CITY OF CORONA

EVALUATION OF PFAS AND 1,2,3-TCP TREATMENT SOLUTIONS

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EVALUATION OF PFAS TREATMENT SOLUTIONS

1. Introduction

1.1 City's Drinking Water Sources

The City of Corona (City) provides potable water to its residents through a number of sources. Groundwater wells, owned and operated by the City, provide nearly half of the supply. Currently, a large portion of the groundwater is treated through a reverse osmosis (RO) membrane system known as the Temescal Desalter (Desalter). A portion of the remaining groundwater is sent to the City Park Ion Exchange Treatment Plant (IXTP) where perchlorate and nitrate are removed using targeted ion exchange (IX) treatment. Five blending facilities throughout the distribution system also provide a means of accomplishing water quality goals. Through these methods, the City meets current Maximum Contaminant Levels (MCL). The overall blending flow diagram for the existing distribution system is shown in **Appendix A**.

1.2 Contaminants and Limits

In April 2016, per- and polyfluoroalkyl substances (PFAS) were detected in several of the City's operating wells. The PFAS are a group of persistent anthropogenic organic compounds that may cause adverse health effects at trace level concentrations. The state of California has established stringent drinking water notification levels (NL) and response levels (RL) for two of the PFAS compounds, namely the perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA) (Table 2). In addition to PFAS, 1,2,3-Trichloropropane (1,2,3-TCP) is another organic trace contaminant that is detected in the City's drinking water sources. Most of the wells have moderate to low levels of 1,2,3-TCP. With a combination of treatment by the Temescal Desalter and blending, the City was able to control the 1,2,3-TCP at below the MCL.

The Temescal Desalter can provide effective treatment for PFOS and PFOA. However, the contaminants are rejected and concentrated in a brine stream that is subsequently discharged to the Santa Ana River Interceptor. Being environmentally conscious and in anticipation of possible future regulatory limits for such discharge, the City wants to evaluate options for removal of PFAS from water, including brine treatment and wellhead treatment by adsorption process.

The existing IXTP uses both regenerable and single-use IX resins which target nitrate and perchlorate removal. The resins can provide incidental removal of PFAS, but both the resins and the empty bed contact times (EBCT) are not designed for effective removal of PFAS. In addition, the City is currently incurring a higher-than-expected salt cost for regeneration of the resin for nitrate removal. The City is interested in converting the existing IXTP system to a granular activated carbon (GAC) system for removal of PFAS and 1,2,3-TCP or a single-use resin system for PFAS removal.

Based on the Scope of Service prepared by the City and the meeting discussions between the City and the project team in November of 2019, PFAS (specifically PFOS and PFOA) and 1,2,3-TCP were identified as the main contaminants of interest. Nitrate and perchlorate treatment, although not explicitly mentioned as part of the evaluation in this project, is also considered in the preliminary engineering design because the conversion of existing IXTP will impact its nitrate and perchlorate removal capabilities. The drinking water regulatory limits for these contaminants are presented in Table 1.

Table 1. California Drinking Water Regulatory Limits for the Contaminants of Interest

Contaminants	MCLs	Notification Levels	Response Levels
PFOS (ng/L)	N/A[(1)]	6.5	40
PFOA (ng/L)	N/A[(1)]	5.1	10
1,2,3-TCP (ng/L)	5	-	-
Nitrate (as N) (mg/L)	10	-	-
Perchlorate (μg/L)	6[(2)]	-	-

NOTES:
(1) MCL has not been established. The current notification levels and response levels are shown.
(2) MCL is under review and may be lowered in the near future.

1.3 Specific Sites of Interest

Based on the Scope of Service prepared by the City and the meeting discussions, a total of six water sources (sites) have been identified for treatment evaluations. Table 2 presents the six water sources and their respective site characteristics including flow rates and contaminant concentrations.

Of the six sites, Well 7A, 8A, and 17A are drinking water wells. Well 8A and 17A are directed to the influent to the IXTP. Well 7A does not currently go through any treatment prior to being blended directly with the effluent from the IXTP. The IXTP influent, in addition to Well 8A and 17A, also includes City's Well 33. The designed capacity of the IXTP is 2,400 GPM, of which approximately 1,600 GPM goes through the treatment and approximately 800 GPM is bypassed. The connections of these water sources can be found in **Appendix A**.

The two remaining sites are not drinking water sources. The Desalter Brine is the rejected brine from the Temescal Desalter RO treatment system. The Desalter operates four trains of RO systems, each with a two-stage RO system. The overall recovery of the Desalter is approximately 86%, with a permeate production capability of approximately 7,000 GPM. The Desalter receives a portion of the City's drinking water wells, as well as a portion of the effluent from the IXTP as the influent. Detailed connections can be found in **Appendix A**.

The WWTP Effluent is the effluent from the City's Water Reclamation Facility #1 (located at 2205 Railroad St., Corona, CA). The WWTP consists of preliminary treatment, two secondary treatment facilities (activated sludge and oxidation ditch in parallel), and tertiary treatment, which produces Title 22 recycled water that can be used for irrigation or discharged[1]. The

[1] City of Corona, 2015 Urban Water Management Plan Volume 1 – Report, https://www.coronaca.gov/home/showdocument?id=4318

maximum flow of the tertiary treatment facility is about 6,250 GPM (9 MGD). The total capacity of the WWTP #1 is about 7,986 GPM (11.5 MGD).

Table 2. Contaminant Concentrations at the Selected Sites

Location	Flow	Nitrate	Perchlorate	1,2,3-TCP	PFOA	PFOS
Unit	gpm	mg/L as N	µg/L	ng/L	ng/L	ng/L
Well 7A	640	12.8	5.45	5.34	140	140
Well 8A	1,110	14.2	4.76	23.14	180	170
Well 17A	550	9.6	2.86	12.68	230	210
IXTP Influent	2,400	8.6	4.6	17	130	120
WWTP Effluent	6,250 (post tertiary)	5.0	ND	ND	20	4.6
Desalter Brine	980	52	NM	16.2	320	294
NOTES: NA – Not Applicable, NM – Not Measured, ND – Non-Detect						

1.4 Technical Memorandum Objectives

The primary purpose of the study was to identify and evaluate water treatment options by GAC or IX adsorption process to address PFOA, PFOS, and 1,2,3-TCP at the specific sites of interest identified above. As part of the study, rapid small-scale column testing (RSSCT) was performed on water samples from these locations with multiple types of IX and GAC media. Preliminary layouts and cost estimates were also developed.

2. Preliminary and RSSCT Testing Evaluations

The GAC and IX processes were selected by the City as the preferred main treatment options for evaluation for PFAS and 1,2,3-TCP. In order to evaluate the performance of different media, a series of tests were carried out, as detailed below.

2.1 Testing Methods

2.1.1 Batch Adsorption Tests for IX Resins

The purpose of the Batch Adsorption Screening Tests is to pre-select suitable IX resins for the selected source waters. Although a variety of commercial IX resins exist for PFAS removal, limited scope and budget of the RSSCT required to screen resins for actual testing. In addition, the water qualities of the Desalter Brine and the WWTP effluent are more complex than drinking water, consisting of high concentrations of dissolved organics and/or dissolved solids. A preliminary batch adsorption test can help quickly determine the best IX resin candidates for the appropriate water sources.

A detailed Preliminary Batch Adsorption Test Plan has been prepared and is included in **Appendix B**. A brief summary of the method is also presented below.

a) Three water samples were selected for the Batch Adsorption Test to represent groundwater, Brine, and WWTP Effluent, as presented in Table 3.

Table 3. Selected water quality parameter comparison of the selected water samples

	Well 17a	Desalter Concentrate	WWTP #1 Effluent
PFOS (ng/L)	178.8	294	4.97
PFOA (ng/L)	182.5	320	18
1,2,3-TCP (ng/L)	12.7	16.2	NM
TDS (mg/L)	998	6,359	712.2
TOC (mg/L)	N/A	N/A	7.1
DOC (mg/L)	N/A	3.5	N/A
Sulfate (mg/L)	236.6	1,838	166.1
NOTES: (1) Data represented are averaged results based on the water quality data provided by the City.			

b) Five commercial IX resins were selected as presented in Table 4. Table 5 presents the selected resin for each source water.

Table 4. Pre-selected resin and their properties

	Chemical structure	Functional Group	Single-use or regenerable	Applications
Resin #1	Polystyrene with divinylbenzene crosslink	Proprietary quaternary ammonium	Single-use	Groundwater/ Drinking Water
Resin #2	Polystyrene with divinylbenzene crosslink	Proprietary quaternary ammonium	Regenerable	Groundwater
Resin #3	Polystyrene with divinylbenzene crosslink	Proprietary tertiary amine	Regenerable	High Chloride/TDS
Resin #4	Polystyrene with divinylbenzene crosslink	Proprietary quaternary ammonium	Single-use	Groundwater/ Drinking Water
Resin #5	Polystyrene with divinylbenzene crosslink	Quaternary ammonium (Tri-n-butyl amine)	Single-use	Groundwater/ Drinking Water

Table 5. Water samples and the resin candidates to be tested in batch adsorption experiments

	Well 17a	Desalter Concentrate	WWTP #1 effluent
Resin #1	√		
Resin #2		√	√
Resin #3		√	
Resin #4	√		√
Resin #5		√	

c) Batch Adsorption Tests were carried out by mixing a predetermined amount of the IX resins with the selected water samples for predetermined durations. The PFAS concentrations in the water before and after the adsorption is measured to evaluate removal by different media. The testing conditions are presented in Table 6. Because Well 17A is a drinking water source with relatively low concentrations of dissolved organic matter, only 5-minute batch adsorption experiments were conducted. For WWTP Effluent and Desalter Brine, 5-minute and 30-minute adsorption experiments were conducted.

Table 6. Batch adsorption testing conditions

Water sample	Resin mass (g)	Sample volume (mL)	Reaction time (min)	Mixing condition (RPM)
Well 17A	1	800	5	80
WWTP #1 Effluent	1	800	5 & 30	80
Desalter Concentrate	0.68	550	5 & 30	80
Note: (1) The sample volume and resin mass are reduced proportionally for Desalter Concentrate to accommodate the experiment with one additional resin.				

d) The data and conclusions from the Batch Adsorption Tests will be presented in Section 3.2. All laboratory results are included in **Appendix C.**

2.1.2 IX RSSCT Verification Testing

The RSSCTs are designed to systematically scale-down and speed-up the treatment and contaminant break through process so that a meaningful evaluation can be done in a shorter timeline with a lower volume of water samples.[2] This is achieved by reducing the size of the adsorption media via grinding. The method has been widely tested with GAC, but comparatively less so with IX resins, mostly due to the concern that grinding will damage the structural property of the polymer resins. Recently a few studies (published and unpublished) have shown the effectiveness of using RSSCT with ground resins.[3] The project team has also communicated with several engineering and research teams with extensive knowledge on the subject and developed and adopted a protocol suitable for IX resins.

In order to verify the methods for IX RSSCT, a single-column RSSCT with IX resin was proposed. Concurrent with this project, the project team was operating IX pilot systems for a drinking water PFAS removal evaluation for another client in the Southern California area. The single-column RSSCT verification test was planned to use the same source water as the pilot tests to compare the breakthrough curves between the two systems and generate conversion factors to better correlate the RSSCT results with pilot results.

Verification tests were conducted for approximately two weeks and samples were taken and submitted for laboratory analysis. The testing method and preliminary results are presented and discussed in **Appendix D**.

2.1.3 RSSCT Treatment Evaluation

RSSCTs were conducted to help determine the effectiveness of PFAS and 1,2,3-TCP removal by different media in the six selected water sources. Each water source was evaluated with two types of GAC and one IX resin. The GAC used were Filtrasorb 400 (F400) and Filtrasorb 600 (F600) from Calgon Carbon, which have been widely used in drinking water treatment. The IX resins were selected from several different commercial products. The resin candidates for IXTP Influent, Desalter Brine, and WWTP Effluent were determined based on the Preliminary Batch Adsorption Tests (see Section 3.2.1).

Table 7 presents the combination of the water sources and the media to be evaluated in the RSSCT. A detailed testing method is presented below.

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[2] Crittenden, John C., *et al*. "Predicting GAC Performance With Rapid Small-Scale Column Tests." Journal (American Water Works Association), vol. 83, no. 1, 1991, pp. 77–87. JSTOR, www.jstor.org/stable/41293124

[3] Charles E. Schaefer, Dung Nguyen, Paul Ho, Jihyon Im, and Alan LeBlanc, Industrial & Engineering Chemistry Research 2019 58 (22), 9701-9706

Table 7. Water Sources and Media in the RSSCT

Water Sources	Treatment Media		
Well 7A	Calgon F400	Calgon F600	ECT2 SORBIX LC4
Well 8A	Calgon F400	Calgon F600	DOWEX PSR2+
Well 17A	Calgon F400	Calgon F600	Purolite PFA694E
IXTP Influent	Calgon F400	Calgon F600	Purolite PFA694E
Desalter Brine	Calgon F400	Calgon F600	ECT2 SORBIX A3F
WWTP Effluent	Calgon F400	Calgon F600	DOWEX PSR2+

a) Water Qualities

Table 8 presents more comprehensive water quality parameters of the six water sources, including the contaminants of interests, and parameters that may impact the adsorption and IX treatment such as TDS, sulfate, alkalinity, and chloride.

Water Samples were collected by the City from the sources in 55-gallon drums and transported to the RSSCT test location at the IXTP. New samples were collected every week.

Prior to feeding the RSSCT columns, the feed waters were filtered by 0.45 µm polyethersulfone filters to remove large particles and prevent clogging of the columns. Measurements of PFAS and 1,2,3-TCP before and after prefiltration are conducted. Prefiltration does not impact PFAS and 1,2,3-TCP concentrations in most water samples. An incidental removal of PFOS by the prefilter was observed (Approximately 22%) in Desalter Brine. This is possibly due to the removal of PFOS adsorbed onto particulate matters in the water and subsequent filtration. The water quality data is available in **Appendix D**.

Table 8. Water Qualities of the Six Water Sources

Location	Nitrate	Perchlorate	1,2,3-TCP	PFOA	PFOS	Total PFAS(1)	TDS	Sulfate	Alkalinity ($CaCO_3$)	Chloride	DOC
Unit	mg/L as N	µg/L	ng/L	ng/L	ng/L	ng/L	mg/L	mg/L	mg/L	mg/L	mg/L
Well 7A	12.8	5.45	5.34	111.5	113.3	344	821	180	230	140	0.64
Well 8A	14.2	4.76	23.14	121.6	117.8	388	1,060	237	300	190	0.74
Well 17A	9.6	2.86	12.68	182.5	178.8	564	988	237	277	180	0.77
IXTP Influent	8.6	4.6	18.8	140	136.7	415	1,000	240	320	NM	0.8
WWTP Effluent	5.0	NM	ND	20	4.6	67.3	712	166	129	NM	7.1
Desalter Brine	52	NM	16.2	320	294	1,103	6,360	1,838	1,400	1,192	3.53

NOTES:

(1) Total PFAS is the sum of 18 PFAS compounds measured by EPA method 537.1

(2) NM – Not Measured

b) RSSCT Design

The designed RSSCT experiments simulate full size GAC adsorption and IX vessels with the characteristics below. Studies have shown that in groundwater/drinking water conditions with low concentrations of competitive species (such as DOC), constant diffusivity (CD) scaling approach for RSSCT can accurately simulate the larger scale GAC systems for PFAS adsorption.[4] For Well 7A, Well 8A, Well 17A, and IXTP Influent, CD scaling was used to simulate full-size GAC adsorbers with 10 min of EBCT, and IX adsorbers with 3 min of EBCT.

