - Nafion by-products
  - Other PFAS compounds
- Secondary Target Contaminants
  - 1,4-Dioxane
  - NDMA
  - General background Pharmaceuticals and Personal Care Products (PPCPs) and Endocrine Disruptive Compounds (EDCs)
  - Hexavalent chromium
  - Brominated Compounds

A description of these potential target contaminants follows.

2.1.1 Per- and Polyfluoroalkyl Substances (PFAS)

PFASs are a group of organic chemical compounds that are used in a wide variety of manufactured products including firefighting foams, coating for food packaging, ScotchGard™, and Teflon™, among other products (Fulmer 2016). PFAS are extremely resistant to degradation which helps these products resist stains, grease, and water. As referenced by Dickenson and Higgins (2016), PFAS can be found in source waters outside of industrial releases including street and stormwater runoff and land application of contaminated biosolids. Lists of compounds that make up PFASs, molecular weight, and chemical formula can be found in several references (including Dickenson and Higgins 2016; Sun et al. 2016; and Water Research Foundation 2016). A specific type of PFAS that is of interest is a chemical known by its trade name as GenX, which was detected by Sun et al. (2016) in the Cape Fear River at an average concentration of 631 nanograms per liter (ng/L).

2.1.2 GenX

GenX is a synthetic industrial chemical that was developed to replace PFOA, also used in products such as Teflon™. GenX is used as a processing aid for the production of fluoropolymers like Teflon™. According to Heydebreck et al. (2015), it is the ammonium salt of perfluoro-2-propoxypropanoic acid (PFPrOPrA). PFPrOPrA has the chemical formula $C_6HF_{11}O_3$, a molecular weight of 330 daltons, and Chemical Abstracts Service (CAS) Registry No. 13252-13-6 (Fulmer 2016). According to *The Intercept*, June 17, 2017 (Lerner 2017).

2.1.3 Nafion By-Products

Nafion by-products 1 and 2, a group of synthetic industrial chemicals similar to GenX, are two additional chemicals that have been detected in the Cape Fear River after GenX was first detected. Nafion itself is produced by the Chemours Company. Nafion was first developed in the 1960s by Dr. Walther Grot at DuPont by modifying Teflon™. Nafion is used in chemical processing, fuel cell technology, hydrogen production, paints, and chlorine production (Winkel 2018). Nafion was the first synthetic polymer developed with ionic properties, combining the physical and chemical properties of its Teflon™ base material with ionic characteristics giving it resistance to chemicals as it does not easily release fragments or degrade into its surroundings (Perma Pure 2014). Nafion can withstand extremely high working temperatures, up to 190 degrees Celsius, and functions well as an ion exchange polymer (Perma Pure 2014). Nafion is developed by the polymerization of a perfluorinated vinyl ether comonomer with TFE, resulting in the chemical formula $C_7HF_{13}O_5S - C_2F_4$ (Mauritz and Moore 2004).

2.1.4 1,4-Dioxane

1,4-Dioxane is a synthetic industrial chemical that is a by-product present in many goods including paint strippers, dyes, greases, antifreeze, and in some consumer products including deodorants, shampoos, and cosmetics (ATSDR 2012; Mohr 2001). Traces of 1,4-dioxane may also be present in food supplements due to food-containing residues from packaging adhesives and or food crops treated with pesticides containing 1,4-dioxane. It is completely miscible in water and is unstable at high temperatures and pressures and may be explosive in nature with long periods of exposure to light or air (EPA 2006). Dr. Knappe began testing for 1,4-dioxane in NC surface water in 2013 and approached drinking water utilities and the North Carolina Department of Environmental Quality (NCDEQ) in 2014 to present evidence that 1,4-dioxane was present in the Cape Fear River basin waterways feeding public drinking water supplies (Clabby 2016).

2.1.5 N-Nitrosodimethylamine

N-Nitrosodimethylamine (NDMA) is a semi-volatile organic chemical that forms in industrial processes and is not produced in pure form or commercially used in the United States, except for research purposes (ATSDR 1989; HSDB 2012). NDMA has the CAS Registry No. 62-75-9, and a molecular weight of 74.08 grams per mol (g/mol). It was previously used in the production of rocket fuel, antioxidants, and additives for lubricants and softeners. NDMA is an unintended byproduct of the chlorination of wastewater and drinking water treatment plants using disinfection treatment technology (Bradly et al. 2005, Mitch et al. 2003).

2.1.6 Pharmaceuticals and Personal Care Products and Endocrine Disrupting Compounds

As mentioned above with 1,4-dioxane, PPCPs and EDCs are present in the environment and have been detected in many water bodies around the world. The presence of these compounds in the environment was discussed and published by Stumm-Zollinger et. al 1965; they indicated that steroid hormones are not completely eliminated by wastewater treatment. As reproductive efficiency of fish atment facilities declined in the 1990s, PPCPs and EDCs in the environment came to the forefront (Snyder et al., 2010). Acetaminophen, ibuprofen, caffeine, and atrazine are all well-known PPCPs and EDCs found in source drinking water (Snyder et al., 2010).

2.1.7 Hexavalent Chromium

Hexavalent chromium (chromium-6) is usually produced in industrial processes and is added to alloy steel to increase hardenability and corrosion resistance (USDL 2018). Chromium-6 may also be used in dyes, paints, inks, and plastics and as an anticorrosive agent added to paints, primers, and coatings. According to a report by the Engineering Working Group in September 2016, the tap water supplied to over 218 million people contains levels of chromium-6 above 0.02 parts per billion (ppb); a public health goal of 0.07 ppb has been set by North Carolina and New Jersey. Chromium-6 has a health advisory level of 100 micrograms per liter (µg/L) (EPA 2012 DSWHA).

2.1.8 Brominated Compounds

Bromide-based compounds, including bromomethane and bromochloromethane, can occur both naturally in coastal environments and can be man-made as well. These chemicals are disinfection by-products originating from the group of four chemicals known as trihalomethanes. Bromomethane, CH_3Br, also known as methyl bromide, is mostly used as a solvent in the planting and manufacturing of pesticides. Between 2010 and 2015, bromomethane was detected in the water of 345 utilities located in 32 states with a total service area population of approximately 5.2 million people (Environmental Working Group 2018).

Bromochloromethane, CH_2BrCl (Halon 1011), was developed to be a less toxic version of carbon tetrachloride to be used in fire-extinguishing but banned by the National Fire Protection Agency (NFPA) in favor of using safer halons.

Bromate, BrO_3-, is an ion that is contained in compounds such as sodium-bromate and potassium-bromate. Bromates are formed most commonly during water treatment in the ozone process when ozone is used to treat the water source containing naturally occurring bromide. Bromate formation is dependent on many factors including ozone concentration, bromide ion concentration, water pH, and contact time. Both the World Health Organization (WHO) and EPA have set the MCL in public water systems at 10 ppb; bromate is included in the current EPA review of disinfectant by-product regulations so the current MCL level will be reconsidered in the near future.

2.2 Target Contaminant Identification

Many contaminants exist at concentrations that may represent a human health risk in rivers and lakes utilized as drinking water source; yet these contaminants are unregulated by EPA or state agencies. Creating new regulations for water contaminants has proven to be a lengthy and costly process for the EPA, with 15 years being the average time it takes to create new regulations for a drinking water contaminant. As a result, some states have created additional regulations for the removal of contaminants, in addition to the national drinking water regulations. For example, the North Carolina Department of Health and Human Services has established an advisory level of 140 ng/L for the concentration of GenX in drinking water.

The Unregulated Contaminant Monitoring Rule (UCMR) is a data collection program administered by EPA to collect data for contaminants suspected to be present in drinking water and may have impact on public health, but do not have regulations or health-based standards set under the Safe Drinking Water Act (SDWA). These contaminants are sometimes called Contaminants of Emerging Concern (CECs), but are not necessarily new contaminants to society. The UCMR monitoring provides EPA with nationally representative data on the occurrence of contaminants in drinking water, the number of people potentially being exposed, and an estimate of the levels of that exposure.

UCMR-3 took place from 2013 to 2015. UCMR-4 will begin in 2018 and continue to 2020. UCMR-3 asked participating utilities to collect data on raw and treated water for thirty contaminants.

To refine the list of Target Contaminants for this analysis, information was reviewed from the following sources:

- Historical water quality data
- UCMR data
- Related and relevant studies and academic research findings
- Data collected by NCDEQ

The list of contaminants found in the Cape Fear River were cross-referenced with the following criteria:

- Contaminants believed to have negative impacts on human health as indicated by an established limit or health advisory level at the federal or state level, including values from other states
- Contaminants at or above concentrations that are regulated (EPA, other states) for health impacts. Contaminants demonstrated by prior testing to be well below regulated levels were not included as target contaminants for testing.
- Contaminants that have approved methods for being measured in a lab
- Contaminants being evaluated for future regulations by the EPA (UCMR-3, -4)

A summary of the target contaminants that have health advisory criteria and are being monitored is presented in **Table 2-1**. Occurrence data confirm that treatment decisions are mainly affected by PFAS and 1,4-Dioxane. Concentrations of NDMA, Cr(VI), and PPCPs were found to be low in the lower Cape Fear River.

2.3 Preliminary Treatment Goals

For the target contaminants in this study, it is necessary to set treatment goals for removal. We understand the County's goal for this project is to select the best combination of PFAS removal efficiency and cost for implementation at the Northwest WTP. Accordingly, the comparison of options included herein are based on removing at least 90 percent of GenX and consequently over 90 percent of most of the PFAS contaminants. Certain technologies (GAC and IX) discussed herein are costed for 90 percent GenX removal, and will not remove 90 percent of several other PFAS (e.g. PFMOAA and PFO2HxA) though the majority of PFAS will have at least 90 percent removal. Since removing 90 percent or more of the PFAS requires a major project, it is logical to assess removals for other contaminants while comparing the technologies; hence the secondary target contaminants are also evaluated. These secondary target contaminants are compounds known to occur in the lower Cape Fear River that EPA has given some indication of potentially regulating in the future. Higher or lower percent removal targets can be selected by the County if desired. Changing the percent removal targets would affect all options capital and operations and maintenance (O&M) costs.

Table 2-1 Preliminary List of Target Contaminants for Brunswick County Northwest WTP Treatment Evaluation

Contaminant	Health Advisory Level (µg/L)	Standards and Advisory Level References and Comments	Cape Fear River Occurrence Value (µg/L), unless otherwise specified	Comment
1,4-dioxane	0.46 (screening level for tap water) 3 (NC DEQ groundwater standard)	EPA 2017b, Regional Screening Level (RSL) Summary Table 15A NCAC 02L .0202, Groundwater Standards	0.9 - 7.7	Knappe, WRRI Report
Perfluorobutanoic acid (PFBA)			<0.01 - 0.104, 0.023 - 0.0243	Sun et al. 2016, HB 56 Pilot
Perfluoropentanoic acid (PFPeA)			<0.01 - 0.116, 0.0556 - 0.0587	Sun et al. 2016, HB 56 Pilot
Perfluorohexanoic acid (PFHxA)			<0.01 - 0.024, 0.0645 - 0.0652	Sun et al. 2016, HB 56 Pilot
Perfluoroheptanoic acid(PFHpA)			<0.01 - 0.024, 0.0423 - 0.0426	Sun et al. 2016, HB 56 Pilot
Perfluorooctanoic acid (PFOA)	0.07*	EPA health advisory for PFOS + PFOA = 0.070 µg/L	<0.01 - 0.017, 0.0233 - 0.0237	Sun et al. 2016, HB 56 Pilot
Perfluorooctanesulfonic acid (PFOS)	0.07*	EPA health advisory for PFOS + PFOA = 0.070 µg/L	<0.025 - 0.040, 0.02 - 0.0214	Sun et al. 2016, HB 56 Pilot
Perfluorononanoic acid(PFNA)	0.013	NJ MCL	<0.01, 0.052 - 0.065	Sun et al. 2016, HB 56 Pilot
Perfluorodecanoic acid (PFDA)			<0.01, 0.047 - 0.059	Sun et al. 2016, HB 56 Pilot
Perfluoroundecanoic acid(PFUnA)			ND	HB 56 Pilot
Perfluorododecanoic acid(PFDoA)			ND	HB 56 Pilot
Perfluorotridecanoic acid (PFTrDA)			ND	HB 56 Pilot
Perfluorotetradecanoic acid (PFTeDA)			ND	HB 56 Pilot
Perfluorohexadecanoic acid (PFHxDA)			ND	HB 56 Pilot
Perfluorobutanesulfonic acid (PFBS)			<0.01, 0.059 - 0.063	Sun et al. 2016, HB 56 Pilot
Perfluoropenanesulfonic acid (PFPeS)			0.013	
Perfluorohexanesulfonic acid (PFHxS)	0.027 - 0.093	MN Guidelines - TX Guidelines (Lower Limit - Upper Limit)	<0.01 - 0.014, 0.092 - 0.093	Sun et al. 2016, HB 56 Pilot
Perfluoroheptanesulfonic acid (PFHpS)			ND	HB 56 Pilot
Perfluorononanesulfonic acid (PFNS)			ND	HB 56 Pilot
Perfluorodecanesulfonic acid (PFDS)			ND	HB 56 Pilot
N-ethyl perfluorooctanesulfonamidoacetic acid (NEtFOSAA)			ND	HB 56 Pilot
N-methyl perfluorooctanesulfonamidoacetic acid (NMeFOSAA)			ND	HB 56 Pilot
Perfluorooctane sulfonamide (PFOSA)			ND	HB 56 Pilot
Perfluoro-2-proxypropanoic acid (GenX)	0.140 (NC DEQ health goal)	0.140 µg/L is NC DEQ health goal for exposure in drinking water	0.055 - 4.56, 0.028 - 0.029	Sun et. al 2016, HB 56 Pilot
Perfluoro-4-methoxybutanoic acid (PFMOBA)			<0.01	Late 2017, NCSU/EPA
Perfluoro-3-methoxypropanoic acid (PFMOPrA)			<0.01	Late 2017, NCSU/EPA
Perfluoro-2-methoxyacetic acid (PFMOAA)			0.3 - 0.4	Late 2017, NCSU/EPA
Perfluoro(3,5-dioxahexanoic) acid (PFO2HxA)			0.01 - 0.072	Late 2017, NCSU/EPA
Perfluoro(3,5,7-trioxaoctanoic) acid (PFO3OA)			<0.01 - 0.015	Late 2017, NCSU/EPA
Perfluoro(3,5,7,9-tetraoxadecanoic) acid (PFO4DA)			<0.01	Late 2017, NCSU/EPA
Nafion BP1(Other)			0.052	EPA, October 19, 2017
Nafion BP2(Other)			0.01 - 0.016	Late 2017, NCSU/EPA

Section 3

Granular Activated Carbon

3.1 Process Description

Granular activated carbon (GAC) has been identified as a potential treatment technique for the removal of PFAAs and PFSAs (Dickinson 2016). GAC removal of the target contaminants occurs through adsorption and/or biofiltration. Granular media is produced from carbonaceous material such as wood, coal, and coconut shells which is activated by heat. GAC is used in water treatment to remove a wide variety of chemicals, taste and odor precursors, color forming organics, and some disinfection by-product precursors. **Figure 3-1** provides a series of magnifications of the GAC particle.

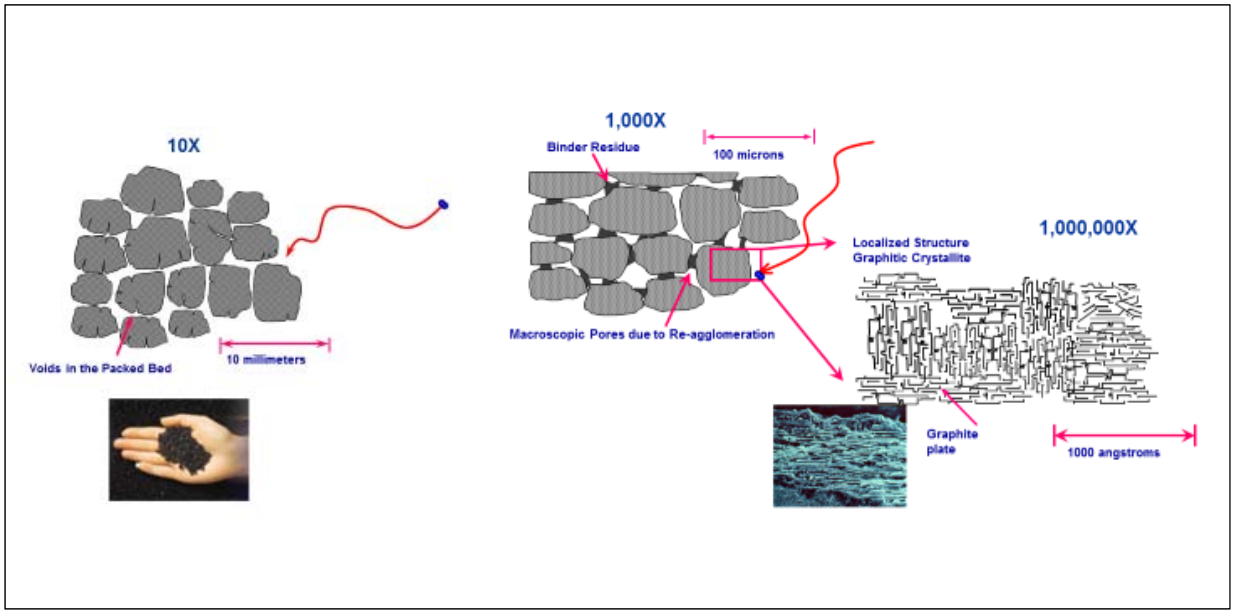

Figure 3-1
Granular Activated Carbon (courtesy of Calgon Corporation)

GAC can be added to the treatment process through two possible methods:

- Gravity filters
- Pressure contactors

Equipment included in GAC treatment are shown in **Figures 3-2 and 3-3**.

Figure 3-2
GAC Gravity Filter

Figure 3-3
GAC Pressure Contactors

Design of the GAC filters and contactors is affected by the following parameters:

- Loading rate
- Empty Bed Contact Time (EBCT) – sufficient time is needed for the contaminants to be adsorbed onto the GAC for adequate removal
- Media replacement/regeneration frequency

The evaluation of replacing the anthracite with GAC in the existing filters at the Northwest WTP indicates that insufficient EBCT would be provided and that the quantity of media would require frequent replacement; therefore, replacement of the existing media alone with GAC for target contaminant removal is not recommended.

GAC application post-filter is a feasible alternative. Filtration would continue with the existing filters and contaminant removal post-filtration will occur through GAC adsorption.

Figure 3-4 provides a flow schematic indicating how GAC can be incorporated into the existing treatment process. For the Northwest WTP, the use of pressure contactors should be more cost-effective than the construction of new concrete gravity filters. Hence, the GAC option evaluation focuses on post-filter pressure contactors.

