# FINAL REPORT

## Full-Scale Fixed-Bed Biological Perchlorate Destruction Demonstration

Construction of a Fixed-Bed Bioreactor Wellhead Treatment System

## ESTCP Project ER-201169

JANUARY 2019

Jess Brown
**Carollo Engineers, Inc.**

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West Valley Water District
Fixed-Bed Biological Perchlorate Destruction Demonstration Project

# Final Report
# CONSTRUCTION OF A FIXED-BED BIOREACTOR WELLHEAD TREATMENT SYSTEM

January 2019

This document has been reviewed and approved by Jess Brown, PhD, Principal Investigator.

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# Abbreviations

| | |
|---|---|
| µg/L | micrograms per liter |
| ACH | aluminum chlorohydrate |
| Basin | Rialto Colton Groundwater Basin |
| CDPH | California Department Public Health |
| CEQA | California Environmental Quality Act |
| cf | cubic feet |
| DO | dissolved oxygen |
| DOD | Department of Defense |
| EBCTs | empty bed contact times |
| EPS | extracellular polymeric substance |
| ft | feet |
| FXB | fixed-bed biological treatment |
| GRCs | gas release cycles |
| gpm | gallons per minute |
| IC | ion chromatograph |
| IX | ion exchange |
| MCL | maximum contaminant level |
| mg/L | milligrams per liter |
| MMR | monthly monitoring report |
| peroxide | hydrogen peroxide |
| PS | pump station |
| psig | pounds per square inch gauge |
| SARWQCB | Santa Ana Regional Water Quality Control Board |
| SCADA | supervisory control and data acquisition |
| scfm/sf | standard cubic feet per minute per square foot |
| TCE | trichloroethylene |
| VOCs | volatile organic compounds |
| TSS | Total suspended solids |
| Water Board | State Water Resources Control Board |
| WWTP | wastewater treatment plant |
| WTP | water treatment plant |
| WTS | water treatment system |
| WVWD | West Valley Water District |

Final Report

# CONSTRUCTION OF A FIXED-BED BIOREACTOR WELLHEAD TREATMENT SYSTEM

## 1.1 Executive Summary

### 1.1.1 Purpose of the Project

The objective of this project was to evaluate the efficacy of a two-stage fixed-bed biological treatment (FXB) system to treat perchlorate-impacted groundwater in Rialto, California and produce water that meets all drinking water standards. Perchlorate is a widespread groundwater contaminant in California, and conventional treatment options that produce high-strength brines are becoming exceedingly expensive, especially in inland areas with limited options for disposal.

The FXB system process is a cost-effective and sustainable alternative for removing perchlorate from groundwater as it does not produce a concentrated waste stream and, therefore, waste disposal costs tend to be lower than other treatment options. Backed by almost 20 years of bench- and pilot-scale experience, a full-scale FXB biological treatment facility was designed, constructed, and tested to address systemic perchlorate contamination of groundwater utilized by the West Valley Water District. Specific objectives were to demonstrate the system's treatment efficiency, ease of operation, and suitability for use by the West Valley Water District and other communities that rely on perchlorate-impacted groundwater. The project was funded by the Department of Defense and by the State Water Resources Control Board (Water Board) Cleanup and Abatement Account.

### 1.1.2 Project Results

After two years of design and construction spanning January 2016 through July 2017, the FXB system was started up on November 9th, 2017. Rapid perchlorate and nitrate removal were observed within four weeks of operation during biological acclimation. During a ten week period from February 15th to April 23rd, perchlorate in the biofilter effluent was 1.4 ± 3.2 µg/L. Turbidity in the biofilter effluent remained at 0.07 ± 0.1 NTU with 96.8 percent of samples below the 0.3 NTU threshold. Furthermore, complete and consistent removal of 1.85 µg/L trichloroethylene (TCE) was observed. Treatment performance and rapid recovery after shutdowns or challenge events confirmed the flexibility and robustness of the system.

### 1.1.3 Conclusions and Recommendations

The full-scale FXB system successfully removed perchlorate and produced water that met all performance goals and water quality objectives. Several key findings and lessons were learned from this project, including the optimal chemical dose, backwash frequency, and plant hydraulics to be incorporated in future designs and operations.

## 1.2 Background

### 1.2.1 Project Description and Location

West Valley Water District (WVWD) is located in San Bernardino and Riverside Counties, approximately 50 miles east of Los Angeles, CA. WVWD serves approximately 66,000 residents in the communities of Rialto, Fontana, Colton, and Jurupa Valley. A portion of the water supplied by WVWD is pumped from wells in the Rialto-Colton Groundwater Basin, which is contaminated with a major perchlorate plume that has threatened the Basin's water supply since its detection in 1997. Furthermore, large portions of the groundwater in this basin are contaminated with nitrate and volatile organic compounds (VOCs), including TCE.

In 2009, the West Valley Water District (WVWD) began the process of developing a project to address the contamination impacting the Rialto Colton Groundwater Basin (Basin). In January 2010, a single-pass perchlorate ion exchange (IX) system was installed adjacent to Reservoir 3A-2 to address the issue of perchlorate contamination. To further add operational flexibility and meet peak demands, a fluidized bed bioreactor referred to as the FBR was constructed in 2010 and completed in 2013 at WVWD's headquarters (855 West Base Line Road, Rialto, CA). This groundwater wellhead treatment system removes perchlorate, nitrate, and TCE from groundwater coming from the West Valley Water District's Well No. 11 and City of Rialto's Well No. 6.

The perchlorate concentrations at Well 6 peaked at 460 µg/L in December 2013 following an increase in production from the well. However, since December 2013, the perchlorate concentration has continued to decline, yet concentrations are still greatly above the California perchlorate maximum contaminant level (MCL) of 6 µg/L. Nitrate concentrations have never exceeded the MCL at Well 6, and currently reside at 3 to 4 milligrams per liter (mg/L) as N. TCE concentrations at Well 6 since approximately 2009 have continued to occasionally exceed the MCL, with concentrations ranging between 2 and 6 µg/L.

Perchlorate concentrations at Well 11 peaked at 27 µg/L in 2011. However, since that time, perchlorate concentrations have trended downward, and are currently at or below 4 to 5 µg/L. Nitrates peaked at 11.8 mg/L as N in 1999, and since then have continued to trend downwards. Currently, nitrate concentrations reside below the MCL at between 5 and 7 mg/L as N. TCE concentrations at Well 11 have been non-detect in recent sampling, and have always been below 1 µg/L according to historical data.

Currently, the FBR provides approximately 2,000 gallons per minute (gpm) of treated groundwater to be used by the WVWD and Rialto for drinking water supply. To improve the resiliency and increase capacity of the drinking water supply, the United States Department of Defense (DOD), which participated and assisted WVWD in the design and construction of the FBR system, made available a grant of $3.4 million in 2013 for WVWD to add a FXB system to be installed in parallel with the full-scale FBR system. Although the FBR facility was originally designed for future installation of a parallel, identical FBR treatment train, a two-stage FXB treatment system was selected in lieu of installing an additional 2,000 gpm of FBR capacity.

The objective was to test multiple perchlorate removal bio-technologies (i.e., an FBR and FXB side-by-side) in the Basin to determine the most efficient and cost-effective technology that could then be utilized in the cleanup of perchlorate nationwide. The DOD and other water authorities believed that side-by-side comparison of these two reactors provided optimal conditions to evaluate both technologies, since both received the same contaminated groundwater, allowing for the most accurate comparison possible.

Because WVWD is limited by water rights to produce a total of 2,000 gpm from Wells 6 and 11, the FXB system will produce approximately 450 gpm, and the FBR system will produce approximately 1,550 gpm when both systems are in operation.

### 1.2.2 Contaminants of Interest

#### 1.2.2.1 Perchlorate

Perchlorate, a powerful oxidant used in solid propellant for rockets, missiles, and fireworks, was relatively unknown to the general public prior to 1997. Since then, the limit of detection for perchlorate decreased 100-fold, leading to its discovery in drinking water sources in 26 states (Brandehuber et al., 2009). There is no federal MCL for perchlorate in drinking water, though Massachusetts and California have established MCLs at 2 and 6 µg/L, respectively. In December 2010, California's Office of Environmental Health Hazard Assessment proposed to decrease the public health goal for perchlorate from 6 to 1 µg/L. In February 2011, the USEPA announced its decision to develop a federal standard for perchlorate in drinking water.

#### 1.2.2.2 Nitrate

Nitrate is another common groundwater contaminant in California. In 2009, the California Legislature initiated a study of nitrate contamination in California's agricultural areas, where groundwater provides much of the drinking water supply to communities and nitrate addition through fertilizer application and cattle operations is prevalent. The recently released study confirms widespread contamination of groundwater aquifers in these areas, particularly in the Central Valley and the Salinas Valley, in which many locations have nitrate concentrations in excess of twice the California MCL of 10 mg-N/L. The problem is not restricted exclusively to these areas of the state. More than 85 percent of California's community drinking water systems rely on groundwater for some or all of their drinking water, and more than 1,800 of the state's public potable water wells are contaminated with nitrate above the MCL. Similar problems occur across the United States in areas where agriculture contributes to a large part of the economy.

#### 1.2.2.3 Volatile Organic Compounds

VOCs are a class of organic chemicals, typically found in adhesive and solvent products that have a high vapor pressure and readily volatize to the atmosphere. These organic compounds react with nitrogen oxides in the atmosphere in the presence of sunlight to form ozone which causes respiratory problems and thus is a human health threat. TCE is a particular VOC of concern which has a California MCL of 5 µg/L.

#### 1.2.2.4 Historical Trends

Raw water to be treated by the new FXB treatment plant comes from WVWD Wells 6 and 11. Historical water quality data for perchlorate, nitrate, and TCE concentrations in Wells 6 and 11 are provided in Table 1.

Table 1 Wells 6 and 11 Water Quality Data (2013 – 2017)

| Parameter | Perchlorate (µg/L) | | Nitrate (mg/L as N) | | TCE (µg/L) | |
|---|---|---|---|---|---|---|
| | Well 6 | Well 11 | Well 6 | Well 11 | Well 6 | Well 11 |
| No of Samples Analyzed | 18 | 12 | 17 | 11 | 13 | 10 |
| Minimum | 90 | 0.4 | 2.9 | 4.5 | 1.9 | <0.5 |
| Average(1) | 239 | 3.7 | 3.3 | 6.2 | 4.6 | <0.5 |
| Maximum | 460 | 9.8 | 4.5 | 7.2 | 6.9 | <0.5 |
| Maximum Contaminant Level | 6 | | 10 | | 5 | |

Notes:
(1) Since 2013, there is a general trend of decreasing perchlorate and TCE concentrations in both wells.

Between 2013 and 2015, nitrate concentrations varied between 2.9 mg/L and 7.2 mg/L as N (between 12.8 and 31.9 mg/L as $NO_3^-$) between the two source wells. Perchlorate concentrations varied between 0.4 µg/L and 460 µg/L. The majority of perchlorate comes from Well 6, whereas average perchlorate concentrations in Well 11 are below the MCL. Similarly, elevated TCE concentrations are seen in Well 6, ranging from 1.9 to 6.9 µg/L. All TCE samples taken from Well 11 during the above time period were below the method detection limit of 0.5 µg/L.

### 1.2.3 Technical Details of the FXB system and process overview

Both abiotic (e.g., ion exchange, reverse osmosis (RO)) and biological (e.g., fluidized-bed and fixed-bed) processes have been developed and evaluated for treating perchlorate- and nitrate-contaminated drinking water. The main drawback with abiotic approaches is that they are phase transfer technologies which create a concentrated perchlorate/nitrate-laden waste stream that must be further treated or disposed. Concentrate management can be a significant annual cost, making phase-transfer treatment technologies economically infeasible and environmentally unsustainable.

In contrast to the aforementioned abiotic technologies, the proposed Biologically-Tailored Two-Stage Treatment Approach process involves biological reduction of perchlorate and nitrate to chloride and nitrogen gas, respectively, thereby eliminating these contaminants from the environment. Unlike phase transfer processes, perchlorate and nitrate are not concentrated, but rather converted to innocuous end-products in a single reactor and do not generate a waste stream, making it an attractive alternative.

#### 1.2.3.1 FXB Process Flow

The FXB process uses a fixed-bed bioreactor and a biofilter in series (Figure 1) to remove perchlorate, nitrate, and other contaminants, including many VOCs, from groundwater. The bioreactor uses a stationary bed of GAC as an attached-growth medium for the existing bacteria in the groundwater to form biofilms. In order to encourage the growth of these biofilms, the raw water is amended with acetic and phosphoric acids upstream of the anoxic bioreactor. Acetic acid is applied as an electron donor used by the bacteria for the reduction of oxygen, perchlorate, nitrate, and other terminal electron acceptors present in the water. Phosphoric acid is applied as a supplemental source of phosphorus required by the bacteria for healthy growth.

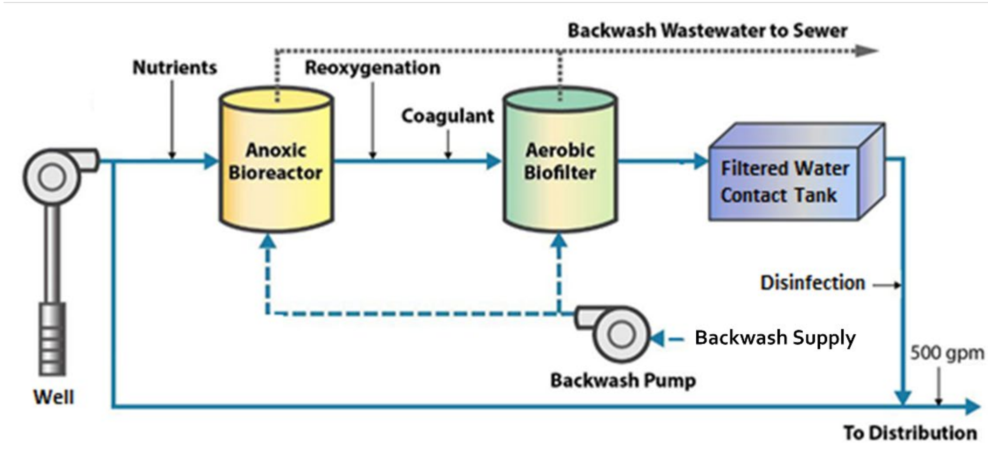


Figure 1 FXB System Process Flow Diagram

After dissolved oxygen (DO) is removed from the water in the top part of the bed, the bacteria then reduce perchlorate and nitrate to chloride and oxygen, and nitrogen gas. The nitrogen gas is subsequently released to the atmosphere. Once treated by the anoxic bioreactor, water is reoxygenated with hydrogen peroxide and fed a particle-conditioning agent before an aerobic biological polishing filtration step. The aerobic biofilter provides additional oxidation and filtration capacity before effluent is disinfected and pumped into the distribution system.

Biofilter effluent is conveyed to a 15,000 gallon treated water tank, which serves as a buffer against contaminant breakthrough prior to the distribution system. Upon leaving the tank, the water is chlorinated before entering a chlorine contact pipe, which provides sufficient contact time for 4-log virus inactivation, before the water enters Reservoirs 3A-1 and 3A-2 (distribution system point of entry). CT calculations are provided in Appendix A (Table 13).

Over time, biomass and other solids accumulate in the media bed, resulting in a gradual increase in headloss across the system. The excess biomass and accumulated solids are periodically removed from the media bed by backwashing. Backwashing of FXB vessels is done in the same manner as conventional granular media filters. Backwash cycles are initiated based off either a time setpoint (18 hours for the bioreactor; 72 hours for the biofilter) or a headloss setpoint (15 psi differential pressure), depending on which comes first.

Schematics showing the site overview, layout of the water treatment plant, and process flow diagram of the water treatment plant are provided in Appendix B.

#### 1.2.3.2 System Operation

*Normal Operation*

Following approval of the use of the FXB system for potable use, both the FXB and FBR systems would operate in parallel to provide treated water to the distribution system. Because the District is limited by water rights to produce a total of 2,000 gpm from Wells 6 and 11, it is expected that the FXB system will produce approximately 450 gpm, and the FBR system will produce approximately 1,550 gpm when both systems are in operation. It is expected that Well 6 will continue to serve as the primary water source for the water treatment system (WTS), and Well 11 will serve as a standby source. Figure 2 shows the system configuration when the FXB system provides treated water to the distribution system.

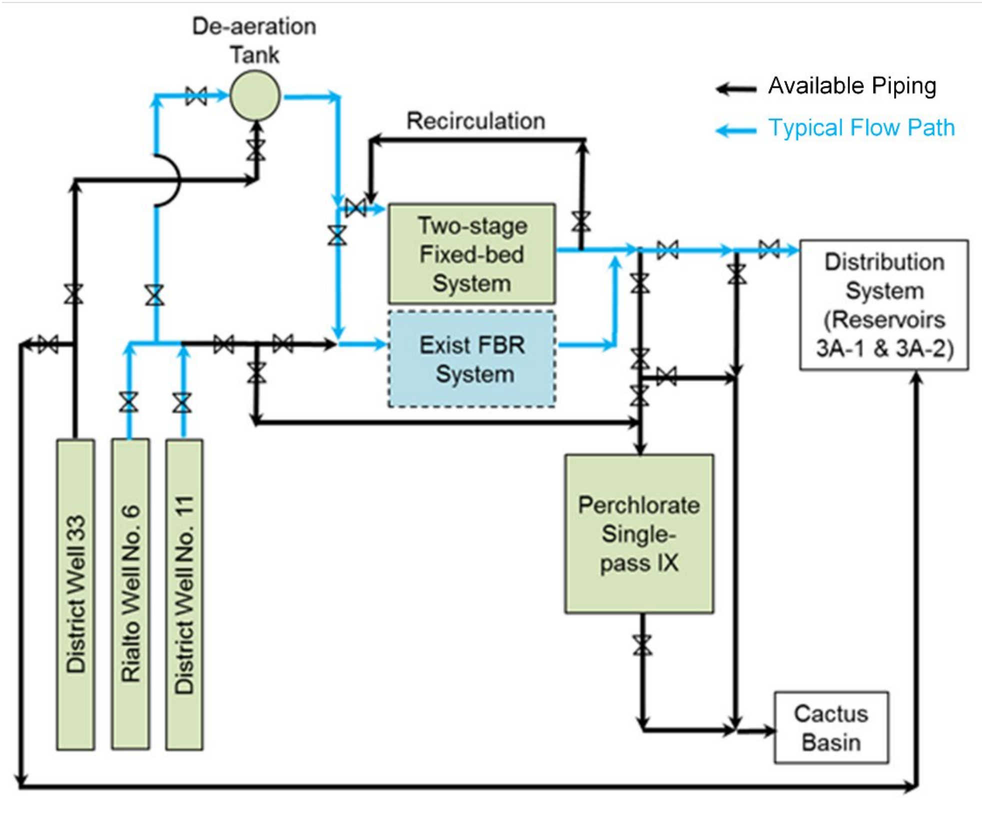


Figure 2 WTS Treated Water Process Flow (blue lines indicate flow path)

### *Backwashing*

As biomass accumulates on the media in each vessel, headloss will gradually increase. Backwashing the bioreactor and biofilter will remove excess biomass and accumulated solids and return them to a clean bed condition. Backwash supply water is provided from the WVWD distribution system. The water is dechlorinated and then conveyed from a tie-in at the Booster Pump Station 4-2 header. Distribution system pressure drives the backwash supply water through the FXB process and out into the backwash waste tank. The backwash system is also equipped with blowers that provide air scouring to separate excess biomass from the media. During normal operation, bioreactor backwashes are performed every 12-24 hours and biofilter backwashes are performed every 72 to 96 hours.