For Desalter Brine and WWTP Effluent, due to the higher concentrations of DOC that could interfere with the adsorption, both the CD and proportional diffusivity (PD) (only with F400 GAC) RSSCT scaling approaches have been evaluated. Table 9 presents the test conditions of the RSSCT. The results from the RSSCT columns using CD and PD showed that the difference between the two scaling approaches are relatively minor. Detailed comparison and discussions between the two scaling approaches are included in **Appendix D**. Data from the CD columns are used in the results and discussions in Section 3.2.

Table 9. RSSCT Testing Parameters

Table 9-1 Simulated full-size vessels					
	GAC	**IX**			
	F400 & F600	**PFA694E**	**PSR2+**	**LC4**	**A3F**
Media size (mm)	1.11	0.675	0.7	0.6	0.62
Column diameter (ft)	12	8			
Bed depth (ft)	8	6			
EBCT (min)	10	3			
Hydraulic loading (GPM/ft^2)	5.97	14.9			
Flow rate (GPM)	675	750			
Bed volume (cf)	905	300			

Table 9-2 Well 7A RSSCT Columns			
RSSCT Parameters	**Column 1**	**Column 2**	**Column 3**
Scaling Approach	CD	CD	CD
Media	F400	F600	LC4
Media size (mm)	0.115	0.115	0.115
Column diameter (cm)	0.46	0.46	0.46
Bed depth (cm)	2.7	2.7	2.7
EBCT (min)	0.107	0.107	0.11
Hydraulic loading (cm/min)	25.3	25.3	25.3
Flow rate (mL/min)	4.2	4.2	4.2
Bed volume (mL)	0.45	0.45	0.46
Mass of media (g)	0.255	0.247	0.238

[4] Zeng, C, *et al*. Removing per and polyfluoroalkyl substances from groundwaters using activated carbon and ion exchange resin packed columns. AWWA Wat Sci. 2020; e1172. doi.org/10.1002/aws2.1172

Table 9-3 Well 8A RSSCT Columns			
RSSCT Parameters	**Column 1**	**Column 2**	**Column 3**
Scaling Approach	CD	CD	CD
Media	F400	F600	PSR2+
Media size (mm)	0.115	0.115	0.115
Column diameter (cm)	0.46	0.46	0.46
Bed depth (cm)	2.7	2.7	2.05
EBCT (min)	0.107	0.107	0.08
Hydraulic loading (cm/min)	25.3	25.3	25.3
Flow rate (mL/min)	4.2	4.2	4.2
Bed volume (mL)	0.45	0.45	0.34
Mass of media (g)	0.255	0.247	0.191

Table 9-4 Well 17A RSSCT Columns			
RSSCT Parameters	**Column 1**	**Column 2**	**Column 3**
Scaling Approach	CD	CD	CD
Media	F400	F600	PFA694E
Media size (mm)	0.115	0.115	0.115
Column diameter (cm)	0.46	0.46	0.46
Bed depth (cm)	2.7	2.7	2.2
EBCT (min)	0.107	0.107	0.087
Hydraulic loading (cm/min)	25.3	25.3	25.3
Flow rate (mL/min)	4.2	4.2	4.2
Bed volume (mL)	0.45	0.45	0.366
Mass of media (g)	0.255	0.247	0.21

Table 9-5 IXTP Influent RSSCT Columns			
RSSCT Parameters	**Column 1**	**Column 2**	**Column 3**
Scaling Approach	CD	CD	CD
Media	F400	F600	PFA694E
Media size (mm)	0.115	0.115	0.115
Column diameter (cm)	0.46	0.46	0.46
Bed depth (cm)	2.7	2.7	2.2
EBCT (min)	0.107	0.107	0.087
Hydraulic loading (cm/min)	25.3	25.3	25.3
Flow rate (mL/min)	4.2	4.2	4.2
Bed volume (mL)	0.45	0.45	0.366
Mass of media (g)	0.255	0.247	0.21

Table 9-6 WWTP Effluent RSSCT Columns				
RSSCT Parameters	**Column 1**	**Column 2**	**Column 3**	**Column 4**
Scaling Approach	CD	CD	CD	PD
Media	F400	F600	PSR2+	F400
Media size (mm)	0.15	0.15	0.15	0.15
Column diameter (cm)	1.0	1.0	1.0	1.0
Bed depth (cm)	3.84	3.84	0.64	7.2
EBCT (min)	0.486	0.486	0.081	1.35
Hydraulic loading (cm/min)	7.89	7.89	7.89	5.34
Flow rate (mL/min)	6.2	6.2	6.2	4.2
Bed volume (mL)	3.01	3.01	0.5	5.67
Mass of media (g)	1.65	1.61	0.276	3.1

Table 9-7 RO Brine RSSCT Columns				
RSSCT Parameters	**Column 1**	**Column 2**	**Column 3**	**Column 4**
Scaling Approach	CD	CD	CD	PD
Media	F400	F600	A3F	F400
Media size (mm)	0.115	0.115	0.115	0.15
Column diameter (cm)	0.46	0.46	0.46	1.0
Bed depth (cm)	2.7	2.7	2.61	7.2
EBCT (min)	0.107	0.107	0.103	1.35
Hydraulic loading (cm/min)	25.3	25.3	25.3	5.34
Flow rate (mL/min)	4.2	4.2	4.2	4.2
Bed volume (mL)	0.45	0.45	0.43	5.67
Mass of media (g)	0.255	0.247	0.243	3.1

c) Media Preparation and RSSCT Columns

The RSSCT columns used in the experiments are stainless steel Restek liquid chromatography columns with 0.46 cm inner diameter and 10 cm length. PEEK (Polyetheretherketone), EPDM (Ethylene propylene diene monomer), HDPE (high-density polyethylene), and PP (polypropylene) materials are used in the tubing and connectors to minimize interference with PFAS. In the case of the WWTP Effluent, significant clogging and a decrease in flow rate was observed with the small media size (0.115 mm) and column. Subsequently, the experiments with WWTP Effluent were conducted with 0.15 mm media size in a 1 cm glass column. The RSSCT with PD scaling were also conducted with 0.15 mm media size in a 1 cm glass column.

Water samples were fed to the columns via a variable speed peristaltic pump. The flow rate was calibrated prior to the testing and measured and adjusted during the course of the testing to maintain the desired flow rate.

The GAC were ground using a blender and sieved by mesh 120 and mesh 140 sieves. The media between the sieves were used to achieve an average particle size of 0.115 mm. To achieve the average particle size of 0.15 mm, mesh 80 and mesh 120 sieves were used to sieve the ground media.

The IX resins were ground using mortar and pestle and sieved by mesh 120 and mesh 140 sieves. Prior to grinding, the media was vacuum dried under 60 °C overnight. The ground and sieved media was soaked in deionized water overnight and sieved by mesh 120 and mesh 140 sieves again.

The grounded dry media were weighed to the desired mass for the corresponding columns per Table 8. The weighed media were then stored in deionized water and wet-packed into the columns within 48 hr.

The media were packed in columns bedded with a layer of glass wool. After adding the desired amount of media in the column, another layer of glass wool was added on top of the media bed. Each packed column was flushed with deionized water for approximately 12 – 16 hr before starting the experiment.

Figure 1 presents a photo of the RSSCT column set up for the treatment evaluation testing.

Figure 1. RSSCT column set up

d) Sampling

Samples were collected in 1 L narrow mouth PP sampling bottles, twice a day via a timed rotating automatic sampler. After collection, the samples were transferred into two 250 mL PP bottles with Trisma preservative for PFAS analysis, as well as three 40 mL amber glass vials with HCl preservative for 1,2,3-TCP analysis. Selected samples were submitted to the certified laboratory (Eurofins) for analysis every two to three days. The rest of the samples were stored in a 4°C fridge at the City's Temescal Desalter. Additional samples were submitted as needed based on the results from the previously submitted samples. PFAS was analyzed by EPA 537.1 method and 1,2,3-TCP was analyzed by SRL-524M method. The detailed analytical methods are attached in **Appendix E**. All laboratory results are included in **Appendix C.**

2.2 Results and Discussions

2.2.1 Preliminary Batch Adsorption

Table 10 presents the Preliminary Batch Adsorption results with IXTP Influent, WWTP Effluent, Desalter Brine, and the five selected resins. Figure 2 presents the ratios of the PFAS concentrations after and before adsorption (C/C_0). A lower C/C_0 indicates better removal performance.

Overall, the removal performances of different resins did not show drastic differences in most cases. Based on Figure 2, Resin #1 (Purolite PFA694E) in Well 17A, Resin #4 (DOWEX PSR2+) in WWTP Effluent, and Resin #2 (ECT2 Sorbix A3F) in Desalter Brine slightly outprformed the other resin candidates. They were thusly chosen as the IX resin candidates used in the subsequent RSSCT experiments.

Table 10. Preliminary Batch Adsorption Results

	5 min Adsorption		**30 min Adsorption**	
	PFOS (ng/L)	**PFOA (ng/L)**	**PFOS (ng/L)**	**PFOA (ng/L)**
Well 17A				
Raw	240	250	-	-
Resin #1	210	220	-	-
Resin #4	210	240	-	-
WWTP Effluent				
Raw	3.4	14	3.4	14
Resin #2	3.0	12	2.2	9.0
Resin #4	3.1	13	2.3	9.2
Desalter Brine				
Raw	350	390	350	390
Resin #2	220	300	120	190
Resin #3	270	370	190	250
Resin #5	260	330	140	200

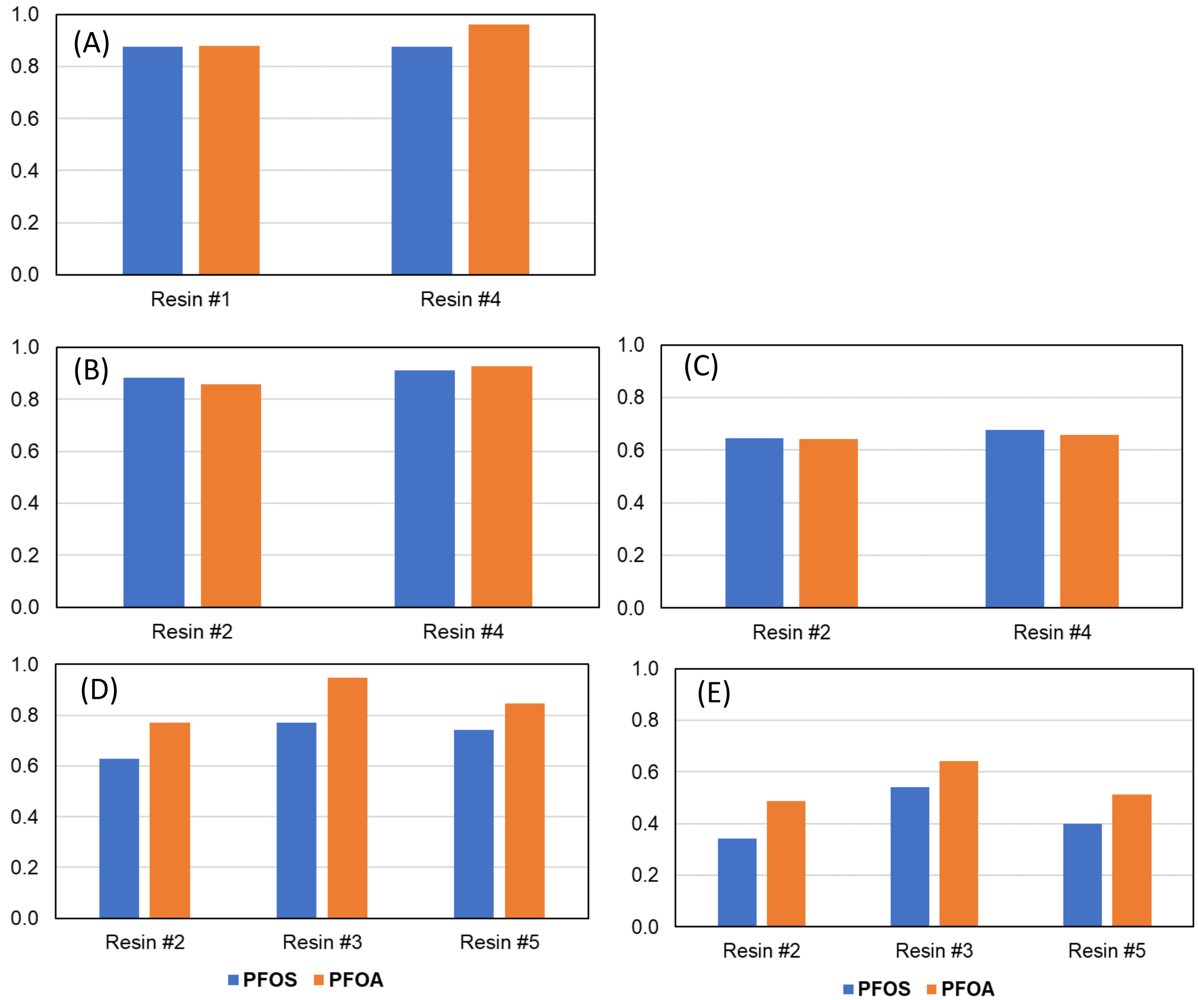

Figure 2. Prelminary Batch Adsorption Results for (A) 5 min adsorption with Well 17A; (B) 5 min adsorption with WWTP Effluent; (C) 10 min adsorption with WWTP; (D) 5 min adsorption with Desalter Brine; and (E) 10 min adsorption with Desalter Brine.

2.2.2 RSSCT Results

a) Performance Projection by Technology Providers

The bed volume capacities of F400 in treating PFOS, PFOA, and 1,2,3-TCP under the six water conditions were evaluated by Calgon Carbon via modeling projection. A projection model has not been sufficiently developed for F600. An empirical PFOA bed volume capacity estimation of Sorbix LC4 (Well 7A), Sorbix A3F (Desalter Brine), and Purolite PFA694E (Well 17a and IXTP Influent) was also provided by ECT2. Since PFOA will drive the breakthrough, PFOS bed volume capacity estimation was not provided.

Table 11 presents the results of the performance projections. It is noted that in Calgon's modeling, the treatment targets were set at 2 ng/L for PFOS and PFOA to meet the notification level limits. When the response levels are used as treatment targets, the projected bed volume capacities will be slightly higher, but the difference is not expected to be significant considering the relatively small difference between the response and notification levels.

