Orange County Water District

PFAS Phase I Pilot-Scale Treatment Study Final Report

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This report summarizes the approach and findings of the Orange County Water District (OCWD) per- and polyfluoroalkyl substances (PFAS) pilot-scale treatment study (Phase I) conducted between December 2019 (commissioning) to January 2021. The report is organized as follows:

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EXECUTIVE SUMMARY

The objective of the Phase I Orange County Water District (OCWD) per- and polyfluoroalkyl substances (PFAS) pilot-scale treatment study was to test different types of adsorbent media including granulated activated carbon (GAC), ion exchange (IX) resins, and alternative (novel) adsorbents to remove PFAS from affected wells operated by retail agencies (Producers) within the Orange County Groundwater Basin. Fourteen different media were evaluated via pilot testing from December 2019 through January 2021 using empty bed contact times (EBCTs) matching those recommended for full-scale design (10 min for GAC, 2 min for IX, and 2 to 5 min for alternative adsorbents).

All products initially demonstrated removal of perfluorooctanoic acid (PFOA) to below detection limit (2 nanograms per liter [ng/L]); media performance was then compared based on time to reach initial breakthrough (>2 ng/L) and significant breakthrough (defined here as 60% exhaustion when effluent concentration is approximately 60% of influent concentration).

For IX media tested in the OCWD pilot, Evoqua PSR2+ demonstrated the latest PFOA breakthrough (i.e., longest media life), with no breakthrough for PFOS yet at the time of this report for any IX media. For the one short-chain compound from EPA Method 537.1 that occurs at sufficiently high concentrations in the OCWD pilot influent, perfluorobutane sulfonic acid (PFBS), Evoqua PSR2+ also demonstrated the latest breakthrough compared to the other three IX resins. For PFOA and PFBS, the other three IX resins showed a generally similar performance to one another, where ECT2 Sorbix LC4 resin exhibited PFOA breakthrough slightly earlier than the other two resins Purolite Purofine PFA694E and Calgon CalRes 2301.

For GAC, virgin and reactivated Calgon F400 showed the strongest performance exhibiting later initial PFOA breakthrough and the lowest sustained PFOA effluent concentration throughout most of the approximately 13 months of pilot operation (at the time of this report); two other bituminous GACs (Calgon F600, Cabot Norit GAC400) showed similar long-term performance despite earlier initial breakthrough. All three bituminous GACs showed similar effluent concentrations at approximately 13 months of pilot operation. The non-bituminous and sub-bituminous GACs tended to perform slightly less well for PFOA. Calgon F400 also performed well for the removal of PFOS relative to the other GACs. This information together with RSSCT findings reported separately can be considered to identify the strongest performing GAC media for Orange County groundwater.

The two alternative adsorbents tested showed the widest range in performance of all 14 media piloted though recognizing different EBCTs were used: Cyclopure DEXSORB+® at 5 min EBCT exhibited the earliest initial PFOA breakthrough, while CETCO FLUORO-SORB® 200 at 2 min EBCT exhibited the latest initial PFOA breakthrough. Thus, CETCO FLUORO-SORB® 200 may be the longest-lasting media in this study for PFOA removal despite its relatively low EBCT at 2 min. However, additional piloting duration will be valuable to confirm relative performance of the longest-lasting media (Calgon F400 and other bituminous GACs, Evoqua PSR2+, and CETCO FLUORO-SORB® 200) since 60% breakthrough has not quite yet been reached by these products at the time of this report and is more relevant to full-scale performance than time to initial breakthrough. Overall,

piloting identified that the longest-lasting adsorbent(s) in each media category (GAC, IX, or alternative adsorbents) outperformed the next tier of products in their category significantly by at least four to five months of media life (by the time of this report) with respect to the 60% breakthrough criterion.

For PFOS, overall the breakthrough was significantly later than PFOA for all IX and alternative adsorbents that to date still show no PFOS breakthrough after 13 months (for IX) and 11 months (for alternative adsorbents) of piloting. PFOS breakthrough was also later than PFOA for GAC but less delayed compared to the other media. With respect to short-chain PFAS, PFBS removal was sustained for the longest by IX followed by alternative adsorbents, and then GAC with the shortest time to breakthrough.

1. INTRODUCTION

1.1 Background

The Orange County Water District (OCWD) manages the Orange County Groundwater Basin underlying North and Central Orange County, which serves as the primary water supply for 19 large cities and water districts. Per- and polyfluoroalkyl substances (PFAS) have been detected in the Orange County Groundwater Basin at low nanogram per liter (ng/L) range concentrations. PFAS are chemicals that have been used in a wide range of products and industries since the 1940s. PFAS chemicals are both hydrophobic and hydrophilic, as well as oleophobic, which makes these chemicals useful for a wide variety of products and applications, including but not limited to:

- Consumer products, including stain- and water-repellent fabrics (e.g., GORE-TEX®, ScotchGard®, Stainmaster®), manufacturing of non-stick products (e.g., Teflon™), polishes, waxes, paints, and cleaning products
- Paper packaging and wrappers for food (e.g., microwave popcorn bags, pizza boxes)
- Polymers used in aircraft and electronics manufacturing
- Aqueous film fire-fighting foams (AFFF) used at military bases, airports, and training facilities
- Roofing and other building materials

In California, the State Water Resources Control Board (SWRCB) Division of Drinking Water (DDW) has set some of the most stringent PFAS advisories in the country. The state's Notification Levels (NLs) are 5.1 ng/L for perfluorooctanoic acid (PFOA), 6.5 ng/L for perfluorooctane sulfonic acid (PFOS), and the Response Levels (RLs) are 10 ng/L for PFOA, 40 ng/L for PFOS. For perfluorobutane sulfonic acid (PFBS), an NL of 500 ng/L and an RL of 5,000 ng/L have been recommended to DDW by the state's Office of Environmental Health Hazard Assessment (OEHHA), with adoption likely in March 2021.

Because local groundwater used for drinking water supply exceeds the PFOA RL in certain locations, OCWD initiated a PFAS Treatment Study consisting of both pilot and laboratory testing. OCWD led and operated the pilot with technical advisory support from Jacobs

Engineering Group, Inc. (Jacobs). Jacobs executed the remainder of the scope of work including rapid small-scale column testing (RSSCT) of granular activated carbon (GAC) and alternative adsorbents to compliment the pilot study. RSSCT did not include ion exchange (IX) resins due to the lack of an industry-accepted methodology, while the pilot included all products (GAC, IX, and alternative adsorbents). To the project team's knowledge, the OCWD pilot is the nation's largest PFAS adsorptive media pilot test with respect to the number of treatment media that were evaluated (14 media).

1.2 Objective

The overall purpose of the OCWD PFAS Treatment Study was to identify effective treatment technologies to restore the local groundwater quality and meet the Producer's drinking water regulatory requirements to improve public health. The technical objective of the PFAS pilot-scale treatment study was to test different types of adsorbent media including GAC, IX, and alternative adsorbents to remove PFAS from Orange County's groundwater. The alternative adsorbents were "novel" adsorbents not classified as GAC or IX and only recently commercially available.

Understanding removal of PFOA was a primary goal of the pilot testing, as this PFAS compound most commonly exceeds its California RL in select Producer groundwater wells, whereas PFOS does not as regularly exceed its RL. This report presents the results of the pilot-scale test as a component of the overall OCWD PFAS Treatment Study. The overall findings including the bench scale testing (RSSCT) are provided separately in the Jacobs PFAS Treatment Study Final Report (Jacobs 2021).

2. PILOT SITE DESCRIPTION AND WATER QUALITY

OCWD owns and operates 21 spreading basins and approximately 6 miles of the Santa Ana River channel near OCWD's Field Headquarters (FHQ) in Anaheim, CA. The basins and riverbed (along with the off-river system) are used to recharge water into the Orange County Groundwater Basin (aquifer). One of the basins used for recharge is Warner Basin, located adjacent to FHQ. The Bessie well is a non-potable, OCWD-owned irrigation well that was used to supply water to the PFAS pilot. The well is located immediately adjacent to Warner Basin. Figure 1 shows the location of FHQ, Warner Basin and Bessie well.

Table 1 summarizes the PFAS occurrence and concentrations for the Bessie well based on samples collected during the pilot testing period. Table A-1 (see attachment) summarizes general water quality parameters for Bessie well from the pilot testing period. More details on the sampling and analytical approach are provided later in this report. Testing data from the Bessie well indicates the presence of PFAS in its produced groundwater. The concentration of PFOA is 16 ± 2 ng/L and the concentration of PFOS is 23 ± 1.8 ng/L (mean and standard deviation). Of the 18 different PFAS compounds measurable by the EPA Method 537.1 with a detection limit of 2 ng/L for all compounds, only seven are consistently detected in Bessie well groundwater, indicative of PFAS occurrence in the groundwater basin. Of these, two PFAS are considered to be short-chain (PFBS and PFHxA) compounds (ITRC, 2020). Based on PFAS types and concentrations

from historical water quality data for the Bessie well, in addition to general water quality, this well was deemed representative of the general aquifer conditions and therefore appropriate to serve as the pilot location (pilot influent water supply).

Figure 2 shows a photograph of the Bessie well facilities at ground surface. The well is typically used for landscape irrigation at FHQ and truck tank filling, however these uses were discontinued shortly after pilot commissioning. The completed well has a total depth of 302 ft below ground surface (bgs), with a screened interval at depths between 172 ft and 189 ft bgs.

Figure 1. Aerial map of OCWD Field Headquarters (FHQ), Field Research Laboratory (FRL), and Warner Basin. The PFAS Pilot (★) is located at Bessie Well on west side of Warner Basin.

Figure 2. OCWD Bessie well facilities

Table 1. Summary of PFAS concentrations of Bessie well water measured during the pilot testing period (data range December 2019 to October 2020, n= 20) for EPA Method 537.1

PFAS	Average PFAS Concentration (ng/L)	Standard Deviation
PFOA	16	2.0
PFOS	23	1.8
PFBS	14	1.3
PFHxS	11	0.8
PFHxA	2.8	0.3
PFNA	2.2	0.7
PFDA	3.1	0.6

Note: Eleven (11) other PFAS compounds were measured by EPA Method 537.1 and not detected (i.e., total of 18 PFAS compounds are measured by EPA Method 537.1, per Table A5 in Attachment). Additional PFAS (PFBA, PFPeA, and PFPeS) were detected via more limited testing using EPA Method 533, as noted in the Attachment.

3. ADSORBENT MEDIA SELECTION FOR PILOT

OCWD received a comprehensive adsorbent media product review from Jacobs as part of the PFAS Treatment Testing Support Services Project scope. While most adsorptive media pilots for various contaminant targets are typically limited to approximately two to four different media, OCWD elected to increase the scope of the media testing (for both pilot and RSSCT) beyond this due to the number of potential media identified by Jacobs' review and OCWD interest in casting a wide net to identify the best and most cost-effective media for Orange County groundwater.

Table 2 lists the 14 products chosen for the pilot. All GAC and IX media are NSF 61 certified. For the alternative adsorbents, CETCO FLUORO-SORB® 200 is NSF 61 certified while Cyclopure is in the process of pursuing certification for DEXSORB+®.

Table 2. Media products tested in the OCWD PFAS Pilot and subset of products evaluated separately by laboratory testing (RSSCT)

Vendor	Product	Media Material/Type	GAC Pilot	IX Pilot	RSSCT (Lab)
Granular Activated Carbon (GAC)					
Calgon	FILTRASORB 400 (F400)	Bituminous GAC (virgin)	X		X
Calgon	FILTRASORB 400 (F400)	Bituminous GAC (reactivated)	X		X
Calgon	FILTRASORB 400 (F600)	Bituminous GAC	X		X
Cabot	Norit GAC400	Bituminous GAC	X		X
Cabot	Norit HYDRODARCO 4000	Lignite-based GAC	X		X
Evoqua	UltraCarb 1240LD	Sub-Bituminous GAC (low density)	X		X
Evoqua	AquaCarb 1230CX	Enhanced Coconut Shell GAC	X		X
Jacobi	AquaSorb F23	Enhanced Blended GAC	X		
Ion Exchange (IX) Resins					
Purolite	Purofine PFA694E	Single use anion exchange resin		X	
Calgon	CalRes 2301	Single use anion exchange resin		X	
Evoqua	PSR2+	Single use anion exchange resin		X	
ECT2	Sorbix LC4	Single use anion exchange resin		X	
Alternative (Novel) Adsorbents					
CETCO	FLUORO-SORB® 200	Surface modified bentonite clay		X	X
Cyclopure	DEXSORB+®	Cyclodextrin-based adsorbent		X	X

4. PILOT DESIGN

OCWD Research and Development (R&D) Department developed a detailed pilot test plan (OCWD, 2020). This section summarizes the test plan and pilot design.