### *Backwash Waste Recovery*

Waste backwash water is conveyed to a 65,500-gallon bolted steel backwash waste tank. A process flow diagram for the supply of backwash waste water to the recovery tank and a schematic showing the booster pump station 4-2 are provided in Appendix B. The tank is equipped with a vertical shaft flocculator for flocculation, and a conical concrete base to facilitate collection of settled sludge. The backwash waste tank can be operated in two modes:

1. Equalization Mode: When backwash waste is conveyed to the tank, the mixer is enabled at an operator-adjustable speed to keep the waste homogenized. The backwash waste tank sludge pump is then used to meter the waste to the sewer at an adjustable rate until the tank reaches a low-level setpoint.

2. Settling Mode: Coagulant is dosed to the backwash waste as it is conveyed to the tank. When the backwash cycle has completed, the mixer operates in three stages at operator-adjustable speeds and times to provide flocculation mixing. Baffles on the tank wall prevent swirling and maximize the transfer of mixing energy to the water to facilitate flocculation. When the flocculation sequence is complete, the mixer is stopped, and the sludge pump is activated after a 180-minute settling period. The sludge pump will meter sludge to the sanitary sewer at an adjustable rate, for an adjustable period of time. After sludge has been drawn from the bottom of the tank, the remaining supernatant is pumped back to the FXB process via a recovered water pump. The recovered water is applied upstream of the aerobic biofilter.

*Backwash Waste Discharge Limits*

Sludge disposed to the sanitary sewer is subject to the following limits in accordance with the Rialto Sewer Use Ordinance #1523 Wastewater Discharge Permit (Table 2).

Table 2 Sludge Discharge Limitations

| Conventional Pollutants | Symbol | Maximum Daily Concentration (mg/L) |
|---|---|---|
| pH | pH | *5.0 – 11.5 SU* |
| Flow Volume | Q | *15,000* |
| Biological Oxygen Demand | BOD5 | *250 lbs/day* |
| Total Suspended Solids | TSS | *250 lbs/day* |
| Total Dissolved Solids | TDS | 800 |
| Perchlorate | ClO4 | <0.006 |
| Trichloroethylene | TCE | < 0.005 |

## 1.3 Objectives

The overall goal of this project is to demonstrate that FXB is a cost-effective, sustainable solution for removing perchlorate from groundwater used by West Valley Water District. Specific objectives of the project were to:

- Demonstrate the treatment efficiency of the FXB system.
- Demonstrate the ease of operation of the FXB system.
- Demonstrate sustained perchlorate removal.
- Characterize process robustness.
- Provide sufficient operational and performance data to support the application of a water supply permit from Water Board to operate a full-scale system.

## 1.4 Permitting, Design, Construction, and Monitoring

### 1.4.1 Permitting

Permitting and coordination with appropriate regulatory entities were required for several components of the project:

- **Environmental Review Documents (CEQA/NEPA, as applicable):** The West Valley Water District prepared a mitigated negative declaration for the groundwater treatment system in August 2009, which was adopted in September 2009. For the FXB project, an addendum to the mitigated negative declaration was prepared and then issued in May 2016, and was then adopted by the West Valley Water District Board of Directors via resolution on May 6, 2016. A notice of determination associated with the addendum was filed with the State Clearinghouse.

- **California Department Public Health (CDPH) 97-005 permit:** The water source for the treatment facility is classified as an extremely impaired drinking water source by DDW. As such, the 97-005 drinking water permit for the WVWD treatment facility (i.e., FBR) was modified for this project to include the new FXB demonstration plant, operations and maintenance plan, and permit to allow for discharge to the distribution system.
- **Santa Ana Regional Water Quality Control Board (SARWQCB) waste discharge permit:** Required for removal of contaminated/unsuitable material from the site that may be disturbed during excavation required for construction of the backwash waste equalization tank and pump station (PS).
- **San Bernardino County Flood Control District spreading agreement:** Needed to secure a permit for access to the Cactus Basin property adjacent to the project site for placement of a temporary staging/laydown area, as well as for installation of the proposed backwash supply and treated water pipes. As the Cactus Basin falls within the Rialto Groundwater Management Plan, which is dictated as an existing/potential beneficial use municipal and domestic supply (MUN), Furthermore, the existing permit for discharge was amended to include treated water produced during FXB testing and startup to the Cactus Basin. This includes weekly, monthly, quarterly, and annual sampling of effluent discharge.
- **City of Rialto discharge permit to the waste water treatment plant (WTP):** Coordination with the City of Rialto Wastewater Treatment Plant (WWTP) for facility discharges to the sanitary sewer to meet limits on volume, BOD, and TDS.

### 1.4.2 Design

The full-scale FXB system was constructed in and around the existing FBR facility and designed to produce up to 1,900 gpm of treated water. The full-scale FXB facility has the following features:

- Nameplate process capacity of 1,095 gpm.
- Hydraulic capacity of 1,900 gpm.
- Fixed-bed bioreactor for perchlorate and nitrate removal.
- Fixed-bed biofilter for removal of turbidity and any residual electron donor.
- Chlorine contactor pipe.
- Water quality monitoring panel.
- Chemical metering pumps.
- Backwash waste (equalization) tank and associated pumps.
- Bulk storage tank and secondary containment for hydrogen peroxide (peroxide).

The existing treatment building houses all components of the FXB system with the exception of the backwash waste equalization tank, backwash waste pumps, and peroxide tank.

#### 1.4.2.1 FXB Bioreactor and Biofilter

Two new horizontal variable speed centrifugal pumps (operated in a lead/lag configuration) boost de-aerated raw water to the bioreactor. The nominal design flow rate is 1,095 gpm, and the hydraulic capacity of the FXB system is 1,900 gpm. The FXB bioreactor and biofilter are 12-foot diameter epoxy-coated steel pressure vessels. Bioreactor media is comprised of 60-inches of GAC, and the biofilter media is comprised of 15 inches of silica sand overlain by 33 inches of GAC. This accommodates a maximum loading rate of 8.4 gpm/sf. Average empty bed contact times (EBCTs) are ~ 9 minutes. The media support underdrain is a distributor plate with nozzles. A conceptual rendering and actual photo of the FXB vessels are presented in Figures 3 and 4.

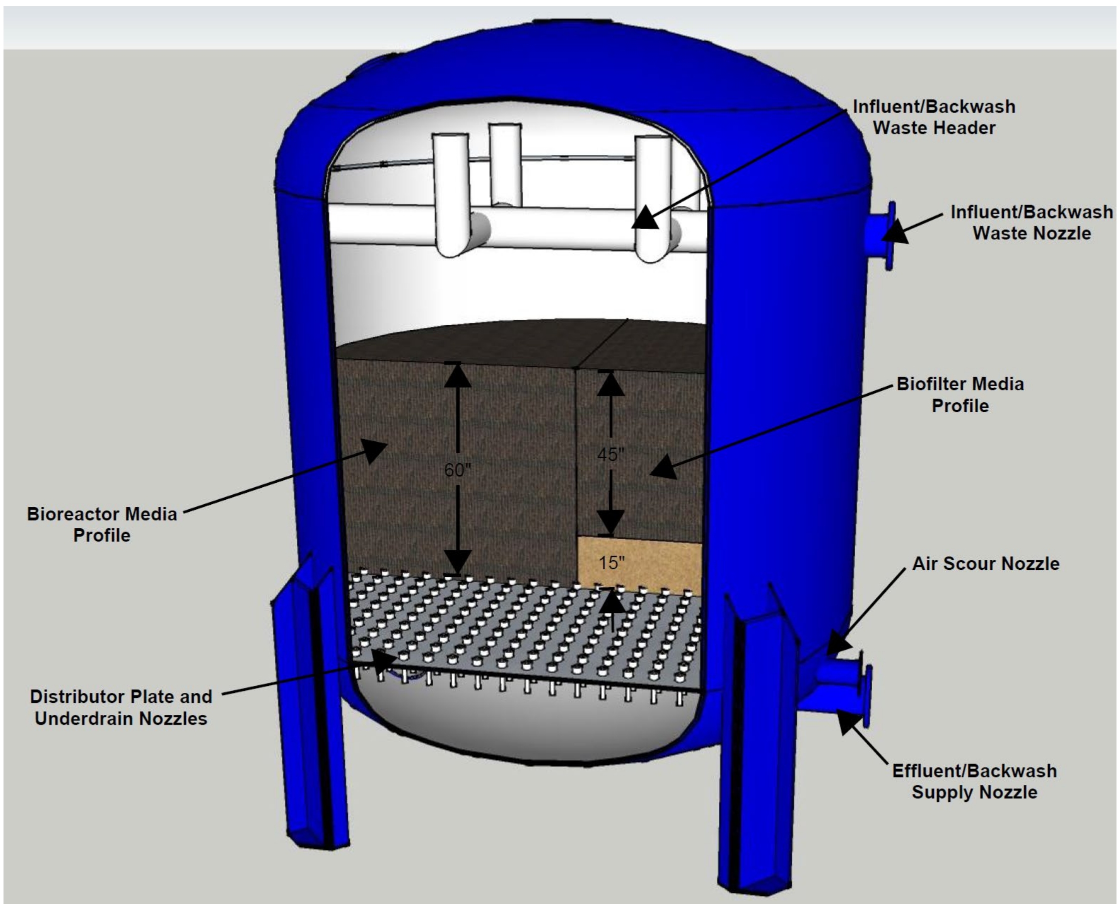


Figure 3 FXB Vessel Design


Figure 4 Completed Bioreactor

#### 1.4.2.2 Chemical Storage and Feed

The FXB bioreactor feed water is amended with electron donor (acetic acid) and nutrient (phosphoric acid), and the FXB bioreactor effluent (i.e., FXB biofilter feed) is re-oxygenated using peroxide, and dosed with coagulant to enhance turbidity removal. The system was designed such that typical raw water concentrations of perchlorate and nitrate are 66 µg/L and 3.5 mg/L as N (respectively) and are to be reduced to target effluent concentrations of ≤0.5 µg/L and ≤0.5 mg/L as N. Hydrogen peroxide is used to dechlorinate distribution water prior to backwashing. Coagulant is also dosed during the backwash recovery process to improve settling. Sodium hypochlorite is dosed downstream of the biofilter to provide residual disinfection prior to distribution. A photo of the chemical feed pumps is provided in Figure 5.

Figure 5 Chemical Feed Pumps

#### 1.4.2.3 Backwash Supply

The FXB system backwashes the bioreactor and biofilter to remove excess biomass from the system along with any solids deposited in the media bed over the course of a run cycle. Vessels are drawn down prior to backwashing via siphon nozzles located with inverts approximately 12 inches above the top of the media bed, and angled up to the vessel wall at 55 degrees.

Backwash water for the FXB process is supplied by existing WVWD Booster Pump Station 4-2. A 14-inch pipeline conveys water from the booster PS, located approximately 300 feet (ft) north of the treatment facility, to the FXB system (Figure 6). The backwash supply pipe ties into the 30-inch discharge header at the PS with a double-check style backflow preventer and pilot-operated pressure reducing valve. The pressure reducing valve reduces the pressure in the backwash pipe by approximately 50 pounds per square inch gauge (psig), and a proportionally-controlled butterfly valve regulates the flow of backwash water to the FXB system. The water from Booster Pump Station 4-2 has a chlorine residual of approximately 1.5 mg/L. Peroxide is applied to the backwash supply line at the tie-in location at the Booster Pump Station 4-2 for dechlorination.

New constant-speed air scour blowers allow for separate and/or combined air and water washes of the FXB vessels.

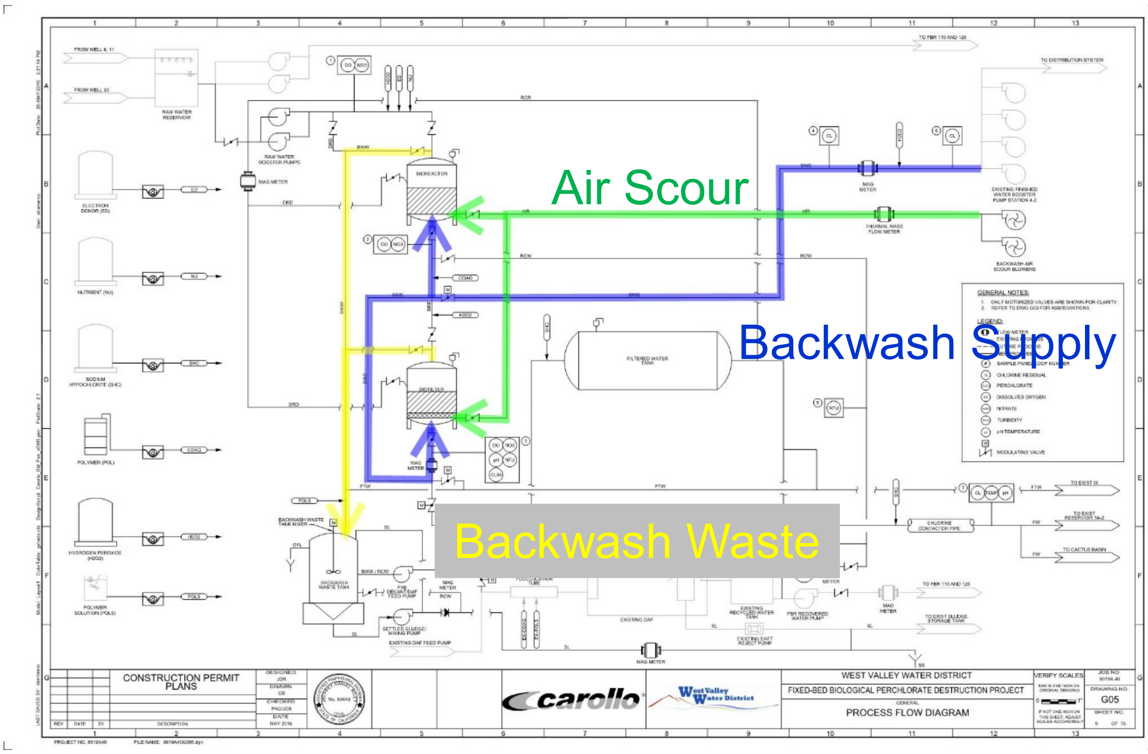


Figure 6 Backwash Process Flow

### 1.4.2.4 Backwash Waste

Backwash waste and filter-to-waste water is conveyed to a 20-foot diameter, backwash waste equalization tank located to the west of the existing concrete FBR waste tank. A conical bottom (angled 55 degrees from horizontal) is cast into the backwash waste equalization tank foundation as shown in Figure 7. The volume of the straight-shell portion of the tank is 57,000 gallons, and the conical bottom is around 11,200-gallons, for a total volume of approximately 68,202 gallons. The tank is equipped with a 2 hp paddle mixer and baffles. Backwash waste from the FXB vessels is dosed with 2 to 4 mg/L of ACH coagulant and gently agitated in the waste tank to facilitate flocculation. Following flocculation, the solids settle over several hours before sludge is drawn from the bottom of the tank using a peristaltic hose pump, and supernatant is pumped back to the biofilter influent by the horizontal centrifugal supernatant pump. The settled solids are either conveyed to the sanitary sewer, or to the existing sludge storage tank used by the FBR.

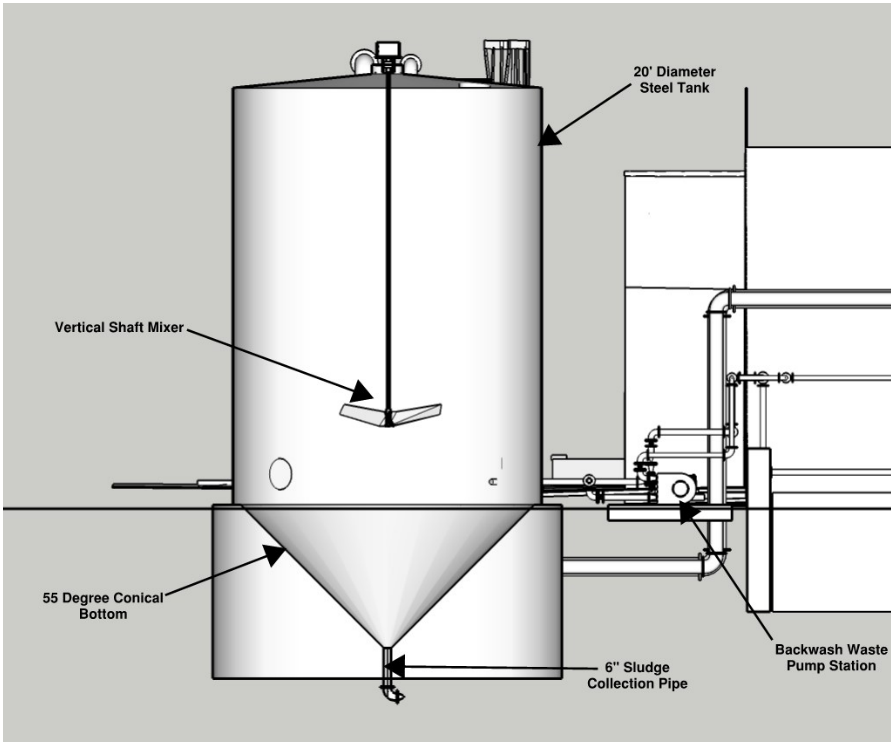


Figure 7 Backwash Waste Tank Design

The total suspended solids (TSS) and total waste water discharge limits established by City of Rialto are currently 500 pounds per day and 25,000 gallons per day, respectively. A photo of the completed backwash waste tank is shown in Figure 8.