The F400 modeling projection shows that PFOA drives the breakthrough. F400 in WWTP Effluent, which has the PFOA concentration 5 – 15 times lower than the other sources, was projected with a capacity of 69,000 bed volumes. Desalter Brine had the lowest F400 capacity (16,500 bed volumes). The differences in drinking water sources, namely Well 7A, 8A, 17A, and IXTP Influent, were comparatively minor. Well 7A had the highest bed volume projection (26,500) followed by IXTP Influent (24,000). The WWTP Effluent and Desalter Brine had more complex water quality conditions compared with drinking water sources, including the high levels of dissolved ions and total organic carbon (TOC). The degree of accuracy of the modeling projections to fully take into account of these interferences remains to be examined.

For the IX Resin projections, Well 7A, 17A, and IXTP Influent were at 230,000 with their respective resin candidates. Desalter Brine had the lowest performance projection at 50,000 bed volumes.

Table 11. Modeling Projection of the F400 bed volume capacities

Source	1,2,3-TCP		PFOS		PFOA		
	Raw (ng/L)	F400 Bed Volumes	Raw (ng/L)	F400 Bed Volumes	Raw (ng/L)	F400 Bed Volumes	Resin Bed volumes
Well 7A	5.74	70,500	150	33,750	140	26,250	230,000
Well 8A	26.8	45,750	170	30,000	180	23,250	NA(2)
Well 17A	16.4	47,250	210	27,000	230	21,000	230,000
Desalter Brine	16.2	37,500	420	20,250	380	16,500	50,000
IXTP Influent	21.1	45,000	150	31,500	150	24,000	230,000
WWTP Effluent	-(3)	-(3)	6.6	>75,000	24	69,000	NA(2)

NOTES:

(1) Historical maximum raw water concentrations were used for the projections.
(2) Modeling or empirical estimation for PSR2+ was not available.
(3) 1,2,3-TCP in raw WWTP Effluent was non-detectable.

b) Drinking Water Sources (Well 7A, 8A, 17A, and IXTP Influent)

The PFOS, PFOA, and 1,2,3-TCP breakthrough curves of the selected media for Well 7A, 8A, 17A, and IXTP Influent are presented in Figure 4 and Figure 5. Table 12 summarizes the approximate bed volumes treated before PFOA reaches the response level. It is noted that the breakthrough curves in Figure 4 are approximate trendlines only, thus the bed volumes at the time of breakthrough only serve as rough estimations.

Among the water sources, PFOS and PFOA breakthrough occurred later in Well 7A and IXTP Influent as compared to Well 8A and 17A. This correlates with the raw water PFAS concentrations at these sources. Well 7A and IXTP Influent had PFOS and PFOA at about 140 ng/L. Comparatively, Well 17A had about 230 ng/L PFOS and PFOA, roughly 60% higher than Well 7A and IXTP Influent. Well 8A had 180 ng/L PFOS and PFOA, roughly 30% higher than Well 7A and IXTP Influent. Higher PFAS concentration contributes to a faster saturation of the media and earlier breakthrough. In all cases, PFOA breakthrough occurred earlier than PFOS and determines the bed volume capacity of the medias.

Comparing the different media used, F400 was able to treat more bed volumes of water than F600 before reaching breakthrough. IX resins showed higher bed volume capacity than GACs for PFAS. It is important to note that bed volume treated between GAC and IX does not equal to volume of water treated because the bed volumes differ in size. Based on the full size example presented in Table 9, GAC bed volume is about three times that of IX resins (three times bed volume treated for IX is comparable to one bed volume treated for GAC). The relationship between bed volume and actual volume treated is illustrated in Figure 3.

IX Resins show good longevity in PFAS removal under these water conditions. However, the resin was not able to remove 1,2,3-TCP. As presented in Figure 5, the F400 and F600 was able to effectively remove 1,2,3-TCP to non-detectable levels for more than 80,000 bed volumes. Some incidential 1,2,3-TCP removal was observed with the IX resins, but they were not able to effectively control 1,2,3-TCP to below MCL levels. It is noted that for this particular sample collected from Well 7A, the 1,2,3-TCP was non-detectable in the raw water. Historical data does show 1,2,3-TCP exists in Well 7A (average at 5.34 ng/L, Table 8). This needs to be factored in when considering IX resin treatment at Well 7A.

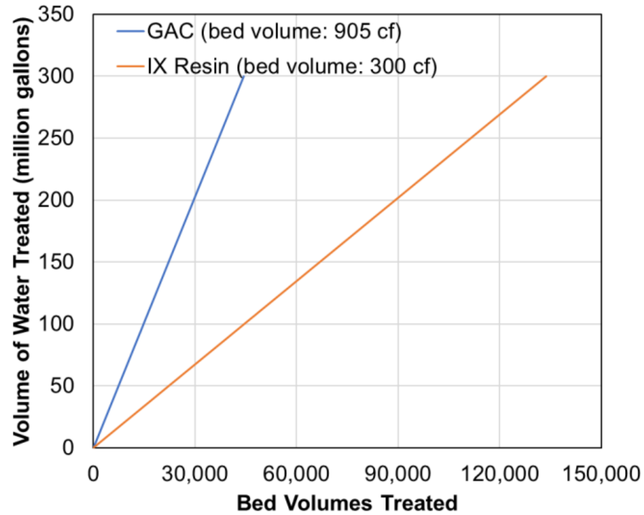

Figure 3 Bed Volumes vs. Actual Volume of Water Treated for GAC and IX Resin

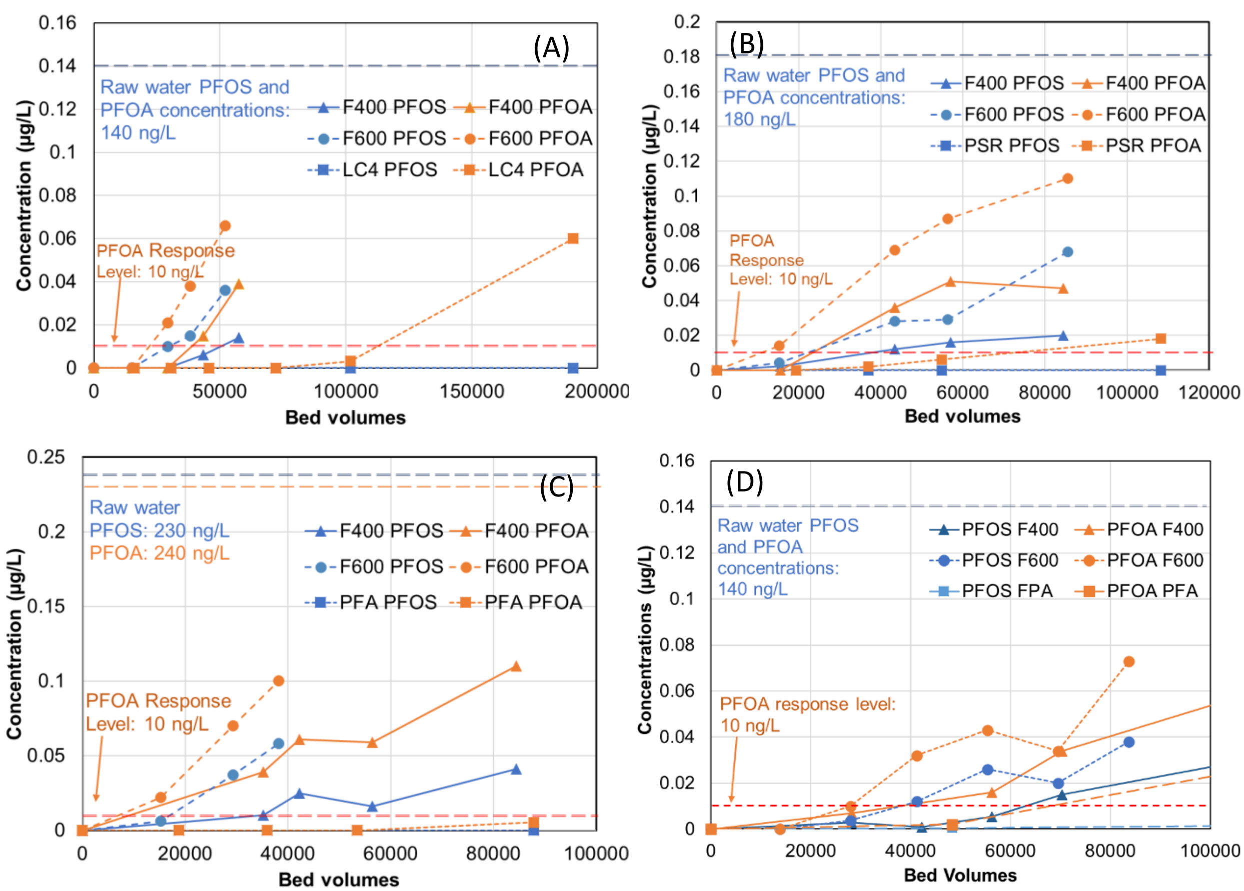

Figure 4. PFOS and PFOA Breakthrough Curves for (A) Well 7A; (B) Well 8A; (C) Well 17A, and (D) IXTP Influent

Table 12. RSSCT Estimated Bed Volumes Treated Before PFOA Breakthrough Exceeds Drinking Water Response Level

Bed Volume Treated	F400	F600	IX Resin
Well 7A	40,000	22,000	120,000
Well 8A	20,000	18,000	75,000
Well 17A	10,000	10,000	90,000
IXTP Influent	40,000	22,000	70,000
WWTP Effluent(1)	10,000	7,000	130,000
Desalter Brine(1)	13,000	5,000	5,000

NOTES:

(1) Drinking Water Response Levels do not apply to WWTP Effluent and Desalter Brine, and are used as reference points for comparison purposes.

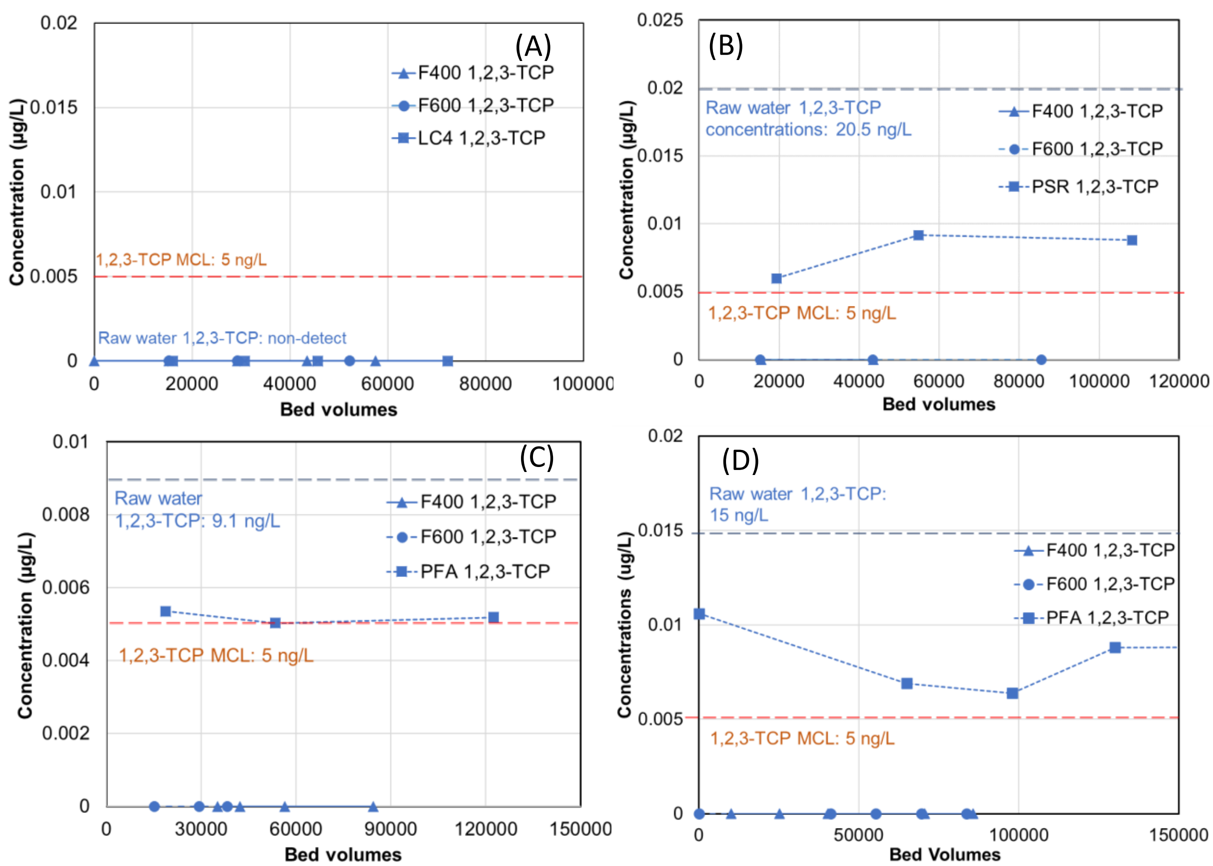

Figure 5. 1,2,3-TCP Breakthrough Curves for (A) Well 7A; (B) Well 8A; (C) Well 17A, and (D) IXTP Influent

c) WWTP Effluent and Desalter Brine

Compared with the drinking water sources, the WWTP Effluent and Desalter Brine pose more challenging water conditions. Desalter Brine is a high strength stream with total PFAS at 1,103 ng/L, TDS at 6,360 mg/L, sulfate at 1,838 mg/L, Alkalinity at 1,400 mg/L ($CaCO_3$), chloride at 1,192 mg/L, and DOC at 3.53 mg/L. Although WWTP Effluent has low concentrations of PFAS, it has a high TOC concentration of 7.1 mg/L. High concentrations of anionic species will impact PFAS removal by IX resins, and high concentrations of total/dissolved organic contents will foul and /or compete with the adsorption and removal of the target contaminants by GAC.

The PFAS breakthrough results have shown the impacts of these challenging conditions (Figure 6). In WWTP Effluent, PFOA breakthrough occurred fairly early with F400 and F600 GAC, exceeding California drinking water response level at approximately 10,000 bed volumes. The breakthrough with IX resin in WWTP Effluent occurred much later in comparison, lasting more than 120,000 bed volumes. As mentioned, the early breakthrough with GAC is likely due to the fouling and/or competition by the organics in the water.

For Desalter Brine, PFOA from the F600 and IX resin columns exceeded the California drinking water response level at only approximately 5,000 bed volumes. The F400 column exceeded the California PFOA drinking water response level at approximately 13,000 bed volumes. The estimated bed volume capacities are presented in Table 12.

Similar to the cases in drinking water, in WWTP Effluent and Desalter Brine, PFOA determines the breakthrough. For the IX resin in Desalter Brine, although PFOS was effectively controlled at a low level, early PFOA breakthrough still rendered the overall PFAS treatment ineffective.

For 1,2,3-TCP treatment, the GAC was able to achieve non-detectable removal in Desalter Brine during the duration of the testing. 1,2,3-TCP was not detected in the raw WWTP Effluent. The IX resin showed a limited level of removal of 1,2,3-TCP in Desalter Brine (<25%). The IX resin used in Desalter Brine (Sorbix A3F) was a macro-porous type resin. It is possible that a small portion of the 1,2,3-TCP was removed via adsorption into the macro-pores. However, this mechanism cannot achieve high removal, since the primary removal mechanism of the resin is still ion exchange which exert no effect on 1,2,3-TCP.