A key factor controlling PFAS breakthrough is the empty bed contact time (EBCT). EBCT is equal to the volume of the empty (treatment) bed (i.e., pilot column or full-scale vessel) divided by the flowrate and is calculated as the time required for the fluid to pass through

the (empty) volume occupied by the media. EBCTs chosen for this pilot study were 10-minute for GAC and 2-minute for IX columns. These EBCTs are typically recommended for full-scale treatment systems. Running the pilot system at the same EBCT as a full-scale design allowed for a more confident projection of full-scale GAC and IX product performance based on the pilot-scale results. The pilot timescale matches full-scale for the same EBCT, e.g., IX media at 2 min EBCT showing 60% breakthrough at eight months would be expected at full-scale also show 60% breakthrough at eight months. Furthermore, sufficient contact time is needed to capture the mass transfer zone (which is the portion of the GAC or IX bed that is still adsorbing PFAS; this zone moves further and further down the bed as the media becomes exhausted). Experience suggested that 2- (IX) and 10-minute (GAC) EBCT is sufficient to capture the mass transfer zone.

For alternative adsorbents, the individual vendors recommended a 2 min EBCT for CETCO's FLUORO-SORB® 200 and 5 min EBCT for Cyclopure's DEXSORB+®. Commissioning of the alternative adsorbents was 2.5 months later than GAC and IX products due to need to confirm selected EBCT via bench-scale testing. CETCO collaborated with Colorado School of Mines (CSM) with input from Jacobs to complete the RSSCT at CSM using Bessie groundwater in order to determine the recommended EBCT (2 min). For DEXSORB+®, Cyclopure also completed an RSSCT using OCWD groundwater in order to determine the recommended EBCT (5 min).

Hydraulic/operational parameters for GAC, IX and alternative adsorbents are provided in Table A-2 (see Attachment) with more details provided in the pilot test plan (OCWD, 2020).

5. PILOT COMMISSIONING

A premanufactured building was purchased and installed by OCWD on a new concrete pad to house the pilot system (Figure 3). The pilot system was rented from Evoqua and consisted of a standard pre-filter skid (Figure 4) utilizing 5-micron cartridge filters to remove suspended solids to protect the pilot adsorption media and three separate media pilot skids (two for GAC and one for IX) shown in Figure 5, 6, and 7.

The media pilot skids generally consisted of a metal skeleton-frame to house multiple transparent polyvinyl chloride (PVC) columns. The GAC columns had a diameter of 3 inches and height of 4.5 feet, and IX columns (also used for alternative adsorbents) had a diameter of 2 inches and height of 2.5 feet.

Pilot commissioning (start of flow) occurred December 18, 2019 for GAC and IX media. Evoqua and Jacobs assisted OCWD R&D staff with pilot commissioning including loading of various media and general training. For Evoqua media, the GAC and IX media were pre-loaded by Evoqua prior to pilot delivery. All other media were loaded on site by OCWD staff. The alternative adsorbents pilot columns were commissioned approximately 2.5 months later on March 4, 2020 by OCWD staff with staff from Cyclopure onsite to assist. For GAC, IX, and alternative adsorbents, all media providers were consulted prior to commissioning regarding their input and agreement for key design criteria, loading instructions, etc. All media were placed inside the columns to a specified depth (Table A-2) and carefully filled and tapped to avoid air gaps per vendor instructions.

PFAS PILOT PROGRAM

Commissioned December 2019

The Orange County Water District (OCWD) PFAS Pilot Program is testing various technologies to remove per- and polyfluoroalkyl substances, or PFAS, from groundwater. PFAS is a family of manmade heat and water resistant chemicals found in numerous everyday consumer products and commercial products or manufacturing industries that have infiltrated groundwater supplies over several decades. While the levels of PFAS in Orange County groundwater wells are relatively low, OCWD and its retail water agencies are exploring long-term solutions to ensure that Orange County water supplies continue to meet all state and federal water quality standards. Groundwater is an important supply for drinking water in Orange County.

The goal of the pilot program is to help retail water agencies in Orange County determine the best treatment methods available to them. At this site, OCWD will be testing different types of granular activated carbon (GAC) and ion exchange (IX) products, as well as novel adsorbents just emerging in the market, to determine which applications are best suited for Orange County's diverse aquifer water quality and geochemistry. All of the treatment methods are expected to remove PFAS from groundwater to below detectable levels. A regional planning study will be completed to evaluate how such treatment could be rapidly implemented and to conduct preliminary engineering design work.

JACOBS · EVOQUA WATER TECHNOLOGIES · carollo · CABOT · CalgonCarbon · cyclopure · ect2 · CETCO · Jacobi CARBONS · Purolite

PFAS CAN BE FOUND IN:

carpets · clothing · furniture fabrics · paper food packaging · water, grease or stain resistant materials · fire-fighting foam

What Are PFOA and PFOS?
Perfluorooctanoic acid (PFOA) and perfluorooctane sulfonate (PFOS) are chemicals that are prevalent in the environment and were once commonly used in many consumer products. They are part of a larger group referred to as per-and polyfluoroalkyl substances (PFAS). Although PFOA and PFOS are no longer manufactured in the United States, other countries still make products that contain these chemicals, which may be imported into the United States. [Note: other PFAS are still made and used in the US.]

What Are Ways People Are Exposed to PFOA and PFOS?
Water is just one of many ways that people come in contact with these substances. These chemicals are resistant to heat, water and oil and have been used for decades in hundreds of industrial applications and consumer products. PFAS have been found both in the environment and in blood samples of the general U.S. population. The U.S. Food and Drug Administration (FDA) has also detected PFAS chemicals in the U.S. food supply. Due to the prolonged use of PFOA and PFOS in many common consumer products, the chemicals have been known to enter the water cycle through conventionally treated wastewater discharges from sewage treatment facilities, landfills and locations where the substances were used outdoors. Most people have been exposed to these chemicals through consumer products, but drinking water can be an additional source of exposure in communities where these chemicals have entered water supplies.

All water agencies in OCWD's service area operate their water systems following all drinking water requirements for PFOA and PFOS established by the Environmental Protection Agency and Division of Drinking Water.

OCWD and Retail Water Agencies in Orange County are Committed to Clean Drinking Water

To meet the state's recommended PFAS levels, water providers are taking actions such as:

- Removal of water supply sources from service
- Use of imported water that meets the state's recommended levels of PFAS
- Blending multiple water supply sources to meet the state's recommended levels of PFAS
- Pilot testing of water treatment processes for PFAS

How Can I Learn More?
For more information about the PFOA/PFOS or water quality testing, visit www.ocwd.com or contact your local water provider for information specific to your community.

Figure 3. OCWD PFAS Pilot building adjacent to Warner Basin (upper) and informational pilot sign posted on building (lower)

Figure 4. Pre-filtration skid in pilot building

Figure 5. GAC skids (left, partial view of four of eight columns) and IX/alternative adsorbent skid (right) placement in pilot building

Figure 6. Two GAC pilot skids in pilot building

Figure 7. IX and alternative adsorbent pilot skid (left) and closer view (right) showing color of four IX resins at the beginning of the pilot test

The columns were supplied with non-chlorinated groundwater extracted directly from the Bessie well using a newly installed 1.4-inch electric submersible pump (Groundfos 5 SQ05-140). These small pumps (including a second pump as back-up) were installed because initial use of the existing larger turbine pump led to near immediate clogging of the pilot pre-filters. Water from the single pump was split after pre-filtration to feed all three pilot skids.

The following steps were taken before starting the pilot operation:

1. **Hydrostatic testing prior to media loading (column packing):** The system was tested prior to loading the media to ensure that the pump could supply enough flow and pressure to meet specifications for all three column skids. OCWD installed two submersible pumps to run the pilot, one pump to supply the pilot and achieve a pressure of ~29 psi and a flow rate of 4 gallons/min, and the second pump as a standby unit.

2. **Flushing of system prior to media loading:** Bessie Well water was pumped through the pilot system for a couple of minutes to rinse system of dust and any other contaminants.

3. **Media loading:** Procedure for media loading was dependent on the type of media. The media were loaded based on instructions from the media vendors. Detailed loading instructions for GAC, IX and alternative adsorbents can be found in the pilot test plan (OCWD, 2020).

4. **Installation of cartridge filters:** Cartridge filters were installed on the pre-filtration skid to filter the influent to the one IX skid and two GAC skids. The cartridge filters ensured that no particulate matter enters and interfere with normal operation of columns. Cartridge filters were required for IX to match full scale operations. Cartridge filters are not required for GAC but installed at the pilot scale to avoid need for backwashing during pilot testing which may be conducted for full-scale GAC systems.

   4a. Pre-Filtration skid design: The filtration skid (filter skid) was a standalone skid to filter the main influent line coming directly from the submersible pump. The filtered water fed all three column skids. The filter skid had two (2) 5-micron filter/filter housings. These filters were installed and operated in parallel to one another; both filters were operated to minimize the loading rate on the individual filters.

   4b. IX skid design: IX skid consisted of six test columns. The skid had one (1) 5-micron cartridge filter on the inlet feed and one (1) 5-micron cartridge filter on the outlet side of the skid. These filters were used to remove suspended solids (inlet) and to prevent any resin media to be discarded to the outlet drain. The inlet cartridge filter was used despite the redundancy with the pre-filtration skid for added protection of IX pilot media.

4c. GAC skid design: GAC skid consisted of two (2) skids with four test columns each (total of 8 columns). A separate cartridge filter for these skids was not employed on the GAC skids, rather, a common filter (see 5a above) was installed in-line from the tube feeding all three pilot skids (separate from the additional filter on the IX skid).

5. **Well purging (only performed once before the start of the pilot operation) and flow start:** The well was purged (i.e., flushed) to remove static water from the well casing, ensuring the water pulled for the pilot was recent formation water.
    a. Bessie Well turbine pump was operated for about 15 minutes.
    b. One pilot (submersible) pump was then operated with disharge to waste for 10 minutes before turning on the flow to the columns.
    c. Flow to the columns was started after the purging step and flows were adjusted to ensure they were within the design parameters.
6. **Column Start up:** Once the above steps were completed, pilot influent flow was initiated, introducing flow to each column in the pilot. Detailed start up procedure (including backwash instructions) for GAC, IX and alternative adsorbents can be found in the pilot test plan (OCWD, 2020).

6. PILOT OPERATION

6.1 Pilot Monitoring and Maintenance

The OCWD staff operator (Field Research Laboratory, R&D Department) ensured the continuous and normal operation of the pilot system. The pilot system was monitored daily for the first two weeks of operation. Subsequently, the frequency of operational monitoring visits was reduced to 2-3 times per week.

The operator recorded the data for the following parameters for each column (i.e., each piloted media) on a twice weekly frequency:

- Flow meters (Figure 8a) located on pilot columns influent (GAC) or effluent (IX/ alternative adsorbents) streams
- Pressures gauges (Figure 8b)

Flow rates were adjusted on individual columns as necessary to maintain design flow rates. Cartridges filters were also replaced as necessary (shown in Figure 9) when the differential pressure reached 10 psi ($\Delta P \geq 10$ psi).