Figure 8 Completed Backwash Waste Tank

### 1.4.3 Construction

FXB plant construction spanned June 2016 through July 2017. Below are a few photos showcasing construction progress.


Figure 9 Construction of the Backwash Waste Tank

Figure 10 Delivery of the FXB Vessels and Treated Water Contact Tank

Figure 11 Installation of the FXB Vessels

### 1.4.4 Water Quality Monitoring

The FXB system is equipped with a number of in-line water quality analyzers, as detailed in Table 3. Analyzers have alarms associated with them that alert operators to any irregularities in the process, and shut down the FXB system in the event of critical alarms (perchlorate, nitrate, and turbidity excursions, etc.). The FXB system is designed such that perchlorate above 2.9 ppb shuts the FXB system down, allowing the non-compliant water to be captured within the FXB system, thereby protecting the distribution system. Analyzers are also used for general process monitoring and control, including chemical dose control.

Table 3 FXB Process In-Line Monitoring

| Location | Parameter | Frequency | Analysis |
|---|---|---|---|
| Raw Water | Flow | Continuous | In-Line Flow Meter |
| | Nitrate/Nitrite | Continuous | In-Line Analyzer |
| | Dissolved Oxygen | Continuous | In-Line Analyzer |
| Bioreactor Effluent | Nitrate/Nitrite | Continuous | In-Line Analyzer |
| | Dissolved Oxygen | Continuous | In-Line Analyzer |

Table 3 FXB Process In-Line Monitoring (Continued)

| Location | Parameter | Frequency | Analysis |
|---|---|---|---|
| Biofilter Effluent | Flow | Continuous | In-Line Flow Meter |
| | Perchlorate | 30 minutes | Ion chromatograph |
| | Nitrate/Nitrite | Continuous | In-Line Analyzer |
| | Dissolved Oxygen | Continuous | In-Line Analyzer |
| | pH/Temperature | Continuous | In-Line Analyzer |
| | Turbidity | Continuous | In-Line Analyzer |
| CT Pipe Effluent | Free Chlorine Residual | Continuous | In-Line Analyzer |
| Recovered Water | Turbidity | Continuous | In-Line Analyzer |
| Distribution System | Free Chlorine Residual | Continuous | In-Line Analyzer |
| Dechlorinated Backwash Supply | Free Chlorine Residual | Continuous | In-Line Analyzer |

A single sample panel houses all water quality monitoring instruments included in the package system, with the exception of a remote analyzer to be used for monitoring of CT pipe effluent (Figure 12).

Figure 12 Water Quality Monitoring Instruments

The FXB system equipped with an in-line ion chromatograph (IC), which samples for perchlorate in the biofilter effluent approximately every 30 minutes and exports data to the FXB system programmable logic controller (Figure 13). High perchlorate alarms (≥2.9 ppb) triggered at the PLC based on IC data trigger an immediate shutdown of the FXB system.

Figure 13 Ion Chromatograph

### 1.4.5 Proformance Data Management and Analysis

To enhance the performance monitoring capabilities, a Microsoft Access-based data management and analysis tool, called *"Proformance,"* was developed. Using the inline data collected through the supervisory control and data acquisition (SCADA) system, the tool provides rapid assessment of system performance by creating performance trend plots and running statistical analysis (Figure 14).

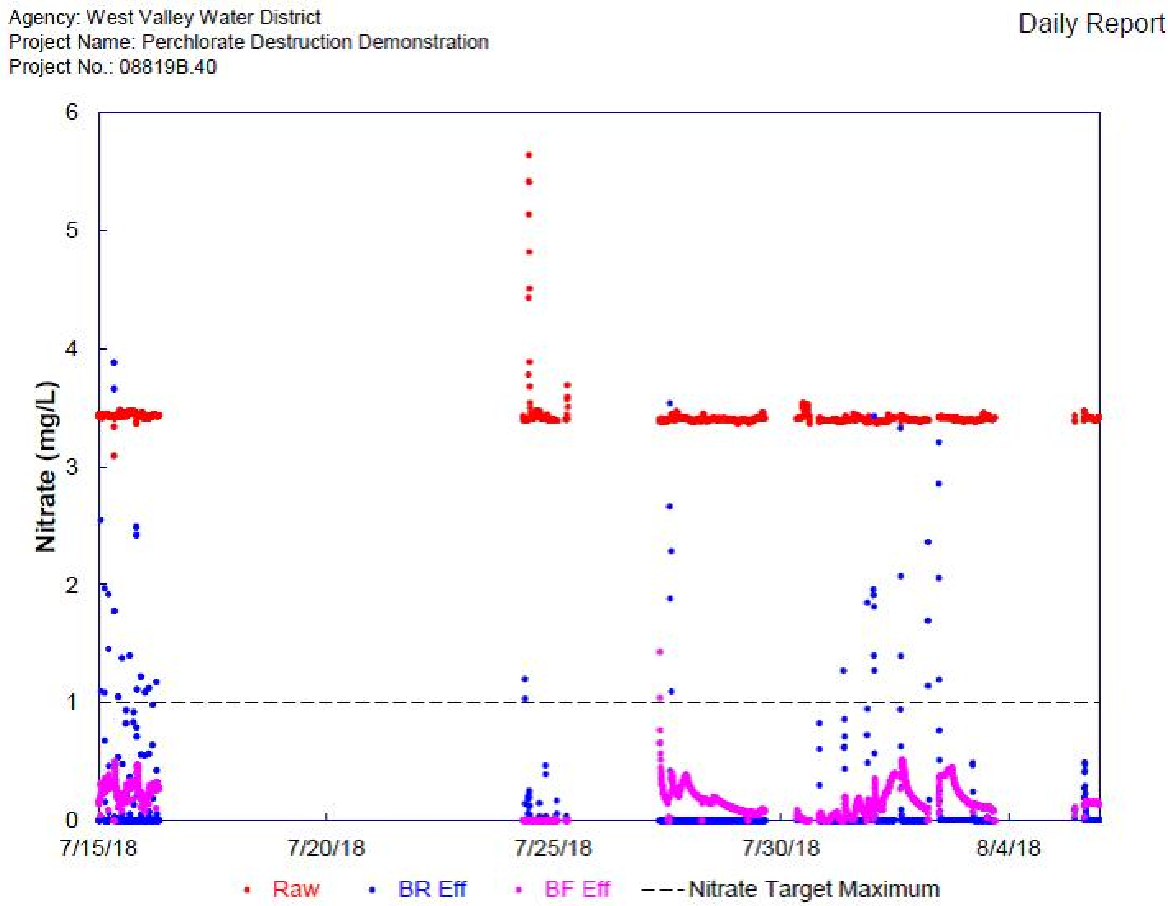


Figure 14 Plot Generated by Performance. Data Shown Correspond to the End of Challenge Testing and Beginning of Hydraulic Optimization

The tool has the following capabilities:

- Copy and store the raw in-line data (daily extracted from the SCADA system) as a separate master file within the program.
- Copy and store the lab results.
- Copy and store the field data collected on-site.
- Copy and store on-site events log sheet.
- Process the master data and create a separate data table that is used for statistical analysis and creating trend plots.

Visually, *Proformance* generates plots of:

- Raw water, bioreactor effluent, and biofilter effluent nitrate.
- Biofilter effluent perchlorate and turbidity.
- Raw water, bioreactor effluent, and biofilter effluent DO.
- Bioreactor and biofilter head loss.
- Overlaid plots of different parameters, such as effluent perchlorate and head loss or chemical feed.

- Run statistical analysis and generates values for minimum, maximum, average, standard deviation, 95th percentile, etc. for the various parameters monitored.
- Allow viewing performance trend plots and statistical data for any specified period.
- Generate a monthly monitoring report (MMR).

The *Proformance* tool was used starting from March 1st, 2018 to evaluate the system performance to see if any deviations from the typical performance trend were observed on a daily basis.

### 1.4.6 Alarms

The WVWD FXB system was programmed mid-February with a set of alarms that would alert the operators if a performance anomaly was detected (Figure 15). If a serious alarm was triggered, such as high effluent perchlorate, high differential pressure, or a chemical feed failure, then the plant would automatically shut down in order to protect public health. When any alarm occurred, an email and text message was sent to an operator to notify them of the incident. At this point they would acknowledge the alarm, fix the issues, and put the system back inline.

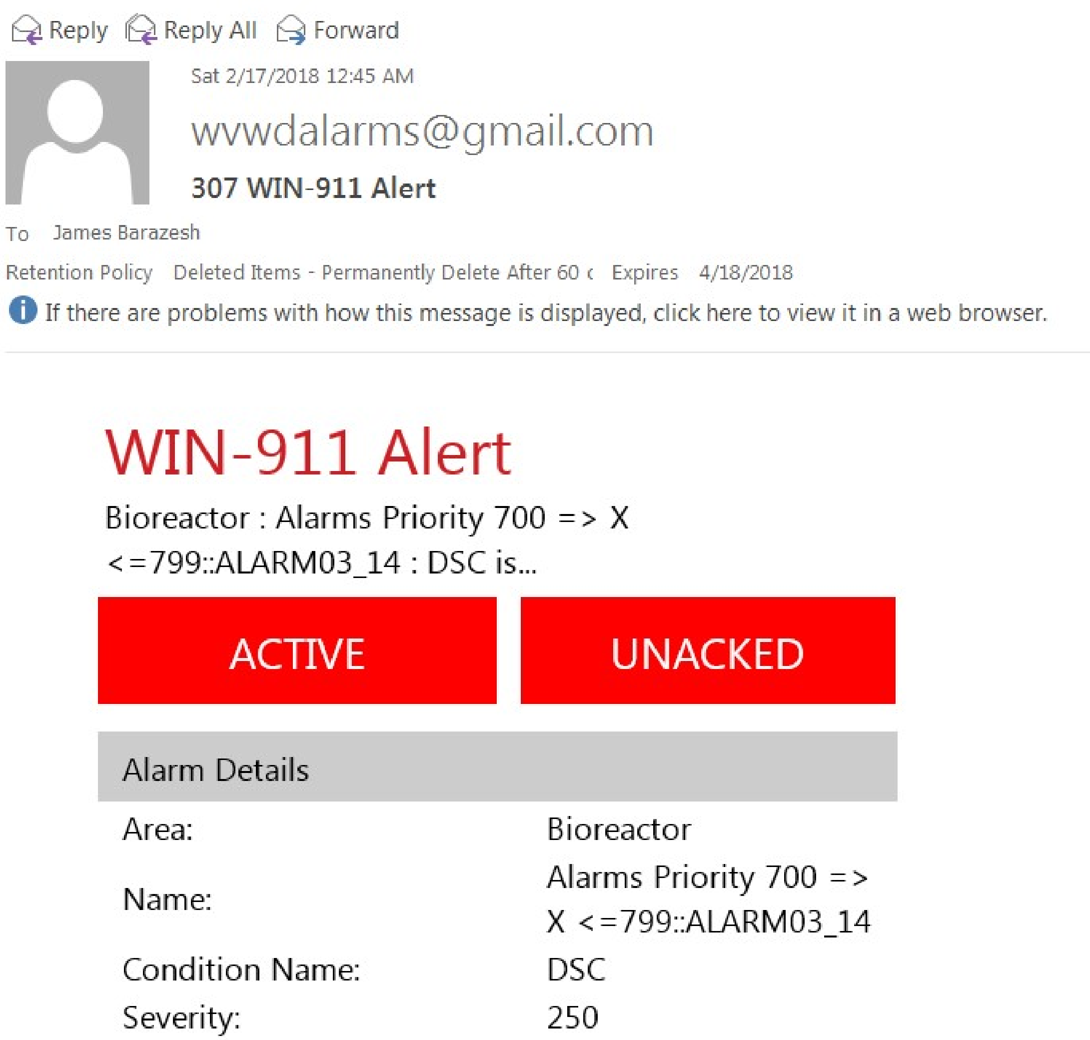


Figure 15 Alarm Issued by the FXB during a System Error

## 1.5 Demonstration Phase Operation

The overall objective of the demonstration was to evaluate perchlorate and nitrate removal across the full-scale FXB system. Testing phases included Biological Acclimation, Mechanical Equipment Modifications and Shakedown, Optimization, Optimal Operation, and Robustness Characterization.

**Demonstration Testing Phase 1** (Start up and Biological Acclimation): The purpose of this phase was to develop efficient perchlorate- and nitrate-reducing biological activity in the FXB bioreactor using microorganisms indigenous to the local groundwater.

**Demonstration Testing Phase 2** (Mechanical Equipment Modifications and Shakedown): The purpose of this phase was to make key mechanical modifications to improve the hydraulic performance of the FXB, including a vessel draindown and sludge pump modification. During this time the analytical detection of the IC was improved.

**Demonstration Testing Phase 3** (EBCT, Acetic Acid, and Backwash Optimization): The purpose of this phase was determine the minimum EBCT and acetic acid dose required to achieve target perchlorate and nitrate removal goals while maintaining process efficiencies of 95 percent or greater.

**Demonstration Testing Phase 4** (Optimal Operation): The purpose of this phase was to demonstrate sustained (~4 weeks), target perchlorate and nitrate removal using the optimal EBCT, acetic acid dose, and backwashing protocol determined during Phase 3 of testing.

**Demonstration Testing Phase 5** (Final Hydraulic Optimization): The purpose of this phase was to optimize the backwashing protocol to reduce the frequency but increase the backwash aggressiveness (e.g., air scour rate and duration, fluidization rate and duration) while maintaining complete contaminant removal. An overly aggressive biomass control strategy (i.e., backwashing) was in place to minimize the concentration of perchlorate reducers and provide a worst-case scenario on the system performance prior to robustness testing.

**Demonstration Testing Phase 6** (Robustness Characterization): The purpose of this phase was to determine how the FXB system responds to various process disturbances. Perchlorate and nitrate removal during both chemical (e.g., acetic and phosphoric chemical feed failure) and operational (e.g., system shutdown) disturbances were monitored and the time required for system recovery time was determined.

Figures 16, 17, and 18 below show the contaminant removal results across the various testing phases. Results from each testing phase, is described in more detail in subsequent sections.

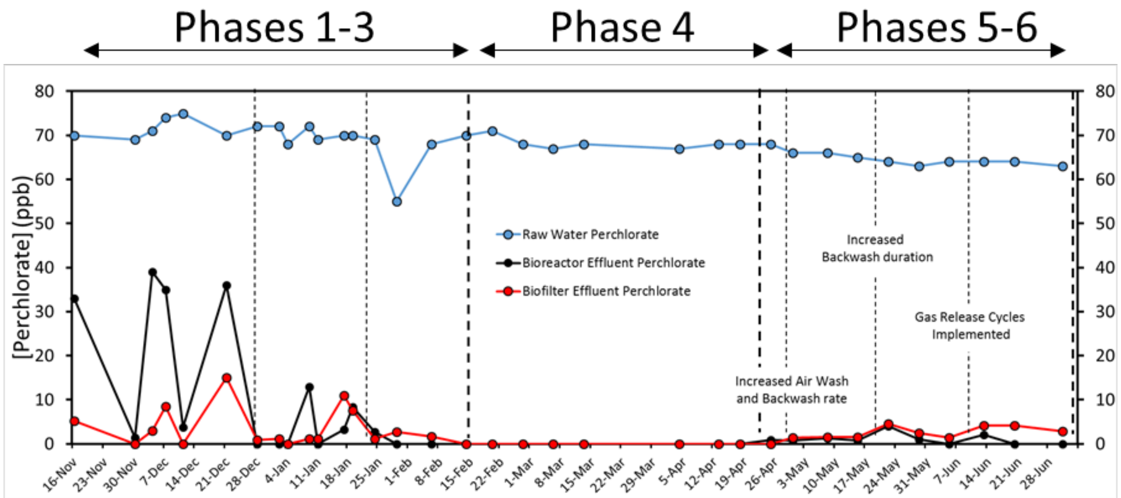


Figure 16 Perchlorate Removal during Demonstration Scale Testing

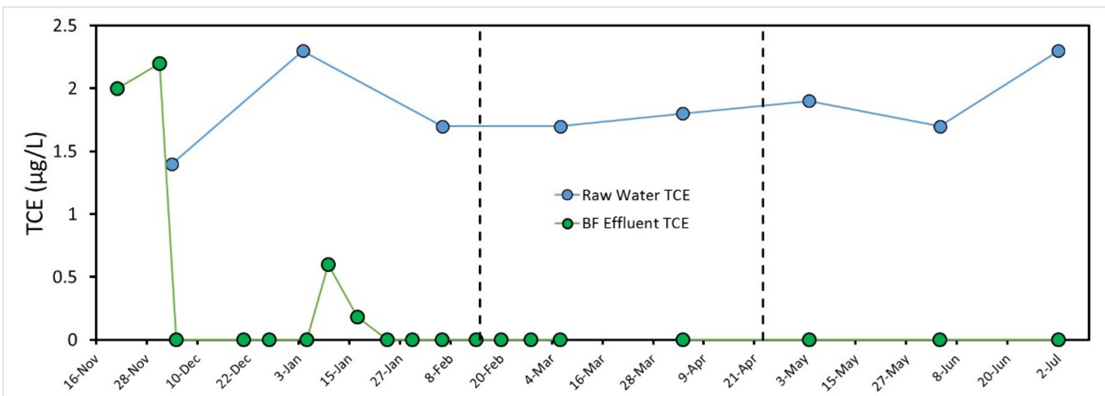


Figure 17 TCE Removal during Demonstration Scale Testing

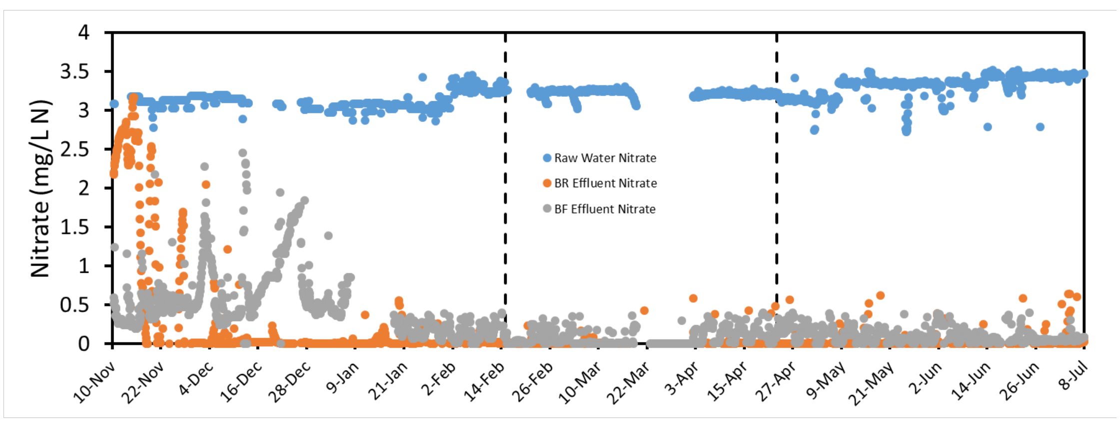


Figure 18 Nitrate Removal during Demonstration Scale Testing

### 1.5.1 Demonstration Testing Phase 1: Start up and Biological Acclimation

The FXB system was started up on November 9th, 2017 at a flow rate of 450 gpm, resulting in an EBCT of 9.4 minutes. Raw water perchlorate and nitrate were approximately 70 µg/L and 3.2 mg/L, respectively. Initially, acetic acid was dosed into the system at 32 mg/L which was later varied from 28 to 40 mg/L between December 2017 and February 2018. The phosphoric acid dose was maintained at 1 mg/L over this entire period.