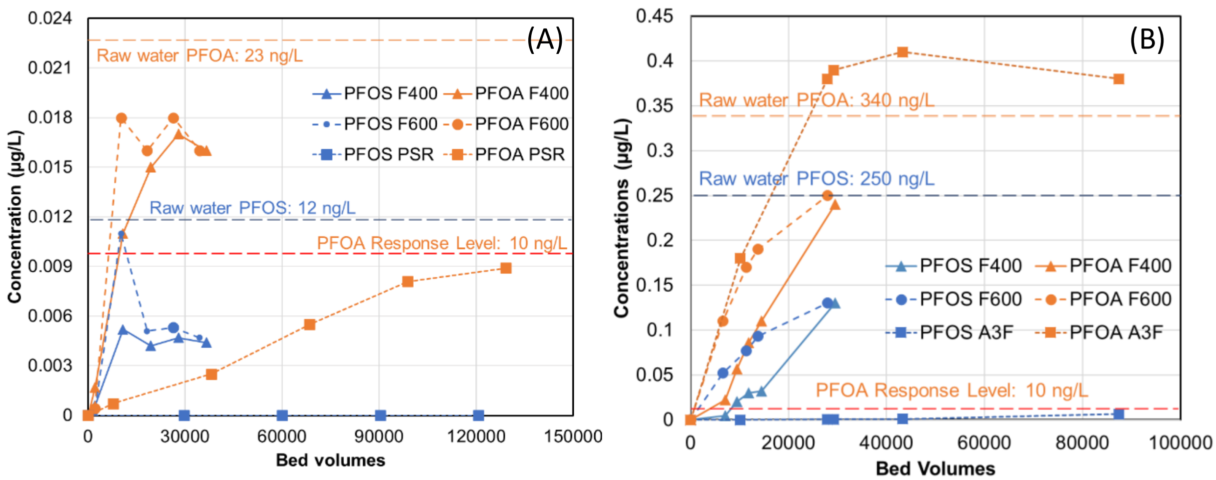

Figure 6. PFOS and PFOA Breakthrough Curves for (A) WWTP Effluent and (B) Desalter Brine

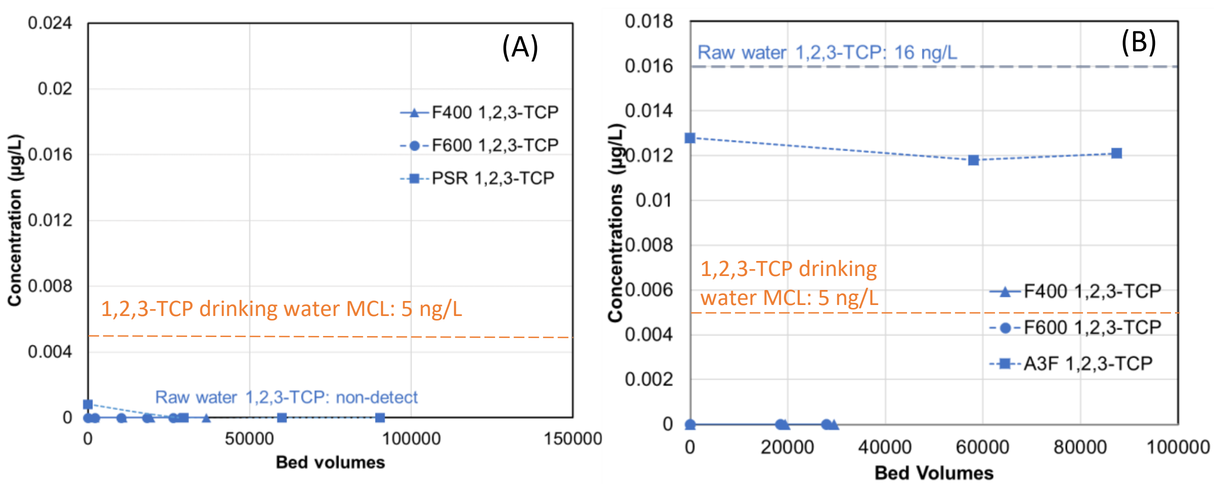

Figure 7. 1,2,3-TCP Breakthrough Curves for (A) WWTP Effluent and (B) Desalter Brine

2.3 Comparison between RSSCT and Modeling Projections

The PFOA bed volume capacity estimated from the RSSCT and the modeling projections is presented in

Table 13. A similar trend between the two estimations can be observed although there are discrepancies with specific results, which is expected since the projections were conducted with different methods. For treatment of drinking water sources, F400 has the highest capacity with Well 7A and IXTP Influent. A major difference is observed with the WWTP Effluent. The modeling projection showed exceptional capacity of 69,000 bed volumes, while the RSSCT showed the least

capacity at only 10,000. This is likely attributed to the interference of TOC concentration in the water. The modeling may not be able to accurately predict the competitive and/or fouling behavior of organics for F400.

The bed volumes projection for IX resins were significantly higher than what were observed from the RSSCT. The projection was conducted based on empirical data from previous bench and pilot testing conducted under similar water conditions. The projection may not be able to accurately account for all the specific water quality parameters in the water sources and impacts that these parameters impose on the actual performance due to competition, masking of adsorption sites, etc. The RSSCT generated more conservative results. For a higher degree of certainty on the resin performance, a pilot testing is needed.

Table 13. PFOA Bed Volume Capacity Comparison between Projections and RSSCT

Water Sources	F400 Bed Volumes		IX Resins Bed Volumes	
	RSSCT	Projection	RSSCT	Projection
Well 7A	40,000	26,250	120,000	230,000
Well 8A	20,000	23,250	75,000	-
Well 17A	10,000	21,000	90,000	230,000
IXTP Influent	40,000	24,000	70,000	230,000
WWTP Effluent	10,000	69,000	130,000	-
Desalter Brine	13,000	16,500	5,000	50,000

2.4 Conclusions from RSSCT

The following conclusions can be drawn from the RSSCT tests

a) For both GACs and all IX resins evaluated, PFOA breakthrough occurs earlier than PFOS.
b) F400 GAC is more effective than F600 GAC in removal of PFOS and PFOA, as demonstrated by the longer bed volume capacity in most of the water conditions.
c) Both GACs were able to effectively remove 1,2,3-TCP, achieving non-detectable removal during the duration of the tests for all of the water sources.
d) The selected IX resins were able to achieve longer bed volume capacity compared with GACs in treating PFOS and PFOA from the drinking water sources. Cost estimates are needed to compare the life cycle cost of each option.
e) IX resins cannot effectively remove 1,2,3-TCP. GAC will be needed if 1,2,3-TCP removal is required.

The bed volume capacity from RSSCT serves as a preliminary evaluation and estimation, suitable for Class 5 to 4 cost estimates. If a more accurate prediction of media replacement and O&M costs are required, pilot testing is recommended.

3. Preliminary Design

A number of combinations of treatment options were considered including IX, GAC, and RO. For all options, treatment at Well 7 is assumed to be local to the wellhead. This is because Well 7 effluent is not directed to the IXTP. The sizing of GAC systems assumes an EBCT of approximately 10 minutes for removal of PFOA, PFOS, and 1,2,3-TCP. Currently, the City is operating Wells 7A, 8A, 17A, and 33 at lower flow rates than the maximum capacity of the wells. This is due to the need to account for blending and treatment of certain contaminants in these wells. Preliminary Design and Cost Estimates have been based on the maximum capacity of the wells as provided by the City rather than the current flow rates and represent an increase in groundwater extraction compared with current operation.

3.1 Treatment Options

Specific preliminary options which were considered are as follows:

- <u>New Wellhead GAC</u> – Install GAC systems at individual wellheads for removal of 1,2,3-TCP, PFOA, and PFOS.
- <u>Convert IXTP Media to GAC</u> – Convert the IX vessels and media to GAC systems for removal of 1,2,3-TCP, PFOA, and PFOS.
- <u>Convert IXTP Media to GAC, New IX System</u> – Convert the IX vessels and media to GAC systems for removal of 1,2,3-TCP, PFOA, and PFOS. Install a new IX system in the vicinity of the IXTP.
- <u>Convert IXTP Media to GAC, Expand Desalter RO</u> – Convert the IXTP to GAC for removal of 1,2,3-TCP, PFOA, and PFOS and divert flow for further treatment at the existing Desalter for nitrate and perchlorate. Assumes sufficient existing capacity at the Desalter and in the pipelines.
- <u>Convert IXTP Media to GAC, New RO Facility</u> - Convert the IXTP to GAC for removal of 1,2,3-TCP, PFOA, and PFOS and construct a new RO facility in the vicinity of the IXTP for nitrate and perchlorate.
- <u>Replace IXTP with RO</u> – Replace the IXTP with RO. Construct a new brine line pipeline.
- <u>Keep IXTP and Expand Desalter RO</u> –Direct flows from IXTP effluent to the Desalter prior to distribution.
- <u>WWTP Effluent Treatment</u> – Install GAC or IX treatment for PFOA and PFOS (no 1,2,3 TCP)
- <u>Desalter Brine Treatment</u> – Install GAC or IX treatment for PFOA and PFOS.

The last five options on the list were eliminated from further consideration for the following reasons:

<u>Convert IXTP Media to GAC, New RO Facility</u> - The existing IXTP site does not have sufficient existing capacity in terms of brine discharge, electrical load, and footprint.

<u>Replace IXTP with RO:</u> The City prefers removal of PFAS from the water cycle rather than discharge through brine disposal. This option removes the PFAS and other contaminants from the drinking water system, but still requires discharge of contaminated brine. Additionally, the

existing IXTP site does not have enough existing capacity for a new RO system in terms of brine discharge, electrical load, and footprint.

Keep IXTP and Expand Desalter RO: The City prefers removal of PFAS from the water cycle rather than through brine disposal. This option removes the PFAS and other contaminants from the drinking water system, but still requires disposal of PFAS contaminated liquids.

WWTP Effluent Treatment: Preliminary column tests indicated that the water quality does not lend itself to efficient use of GAC or IX media.

Desalter Brine Treatment: Preliminary column tests indicated that the water quality does not lend itself to efficient use of GAC or IX media.

Options which remain for further evaluation are as follows:

Option 1 – New Wellhead GAC

Option 2 – Convert IXTP Media to GAC

Option 3 – Convert IXTP Media to GAC, New IX System

Option 4 – Convert IXTP Media to GAC, Expand Desalter RO

For the four options, the target EBCT for PFOA/PFOS removal is 10 minutes per vessel for GAC. The resulting quantities of GAC media are the recommended minimums to meet this EBCT.

As noted, Well 7A treatment will consist of onsite wellhead GAC treatment as shown in Figure 8. The existing Desalter and blending stations will treat for nitrate and perchlorate while the GAC vessels will treat for 1,2,3-TCP, PFOA, and PFOS. A pre-filter will be installed to protect the media from silting and total suspended solids (TSS). Based on a maximum flow capacity of 1,300 GPM, the vessel configuration consists of two (2) fourteen-foot diameter vessels in lead/lag configuration, each containing a minimum of 1,738 cubic feet of GAC media to meet an EBCT of 10 minutes per vessel.

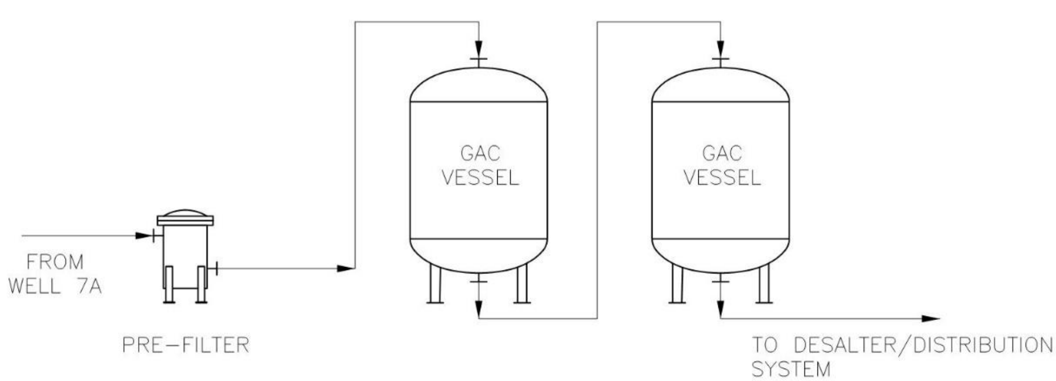

Figure 8. Well 7A Process Flow Diagram

3.1.1 Option 1 – New Wellhead GAC

This option, as shown in Figure 9, consists of local wellhead treatment for 1,2,3-TCP, PFOA, and PFOS for the three wells. A pre-filter will be installed at each wellhead to protect the media from silting and TSS. The GAC systems will consist of a lead/lag configuration and will be sized for the rated flow of each well. The systems at Well 8A and Well 17A will be installed for removal of PFOA, PFOS, and 1,2,3-TCP. The system at Well 33 will primarily target 1,2,3-TCP removal due to the relatively low concentrations of PFOA/PFOS. Based on a maximum flow capacity of 1,500 GPM, the vessel configuration for Well 8A consists of four (4) 12-foot diameter vessels in two parallel trains of lead/lag configuration, each containing a minimum of 1,003 cubic feet of GAC media to meet an EBCT of 10 minutes. Based on a maximum flow capacity of 1,500 GPM, the vessel configuration for Well 17A consists of four (4) 12-foot diameter vessels in two parallel trains of lead/lag configuration, each containing a minimum of 1,003 cubic feet of GAC media to meet an EBCT of 10 minutes. Based on a maximum flow capacity of 1,500 GPM, the vessel configuration for Well 33 consists of four (4) 12-foot diameter vessels in two parallel trains of lead/lag configuration, each containing a minimum of 1,003 cubic feet of GAC media to meet an EBCT of 10 minutes.