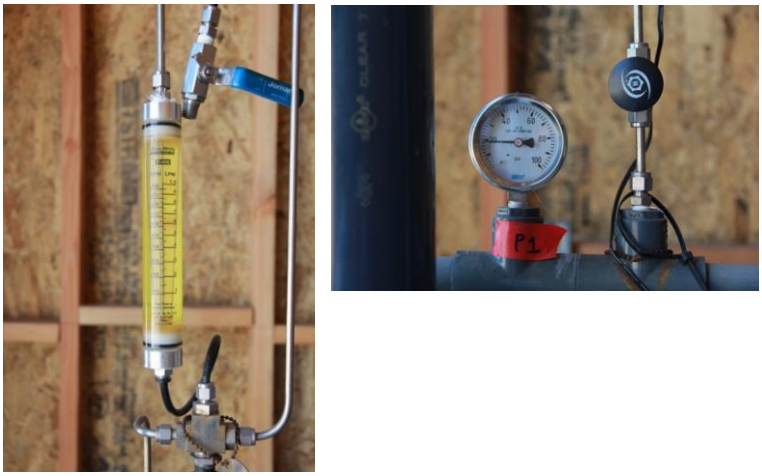

Figure 8. Flow meter of one the GAC columns (left) and pressure meter (vacuum gauge) (right) at the OCWD PFAS Pilot

Figure 9. Influent cartridge filters (left) and cartridge filter replacement (right)

6.2 Pilot Analytical Sampling Schedule

The analytical sampling schedule is shown in Table A-3 (see Attachment). PFAS samples were collected initially every other week and later decreased to every six weeks. QA/QC samples during field sampling included one sample duplicate, one sample spike, and one spike duplicate, during every sampling event. Field reagent blanks (FRBs) were also collected during a subset of the sampling events. OCWD Water Quality Department staff followed standard PFAS sampling protocols to avoid cross-contamination. General water quality parameters were also measured (see Table A-3), but less frequently than PFAS.

Higher initial PFAS sampling frequency allowed for more confident identification of initial breakthrough of PFAS in column effluents (above the detection limit), as well as the rate of change (rate of advance of breakthrough) over time. The breakthrough curve shape is useful for modeling the predicted lead-lag bed full-scale performance, as described in the Jacobs Final Report (Jacobs, 2021).

Beyond PFAS analysis by EPA Method 537.1, limited pilot sampling was also conducted using EPA Method 533 (two sampling events) which can detect 11 additional PFAS compounds (see Table A-5) as well as for *N*-nitrosamines (including *N*-nitrosodimethylamine), volatile organics compounds (VOCs), and 1,4-dioxane (see Table A-3 for all methods).

Total oxidizable precursors (TOP) PFAS assay was also conducted on a limited set of pilot samples as supplementary research (data not included in this report) and overall indicated very low concentrations of PFAS precursors (100 to 600 picomolar per liter[1]) in the influent groundwater and limited or inconsistent removal by the treatment media. Excitation emission matrix spectroscopy (EEMs) was also conducted for research purposes (data not included in this report) and overall indicated that the pilot influent water quality has a higher component of humic acids in the dissolved organic carbon (DOC) relative to Producer well water, which decrease the expected life of media (in particular, GAC) (Dickenson and Higgins, 2016; Dudley, 2012) and therefore makes the pilot results potentially more conservative relative to Producer treatment systems.

7 RESULTS

7.1 Pilot Operations

In general, the individual column flow rates held at ±10% of the flow rates set at the beginning of the testing, with occasional flow rate adjustments needed at approximately two to three-week intervals. The flow rates were approximately 0.1625 gpm for GAC columns, 0.2 gpm for IX, and 0.0875 gpm and 0.1125 gpm for alternative adsorbents (Cyclopure DEXSORB+® and CETCO FLUORO-SORB® 200, respectively). The

[1] Converted to equivalent mass of PFOA for reference, 100 to 600 picomolar PFOA per liter (pM/L) is equivalent to 40 to 250 ng/L PFOA. For the total organic precursor assay, the unknown precursors are oxidized to a mixture of various short- and long-chain PFAS which are then reported as a sum in pM/L.

cumulative volume of water treated by the pilot columns is shown in Figure 10. The cumulative volume of water treated varies slightly between columns but products remained within ±10% of one another within each grouping (e.g., GAC or IX), and was consistent throughout pilot operation, supporting consistent EBCTs maintained during testing.

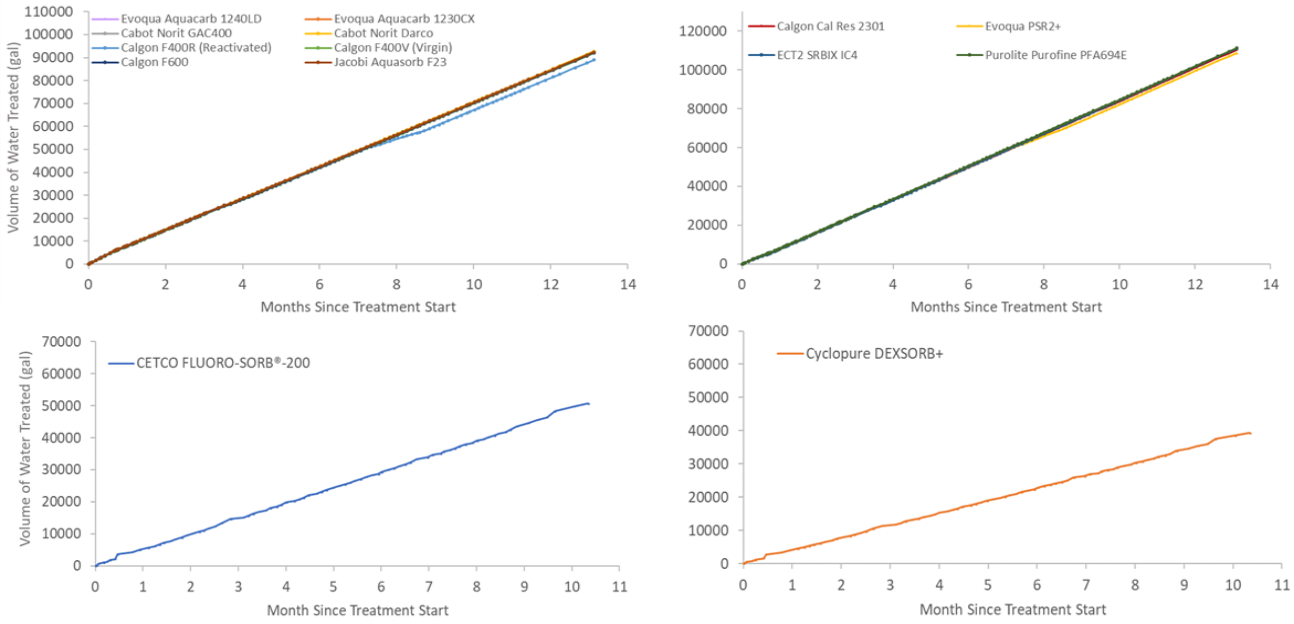

Figure 10: Volume of water treated (gal) with time in the GAC (top left), IX (top right), CETCO FLUORO-SORB 200 (bottom left), and Cyclopure DEXSORB+ (bottom right) pilot treatment columns through January 2021.

During the 12-month pilot operation described in this report, the influent cartridge filters were replaced approximately every 4 weeks when the difference between the inlet and the outlet pressure gauges reached 10 psi (ΔP≥10 psi). The secondary cartridge filters (located sequentially after the influent cartridge filter) on GAC and IX skids were replaced twice during the 12-month period when the flow rate could not be adjusted to the original operational flow rate.

There was a color change nearly immediately after operations began for the IX resins (see Figure 7) which became a darker shade of brown and black over time. The change in color is typically due to surface fouling from non-targeted inorganics (Fe and Mn) and/or background DOC. For GAC, as expected, there was no color change. Like IX, the alternative adsorbents also changed color with time: FLUORO-SORB® 200 changed color from light grey to darker grey and DEXSORB+® changed from light yellow to dark brown.

Although only one pump was needed to supply the Bessie well water to the pilot to achieve the pre-cartridge filtration-required pressure (~29 psi) and flow rate (4 gpm), prior to commissioning two pumps were installed so that the second could serve as a backup in case of pump failures. After about nine months of pilot operation, the first pump could not provide the required pressure to the skid system. The pilot operation was thus switched to the secondary pump. There were no other operational issues during the pilot operation.

Pilot operation by OCWD has continued after the date of this report at a reduced PFAS sampling frequency to further define the breakthrough curves (i.e., to reach PFAS effluent

concentrations representing near exhaustion of media capacity). However, observation of initial PFOA breakthrough (above detection limit) and partial PFOA exhaustion (i.e., 30 to >90% exhaustion depending on the media) has occurred, which is sufficient to inform media selection and to provide breakthrough curves used for lead-lag performance modeling of the full-scale system.

7.2 Pilot Water Quality

Table A-1 (see attachment) summarizes general water quality parameters for Bessie well (pilot influent) from the pilot testing period. As summarized in Section 2 (Pilot Site Description and Water Quality), Table 1 summarizes the PFAS occurrence and concentrations for the Bessie well based on samples collected during the pilot testing period. Of the 18 different PFAS compounds measurable by EPA Method 537.1 with a detection limit of 2 ng/L for all compounds, only seven are consistently detected in Bessie well groundwater, two of which are short-chain PFAS (PFBS and PFHxA).

Of the EPA Method 533 analytes not also included in Method 537.1 (11 additional PFAS compounds), only perfluorobutanoic acid (PFBA), perfluoropentanoic acid (PFPeA), and perfluoropentanesulfonic acid (PFPeS) were detected in Bessie well (see Table A-8 in the attachment) based on two sampling events conducted (6/22/2020 and 8/3/2020). These are all short-chain PFAS. *N*-nitrosamines and VOCs were not detected. Using EPA Method 522, 1,4-dioxane was detected at a mean concentration of 0.17 μg/L (see Table A-9).

Table A-4 (see Attachment) compares water quality of the OCWD PFAS pilot influent (Bessie well) with Groundwater Producer wells that were selected for RSSCT (see Jacobs Final Report, 2021) of GAC and alternative adsorbents. Based on the similarity of PFAS occurrence and general water quality, Bessie well was considered sufficiently representative of the Producer well water qualities and therefore suitable for the pilot (influent water supply).

7.3 PFAS Removal

Figure 11 presents all media (GAC, IX, and alternative adsorbents) breakthrough curves showing PFAS concentration in effluent versus time or bed volumes, measured to date for the OCWD pilot (i.e., approximately 13 months for GAC and IX, and 11 months for alternative adsorbents). Non-detect (ND) measurements are plotted at zero. Breakthrough curves are used to evaluate IX, GAC, or alternative adsorbent performance. Instead of time, the data can also be plotted in terms of bed volumes (shown on secondary x-axis in Figure 11) or cumulative volume treated (not shown). Once PFAS is detected in the effluent samples, this indicates initial PFAS compound breakthrough above the analytical detection limit. Chain length dependent breakthrough is typically observed for GAC and IX with short-chain compounds breaking through before long-chain (e.g., Liu et al., 2019) as was observed for the OCWD pilot. After this initial breakthrough, the effluent PFAS concentration from the columns typically continues to increase until (at the point of product exhaustion) the effluent concentration matches the influent concentration (no PFAS compound removal). A full-scale system is not typically operated to the point of exhaustion,

but it is useful during piloting to operate longer to characterize a more complete breakthrough curve, such as for comparing media performance. Additionally, once significant breakthrough is reached for one PFAS (e.g., PFOA), it may not yet be reached for other PFAS (e.g., later breakthrough of PFOS) requiring longer pilot operation.

Long-chain PFAS detected in Bessie water were PFOA, PFOS and PFHxS. PFOA has the lower NL/RL relative to PFOS and was shown to be less adsorbable than PFOS, thus dictating the changeout frequency and operational economics for treatment of Orange County groundwater. The average PFOA influent concentration in the Bessie well water was approximately 16 ng/L (dashed line in Figure 11).

As initially expected, complete removal of PFOA (i.e., non-detect column effluent) was observed initially for all adsorbent media, per Figure 11. Additional PFAS from EPA Method 537.1 beyond PFOA, PFOS, PFHxS, and PFBS are not shown in Figure 11 as they were not detected or were detected too close to the detection limit (2 ng/L) to develop a breakthrough curve.

As an alternative visual representation of the same data, Figure 12 shows stacked bar charts for all detected PFAS using EPA Method 537.1 as an indication of “total measured PFAS” concentration in treated water, indicating the overall removal of total PFAS by the various media for those (limited) PFAS detected in the source water. Figure 12 shows that after several months of treatment, IX and alternative adsorbents remove more “total measured PFAS” than GAC (where total measured PFAS is the sum of PFOA, PFOS, PFHxS, PFBS, and PFHxA).