Rapid perchlorate and nitrate removal were observed within the first two weeks of operation via adsorption onto virgin GAC within the bioreactor. Subsequently, nitrate- and perchlorate-reducing bacteria began to colonize the GAC which desorbed contaminants and resulted in a temporary increase in effluent nitrate and perchlorate from November 30th to December 10th. Low-level nitrite accumulation (i.e., 0.31 mg/L) was detected within the first week of biological acclimation, after which point complete denitrification was observed for the extent of the demonstration testing. Acetic acid dose was dropped to 28 mg/L January 10th, resulting in a brief increase in bioreactor and biofilter effluent nitrate, turbidity, and perchlorate, at which point the acetic acid dose was increased to 30 mg/L on January 19th.

Hydrogen peroxide was dosed into the bioreactor at a concentration of 16 mg/L beginning on December 28th, 2017. Dismutation of hydrogen peroxide on GAC resulted in dissolved oxygen concentrations in the biofilter effluent consistently above 3 mg/L. Aluminum chlorohydrate (ACH) was dosed upstream of the biofilter beginning on January 12th at a concentration of 4 mg/L, resulting in a decrease in average effluent turbidity from 0.48 NTU to 0.13 NTU.

#### 1.5.1.1 Microbial Community Analysis

Further evidence for the development of denitrifying and perchlorate-reducing microbial populations is provided from the results of 16S rRNA gene sequencing (Figure 19). After complete nitrate and perchlorate removal was observed, bioreactor media samples were taken on January 11th and the microbial community within the bioreactor was analyzed. At the genus level, the second most abundant bacteria was *Dechloromonas*, one of two main perchlorate-reducing genera. The most abundant genus was *Rubrivivax*, a genus known to include many nitrate-reducing species. *Hydrogenophaga*, the third most abundant genus, is also a known to include many nitrate-reducing species. Collectively, the dominance of nitrate- and perchlorate-reducing bacteria demonstrates the successful adaption of the system.

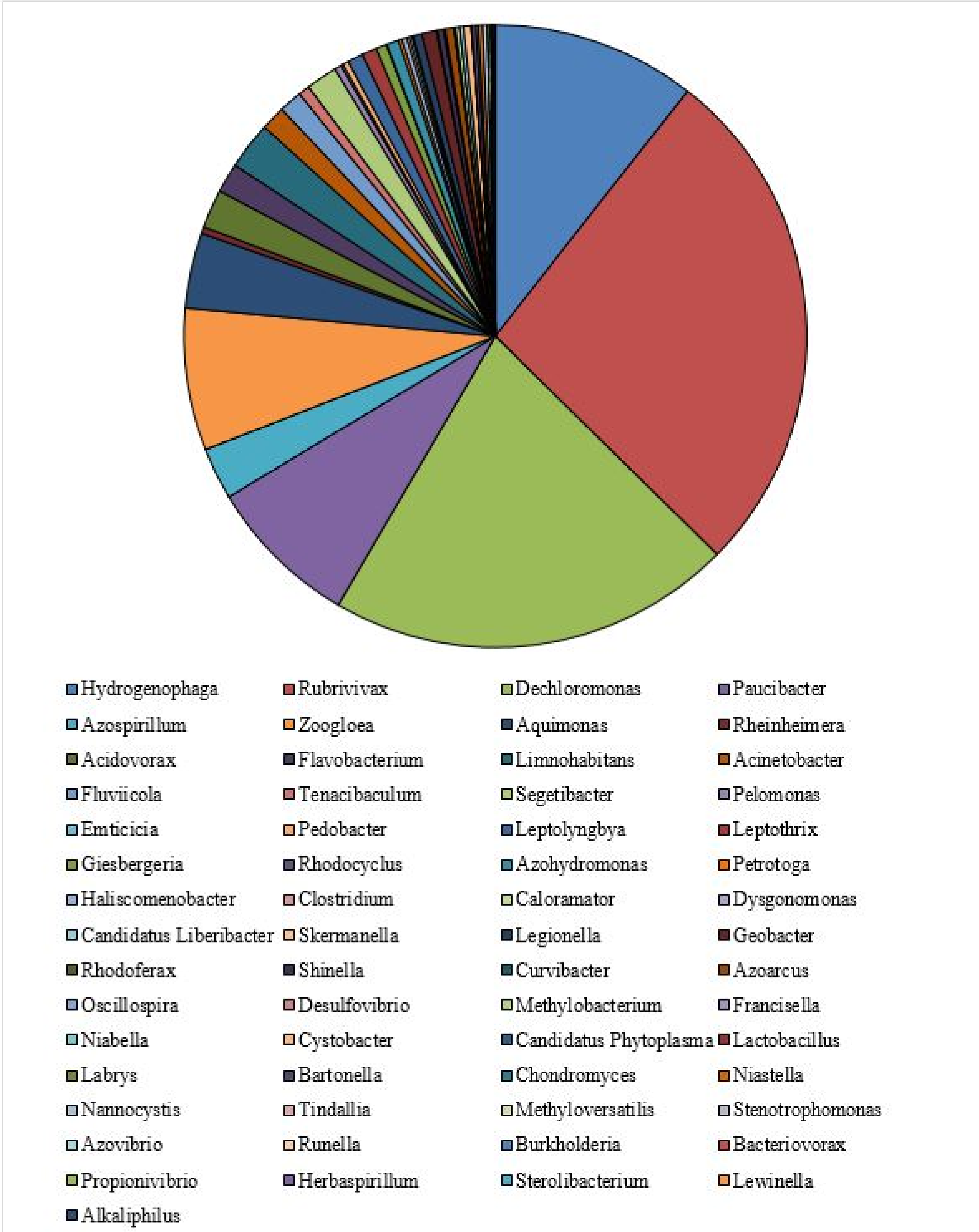


Figure 19 Microbial Community Analysis

### 1.5.2 Demonstration Testing Phase 2: Mechanical Equipment Modifications and Shakedown

#### 1.5.2.1 Vessel Draindown Modifications

The treatment vessel draindown connections were designed with a screen insert that served as a nucleation surface for biomass growth which negatively impacted backwash performance

(Figure 12; left). In March 2018, the vessel draindown connects were modified to eliminate the biofouling issue. The screen insert was removed and replaced with 45° upturn elbows to prevent media washout during a backwash (Figure 20; right).


Figure 20 Vessel Draindown Modifications

#### 1.5.2.2 Sludge Pump Modifications

Vibration of the peristaltic sludge pump caused shaking in the connecting pipe which led to a crack (Figure 21; left). To address this, bellow joints and kickers were installed on both the suction and discharge of the pump and the discharge piping was rebuilt with galvanized steel incorporating 2, 45° elbows (Figure 21; right). Furthermore, a 2" flex coupling and pulsation dampener were installed on the discharging piping. The changes abated the shaking even when the peristaltic sludge pump was operating at 100 percent speed.


Figure 21 Sludge Pump Modifications

#### 1.5.2.3 Analytical Detection Optimization

The FXB uses an in-line Dionex ICS 5000 IC to sample for perchlorate in the biofilter effluent every 30 minutes. Since the plant inception, there have been analytical detection issues on the IC and communication issues between the IC and the SCADA PLC:

- **11/09/2017:** Limited communication between the Dionex IC and SCADA until late January, resulting in no real time feedback of system performance.
- **12/01/2017:** Power outage resulted in damages to the IC software which caused 1 month of no connection between the Dionex IC and SCADA.
- **01/27/2018:** Communication between SCADA and the IC reestablished, however, the system could only run limited number of samples before shutting off. Issue was resolved by replacing all the consumables used by the IC (i.e., eluent generator, suppressor, columns, CRTC), deleting all the stored data, and backing up the system.
- **02/08/2018:** Wavy chromatograms with multiple peaks eluting around the retention time of perchlorate. Dionex IC was replumbed to utilize IC pure water and a new type of CRTC trap column was installed.
- **04/22/2018:** Poor chromatograms not resolved and the system was replumbed back to the original configuration. Thermofisher representative resolves issue by correcting errors in the dilution pump and sample loop volumes.

Current Status of the IC:

- We are able to remote into the Dionex IC and perform all tasks remotely if needed.
- Significant changes to the quantification method to lower our detection limit to around 1.8 - 2 ppb which increases to 3 - 4 ppb over the course of a month. New columns have a very low conductivity baseline and highly symmetrical compact peaks. Constantly running treated water samples exhausts active silica sites which increases the baseline, broadens the peaks, and shifts the peak retention time. This results in lower resolution of peaks and increased detection limit, causing samples to underestimate perchlorate in the biofilter effluent.
- Part of the issue is that while we have exceptional detection in IC pure water, background conductivity of the treated water is high and perchlorate is eluting on a slope which makes it very difficult for the system to automatically detect anything less than 2 ppb.

#### 1.5.2.4 Reclaim Water Recirculation Contamination

When the FXB system backwashes the bioreactor to remove excess biomass from the system along with any solids deposited in the media bed over the course of a run cycle, the entire contents of the bioreactor (~9,300 gallons) are displaced and sent to the backwash waste tank along with ~18,000 gallons of backwash supply water provided from the WVWD Booster Pump Station 4-2. Of the 9,300 gallons in the bioreactor, approximately 5,500 gallons are raw water above the media that contains 3.4 mg/L nitrate and 70 µg/L perchlorate. The backwash supply water from the distribution system contains 0.6 mg/L nitrate. Therefore, ~27,000 gallons are supplied to the backwash waste tank that have been diluted to a concentration of 15 µg/L perchlorate and 0.8 mg/L nitrate.

In order to maximize the water recovery from the FXB system, water is recovered from the backwash waste tank after solids settling and sludge disposal and reclaimed to the biofilter at a rate of 50 to 75 gpm. This reclaim water, which contains 15 µg/L perchlorate and 0.8 mg/L nitrate, is further diluted with bioreactor effluent (~375 gpm). Accordingly, this leads to systemic, low-level (~2.5 µg/L) perchlorate leaving the biofilter effluent during periods when the system is reclaiming. These issues have been resolved by two modifications to the plant. The first involved a modified draindown from the bottom of the bioreactor instead of the top, which provides additional treatment of the perchlorate-laden water as it moves through the bed and into the backwash waste tank. The second modification involved reclaiming the recovered water to the front of the bioreactor, thereby allowing for further treatment.

### 1.5.3 Demonstration Testing Phase 3: EBCT, Acetic Acid, and Backwash Optimization

Process optimization began once stable nitrate and perchlorate removal performance was established (~ January 25$^{th}$). This included optimization of chemical dosing and backwash settings. Chemical doses were optimized by determining the lowest doses required to meet all water quality requirements. Over the period from January 25$^{th}$ to February 15$^{th}$, the system flow was varied from 350 to 540 gpm to observe the effects of EBCT on contaminant removal. Although perchlorate and nitrate were degraded to non-detectable values over the entire period, curtailed bioreactor run times were observed at the higher flow rates. Complete and consistent perchlorate reduction was able to be achieved through decreasing the acetic acid dose used during acclimation (average ~ 33 mg/L) to 30.5 mg/L while increasing the phosphoric acid dose to 1.75 mg/L. Hydrogen peroxide concentration varied between 15 to 18 mg/L to ensure a residual effluent dissolved oxygen above 4 mg/L. Changes in hydrogen peroxide were directly related to changes in acetic acid dosing as excess acetic acid carrying over from the bioreactor to the biofilter consumed hydrogen peroxide and lowered the dissolved oxygen concentration. As effluent turbidity was consistently below 0.3 NTU, the interstage ACH dose remained at 4 mg/L. The optimized chemical dosing parameters are summarized in Table 4 below.

Table 4 Operational Chemical Parameters Prior to Optimal Operation

| Parameter | Value |
|---|---|
| System Flow (gpm) | 450 |
| Empty Bed Contact Time (EBCT; min) | 9.4 |
| Acetic Acid Dose (mg/L) | 30.5 |
| Phosphoric Acid Dose (mg/L) | 1.75 |
| Interstage Coagulant Dose (mg/L) | 4 |
| Interstage Hydrogen Peroxide Dose (mg/L) | 18 |
| Bioreactor run time between Backwash (hrs) | 20 – 30 |

Backwash optimization consisted of observing the turbidity entering the backwash waste tank over the duration of a backwash while varying the duration of the air scour, air wash, and high-rate backwash. Backwash air scour varied between 120 to 300 seconds, air wash varied between 75 to 170 seconds at a fixed flow rate of 1360 gpm, and the high-rate backwash was varied from 300 to 360 seconds at a fixed flow rate of 1810 gpm. An optional third backwash was tested at 680 gpm to improve flow equalization, however, it was abandoned during the optimal operation phase. An optimal backwash coagulant dose of 21 mg/L ACH was determined via jar tests. The optimized backwash parameters are summarized in Table 5 below.

Table 5 Operational Backwash Parameters Prior to Optimal Operation

| Parameter | Value |
|---|---|
| Draindown Volume (gallons) | 3000 |
| Air Scour (seconds) | 300 |
| Air Wash time (seconds) / flow rate (gpm) | 120/680 |
| Backwash 1 time (seconds) / flow rate (gpm) | 30/680 |
| Backwash 2 time (seconds) / flow rate (gpm) | 335/1810 |
| Backwash 3 time (seconds) / flow rate (gpm) | 0/680 |
| Backwash Coagulant (mg/L) | 21 |

### 1.5.4 Demonstration Testing Phase 4: Optimal Operation

Using the optimized chemical feed process parameters and backwash determined in Phase 3, the FXB system was operated continuously for approximately ten weeks February 15th to April 23rd. During this time, there was a complete system shutdown from March 17th to April 2nd to accommodate the key design changes to the plant. Table 6 summarizes the nitrate, dissolved oxygen, turbidity, and lab-determined perchlorate and TCE in the raw water, bioreactor effluent, and biofilter effluent over this time period.

Table 6 Contaminant Removal during Optimal Operation

| | | Raw Water | Bioreactor Effluent | Biofilter Effluent |
|---|---|---|---|---|
| Perchlorate (µg/L) | Average | 68.33 | 0.10 | 0.00 |
| | Stdev | 1.32 | 0.31 | 0.00 |
| Nitrate (mg/L N) | Average | 3.22 | 0.01 | 0.01 |
| | Stdev | 0.04 | 0.05 | 0.05 |
| Oxygen (mg/L) | Average | 7.89 | 0.04 | 5.06 |
| | Stdev | 0.81 | 0.09 | 1.01 |
| TCE (µg/L) | Average | 1.85 | N/A | 0.00 |
| | Stdev | 0.31 | N/A | 0.00 |
| Turbidity (NTU) | Average | N/A | N/A | 0.07 |
| | Stdev | N/A | N/A | 0.11 |

A detailed analysis of the trends for each contaminant over this period is provided below.

#### 1.5.4.1 Perchlorate

Figure 22 shows the lab-determined and inline analyzer results for biofilter effluent perchlorate from February 15th to April 23rd. Average biofilter perchlorate over this period was 1.4 ± 3.2 µg/L, although spikes above the 2.9 µg/L limit were observed during this time. However, as mentioned in section 5.2.3, the inline IC was compromised during a period from February to the end of April. Therefore, interpretation of the results from the inline analyzer requires caution, particularly since cross-referenced samples from the clinical lab yielded non-detect values. Nonetheless, additional research is needed with more finite resolution to validate these results and confirm complete and consistent perchlorate removal.