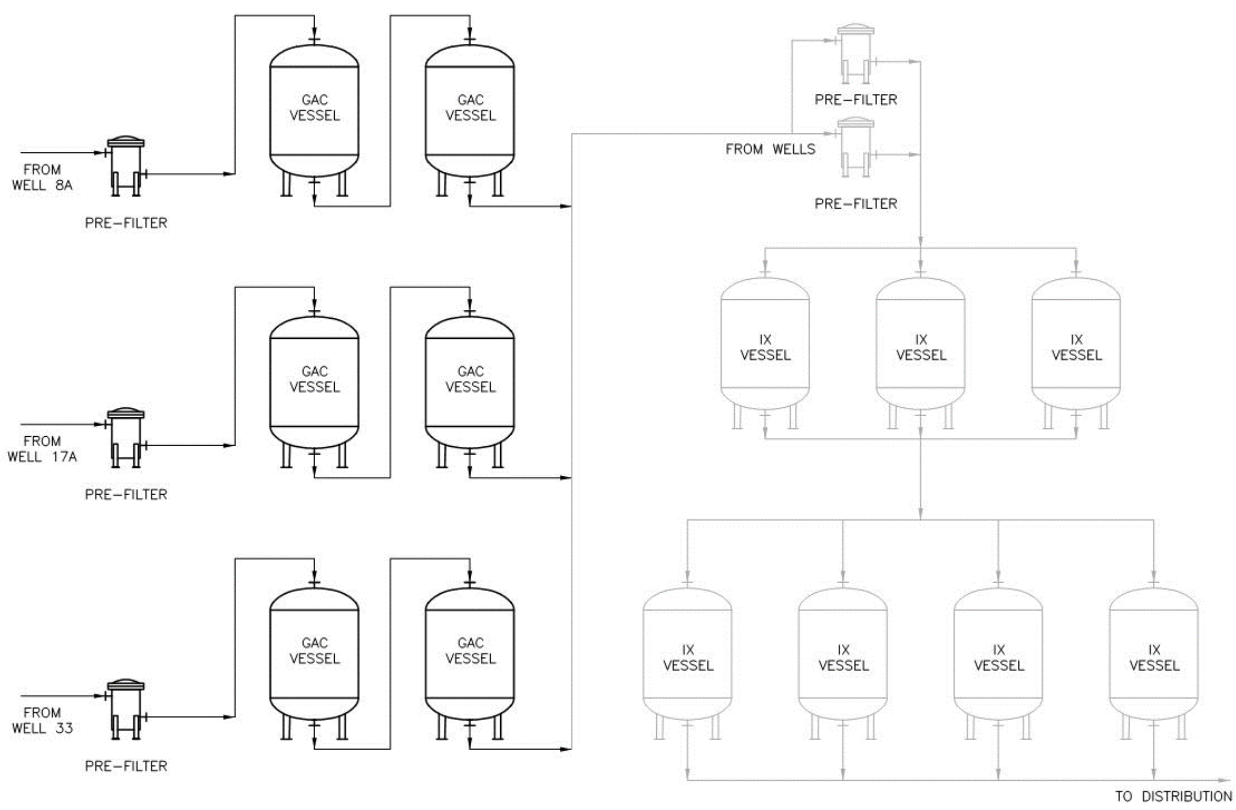

Figure 9. Option 1 Process Flow Diagram

3.1.2 Option 2 – Convert IXTP Media to GAC

Two versions of this option were considered. Option 2A, as shown in Figure 10, consists of conversion of the entire IX system at the IXTP to GAC with a lead-lag configuration. Additionally, modifications to the existing vessels will be made to accommodate the new media, such as removal of the internal regeneration manifold pipes, and some interconnecting piping will be modified. New piping and valves will be installed in the IXTP building to accommodate lead-lag operation for the GAC vessels. Based on the size and number of existing vessels, one new GAC vessel will also be installed to accomplish a 9.8-minute EBCT for PFOS, PFOA, and 1,2,3-TCP.

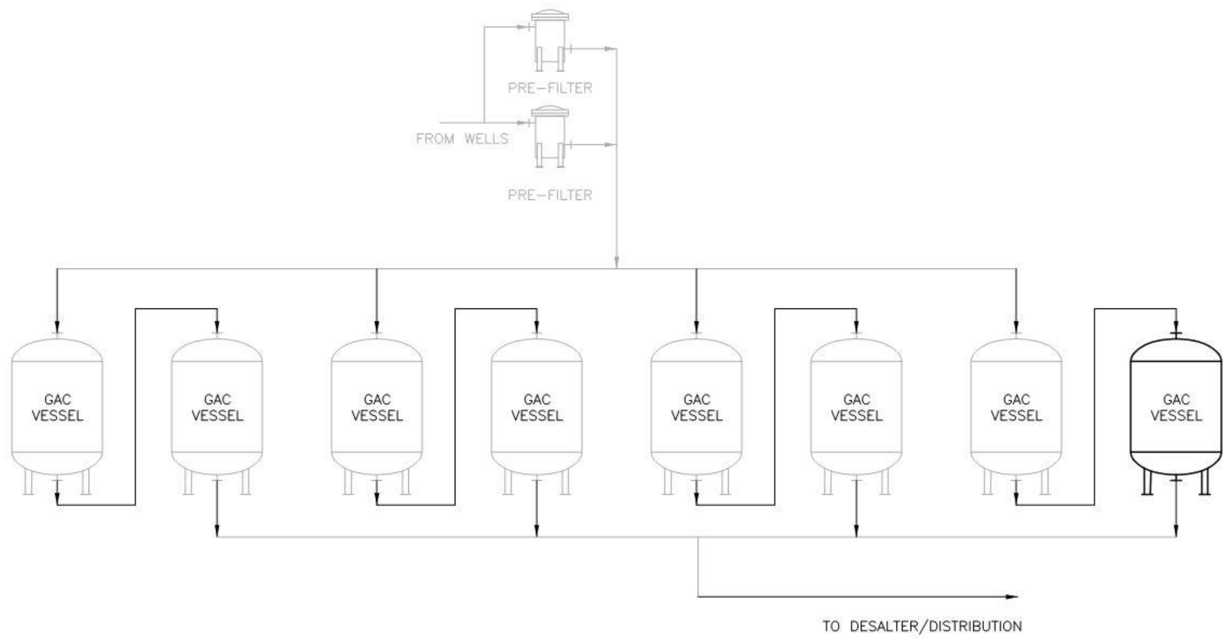

Figure 10. Option 2A Process Flow Diagram

Option 2B, as shown in Figure 11, consists of conversion of only the regenerable nitrate IX system at the IXTP to GAC with a parallel single pass configuration. Additionally, modifications to the existing vessels will be made to accommodate the new GAC media. The resulting EBCT will also be approximately 9.8 minutes per vessel, however, there will only be a single pass for treatment and no lag vessel. The resulting configuration would include a single pass IX system for perchlorate removal and a single pass GAC system for PFOS, PFOA, and 1,2,3-TCP removal. The parallel configuration will require considerations related to both operational costs and permitting. The Department of Drinking Water (DDW) may not allow parallel configuration for treatment. Additionally, lead/lag configurations allow for more efficient use of the GAC media, which can reduce changeout frequency and annual costs. As there is no downstream vessel in parallel configuration, changeout typically must occur earlier in order to prevent breakthrough above acceptable levels.

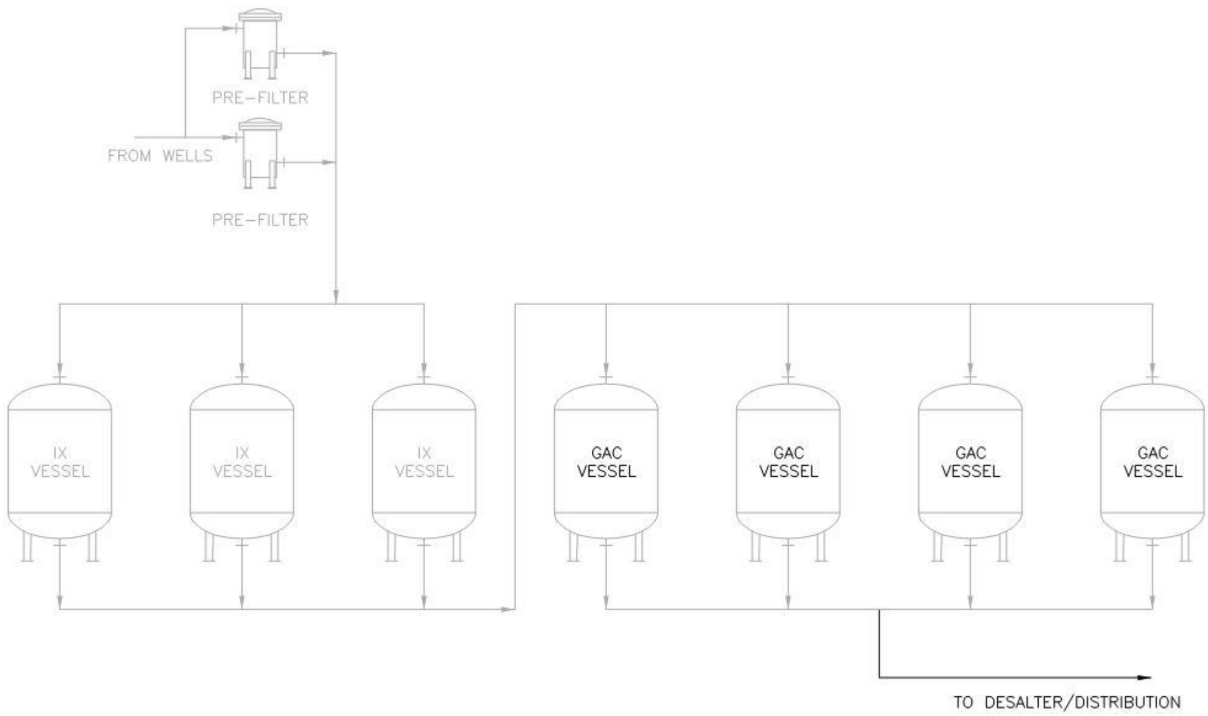

Figure 11. Option 2B Process Flow Diagram

3.1.3 Option 3 – Convert IXTP Media to GAC, New IX System

This option, as shown in Figure 12, consists of conversion of both single use IX and regenerable IX systems at the IXTP to GAC and construction of a new regenerable IX system in the vicinity of the IXTP. The new regenerable IX system will be an automated system sometimes referred to as continuously regenerable. This system will treat for perchlorate and nitrate followed by GAC treatment for PFOA, PFOS, and 1,2,3-TCP. While an extension of the brine line connection to the new IX system is required, the existing brine line capacity will be sufficient as brine generation is expected to be lower than current brine generation at the IXTP. Modifications to the existing vessels will be made to accommodate the new media and some interconnecting piping will be modified. New piping and valves will be installed in the IXTP building to accommodate lead-lag operation for the GAC vessels. One new GAC vessels will also be installed to accomplish an EBCT of 9.8 minutes.

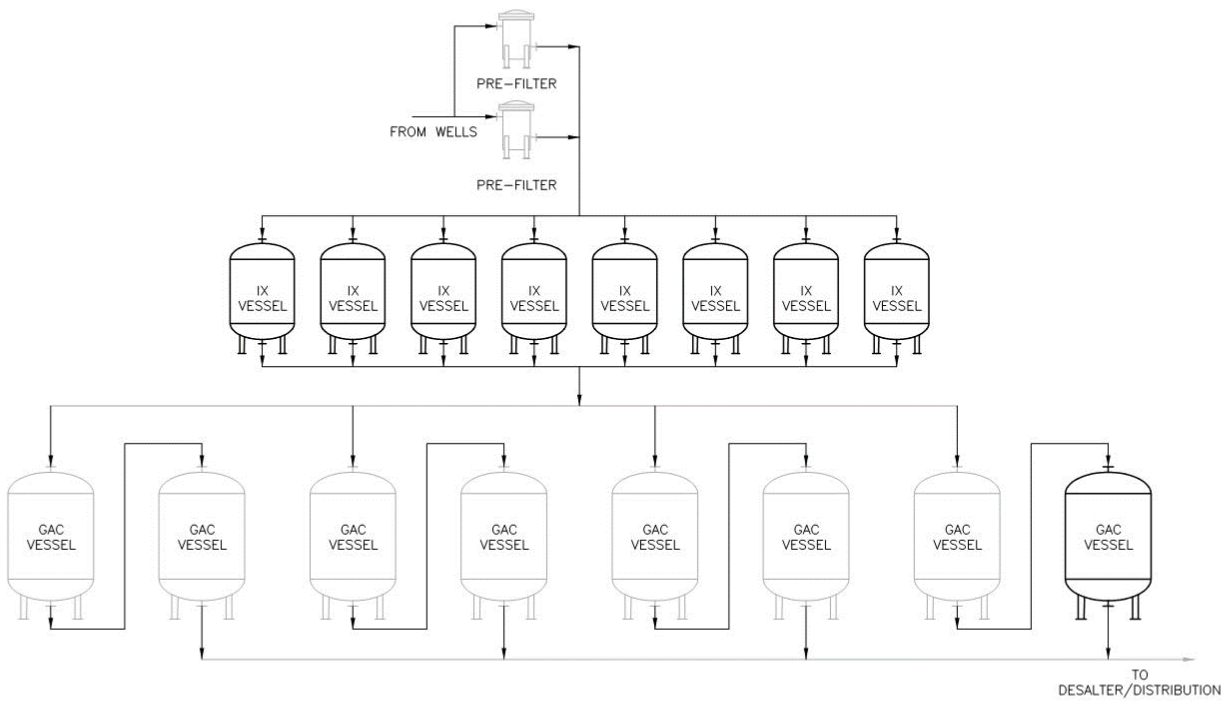

Figure 12. Option 3 Process Flow Diagram

3.1.4 Option 4 – Convert IXTP Media to GAC, Expand Desalter RO

This option, as shown in Figure 13, consists of conversion of both single use IX and regenerable IX system at the IXTP to GAC, and diversion of flow to the existing Desalter for nitrate and perchlorate removal. Modifications to the existing vessels will be made to accommodate the new GAC media. New piping and valves will be installed in the IXTP building to accommodate lead-lag operation for the GAC vessels. One new GAC vessel will also be installed to accomplish an EBCT of 9.8 minutes. Some factors will need to be investigated further for this option including the existing Desalter capacity, existing pipeline capacity between the IXTP and the Desalter, and the resulting effects of this arrangement on current distribution and treatment networks.

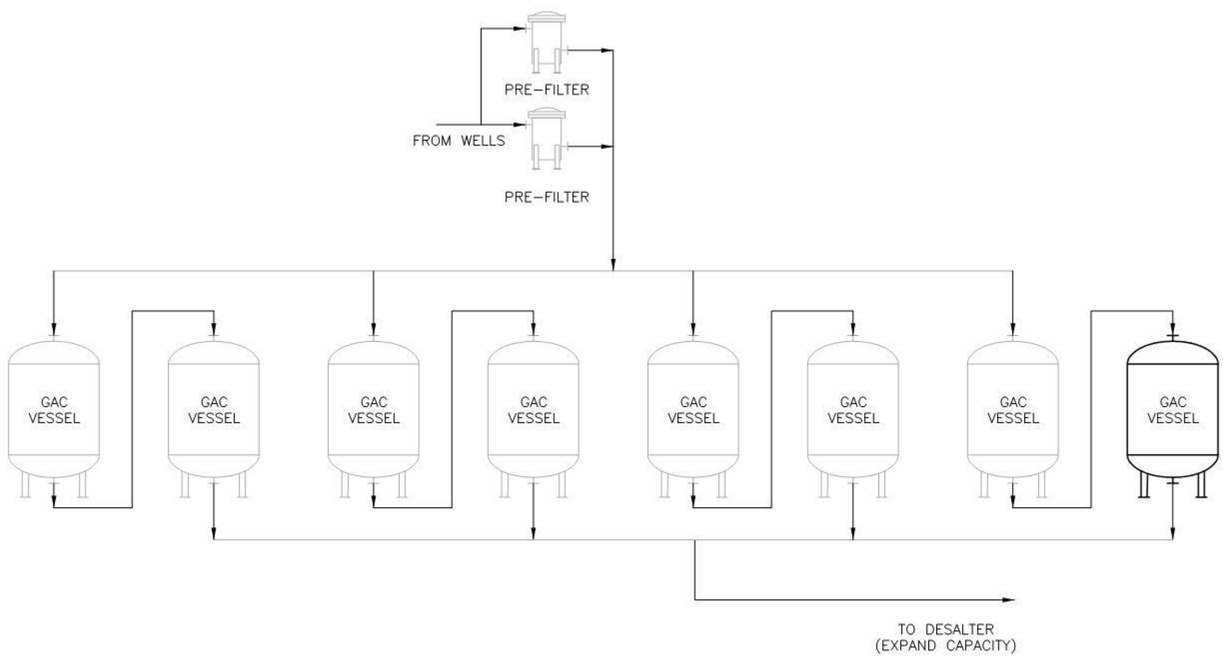

Figure 13. Option 4 Process Flow Diagram

3.2 Site Layouts

Site layouts were created for the four options. For all options, treatment at Well 7 is assumed to be local to the wellhead and the layout is shown in Figure 14. There is sufficient space on the east side of the site for the footprint of two 14' diameter GAC vessels configured in lead/lag and the associated concrete pad foundation. Yard piping will connect the system to the discharge pipe from the wellhead. Water will flow from the well, through the system, and return to the well effluent pipe for distribution. A single cartridge filter is also included. Truck access at the site is limited and consists of a small alley to the south which does not allow through access, and a shopping center parking lot to the north. Because of the site access constraints, a smaller truck may be required for media changeouts which would be coordinated with the GAC supplier.