For all media, Table 3 summarizes the observed pilot time to reach initial breakthrough as well as time to reach 60% exhaustion with respect to PFOA removal. These times are equivalent to predicted full-scale treatment system time/performance for a lead bed. Time to initial breakthrough (PFAS beginning to appear above the detection limit) is of interest but not necessarily the most relevant for assessing media performance compared to time to more significant breakthrough, here defined as 60% exhaustion to represent significant but not complete exhaustion. For the OCWD pilot given an average influent concentration of approximately 16 ng/L PFOA, 60% exhaustion corresponds to an effluent concentration of 9.6 ng/L (which is also approximately the RL of 10 ng/L). Table 3 indicates that the longest-lasting adsorbent(s) in each media category (GAC, IX, or alternative adsorbents) outperformed the next tier of products in their category significantly by at least four to five months with respect to the 60% breakthrough criterion.

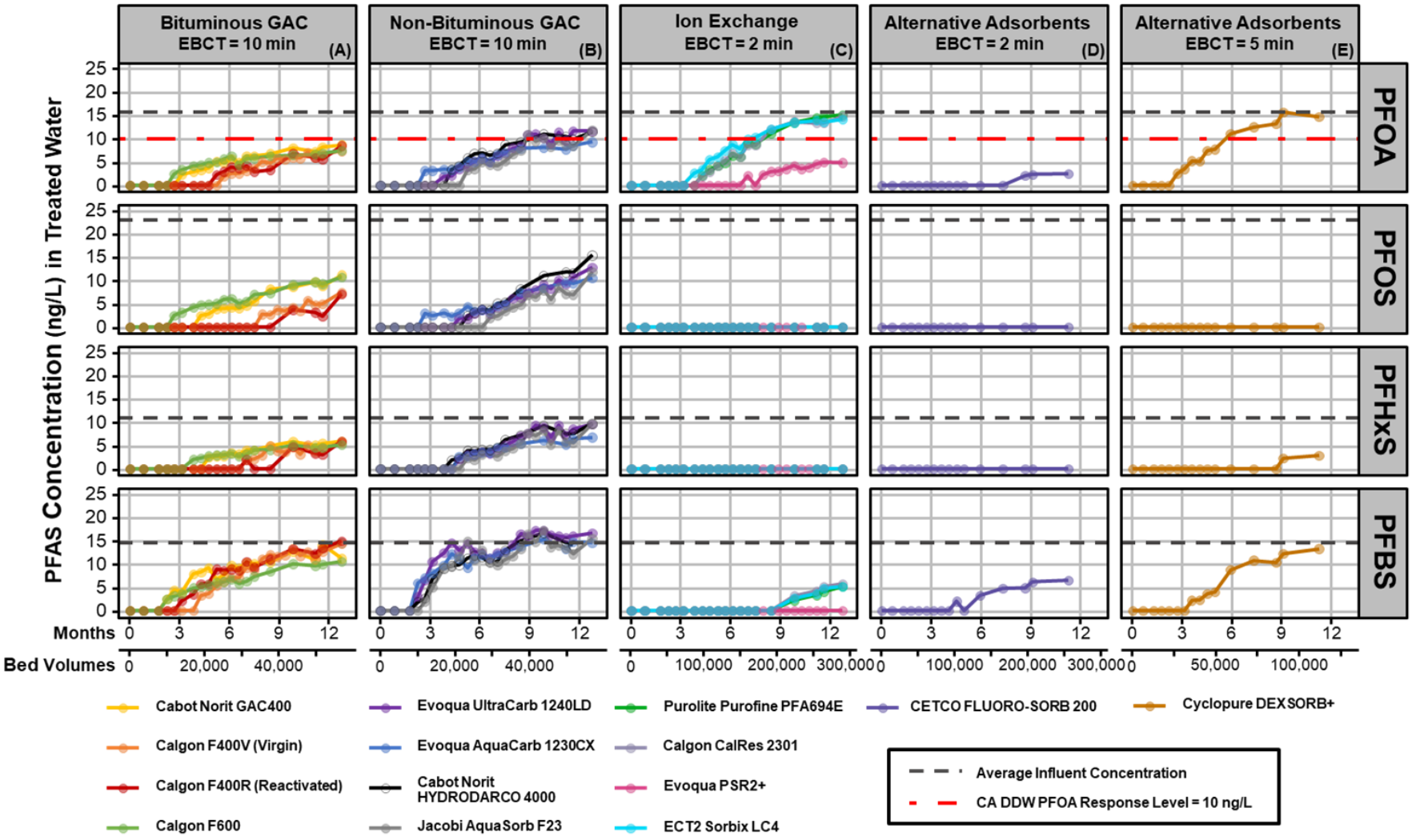

Figure 11: Breakthrough of PFOA, PFOS, PFHxS (long-chain) and PFBS (short-chain) in GAC (columns A and B), IX (column C) and alternative (novel) adsorbent (columns D and E) treated water over time and bed volumes for the OCWD PFAS pilot. For GAC, 10,000 bed volumes correspond to 16,400 gal of water treated by the pilot; for IX, 3,800 gal of water; for CETCO FLUORO-SORB® 200, 2200 gal; for Cyclopure DEXSORB+®, 4200 gal. PFHxA not plotted due to its low concentration in influent near the detection limit.

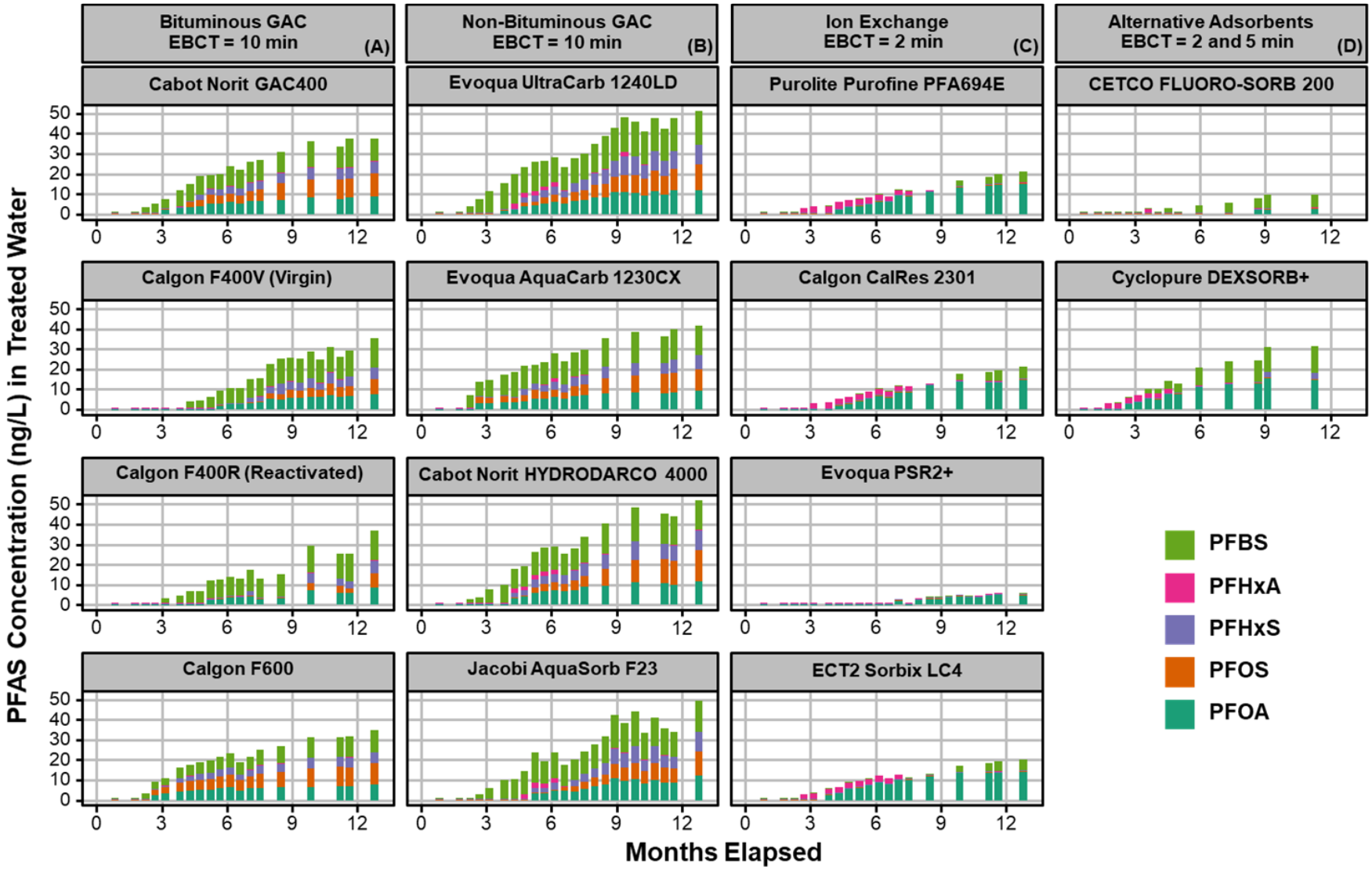

Figure 12: Same information as Figure 11 but presented as total measured (detected) PFAS via EPA Method 537.1 in a stacked bar chart showing breakthrough of PFOA, PFOS, PFHxS (long-chain); and PFHxA and PFBS (short-chain) in GAC, IX and alternative (novel) adsorbent-treated water over time. Other measured PFAS were not detected or inconsistently detected near the detection limit.

Table 3. OCWD pilot summary of treatment months for effluent PFOA concentration to reach initial breakthrough and later reach approximately 60% of influent concentration (60% exhaustion)

Adsorbent Media	Time (Months) to Reach PFOA Breakthrough	
	Initial Breakthrough Above Detection Limit	**Effluent Concentration at ~60% of Influent Concentration[(a)]**
Granular Activated Carbon		
Calgon F400 (Virgin and Reactivated)	5.7 (V), 5.2 (R)	> 13
Calgon F600	2.7	> 13
Cabot Norit GAC 400	3.1	> 13
Evoqua AquaCarb 1230CX	2.7	12.8
Cabot Norit HYDRODARCO 4000	4.3	9.0
Jacobi AquaSorb F23	5.2	8.9
Evoqua UltraCarb 1240LD	3.8	8.7
Ion Exchange (IX) Resins		
Evoqua PSR2+	7.1	> 13
Calgon CalRes 2301	4.3	7.9
Purolite Purofine PFA694E	4.3	7.9
ECT2 Sorbix LC4	3.9	7.1
Alternative (Novel) Adsorbents		
CETCO FLUORO-SORB® 200	8.7	> 11
Cyclopure DEXSORB+®	2.7	5.6

Notes: (a) For the OCWD pilot given an average influent concentration of approximately 16 ng/L PFOA, 60% exhaustion corresponds to an effluent concentration of 9.6 ng/L.

“>” greater than symbol denotes effluent concentration has not yet reached 60% of the influent concentration. More pilot time is needed (ongoing at time of this report) to determine the months required to reach 60% exhaustion.

7.3.1 PFAS Removal by GAC

Figures 11a and 11b present GAC breakthrough curves for the OCWD pilot testing period to date where each GAC product was piloted at an EBCT of 10 min. Table 3 summarizes this same information in terms of time to initial breakthrough and time to more significant breakthrough (at 60% exhaustion) for PFOA. Breakthrough of 60% is a useful reference point representing significant, but not complete, exhaustion, which in the case of this pilot influent corresponded to an effluent concentration of 9.6 ng/L PFOA.