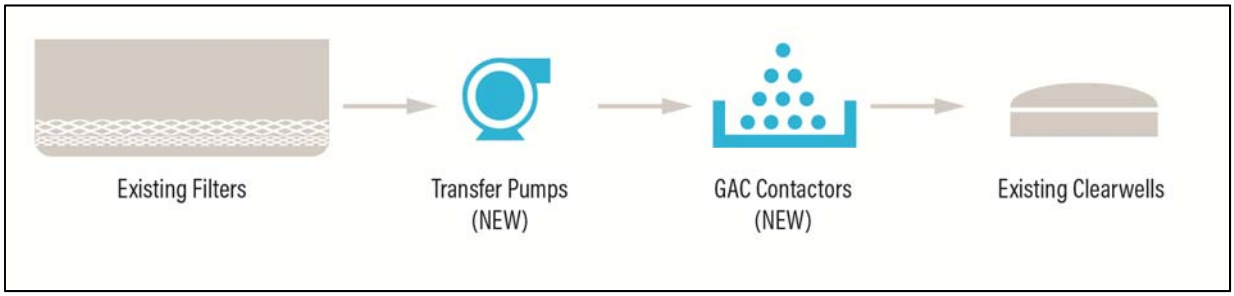

Figure 3-4
Post-Filter GAC Process Flow Schematic

Each GAC pressure contactor would include a steel tank with elliptical top and bottom heads, supported by four structural steel legs. The GAC pressure contactors would be furnished as a packaged system, with the manufacturer supplying all the controls, piping, valves, and appurtenances to minimize the connection points for the backwash system. Each vessel would include the following connections:

- Top head
  - Inlet for filtered water and backwash water discharge and vent
  - Inlet for media loading
- Bottom head
  - Backwash inlet
  - Outlet for media unloading
  - Manway

- Side wall
  - Outlet for media unloading
  - Sample taps at even increments across the GAC bed
  - Manway

The water from the existing filters would flow from the inlet header through an inlet valve and piping to the top of the GAC pressure contactors. The filtered water would be treated by flowing through GAC. The filtrate would be collected by an underdrain system located in the bottom of the tank, which also serves as the inlet distributor for the backwash system. The filtrate discharges to the filtrate header.

3.2 Application Experience

Full-scale testing conducted at two sites as part of the Water Research Foundation project (Dickinson and Higgins 2016) indicate that GAC is effective at removing longer chain PFAAs and PFSAs over PFCAs; GAC was less effective for the removal of shorter chain PFAS.

The House Bill 56 pilot study at the Sweeney WTP is evaluating the effectiveness of GAC for the removal of the PFAS and CECs. The GAC pilot test scenarios and media are listed in **Table 3-1**.

Table 3-1. House Bill 56 GAC Pilot Test Scenarios – Phase 1

Pilot Column	Pilot GAC Media	Contact Time (minutes)	Feed Water
1	Calgon F400	10	Settled water following intermediate ozonation (simulates replacing GAC in existing filters)
2	Calgon F300	10	Settled water following intermediate ozonation (simulates replacing GAC in existing filters)
4	Calgon F400	10	Effluent from biologically active filtration
5	Evoqua Aquacarb 1230CX	10	Effluent from biologically active filtration

Source: Black & Veatch. January 9, 2018. Final Progress Update No. 3 Emerging Contaminants Treatment Strategy Pilot Study, prepared for Cape Fear Public Utility Authority

Phase 1 of the tests results reported in Progress Report Update No. 3 dated January 9, 2018 indicate that PFAS were observed in the pilot GAC media effluent except for the long chain PFAS; breakthrough resulted after one month of testing. The HB 56 interim results are consistent with the Dickinson and Higgins (2016) results. The GenX breakthrough data versus time for the House Bill 56 (HB 56) pilot test results for GAC and IX are shown on **Figure 3-5**.

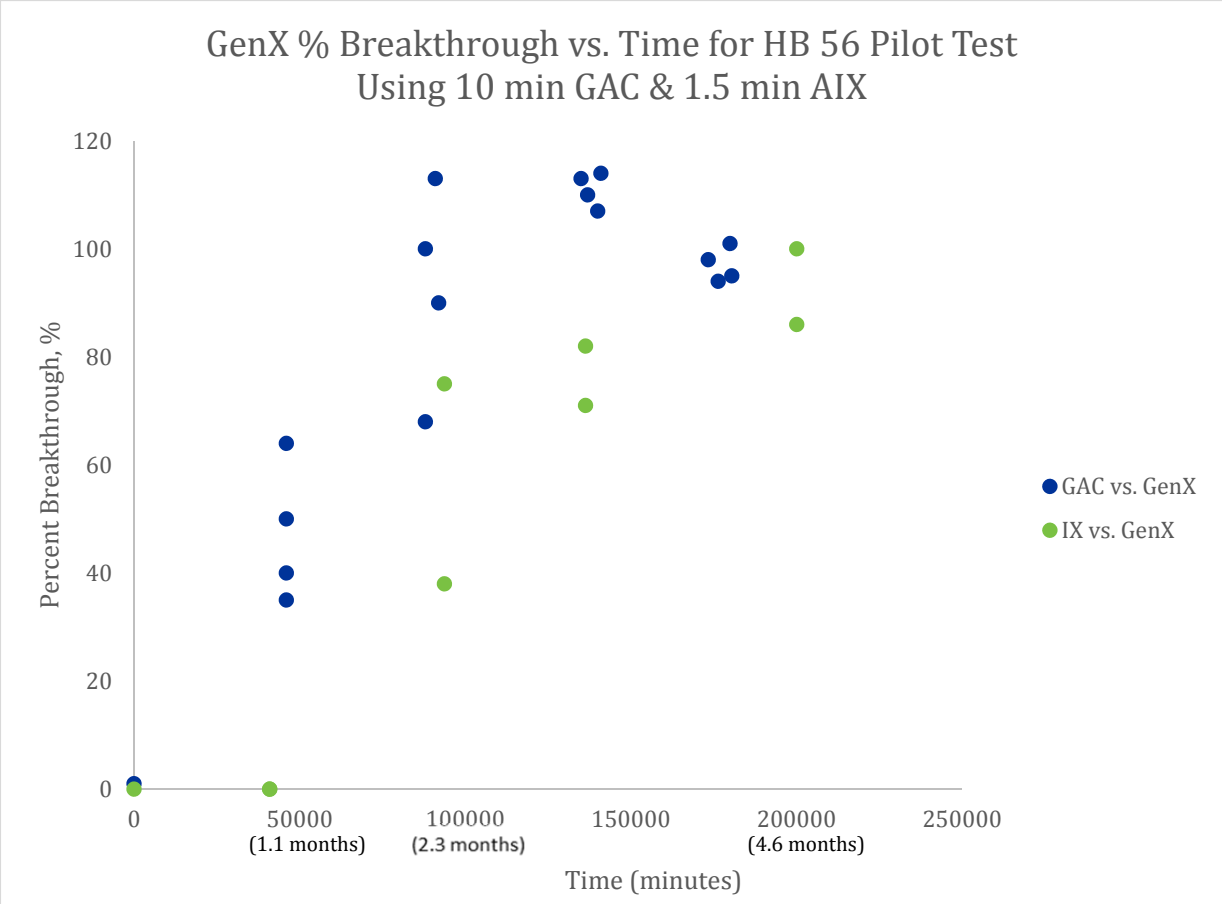

Figure 3-5
HB 56 Pilot GenX Breakthrough Versus Time Pilot Test Results

The second phase of the pilot study began on January 16, 2018 and includes the GAC media and contact time listed in **Table 3-2**. The EBCT is increased from 10 to 20 minutes by flowing through two columns (10 and 11) in series. The pilot testing is ongoing and expected to continue through the first quarter of 2018.

Table 3-2. HB 56 GAC Pilot Test Scenarios – Phase 2

Pilot Column	Pilot Media	Contact Time (minutes)	Feed Water
10*	Calgon Filtasorb 400	10	Settled water following intermediate ozonation (simulates replacing GAC in existing filters)
11*	Calgon Filtasorb 400	10	Settled water following intermediate ozonation (simulates replacing GAC in existing filters)
12	Cabot Hydrodarco 4000	10	Effluent from biologically active filtration
13	Cabot GAC 400	10	Effluent from biologically active filtration

Source: Black & Veatch. February 26, 2018. *Final Progress Update No. 4 Emerging Contaminants Treatment Strategy Pilot Study*, prepared for Cape Fear Public Utility Authority

Parsons performed pilot testing on a residential well in Fayetteville, North Carolina. The results submitted to NCDEQ on January 11, 2018 indicate that GAC was effective in removing C3 dimer (GenX) and other PFAS (Garon (2018)). A WHS-400 GAC adsorption system consisting of dual carbon contactors. Parsons also conducted bench-scale tests to evaluate the removal of C3 dimer using Calgon Carbon F600 GAC.

GenX breakthrough curves from various studies are shown on **Figure 3-6**; these curves were assembled and compared by Dr. Detlef Knappe of North Carolina State University to illustrate the HB 56 pilot test data with 10 minutes GAC EBCT and 1.5 minutes EBCT for the ion exchange along with projected curves from Calgon Carbon and full-scale results from another utility. The full-scale results and the HB 56 pilot results are in general agreement that 10 minutes EBCT of GAC starts passing GenX after 1 month and the adsorptive capacity for GenX is largely spent after two months for the GAC's tested.

The accelerated column test (ACT) is a bench-scale test with crushed GAC to expedite the test (similar to the rapid small-scale column test (RSSCT)). The ACT tests were done by Calgon Corporation. The ACT tests show longer GAC life for a 20-minute EBCT, particularly for one of the GACs tested. Separate GAC testing by Parsons reported in Chemours letter dated January 11, 2018 to NCDEQ showed their ACT tests did not agree with their pilot test findings. Given the detail of the HB 56 study and the general agreement of the Pender full-scale results, post-filter GAC application in this report assumes that two 10-minute EBCT GAC vessels in series would allow the first 10-minute vessel to run for two months before changing, so the effective life of 20 minutes of GAC is 4 months.

Therefore, for the Northwest WTP, thirty GAC pressure contactor would be needed, assuming 40,000-pound vessels and a density of 28 pounds per cubic foot (lbs/ft^3). The media would be replaced in one set of vessels after two months and the lead/lag vessel would be alternated. After the next two months, the media in the second set of vessels would be replaced, and the lead/lag vessel would again be alternated.

GAC alone is not effective for the removal of all target contaminants. For example, GAC does not remove 1,4-dioxane so AOP is required in addition to GAC. Also, GAC is less effective for PFMOAA and PFO2HxA than for GenX. However, post-filter GAC in combination with other treatment alternatives, such as ozone with biofiltration, ultraviolet radiation and advanced oxidation (UV/AOP), are discussed in Section 9 and has merit in achieving 90-percent removal of most of the target contaminants.

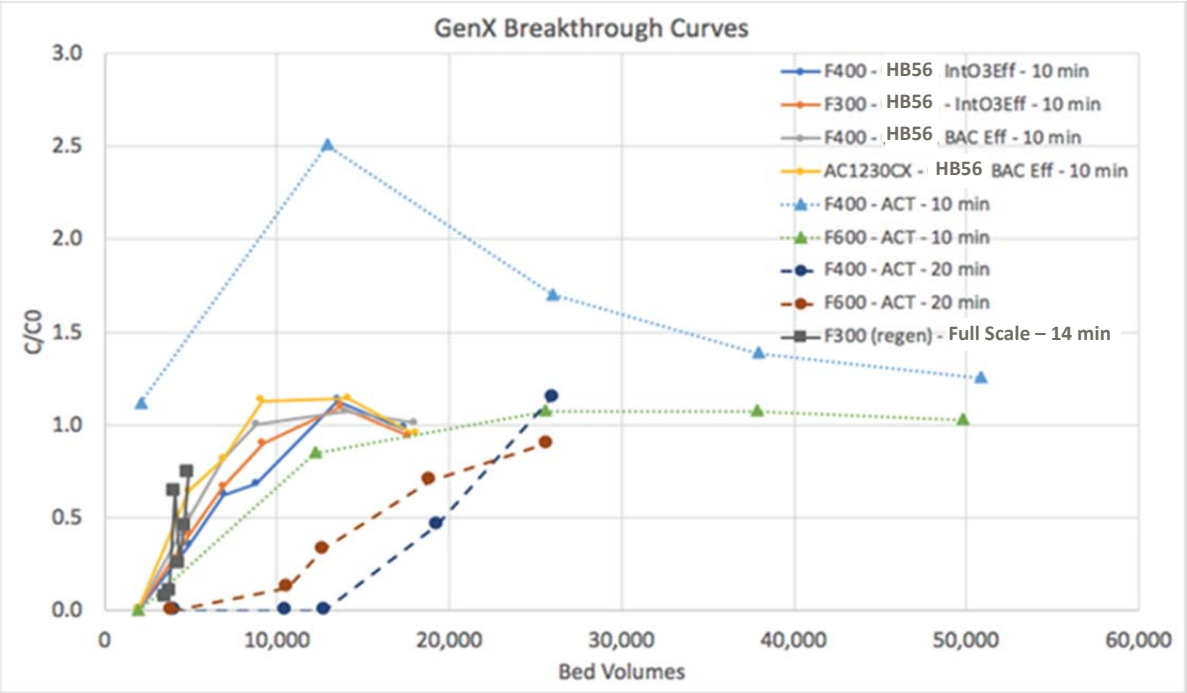

Figure 3-6
GenX Breakthrough Curves

3.3 Summary

Advantages and disadvantages associated with GAC treatment are provided in **Table 3-3.**

Table 3-3. Advantages and Disadvantages of GAC Treatment

Advantages	Disadvantages
Effective for strongly adsorbing compounds - Many SOCs/PPCPs/EDC such as pesticides, PFOA, PFOs	Much less effective (shorter life) for Gen-X (Above non-detect within a month) in the HB 56 10 min EBCT tests. Less effective for PFMOAA and PFO2HxA than for GenX.
EPA termed BAT for many SOCs	Not very effective for 1,4 dioxane and some other compounds. Consequently, UV-AOP or Ozone -AOP are required in addition to GAC to achieve target contaminant removals.
Some bio-removal continues long after adsorptive sites are filled	Amount removed decreases with time as adsorptive sites are filled
Proven Process on Cape Fear River source water	Following a sudden large drop in concentration of a compound like Gen-X in the Influent, the GAC releases some of the compound as it seeks the new equilibrium
	Spent GAC requires disposal or reactivation

Section 4

Ion Exchange

4.1 Process Description

Ion exchange has been identified as a promising treatment technique for the removal of PFAAs and PFSAs (Dickinson and Higgins 2016). In the ion exchange process, chemicals are removed through a substitution reaction using a resin. The resins are composed of bead-shaped particles similar to those shown on **Figure 4-1**. The beads are typically 20 by 30 mesh (approximately 0.03 inch by 0.01 inch) which is similar in size to a grain of sand. Resin beds contain these beads in columns that are 4 to 5 feet deep. The resin is either negatively (anionic) or positively (cationic) charged:

- Anionic
  - Exchange for negative ions
  - Typically charged with hydroxide (OH-) or chloride (Cl-) ions
- Cationic
  - Exchange for positive ions
  - Typically charged with hydrogen (H+) or sodium (Na+) ions

The removal of the target contaminants requires an anionic exchange resin (AER).

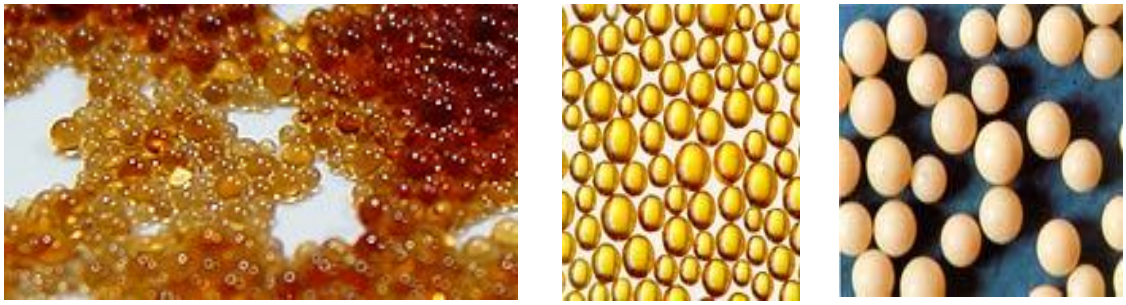

Figure 4-1
Ion Exchange Resin

Two options are being considered for implementing anionic ion exchange (IX) in the existing treatment process:

- Post-filter
- Post-filter in addition to GAC

Figure 4-2 provides a flow schematic indicating how IX can be incorporated into the existing treatment process at the Northwest WTP. The post-filter application in addition to GAC is intended to combine the benefits of both GAC and IX since IX is significantly better than GAC at removing many per- and polyfluorinated alkyl substances including GenX, and GAC offers much better removal of other secondary TC such as pharmaceuticals and personal care products (PPCPs) as well as providing the option of bio-removal for some organic compounds to reduce changeout frequency and associated costs.

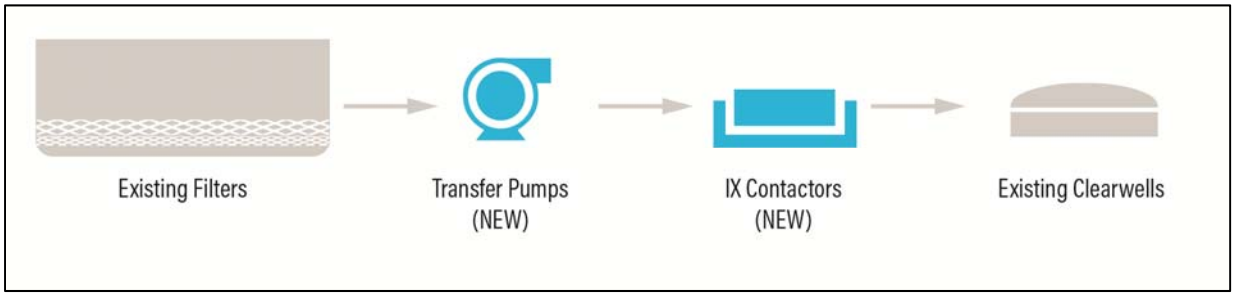

Figure 4-2
Post-Filter Ion Exchange Process Flow Schematic

Figure 4-3 provides a photograph of a typical ion exchange vessel. The ion exchange system is available as a package system manufactured by companies such as Evoqua, AdEdge Water Technologies LLC, Tonka Equipment Company, or the Purolite Company. The system would be rated for up to 1.5 mgd per vessel with 26 vessels to provide 3 minutes empty bed contact time at 36 mgd (1.5-minute vessel followed by a second 1.5-minute vessel). In the option of combining ion exchange with GAC, there would be 10 minutes of GAC followed by 1.5 minutes of anion exchange. The package system will include the following components:

- Ion exchange vessels with anion exchange resin
- Piping including face piping and common headers for influent, effluent, backwash, rinse, regenerant feed
- Process control valves, flow meters, flow control valves, and isolation valves
- Instruments to measure flow, pressure, and perform water sampling
- Master control panel and electrical components

The system will be supplied with a stainless steel hydraulic panel to monitor the system inlet and outlet for pressures and water sampling.

Figure 4-3
Ion Exchange Pressure Vessel

Each vessel will be provided with a grid consisting of a pipe header and laterals with orifices for proper flow distribution. The grid will be of a proven design, and properly supported and reinforced, located at the top of the resin bed. Cleaning provisions will also be provided, consisting of a separate feed/distribution system, properly sized and supported as required.

4.2 Application Experience

IX has been used in North Carolina as an effective water treatment technology; however, the applications have not involved the target contaminants of this project. IX is being used for removing natural organic matter to help lower concentrations of disinfection by-products in Dare County (Skyco plant), Currituck County, and the Castle Bay water system near Wilmington; the three systems use fixed bed IX for treatment of groundwater. Johnston County uses Magnetic Ion Exchange Resin (MIEX) for a surface water which is another example of IX resin applicability for removing natural organic matter.

Full-scale testing conducted at two sites as part of the Water Research Foundation project (Dickinson and Higgins 2016) indicate that IX is effective at removing longer chain PFAAs and PFSAs over PFCAs; IX was less effective for the removal of shorter chain PFAS. Dickinson and Higgins (2016) indicated that the two sites did not specifically target these contaminants; they recommended that full-scale testing be conducted to specifically target PFSAs where frequent resin changes would be required.

The HB 56 pilot testing at the Sweeney WTP is evaluating the effectiveness of IX for the removal of the PFAS and CECs. The pilot test resins that are being tested are listed in **Table 4-1**.