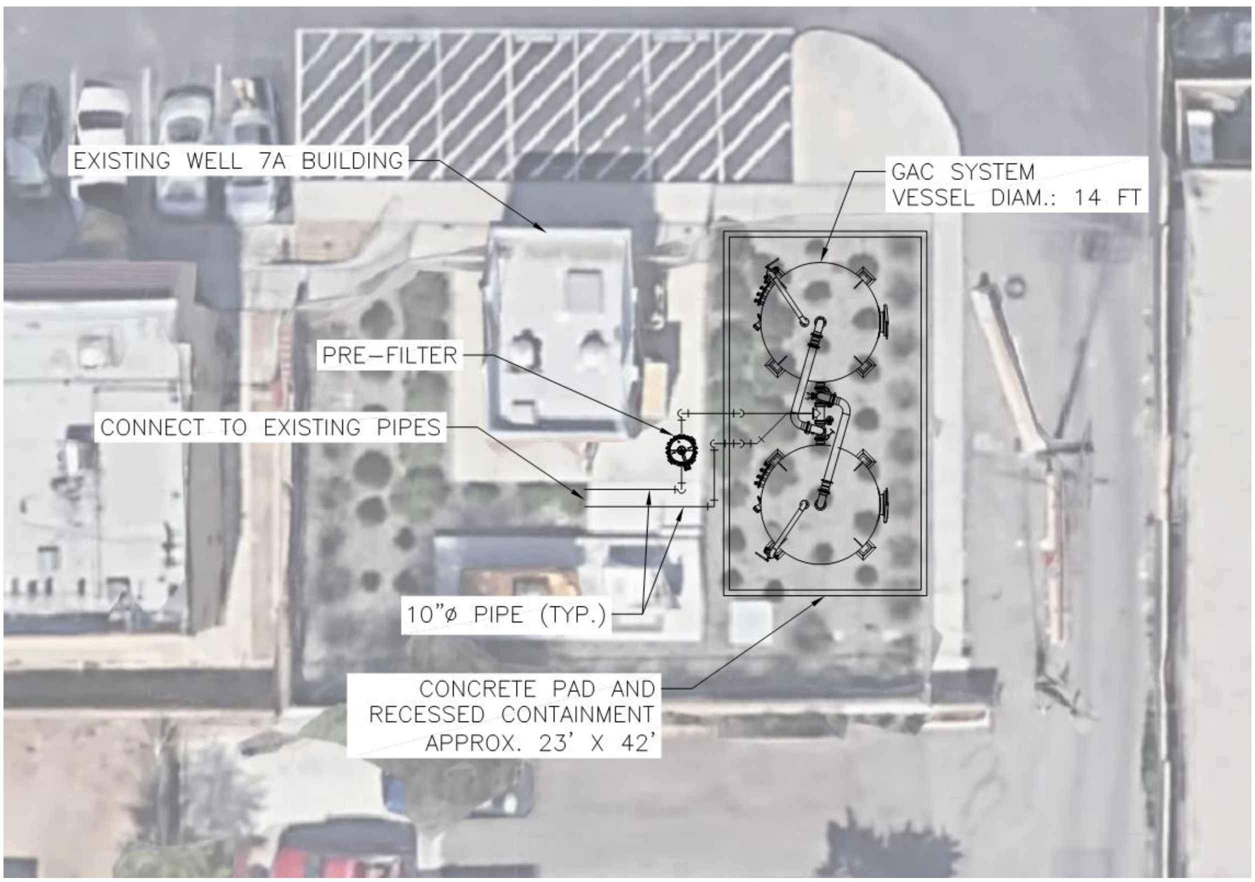

Figure 14. Well 7 Site Layout

3.2.1 Option 1 – New Wellhead GAC

The preliminary site layout for Option 1 is shown in Figure 15, Figure 16, and Figure 17, for Well 8A, Well 17A, and Well 33, respectively. The site at Well 8A consists of a large paved area. Four 12-foot diameter GAC vessels configured in two lead/lag pairs are shown. Two cartridge filters are also included. There is an open area south of the proposed system location allowing for truck access and one existing gated entrance on the west side of the site for truck access. No additional construction of new entrances was considered for this option.

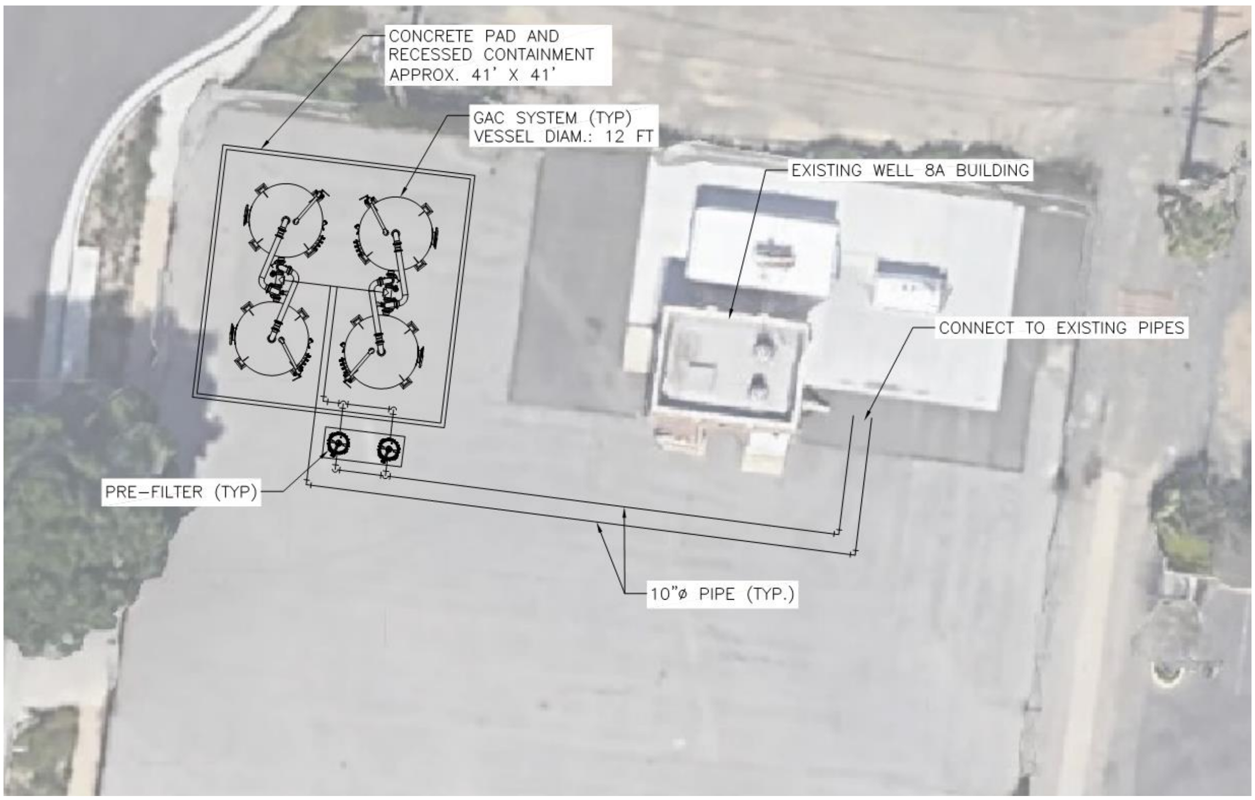

Figure 15. Option 1 – Well 8A Site Layout

The site at Well 17A consists of a small landscaped area. Four (4) 12-foot diameter GAC vessels configured in two parallel trains of lead/lag configuration are shown. A cartridge filter is also included. The only vehicle access at the site is the public road, Quarry Street, to the north. For media changeout, traffic control may be required while the truck is parked on the side of the street. The area considered for the new treatment system is also currently intended for a new generator. This may reduce the feasibility of constructing this system at this location.

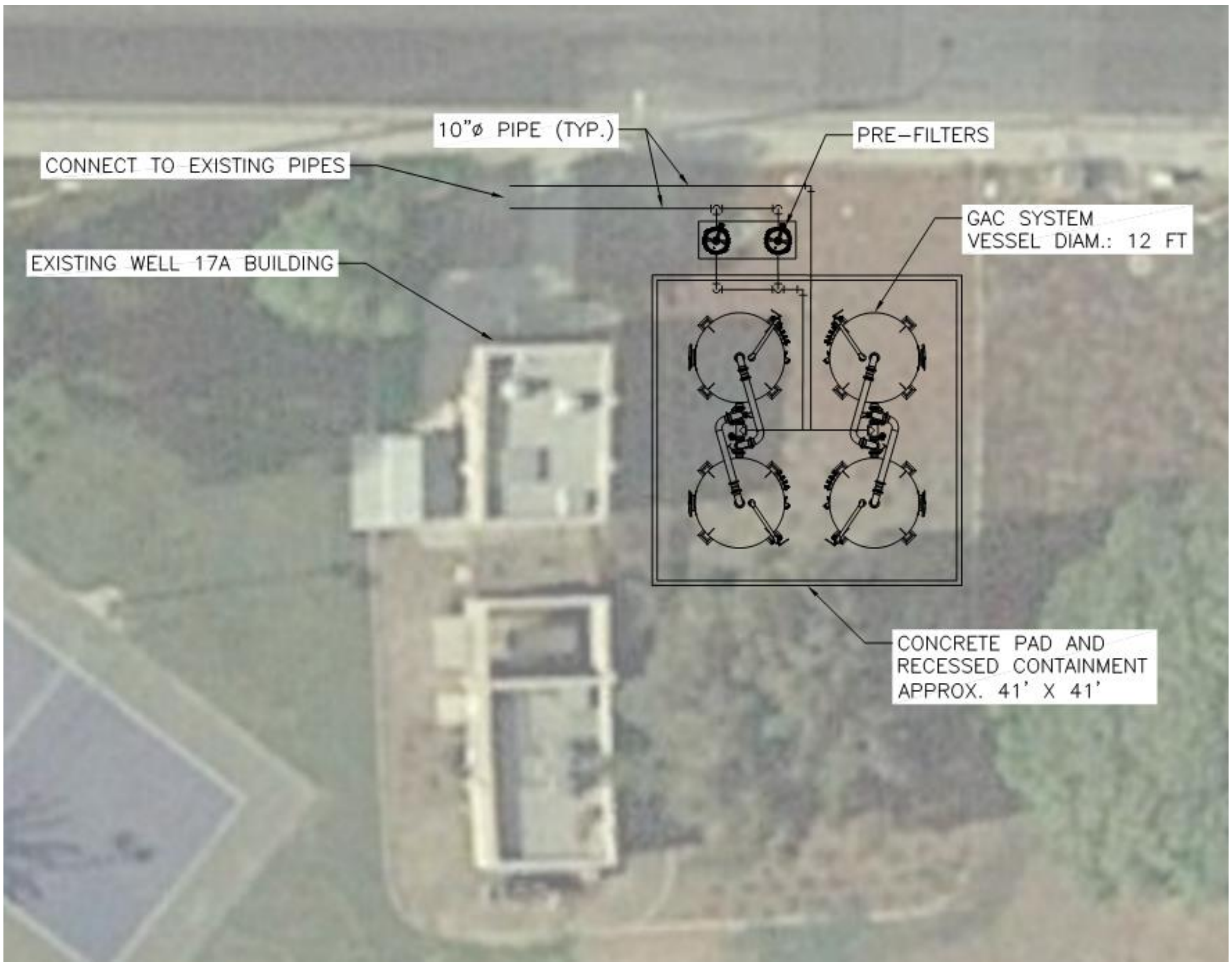

Figure 16. Option 1 – Well 17A Site Layout

The site at Well 33 consists of multiple structures on the north and east sides. Four (4) 12' diameter GAC vessels configured in two parallel trains of lead/lag configuration are shown to the southwest. Two cartridge filters are also included. The only vehicle access at the site on the northeast of the site from Grant Street. A new entrance may be needed on the south side of the property. The system is sized to meet a minimum EBCT of 10 minutes for removal of 1,2,3-TCP and will also provide removal of PFOS and PFOA, although the PFOS and PFOA concentrations at this wellhead are below the current notification levels. Should the system be sized for 1,2,3-TCP only, and an EBCT of 8 minutes is used, the system size is expected to remain the same, with a lower volume of GAC installed inside the vessels.

Figure 17. Option 1 – Well 33 Site Layout

3.2.2 Option 2 – Convert IXTP Media to GAC

The preliminary site layout for Option 2A and Option 2B are shown in Figure 18 and Figure 19, respectively. Option 2A will include modification of all existing vessels. The existing arrangement consists of seven (7) 12’ diameter vessels. To accomplish the required EBCT for PFOA/PFOS, and allow for lead/lag configuration, four pairs of vessels are required. One new vessel is shown on the layout. The location of the proposed new vessel is currently open for use. Piping within the facility will be modified to allow for the necessary connections to the vessels as well as the new valve manifolds and some modifications to the nitrate vessels will also be made to accommodate the new media. Another potential layout would involve relocating the inlet filters and installing a vessel in the current inlet filter location. The system would then operate as it does currently in a “grouped” lead/lag configuration. Costs associated with this alternative are expected to be similar to Option 2A.