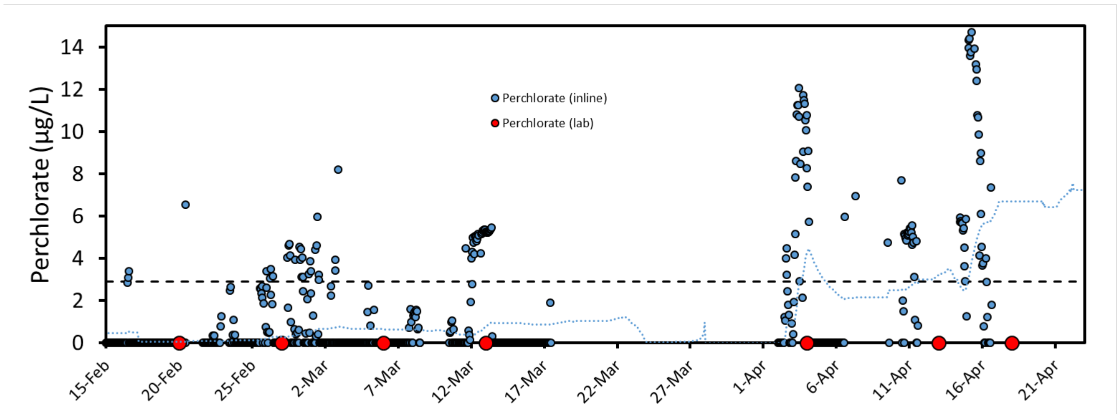


Figure 22 Perchlorate Removal during Optimal Operation

### 1.5.4.2 Nitrate

As shown in Figure 23 and Table 4, complete and sustained removal of nitrate was observed in the bioreactor and biofilter (i.e., nitrite did not accumulate in the system, suggesting complete reduction to nitrogen gas) from February 15th to April 23rd. Brief spikes in nitrate occurred in the bioreactor and biofilter shortly after a backwash due to the dilution of each vessel with distribution water containing ~0.6 mg/L nitrate, however, values never exceeded 1 mg/L and dropped to pre-backwash levels within 30 minutes. Similar nitrate removal was observed before and after the system was shutdown for two weeks, demonstrating the resilience and robustness of the system.

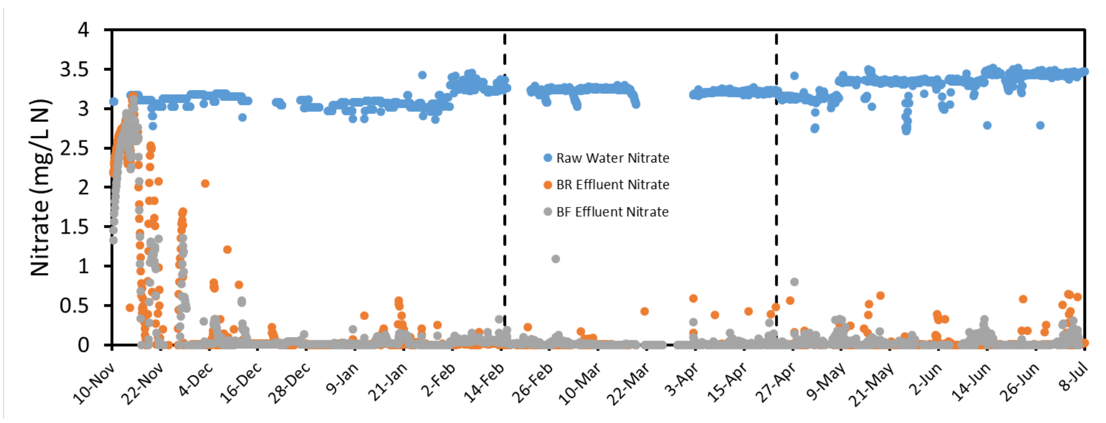


Figure 23 Nitrate Removal during Optimal Operation

### 1.5.4.3 Oxygen

Figure 24 presents the raw water, bioreactor effluent, and biofilter oxygen from February 15th to April 23rd. Raw water oxygen maintained at near saturation (7.89 ± 0.8 mg/L), while complete removal of oxygen was observed from the bioreactor (0.04 ± 0.1 mg/L) over the entire period. Dismutation of hydrogen peroxide on GAC resulted in dissolved oxygen concentrations in the biofilter effluent consistently above 3 mg/L, with an average value of 5.06 ± 1 mg/L.

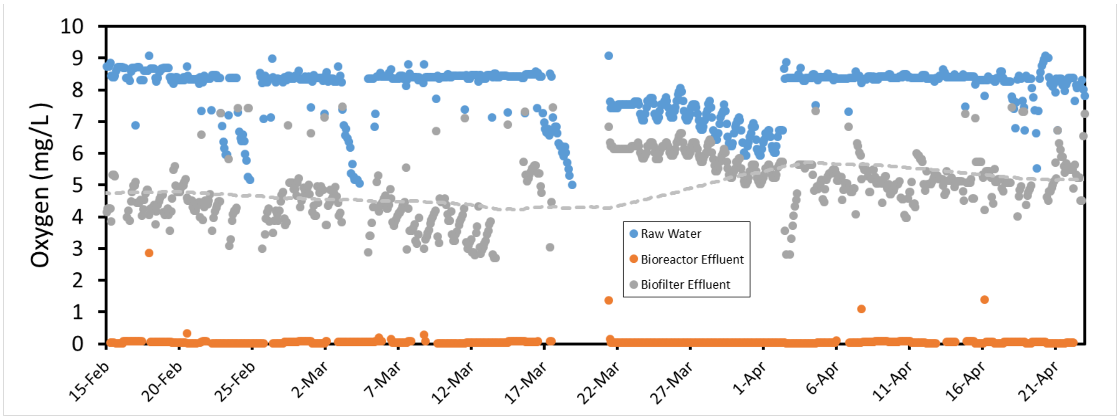


Figure 24 Oxygen Removal during Optimal Operation

### 1.5.4.4 Turbidity

Figure 25 presents biofilter effluent turbidity from February 15th to April 15th. The turbidity goal was achieved consistently with 96.7 percent of the final effluent turbidity sampled every 15 minutes remaining less than 0.3 NTU. Brief spikes above 0.3 NTU were observed shortly after either a bioreactor backwash, caused by higher turbidity loading onto the biofilter immediately following a bioreactor backwash (i.e., backwashing loosens the fixed biofilms, some of which breaks through the bioreactor when it goes back into service immediately following a backwash event). Bench-scale turbidity measurements indicated that the turbidity increased as high as 0.6 NTU, however, the in-line turbidimeter reported values as high as 1.3 NTU. Control experiments revealed that false higher turbidity values were reported by the in-line analyzer due to the stopping and starting of flow to the analyzer via the solenoid valves, which introduced air into the system. This was further evidenced by similar increases in the in-line analyzer turbidity measurements during both a bioreactor and biofilter backwash, although bench scale analysis indicated no actual increases in turbidity were occurring during a biofilter backwash.

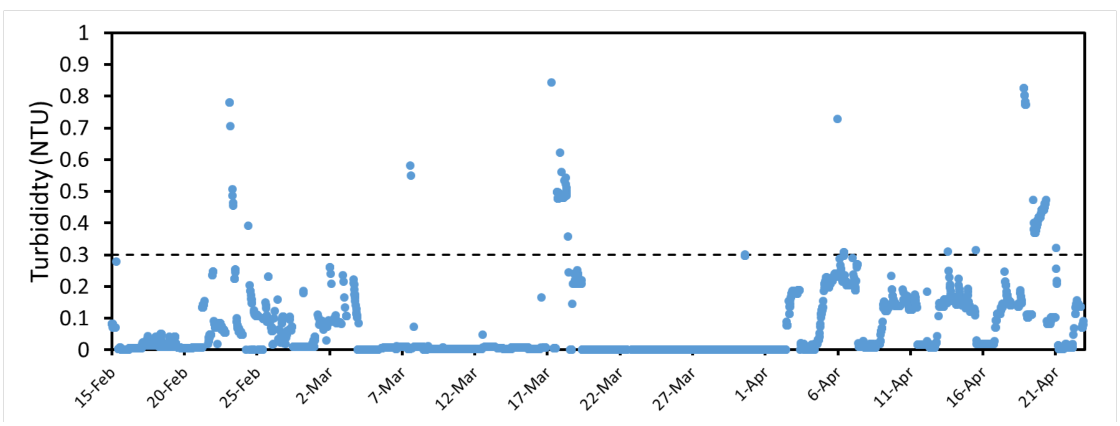


Figure 25 Turbidity Removal during Optimal Operation

#### 1.5.4.5 TCE

As evidenced by Figure 16 above, complete and consistent removal of TCE from 1.85 ± 0.31 µg/L to non-detect values was observed beginning on January 20th, 2018 and remained as such for the remainder of the demonstration testing phase (including robustness testing).

### 1.5.5 Demonstration Testing Phase 5: Final Hydraulic Optimization

In addition to the chemical optimization undertaken in Phase 3 of the demonstration testing, hydraulic process optimization was undertaken once stable nitrate and perchlorate removal performance was established for the optimal operation period. The objective of this phase was to observe if longer runtimes could be achieved through less frequent, but more aggressive backwashes (i.e., increased air scour, air wash, and backwash rate and duration) without compromising contaminant removal. Extending the frequency at which backwashes are performed results in lower operational costs for the plant, less risk of a backwash-related chemical feed failure, and less oversight needed by the operators to operate the FXB. Changes to the backwash regime took place between April 20th, and July 2nd. On May 16th, draindown volumes were increased from 2500 gallons to 3450 gallons to accommodate an increase in the high-rate backwash rate from 1975 gpm to 2090 gpm and low-rate backwash from 680 gpm to 800 gpm. Air scour was also increased from 300 to 420 seconds. To balance out the increased loss of biomass from the aggressive backwash regime and maintain a healthy population of perchlorate-reducing bacteria, acetic acid and phosphoric acid doses were both increased by ~1.5 mg/L to 34.5 and 3.75 mg/L, respectively. Gas release cycles (GRCs) were also implemented beginning on June 10th. GRCs consisted of a 30 to 45 second chlorinated, high-rate backwash though the bioreactor to purge any entrapped $N_2$ gas and redistribute the media in order to prevent short circuiting and promote increased contact time between the substrate, contaminant, and biomass.

Counterintuitively, the increased aggressiveness of the backwashes resulted not only in worse contaminant removal but also shorter run times in the bioreactor before a backwash was needed. Average lab-reported bioreactor and biofilter effluent perchlorate increased to 1.1 ± 1.2 µg/L and 2.7 ± 1.5 µg/L. Furthermore, the increased flow rate during backwashing resulted in air locking and poor biomass expulsion from the bioreactor which materialized as rapid headloss accrual and 12 to 15 hour bioreactor runtimes.

Although the hydraulic changes resulted in worse-contaminant removal in the bioreactor relative to removal in Phase 4, these hydraulic conditions and chemical dosages were employed for robustness testing in order to estimate contaminant breakthrough under worse case scenarios. Following robustness testing, the plant was reverted back to the operating conditions utilized in Phase 4.

### 1.5.6 Demonstration Testing Phase 6: Robustness Characterization

#### 1.5.6.1 Robustness Testing Goals

This robustness testing protocol was developed to supplement the robustness testing plan presented in the 97-005 Technical Memorandum prepared in 2017 for the Fixed Bed Biological Perchlorate Destruction Project. The testing protocol identified the potential failure modes of the FXB system that could contribute to impacts on water quality and public health, methods of testing, data collection and analysis, and schedule of work. Results of this testing will be used in the assessment of human health risks required by Process Memo 97-005.

This testing provided data on finished water quality following system failure/upset via each of the failure modes evaluated. The goal of this evaluation was to demonstrate that the FXB system is robust, and that any failures/upsets within the system presented a minimal risk of adverse health effects.

#### 1.5.6.2 Evaluation Criteria

The following contaminants and MCLs were considered in the robustness testing (Table 7). It should be noted that exceedance of some of these values was expected during robustness testing, and that the goal of the tests was to assess the response of the system to failures and water quality excursions, and to demonstrate that the system was robust enough to capture any resulting non-compliant water prior to entering the distribution system.

Table 7 Evaluation Criteria

| Parameter | Maximum Contaminant Level | Typical Raw Water Level | Typical Treated Water Level |
|---|---|---|---|
| Perchlorate | 6 µg/L | 70 µg/L | <2 µg/L |
| Nitrate | 10 mg/L as N | 3.5 mg/L as N | <0.5 mg/L as N |
| TCE | 5 µg/L | 3 µg/L | <1 µg/L |
| Turbidity | <0.3 NTU, 95% of Samples | - | 0.1 NTU |

#### 1.5.6.3 Robustness testing conditions

Robustness testing was performed at the WTS facility located at WVWD headquarters. Robustness testing took place under normal operating conditions, with feed water from Wells 6 and 11, during parallel operation of the FBR system. Prior to each test, the system was brought to an optimized steady state operating condition to facilitate comparable starting conditions for each test, and to simulate the impacts to the system of each failure when discharging to the distribution system. During challenge testing the system was configured to discharge to the Cactus Basin.

#### 1.5.6.4 Water Quality Monitoring

During robustness testing, water quality was monitored using a combination of in-line analyzers, grab samples analyzed at the plant laboratory, and grab samples analyzed by an outside laboratory (Clinical Lab of San Bernardino – CA SWRCB ELAP Accreditation/Registration number 1233). All samples analyzed by the clinical lab were performed utilizing EPA or other ELAP approved methodologies. All analytical data collected during challenge testing have been provided as supplemental information. While water quality monitoring focused on parameters pertaining to public health impacts (perchlorate, nitrate, TCE), some analyses were conducted to assess process performance as a result of the robustness tests (acetate, orthophosphate).

### 1.5.7 Pre-Testing Conditions

Prior to starting the test, the FXB continued discharging to the flood control basin adjacent to the treatment plant using the following operational conditions (Table 8).

Table 8 Operational Parameters Prior to Challenge Testing

| Parameter | Value |
|---|---|
| System Flow (gpm) | 400 |
| Empty Bed Contact Time (EBCT; min)(1) | 9.51 |
| Acetic Acid Dose (mg/L) | 34 |
| Phosphoric Acid Dose (mg/L) | 3.75 |
| Interstage Coagulant Dose (mg/L) | 4 |
| Interstage Hydrogen Peroxide Dose (mg/L) | 16.5 |
| Bioreactor run time between Backwash (hrs) | 12 |
| Gas Release Cycle frequency (hrs)(2) | 2 |

Notes:
(1) EBCT: Empty bed volume divided by flow rate.
(2) Gas Release Cycle are a 30-45 second high-rate backwash to remove entrapped $N_2$ gas bubbles and improve hydraulic performance.

Twelve hour run times and between backwashes were selected to provide complete and consistent removal of nitrate and perchlorate throughout the depth of the bioreactor. As mentioned previously, due to buildup of $N_2$ gas during denitrification, channeling and inhibited diffusion of contaminants through the biofilm progressively shifted contaminant removal to lower portions of bioreactor bed (Figure 26). Data correspond to the time after a bioreactor backwash that the depthwise profile was taken (i.e., 1 hr means depthwise samples were taken 1 hour after a bioreactor was backwashed).

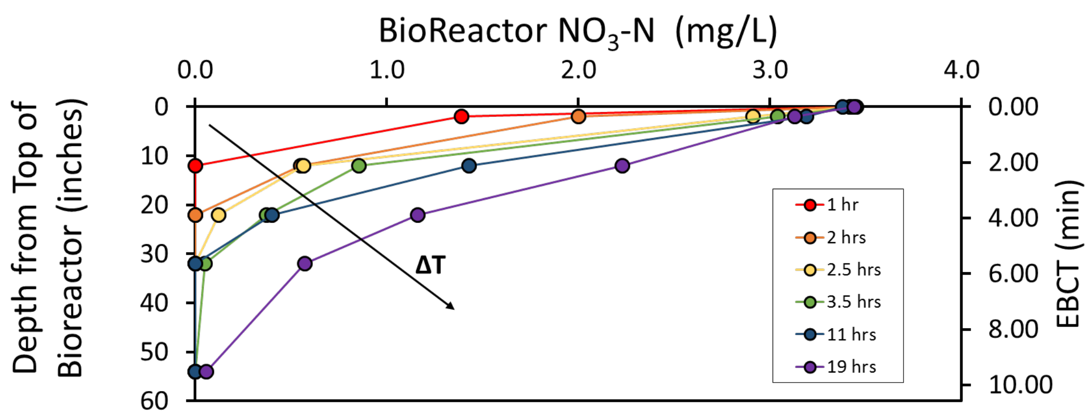


Figure 26 Depthwise Nitrate Removal over a Bioreactor Run

To address this diminishing performance, GRCs which consist of a 30 to 60 second backwash at 1810 to 1975 gpm have been implemented every 2 hours to purge the entrapped $N_2$ gas bubbles. GRCs have been proven to reduce the headloss accumulation in the bioreactor and improve contaminant removal in the bottom ports, however, a temporary increase (~10 minutes) in the bioreactor effluent nitrate and dissolved oxygen occurs due to the dilution of the bioreactor with distribution water which contains 0.6 mg N/L nitrate and 8 mg/L dissolved oxygen.

### 1.5.7.1 Robustness Tests and Schedule

Robustness tests will include the following:

- Acetic acid (electron donor) feed failure test.

- Combined Phosphoric acid (nutrient) and 24-hour system shutdown test.
- Simulation of an emergency shutdown due to a system failure/critical alarm.
- Chlorinated backwash test.

Each of these tests is described in detail in this section. The proposed FXB system robustness testing schedule is presented in Table 9.

Table 9 Robustness Testing Schedule

| Event | Start Date | Estimated Duration |
|---|---|---|
| Acetic Acid Failure Test | July 2, 2018 | 1 day |
| Phosphoric Acid Failure/ Shutdown Test | July 6, 2018 | 2 days |
| Emergency Shutdown Test | July 9, 2018 | 1 day |
| Chlorinated Backwash Test | July 11, 2018 | 1 day |

### 1.5.7.2 Acetic Acid Feed Failure Test

*Overview*

Acetic acid (electron donor) is the primary chemical fed to the FXB process that facilitates the biological reduction of contaminants such as perchlorate and nitrate. Therefore, in the absence of the electron donor, reduction of these compounds is not able to be completed, as the microbes do not have a sufficient carbon and electron source to sustain growth and facilitate redox reactions. Depending on the extent of the failure and the concentrations of contaminants in the raw water, this may result in higher than the target levels (i.e., 1 mg/L nitrate as N, 1 µg/L perchlorate) in the treated effluent. Inadequate acetic acid dose may also result in the presence of nitrite in treated effluent due to incomplete nitrate reduction.