Table 4-1. HB 56 Ion Exchange Pilot Test Scenarios – Phase I

Testing Phase	Pilot Column	Pilot Media	Contact Time (minutes)	Feed Water
I[1]	5	Evoqua Aquacarb PSR-2	1.5	Effluent from biologically active filtration
1[1]	6	Evoqua Aquacarb 2304	1.5	Effluent from biologically active filtration
2[2]	7[3]	Purolite PFA694E	1.5	
2[2]	8[3]	Purolite PFA694E	1.5	
2[2]	9	Calgon CalRes 2301	1.5	

Sources:

1. Black & Veatch. November 3, 2018. *Final Progress Update No. 1 Emerging Contaminants Treatment Strategy Pilot Study*, prepared for Cape Fear Public Utility Authority
2. Black & Veatch. February 26, 2018. *Final Progress Update No. 4 Emerging Contaminants Treatment Strategy Pilot Study*, prepared for Cape Fear Public Utility Authority.
3. Operated in series to represent longer contact time.

Phase 1 results provided in Progress Update No. 4 dated February 26, 2018 indicate that PFAs were observed in the pilot IX resin effluent except for the long chain PFAS; the Phase 1 results are consistent with the Dickinson and Higgins (2016) results. The HB 56 Pilot Phase 1 results from

the first two resins tested showed that GenX had about 38 to 75% breakthough after 2.3 months and near 100% breakthrough for both resins after 4.6 months as shown in **Figure 4-4**.

PFASs with carboxylic acid function groups have shown early breakthrough; PFASs molecules with sulfonate functional groups have not shown breakthrough.

Three new IX pilot columns have been installed for the Phase 2 pilot testing to evaluate the performance of two additional resins and the effect of increasing EBCT on PFAS removal for both GAC and IX. To increase the EBCT, the flow will go through two columns in series, each with an EBCT of 1.5 minutes for the IX, resulting in a total EBCT of 3 minutes. The HB 56 pilot testing is ongoing and expected to continue through the first quarter of 2018.

Based on the HB 56 pilot test results, IX treatment is ineffective alone in removing some target contaminants, such as PPCPs. IX also does not remove 1,4 Dioxane so AOP is required along with IX. The use of IX in combination with other treatment technologies such as GAC and UV/AOP are discussed in Section 9 and has merit in achieving 90 percent removal of the target contaminants.

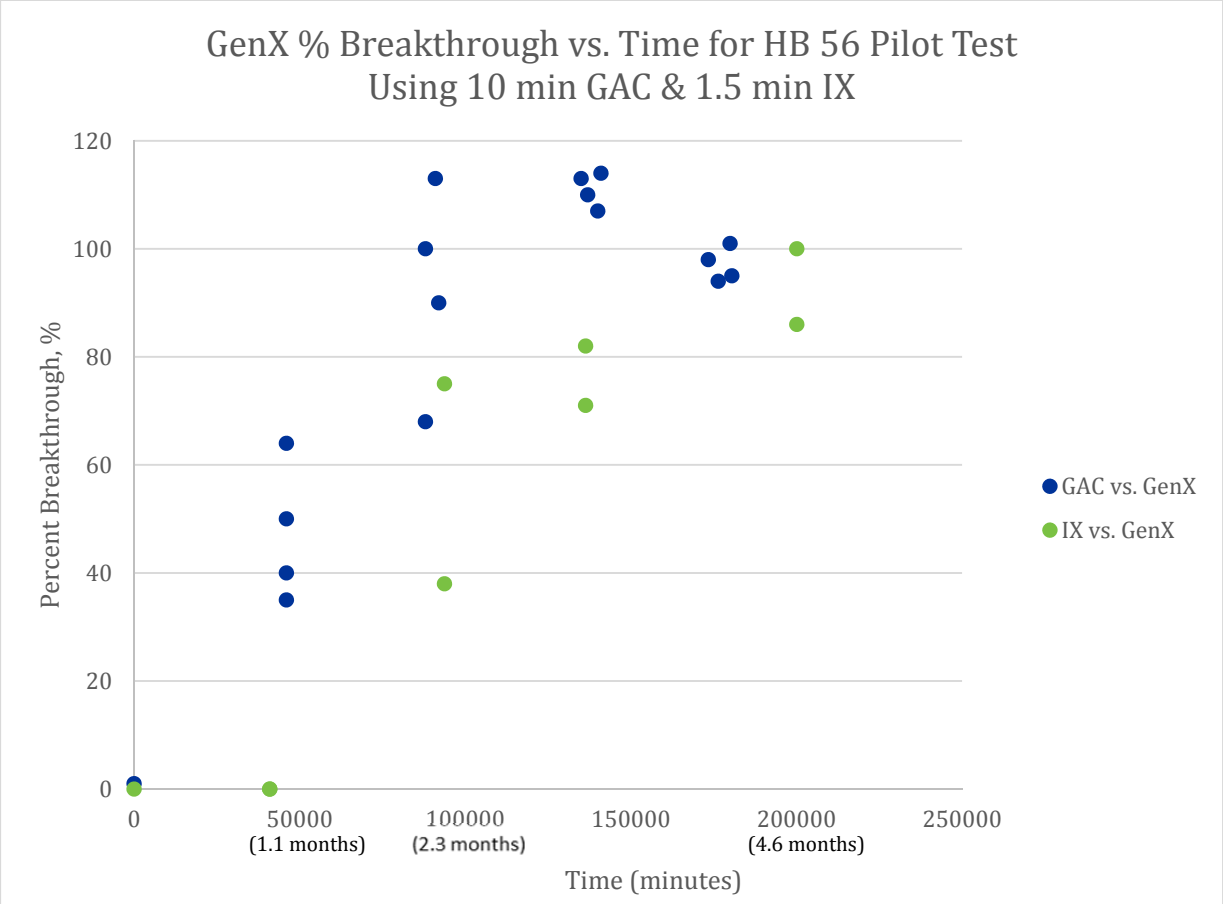

Figure 4-4
House Bill 56 Pilot Test Results for GenX Percent Removal with GAC and IX

4.3 Summary

Major advantages and disadvantages of IX treatment are listed in **Table 4-2**.

Table 4-2. Major Advantages and Disadvantages of Ion Exchange Treatment

Advantages	Disadvantages
Excellent Removal of Most PFAS – Better than GAC, especially for GenX	Not Effective for PPCPs hence GAC joint use with IX is needed if PPCP removal is desired
Extra Barrier for Anions – PFAS, organics, bromide, etc.	Spent IX resin requires disposal
Disinfection Byproduct Control (D/DBPR - Stages 1 and 2 and future 3/NDMA)	Not effective for 1,4 Dioxane hence AOP is required along with the IX

Section 5

Reverse Osmosis

5.1 Process Description

In reverse osmosis (RO), water molecules pass through a semi-permeable membrane (permeate) in the direction opposite of natural osmosis (fluid with low concentration diffusing into a fluid of higher concentration in an effort to reach equilibrium) by applying a hydrostatic pressure greater than the osmotic pressure. The rate water molecules diffuse through the membrane is higher than the rate salts, metals, and contaminants diffuse through the membranes, so the result is permeate with a lower concentration of dissolved constituents. RO can be implemented after the granular media filters at the Northwest WTP to reduce dissolved contaminants as shown in **Figure 5-1**.

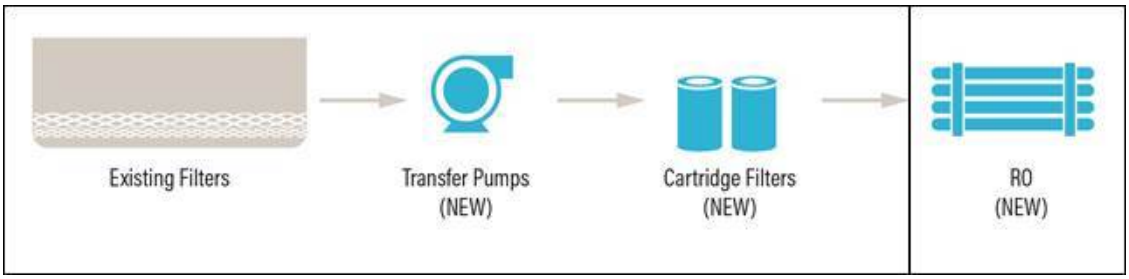

Figure 5-1
Post-Filter RO Process Flow Schematic

Figure 5-2 provides an example of a treatment process schematic for a two-stage RO system treating feedwater with minimal suspended solids. Similar RO systems are used extensively throughout the United States to remove total dissolved solids, hardness, metals, color, organics and radionuclides. Hundreds of RO facilities have been constructed to treat brackish or hard water to augment scarce water supplies. RO treatment plants range in capacity from a few hundred gallons per minute (gpm) to 100 mgd.

RO systems use a semi-permeable membrane that rejects dissolved ions, organics, and metals using a combination of ionic charge and molecular size. The RO membranes being proposed for this project and being tested in the pilot study are standard commercially available brackish water RO membranes rated for 99.3 percent rejection of a standard 2000 mg/L sodium chloride salt solution; this is considered a high rejection, broad spectrum RO membrane. Computer models provided by each membrane manufacturer are used to estimate treated water quality for major ions and pressures, but the rejection characteristics of trace contaminants is determined from pilot tests and full-scale operational data.

The associated pilot test of RO at the Northwest WTP is using the same membrane material and configuration as a potential full-scale system, but the membrane elements have only 80 to 85 ft^2 of membrane area compared to 400 to 440 ft^2 of membrane area for a standard 8-inch diameter by 40-inch long RO element.

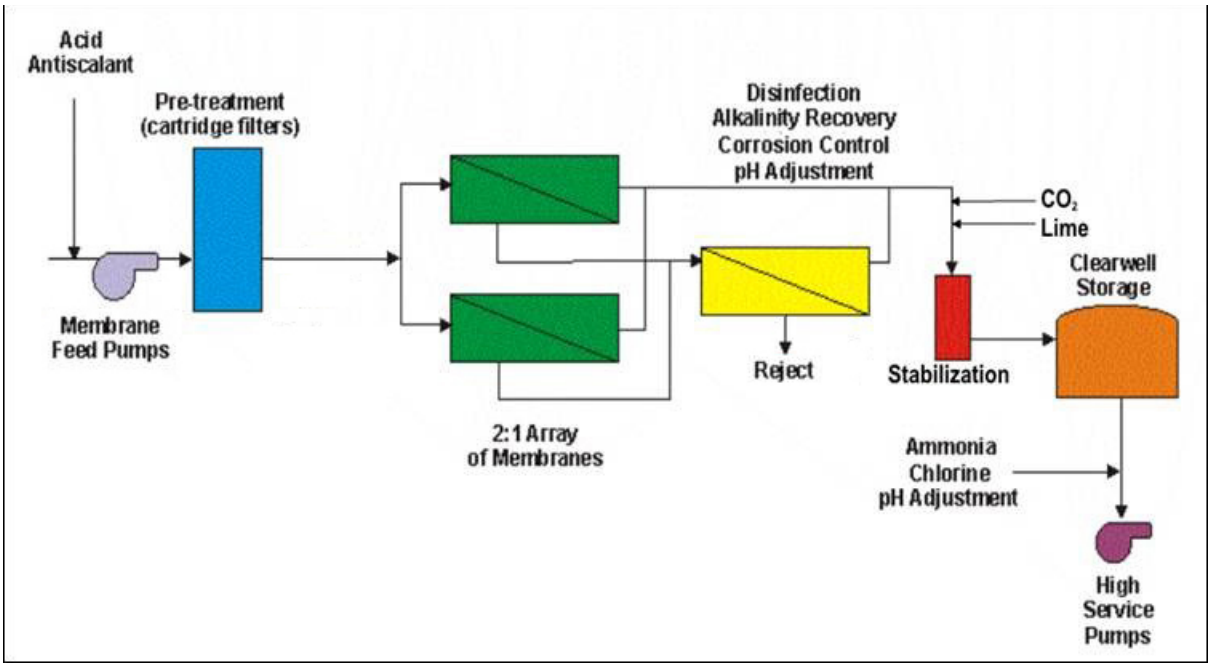

Figure 5-2
RO Process Schematic Example

RO systems require feedwater with low concentrations of suspended solids to avoid fouling the membranes. RO membranes operate in cross-flow mode; there is a constant residual stream of concentrated salts and contaminants discharged from the RO units (10 to 20 percent of feedwater). The system operates at an average flux of 15 gallons per day per square foot (gfd) so a 36-mgd facility requires approximately 2,400,000 ft^2 of membrane which is contained in 6000 standard 8-inch diameter by 40-inch long spiral-wound RO elements. Typically, 6 to 8 elements are contained in a pressure vessel that has a feed port, residual port and a permeate port.

Typical large municipal RO units have 2 to 5 mgd of permeate capacity with the size depending on the number of units needed for turndown capacity, desirable feedwater pump size, etc. The RO units have stacked 8-inch diameter pressure vessels and are approximately 25 feet long and the width varies from 10 feet for a 1-mgd unit to 15 to 20 feet for a 5-mgd unit. The height can also be varied from 6 to 20 feet above the floor to reduce the overall floor space needed for the RO units.

As the water permeates through the membranes, the salts become more concentrated on the feedwater side and become saturated. The salts, metals, and minerals are kept in the dissolved state using scale inhibitors and pH adjustment to prevent precipitation. Cape Fear River water has low concentrations of dissolved salts and hardness, so the precipitation potential is reduced. Since the source water is treated with alum, the main precipitation concern is colloidal aluminum fouling the membranes. The flux, feedwater dissolved solids, recovery, membrane salt rejection, and membrane age are the main factors affecting feedwater pressure; for the Northwest WTP RO system, the feedwater pressure is expected to be less than 130 pounds per square inch (psi).

The residual stream from the RO has the concentrated minerals and salts in the feedwater, but the TDS concentration for the Northwest WTP will be less than 1300 mg/L, which is significantly less than the concentration that has any effect on effluent toxicity.

Equipment included in RO treatment are shown on **Figures 5-3 through 5-5**.

Figure 5-3
Horizontal Cartridge Filter

Figure 5-4
Horizontal Spilt Case RO Feed Pumps

Figure 5-5
Two-Stage RO Membrane Skids Using Standard 8-Inch Diameter Pressure Vessels

In contrast to the GAC option, RO requires 10 to 20 percent more feedwater than the required permeate flow to account for the discharge of a concentrated residual flow. It is assumed that the brine concentrate would be discharged as a river outfall, which would require an NPDES permit. The RO effluent also has low pH with minimal hardness and total dissolved solids, and will require pH adjustment and addition of calcium and alkalinity to reduce its corrosivity.

For the Northwest WTP, the following major components are needed for a low-pressure RO treatment system with 36-mgd permeate capacity:

- Seven duty 5.15-mgd permeate capacity 4 (82:41 array based on 400 ft^2 membrane elements) RO units and one stand-by 5.15-mgd permeate capacity two-stage RO unit
- Eight 500-horsepower (hp) RO feedwater pumps rated at 135 psi total dynamic head (TDH) @ 5.65 mgd and 75 percent pump efficiency
- Eight 5.15-mgd, 5-micron feedwater cartridge filters
- 4000-pound-per-day (lb/day) emulsified lime chemical feed system for 20 mg/L of alkalinity
- 5500-lb/day carbon dioxide feed system for final pH of 7.4
- 700- lb/day scale inhibitor (antiscalant) feed system
- Permeate Storage for RO System Flushing
- RO Membrane Clean-in-Place (CIP) system

- Brine discharge force main using residual RO pressure
- 15,000-ft^2 Building for RO equipment and ancillary facilities

Initial start-up conditions indicate that the RO feedwater pressure is approximately 100 psi. It was assumed that the ultimate pressure may reach 150 psi for 7-year-old fouled membranes treating colder water. This condition requires a 500-hp pump which is reasonable for 480-VAC variable frequency drives (VFDs). A typical layout of an RO equipment building is shown on **Figure 5-6**.

Each RO unit has a narrow operating range (4.5 to 5.2 mgd). Flow variation is obtained by starting and stopping the units. The potential for biological fouling is minimized when the RO units are operating. When the RO units are offline due to reduced demand, the units have to be flushed periodically with permeate to inhibit biological activity.

The operational manhours for control of RO systems is relatively low due to modern control and automation systems. Operators set the recovery within an approved design range (80 to 85 percent for a two-stage system) and set the desired flow rate (4.5 to 5.2 mgd per skid). The system modulates the concentrate valve to maintain the target recovery ratio (permeate flow/feedwater flow). The feedwater pump VFD will adjust the pump speed to provide the required feedwater flow and pressure to achieve the required permeate flow.

Computer models are used to estimate treated water quality of major ions and pressures, but the rejection characteristics of trace contaminants are determined from pilot tests and full-scale operational data. Pilot tests use the same membrane material and configuration as the full-scale system, but the membrane elements have only 80 to 85 ft^2 of membrane area compared to 400 to 440 ft^2 of membrane area for a standard 8-inch diameter by 40-inch long RO element.

5.2 Application Experience

Dickinson and Higgins (2016) indicate that RO is effective at removing both long and short chain PFAAs and PFSAs, but would likely represent a higher initial capital cost. Their evaluation was based on two California potable water reuse sites that use the following membranes:

- Polyamide Hydranautics ESPA2 membranes in a three-stage array with 12 gfd flux rate and 85 percent recovery
- Toray and Hydranautics RO membranes with a flux rate of 11.6 to 11.9 gfd and 80 percent recovery

All PFASs were below the method reporting limits in the RO permeate.

Pilot testing of RO, prior to chlorine disinfection is being conducted at the Northwest WTP. RO is expected to remove the majority of CECs present to acceptable levels. There is typically some passage of N-Nitrosodimethylamine (NDMA), 1,4-dioxane, and the following PPCPs: tris(2-chloroethyl) phosphate (TCEP), tris (1-chloro-2-propyl) phosphate (TCPP), tris(1,3-dichloroisopropyl)phosphate (TDCPP), triclosan, and N,N-Diethyl-meta-toluamide (DEET).

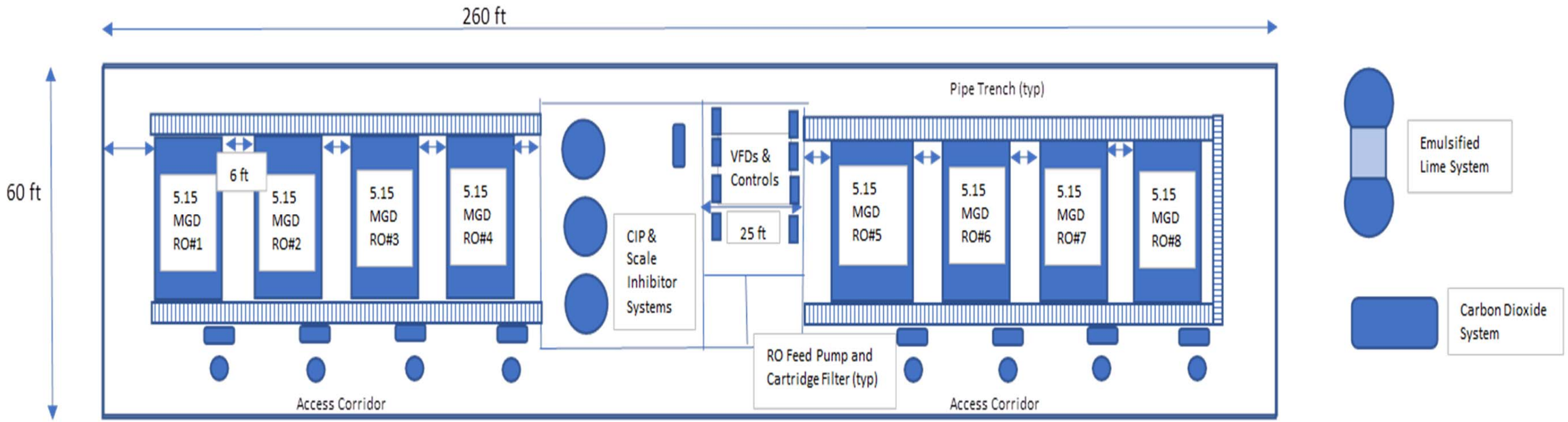

Figure 5-6
Typical 36-mgd RO Equipment Building

It should be noted that the HB 56 study did not evaluate membrane treatment technology such as nanofiltration (NF) or RO. Low pressure RO/nanofiltration (LPRO/NF) was eliminated from the study during the desktop alternative analysis because of the perceived challenges for permitting the waste discharge, the higher cost and the additional property that the Sweeney WTP would need to purchase. It would also be unusual to pair LPRO/NF with ozone biofiltration, an advanced oxidation treatment technique utilized at the Sweeney WTP. Therefore, the early conclusion to eliminate LPRO/NF from consideration was specific to the Sweeney WTP and should not be applied to the Northwest WTP.