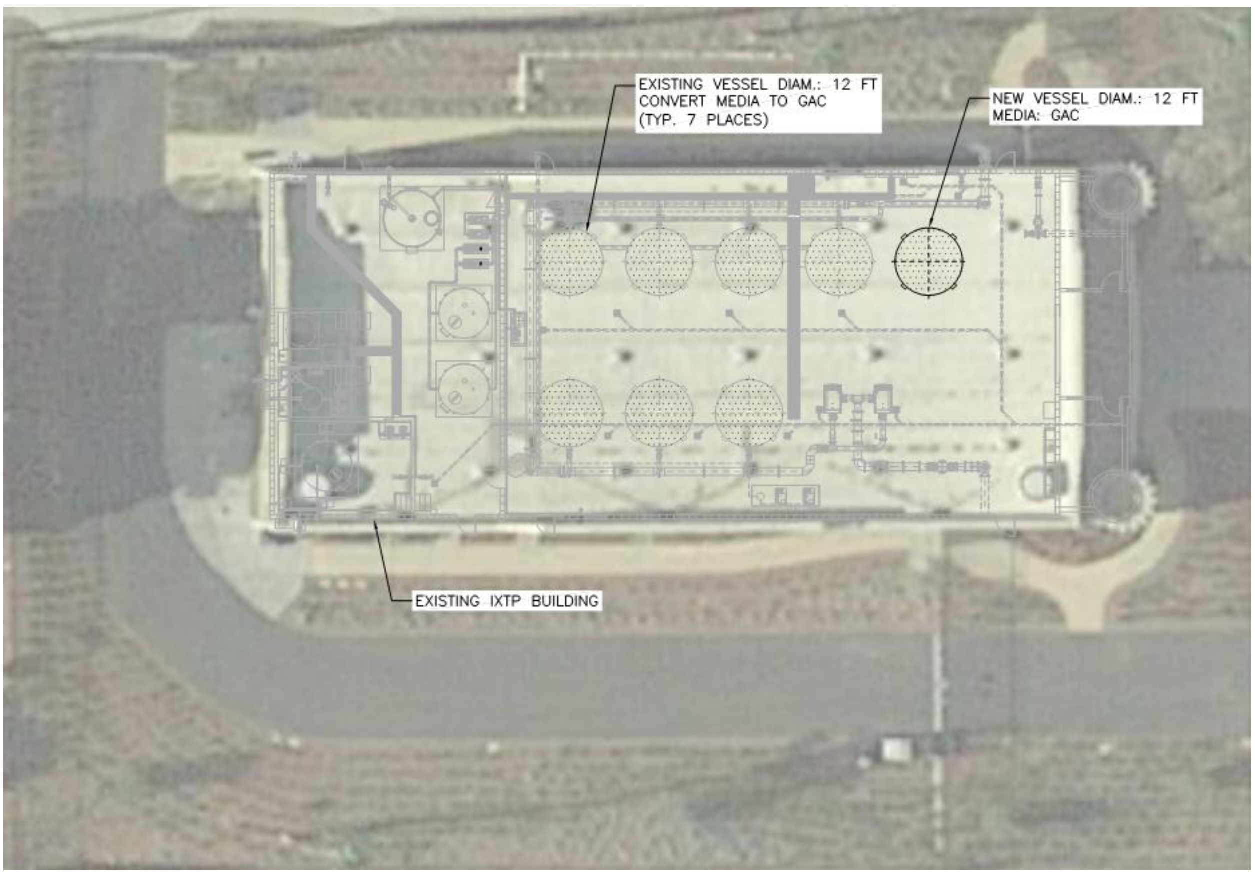

Figure 18. Option 2A – Site Layout

Option 2B will include modification of only the four existing nitrate IX vessels. The existing arrangement consists of four (4) 12' diameter vessels. To accomplish the required EBCT for PFOA/PFOS with a parallel configuration, conversion of these 4 vessels is required. Additionally, some modifications will be made to the vessels to accommodate the GAC media such as the potential removal of the internal IX brine distribution piping.

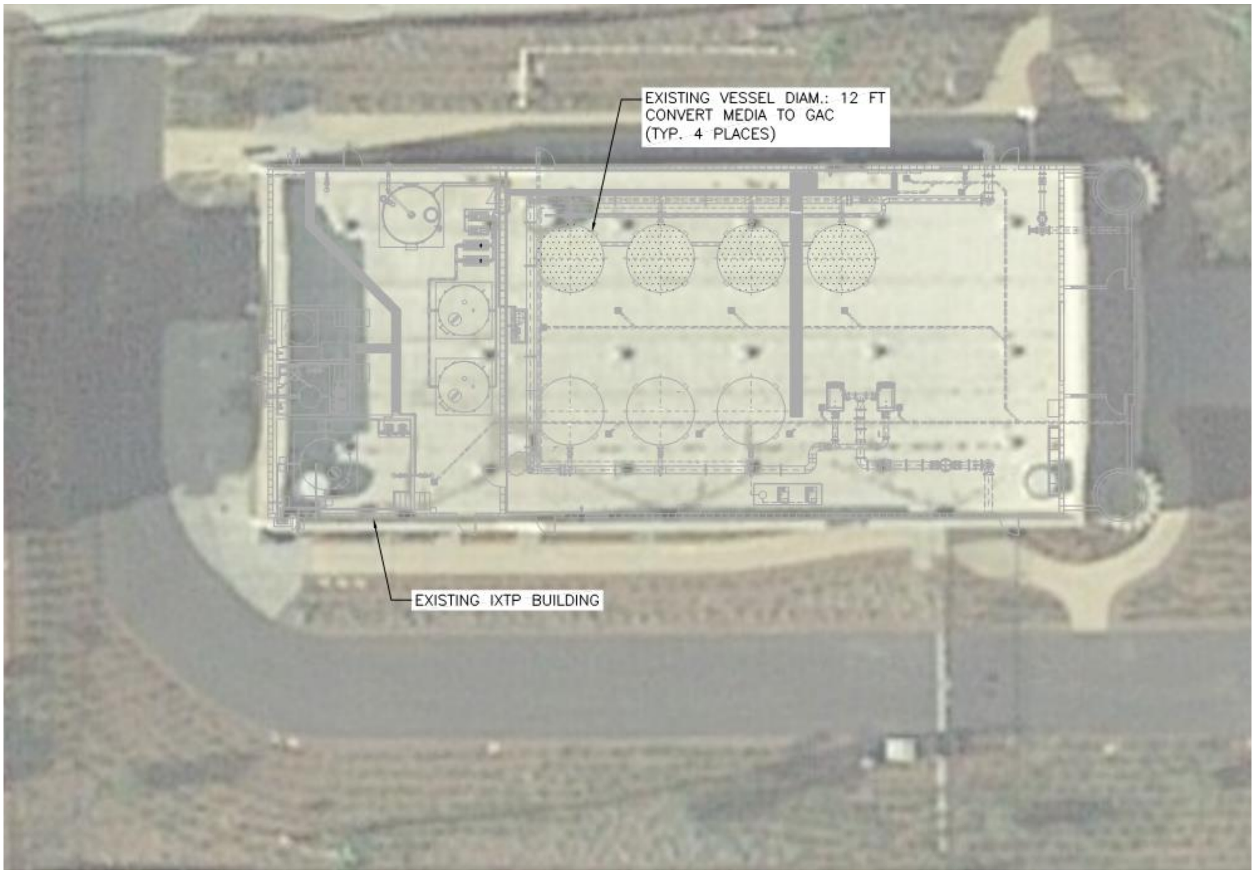

Figure 19. Option 2B – Site Layout

3.2.3 Option 3 - Convert IXTP Media to GAC, New IX System

The preliminary site layout for Option 3 is shown in Figure 20. This option consists of fully converting the IXTP to GAC as described in Option 2A. Additionally, a new regenerable IX system would be installed in the southwest corner of the site within the fenced area. The proposed system layout is shown as approximately 20' x 25' on a 30' x 30' concrete pad. Yard piping will be installed to accommodate the use of this system and the brine discharge. The existing brine system at the IXTP may be retained and reused for the new regenerable IX system. Yard piping will also be installed to accommodate the use of the existing system.

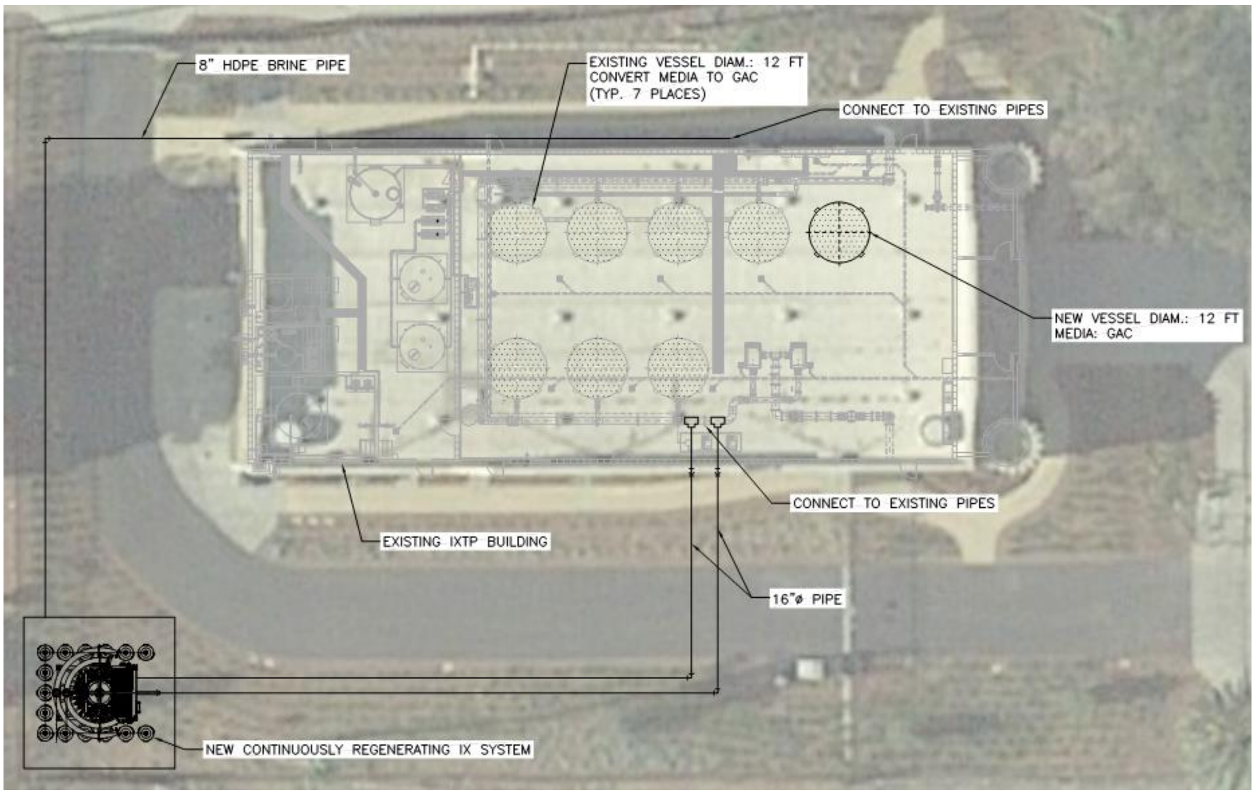

Figure 20. Option 3 – Site Layout

3.2.4 Option 4 - Convert IXTP Media to GAC, Expand Desalter RO

The preliminary site layout for Option 4 is shown in Figure 21. This option consists of fully converting the IXTP to GAC as described in Option 2A. Additionally, the discharge from the site would be conveyed to the existing Desalter. An investigation into pipeline capacities, distribution requirements, and the Desalter capacity will need to be performed to verify the viability of this option. Currently, the Desalter is not expected to have the capacity for the additional flow or the available space for increasing capacity in this manner.

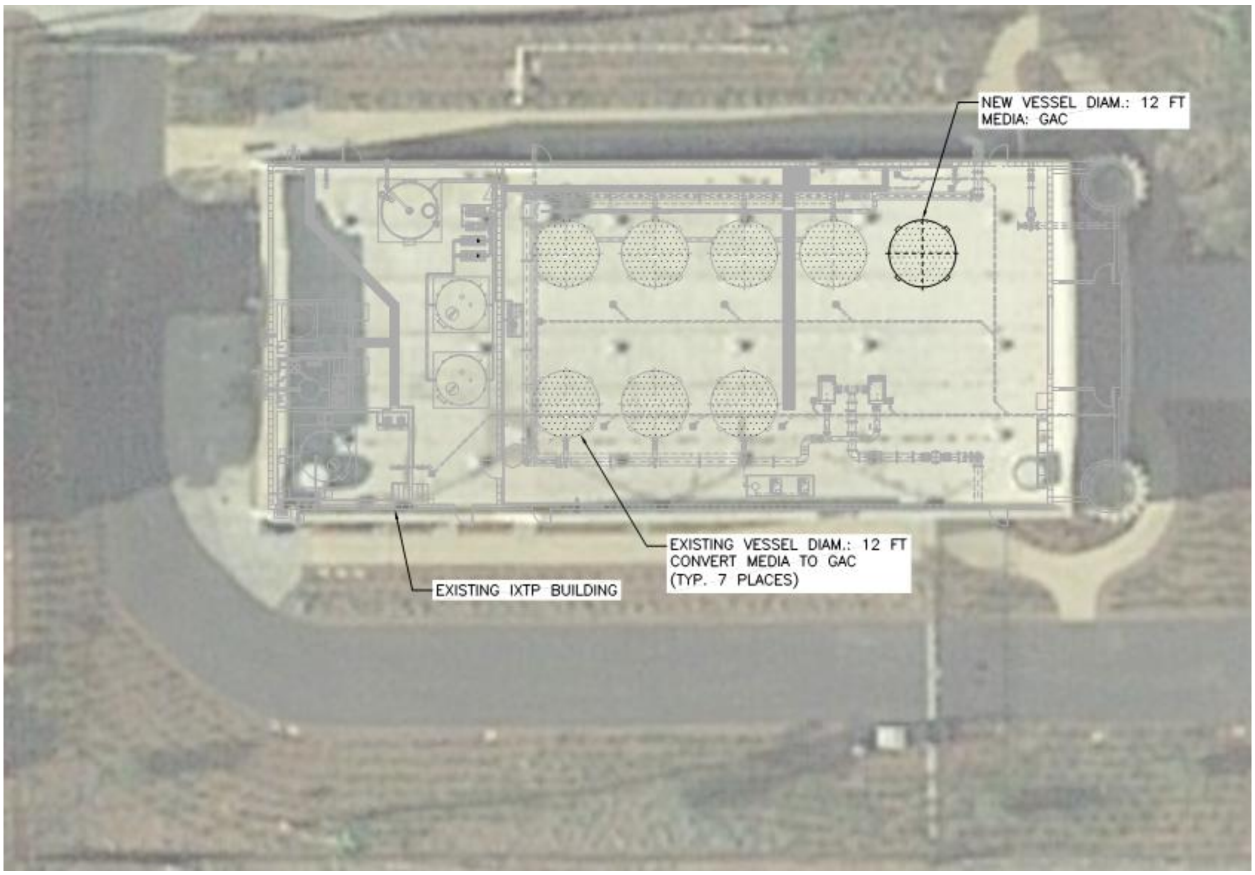

Figure 21. Option 4 – Site Layout

3.3 Cost Estimates

Preliminary capital and annual cost estimates have been developed for each option and are shown in Table 14 and Table 15, respectively. Detailed cost estimate tables are included in **Appendix F**. The cost estimates include, but are not limited to, the following major items.