An electron donor feed failure was simulated by shutting off the acetic acid pump and associated alarms. Testing determined the time required for perchlorate and nitrate breakthrough in the FXB system effluent following the failure.

*Objectives*

The objective of this test was to demonstrate that:

- Redundant features of the FXB system (including the biofilter and treated water tank) allow the resulting contaminant breakthrough to be detected and captured before it is able to reach the distribution system.
- Resulting contaminant breakthrough (nitrate) will be detected in the bioreactor effluent before it is detected in the biofilter effluent, preventing the need to turn over water in the treated water tank.
- Contaminant breakthrough occurs an appreciable amount of time following the failure of the acetic acid feed.

*Testing Procedure*

Prior to initiating the test, a backwash was performed and the system was allowed to run until nitrate and perchlorate values stabilized at non-detect. The acetic acid metering pump was then placed in MANUAL mode within SCADA and all alarms and interlocks associated with the acetic acid pump were disabled to allow the FXB system to continue running following the failure.

The test was initiated by stopping the feed of acetic acid to the system by setting the pump speed at 0 percent and then closing the isolation valve at the acetic acid injection quill. Time for the failure test began as soon when the pump is stopped.

Bioreactor effluent grab samples were collected every 30 minutes as indicated in Table 8 (Acetic Acid Feed Failure Test Sampling Plan), for a maximum of 4-hours. The system continued to operate until perchlorate breakthrough was detected in the biofilter effluent, considered to be three consecutive samples with a value of 4 µg/L or higher, based on the limit of detection of the in-line IC. Once perchlorate breakthrough was detected, the acetic acid feed was restored by placing the pump into AUTO mode. Operation and sampling in this state continued as indicated in Table 10 until biofilter effluent perchlorate stabilizes at pre-test levels.

*Acetic Acid Sampling Plan*

Table 10 Acetic Acid Feed Failure Test Sampling Plan

| Analysis | Parameter | Sampling Location | | | | | |
|---|---|---|---|---|---|---|---|
| | | Raw Water | Bioreactor Effluent | Biofilter Effluent | Treated Water Tank Effluent | Bioreactor Depthwise Profile | Biofilter Depthwise Profile |
| In-Line | Perchlorate | | | Every 30 min | | | |
| | Nitrate | Continuous | Continuous | Continuous | | | |
| WVWD Lab | Perchlorate | | -Every 30 min for first 4 hours<br>-Every 30 min after ACA feed restoration until BF perchlorate = ND | | -Every 30 min after ACA feed restoration until 1 HRT following BF perchlorate = ND | | |
| | Nitrate | | | | | -1X prior to starting test<br>-1X at biofilter breakthrough<br>-1X at end of test | -1X prior to starting test<br>-1X at biofilter breakthrough<br>-1X at end of test |
| Outside Lab | Perchlorate | -1X prior to starting test<br>-1X at biofilter breakthrough<br>-1X at end of test | -1X prior to starting test<br>-1X at biofilter breakthrough<br>-1X at end of test | -1X prior to starting test<br>-1X at biofilter breakthrough<br>-1X at end of test | -1X prior to starting test<br>-1X at biofilter breakthrough<br>-1X at end of test | -1X prior to starting test<br>-1X at biofilter breakthrough<br>-1X at end of test | -1X prior to starting test<br>-1X at biofilter breakthrough<br>-1X at end of test |
| | Nitrate | -1X prior to starting test<br>-1X at biofilter breakthrough<br>-1X at end of test | -1X prior to starting test<br>-1X at biofilter breakthrough<br>-1X at end of test | -1X prior to starting test<br>-1X at biofilter breakthrough<br>-1X at end of test | -1X prior to starting test<br>-1X at biofilter breakthrough<br>-1X at end of test | | |
| | TCE | -1X prior to starting test<br>-1X at biofilter breakthrough<br>-1X at end of test | -1X prior to starting test<br>-1X at biofilter breakthrough<br>-1X at end of test | -1X prior to starting test<br>-1X at biofilter breakthrough<br>-1X at end of test | | | |
| | Dissolved Organic Carbon | | -Every 30 min for first 4 hours | | | | |

### *Acetic Acid Challenge Test Results*

Electron donor was discontinued at 11:00 AM July 2nd, 2018 (Figure 27). Within 30 minutes, bioreactor Effluent DOC dropped from 1 to 0.22 mg/L while bioreactor effluent nitrate and perchlorate increased from non-detect to 0.22 mg/L and 29.3 µg/L, respectively. Bioreactor nitrate and perchlorate reached a maximum of 1 mg/L nitrate and 49 µg/L after 244 minutes and 180 minutes after acetic acid was discontinued, respectively. Breakthrough of nitrate and perchlorate in the Biofilter occurred after 50 minutes and 150 minutes after acetic acid was discontinued, respectively, reaching values of 0.4 mg/L N and 10 µg/L. These results indicate that the biofilter provides a buffering effect where contaminant breakthrough is delayed and dampener relative to the bioreactor. During each GRC ~ 2000 gallons of distribution water containing 0.6 mg/L nitrate was introduced into the bioreactor which diluted the bioreactor effluent and resulted in temporary dips in the nitrate concentration.

Acetic acid was reinstated after 232 minutes of being off at 2:52 PM on July 2nd, 2018. Although the first sample with Biofilter perchlorate in excess of 4 ppb was observed after 150 minutes, acetic acid was not reinstated until three samples were observed exceeding 4 ppb and after 20 minutes following a GRC. Rapid reacclimation was observed within the bioreactor as effluent nitrate and perchlorate were reduced to pre-test levels within 36 minutes and 60 minutes of reintroducing acetic acid, respectively. Unlike the bioreactor, the biofilter demonstrated slower desorption of contaminants once acetic acid was introduced. Perchlorate dropped below 2.9 ppb after 403 minutes while nitrate dropped and stabilized at 0.06 mg/L after the same amount of time. Complete TCE removal in the bioreactor and biofilter was observed throughout the entirety of the test independent of acetic acid dosing (Figure 27). Note, bioreactor effluent TCE samples are graphically hidden behind the biofilter effluent TCE values, both of which are 0 µg/L (Figure 28).

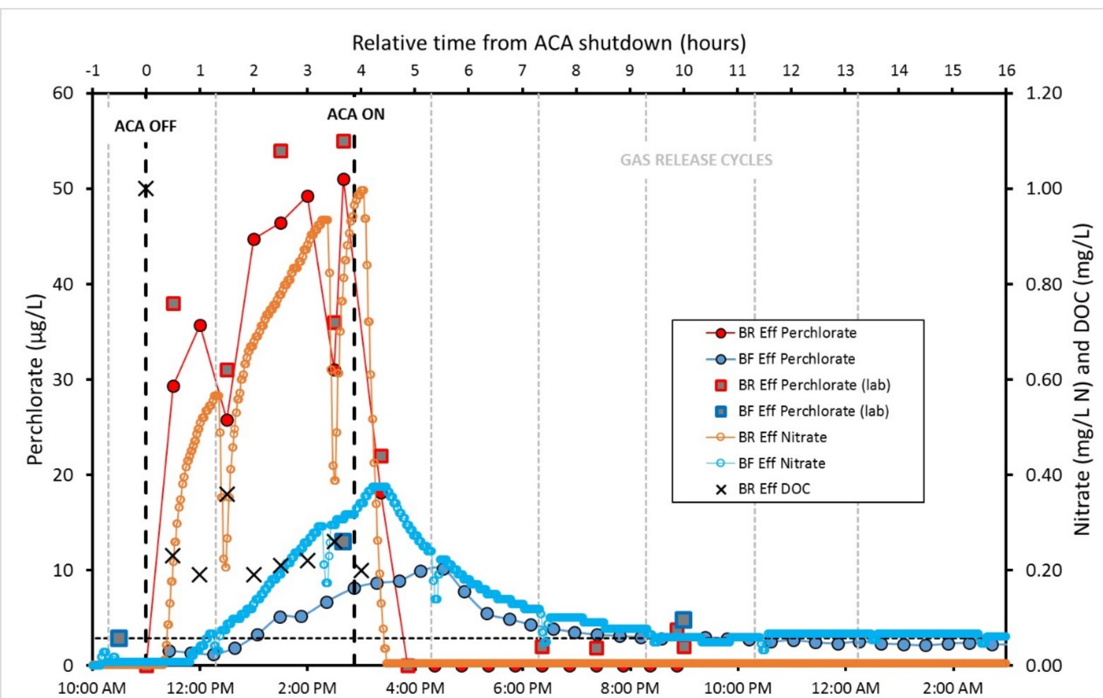


Figure 27 Acetic Acid Chemical Feed Failure Challenge Test

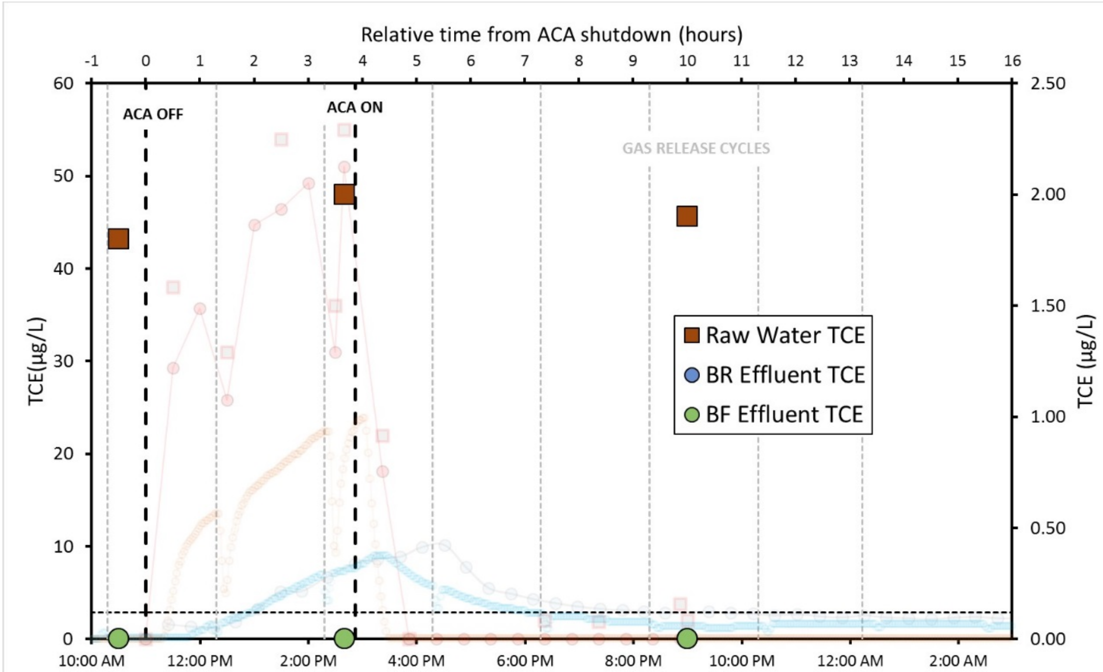


Figure 28 TCE Removal during ACA Shutdown

Bioreactor and biofilter depthwise contaminant removal profiles were taken over the course of the challenge tests (Figures 29, 30, 31, 32) and correlated to the EBCT at that location. For example, water collected at the second port located 12 inches below the top of the media is subject to 2.12 minutes of treatment, while samples collected at the bioreactor effluent were subject to 9.58 min of treatment. Baseline samples were taken prior to initiating the challenge test (i.e., Pre Test Samples). Depthwise samples were then collected across the bioreactor when perchlorate breakthrough from the biofilter was observed (i.e., biofilter breakthrough samples). Finally, a depthwise profile was collected when perchlorate from the bioreactor returned to pre-test conditions (i.e., End of Test). Prior to initiating the test, complete nitrate and perchlorate removal was observed within 30 and 54 inches into the bed. As expected, a considerable decline in contaminant removal was observed throughout the bed after acetic acid was discontinued (~ 3.67 hours). Once acetic acid was reinstated, however, significantly improved contaminant removal was observed deeper into the bed relative to the upper portions. Similar profiles were observed in the biofilter.

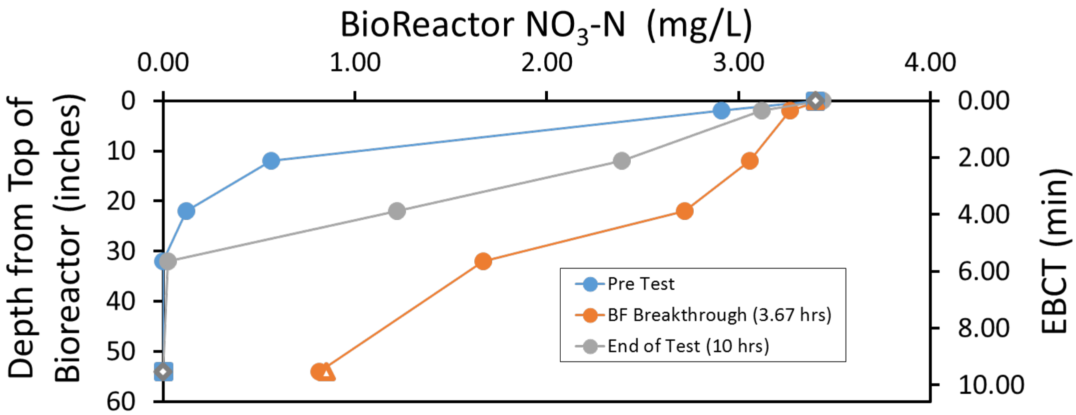


Figure 29 Bioreactor Nitrate Depthwise Profile

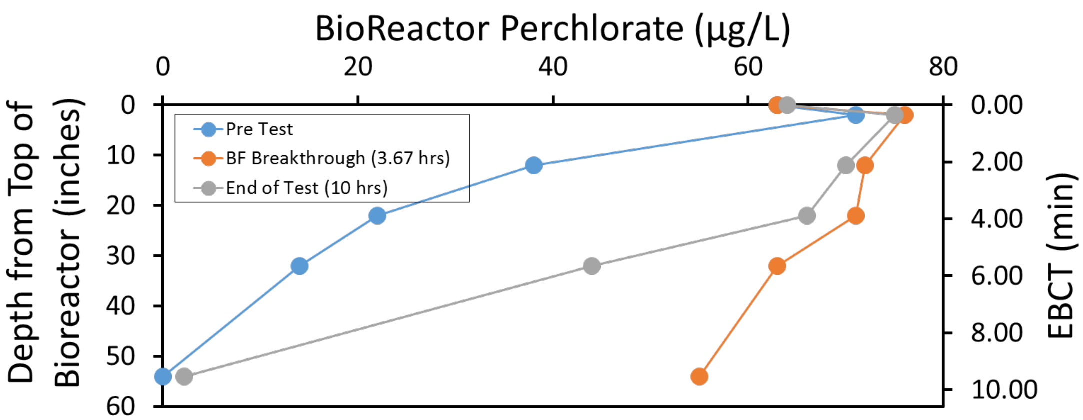


Figure 30 Bioreactor Perchlorate Depthwise Profile

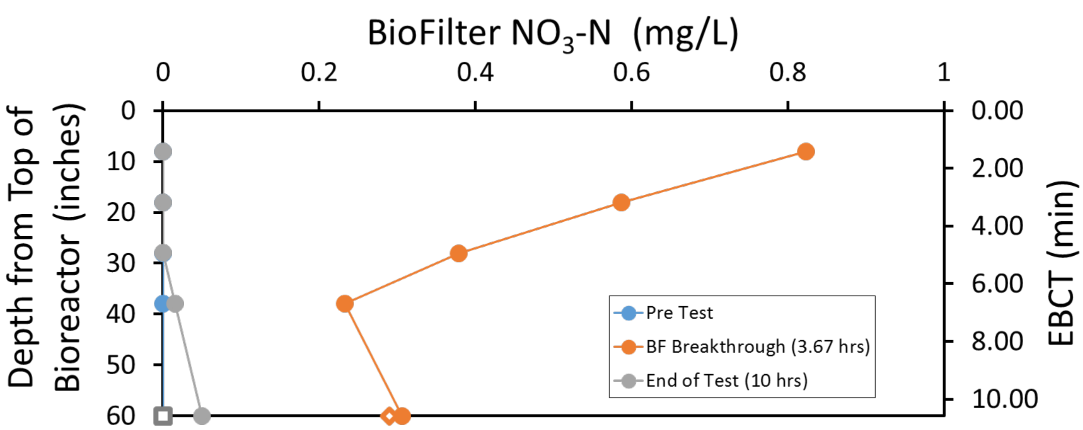


Figure 31 Biofilter Nitrate Depthwise Removal

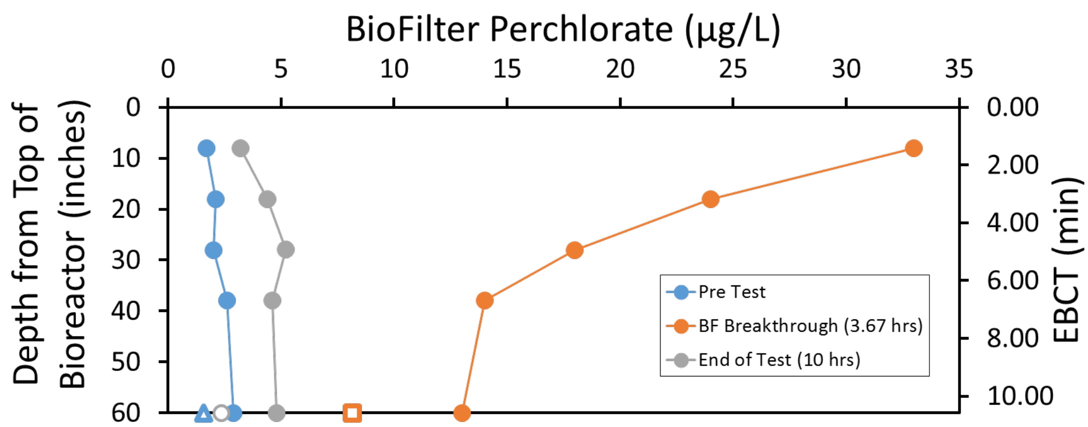


Figure 32 Biofilter Perchlorate Depthwise Removal

By comparing the normalized removal of both nitrate and perchlorate over the depth of the media we can determine the selectivity of contaminants to microbial reduction (Figure 33). Even in pre-test conditions, perchlorate removal lags nitrate removal, which is expected given the significant differences in contaminant concentrations (i.e., nitrate concentration is 100x perchlorate concentrations). These results caution the use of nitrate removal as a surrogate parameter for perchlorate removal.