5.3 Summary

Advantages and disadvantages associated with RO treatment are listed in **Table 5-1**.

Table 5-1. Advantages and Disadvantages of RO Treatment

Advantages	Disadvantages
Best Technology for removing PFAS - will give non-detect for the largest number of parameters	Higher capital cost than GAC or IX
Barrier Approach – effluent contaminant concentrations will not rise as significantly with time of use or have breakthrough potential as much as is possible with GAC and IX	▪ O&M Needs for RO membrane systems include annual or semi-annual chemical cleaning of the membrane elements while in the pressure vessels. ▪ Periodic flushing of the membranes with permeate when RO Units are off-line for more than 1 day ▪ Fouling potential
Barrier to pathogens although need to add tracers to feedwater to verify integrity	Permeate requires stabilization with calcium, alkalinity and orthophosphate to minimize the corrosion potential
Reduces TOC so the Disinfection Byproduct formation potential is minimal. (D/DBPR - Stages 1 and 2 and future 3/NDMA)	RO concentrate with the dissolved solids in the feedwater requires disposal and a NPDES Permit
Greatest protection from future unidentified PFAS	
Lower O&M costs than GAC	

Section 6

Ozone with Biofiltration

6.1 Process Description

Ozonation of the settled water is intended to provide primary disinfection for *Giardia* and virus inactivation, taste and odor control, and enhance the downstream biological filtration process for both particle removal and disinfection by-product precursor reduction. With biofiltration, GAC migrates from adsorption to biofiltration after several months of operation. Ozonation makes more of the natural organic material biodegradable. **Figure 6-1** illustrates the impact of GAC in removing TOC over time. The ozonation process reduces the demand on the GAC media. A process schematic for implementing ozone with biofiltration at the Northwest WTP is shown on **Figure 6-2**.

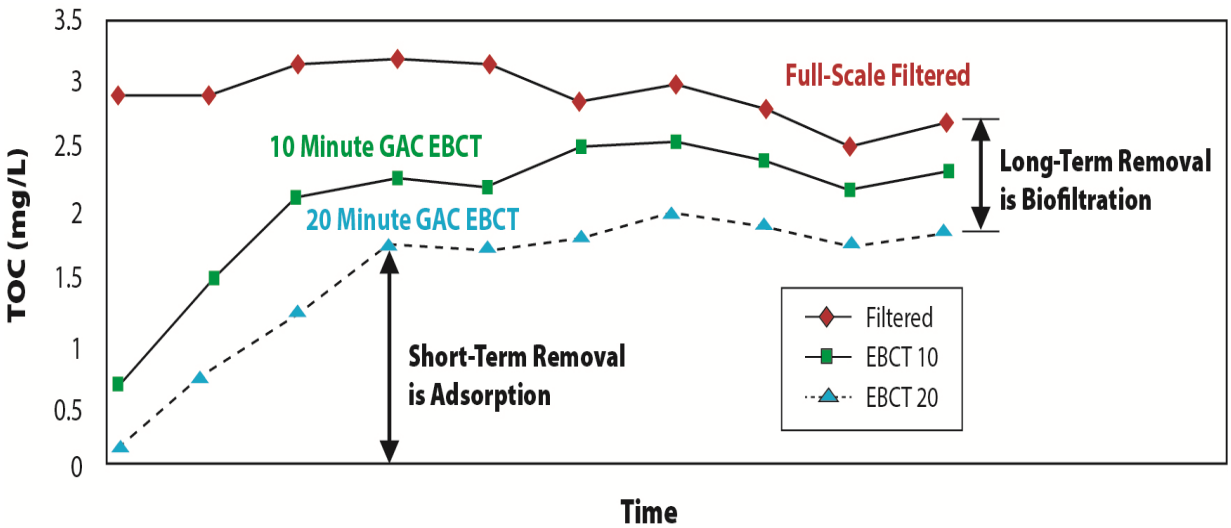

Figure 6-1
Example of TOC Removal Impact of Biofiltration

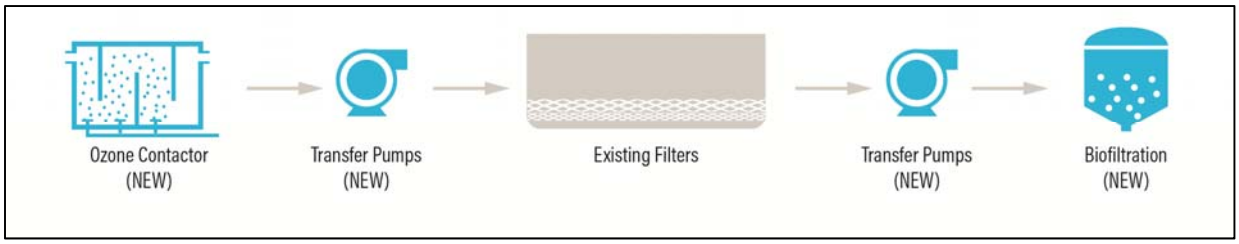

Figure 6-2
Process Flow Schematic with Ozone/Biofiltration

6.1.1 Ozone System

The possible ozone system for the Northwest WTP would include a high concentration ozone generation system using liquid oxygen (LOX) as the feed gas. The recommended contacting system would be a horizontal flash mixer followed by a serpentine contactor. The ozone dissolution and contacting system would use sidestream injection, in lieu of traditional fine-bubble diffusers, to enhance treatment performance and minimize the need for confined-space entry to the contactor for diffuser maintenance. A key advantage of the flash reactor sidestream injection technology, used either in a horizontal or vertical configuration, is that it does not require hydrostatic pressure (typically 18-20 feet) to achieve reasonable ozone mass transfer rates, as do fine-bubble diffusion systems, and hence, can be used in combination with shallow-depth ozone contactors.

Figure 6-3 provides an example of a plan and section view of a horizontal pipe flash reactor dissolution system. The flash reactors are installed on the two settled water pipes. Each pipe discharges into an ozone contactor train. Internal baffles are positioned upstream and downstream of the flash reactor to prevent migration of accumulated ozone gas in the horizontal pipe during low plant flow conditions. A bypass is provided between the pipes to transfer settled water flow from one contactor train to another.

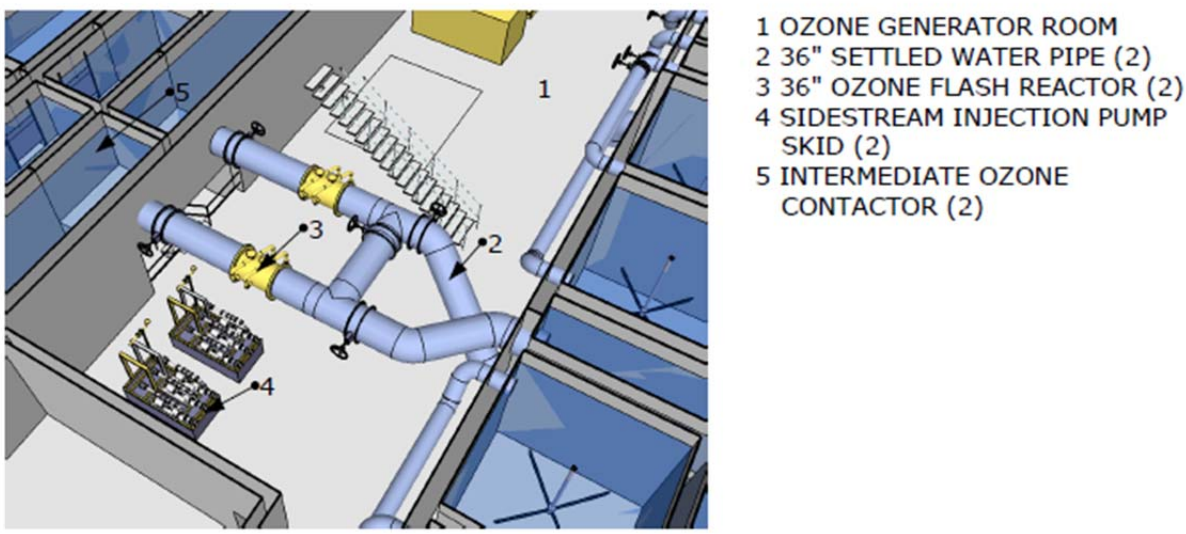

Figure 6-3
Example of Horizontal Ozone Flash Reactor and Contacting System

The ozone system consists of the following major components:

- LOX storage and feed gas system
- Ambient-air vaporizers
- Ozone generation and cooling water system
- Mazzei flash reactors (one per contactor train)
- Injection skids (with redundant pumps and injectors)

- Ozone dissolution and contacting system
- Ozone offgas system

Figure 6-4 provides a photograph of the vertical LOX tanks and ambient air vaporizers at the Corbalis WTP in Virginia. Vertical tanks are often used when limited space is a constraint. The tanks are filled from both the top and bottom to control internal pressure build-up. The vaporizers are simple tube-and-fin heat exchangers that use atmospheric heat collected at the fins to vaporize the LOX as it passes through the tubes. The process slowly builds ice on the vaporizers as moisture in the air freezes to the cold fins. Consequently, the vaporizers must be alternated at timed intervals (typically every 4 to 8 hours) to allow for a defrost cycle.

Figure 6-4
Vertical LOX Tanks and Ambient Air Vaporizers at Corbalis WTP

Qualified manufacturers for providing ozone generation equipment include: Ozonia, ITT-WEDECO, and Fuji Electric. **Figure 6-5** provides a photograph of the Ozonia generators and power supply units at the Corbalis WTP. These types of generators are classified as high concentration, medium frequency, tube- and shell-style generators. The generators typically operate economically at an ozone-in-oxygen concentration of 10 to 12 percent by weight, but can increase ozone production output by 30 to 40 percent by decreasing the ozone concentration to 6 to 8 percent, albeit at a more costly rate of oxygen usage.

Figure 6-5
Ozone Generators at Corbalis WTP

A schematic of the Mazzei flash reactor and sidestream injection booster pump skids, and a photograph of a typical ozone off-gas destruct unit are presented in **Figures 6-6 and 6-7**, respectively.

For the Northwest WTP, the ozone generation room, flash reactor room and ozone offgas destruct room will be housed in a new ozone building. The ozone contacting basins are proposed to be located outside, and adjacent to the ozone building. The ozonated water will flow to ozone contactor trains with a serpentine baffle layout, and exit through an outlet gate. Post-ozone treatment chemicals will be added in a chemical mixing chamber near the outlet of each ozone contactor train using a pumped injection mixing system.

The ozone sample gallery will include ozone residual sample piping and analyzers for each contactor train. Ozone residual sample collection taps will be provided at the beginning, middle and end of each pass of the serpentine contactor trains. Sample probes will be provided with the capability to move the sample probe from one tap to another to respond to changing ozone residual profiles, as water moves through the contactors under different flow or water temperature conditions.

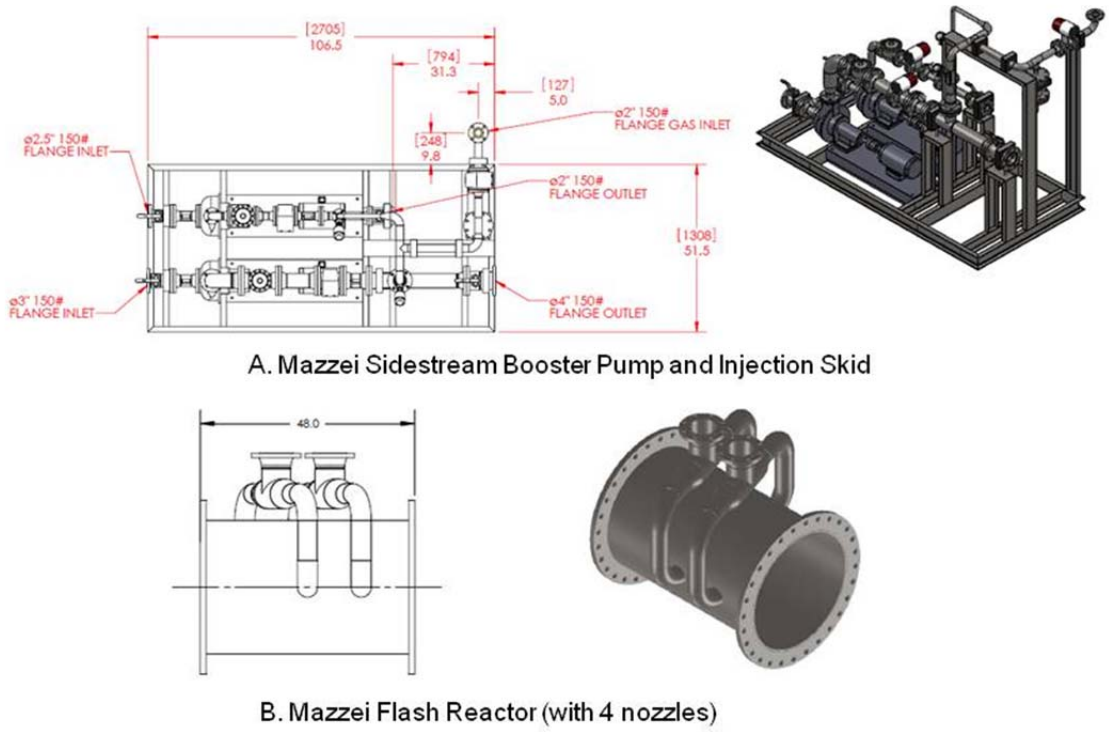

Figure 6-6
Typical Flash Reactor and Sidestream Injection Pump Skids (Mazzei Injector Corporation)

Figure 6-7
Ozone Offgas Blower and Destruct Unit Skid at Fairfax Water Corbalis WTP

Ozone is a hazardous gas, so the design will include control measures such as ambient ozone and oxygen monitors to automatically shut down the system in the event of a leak.

6.1.2 Biological Filtration

The biological filtration process serves the dual purpose of particle removal and removal of biodegradable organic carbon through biological oxidation. Particle removal across a biological filter is achieved in the same way as a non-biological (chlorinated) filter—that is, by particle transport and attachment to filter media. The efficiency of particle or turbidity removal depends to a large extent on coagulation chemistry and the efficiency of the upstream clarification process.

Biological filtration is often used downstream of ozonation for removal of biodegradable ozone byproducts such as aldehydes and ketoacids. These byproducts are easily biodegradable and so enhance biological activity within the filter bed for removing other biodegradable organic compounds. Removal of these compounds reduces the potential for bacterial regrowth in the distribution system.

Ozone-enhanced biological filtration is also effective in removing algal-derived taste and odor (T&O) causing compounds for warm water conditions (including MIB and geosmin) and can reduce disinfection by-products by removing precursor material.

6.2 Application Experience

The ozone-biofiltration process is currently used at the Sweeney WTP and at the Cary-Apex WTP on the Cape Fear River (Cary-Apex being upstream on Jordan Lake). Ozone-biofiltration is widely used surface water treatment approach both in the region and nationally, including WTPs in Raleigh, Asheville, Greenville, Fairfax, Henrico, among others. Ozone is not typically implemented for removal of the primary TC (PFAS), but rather for partial removal of organic matter, PPCPs and EDCs, and for taste and odor issues. Ozone also has the benefit of oxidizing 1,4-Dioxane. The Sweeney WTP has been reported to remove approximately 60 to 70% of 1,4-Dioxane at typical influent concentrations.

Implementation of ozonation prior to GAC serves as an oxidizing phase that reduces the GAC removal requirements, hence reducing GAC media changeout frequency and costs. However, ozone with biofiltration alone is ineffective in removing the primary TC (PFAS). Ozone with biofiltration plus post-filter GAC is discussed in Section 9 and has merit in achieving more than 90 percent reduction of most of the TC.

6.3 Summary

Major advantages and disadvantages associated with ozone and biofiltration treatment are provided in **Table 6-1**.

Table 6-1. Major Advantages and Disadvantages of Ozone and Biofiltration Treatment

Advantages	Disadvantages
Extra barrier – ozone gives some oxidation of 1,4-Dioxane – especially if add H_2O_2 for AOP	Cost and complexity to operate
OBF removes biodegradable ozone byproducts such as carboxylic acids and aldehydes – bulk TOC removal	Ozone forms some NDMA (but lowers FP) and NDMA formed can be biodegraded
Removals of some SOC/PPCPs	OBF does not remove PFAS well (still need post treatment) – more an alternate to UV-AOP in this case
Longer GAC life for bulk organics	
Additional disinfection (SWTR)	
Taste & Odor/Aesthetics	
Disinfection byproduct control (D/DBPR)	

Section 7

UV/AOP

7.1 Process Description

Advanced Oxidation Process (AOP) is used in conjunction with UV to remove compounds that are not fully removed by granular activated carbon (GAC), ion exchange (IX), or reverse osmosis (RO). Accordingly, AOP is particularly useful for compounds such as:

- 1,4-Dioxane
- NDMA

Hence, the implementation of UV/AOP downstream of GAC and IX treatment is being considered at the Northwest WTP, along with possible future use downstream of RO. UV/AOP is not included downstream of RO (Section 9) because RO is expected to provide about 90-percent removal of 1,4-dioxane and because NDMA levels were very low in prior sampling under the EPA Unregulated Contaminant Monitoring Rule (UCMR) program. This assumption will be checked against the pilot data when it is available. The potential process flow schematic for the addition of UV/AOP at the Northwest WTP is shown on **Figure 7-1**.

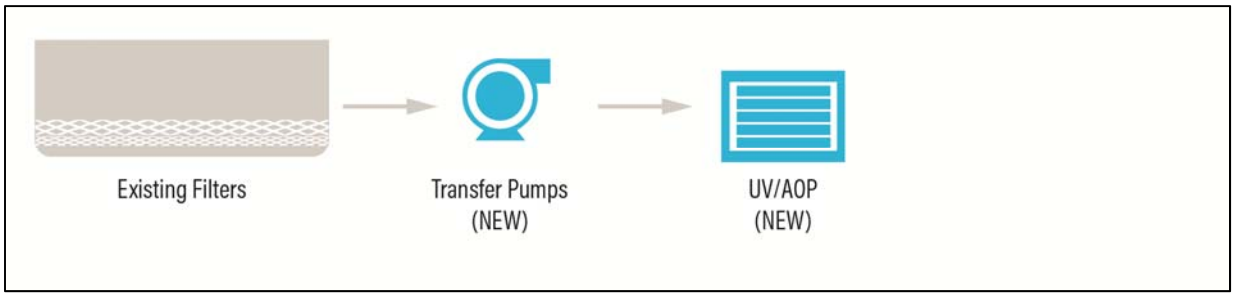

Figure 7-1
Post-Filter UV/AOP Process Flow Schematic

7.1.1 AOP

AOP relies on the formation of hydroxyl radicals or chlorine radicals to degrade chemical contaminants, usually through the application of peroxide or chlorine in drinking water treatment. At low pH, chlorine reacts with UV to create hydroxyl and chlorine radicals. The chlorine-AOP reaction is highly pH dependent. For this application, the estimated dosage requirement is 10 mg/L for peroxide and 5 mg/L for chlorine. If this technology is selected then a more detailed analysis of chemical and UV dosing will be needed to optimize the treatment.