As expected, complete removal of PFOA (i.e., non-detect column effluent) was observed initially for all GAC media. Out of the eight GAC products tested, three products

demonstrated an earlier breakthrough of PFOA reaching 60% exhaustion (~10 ng/L) at approximately nine months (Evoqua UltraCarb 1240LD, Cabot Norit HYDRODARCO 4000, Jacobi AquaSorb F23) (Figure 11a). Two of these three GACs also demonstrated earlier initial breakthrough, while Jacobi AquaSorb F23 exhibited later initial breakthrough. The other five GAC products' effluents remained below 60% exhaustion after approximately 13 months of pilot operation at the time of this report (Figure 11a) except for Evoqua AquaCarb 1230CX which just reached this threshold at 13 months. Overall, virgin and reactivated Calgon F400 showed the strongest performance exhibiting later initial PFOA breakthrough and the lowest sustained PFOA effluent concentration throughout most of the approximately 13 months of pilot operation (at the time of this report); two other bituminous GACs (Calgon F600, Cabot Norit GAC400) showed similar long-term performance despite earlier initial breakthrough. All three bituminous GACs showed similar effluent concentrations at approximately 13 months of pilot operation. The non-bituminous and sub-bituminous GACs tended to perform slightly less well for PFOA. For Calgon F400, both a reactivated and virgin form were tested and showed little difference (all other GAC/IX/alternative media tested in the pilot were virgin media).

Additional pilot time is needed to determine which bituminous GAC product reaches 60% breakthrough first for PFOA. The rate of advance (slope) of the breakthrough curves is relevant to lead-lag GAC modeling to determine predicted full-scale media life. It must be noted that in the case of GAC and alternative adsorbents, RSSCT data (Jacobs Final Report, 2021) is available from the overall study to provide additional insight on the impact of site-specific water quality and can be coupled with pilot results to identify strongest performing products. RSSCT was completed for site-specific (representative) Producer wells. It was found that character of the background DOC varied somewhat across the Producer wells (versus pilot). Industry understanding and findings from this study indicate DOC can have a significant influence on GAC life for organic contaminant removal (Dickenson and Higgins, 2016; Dudley, 2012). This contrasts with IX, where DOC is a factor but is likely less significant (Dixit et al., 2019; Franke et al., 2019). In the RSSCT testing (Jacobs Final Report, 2021) and consistent with the pilot, Calgon F400 was identified as consistently one of the longest lasting GAC media for Producers, along with Evoqua UltraCarb 1240LD. Evoqua UltraCarb 1240LD did not perform as strongly in the pilot perhaps suggesting potential greater sensitivity of this media to the DOC composition and characteristics of the pilot influent.

With respect to PFOS, the average PFOS concentration in the Bessie well influent was approximately 23 ng/L. Two GAC products broke through above the PFOS analytical detection limit at approximately three months of operation and three more products broke through between four and six months. The product with strongest performance (longest life) for PFOA (Calgon F400) also exhibited the longest life relative to other products for PFOS, with a significantly delayed relative PFOS initial breakthrough at approximately eight months (Figure 11a, 11b). The next longest-lasting GAC product for PFOS removal was Jacobi AquaSorb F23 (based on initial breakthrough time). For the other long-chain PFAS, PFHxS, initial breakthrough was seen in all the eight GAC treatment columns between four and seven months (Figure 11a, 11b). Overall, the bituminous GACs exhibit lower effluent PFOS concentrations after 13 months of piloting compared to the non-

bituminous and sub-bituminous GACs (i.e., longer life before reaching more significant PFOS breakthrough).

For short chain-compounds, Bessie well water had detectable concentrations of only two short-chain PFAS via Method 537.1: PFBS and PFHxA[2]. The average influent concentrations were approximately 15 ng/L for PFBS and approximately 3 ng/L for PFHxA (which is near the PFHxA analytical detection limit). PFBS breakthrough above the detection limit was observed in all eight GAC treatment columns between two and four months, which is much sooner than IX (which showed PFBS breakthrough after eight months for some media). The PFHxA concentrations in GAC treated effluent ranged from below the detection limit for some products to slightly above 2 ng/L (data not shown), with breakthrough more difficult to discern due to the consistently low influent concentration.

In summary, the strongest performing (longest lasting) media for PFOA (Calgon F400) also performed well for PFOS relative to the other GACs. Other bituminous GAC products performed well in terms of product life for PFOA removal (i.e., similar effluent concentration after 13 months for Calgon F400, Calgon F600, and Cabot Norit GAC400). The GAC pilot results, together with RSSCT results (Jacobs Final Report, 2021) can be used to rank relative GAC media performance.

7.3.2 *PFAS Removal by IX Resins*

As expected, complete removal of PFOA (i.e., non-detect column effluent) was observed initially for all four IX media tested (EBCT = 2 min). Evoqua PSR2+ showed no initial breakthrough of PFOA until eight months (Figure 11), much later than the other three IX products. Thus, Evoqua's PSR2+ is the longest life IX media for PFOA for the pilot site water quality considered representative of local groundwater. At the time of this report, Evoqua PSR2+ in pilot has reached only approximately 30% PFOA exhaustion after 13 months compared to 90% exhaustion for the other IX media. The other three IX products exhibited a similar PFOA breakthrough performance with respect to the initial breakthrough time and curve shape, as well as time that the IX treated effluent reached approximately 60% of the influent concentration, where ECT2 Sorbix LC4 resin exhibited breakthrough slightly earlier than the other two resins Purolite Purofine PFA694E and Calgon CalRes 2301.

For reference, full-scale system IX media life (media change-out time) is estimated to correspond to approximately 66 to >90% exhaustion based on lead-lag modeling (depending on the IX product and using pilot data) which takes into account the full-scale lead-lag configuration (Jacobs Final Report, 2021). Thus, piloting (which represents the lead bed) until full 100% exhaustion is reached is not necessary.

With respect to PFOS, as noted previously the average PFOS concentration in the Bessie well influent was approximately 23 ng/L. There was no breakthrough of PFOS in any of the IX products at the time of this report after 13 months of pilot operation (Figure 11c), which

[2] EPA Method 533 also identified PFBA, PFPeA, and PFPeS in the pilot influent. However, influent and effluent for the pilot was only sampled using Method 533 in two sampling events, thus detailed breakthrough curves were not developed. Results for effluent for these compounds are discussed in Section 7.3.4.

is consistent with the industry observation that IX media tend to better remove per/polyfluorinated sulfonates over carboxylic acids (e.g., PFOS breaks through later than PFOA) which is attributed to the lower charge density of PFOS (Dixit et al., 2019). Similarly, no breakthrough of PFHxS was observed thus far for any of the IX products (Figure 11c).

For short chain-compounds, as noted previously the pilot influent (Bessie well water) had detectable concentrations of PFBS (15 ng/L) and PFHxA (approximately 3 ng/L near the PFHxA analytical detection limit) via EPA Method 537.1. PFHxA data is not included in Figure 11 due to low influent concentration and variability. Breakthrough of PFBS above the detection limit was seen in three of the four IX products after approximately eight months (Figure 11c); at the time of this report at approximately 13 months of pilot data, there is yet no PFBS detection for the Evoqua's PSR2+ product. For PFHxA, effluent concentrations were still consistently ND for Evoqua PSR2+ at the time of this report; for the other 3 IX media, the PFHxA concentrations were variable ranging from ND to approximately 3 ng/L making it difficult to infer whether breakthrough occurred but this is likely.

In summary, Evoqua's PSR2+ demonstrated the longest IX media life for PFOA and short-chain compounds for the OCWD pilot, with no breakthrough for PFOS yet at the time of this report (13 months) for any IX media. This indicates that compared to other tested IX products, PSR2+ media is expected to show the longest media life for the target PFAS (PFOA) for treatment of representative groundwater. Based on the pilot, the other three IX resins tested show a similar performance to one another with ECT2 Sorbix LC4 exhibiting slightly earlier PFOA breakthrough.

7.3.3 PFAS Removal by Alternative Adsorbents

Piloting began for two alternative (novel) adsorbents approximately two and a half months after the GAC and IX products, hence the data presented in this report are for a runtime of approximately 11 months to date. Breakthrough curves for alternative adsorbents are shown in Figure 11d and 11e. The two alternative media products featured different EBCTs and thus had different bed volumes passed through the columns per unit time.

Cyclopure DEXSORB+® (5 min EBCT) exhibited initial PFOA breakthrough (above the detection limit) after approximately two months of treatment and reached the reference point of 60% exhaustion (or RL of 10 ng/L PFOA) after approximately five months of treatment, making it the most rapid PFOA breakthrough of any media (GAC, IX, or alternative adsorbent) tested in this study (i.e., least well-performing in terms of frequency of anticipated media change-out for given EBCT) however noting that the GAC medias featured a longer EBCT (10 min) (i.e., later DEXSORB+® breakthrough would be expected for a 10 min EBCT for direct comparison to GAC).

In contrast, the other alternative adsorbent CETCO FLUORO-SORB® 200 (2 min EBCT) featured initial PFOA breakthrough much later at eight months. Thus far this media has exhibited the longest life of any media tested in this pilot study in terms of time to initial breakthrough; however, more pilot time is needed to confirm whether it is also the longest life with respect to time to more significant breakthough (e.g., 60%) in case the PFOA

breakthrough based on the slope of the breakthrough curve which thus far appears quite gradual (as of 11 months piloting, per Figure 11d). Thus, in this pilot the two alternative adsorbents showed the earliest, and the latest, breakthrough of PFOA compared to all media tested (GAC, IX, and alternative adsorbents).

Neither alternative adsorbent has exhibited breakthrough of long-chain PFOS as of 11 months of piloting. CETCO FLUORO-SORB® 200 also to date has no breakthrough for long-chain PFHxS, while Cyclopure DEXSORB+® exhibited initial PFHxS breakthough at 9 months (Figure 11d and 11e).

For the short chain-compounds (PFBS, PFHxA) detected by EPA Method 537.1, initial PFBS breakthrough was observed for both alternative adsorbent products at approximately four months. Cyclopure DEXSORB+® (5 min EBCT) reached near-exhaustion for PFBS at approximately 11 months, while CETCO FLUORO-SORB® 200 (2 min EBCT) is at approximately 40% PFBS exhaustion by this same time. For PFHxA (Figure 11d and 11e), the concentrations in the treated effluent were variable due to the near-detection limit concentrations in the influent, ranging from ND to 3 ng/L and making the PFHxA time to breakthrough less discernable.

7.3.4 Removal of Other Constituents by Pilot Treatment

As noted in Section 7.2 (Pilot Water Quality), of the EPA Method 533 analytes not also included in Method 537.1, only the short-chain compounds PFBA, PFPeA, and PFPeS were detected in the influent to the pilot (see Table A-8 in the attachment) based on two sampling events conducted (6/22/2020 and 8/3/2020). PFBA and PFPeA were detected in all media effluents at the first sampling date with no removal indicating that 100% breakthrough was reached by as late as six months (for GAC and IX adsorbents) or four months (for alternative adsorbents which began piloting later). PFPeS was non-detect in all effluents both dates indicating no breakthrough yet by these times. These results are consistent with the expectation (and pilot observation for other PFAS) that per/polyfluorinated sulfonates show breakthrough later than the carboxylic acids.

N-nitrosamines and VOCs were not detected in the pilot influent, thus treatment performance cannot be assessed for these organics.

Using EPA Method 522, 1,4-dioxane was detected in the pilot influent at a mean concentration of 0.17 μg/L (see Table A-9). No removal was observed by the pilot media (effluent concentrations similar to influent concentrations).

With respect to the water quality of pilot influent versus effluent for general water quality (non-PFAS parameters), the Attachment presents data for pilot influent and the 14 column effluents (8 GAC, 4 IX, and 2 alternative adsorbents) with additional discussion. The concentrations of most inorganic parameters did not change between influent and effluents indicating that these constituents were not removed by the treatment columns. For TOC, comparison of influent and effluent data reveals that (as expected) TOC was initially removed significantly by GAC (>80%) and to a lesser degree by IX (60-70%), and that this TOC removal lessened over time as the media became exhausted. The alternative

adsorbents removed less than 10% TOC from beginning of pilot operation. The attachment presents additional discussion.

8 CONCLUSIONS

For IX media tested in the OCWD pilot, Evoqua PSR2+ demonstrated the latest PFOA breakthrough (i.e., longest media life), with no breakthrough for PFOS yet at the time of this report for any IX media. For the one short-chain compound from EPA Method 537.1 that occurs at sufficiently high concentrations in the OCWD pilot influent, PFBS, Evoqua PSR2+ also demonstrated the latest breakthrough compared to the other three IX resins. While this report focuses on observed media life, media purchase, handling, and disposal costs must be taken into account along with performance life to identify the best value product for a given treatment system for all media types.