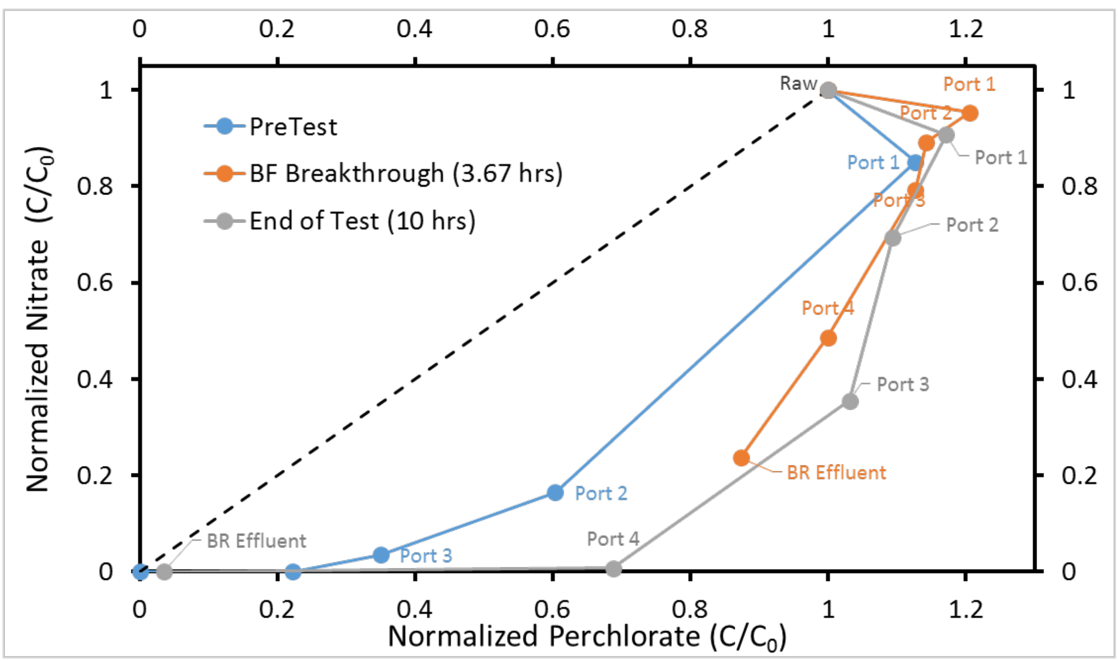


Figure 33 Normalized Contaminant Removal during the ACA Challenge Test

### 1.5.7.3 Combined Phosphoric Acid Feed Failure and System Shutdown Test

*Overview*

Phosphorus is a micro-nutrient, which is required for the growth and activity of healthy microorganisms in a bioreactor. In the absence of phosphorus, limited growth or even inhibition can be observed, resulting in poor contaminant removal performance. In addition, under nutrient limited conditions, microorganisms produce extracellular polymeric substance (EPS) in excess, which results in increased headloss through the FXB vessels.

A nutrient feed failure was simulated by shutting off the phosphoric acid pump and associated alarms. Testing determined the time required for perchlorate and nitrate breakthrough in the FXB system effluent following the failure.

Midway through the phosphoric acid feed failure challenge test, Well 6 failed due to extreme heat and the system was taken offline. Therefore, the phosphoric acid feed failure challenge test was augmented with the 24-hour shutdown test to simulate a worse-case scenario.

During a planned or accidental system shutdown, the limitation of microbial food sources (i.e., electron donor and acceptor) may stress the microorganisms present in the system. This could result in a need for re-acclimation period after the system operation is resumed. Based experience with piloting and full-scale operation of FXB systems, a 24 hour shutdown is expected to have a low impact on nitrate removal performance upon restart of the system, and no noticeable impact on perchlorate removal performance.

An extended system shutdown test (~ 45 hours) was performed by taking the system offline, and then restarting it 45-hours later with the phosphoric acid nutrient feed still turned off. Water quality was monitored upon restarting the system to determine if any contaminant breakthrough occurred.

*Objectives*

The objective of this test was to demonstrate that:

- Redundant features of the FXB system (including the biofilter and treated water tank) allow the resulting contaminant breakthrough to be detected and captured before it is able to reach the distribution system.
- Resulting contaminant breakthrough (nitrate) will be detected in the bioreactor effluent before it is detected in the biofilter effluent, preventing the need to turn over water in the treated water tank.
- Contaminant breakthrough occurs an appreciable amount of time following the failure of the phosphoric acid feed.
- No biological re-acclimation period is required following an extended shutdown of the FXB process.
- Contaminant breakthrough is limited to non-existent upon restarting the process, and does not present a risk to public health.
- Wasting or recycling of treated water is not necessary upon restarting.
- The system can be returned to a stable, steady-state operating condition rapidly upon restarting.

*Testing Procedure*

Prior to initiating the test, a backwash was performed and the system was allowed to run until nitrate and perchlorate values stabilized at non-detect. The phosphoric acid metering pump was then placed in MANUAL mode within SCADA and all alarms and interlocks associated with the phosphoric acid pump were disabled to allow the FXB system to continue running following the failure.

The test was initiated by stopping the feed of phosphoric acid to the system by setting the pump speed at 0 percent and then closing the isolation valve at the phosphoric acid injection quill. Time for the failure test began as soon when the pump is stopped. Bioreactor effluent grab samples were collected every 30 minutes as indicated in Table 11 (Phosphoric Acid Feed Failure Test and System Failure Sampling Plan), for a maximum of 4-hours. The system continued to operate until Well 6 failed, at which point the system was placed into standby mode for 45 hours. The system was then restarted with the phosphoric acid metering pump still disabled and continued until perchlorate breakthrough was detected, considered to be three consecutive samples with a value of 4 µg/L or higher, or for a maximum of 4 hours if no perchlorate breakthrough was observed.

*Phosphoric Acid Feed Failure/ System Shutdown Sampling Plan*

Table 11 Phosphoric Acid Feed Failure Test and System Shutdown Sampling Plan

| Analysis | Parameter | Sampling Location | | | | | |
|---|---|---|---|---|---|---|---|
| | | Raw Water | Bioreactor Effluent | Biofilter Effluent | Treated Water Tank Effluent | Bioreactor Depthwise Profile | Biofilter Depthwise Profile |
| In-Line | Perchlorate | | | Every 30 min | | | |
| | Nitrate | Continuous | Continuous | Continuous | | | |
| WVWD Lab | Perchlorate | | -Every 30 min for first 4 hours<br>-Every 30 min after PHA feed restoration until BF perchlorate = ND | | Every 30 min after PHA feed restoration until 1 HRT following BF perchlorate = ND | | |
| | Nitrate | | | | | -1X prior to starting test<br>-1X at system shutdown<br>-1X at system restart<br>-1X at end of test | --1X prior to starting test<br>-1X at system shutdown<br>-1X at system restart<br>-1X at end of test |
| Outside Lab | Perchlorate | -1X prior to starting test<br>-1X at system shutdown<br>-1X at system restart<br>-1X at end of test | -1X prior to starting test<br>-1X at system shutdown<br>-1X at system restart<br>-1X at end of test | -1X prior to starting test<br>-1X at system shutdown<br>-1X at system restart<br>-1X at end of test | -1X prior to starting test<br>-1X at system shutdown<br>-1X at system restart<br>-1X at end of test | -1X prior to starting test<br>-1X at system shutdown<br>-1X at system restart<br>-1X at end of test | -1X prior to starting test<br>-1X at system shutdown<br>-1X at system restart<br>-1X at end of test |
| | Nitrate | -1X prior to starting test<br>-1X at system shutdown<br>-1X at system restart<br>-1X at end of test | -1X prior to starting test<br>-1X at system shutdown<br>-1X at system restart<br>-1X at end of test | -1X prior to starting test<br>-1X at system shutdown<br>-1X at system restart<br>-1X at end of test | -1X prior to starting test<br>-1X at system shutdown<br>-1X at system restart<br>-1X at end of test | | |
| | TCE | -1X prior to starting test<br>-1X at system shutdown<br>-1X at system restart<br>-1X at end of test | -1X prior to starting test<br>-1X at system shutdown<br>-1X at system restart<br>-1X at end of test | -1X prior to starting test<br>-1X at system shutdown<br>-1X at system restart<br>-1X at end of test | | | |
| | Ortho Phosphate | | Every 30 min for first 4 hours | | | | |

### *Phosphoric Acid Challenge Test Results*

Electron donor was discontinued at 9:30 AM July 6th, 2018 (Figure 34). Bioreactor effluent orthophosphate dropped exponentially from ~1 to 0.02 mg/L over 3.25 hours. No increases in bioreactor effluent nitrate and perchlorate were observed, with values staying at zero and ~2 µg/L. Similarly, biofilter nitrate and perchlorate remained at 0.08 mg/L and ~ 3 µg/L over the first 4 hours. Elevated biofilter concentrations were observed relative to those observed during the acetic acid test as the system was reclaiming water from the backwash waste tank prior to initiating the test, which contains ~ 15 µg/L perchlorate and ~ 0.8 mg/L nitrate.

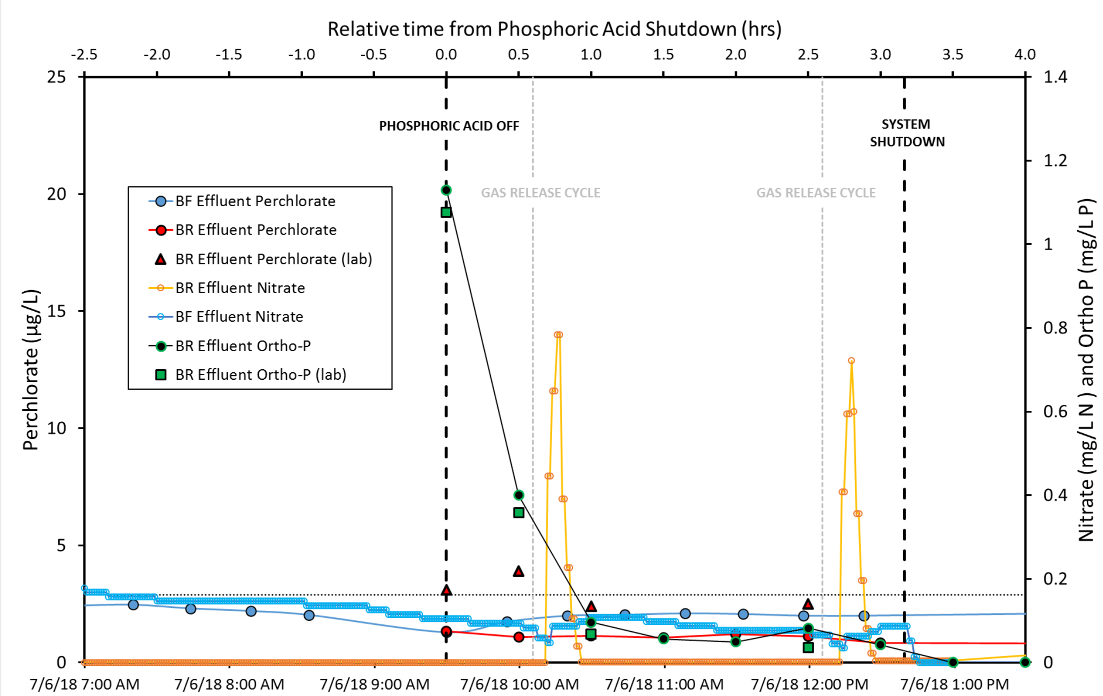


Figure 34 Phosphoric Acid Chemical Feed Failure Challenge Test

The system was shut down after 3.5 hours due to a well failure and remained offline for ~45 hours (Figure 35). Upon restart of the FXB, bioreactor effluent nitrate sharply increased to 0.74 mg/L before returning to pre-test levels within 28 minutes. Interestingly bioreactor perchlorate was non-detect for 2.5 hours following the system restart, at which point it increased and stabilized around 2-3 µg/L. This late bioreactor breakthrough is possibly due to the combination of the system shutdown with the buildup of $N_2$ gas during denitrification, which progressively shifts contaminant removal to lower portions of bioreactor bed. Biofilter nitrate increased to 0.28 mg/L which slowly decreased to zero over 2 hours. No significant perturbations in biofilter effluent perchlorate were overserved from the prolonged system shutdown and lack of phosphoric acid feed. These results indicate that neither a phosphoric acid feed failure nor an extended system shutdown have a significant effect on contaminant removal.

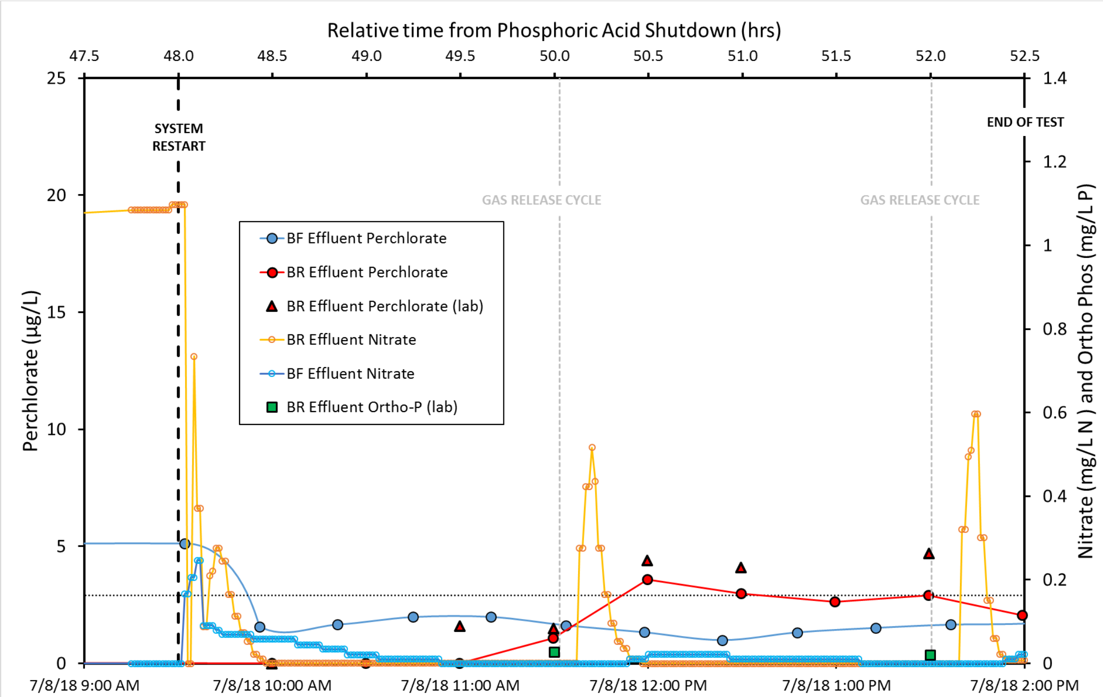


Figure 35 System Shutdown Challenge Test

### 1.5.7.4 Emergency Shutdown/System Failure

*Overview*

Under normal operating conditions, the FXB plant will react to failure of a chemical feed or analyzer by shutting down. When the condition has been cleared, the plant will be restarted and water production will resume. While part of this robustness testing was to test contaminant breakthrough in the event of a chemical feed failure, this test presented a more "real world" scenario in which a chemical metering pump faults, causing the system to shut down.

This test involved deactivating a chemical metering pump, which caused a system shutdown. The system was then restarted after clearing the failure condition. Water quality was monitored upon restarting the system to determine if any contaminant breakthroughs occurred.

*Objectives*

The objective of this test was to demonstrate that:

- Failure of a chemical feed system will result in an immediate shut down of the FXB plant, thus preventing any contaminant breakthrough.
- Contaminant breakthrough is limited to non-existent upon restarting the process, and does not present a risk to public health.
- Wasting or recycling of treated water is not necessary upon restarting.
- The system can be returned to a stable, steady-state operating condition rapidly upon restarting.

*Testing Procedure*

The test was initiated by de-activating the acetic acid feed pump which resulted in the FXB system automatically shutting down. After a period of 12 minutes where the system was shut down, the acetic acid feed pump was re-enabled and the FXB system was restarted in normal production mode. Perchlorate was monitored in-line for biofilter effluent, and nitrate was monitored in-line for bioreactor and biofilter effluent. Perchlorate grab samples were taken at the bioreactor effluent every 30 minutes during the test. The test ended when bioreactor and biofilter effluent nitrate values stabilized at their pre-shutdown levels.

*Emergency Shutdown/ System Failure Results*

As expected, the short duration emergency shutdown had no impact on the system performance as bioreactor and biofilter effluent nitrate and perchlorate remained below the detection limit 4 hours after the system failure (Figure 36).