AOP can be achieved with ozone-peroxide as well as with UV-peroxide. Consequently, the ozone option as described in Section 6 can provide AOP, and is hence an option for 1,4-dioxane control as is the UV-AOP option discussed in this Section.

7.1.2 Ultraviolet Disinfection

Two types of UV reactors are commercially available for municipal drinking water treatment applications: low pressure high output (LPHO) and medium pressure (MP) reactors. There are significant differences in capital and operating costs for these systems, with LPHO systems typically having higher capital costs and lower O&M costs than MP systems. In addition, the electrical requirements can be 2 to 3 times higher for MP systems than LPHO systems, due to differences in the germicidal efficiency of the UV lamps used. Consequently, these systems are typically pre-selected by the owner based on an evaluated bid and life-cycle cost approach so that the UV system can be efficiently designed around the selected vendor and UV equipment system during final design.

UV transmittance (UVT) is the most critical water quality parameter for sizing UV reactors. Other design parameters that affect sizing and configuration of the UV system include the combined lamp aging and fouling (CAF) factor and maximum head loss across the UV reactor. RO produces a high-quality discharge that reduces the power demand of the UV reactor. For this application, the UV dose is estimated to be approximately 0.5 kilowatt-hour (kW-hr) per 1,000 gallons.

Commercially available UV reactors for drinking water applications are closed-vessel designs installed in pressurized pipelines. The primary components of a closed-vessel UV reactor include:

- UV reactor vessel
- UV lamps
- Quartz sleeves (enclosing the lamps)
- Lamp ballasts
- UV intensity sensors
- Flow and UVT sensors
- Temperature-flow sensors
- Lamp cleaning system

The four major UV equipment suppliers for municipal UV drinking water applications in the United States are Calgon, ITT-WEDECO (Xylem), and Trojan Technologies. **Table 7-1** presents a comparison of the types of UV systems (MP vs. LPHO) and design features for large UV reactors offered by these companies. An example of a UV reactor configuration is shown on **Figure 7-2**.

Each UV treatment train consists of the following components:

- UV piping system to receive water
- Flow meter
- UV (MP or LPHO) reactor
- Outlet control valve for automatic start-up and shutdown of the UV trains and for flow modulation, as necessary, to maintain flows below validated setpoint limits.
- Weir chambers to receive UV-treated flows from each UV train.

Table 7-1. Major UV System Suppliers and UV Reactor Design Features

Description	Calgon Sentinel/ Chevron	WEDECO K143	Trojan Torrent	Ozonia Aquaray
Type of Reactor	MP	LPHO	LPHO	MP
Maximum Flange Size	48-inch diameter	48-inch diameter	48-inch diameter	36-inch diameter
Lamps per Bank	1 to 3	12	8	8, 10, 12
Banks per Reactor	1 to 3	2 to 12	2 to 6	1
Validated Flow Range	1-50 mgd	2-40 mgd	5-52 mgd	5.3 – 55.4 mgd
Lamp Type	MP	LPHO Amalgam	LPHO Amalgam	MP
Lamp Life	5,000 hr	12,000 hr	12,000 hr	10,000 hr
Cleaning System	Mechanical Wiper	Off-line Acid	Physchem Wiper	Mechanical Wiper
Sleeve Life	10 yrs	20 yrs	10 yrs	10 yrs
Lamps per Ballast	1	2	2	1
Ballast Life	15 yrs	5 yrs	10 yrs	10 yrs
UV sensors	1 / lamp	1 / bank	1 / bank	1 / lamp
UV sensor life	10 yrs	10 yrs	2 yrs	2 yrs
Power Supply	480 V, 60 Hz, 3 Ph	480 V, 60 Hz, 3 Ph	480 V, 60 Hz, 3 Ph	480 V, 60 Hz, 3 Ph

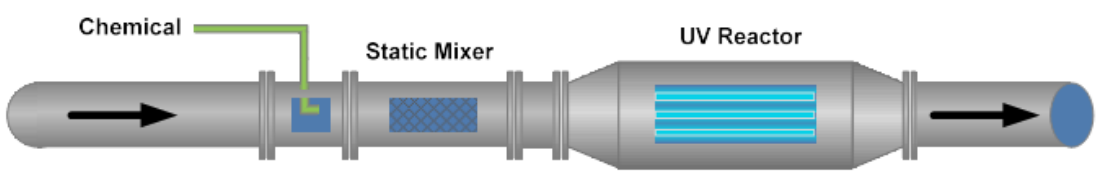

Photo Credit: Xylem (http://www.weat.org/Presentations/2016_A-14%20ROBISON_Texas%20Reuse_07-15-16.pdf)

Figure 7-2
Example of UV-AOP Reactor

7.2 Application Experience

UV/AOP has not been widely implemented in drinking water treatment for the target contaminants. However, the technology has been widely applied to potable water reuse, particularly in the State of California. California regulations for indirect potable water reuse

(groundwater replenishment, subsurface application) requires implementation of RO and AOP for Full Advanced Treatment (FAT).[1]

The first UV/AOP hypochlorite system was added to the Terminal Island Water Reclamation Plant and Advanced Water Purification Facility in San Pedro, California.[2] The AOP specifications included 6-log virus credit, 0.5 log 1,4-dioxane removal, and less than 10 ppt NDMA in effluent with a UV dose of 920 mJ/cm^2 and free chlorine dose of 2 to 4 mg/L.[3]

UV/AOP has also been added downstream of the RO process at the Leo J. Vander Lands Advanced Water Treatment Facility in Long Beach, California. AOP has been incorporated through the addition of up to 3.5 mg/L of peroxide. The UV/AOP system is designed to achieve a net log removal of NDMA between 1.62 to 2.03 and a 0.5 log reduction of 1,4 dioxane.[4]

Bench scale testing of UV/AOP is currently being conducted at the Northwest WTP to meet the following objectives:

- Evaluate whether UV/AOP using chlorine can be used to remove 1,4-dioxane, NDMA and/or PPCPs
- Evaluate temporal variability of treatment using UV/AOP with chlorine over three-time points, collected monthly

UV/AOP alone is not anticipated to remove the target contaminants. However, UV/AOP in combination with other treatment technologies, such as GAC and GAC/IX, may have merit in removing approximately 90 percent of most of the target contaminants and is being considered for the Northwest WTP, as discussed in Section 9.

7.3 Summary

Major advantages and disadvantages of UV/AOP treatment are listed in **Table 7-2**.

Table 7-2. Major Advantages and Disadvantages of UV/AOP Treatment

Advantages	Disadvantages
Oxidant Barrier – mainly for 1,4 Dioxane, NDMA	Power Requirement / O&M Cost
Removals of some SOC/PPCPs	UV/AOP does not remove PFAS well (still need other post treatment)
Additional Disinfection/Pathogen Inactivation	
Taste & Odor/Aesthetics	
Disinfection Byproduct Control (D/DBPR)	

[1] https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/documents/lawbook/RWregulations_20140618.pdf (Last accessed February 27, 2018)
[2] https://watereuse.org/wp-content/uploads/2017/04/WateReuse-OC-Newsletter-2017.1_Spring_Summer.pdf (Last accessed February 27, 2018)
[3] http://www.weat.org/Presentations/2016_A-14%20ROBISON_Texas%20Reuse_07-15-16.pdf (Last accessed February 27, 2018)
[4] http://www.spi-engineering.com/wp-content/uploads/2016/03/2016-AWWA-Wesner-LVL.pdf (Last accessed February 27, 2018)

Section 8

Existing Facilities Expansion

The Northwest WTP is currently rated at a finished water treatment capacity of 24 mgd. The County has approached the need to expand the Northwest WTP through a three-phased process, and has previously completed Phase 1 (2011) and 2 (2015) of the expansion. With the completion of the upcoming Phase 3, the Northwest WTP will be ready to be rated at 36-mgd finished water capacity.

The purpose of this section is to describe the major facilities that will need to be expanded for the Phase 3 Northwest WTP Improvements Project. The Phase 3 scope of work was evaluated in 2010 and then again in 2014, with modifications to the future planned improvements being made with each update. With the recent discovery of GenX, Nafion by-products, and other emerging contaminants, and the associated need to add advanced treatment technologies to the Northwest WTP, the scope of Phase 3 again requires modifications. Advanced treatment technologies that are being considered as part of the expansion and their associated costs are discussed in Section 9. This section discusses elements of the expansion that are required regardless of the advanced treatment technology selected. The plant expansion is illustrated on **Figure 8-1**.

8.1 Parallel Raw Water Transmission Main

Raw water for the Northwest WTP is purchased from the Lower Cape Fear Water and Sewer Authority (LCFWASA). The water is conveyed by the Kings Bluff Pump Station, which is located upstream of Lock and Dam No 1, through a 48-inch diameter main, to a 3-million-gallon ground storage tank. Raw water is then conveyed by gravity through 48-inch and 36-inch diameter raw water mains to the Northwest WTP. Based on previous studies, the County has planned for a new parallel raw water main extending approximately 1,860 feet to feed the rapid mix basins. The planning-level opinion of probable capital cost estimate for the parallel raw water transmission main including 30-percent contingency is $1.1 million.

8.2 New Rapid Mix and Raw Water Flow Meters

The addition of new centralized rapid mixing and raw water flow meters is included as part of the Northwest WTP upgrade and expansion to provide efficient use of coagulant chemicals and to initiate coagulation upstream of the basins converted to Superpulsators® as shown on the site plan. Three rapid mixers are included for firm capacity equal to the Superpulsators® capacity even when one mixer is out of service. Each rapid mixer will have an upstream flow meter for metered pacing of coagulant chemicals. The rapid mixers are sized for 1 minute of contact time in the mixer with variable speed drives for controlling mixing intensity. Coagulation continues in the piping and vacuum chambers downstream of the mixers. The planning-level opinion of probable capital cost estimate for the rapid mixers and flow meters including 30-percent contingency is $2.9 million.

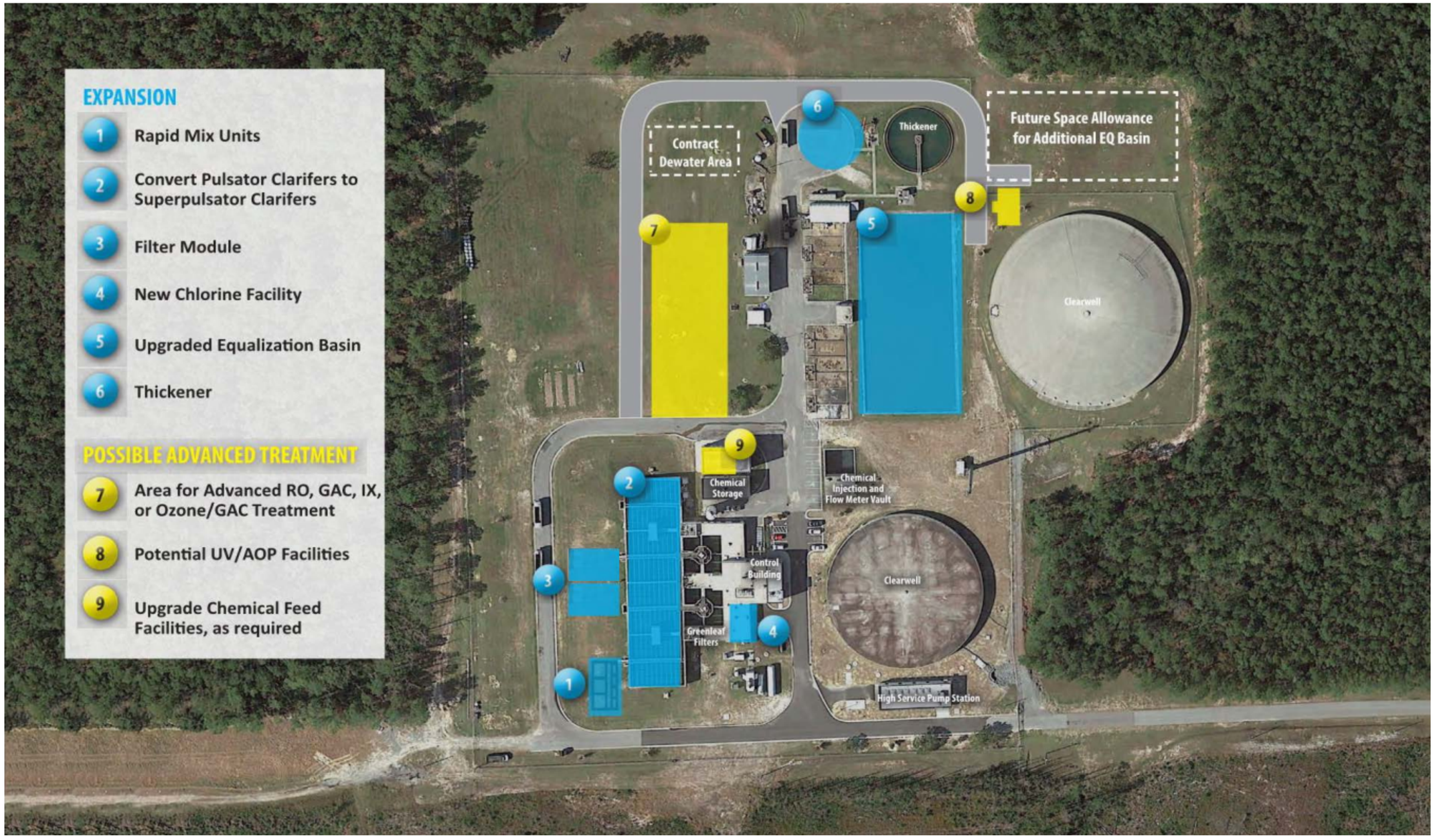

Figure 8-1 – Site Plan

8.3 Conversion of Existing Pulsator® Clarifiers to Superpulsators®

The Northwest WTP has two Pulsator upflow clarifier treatment trains with two clarification units in each train; each unit is rated at 6 mgd. To provide sufficient capacity for the expansion, the existing Pulsators® will need to be converted to Superpulsators®. The conversion to Superpulstators® will include the following improvements based on previous recommendations provided by the manufacturer:

- Retrofit with inclined plates
- Replacement of 8-inch circular collection pipe laterals with 12-inch laterals

Hydraulics will be checked in design and may result in raising of the Pulsator walls and the vacuum chamber walls, so cost is being carried for those items in case needed. Each Superpulsator® will have a capacity of up to 12 mgd with a hydraulic loading rate of up to 2 gpm/ft^2. The planning-level opinion of probable capital cost estimate for the conversion of the existing Pulsators® to Superpulsators®, including 30-percent contingency, is $8.5 million.

8.4 Addition of Greenleaf Filters with Pumped Backwash and Air Scour

The capacity expansion requires installation of two additional Greenleaf filter modules with pumped backwash and air scouring. Each Greenleaf filter module will have four cells as with the existing modules, each cell approximately 24 feet by 24 feet, similar to the existing Greenleaf filters. Each filter will have 9 inches of sand, and 18 inches of anthracite to match the existing filters. To provide the extra capacity for plant losses (backwashing, clarification blowdown, and concentrate loss in the RO option), the total amount to be filtered while producing a net capacity of 36 mgd would be 39 – 45 mgd. The low end of the range (39 mgd) is for conditions without RO advanced treatment, while the high end of the range (45 mgd) is for conditions with a 2-stage RO advanced treatment system following the filters. The planning-level opinion of probable capital cost estimate for two additional Greenleaf filter modules with pumped backwash and air scouring, including 30-percent contingency, is $12.5 million.

8.5 Chemical Storage and Feed Improvements

Chemical feeds through the Northwest WTP are listed in **Table 8-1**. Chlorine dioxide is used for oxidation and disinfection. Sodium hydroxide is fed to raise the pH. Polyaluminum chloride is the primary coagulant. Powdered activated carbon (PAC) is stored in a silo and added just as needed for taste and odor control. Coagulant aid polymer assists in holding together the Pulsator® sludge blanket. Sodium fluorosilicate is added as a fluoride source to help lessen customer tooth decay. Phosphate is for corrosion control and particularly Lead and Copper Rule Compliance. Chlorine is added for disinfection. Ammonia is added to react with the chlorine to form chloramines for a residual disinfectant carried into the distribution system that forms less disinfection byproducts than free chlorine.

Table 8-1. Chemicals Used at the Northwest WTP

Chemical	Application Points	Use
Chlorine Dioxide (Chlorine + Sodium Chlorite)	Pre-Rapid Mix Filter Influent Channel Post-filter	Oxidation Disinfection
Sodium Hydroxide (Caustic)	Rapid Mix Post-Filter	pH Adjustments
Polyaluminum Chloride (PAX)	Rapid Mix	Coagulation
Powdered Activated Carbon (PAC)	Rapid Mix	Taste and Odor Control (Infrequently Used)
Coagulant-Aid Polymer	Rapid Mix Effluent	Coagulation Aid
Sodium Fluorosilicate	Post-Filter in Clearwell Influent Piping	Fluoridation
Phosphate	Post-Filter in Clearwell Influent Piping	Corrosion Inhibition
Chlorine	Post-Clearwell	Disinfection
Ammonia	Post-Clearwell	Disinfection

The plant is designed for five 500-pounds-per-day (ppd) chlorine dioxide generators with four generators currently installed. There is one 10,000-gallon sodium chlorite tank. There are two 6,750-gallon caustic tanks and three 18,000-gallon PAX tanks. The PAC silo is 12-foot diameter by 19-foot-3-inch straight wall height. There is one 10,000-gallon phosphate tank.

The plant was recently expanded with storage capacity added to provide for the future expansion as shown in **Table 8-2**, with the exception of chlorine gas storage which requires both upgrade and expansion as discussed in Section 8.6. An allowance of $400,000 is included in the probable capital cost for the expansion for improvements that may be necessary to increase the capacity of chemical feed equipment.

8.6 Upgrades to Chlorine Facility

The chlorine facilities require upgrades to increase capacity, add containment around the 1-ton cylinders, and to implement safety measures such as all-vacuum operation and scrubber addition. The exact location of the new chlorine room will be refined during preliminary design, and is currently planned to go in the room previously used for high service pumping. Additions are to include new all-vacuum system with four on-line cylinders with automatic switchover to four more cylinders, leak detection and scrubber. Micromotion flow meters will continue to be used in place of scales for chlorine gas as the plant has successfully done for 17 years. The planning-level opinion of probable capital cost estimate, including building addition to enclose the chlorine facilities and 30-percent contingencies, is $1.6 million.