For GAC, virgin and reactivated Calgon F400 showed the strongest performance exhibiting later initial PFOA breakthrough and the lowest sustained PFOA effluent concentration throughout most of the approximately 13 months of pilot operation (at the time of this report); two other bituminous GACs (Calgon F600, Cabot Norit GAC400) showed similar long-term performance despite earlier initial breakthrough. The non-bituminous and sub-bituminous GACs tended to perform slightly less well for PFOA. This information together with RSSCT findings reported separately can be considered to identify the strongest performing GAC media for Orange County groundwater.

With respect to alternative (novel) adsorbents, Cyclopure DEXSORB+® at 5 min EBCT exhibited the earliest initial PFOA breakthrough, while CETCO FLUORO-SORB® 200 at 2 min EBCT exhibited the latest initial PFOA breakthrough, compared to all media tested (including GAC and IX). Pending additional longer-term pilot results for confirmation, CETCO FLUORO-SORB® 200 may be the longest-lasting media in this study for PFOA removal despite its relatively low EBCT at 2 min.

For PFOS, overall the breakthrough was significantly later than PFOA for all IX and alternative adsorbents that to date still show no PFOS breakthrough after 13 months (for IX) and 11 months (for alternative adsorbents). PFOS breakthrough was also later than PFOA for GAC, but less delayed compared to the other media. With respect to short-chain PFAS, PFBS removal was sustained for the longest by IX, followed by alternative adsorbents, and then GAC with the shortest time to breakthrough. As such, all four IX products tested outperformed all eight GAC products with respect to PFBS breakthrough.

Overall, the pilot testing demonstrated that all adsorbents evaluated can successfully remove PFAS to meet California drinking water advisories. Testing local groundwater from the Orange County Groundwater Basin has helped support individual Producer treatment system design which takes into account not only media performance and Producer preference, but also site-specific considerations at the Production well locations and budget. Pilot- and laboratory-scale testing of a range of adsorbents proved useful for identifying suitable media to support Producer media selection, since within each media category (GAC, IX, and alternative adsorbents), certain products emerged as superior. Individual product performance within each media category varied sometimes dramatically,

which can translate into significant annual O&M savings due to reduced frequency of media replacements. Of note was the encouraging result for the alternative (novel) adsorbent CETCO FLUORO-SORB® 200 exhibiting the latest initial breakthrough of all 14 media tested, especially given its expected small footprint (akin to IX).

Based on these results, OCWD is initiating a Phase II PFAS Pilot-Scale Treatment Study to 1) continue to identify promising adsorbents for Producer wellhead treatment systems to remove PFAS from drinking water, and 2) serve as an ongoing research program that supports the water industry more broadly. New adsorbents are being introduced into the market for PFAS and could potentially be compatible with the dual vessels (which can accommodate both GAC and IX media) procured for Producer treatment sites. Thus, while media piloted in Phase I will be utilized near-term, other adsorbents could be considered for future media procurements if they are more cost-effective and/or exhibit superior performance.

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ATTACHMENT

to

PFAS Phase I Pilot-Scale Treatment Study
OCWD Final Report

Table A-1. Water quality summary of Bessie well water (pilot influent) measured during the pilot testing period (data range December 2019 to September 2020, n=6 except where noted)

Parameter Name	Abbrev.	Unit	Min	Max	Average	SD
Aluminum	Al	ug/L	<1	1.1	<1	
Aluminum (dissolved)	Al-DIS	ug/L	<1	<1	<1	
Antimony	Sb	ug/L	<1	<1	<1	
Antimony (dissolved)	Sb-DIS	ug/L	<1	<1	<1	
Arsenic	As	ug/L	5.8	6.6	6.2	0.4
Arsenic (dissolved)	As-DIS	ug/L	5.7	6.5	6.2	0.3
Barium	Ba	ug/L	61.0	78.0	70.2	5.8
Barium (dissolved)	Ba-DIS	ug/L	60.4	76.3	69.8	6.1
Beryllium	Be	ug/L	<1	<1	<1	
Beryllium (dissolved)	Be-DIS	ug/L	<1	<1	<1	
Bicarbonate (as HCO_3) [(a)]	HCO3	mg/L	234	245	237	4.7
Boron	B	mg/L	0.3	0.3	0.3	0.01
Boron (dissolved)	B-DIS	mg/L	0.3	0.3	0.3	0.00
Cadmium	Cd	ug/L	<1	<1	<1	
Cadmium (dissolved)	Cd-DIS	ug/L	<1	<1	<1	
Calcium	Ca	mg/L	77.4	85.7	82.2	3.74
Chloride	Cl	mg/L	116	141	130	9.15
Chromium	Cr	ug/L	<1	<1	<1	
Chromium (dissolved)	Cr-DIS	ug/L	<1	<1	<1	
Cobalt	Co	ug/L	<1	1.1	<1	
Cobalt (dissolved)	Co-DIS	ug/L	<1	1.4	<1	
Copper	Cu	ug/L	2.6	3.4	2.95	0.35
Copper (dissolved)	Cu-DIS	ug/L	2.7	3.1	2.93	0.19
Dissolved Organic Carbon[(b)]	DOC	mg/L	1.3	1.4	1.3	0.04
Iron	Fe	ug/L	5.0	12.1	8.83	2.95
Iron (dissolved)	Fe-DIS	ug/L	0.5	10.6	4.32	4.42
Lead	Pb	ug/L	<1	<1	<1	
Lead (dissolved)	Pb-DIS	ug/L	<1	<1	<1	
Magnesium	Mg	mg/L	20.5	22.9	21.7	1.03
Manganese	Mn	ug/L	207	263	236	21.6
Manganese (dissolved)	Mn-DIS	ug/L	189	257	232	29.9
Mercury	Hg	ug/L	<1	<1	<1	
Mercury (dissolved)	Hg-DIS	ug/L	<1	<1	<1	
Nickel	Ni	ug/L	2.9	3.8	3.4	0.3
Nickel (dissolved)	Ni-DIS	ug/L	2.9	3.9	3.3	0.3
Nitrate Nitrogen	NO3-N	mg/L	0.2	0.5	0.3	0.1
pH [(a)]			7.6	7.7	7.66	0.06
Phosphate Phosphorus(orthophosphate) [(a)]	PO4-P	mg/L	0.4	0.5	0.4	0.03
Selenium	Se	ug/L	<1	<1	<1	

Parameter Name	Abbrev.	Unit	Min	Max	Average	SD
Selenium (dissolved)	Se-DIS	ug/L	<1	<1	<1	
Silver	Ag	ug/L	<1	<1	<1	
Silver (dissolved)	Ag-DIS	ug/L	<1	<1	<1	
Sulfate [(a)]	SO4	mg/L	123	146	131	9.1
Total Alkalinity (as $CaCO_3$) [(a)]	TOTALK	mg/L	192	201	195	3.8
Total Dissolved Solids [(a)]	TDS	mg/L	604	642	624	18.3
Total Organic Carbon (Unfiltered) [(c)]	TOC	mg/L	1.2	1.3	1.3	0.03
Thallium	Tl	ug/L	<1	<1	<1	
Thallium (dissolved)	Tl-DIS	ug/L	<1	<1	<1	
Vanadium	V	ug/L	6.0	7.3	6.7	0.6
Vanadium (dissolved)	V-DIS	ug/L	6.2	7.9	6.9	0.6
Zinc	Zn	ug/L	<1	1.5	1.1	0.5
Zinc (dissolved)	Zn-DIS	ug/L	<1	2.1	1.5	0.7
Ultraviolet (absorbance)	UVAB	1/cm	0.03	0.032	0.031	0.00

Notes: [(a)] data range December 2019 to August 2020 (n= 5)
[(b)] data range June 2020 to September 2020 (n= 8)
[(c)] data range December 2019 to July 2020 (n= 7)

Table A-2a. Hydraulic/operational parameters for GAC columns

Granular Activated Carbon (GAC)					
Parameter	**Value**	**Unit**		**Value**	**Unit**
Diameter	3.04	in	=	0.25	ft
Area	7.27	in^2	=	0.05	ft^2
Bed Depth	52	in	=	4.33	ft
Bed Volume	377.93	in^3	=	0.219	ft^3
Flowrate	0.1625	gpm	=	0.022	ft^3/ min
Hyd. Load. rate (v)	0.43	ft/min	=	3.25	gpm/ft^2
EBCT	**10.07**	**min**			

Table A-2b. Hydraulic/operational parameters for IX columns

Ion (Anion) Exchange Resins (IX)					
Parameter	**Value**	**Unit**		**Value**	**Unit**
Diameter	2.05	in	=	0.17	ft
Area	3.29	in^2	=	0.02	ft^2
Bed Depth	29	in	=	2.417	ft
Bed Volume	95.44	in^3	=	0.055	ft^3
Flowrate	0.20	gpm	=	0.027	ft^3/ min
Hyd. Load. rate (v)	1.17	ft/min	=	10	gpm/ft^2
EBCT	**2.07**	**min**			

Table A-2c. Hydraulic/operational parameters for CETCO FLUORO-SORB® 200 column

CETCO FLUORO-SORB® 200					
Parameter	**Value**	**Unit**		**Value**	**Unit**
Diameter	2.05	in	=	0.17	ft
Area	3.29	in^2	=	0.02	ft^2
Bed Depth	16.0	in	=	1.33	ft
Bed Volume	52.66	in^3	=	0.030	ft^3
Flowrate	0.1125	gpm	=	0.015	ft^3/ min
Hyd. Load. rate (v)	0.658	ft/min	=	5.63	gpm/ft^2
EBCT	**2.03**	**min**			

Table A-2d. Hydraulic/operational parameters for Cyclopure DEXSORB+®

Cyclopure DEXSORB+®					
Parameter	**Value**	**Unit**		**Value**	**Unit**
Diameter	2.05	in	=	0.17	ft
Area	3.29	in^2	=	0.02	ft^2
Bed Depth	31	in	=	2.58	ft
Bed Volume	102.02	in^3	=	0.059	ft^3
Flowrate	0.0875	gpm	=	0.012	ft^3/ min
Hyd. Load. rate (v)	0.512	ft/min	=	4.38	gpm/ft^2
EBCT	**5.05**	**min**			

Table A-3. Pilot testing analytical sampling parameters and frequency

Target	Method	Lab	Pilot sample location	No. of samples per event[a]	Sampling frequency
PFAS	EPA Method 537.1[b]	OCWD Main Lab	Pre-filter and Post-filter Influent; Effluent (GAC, IX, and alternative)	16	Biweekly (initially)
PFAS	EPA Method 533[b]	Eurofins	Pre-filter and Post-filter Influent; Effluent (GAC, IX, and alternative)	16	Limited (2 sample events)
Total Oxidizable Precursor (TOP)	Method in accordance with Houtz and Sedlak 2012	Battelle	Post-filter Influent, Effluent	4	Limited (5 sample events)
Dissolved organic carbon (DOC)	Standard Method 5310C (Gen Lvl II[c])	OCWD Main Lab	Post-filter Influent[d], Effluent	15	Bimonthly
Total organic carbon (TOC)	Standard Method 5310C (Gen Lvl II[c])	OCWD Main Lab	Post-filter Influent[d], Effluent	15	Bimonthly
Alkalinity	EPA Method 2320 (Gen Lvl II[c])	OCWD Main Lab	Post-filter Influent[d], Effluent	15	Bimonthly
Anions (Cl^-, SO_4^{2-} NO_3^-, etc.)	Standard Methods (Gen Lvl II[c])	OCWD Main Lab	Post-filter Influent[d], Effluent	15	Bimonthly
Inorganics/Metals	Standard Methods (Gen Lvl II[c])	OCWD Main Lab	Post-filter Influent[d], Effluent	15	Bimonthly
UV254		OCWD Main Lab	Post-filter Influent[d], Effluent	15	Bimonthly
Excitation emission matrix spectro-scopy (EEMS)	R&D Lab Method[e]	R&D Lab (OCWD)	Post-filter Influent[d], Effluent	15	Bimonthly
Nitrosamines including NDMA	OCWD Lab Method	OCWD Main Lab	Pre-filter and Post-filter Influent[d], Effluent	15	Limited (4 sample events)
1,4-dioxane	OCWD Lab Method & EPA Method 522	OCWD Main Lab & Eurofins	Pre-filter and Post-filter Influent[d], Effluent	15	Limited (3 sample events, each method)
Volatile Organic Compounds	EPA Method 524.2	OCWD Main Lab	Pre-filter and Post-filter Influent[d], Effluent	15	Limited (4 sample events)

(a) Sum of number of sample locations, e.g., with 8 GAC, 4 IX, and 2 alternative adsorbents, there were a total of 14 effluent samples per sampling event if all media were sampled. For TOP, a subset of the effluents (media) were selected to reduce sampling cost.