Well 7A includes the GAC system, pre-filter, yard piping, and valves as necessary to divert water from the well to the treatment system and discharge to existing effluent piping. A recessed concrete foundation and walls are included as well. No controls, additional flow metering, PLC, or SCADA is included.

Option 1 includes the GAC systems, pre-filters, yard piping, and valves at all sites as necessary to connect the new treatment systems to the existing well and effluent pipes. A recessed concrete foundation and walls are included for each system as well. No controls, additional flow metering, PLC, or SCADA is included.

Option 2A includes GAC media for all existing vessels, one new GAC vessel and media, and modification of the existing pipes and valves in the IXTP to accommodate the distribution of flow. Some vessel piping modifications are also included to accommodate the new media and lead/lag configuration. Concrete foundations are not included as the existing foundation was designed for the existing vessels. No controls, additional flow metering, PLC, or SCADA is included.

Option 2B includes GAC media for four existing vessels and some vessel piping modifications to accommodate the new media. Concrete foundations are not included as the existing foundation was designed for the existing vessels. No controls, additional flow metering, PLC, or SCADA is included.

Option 3 includes the scope as described in Option 2A. Scope included as related to the new IX system are yard piping modifications diverting flow to and from the system, an extension of the brine line connection to the IX system location, and a new structure and foundation. Controls, flow metering, PLC, or SCADA as required for the new system, are included.

Option 4 includes the scope as described in Option 2A. This option’s cost estimate assumes adequate Desalter treatment capacity, adequate pipeline capacity between the IXTP and the Desalter, and the ability to manage distribution in such a way that allows for diversion of the full flow to the Desalter.

Table 14. Preliminary Capital Cost Estimates – All Options

<table>
<tr><th colspan="2">Option</th><th>Construction</th><th>Notes</th></tr>
<tr><td colspan="2">Well 7A</td><td>$ 1,632,000</td><td>In addition to chosen option. Removes PFOA, PFOS, and 1,2,3-TCP at the well.</td></tr>
<tr><td rowspan="4">Option 1 – New Wellhead GAC</td><td>Well 8A</td><td>$ 2,614,000</td><td>Removes PFOA, PFOS, and 1,2,3-TCP at the sources.</td></tr>
<tr><td>Well 17A</td><td>$ 2,397,000</td><td>Removes PFOA, PFOS, and 1,2,3-TCP at the sources.</td></tr>
<tr><td>Well 33</td><td>$ 2,368,000</td><td>Removes PFOA, PFOS, and 1,2,3-TCP at the sources.</td></tr>
<tr><td>Total</td><td>$ 7,379,000</td><td>Maintains current IX treatment and removes PFOA, PFOS, and 1,2,3-TCP at the sources.</td></tr>
<tr><td rowspan="2">Option 2 – Convert IXTP Media to GAC</td><td>2A</td><td>$ 1,381,000</td><td>Removes current IXTP treatment for nitrate and perchlorate. Treats for PFOA, PFOS, and 1,2,3-TCP at a central location.</td></tr>
<tr><td>2B</td><td>$ 498,000</td><td>Removes current IXTP nitrate treatment. Treats for PFOA, PFOS, and 1,2,3-TCP at a central location. Parallel configuration might not be permitted.</td></tr>
<tr><td colspan="2">Option 3 – Convert IXTP Media to GAC, New IX System</td><td>$ 6,406,000</td><td>PFOA, PFOS, 1,2,3-TCP, Nitrate, and Perchlorate treatment at a central location. Reduced brine generation and salt costs.</td></tr>
<tr><td colspan="2">Option 4 – Convert IXTP Media to GAC, Expand Desalter RO</td><td>$ 1,381,000</td><td>Does not include upgrades to existing Desalter capacity, pipeline capacity, and distribution capabilities.</td></tr>
</table>

Table 15. Preliminary Operational Cost Estimates – All Options

Option		Carbon Changeout Cost (1)	Carbon Changeout Frequency (months) (2)	Annual Carbon Cost	Estimated Annual IXTP Salt Costs	Total Annual Operational Cost (3)	20-Year Life Cycle Cost (4)
Well 7A		**$ 59,000**	**9.1**	**$ 78,000**	**-**	**$ 111,000**	**$ 4,187,000**
Option 1 – New Wellhead GAC	Well 8A	$ 68,000	4.6	$ 179,000	-	$ 242,000	$ 8,744,000
	Well 17A	$ 68,000	2.3	$ 358,000	-	$ 391,000	$ 11,307,000
	Well 33	$ 68,000	9.1	$ 90,000	-	$ 121,000	$ 4,344,000
	Total	**-**	**-**	**$ 627,000**	**$ 800,000**	**$ 1,554,000**	**$ 44,830,000**
Option 2 – Convert IXTP Media to GAC	**2A**	**$ 71,000**	**8.9**	**$ 96,000**	**$ 0**	**$ 123,000**	**$ 4,456,000**
	2B	**$ 71,000**	**6.7**	**$ 127,000**	**$ 0**	**$ 137,000**	**$ 3,997,000**
Option 3 – Convert IXTP Media to GAC, New IX System		**$ 71,000**	**8.9**	**$ 96,000**	**$ 100,000**	**$ 324,000**	**$ 14,603,000**
Option 4 – Convert IXTP Media to GAC, Expand Desalter RO (5)		**$ 71,000**	**8.9**	**$ 96,000**	**$ 0**	**$ 529,000**	**$ 14,819,000**

(1) Based on regenerated carbon at $1.00 per pound and minimum required carbon volumes as stated in Section 3.1.

(2) Based on F400 RSSCT bed volume results, constant (24/7) flow, and the maximum flow capacity of each location as provided by the City. Well 33 was not part of the RSSCT and assumes the same RSSCT results as Well 7. Actual frequency may vary. Option 2B is based on 75% utilization as compared with Option 2A due to parallel operation with no lead-lag configuration.

(3) Based on annualized GAC changeout costs, filters, salt, Desalter costs, and labor and maintenance at 2% of capital costs. Assumes a cost of $0.85 per 1,000 gallons for treatment at the Desalter based on a 2013 Proposition 84 cost analysis submittal, not adjusted for inflation. Some options retain or eliminate existing treatment systems, the costs of which are not included in the estimates unless noted otherwise. Includes costs associated with existing salt purchase for resin regeneration at the IXTP.

(4) Considers cartridge filters, GAC media changeouts, IXTP salt regeneration, labor and maintenance, and capital costs. Assumes a 2.5% rate of inflation. Does not consider electrical use, well modifications, or other ancillary costs.

(5) Does not include capital associated with increasing capacity at the Desalter and in the conveyance systems.

4. Summary of Findings

The City wishes to further treat for 1,2,3-TCP, PFOA, and PFOS in the drinking water supply as well as prevent discharge of these contaminants in wastewater effluent and brine from the desalter. Locations of interest include Well 7A, Well 8A, Well 17A, IXTP Influent, WWTP Effluent, and the Desalter Brine. Contaminants exceeding the applicable MCL or RL at the specified drinking water system locations are shown in Table 16.

Table 16. Summary of Exceedances at Evaluated Locations

Location	Nitrate	Perchlorate	1,2,3-TCP	PFOA	PFOS
Unit	mg/L as N	µg/L	ng/L	ng/L	ng/L
NL	-	-	-	5.1	6.5
RL	-	-	-	10	40
MCL	10	6	5	-	-
Well 7A	**12.8**	5.45	**5.34**	**140**	**140**
Well 8A	**14.2**	4.76	**23.14**	**180**	**170**
Well 17A	9.6	2.86	**12.68**	**230**	**210**
IXTP Influent	8.6	4.6	**17**	**130**	**120**
WWTP Effluent	5.0	ND	ND	20	4.6
Desalter Brine	52	NM	16.2	320	294

NOTES:
NA – Not Applicable, NM – Not Measured, ND – Non-Detect

RSSCTs were performed on all six water sources. This type of testing was used to provide results much faster than a pilot or full-scale system would allow. Two types of carbon media and four types of resin media were selected for use in the RSSCTs. Both carbon media were used for all six source waters while one resin media was selected for each source water. Conclusions from the RSSCTs are as follows:

- For all media used in the RSSCTs, PFOA breakthrough occurred earlier than PFOS.
- F400 GAC was more effective than F600 GAC in removal of PFOS and PFOA.
- Both GACs were able to effectively remove 1,2,3-TCP while IX resins did not effectively remove 1,2,3-TCP.
- The selected IX resins were able to achieve longer bed volume capacity compared with GACs in treating PFOS and PFOA from the drinking water sources.
- For the source waters requiring reduction of both 1,2,3 TCP and PFAS, GAC is a preferred alternative as IX resins only remove PFAS.

Costs of IX resins were estimated to be approximately 7 times that of GAC per cubic foot. Under this estimation, IX resin was more economical at Well 17A and WWTP Effluent while GAC was more economical at Well 7A, Well 8A, IXTP Influent, and the Desalter Brine. However, 1,2,3-TCP is also a constituent of concern and cannot be treated with IX resin. Because of these factors, GAC was used as the basis for treatment in most options with IX resins being considered as secondary treatment for nitrate and perchlorate in one option.

Certain preliminary options considered were eliminated early in the process due a lack of viability or their inability to meet the project goals. The remaining options considered are shown below:

Option 1 – New Wellhead GAC (Wells 8A, 17A, and 33)

- Removal of all 5 constituents
- Highest life cycle cost and capital costs

Option 2A – Convert IXTP Media to GAC (Lead-Lag Configuration)

- Removal of 1,2,3-TCP, PFOA, and PFOS, but eliminates existing nitrate and perchlorate treatment at the IXTP
- Low capital and life cycle costs
- Will offer additional savings related to elimination of resin replacement and regeneration at the IXTP

Option 2B – Convert IXTP Media to GAC (Parallel Configuration)

- Removal of 1,2,3-TCP, PFOA, PFOS, and perchlorate but eliminates existing nitrate treatment at the IXTP
- Lowest capital and life cycle costs
- Will offer additional savings related to elimination of resin regeneration at the IXTP
- Permit to operate as a parallel system may be more difficult to approve than lead/lag

Option 3 – Convert IXTP Media to GAC, New IX System

- Removal of all 5 constituents
- Moderate life cycle cost and highest capital cost
- Will offer additional savings related to reduction of salt usage and brine discharge at the IXTP
- Reduced brine discharge, allowing the City to potentially utilize the brine line capacity elsewhere

Option 4 – Convert IXTP Media to GAC, Expand Desalter RO

- Removal of all 5 constituents
- Moderate life cycle cost and low capital cost
- Will offer additional savings related to elimination of resin replacement and regeneration at the IXTP
- Does not consider the costs or viability of increased Desalter capacity

The following options are eliminated from final recommendation:

Option 1 – This option addresses all 5 contaminants at all drinking water sites but at high capital and life cycle costs. Sufficient space may not be available at Well 17A due to plans for a generator at the site. Well 33 does not contain PFOA and PFOS at levels exceeding the notification level.

Option 3 – This option is the highest capital cost, most complex, and has a moderate life-cycle cost as well. It addresses all 5 contaminants of concern but is only be sized to treat 1,600 GPM, while bypassing approximately 800 GPM. Because of this bypass, treatment goals for PFOA and PFOS may not be achieved at the IXTP effluent and further reduction will be achieved through blending or at the Desalter.

Option 4 – This option has a relatively low capital but moderate life-cycle costs. Additionally, some significant capital costs and/or feasibility issues related to the Desalter may exist as well. It addresses all 5 contaminants of concern but will only be sized to treat 1,600 GPM at the IXTP, while bypassing approximately 800 GPM. Because of this bypass, the remaining PFOA and PFOS removal will be achieved at the Desalter, resulting in some discharge of the contaminants in the brine.

4.1 Recommendations

To accomplish the treatment goals of this study and remove PFOS, PFOA, and 1,2,3-TCP at the sources, reducing levels in both the potable distribution system and the brine discharge, a combination of treatment options is recommended. Option 2A is recommended but will only be sized to treat 1,600 GPM, while bypassing approximately 800 GPM. Because of this bypass, treatment goals for PFOA and PFOS may not be achieved at the IXTP effluent and further reduction would be achieved through blending or at the Desalter. To address this, it is also recommended to install a GAC system at Well 8A as described in Option 1. Wells 17A and 33 are not included as a part of this recommendation at this time. Well 8A has the ability to bypass the IXTP, reducing the IXTP influent flow by approximately 1,000 GPM (based on current flow rates) and allowing for the full remaining flow to be treated by GAC. Well 7A is recommended as stated in the report. As this recommendation consists of three separate systems, construction can be phased according to the City budget requirements. Recommended phasing is Well 8A, followed by Option 2, followed by Well 7A. A summary of the costs associated with this recommendation are below in Table 17 and Table 18.

Table 17. Preliminary Capital Cost Estimates – Recommended

Recommendation		Construction Cost
Well 7A		$ 1,632,000
Option 1 – New Wellhead GAC	**Well 8A Only**	$ 2,614,000
Option 2 – Convert IXTP Media to GAC	**2A**	$ 1,381,000
	2B (Alternative to 2A)	*$ 498,000*
Total	**Well 7A, 8A, and Opt. 2A**	**$ 5,627,000**
Total	*Well 7A, 8A, and Opt. 2B*	*$ 4,744,000*

Table 18. Preliminary Operational Cost Estimates – Recommended

Option		Carbon Changeout Cost (1)	Carbon Changeout Frequency (months) (2)	Annual Carbon Cost	Estimated Annual IXTP Salt Costs	Total Annual Operational Cost (3)	20-Year Life Cycle Cost (4)
Well 7A		$ 59,000	9.1	$ 78,000	-	$ 111,000	$ 4,187,000
Option 1 – New Wellhead GAC	**Well 8A**	$ 68,000	4.6	$ 179,000	-	$ 242,000	$ 8,744,000
Option 2 – Convert IXTP Media to GAC	**2A**	$ 71,000	8.9	$ 96,000	$ 0	$ 123,000	$ 4,456,000
	2B	*$ 71,000*	*6.7*	*$ 127,000*	*$ 0*	*$ 137,000*	*$ 3,997,000*
Total	**Well 7A, 8A, and Opt. 2A**			**$ 353,000**	**$ 0**	**$ 476,000**	**$ 17,387,000**
Total	*Well 7A, 8A, and Opt. 2B*			*$ 384,000*	*$ 0*	*$ 490,000*	*$ 16,928,000*

(1) Based on regenerated carbon at $1.00 per pound.

(2) Based on F400 RSSCT results and constant (24/7) flow. Actual frequency may vary. Option 2B is based on 75% utilization as compared with Option 2A due to parallel operation with no lead-lag configuration.

(3) Based on annualized GAC changeout costs, filters, salt, Desalter costs, and labor and maintenance at 2% of capital costs. Some options retain or eliminate existing treatment systems, the costs of which are not included in the estimates. Includes costs associated with existing salt purchase for resin regeneration at the IXTP.

(4) Considers cartridge filters, GAC media changeouts, IXTP salt regeneration, labor and maintenance, and capital costs. Assumes a 2.5% rate of inflation. Does not consider electrical use, well modifications, or other ancillary costs.