Table 8-2. Projected Chemical Needs and Bulk Storage Facilities

Chemical Storage Estimate for 36 MGD - Average Flow @ Chemical Use						
Chemical	**Projected Average Flow Rate (mgd)**	**Average Concentration (mg/L)**	**lbs-chemical/ day**	**30-day Storage Requirement**	**Units**	**Existing Storage**
PAX-18	20.0	53	8,840	23,361	gallons	38,000
Caustic	20.0	12	2,002	9,295	gallons	15,000
Corrosion Inhibiter (Phosphate)	20.0	0.80	133	1,020	gallons	10,000
Sodium Chlorite	20.0	1.9	317	3,691	gallons	10,000
Chlorine*	20.0	4.7	784	12	tons	8
Ammonia**	20.0	0.8	133	2	tons	2.1

* Suggested discharge rate < 15lbs/hr – at least 6 one-ton tanks online with auto-switchover to 6 more
** Ammonia storage tank maximum 85% full

Chemical Storage Estimate for 45 MGD - Average Flow @ Average Chemical Use						
Chemical	**Projected Average Flow Rate (mgd)**	**Average Concentration (mg/L)**	**lbs-chemical/ day**	**30-day Storage Requirement**	**Units**	**Existing Storage**
PAX-18	25.0	53	11,051	29,014	gallons	38,000
Caustic	25.0	12	2,502	11,764	gallons	15,000
Corrosion Inhibiter (Phosphate)	25.0	0.80	167	1,281	gallons	10,000
Sodium Chlorite	25.0	1.9	396	4,638	gallons	10,000
Chlorine*	25.0	4.7	980	15	tons	8
Ammonia**	25.0	0.8	167	2	tons	2.1

* Suggested discharge rate < 15lbs/hr – 8 one-ton tanks online with auto-switchover to 8 more preliminarily
** Ammonia storage tank maximum 85% full

8.7 Residuals Improvements

Currently, all sludge from the Pulsators®, all backwash wastewater and filter-to-waste water, and filtrate from the contract belt-press dewatering operations is conveyed to a 260-foot by 120-foot residuals equalization basin for equalization and settling (refer to **Figure 8-2**). These flows enter the basin through a common pipe on the east side. Settled solids are collected in the basin with a 12-inch diameter polyvinyl chloride (PVC) pipe with 2-inch perforations every 2 feet on the bottom of the basin spanning only 100 feet into the effluent side of the basins. A dry-pit pump station is used to pump the sludge from the residuals equalization basin to the 80-foot diameter thickener. Dry-pit sludge pumps are then used to pump sludge from the thickener to the contract belt filter presses where the sludge is dewatered and hauled off-site. The dewatering system is owned and operated by Synagro Technologies, Inc. Decant water from the equalization basin is

removed with a fixed 12-inch decanting pipe with 2-inch perforations on 1-foot centers. Decant from the equalization basin and decant from the thickener are conveyed to the NPDES discharge.

Figure 8-2
Residuals Equalization Basin

The 2014 Northwest Water Treatment Plant Phase II Improvements Study delineated residuals handling improvements that included adding sludge collectors to remove sludge from the floor of the existing equalization basin for the 36-mgd expansion. This approach, which is shown on **Figure 8-3** is still a valid option, though the alternatives are recommended to be limited to cable-driven devices as pneumatic-driven devices have been replaced in many locations due to excessive maintenance issues. For increased reliability, improved operations and to accommodate flows up to 45 mgd, a new (second) thickener is also recommended along with upgraded pumping to and from the thickener. The recycle pumps are currently not working and need replacement. The proposed improvements are shown on the site plan. The planning-level opinion of probable capital cost estimate for the recommended residuals improvements, including 30-percent contingencies, is $4.3 million.

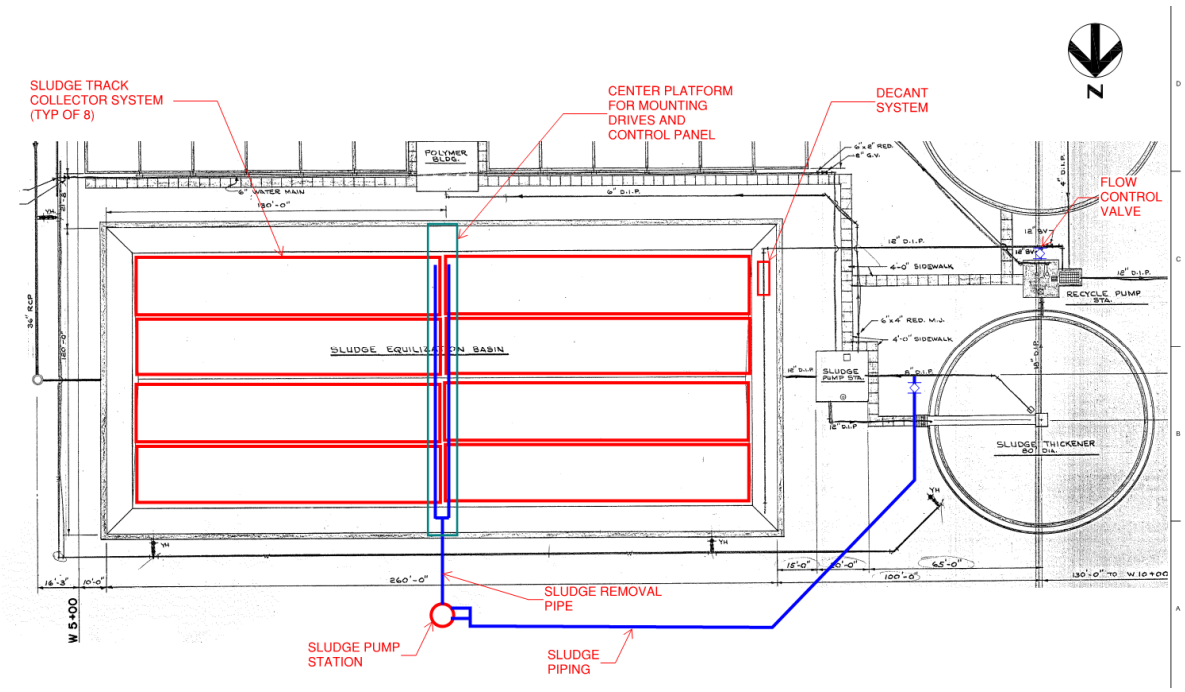

Figure 8-3
Modifications to Add Sludge Collectors to the Equalization Basin Per 2014 Northwest Water Treatment Plant Phase II Improvements Study

8.8 Electrical Improvements

The existing electrical system consists of a 3MVA utility transformer, a 2000kW generator, 4000A ATS, 2000A switchboard MSB, and 2000A switchboard HS with provision for temporary generator connection. It appears the existing electrical distribution system does not have the capacity for the expansion. The planning-level opinion of probable capital cost estimate for the electrical system is $2.4 million for the expansion.

8.9 Miscellaneous Yard Piping and Site Work

Miscellaneous yard piping and site work will also be required as part of the expansion. This includes addressing hydraulic bottlenecks, including the need for additional piping between the rapid mix basins and the Pulsator basins. The planning-level opinion of probable capital cost estimate for the miscellaneous work, including 30-percent contingencies is $4.5 million.

8.10 Summary

A summary of the planning-level opinion of probable capital costs for the expansion is provided in **Table 8-3**.

Table 8-3. Summary of Planning-Level Opinion of Probable Capital Costs for Expansion

Description	Planning-Level Opinion of Probable Capital Costs ($ Million)*
Parallel 36-inch Diameter Raw Water Transmission Main	$1.1
New Rapid Mix and Raw Water Flow Meters	$2.9
Conversion of Existing Pulsator® Clarifiers to SuperPulsator® Clarifiers	$8.5
Addition of Two Greenleaf Filter Modules with Pumped Backwash and Air Scour	$12.5
Chemical Storage and Feed Improvements	$0.4
Upgrades to Chlorine Facility	$1.6
Residuals Improvements	$4.3
Electrical Improvements	$2.4
Miscellaneous Yard Piping and Site Work	$4.5
TOTAL	**$38.2**

*Includes 30-percent contingency and 18-percent implementation

Section 9

Preliminary Findings, Planning-Level Cost Estimates, and Recommendations

9.1 Technologies Summary

Multiple advanced treatment alternatives have been evaluated for the feasibility of removing target contaminants at Brunswick County's Northwest WTP. CDM Smith has concluded that in most cases a combination of advanced treatment processes is required to meet the treatment goals established by Brunswick County for the project.

The advanced treatment technologies evaluated are listed below. A short summary of the technologies treatment effectiveness is also provided.

- **GAC**: Pilot testing has demonstrated effective treatment for GenX and other PFAS; however, long-term effective treatment with GAC requires media changeout to avoid breakthrough of compounds. HB 56 testing, as well as other large scale studies, indicate approximately 8,000 bed volumes (approximately 4 months at 20 minute contact time) is the appropriate frequency of media changeout for GenX and most PFAS (PFO_2HxA and PFMOAA are not as readily adsorbed for example). The use of new GAC has been assumed. There is a potential for cost reduction through use of reactivation, but permitting acceptability, removal of contaminants and effectiveness of the reactivated material would all require further research and/or testing. Pilot scale testing results showed more frequent changeout requirements than accelerated column tests (ACT) indicate. GAC is not effective at removal of 1,4 Dioxane, a secondary target contaminant, plus other secondary contaminants including brominated disinfection by-products.
- **Ion Exchange**: Pilot testing has demonstrated effective treatment for GenX and other PFAS using IX resins. Effective long-term treatment requires media replenishment to avoid breakthrough. It is assumed that reactivation is not cost effective and disposal of the media will be required. IX resins are not effective at removing 1,4 Dioxane.
- **Reverse Osmosis**: Reverse osmosis is expected to provide high level of removal (90 percent or greater) for the largest range of contaminants including most of those on the list of target contaminants. A pilot study is on-going at the Northwest WTP and will provide more detailed information on the removal potential of target contaminants.
- **Ozone with Biofiltration**: Ozone with biofiltration is not effective at removal of GenX and many other PFAS. However, ozone with biofiltration is effective at oxidation of 1,4 Dioxane and removal of PPCPs and disinfection by-product precursors.
- **UV-AOP**: Ultraviolet irradiation combined with advanced oxidation is not effective for removal of GenX and many other PFAS. UV-AOP is effective at oxidation and removal of 1,4 Dioxane.

The primary target contaminants and a select sub-set of secondary target contaminants have been consolidated into categories presented in **Table 9-1**.

A summary of the effectiveness of potential treatment options, developed by combining one or more processes, towards meeting the treatment objectives is shown in Table 9-1.

Table 9-1. Effectiveness of Potential Treatment Options in Removing Target Contaminants

Alternative	Gen X[1]	PFMOAA, PF02HxA	Other PFAS[2]	1,4-Dioxane	PPCPs[3]
Reverse Osmosis	> 95% [4]	> 90% [4]	> 95% [4]	90%+/- [4]	> 90% [4]
Ozone Biofiltration/ GAC	90%+/-	< 90%	> 90% for most PFAS	60-70% [5]	> 90%
Ion Exchange/ GAC/ UV-AOP	> 90%	< 90%,	> 90% for most PFAS	> 90%	> 90%

1 Gen X may be representative of other short chain PFAS
2 Does not include all known PFAS.
3 PPCPs describes a wide variety of contaminants. Results shown apply to representative contaminants with available data. Some PPCPs may not be removed to the extent shown.
4 Confirmed with Pilot Testing Sampling completed through March 30, 2018; refer to Appendix A for tabular results.
5 Based on full-scale data. Potentially up to 90% with higher ozone dose and/or peroxide addition

Of the treatment alternatives evaluated, RO is the most effective advanced treatment technology for removing the target contaminants. However, the following combination of these technologies have been shown to be capable of approximately 90-percent removal for most of the target contaminants and hence are compared to RO in the cost-effective analysis of this report:

- Ozone with biofiltration and post-filter GAC (Ozone/BAF-GAC)
- GAC/IX/UV-AOP

Although these three advanced treatment options are not equal; RO, Ozone/BAF-GAC, and GAC/AIX/UV-AOP are each considered feasible alternatives for consideration at the Northwest WTP. The combinations developed, costed and presented herein are all based on removing at least 90 percent of GenX and hence over 90 percent of most of the PFAS and of 1,4 Dioxane. RO is expected to remove well over 90 percent for all of the PFAS and hence is without question the best technology for PFAS removal. The target goals have a significant impact on costs and the comparison of alternatives. If the target 90 percent removal of all PFAS including PFMOAA and PFO2HxA, that favors RO even more. Similarly, lower targets would help GAC and IX, though the costs of all options would drop if targets are lowered. The planning-level opinion of probable capital costs and annual operation and maintenance (O&M) costs for these alternatives are below.

9.2 Planning-Level Opinion of Probable Capital and O&M Costs

The planning-level opinion of probable capital costs and annual O&M costs for the treatment alternatives are provided in Table 9-2. The capital cost estimates rely on the use of previous estimates and historical data from comparable work, estimating guides, handbooks, cost curves, budget costs from equipment suppliers, and CDM Smith's experience. The planning-level costs includes markups for indirect costs associated with contractor's builders risk insurance, general liability insurance and bonds, general conditions, contractor's overhead and profit, and 30-percent contingency for undefined scope. The capital costs also include the implementation costs Brunswick County would incur as a result of contracting services such as surveying, subsurface investigations, permitting, engineering design and general services during construction. The planning-level opinion of cost is presented in 2018 dollars with an Engineering News Record construction cost index (CCI) of 10959 for March 2018.

The annual planning-level opinion of O&M costs are developed for an average daily flow of 16 mgd over the planning period (25 years). Specific O&M costs are estimated for chemicals, power, operating and maintenance labor, testing, and process maintenance (e.g., GAC media replacement or membrane replacement). Annual O&M costs are prepared for the advanced treatment processes. RO annual costs include an estimated cost to treat a higher raw water flow to compensate for process flow loss associated with the concentrate stream.

Table 9-2 presents the cost summary for the 3 options considered. A discussion of assumptions specific to the development of the planning-level cost estimates of each treatment alternative follows. **Table 9-3** presents the total capital cost for the combination of adding advanced treatment for PFAS and for expanding the Northwest WTP to 36 mgd capacity. Costs are preliminary, budgetary estimates and include 30 percent contingencies.

Table 9-2. Summary of Capital Cost, O&M Costs, and Net Present Worth (NPW) for Three Advanced Treatment Alternatives

	Reverse Osmosis	Ozone/BAF - GAC	IX/GAC/UV-AOP
Opinion of Capital Cost (Advanced Treatment Only)			
Advanced Treatment Improvements	$ 99 M	$ 86 M	$ 73 M
Building for GAC and IX	-	$ 13 M	$ 11 M
TOTAL CAPITAL COSTS	$ 99 M	$ 99 M	$ 84 M
Annual O&M Cost (Advanced Treatment Only)			
Initial Annual Cost	$ 2.9 M	$ 4.7 M	$ 4.7 M
25-yr Present Worth of Annual Costs	$ 59 M	$ 94 M	$ 94 M
25-yr Net Present Worth (Capital + Operating Costs)			
Total 25-yr NPW (Capital + Annual O&M)	**$ 158 M**	**$ 193 M**	**$ 178 M**

Table 9-3. Total Capital Cost (Advanced Treatment + Capacity Expansion)

Opinion of Capital Cost (Advanced Treatment + Capacity Expansion)			
	Reverse Osmosis	**Ozone/BAF - GAC**	**IX/GAC/UV-AOP**
Total Advanced Treatment Cost	$ 99 M	$ 99 M	$ 84 M
Capacity Expansion Cost	$ 38 M	$ 38 M	$ 38 M
Opinion of Total Capital Cost	**$ 137 M**	**$ 137 M**	**$ 122 M**

9.2.1 RO Treatment

9.2.1.1 Capital Costs

The planning-level opinion of probable capital cost was developed based on recent and similar RO construction projects. The estimated cost of a standard RO system with a treated water capacity of 36 mgd is $99 million based on the components described in Section 5.1. The capital cost estimate was based on the following key assumptions:

1. RO equipment and ancillary facilities will be installed in a stand-alone equipment building at the existing WTP site. The building will have a small control room for the operator while working in the RO building, but the existing WTP building will be used for the main control room, lab, training and operator support functions.
2. Existing chemical systems for final disinfection and orthophosphate addition will continue to be used for the RO-treated water. Costs for an emulsified lime feed system and carbon dioxide system have been included in the RO system costs to provide alkalinity, calcium, and pH adjustment of the RO treated water to reduce the corrosion potential of the RO-treated water.
3. Residual pressure from the RO system will be used to discharge the RO concentrate to the Cape Fear River via a pressurized force main.
4. The RO system will operate at 85-percent recovery, which will require the feedwater water capacity to be increased to 43 mgd. With a potential raw water allocation of up to 50 mgd for the Northwest WTP, Brunswick County is considering the requirements for expanding the capacity of the conventional treatment process train. Preliminary engineering will review alternatives for increasing treatment capacity.
5. The RO facility will be designed to produce 36 mgd of treated water with one of the RO units off line for maintenance or chemical cleaning; all other systems will have redundant units.
6. Filtered water from the existing filters will have average turbidities less than 0.1 nephelometric turbidity unit (NTU), no free chlorine, no significant chlorate or chlorite residual from the chlorine dioxide, and negligible concentrations of polymers and dissolved aluminum from the coagulation and filtration processes. If a deviation from these conditions will exist for extended periods then additional pre-treatment systems will be required.

It appears the existing electrical distribution system does not have the capacity or space for the RO process. The planning-level opinion of probable costs for the electrical system upgrade includes a new system for the RO facility.

Table 9-2 presents the planning-level opinion of cost for the RO system.

9.2.1.2 O&M Costs

The primary costs associated with the operation of a RO system are power costs for the RO pumps, chemical costs for pre-treatment of the feedwater and post treatment of the permeate, RO membrane replacement costs, and labor to operate and maintain the RO system. The power and chemical costs are proportional to the volume of treated water produced; it is assumed for this estimate that annual average production is 16 mgd.

RO membranes typically last 7 to10 years when treating feedwater with low concentrations of potential organic or biological foulants and oxidants. Potential scaling minerals can be controlled with pH adjustment and scale inhibitors. The low concentration of dissolved solids in the filtered water will reduce the scaling potential at 85-percent recovery, but there is a moderate fouling potential associated with heterotrophic bacteria and residual aluminum from the coagulation and filtration process. Therefore, a membrane life of 7 years was assumed for estimating the operating costs.

Table 9-2 presents the planning-level opinion of probable O&M costs for the RO alternative. The power costs for the proposed low pressure RO system are approximately 25 percent of the annual operating costs and slightly higher than the estimated labor costs, assuming two operators during the day shift and one operator during the night and weekend shifts. Membrane replacement accrual costs are slightly less than 20 percent of the annual cost; the total RO-related chemical cost represent approximately 20 percent of the annual operating cost.

O&M costs are estimated to be $2.9 million annually at a flow of 16 mgd. The 25-year net present worth of O&M costs is $59 M.

9.2.2 Ozone/BAF-GAC

The application of ozone upstream of the existing filters, conversion of the existing filters to biofiltration, and the addition of post-filter GAC pressure vessels is an option that is anticipated to provide 90-percent removal for most of the target contaminants. A simplified process flow schematic of this alternative is shown in **Figure 9-1**.

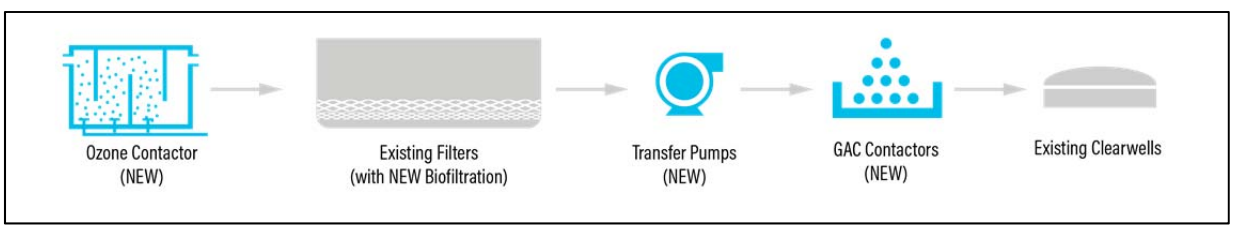

Figure 9-1
Ozone with Post-Filter BAF/GAC Process Flow Schematic

9.2.2.1 Capital Costs

A planning level-opinion of probable capital cost was developed based on similar Ozone/BAF-GAC construction projects. The estimated cost of an Ozone/BAF-GAC system with a water treatment capacity of 36 mgd is $99 million based on the components described in Sections 3.1 and 6.1. The capital cost estimate is based on the following key assumptions:

- GAC contactors constructed for 20-minute empty bed contact time
- Biofiltration occurs within the existing (and proposed future) filters

9.2.2.2 O&M Costs

The value in primary costs associated with the operation of the GAC portion of the system will differ based on changes in EBCT and media replacement and regeneration frequency. Based on pilot testing completed per HB 56, a 20-minute EBCT is assumed with a media change out frequency of 4-months. Under this option, GAC media changeout represents over 80 percent of the annual operating cost. Other costs include filtered water pumping power, liquid oxygen chemical purchase, ozone generator power, water quality testing, and O&M labor.