(b) See Table A-5 for a complete list of PFAS analytes tested under EPA Method 537.1 and EPA Method 533.

(c) For a complete list of chemical analytes tested under OCWD's Gen Lvl II method see Table A3-1 in OCWD (2020) pilot test plan.

(d) For general water quality parameters (TOC, alkalinity, anions, inorganics, metals, UV254) except DOC, both pre- and post-filter influent samples were collected for the first 10 months of pilot operation, after which only post-filter influent was collected.

(e) This is not a standard method. OCWD R&D Laboratory measures EEMS using a Horiba Aqualog instrument.

Water Quality Comparison Between Pilot Influent (Bessie Well) and Groundwater Producer Wells

Table A-4 compares water quality of the OCWD PFAS pilot influent (Bessie well) with Groundwater Producer wells that were selected for RSSCT (see Jacobs Final Report, 2021) of GAC and alternative adsorbents. The water quality data for Bessie well was measured over the piloting period (2019 to 2020) whereas the Producer well quality is historical data over a longer period. In general, the water quality of Producer wells is similar to Bessie well. Total organic carbon (TOC) of Bessie well is greater at 1.3 ± 0.04 mg/L as compared to 0.4 to 0.9 mg/L for all the Producer wells. Dissolved organic carbon (DOC) is also greater for the Bessie well (1.3 mg/L) compared to most Producers (0.4 to 1.4 mg/L). Almost 100% of the TOC was DOC. Differences in levels of DOC has implications in terms of adsorption of PFAS to GAC, and to a lesser degree to IX, as discussed in the Jacobs Final Report (2021).

The concentration of manganese (Mn) was much greater in the Bessie well compared to the Producer wells. The average concentration of Mn was 234 ± 23 µg/L in Bessie well and <5 µg/L in Producer wells. The greater concentration of Mn is not a concern with respect to pilot representativeness for predicting Producer well PFAS treatment performance because Mn (and iron, Fe) are only a concern with respect to potential for precipitation that can cause media fouling/clogging resulting from oxidation (i.e., occurrence is not anticipated to influence PFAS adsorption, but could impact media life if the media requires replacement due to clogging or fouling). Other cations and anions concentrations are not significantly different among the well waters.

Figure A-1 shows the historical data for PFAS levels in Bessie well and the Producer wells. Out of the 18 PFAS measured by EPA Method 537.1 (Table A-5), only seven PFAS were detected in Producer groundwater. The concentration of PFAS in Bessie well was similar to the PFAS in the Producer wells. Only two of the seven PFAS are short-chain PFAS (PFBS and PFHxA).

Based on PFAS occurrence and general water quality, Bessie well is sufficiently representative of the aquifer water quality and therefore suitable for the pilot (influent water supply).

Table A-4. Mean (and standard deviation) water quality of OCWD Bessie well (Pilot well) compared to Groundwater Producer wells selected for RSSCT. OCWD Bessie well data from pilot monitoring December 2019 to September 2020 (per Table A-1), and Groundwater Producer data are for years 2010-2020 unless noted otherwise.

Well Site	TDS (mg/L)	DOC (mg/L)[a]	TOC (mg/L)	Ca (mg/L)	Bicarbonate (as HCO^3) (mg/L)	Cl (mg/L)	Fe (ug/L)	Mg (mg/L)	Mn (ug/L)	NO3-N (mg/L)	PO4-P (mg/L)	SO_4 (mg/L)	UVA (1/cm)
OCWD Pilot Bessie Well	624 (18)	1.3 (0.03)	1.3 (0.04)	82.2 (3.7)	238 (5)	130 (9)	8.8 (2.9)	22 (1)	236 (22)	0.3 (0.1)	0.4 (0.03)	131 (9)	0.03 (0.001)
Anaheim-A-42/1	669 (32)	0.85	0.5 (0.1)	111 (8)	266 (17)	114 (5)	0.8 (0.9)	20 (1)	0.1	2.4 (0.5)	NM	162 (8)	0.01
EOCWD-EOCW-E/1	592 (11)	0.52	0.4 (0.04)	100 (3)	222 (7)	104 (4)	37 (57)	24 (1)	0.9 (1.6)	3.8 (0.3)	NM	128 (7)	NM
Fullerton-F-3A/1	553 (36)	0.51	0.4 (0.05)	98.2 (8.0)	209 (6)	83.3 (4.0)	1.3 (1.2)	17 (2)	0.1	2.5 (0.1)	NM	154 (15)	0.006
Fullerton-F-5/1	531 (89)	1.4	0.3 (0.1)	85.3 (20.7)	257 (202)	79.6 (15.1)	10 (22)	16 (4)	0.5 (0.7)	3.8 (1)	NM	138 (24)	0.007
Garden Grove-GG-21/1	572 (25)	0.21	0.3 (0.02)	108 (3)	235 (6)	88.6 (4.4)	3.3 (6.5)	19 (1)	0.1	3.7 (0.1)	NM	128 (2)	NM
IRWD-OPA1/1	697 (35)	0.47	0.4 (0.1)	124 (7)	259 (10)	109 (5)	14 (24)	34 (2)	0.1	3.2 (0.7)	0.02 (0.004)	179 (6)	NM
Orange-O-8/1	544 (27)	0.25	0.4 (0.04)	108 (2)	220 (7)	91.4 (6.3)	2.6 (2.5)	20 (1)	0.1	3.0 (0.4)	NM	126 (3)	NM
Santa Ana-SA-38/1	354 (45)	0.49	0.3 (0.05)	40.9 (9.9)	179 (7)	46.6 (6.8)	8.1 (8.3)	8.5 (2.2)	1.8 (2.6)	0.7 (0.3)	0.03 (0.006)	69.8 (10.5)	0.02
Serrano Water District-SWD-5/1	674 (55)	0.91	0.5 (0.1)	98.4 (9.1)	265 (12)	115 (8)	4.7 (3.1)	30 (2)	0.1	2.5 (1.3)	NM	161 (11)	0.01 (0.001)
Tustin-T-VNGB/1	410 (11)	0.37	0.2 (0.04)	43.0 (5.0)	168 (4)	63.1 (2.3)	2.3 (2.2)	7.5 (1.2)	0.1	2.8 (0.5)	NM	85.3 (1.7)	0.005

Notes: NM = not measured.

a) DOC values for Groundwater Producers (i.e., all rows except Bessie well) were provided by Jacobs as measured by Battelle as a one-time grab sample from the bulk water received by Battelle before RSSCT.

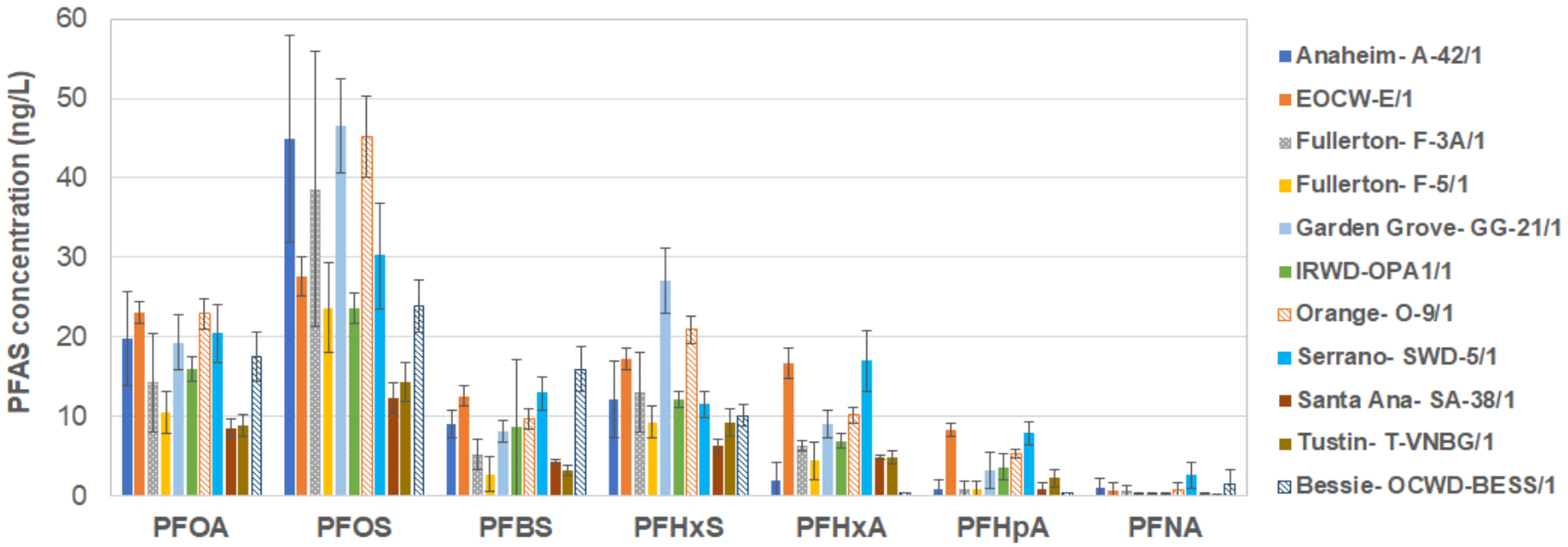

Figure A-1: Mean historical PFAS concentrations of Groundwater Producer wells (selected for RSSCT) compared to PFAS of OCWD Bessie well. Error bars represent standard deviation. Data from 2016-2019 for Bessie and 2016-2020 for Producers (data not available for all years depending on Producer).

Table A-5: EPA Method 537.1 and Method 533 parameters

Parameter Name	Parameter Abbrev.	Method 537.1	Method 533	Reporting Detection Limit (RDL), ng/L (Both Methods)
N-ethyl perfluorooctanesulfonamidoacetic acid	NEtFOSAA	✓		2
N-methyl perfluorooctanesulfonamidoacetic acid	NMeFOSAA	✓		2
Perfluorobutanesulfonic acid	PFBS	✓	✓	2
Perfluorodecanoic acid	PFDA	✓	✓	2
Perfluorododecanoic acid	PFDoA	✓	✓	2
Perfluoroheptanoic acid	PFHpA	✓	✓	2
Perfluorohexanesulfonic acid	PFHxS	✓	✓	2
Perfluorohexanoic acid	PFHxA	✓	✓	2
Perfluorononanoic acid	PFNA	✓	✓	2
Perfluorooctanesulfonic acid	PFOS	✓	✓	2
Perfluorooctanoic acid	PFOA	✓	✓	2
Perfluorotetradecanoic acid	PFTA	✓		2
Perfluorotridecanoic acid	PFTrDA	✓		2
Perfluoroundecanoic acid	PFUnA	✓	✓	2
Hexafluoropropylene oxide dimer acid	HFPO-DA	✓	✓	2
11-chloroeicosafluoro-3-oxaundecane-1-sulfonic acid	11Cl-PF3OUdS	✓	✓	2
9-chlorohexadecafluoro-3-oxanone-1-sulfonic acid	9Cl-PF3ONS	✓	✓	2
4,8-dioxa-3H-perfluorononanoic acid	ADONA	✓	✓	2
Nonafluoro-3,6-dioxaheptanoic acid	NFDHA		✓	2
Perfluorobutanoic acid	PFBA		✓	2
1H,1H, 2H, 2H-Perfluorohexane sulfonic acid	4:2FTS		✓	2
1H,1H, 2H, 2H-Perfluorooctane sulfonic acid	6:2FTS		✓	2
1H,1H, 2H, 2H-Perfluorodecane sulfonic acid	8:2FTS		✓	2
Perfluoro-3-methoxypropanoic acid	PFMPA		✓	2
Perfluoro-4-methoxybutanoic acid	PFMBA		✓	2
Perfluoro(2-ethoxyethane)sulfonic acid	PFEESA		✓	2
Perfluoroheptanesulfonic acid	PFHpS		✓	2
Perfluoropentanoic acid	PFPeA		✓	2
Perfluoropentanesulfonic acid	PFPeS		✓	2

Water Quality Comparison Between Pilot Influent (Bessie Well) and Pilot Effluent

Table A-1 shows the influent water quality summary for pilot influent (Bessie well water) as an average over the pilot testing period (data range December 2019 to September 2020, n=6). To evaluate how the pilot effluent changed over time for non-PFAS parameters, Table A-6 (first sampling event during piloting) and Table A-7 (Month 8 sampling event) present influent/effluent general water quality of the pilot based on a single sampling event from that month during piloting. The data shown is a subset of the water quality data collected for key parameters including of major anions, cations as well as total dissolved solids (TDS) and TOC.