O&M costs are estimated to be $4.7 million annually at a flow of 16 mgd. The 25-year net present worth of O&M costs is $94 M.

9.2.3 GAC/IX/UV-AOP

The implementation of post-filter GAC pressure vessels followed by IX and UV-AOP is an option that is anticipated to provide similar removal as RO. A process flow schematic of this alternative is shown in **Figure 9-2**.

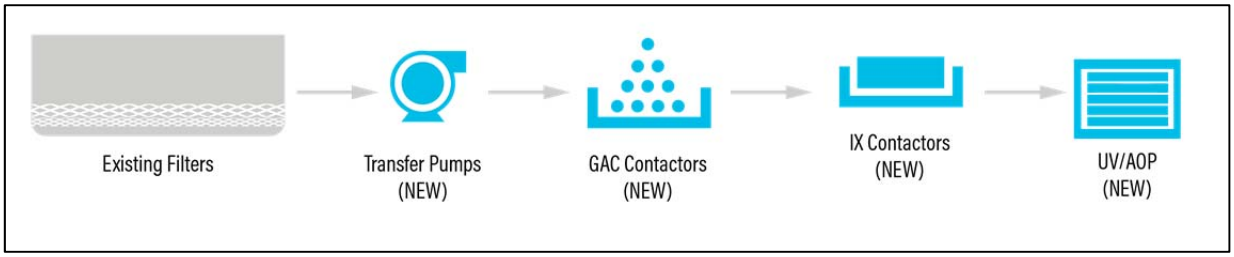

Figure 9-2
Post-Filter GAC/IX/UV-AOP Process Flow Schematic

9.2.3.1 Capital Costs

A planning level-opinion of probable capital cost was developed based on similar GAC/IX/UV-AOP projects. The estimated cost of a GAC/UV-AOP system with a treated water capacity of 36 mgd is $84 million based on the components described in Sections 3.1 and 7.1.2. The capital cost estimate is based on the following key assumptions:

- IX contactors sized for a 1.5-minute EBCT
- GAC contactors constructed for 10-minute EBCT

9.2.3.2 O&M Costs

The value in primary costs associated with the operation of the IX and GAC portion of the system will differ based on changes in EBCT and media replacement and regeneration frequency. Based on pilot testing completed per HB 56, a 1.5-minute IX EBCT and 10-minute GAC EBCT is assumed with a media change out frequency of 4-months. Under this option, GAC and IX media changeout represents over 75 percent of the annual operating cost. Other costs include filtered water pumping power, water quality testing, and O&M labor.

O&M costs are estimated to be $4.7 million annually at a flow of 16 mgd. The 25-year net present worth of O&M costs is $94 M.

9.2.4 Existing Facilities Expansion

The detailed planning-level OPCC for the existing facilities expansion is provided in Section 8.10. The estimated capital cost of facilities to expand the main process area from 24-mgd to approximately 50-mgd is $38 million.

9.3 Recommendation

Based on the evaluation of the alternatives, RO treatment provides the removal of the highest number of target contaminants and is recommended for the Northwest WTP expansion. To demonstrate the effectiveness of RO treatment, a pilot test at the Northwest has been initiated. The RO pilot testing is expected to be completed in approximately 3-4 months.

RO is recommended over the other options for the following reasons:

- RO is the Best Technology for Removal of PFAS. Some PFAS, such as GenX, PFMOAA and PFO2HxA would require very frequent change-out of GAC and IX for removal.
- GAC and IX would likely result in higher finished water concentrations of GenX, PFMOAA, and PFO2HxA than RO (technologies are not equal).
- RO has the lowest net present worth costs for removing 90 percent or more of the Target Contaminants.
- RO is the most robust technology for protecting against unidentified contaminants.
- RO treated water concentrations will not vary as much with influent concentrations as with GAC and IX. RO treated water quality does not rely on frequent media change-out to protect from the spills and contaminants in the Cape Fear River.
- RO does not release elevated concentrations after bed life is spent as can happen with GAC and IX if feed concentration drops.

The overall project includes expansion of the existing facilities to 36 mgd, as discussed in Section 8, and the addition of RO.

Section 10

Implementation Plan

Implementation of RO advanced treatment as part of the water treatment plant expansion will include the following major phases:

- Project Planning – includes Desktop Analysis and Pilot Testing
- Project Permitting
- Design – includes Preliminary Engineering and Final Design
- Bidding
- Construction and Start-up

The following sections describe the current status and path forward for the project.

10.1 Pilot Testing

Pilot testing of RO is currently underway at the Northwest WTP. Goals of pilot testing are to demonstrate the effectiveness of the technology at removing target contaminants, to familiarize Brunswick County staff with the membrane process, and to provide information that will be used to establish the design criteria. Pilot testing began in February 2018 and is expected to continue through at least May 2018.

The performance of the pilot unit is monitored daily by staff at the Northwest WTP. Staff log flow, pressure, conductivity, temperature, and pH at various locations on the pilot unit. Information from the daily logs is transferred to a tracking spreadsheet where performance is monitored and trends are developed over the historical operating period for the pilot unit.

Once per month, samples from the pilot unit feed, combined permeate, and combined concentrate are collected for analysis. The samples are analyzed for PFAS (including GenX, Nafion ByProducts 1 and 2, and numerous others), 1,4-dioxane, and many other target contaminants. The results from the February 26, 2018 sampling event are provided in Appendix A. The pilot unit reduced the concentrations for nearly all of the target contaminants to levels below detection of the analytical method used. The following contaminants were detected in the RO permeate during the February 26, 2018 sampling event:

- PFMOAA = 11 ng/L; greater than 98% removal at membrane
- 1,4-Dioxane = 0.2 µg/L; greater than 94% removal at membrane
- PPCPs: Acetaminophen = 7.8 ng/L
- EDCs: 4-Nonylphenol = 260 ng/L; Sulfadiazine = 29 ng/L

Additional results from other sampling events will be provided with the final pilot plant technical memorandum.

10.2 Permits and Approval

Implementation of the water treatment plant expansion with RO treatment will require permits and approval from various regulatory agencies. Representatives from Brunswick County and CDM Smith have conducted a project scoping meeting with representatives from NCDEQ (multiple divisions), U.S. Army Corps of Engineers, U.S. Fish and Wildlife, and National Oceanic and Atmospheric Administration. Securing an NPDES permit for discharge of the RO concentrate is a critical element for the project. The project team discussed potential options for the concentrate discharge and identified a path ahead.

The next steps in the process of obtaining an NPDES permit for the concentrate discharge are:

- Complete toxicity testing for required species and dilutions of concentrate
- Collect bathymetric information and complete profiling (temperature, salinity) at potential discharge locations
- Complete CORMIX modeling at potential discharge locations
- Prepare and submit NPDES permit application

The activities for the submitting the NPDES permit application are currently underway and submittal of the application is expected in Summer 2018.

10.3 Design, Bidding, and Construction Schedule

The projected completion schedule for various milestones required to implement the water treatment plant expansion with RO advanced treatment is presented in Table 10-1.

Table 10-1. Implementation Schedule

Milestone	Duration	Estimated Completion
Pilot Testing[1]	4 months[1]	June 2018[1]
Preliminary Design	4 months	August 2018
Final Design/ Permitting	9 months	May 2019
Bidding and Award	2 months	July 2019
Construction	18 - 24 months[2]	July 2021

[1] Pilot Testing may be extended to collect additional information

[2] Intermediate milestones can be used to bring advanced treatment facilities on-line ahead of expansion completion; e.g. 18 months for RO facilities and 24 months for expansion

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Appendix A

Results From Pilot Plant Sampling
February 26, 2018 and March 26, 2018

CDM Smith

RESULTS OF PILOT PLANT SAMPLING EVENTS

		FEBRUARY 26 SAMPLING EVENT				MARCH 26 SAMPLING EVENT			
Analyte	Raw Water	Pilot Feed	Pilot Concentrate	Pilot Permeate	Units	Pilot Feed	Pilot Concentrate	Pilot Permeate	Units
PER- AND POLY- FLUORINATED ALKYL SUBSTANCES (PFAS)									
10:2 Fluorotelomer sulfonic acid (10:2 FTS)	< 2	< 2	< 2	< 2	ng/L	< 2	< 2	< 2	ng/L
4:2 Fluorotelomer sulfonic acid (4:2 FTS)	< 2	< 2	< 2	< 2	ng/L	< 2	< 2	< 2	ng/L
6:2 Fluorotelomer sulfonic acid (6:2 FTS)	= 4.8	= 5.8	= 29	< 2	ng/L	= 2.2	= 12	< 2	ng/L
8:2 Fluorotelomer sulfonic acid (8:2 FTS)	< 2	< 2	< 2	< 2	ng/L	< 2	< 2	< 2	ng/L
ADONA	< 2	< 2	< 2	< 2	ng/L	< 2	< 2	< 2	ng/L
F-53B Major	< 2	< 2	< 2	< 2	ng/L	< 2	< 2	< 2	ng/L
F-53B Minor	< 2	< 2	< 2	< 2	ng/L	< 2	< 2	< 2	ng/L
GenX	= 12	= 14	= 140	< 5	ng/L	= 6.7	= 42	< 5	ng/L
Nafion Byproduct 1	< 5	< 5	< 5	< 5	ng/L	< 5	< 5	< 5	ng/L
Nafion Byproduct 2	< 5	< 5	= 11	< 5	ng/L	< 5	= 8.1	< 5	ng/L
N-ethylperfluorooctane sulfonamide (NEtFOSA)	< 2	< 2	< 2	< 2	ng/L	< 2	< 2	< 2	ng/L
N-ethylperfluorooctane sulfonamidoethanol	< 2	< 2	< 2	< 2	ng/L	< 2	< 2	< 2	ng/L
N-methylperfluorooctane sulfonamide (NMeFOSA)	< 2	< 2	< 2	< 2	ng/L	< 2	< 2	< 2	ng/L
N-methylperfluorooctane sulfonamidoethanol	< 2	< 2	< 2	< 2	ng/L	< 2	< 2	< 2	ng/L
Perfluorobutanesulfonic acid (PFBS)	< 3.3	= 3.6	= 24	< 2	ng/L	= 2.3	= 16	< 2	ng/L
Perfluorobutanoic acid (PFBA)	= 7.5	= 7.7	= 49	< 5	ng/L	= 6.7	= 52	< 5	ng/L
Perfluorodecanoic acid (PFDA)	< 2	< 2	= 11	< 2	ng/L	< 2	= 9.5	< 2	ng/L
Perfluoroheptanoic acid (PFHpA)	= 11	= 11	= 77	< 2	ng/L	= 15	= 94	< 2	ng/L
Perfluorohexanesulfonic acid (PFHxS)	= 5.6	= 6	= 40	< 2	ng/L	= 3.5	= 23	< 2	ng/L
Perfluorohexanoic acid (PFHxA)	= 19	= 19	= 130	< 2	ng/L	= 20	= 130	< 2	ng/L
Perfluorododecanoic acid (PFDoA)	< 2	< 2	< 2	< 2	ng/L	< 2	< 2	< 2	ng/L
Perfluorononanoic acid (PFNA)	< 2	< 2	= 12	< 2	ng/L	< 2	= 10	< 2	ng/L
Perfluorooctanesulfonic acid (PFOS)	= 16	= 16	= 94	< 2	ng/L	= 9.8	= 64	< 2	ng/L
N-ethyl Perfluorooctanesulfonamidoacetic acid	< 2	< 2	< 2	< 2	ng/L	< 2	< 2	< 2	ng/L
N-methyl Perfluorooctanesulfonamidoacetic acid	< 2	< 2	< 2	< 2	ng/L	< 2	< 2	< 2	ng/L
Perfluorooctanoic acid (PFOA)	= 9.9	= 9.8	= 64	< 2	ng/L	= 8.5	= 52	< 2	ng/L
Perfluorotridecanoic acid (PFTrDA)	< 2	< 2	< 2	< 2	ng/L	< 2	< 2	< 2	ng/L
Perfluoroundecanoic acid (PFUnA)	< 2	< 2	= 2.6	< 2	ng/L	< 2	= 2.3	< 2	ng/L
Perfluorododecanesulfonic acid (PFDoS)	< 2	< 2	< 2	< 2	ng/L	< 2	< 2	< 2	ng/L
Perfluorodecanesulfonic acid (PFDS)	< 2	< 2	< 2	< 2	ng/L	< 2	< 2	< 2	ng/L

RESULTS OF PILOT PLANT SAMPLING EVENTS

		FEBRUARY 26 SAMPLING EVENT				MARCH 26 SAMPLING EVENT			
Analyte	Raw Water	Pilot Feed	Pilot Concentrate	Pilot Permeate	Units	Pilot Feed	Pilot Concentrate	Pilot Permeate	Units
PER- AND POLY- FLUORINATED ALKYL SUBSTANCES (PFAS)									
Perfluoroheptanesulfonic acid (PFHpS)	< 2	< 2	= 4.1	< 2	ng/L	< 2	= 3	< 2	ng/L
Perfluorohexadecanoic acid (PFHxDA)	< 2	< 2	< 2	< 2	ng/L	< 2	< 2	< 2	ng/L
Perfluoro-2-methoxyethoxyacetic acid	< 5	< 5	< 5	< 5	ng/L	< 5	< 5	< 5	ng/L
Perfluoro-4-isopropoxybutanoic acid	< 5	< 5	< 5	< 5	ng/L	< 5	< 5	< 5	ng/L
Perfluoro-2-methoxyacetic acid	= 1600	= 750	= 5600	= 11	ng/L	= 320	= 950	< 5	ng/L
Perfluoro-4-methoxybutanoic acid (PFMOBA)	< 5	< 5	< 5	< 5	ng/L	< 5	< 5	< 5	ng/L
Perfluoro-3-methoxypropanoic acid (PFMOPrA)	< 5	< 5	< 5	< 5	ng/L	< 5	< 5	< 5	ng/L
Perfluorononanesulfonic acid (PFNS)	< 2	< 2	< 2	< 2	ng/L	< 2	< 2	< 2	ng/L
Perfluoro(3,5-dioxahexanoic) acid	= 32	= 26	= 140	< 5	ng/L	= 12	= 38	< 5	ng/L
Perfluoro(3,5,7-trioxaoctanoic) acid	= 5.2	= 6.1	= 28	< 5	ng/L	< 5	= 9.4	< 5	ng/L
Perfluoro(3,5,7,9-tetraoxadecanoic) acid	< 5	< 5	= 7.2	< 5	ng/L	< 5	< 5	< 5	ng/L
Perfluorooctane sulfonamide (PFOSA)	< 2	< 2	< 2	< 2	ng/L	< 2	< 2	< 2	ng/L
Perfluoropentanoic acid (PFPeA)	= 17	= 17	= 110	< 2	ng/L	= 16	= 100	< 2	ng/L
Perfluoropentanesulfonic acid (PFPeS)	< 2	< 2	= 5.2	< 2	ng/L	< 2	= 5.4	< 2	ng/L
Perfluorotetradecanoic acid (PFTeDA)	< 2	< 2	< 2	< 2	ng/L	< 2	< 2	< 2	ng/L
1,4-DIOXANE									
1,4-Dioxane	= 3.3	= 3.2	= 21	= 0.2	ug/L				

RESULTS OF PILOT PLANT SAMPLING EVENTS

	FEBRUARY 26 SAMPLING EVENT					MARCH 26 SAMPLING EVENT			
Analyte	Raw Water	Pilot Feed	Pilot Concentrate	Pilot Permeate	Units	Pilot Feed	Pilot Concentrate	Pilot Permeate	Units
SEMI-VOLATILE ORGANIC COMPOUNDS									
Chlorpyrifos	< 0.03	< 0.03	< 0.03	< 0.03	ug/L				
Dimethipin	< 0.2	< 0.2	< 0.2	< 0.2	ug/L				
Ethoprop	< 0.03	< 0.03	< 0.03	< 0.03	ug/L				
alpha-Hexachlorocyclohexane	< 0.01	< 0.01	< 0.01	< 0.01	ug/L				
Oxyfluorfen	< 0.05	< 0.05	< 0.05	< 0.05	ug/L				
cis-Permethrin	< 0.0109	< 0.0109	< 0.0109	< 0.0109	ug/L				
trans-Permethrin	< 0.029	< 0.029	< 0.029	< 0.029	ug/L				
Permethrin, cis & trans	< 0.04	< 0.04	< 0.04	< N/A	ug/L				
Profenofos	< 0.3	< 0.3	< 0.3	< 0.3	ug/L				
Tebuconazole	< 0.2	< 0.2	< 0.2	< 0.2	ug/L				
Tribufos	< 0.07	< 0.07	< 0.07	< 0.07	ug/L				
Butylated hydroxyanisole	< 0.03	< 0.03	< 0.03	< 0.03	ug/L				
Quinoline	< 0.02	< 0.02	< 0.02	< 0.02	ug/L				
o-Toluidine	< 0.007	< 0.007	< 0.007	< 0.007	ug/L				
1-Butanol	< 2	< 2	< 2	< 2	ug/L				
2-Methoxyethanol	< 0.4	< 0.4	< 0.4	< 0.4	ug/L				
2-Propen-1-ol	< 0.5	< 0.5	< 0.5	< 0.5	ug/L				
INORGANICS									
Iodide	< 1	= 1.1	= 6.8	< 1	ug/L				
Bromide	= 120	= 110	= 710	< 10	ug/L				
Chlorate	< 10	= 120	= 680	< 10	ug/L				
Chlorite	< 10	= 410	= 2800	< 10	ug/L				
MICROCYSTS AND CYANOTOXINS									
Total Microcystins & Nodularins	< 0.3	< 0.3	< 0.3	< 0.3	ug/L				
Anatoxin-a	< 0.03	< 0.03	< 0.03	< 0.03	ug/L				
Cylindrospermopsin	< 0.09	< 0.09	< 0.09	< 0.09	ug/L				

RESULTS OF PILOT PLANT SAMPLING EVENTS

		FEBRUARY 26 SAMPLING EVENT				MARCH 26 SAMPLING EVENT			
Analyte	Raw Water	Pilot Feed	Pilot Concentrate	Pilot Permeate	Units	Pilot Feed	Pilot Concentrate	Pilot Permeate	Units
HALOACETIC ACIDS									
Bromochloroacetic acid	< 1	= 1.7	= 14	< 1	ug/L				
Bromodichloroacetic acid	< 1	< 1	= 1.3	< 1	ug/L				
Chlorodibromoacetic acid	< 2	< 2	< 2	< 2	ug/L				
Dibromoacetic acid	< 1	< 1	= 9	< 1	ug/L				
Dichloroacetic acid	< 1	= 2.1	= 13	< 1	ug/L				
Monobromoacetic acid	< 1	< 1	= 2.7	< 1	ug/L				
Monochloroacetic acid	< 2	< 2	< 2	< 2	ug/L				
Tribromoacetic acid	< 4	< 4	< 4	< 4	ug/L				
Trichloroacetic acid	< 1	< 1	= 2.3	< 1	ug/L				
Total HAA5	< 2	= 2.1	= 27	< 2	ug/L				
VOLATILE ORGANIC COMPOUNDS									
Acetone	< 5	< 5	< 5	< 5	ug/L				
Acrylonitrile	< 1	< 1	< 1	< 1	ug/L				
Allyl chloride	< 5	< 5	< 5	< 5	ug/L				
tert-Amyl Methyl ether	< 3	< 3	< 3	< 3	ug/L				
Benzene	< 0.5	< 0.5	< 0.5	< 0.5	ug/L				
Benzyl chloride	< 0.5	< 0.5	< 0.5	< 0.5	ug/L				
Bromobenzene	< 0.5	< 0.5	< 0.5	< 0.5	ug/L				
Bromochloromethane	< 0.5	< 0.5	< 0.5	< 0.5	ug/L				
Bromodichloromethane	< 0.5	< 0.5	= 1.3	< 0.5	ug/L				
Bromoform	< 0.5	< 0.5	= 0.6	< 0.5	ug/L				
Bromomethane	< 0.5	< 0.5	< 0.5	< 0.5	ug/L				
1,3-Butadiene	< 5	< 5	< 5	< 5	ug/L				
2-Butanone (MEK)	< 5	< 5	< 5	< 5	ug/L				
n-Butyl acrylate	< 1	< 1	< 1	< 1	ug/L				
tert-Butyl alcohol	< 2	< 2	< 2	< 2	ug/L				
n-Butylbenzene	< 0.5	< 0.5	< 0.5	< 0.5	ug/L				
sec-Butylbenzene	< 0.5	< 0.5	< 0.5	< 0.5	ug/L				
tert-Butylbenzene	< 0.5	< 0.5	< 0.5	< 0.5	ug/L				
Carbon disulfide	< 5	< 5	< 5	< 5	ug/L				
Carbon tetrachloride	< 0.5	< 0.5	< 0.5	< 0.5	ug/L				

RESULTS OF PILOT PLANT SAMPLING EVENTS

	FEBRUARY 26 SAMPLING EVENT					MARCH 26 SAMPLING EVENT			
Analyte	Raw Water	Pilot Feed	Pilot Concentrate	Pilot Permeate	Units	Pilot Feed	Pilot Concentrate	Pilot Permeate	Units
VOLATILE ORGANIC COMPOUNDS									
Chloroacetonitrile	< 5	< 5	< 5	< 5	ug/L				
Chlorobenzene	< 0.5	< 0.5	< 0.5	< 0.5	ug/L				
1-Chlorobutane	< 5	< 5	< 5	< 5	ug/L				
Chloroethane	< 0.5	< 0.5	< 0.5	< 0.5	ug/L				
Chloroform	< 0.5	< 0.5	= 1.4	< 0.5	ug/L				
Chloromethane	< 0.5	< 0.5	< 0.5	< 0.5	ug/L				
Chloroprene	< 5	< 5	< 5	< 5	ug/L				
2-Chlorotoluene	< 0.5	< 0.5	< 0.5	< 0.5	ug/L				
4-Chlorotoluene	< 0.5	< 0.5	< 0.5	< 0.5	ug/L				
Cyclohexanone	< 5	< 5	< 5	< 5	ug/L				
Dibromochloromethane	< 0.5	< 0.5	= 1.4	< 0.5	ug/L				
1,2-Dibromo-3-chloropropane (DBCP)	< 0.2	< 0.2	< 0.2	< 0.2	ug/L				
1,2-Dibromoethane (EDB)	< 0.2	< 0.2	< 0.2	< 0.2	ug/L				
Dibromomethane	< 0.5	< 0.5	< 0.5	< 0.5	ug/L				
1,2-Dichlorobenzene	< 0.5	< 0.5	< 0.5	< 0.5	ug/L				
1,3-Dichlorobenzene	< 0.5	< 0.5	< 0.5	< 0.5	ug/L				
1,4-Dichlorobenzene	< 0.5	< 0.5	< 0.5	< 0.5	ug/L				
Total Dichlorobenzene	< 0.5	< 0.5	< N/A	< 0.5	ug/L				
trans-1,4-Dichloro-2-butylene	< 5	< 5	< 5	< 5	ug/L				
Dichlorodifluoromethane	< 0.5	< 0.5	< 0.5	< 0.5	ug/L				
1,1-Dichloroethane	< 0.5	< 0.5	< 0.5	< 0.5	ug/L				
1,2-Dichloroethane	< 0.5	< 0.5	< 0.5	< 0.5	ug/L				
1,1-Dichloroethylene	< 0.5	< 0.5	< 0.5	< 0.5	ug/L				
cis-1,2-Dichloroethylene	< 0.5	< 0.5	< 0.5	< 0.5	ug/L				
trans-1,2-Dichloroethylene	< 0.5	< 0.5	< 0.5	< 0.5	ug/L				
Di(2-chloroethyl)ether	< 2	< 2	< 2	< 2	ug/L				
Dichloromethane	< 0.5	< 0.5	< 0.5	< 0.5	ug/L				
1,2-Dichloropropane	< 0.5	< 0.5	< 0.5	< 0.5	ug/L				
1,3-Dichloropropane	< 0.5	< 0.5	< 0.5	< 0.5	ug/L				
2,2-Dichloropropane	< 0.5	< 0.5	< 0.5	< 0.5	ug/L				
1,1-Dichloropropanone	< 5	< 5	< 5	< 5	ug/L				

RESULTS OF PILOT PLANT SAMPLING EVENTS

	FEBRUARY 26 SAMPLING EVENT					MARCH 26 SAMPLING EVENT			
Analyte	Raw Water	Pilot Feed	Pilot Concentrate	Pilot Permeate	Units	Pilot Feed	Pilot Concentrate	Pilot Permeate	Units
VOLATILE ORGANIC COMPOUNDS									
1,1-Dichloropropylene	< 0.5	< 0.5	< 0.5	< 0.5	ug/L				
1,3-Dichloropropylene, cis & trans	< 0.5	< 0.5	< N/A	< 0.5	ug/L				
cis-1,3-Dichloropropylene	< 0.5	< 0.5	< 0.5	< 0.5	ug/L				
trans-1,3-Dichloropropylene	< 0.5	< 0.5	< 0.5	< 0.5	ug/L				
Diisopropyl ether	< 0.5	< 0.5	< 0.5	< 0.5	ug/L				
1,4-Dioxane	< 5	< 5	= 29	< 5	ug/L				
Epichlorohydrin	< 1	< 1	< 1	< 1	ug/L				
Ethyl acrylate	< 1	< 1	< 1	< 1	ug/L				
Ethyl Ether	< 2	< 2	< 2	< 2	ug/L				
Ethyl methacrylate	< 1	< 1	< 1	< 1	ug/L				
Ethylbenzene	< 0.5	< 0.5	< 0.5	< 0.5	ug/L				
Ethyl tert-butyl ether	< 3	< 3	< 3	< 3	ug/L				
Hexachlorobutadiene	< 0.5	< 0.5	< 0.5	< 0.5	ug/L				
Hexachloroethane	< 2	< 2	< 2	< 2	ug/L				
2-Hexanone	< 5	< 5	< 5	< 5	ug/L				
Isopropylbenzene	< 0.5	< 0.5	< 0.5	< 0.5	ug/L				
4-Isopropyltoluene	< 0.5	< 0.5	< 0.5	< 0.5	ug/L				
Methacrylonitrile	< 5	< 5	< 5	< 5	ug/L				
Methylacrylate	< 1	< 1	< 1	< 1	ug/L				
Methyl iodide	< 2	< 2	< 2	< 2	ug/L				
Methylmethacrylate	< 1	< 1	< 1	< 1	ug/L				
4-Methyl-2-pentanone (MIBK)	< 2	< 2	< 2	< 2	ug/L				
Methyl-t-butyl ether (MTBE)	< 0.5	< 0.5	< 0.5	< 0.5	ug/L				
Naphthalene	< 0.5	< 0.5	< 0.5	< 0.5	ug/L				
Nitrobenzene	< 5	< 5	< 5	< 5	ug/L				
2-Nitropropane	< 2	< 2	< 2	< 2	ug/L				
Pentachloroethane	< 2	< 2	< 2	< 2	ug/L				
Propionitrile	< 5	< 5	< 5	< 5	ug/L				
n-Propylbenzene	< 0.5	< 0.5	< 0.5	< 0.5	ug/L				
Styrene	< 0.5	< 0.5	< 0.5	< 0.5	ug/L				
1,1,1,2-Tetrachloroethane	< 0.5	< 0.5	< 0.5	< 0.5	ug/L				

RESULTS OF PILOT PLANT SAMPLING EVENTS

		FEBRUARY 26 SAMPLING EVENT				MARCH 26 SAMPLING EVENT			
Analyte	Raw Water	Pilot Feed	Pilot Concentrate	Pilot Permeate	Units	Pilot Feed	Pilot Concentrate	Pilot Permeate	Units
VOLATILE ORGANIC COMPOUNDS									
1,1,2,2-Tetrachloroethane	< 0.5	< 0.5	< 0.5	< 0.5	ug/L				
Tetrachloroethylene	< 0.5	< 0.5	< 0.5	< 0.5	ug/L				
Tetrahydrofuran	< 5	< 5	< 5	< 5	ug/L				
Toluene	< 0.5	< 0.5	< 0.5	< 0.5	ug/L				
Total Trihalomethanes	< 0.5	< 0.5	= 4.7	< 0.5	ug/L				
1,2,3-Trichlorobenzene	< 0.5	< 0.5	< 0.5	< 0.5	ug/L				
1,2,4-Trichlorobenzene	< 0.5	< 0.5	< 0.5	< 0.5	ug/L				
1,1,1-Trichloroethane	< 0.5	< 0.5	< 0.5	< 0.5	ug/L				
1,1,2-Trichloroethane	< 0.5	< 0.5	< 0.5	< 0.5	ug/L				
Trichloroethylene	< 0.5	< 0.5	< 0.5	< 0.5	ug/L				
Trichlorofluoromethane	< 0.5	< 0.5	< 0.5	< 0.5	ug/L				
1,2,3-Trichloropropane	< 0.5	< 0.5	< 0.5	< 0.5	ug/L				
1,1,2-Trichloro-1,2,2-trifluoroethane	< 0.5	< 0.5	< 0.5	< 0.5	ug/L				
1,2,3-Trimethylbenzene	< 0.5	< 0.5	< 0.5	< 0.5	ug/L				
1,2,4-Trimethylbenzene	< 0.5	< 0.5	< 0.5	< 0.5	ug/L				
1,3,5-Trimethylbenzene	< 0.5	< 0.5	< 0.5	< 0.5	ug/L				
Vinyl acetate	< 5	< 5	< 5	< 5	ug/L				
Vinyl chloride	< 0.2	< 0.2	< 0.2	< 0.2	ug/L				
1,2-Xylene	< 0.5	< 0.5	< 0.5	< 0.5	ug/L				
1,3 + 1,4-Xylene	< 0.5	< 0.5	< 0.5	< 0.5	ug/L				
Xylenes, Total	< 0.5	< 0.5	< N/A	< 0.5	ug/L				
TOTAL ORGANIC CARBON									
Total Organic Carbon (TOC)	= 6.83	= 3.08	= 13.5	< 0.5	mg/L				

RESULTS OF PILOT PLANT SAMPLING EVENTS

		FEBRUARY 26 SAMPLING EVENT				MARCH 26 SAMPLING EVENT			
Analyte	Raw Water	Pilot Feed	Pilot Concentrate	Pilot Permeate	Units	Pilot Feed	Pilot Concentrate	Pilot Permeate	Units
EDC/PPCP/HORMONE SMALL VOLUME SCAN									
Acesulfame-K	= 420	= 330	= 3600	< 20	ng/L				
Acetaminophen	= 7.1	= 13	= 25	= 7.8	ng/L				
Albuterol	< 5	< 5	< 5	< 5	ng/L				
Amoxicillin	< 20	< 20	< 20	< 20	ng/L				
4-Androstene-3,17-dione	< 5	< 5	< 5	< 5	ng/L				
Antipyrine	< 5	< 5	< 5	< 5	ng/L				
Atenolol	< 5	< 5	= 40	< 5	ng/L				
Atrazine	= 60	= 58	= 460	< 5	ng/L				
Azithromycin	< 20	< 20	< 20	< 20	ng/L				
Bendroflumethiazide	< 5	< 5	< 5	< 5	ng/L				
Bezafibrate	< 5	< 5	< 5	< 5	ng/L				
Bisphenol A	< 10	< 10	< 10	< 10	ng/L				
Bromacil	< 5	< 5	< 5	< 5	ng/L				
Butalbital	< 5	< 5	= 25	< 5	ng/L				
Butylparaben	< 5	< 5	< 5	< 5	ng/L				
Caffeine	= 26	= 30	= 330	< 5	ng/L				
Carbadox	< 5	< 5	< 5	< 5	ng/L				
Carbamazepine	= 14	= 13	= 94	< 5	ng/L				
Carisoprodol	< 5	< 5	< 5	< 5	ng/L				
Chloramphenicol	< 10	< 10	< 10	< 10	ng/L				
Chloridazon	< 5	< 5	< 5	< 5	ng/L				
Chlorotoluron	< 5	< 5	< 5	< 5	ng/L				
Cimetidine	< 5	< 5	< 5	< 5	ng/L				
Clofibric acid	< 5	< 5	< 5	< 5	ng/L				
Cotinine	= 16	= 15	= 150	< 10	ng/L				
Cyanazine	< 5	< 5	< 5	< 5	ng/L				
2,4-D	< 5	= 10	= 54	< 5	ng/L				
DEET	= 30	= 44	= 240	< 10	ng/L				
Dehydronifedipine	< 5	< 5	< 5	< 5	ng/L				
Desethylatrazine	= 14	= 7	= 34	< 5	ng/L				
Desisopropylatrazine	= 14	= 12	= 160	< 5	ng/L				

RESULTS OF PILOT PLANT SAMPLING EVENTS

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Analyte	Raw Water	Pilot Feed	Pilot Concentrate	Pilot Permeate	Units	Pilot Feed	Pilot Concentrate	Pilot Permeate	Units
EDC/PPCP/HORMONE SMALL VOLUME SCAN									
Diaminochlorotriazine	< 5	< 5	= 63	< 5	ng/L				
Diazepam	< 5	< 5	< 5	< 5	ng/L				
Diclofenac	< 5	< 5	< 5	< 5	ng/L				
Dilantin	< 20	< 20	< 20	< 20	ng/L				
Diltiazem	< 5	< 5	< 5	< 5	ng/L				
1,7-Dimethylxanthine	< 10	< 10	= 20	< 10	ng/L				
Diuron	< 5	= 5.5	= 24	< 5	ng/L				
Erythromycin	< 10	< 10	< 10	< 10	ng/L				
17beta-Estradiol	< 5	< 5	< 5	< 5	ng/L				
Estriol	= 81	< 5	< 5	< 5	ng/L				
Estrone	< 5	< 5	< 5	< 5	ng/L				
Ethylparaben	< 20	< 20	< 20	< 20	ng/L				
17alpha-Ethynyl estradiol	< 5	< 5	= 40	< 5	ng/L				
Flumequine	< 10	< 10	< 10	< 10	ng/L				
Fluoxetine (Prozac)	< 10	< 10	< 10	< 10	ng/L				
Gemfibrozil	< 5	< 5	< 5	< 5	ng/L				
Ibuprofen	< 10	< 10	< 10	< 10	ng/L				
Iohexal	= 43	< 10	= 880	< 10	ng/L				
Iopromide	< 5	< 5	< 5	< 5	ng/L				
Isobutylparaben	< 5	< 5	< 5	< 5	ng/L				
Isoproturon	< 100	< 100	< 100	< 100	ng/L				
Ketoprofen	< 5	< 5	< 5	< 5	ng/L				
Ketorolac	< 5	< 5	< 5	< 5	ng/L				
Lidocaine	= 20	= 15	= 46	< 5	ng/L				
Lincomycin	< 10	< 10	< 10	< 10	ng/L				
Linuron	< 5	< 5	< 5	< 5	ng/L				
Lopressor	< 20	< 20	= 91	< 20	ng/L				
Meclofenamic acid	< 5	< 5	< 5	< 5	ng/L				
Meprobamate	< 5	< 5	= 7.9	< 5	ng/L				
Metazochlor	< 5	< 5	< 5	< 5	ng/L				
Methylparaben	< 20	< 20	< 20	< 20	ng/L				

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Analyte	Raw Water	Pilot Feed	Pilot Concentrate	Pilot Permeate	Units	Pilot Feed	Pilot Concentrate	Pilot Permeate	Units
EDC/PPCP/HORMONE SMALL VOLUME SCAN									
Metolachlor	= 5.8	= 5.2	= 37	< 5	ng/L				
Naproxen	< 10	< 10	< 10	< 10	ng/L				
Nifedipine	< 20	< 20	< 20	< 20	ng/L				
4-Nonylphenol	= 510	= 520	= 840	= 260	ng/L				
Norethisterone	< 5	< 5	< 5	< 5	ng/L				
4-tert-Octylphenol	< 50	< 50	< 50	< 50	ng/L				
Oxolinic acid	< 10	< 10	< 10	< 10	ng/L				
Pentoxifylline	< 5	< 5	< 5	< 5	ng/L				
Primidone	< 5	< 5	= 47	< 5	ng/L				
Progesterone	< 5	< 5	< 5	< 5	ng/L				
Propazine	< 5	< 5	= 9.3	< 5	ng/L				
Propylparaben	< 5	< 5	< 5	< 5	ng/L				
Quinoline	< 5	< 5	= 13	< 5	ng/L				
Salicylic acid	< 100	< 100	< 100	< 100	ng/L				
Simazine	= 68	= 57	= 160	< 5	ng/L				
Sucralose	= 740	< 100	< 100	= 300	ng/L				
Sulfachloropyridazine	< 5	< 5	< 5	< 5	ng/L				
Sulfadiazine	= 150	= 84	= 350	= 29	ng/L				
Sulfadimethoxine	< 5	< 5	< 5	< 5	ng/L				
Sulfamerazine	< 5	< 5	< 5	< 5	ng/L				
Sulfamethazine	< 5	< 5	< 5	< 5	ng/L				
Sulfamethizole	< 5	< 5	< 5	< 5	ng/L				
Sulfamethoxazole	= 10	< 5	< 5	< 5	ng/L				
Sulfathiazole	< 5	< 5	< 5	< 5	ng/L				
Sulfometuron Methyl	< 5	< 5	= 9.5	< 5	ng/L				
Testosterone	< 5	= 5.4	< 5	< 5	ng/L				
Theobromine	= 14	< 10	= 63	< 10	ng/L				
Theophylline	< 20	< 20	< 20	< 20	ng/L				
Thiabendazole	< 5	< 5	< 5	< 5	ng/L				
Triclocarban	< 5	< 5	< 5	< 5	ng/L				
Triclosan	< 10	< 10	< 10	< 10	ng/L				

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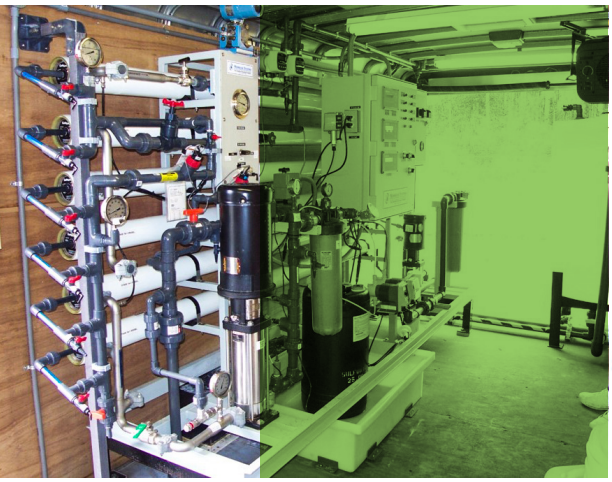
Analyte	Raw Water	Pilot Feed	Pilot Concentrate	Pilot Permeate	Units	Pilot Feed	Pilot Concentrate	Pilot Permeate	Units
EDC/PPCP/HORMONE SMALL VOLUME SCAN									
Trimethoprim	< 5	< 5	< 5	< 5	ng/L				
Tris(2-carboxyethyl)phosphine hydrochloride	< 10	= 13	= 90	< 10	ng/L				
Tris(1,3-dichloro-2-propyl) phosphate	< 100	= 120	= 960	< 100	ng/L				
Warfarin	< 5	< 5	< 5	< 5	ng/L				



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