The concentrations of most inorganic parameters did not change between influent and effluents indicating that these constituents were not removed after passing through the different treatment columns. For example, chloride and nitrate were not reduced in concentration by IX treatment which was expected as these anion exchange resins are typically not selective for chloride or nitrate. Sulfate can potentially be removed by IX resins (Maimaiti et al., 2018) and thus compete with PFAS for IX adsorption sites, but measurable removal of sulfate was not observed in this study. The effluent concentrations of inorganic parameters did not vary with time based on comparison of initial and later effluent quality. No leaching of arsenic was observed from GAC media as has been reported for other studies (Koslow et al., 2003).

For TOC, comparison of influent and effluent data reveals that (as expected) TOC was initially removed significantly by GAC and to a lesser degree by IX, and that this TOC removal lessened over time as the media became exhausted. Initially, GAC removed over 80% of the TOC (82 to 89% depending on the GAC). This decreased to 20 to 34% TOC removal after seven months which held fairly steady at this level over the next six months (based on DOC monitoring[3]). For the IX products, all products initially removed 63-70% TOC[4] which was short-lived, dropping to 8 to 16% removal within 4 months and no removal by eight months. The alternative adsorbents removed less than 10% TOC from beginning of pilot operation. A subset of this data is shown in Tables A-6 and A-7.

Elevated levels of iron and manganese can interfere with system operations by generating precipitate which can block the pore space in the media bed and/or foul the adsorption media. The iron concentrations were approximately 12 µg/L in the Bessie well influent compared to concentrations in all the effluents that were below the detection limit of < 5 µg/L. This suggests the removal of iron in GAC, IX, and alternative adsorbent columns. Manganese (Mn) concentrations were approximately 250 µg/L in the influent as well as all effluents suggesting no removal of Mn by the adsorbents tested.

[3] Due to sampling error, only TOC was measured in influent and effluent for the pilot for first seven months, then only DOC is subsequent months. However, based on influent results, the TOC is equal to DOC at a mean of 1.3 mg/L (i.e., total organic carbon is predominantly in the dissolved form).

[4] With the exception of an outlier showing 2.0 mg/L TOC in Purolite Purafine PFA694E effluent at the first sampling event (first month).

Table A-6: Pilot water quality for influent and effluents at pilot start (Dec 2019 for GAC/IX and Apr 2020 for alternative adsorbents)

	TDS (mg/L)	TOC (mg/L)	DOC (mg/L)	Ca (mg/L)	HCO_3 (mg/L)	Cl (mg/L)	Fe (µg/L)	Mg (mg/L)	Mn (µg/L)	NO3-N (mg/L)	PO4-P (mg/L)	SO4 (mg/L)
PILOT INFLUENT (OCWD BESSIE WELL), POST-FILTER												
December 18, 2019	604	1.28	NM	77.4	239	116	10.5	20.5	207	0.48	0.47	123
April 13, 2020	630	1.22	NM	78.4	235	129	12.1	20.8	253	0.23	0.41	125
PILOT EFFLUENTS, GAC (FIRST MONTH, December 18, 2019)												
Cabot Norit HYDRODARCO 4000	592	0.14	NM	75.2	238	115	<5	20.2	189	0.45	0.46	123
Cabot Norit GAC400	598	0.18	NM	74.5	239	115	10.2	19.8	196	0.45	0.47	122
Calgon F400R (Reactivated)	574	0.23	NM	78	248	115	<5	21.4	152	0.45	0.4	121
Calgon F400V (Virgin)	592	0.15	NM	78.6	241	116	5.5	21	205	0.46	0.46	124
Calgon F600	544	0.15	NM	74.7	239	115	<5	19.8	194	0.43	0.44	121
Evoqua AquaCarb 1230 CX	560	0.16	NM	80.2	237	115	<5	22.1	186	0.46	0.47	123
Evoqua UltraCarb 1240LD	612	0.19	NM	78.2	237	115	<5	21.4	191	0.46	0.44	121
Jacobi AquaSorb F23	450	0.19	NM	75.2	240	114	<5	20.2	190	0.45	0.44	120
PILOT EFFLUENTS, IX (FIRST MONTH, December 18, 2019)												
Calgon Cal Res 2301	586	0.4	NM	74.9	239	116	12.2	20	218	0.01	0.47	120
ECT2 SORBIX IC4	576	0.39	NM	76.6	238	136	11	20.5	200	0.01	0.93	89.4
Evoqua PSR2+	582	0.47	NM	75.8	240	118	11.2	19.8	193	0.01	0.47	120
Purolite Purofine PFA694E	578	2.04[(a)]	NM	79.4	241	126	13.7	20.9	221	0.01	1.08	102
PILOT EFFLUENTS, ALTERNATIVE (NOVEL) ADSORBENTS (FIRST MONTH, April 13, 2020)												
CETCO FLUORO-SORB® 200	616	1.22	NM	77.5	235	128	5.5	20.2	252	0.23	0.43	124
Cyclopure DEXSORB+®	610	1.18	NM	77.5	235	127	<5	20.5	247	0.23	0.42	123

Note: (a) December 18, 2019 measured TOC may be an outlier, later sampling June 8 and June 22 (2020) indicated 1.26 and 1.19 mg/L.

Table A-7: Pilot water quality for influent and effluents after eight months (Aug 2020 for GAC/IX and Dec 2020 for alternative adsorbents)

	TDS (mg/L)	TOC (mg/L)	DOC (mg/L)	Ca (mg/L)	HCO3 (mg/L)	Cl (mg/L)	Fe (µg/L)	Mg (mg/L)	Mn (µg/L)	NO3-N (mg/L)	PO4-P (mg/L)	SO4 (mg/L)
PILOT INFLUENT (OCWD BESSIE WELL), POST-FILTER												
August 3, 2020	642	1.29[(a)]	1.27	85.7	235	134	11.6	22.6	242	0.31	0.42	133
December 7, 2020	596	1.29[(a)]	1.15	80.6	255	124	<5	20.8	232	0.44	0.4	126
PILOT EFFLUENTS GAC (August 3, 2020)												
Cabot Norit HYDRODARCO 4000	622	1.03[(a)]	1.11	84.5	244	134	<5	22.3	234	0.29	0.42	132
Cabot Norit GAC400	612	1.01[(a)]	1.08	85.2	245	134	<5	22.5	228	0.27	0.42	132
Calgon F400R (Reactivated)	628	0.86[(a)]	0.89	84.8	249	133	<5	22.4	242	0.23	0.41	131
Calgon F400V (Virgin)	630	0.84(a)	0.91	84.0	234	135	<5	21.9	241	0.27	0.42	132
Calgon F600	628	1.03[(a)]	1.08	85.2	248	134	<5	22.6	238	0.27	0.40	134
Evoqua AquaCarb 1230 CX	626	0.98[(a)]	1.03	83.7	244	134	<5	21.8	237	0.28	0.42	132
Evoqua UltraCarb 1240LD	642	0.97[(a)]	1.04	84.6	245	135	<5	22.9	245	0.29	0.42	133
Jacobi AquaSorb F23	630	0.91[(a)]	0.97	84.9	245	134	<5	21.9	233	0.27	0.42	132
PILOT EFFLUENTS IX (August 3, 2020)												
Calgon Cal Res 2301	626	1.23[(a)]	1.19	83.2	245	133	<5	22.3	234	0.23	0.42	131
ECT2 SORBIX IC4	624	1.24[(a)]	1.22	83.8.2	245	132	<5	21.7	237	0.3	0.42	130
Evoqua PSR2+	646	1.17[(a)]	1.21	83.8	245	132	<5	21.9	233	0.30	0.43	130
Purolite Purofine PFA694E	626	1.18(a)	1.21	83.6	244	132	<5	21.8	237	0.29	0.42	130
PILOT EFFLUENTS, ALTERNATIVE (NOVEL) ADSORBENTS (December 7, 2020)												
CETCO FLUORO-SORB® 200	604	1.34[(a)]	1.13	77.8	253.6	122	<5	20.3	241	0.43	0.4	123
Cyclopure DEXSORB+®	604	1.25[(a)]	1.20	76.3	252.3	121	<5	20	240	0.43	0.40	124

Note: (a) Data collected on July 20, 2020

Table A-8: Pilot influent and adsorbent media effluent monitoring results for PFAS by EPA Method 533

	PFBA (ng/L)		PFPeA (ng/L)		PFPeS (ng/L)	
Pilot Sampling Location	**6/22/2020**	**8/3/2020**	**6/22/2020**	**8/3/2020**	**6/22/2020**	**8/3/2020**
Post-Filter Influent	28	29	4.6	3.6	2.0	2.1
Cabot Norit GAC400	29	30	4.0	4.0	ND	ND
Calgon F400V (Virgin)	31	31	4.2	4.0	ND	ND
Calgon F400R (Reactivated)	28	31	4.4	4.2	ND	ND
Calgon F600	27	29	3.3	3.0	ND	ND
Evoqua UltraCarb 1240LD	29	30	4.5	3.8	ND	ND
Evoqua AquaCarb 1230CX	29	29	4.3	3.7	ND	ND
Cabot Norit HYDRODARCO 4000	29	29	4.6	3.8	ND	ND
Jacobi AquaSorb F23	29	30	4.4	3.7	ND	ND
Purolite Purofine PFA694E	28	29	4.8	3.8	ND	ND
Calgon CalRes 2301	29	29	5.1	3.8	ND	ND
Evoqua PSR2+	29	30	5.0	5.0	ND	ND
ECT2 Sorbix LC4	28	29	4.9	3.7	ND	ND
Cetco FLUORO-SORB 200	27	29	4.5	3.8	ND	ND
Cyclopure DEXSORB+	28	29	4.3	3.3	ND	ND

Note: Reporting Detection Limit (RDL) for this method is 2 ng/L. PFBA, PFPeA, and PFPeS were the only analytes present above the RDL in the influent.

Table A-9: Pilot influent and adsorbent media effluent monitoring results for 1,4-dioxane

1,4 Dioxane Concentration (ng/L), EPA Method 522			
Pilot Sampling Location	**4/27/2020**	**5/11/2020**	**8/17/2020**
Post-Filter Influent	0.35	0.30	0.34
Cabot Norit GAC400	0.32	0.29	0.33
Calgon F400V (Virgin)	0.34	0.34	0.31
Calgon F400R (Reactivated)	0.35	0.30	0.40
Calgon F600	0.35	0.30	0.34
Evoqua UltraCarb 1240LD	0.34	0.29	0.34
Evoqua AquaCarb 1230CX	0.30	0.32	0.26
Cabot Norit HYDRODARCO 4000	0.34	0.31	0.32
Jacobi AquaSorb F23	0.32	0.30	0.29
Purolite Purofine PFA694E	0.34	0.27	0.34
Calgon CalRes 2301	0.34	0.31	0.32
Evoqua PSR2+	0.34	0.31	0.24
ECT2 Sorbix LC4	0.36	0.29	0.26
Cetco FLUORO-SORB 200	0.36	0.32	0.33
Cyclopure DEXSORB+	0.38	0.33	0.32

Note: There were three other sample dates that used a method with a higher detection limit (DL) of 0.5. The DL for the values shown in the table is 0.07.