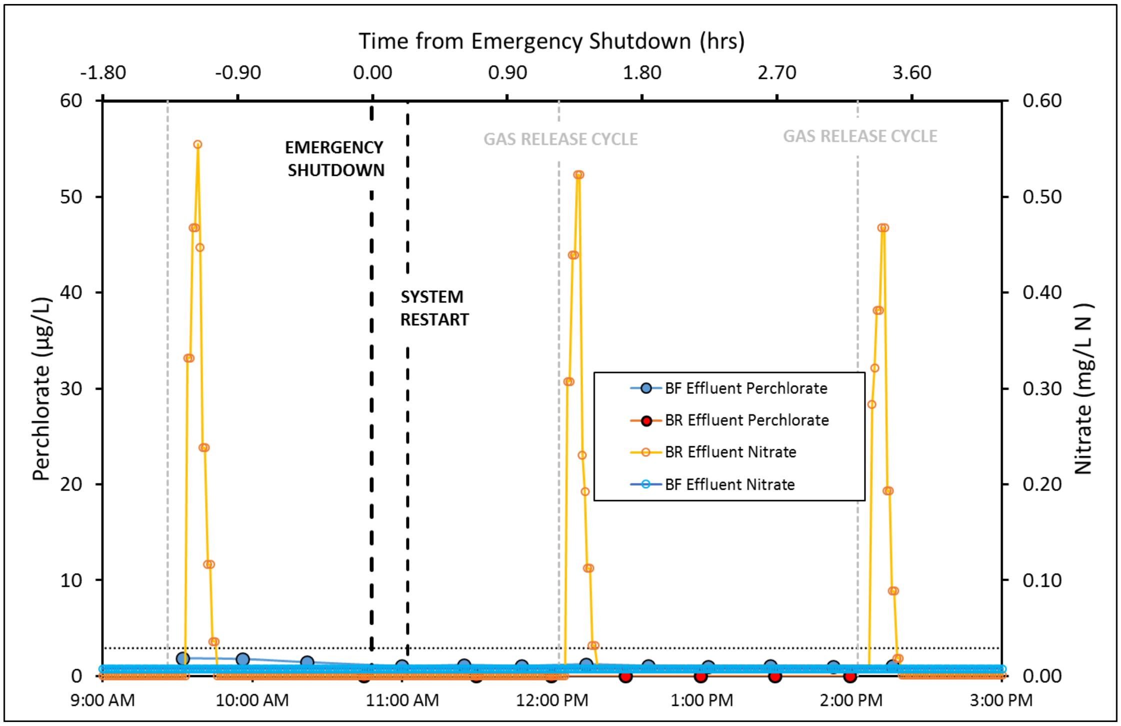


Figure 36 Emergency Shutdown Challenge Test

### 1.5.7.5 Chlorinated Backwash

*Overview*

Regular backwashing of both the bioreactor and biofilter removes excess biomass along with any solids deposited in the media bed over the course of a run cycle. Since biological contaminant removal relies on the growth and activity of microorganisms, a backwash may affect system performance depending on the aggressiveness of the backwash, frequency of backwashing, and the presence of chlorine or hydrogen peroxide in the backwash supply water. Previous piloting has shown that continued backwashing with chlorinated water can negatively impact the health of the biological communities in the FXB system.

The FXB system backwash supply is taken from the distribution system at Booster Pump Station 4-2, where the free chlorine residual is approximately 1.5 mg/L. In order to provide a backwash supply free of chlorine, hydrogen peroxide is dosed to the backwash supply water to quench the chlorine residual. In the event of a failure of the hydrogen peroxide feed system, the FXB system would be backwashed with chlorinated water from the distribution system.

This test involved backwashing the FXB system with chlorinated distribution system water over the entire backwash cycle to simulate such a failure. Water quality was monitored upon restarting the FXB system in production mode to determine if a single chlorinated backwash resulted in the breakthrough of any contaminants.

#### *Objectives*

The objective of this test is to demonstrate that:

- Contaminant breakthrough is limited to non-existent upon restarting the process, and does not present a risk to public health.
- The system can be returned to a stable, steady-state operating condition rapidly upon restarting.

#### *Testing Procedure*

To initiate the test, backwash hydrogen peroxide metering pump was placed in MANUAL mode within SCADA and set at 0 percent speed. The isolation valve at the backwash hydrogen peroxide injection quill was closed, and all alarms and interlocks associated with the backwash hydrogen peroxide pump were disabled to allow the backwash to proceed in spite of the failure.

The bioreactor backwash was performed after 12 hours of bioreactor runtime. Once the backwash was completed the FXB system was restarted in normal production mode. Grab samples were collected as indicated in Table 12 (Chlorinated Backwash Test Sampling Plan).

The test ended when bioreactor and biofilter effluent perchlorate values stabilized at their pre-shutdown levels, or if no contaminant breakthrough was observed, after 4 hours. At the end of the test the backwash hydrogen peroxide pump back was placed into AUTO and all alarms and interlocks associated with the peroxide feed and chlorine residual detection were restored.

#### *Chlorinated Backwash Sampling Plan*

Table 12 Chlorinated Backwash Test Sampling Plan

| | Sampling Location | | | |
|---|---|---|---|---|
| Parameter | Raw Water | Bioreactor Effluent | Biofilter Effluent | Bioreactor Depthwise Profile |
| Perchlorate | -1X prior to starting test<br>-1X at end of test | -Every 30 min from startup to end of test | -Every 30 min from startup to end of test | -1X prior to starting test<br>-1X at restart |
| Nitrate | -1X prior to starting test<br>-1X at end of test | -Every 30 min from startup to end of test | -Every 30 min from startup to end of test | -1X prior to starting test<br>-1X at restart |
| Free Chlorine | - | -1X at restart | - | - |

### *Chlorinated Backwash Results*

Over the course of the ~ 25 minute chlorinated backwash, chlorine levels entering the bioreactor increased to 0.6 mg/L (Figure 37). However, chlorine was rapidly consumed by GAC as it penetrated upwards through the bioreactor, with nearly all of the chlorine being quenched prior to the top portion of the bed which contains a majority of the biomass. Therefore, as expected, the chlorinated backwash had no effect on bioreactor and biofilter contaminant removal (Figure 38).

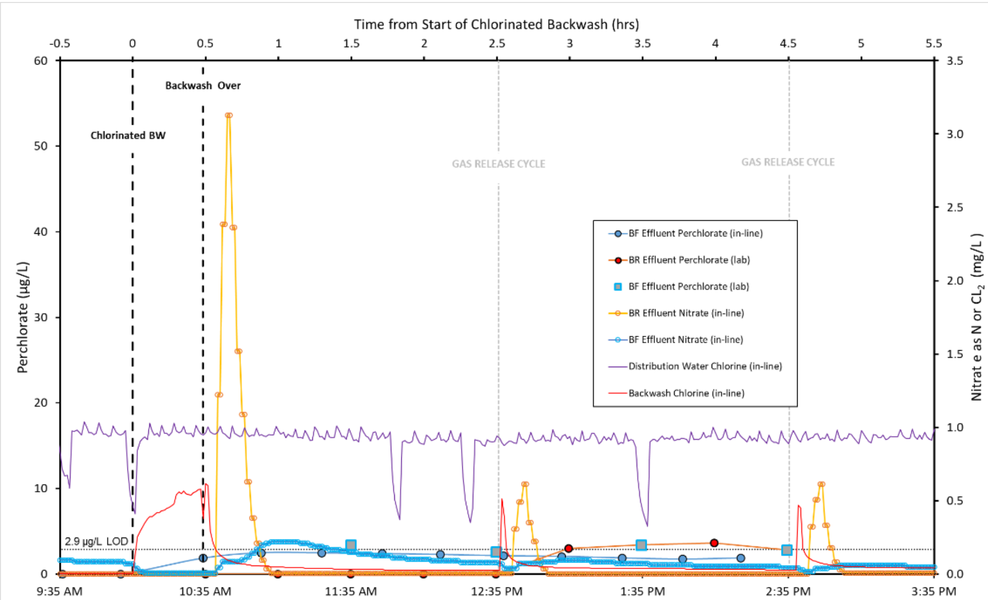


Figure 37 Chlorinated Backwash Challenge Test

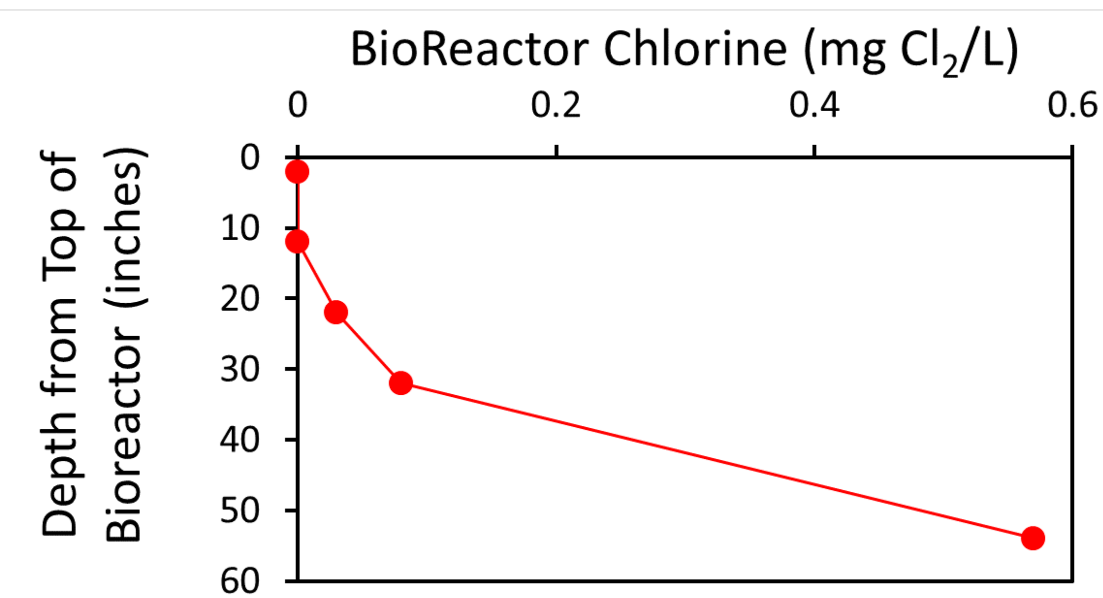


Figure 38 Chlorine Penetration into the Bioreactor

To ensure that the spikes in nitrate following the backwash and GRCs were exclusively due to the introduction of distribution water into the vessel, nitrate profiles were compared to those after a dechlorinated backwash (Figure 39). Identical nitrate profiles under both the chlorinated and dechlorinated backwashes indicate that chlorine did not affect the system performance. No significant perturbations were observed for bioreactor and biofilter effluent nitrate and perchlorate, demonstrating the robustness of the system to a backwash chemical feed failure.

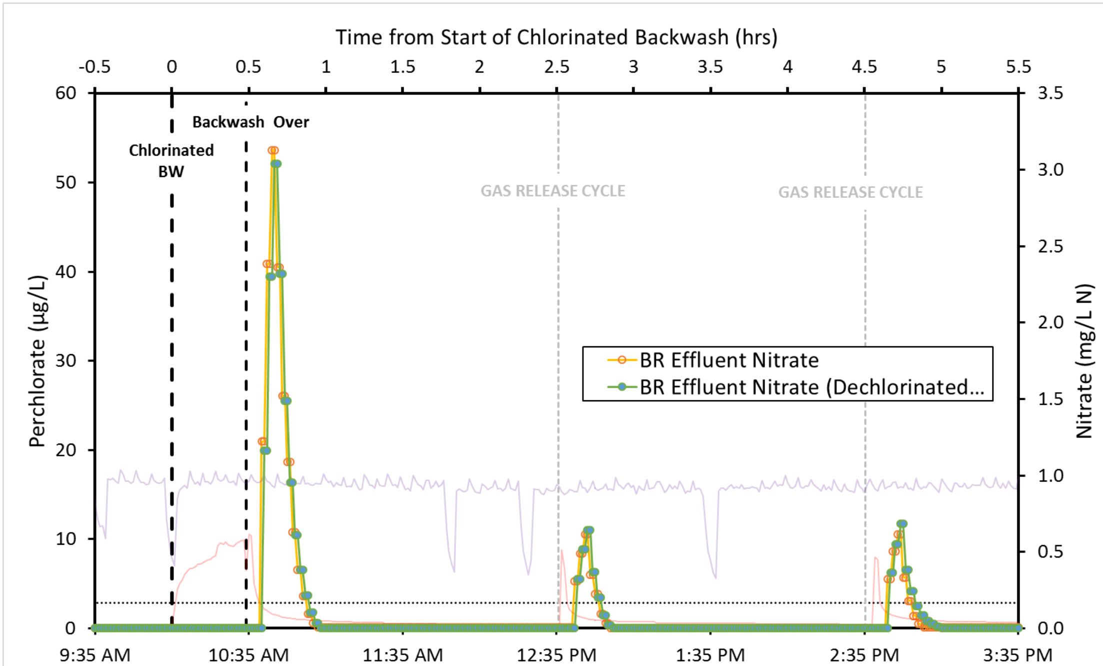


Figure 39 Bioreactor Nitrate Profile after a Chlorinated and Dechlorinated Backwash

## 1.6 Conclusions, Key Lessons Learned, and Recommendations

The goal of this project was to demonstrate that the FXB system is a cost-effective, sustainable solution for treating groundwater impacted by perchlorate. Specific objectives were to demonstrate the system's treatment efficiency, ease of operation, and suitability for use by West Valley Water District to provide safe drinking water to communities of Rialto, Fontana, Colton, and Jurupa Valley. The full-scale FXB system successfully produced high quality water with perchlorate, nitrate-nitrogen, and TCE all well below their MCL's of 6 µg/L, 10 mg/L, and 5 µg/L, respectively. Furthermore, over 95 percent of the system effluent samples were below the 0.3 NTU turbidity threshold.

Challenge testing confirmed the system resiliency to short- and long-term system shutdowns, chlorinated backwash, and a phosphoric acid feed failure. As expected, an acetic acid feed failure resulted in contaminant breakthrough, however, a rapid recovery was observed illustrating the robustness of the system. Most importantly, there was a significant lag phase between contaminant breakthrough from the bioreactor and the biofilter, allowing for preventative measures to be taken in case of an emergency. Finally, the biofilter provided a buffering capacity that dampened the magnitude of contaminant breakthrough.

### 1.6.1 Key Lessons Learned and Recommendations

Several key lessons were learned from this project, particularly during the robustness testing phase. While the bioreactor showed rapid breakthrough but rapid recovery of contaminants during the acetic acid feed failure challenge test, the biofilter slowly desorbed both nitrate and perchlorate. Therefore, it is paramount to prevent periods of extended, high concentration perchlorate breakthrough from the bioreactor and subsequent loading onto the biofilter.

It was also observed that biomass growth and $N_2$ gas accumulation over a run, can diminish contact time between biomass, substrate, and contaminants. This eventually leads to contaminant breakthrough if a bioreactor backwash is not performed to purge entrapped gas and expel excess biomass. Therefore, consistent backwashing of the bioreactor is needed every 18 to 24 hours in order to prevent contaminant breakthrough, especially in low-pressure systems.

As mentioned in Phase 2 of the demonstration testing, reclaim water from the backwash waste tank contains perchlorate and nitrate which bypasses treatment in the bioreactor and leads to low-level perchlorate leaving the biofilter. To avoid this, either the backwash protocol needs to be changed to draindown water at the base of the bioreactor (thus providing treatment prior to the waste tank) or the backwash recovery process needs to be reconfigured to reclaim water to the influent of the FXB system.

Carollo Engineers, Inc. has decided to concomitantly perform both modifications to draindown from the bottom of the bioreactor and reclaim water to the front of the plant. A proposed schematic is provided in Appendix C. Briefly, the backwash recycle valve connection will be replaced with a 6” T connection and a 6”x 3” reducer that will allow for a piping connection from the bottom of the bioreactor and from the reclaim line to the raw water pumps and therefore influent of the plant.

# Appendix A
# DISINFECTION CT

## A.1 CT Calculations

The existing treatment facility uses sodium hypochlorite to achieve primary disinfection and to maintain a disinfectant residual in the distribution system. Disinfection is used to protect the public from three classes of pathogens namely: protozoa, such as *Giardia lamblia* or Cryptosporidium *parvum*; bacteria such as E. *coli*, enterococci, or coliphage; and viruses. Of these potential pathogens, protozoa are the most resistant to chlorine, however they are typically absent from groundwater as the soil column forms a natural filter. Bacteria are the most susceptible to contact with chlorine and under typical conditions most are inactivated in less than a minute. Viruses are more resistant to chlorine than bacteria and less resistant than protozoa, therefore, groundwater disinfection focuses on virus inactivation.

CT is the product of the concentration of disinfectant, frequently chlorine, and the time the chlorine is in contact with the pathogen. CT is measured in units of min-mg/L to achieve a specified inactivation rate for the target pathogen. A one log reduction is a reduction by a factor of 10, therefore one log removal is equivalent to 90 percent removal, 2-log reduction is 99 percent, and 4-log reduction would be 99.99 percent. The required CT is highly dependent on both the pH and the temperature of the water being disinfected and shown in tables published by the Environmental Protection Agency (EPA). These tables provide values in min-mg/L that must be met to achieve inactivation for specific pathogens given the temperature and pH of the water. The tables list the requirements for Giardia *lamblia* and viruses as either is more resistant to chlorine than bacteria, meaning that in satisfying the CT requirement for viruses, the requirement for bacteria has already been achieved.

The time portion of the CT calculation is calculated based on the volume of the CT reactor, a baffling factor ($T_{10}/T$) for the reactor, and the flow rate out of the reactor. The baffling factor for the reactor is a mechanism used to account for "short-circuiting" of flow within the reactor, whereby a portion of the flow through the reactor passes through the reactor faster than the rest of the flow by taking a more direct flow path.

## A.2 Required CT

Water treated by the FXB system will be required to achieve a 4-log virus inactivation CT in accordance with the Groundwater Rule. CT requirements for 4-log virus inactivation at various temperatures and pH values are summarized in Table A.1.

Table A.1 CT Requirement for 4-Log Virus Inactivation

| Temperature | pH 6-9 | pH 10 |
|---|---|---|
| 0.5°C | 12 | 90 |
| 5°C | 8 | 60 |
| 10°C | 6 | 45 |
| 15°C | 4 | 30 |
| 20°C | 3 | 22 |
| 25°C | 2 | 15 |

As Table A.1 shows, the CT requirement is heavily dependent on pH as chlorine tends to form the hypochlorite ion (OCl) at higher pH values. The hypochlorite ion has very low biocidal properties relative to the hypochlorous acid (HOCl) species dominant at and below neutral pH values.

## A.3 CT Achieved

The FXB treatment facility was designed to provide 4-log virus inactivation for treated water. The existing hypochlorite storage and feed system was retained to apply hypochlorite to FXB treated water upstream of a 200-foot long, 24-inch diameter contact pipe. The disinfected, treated water is then sent to either Cactus Basin or Reservoir 3A-2 for distribution.

Hypochlorite will be fed to the process using a flow-pacing strategy. Hypochlorite will be applied to provide a target finished water chlorine residual of 1.5 mg/L, or a compliant CT value, whichever requires the higher dose.

Appendix B

# PROCESS FLOW DIAGRAMS AND TREATMENT PLANT LAYOUT

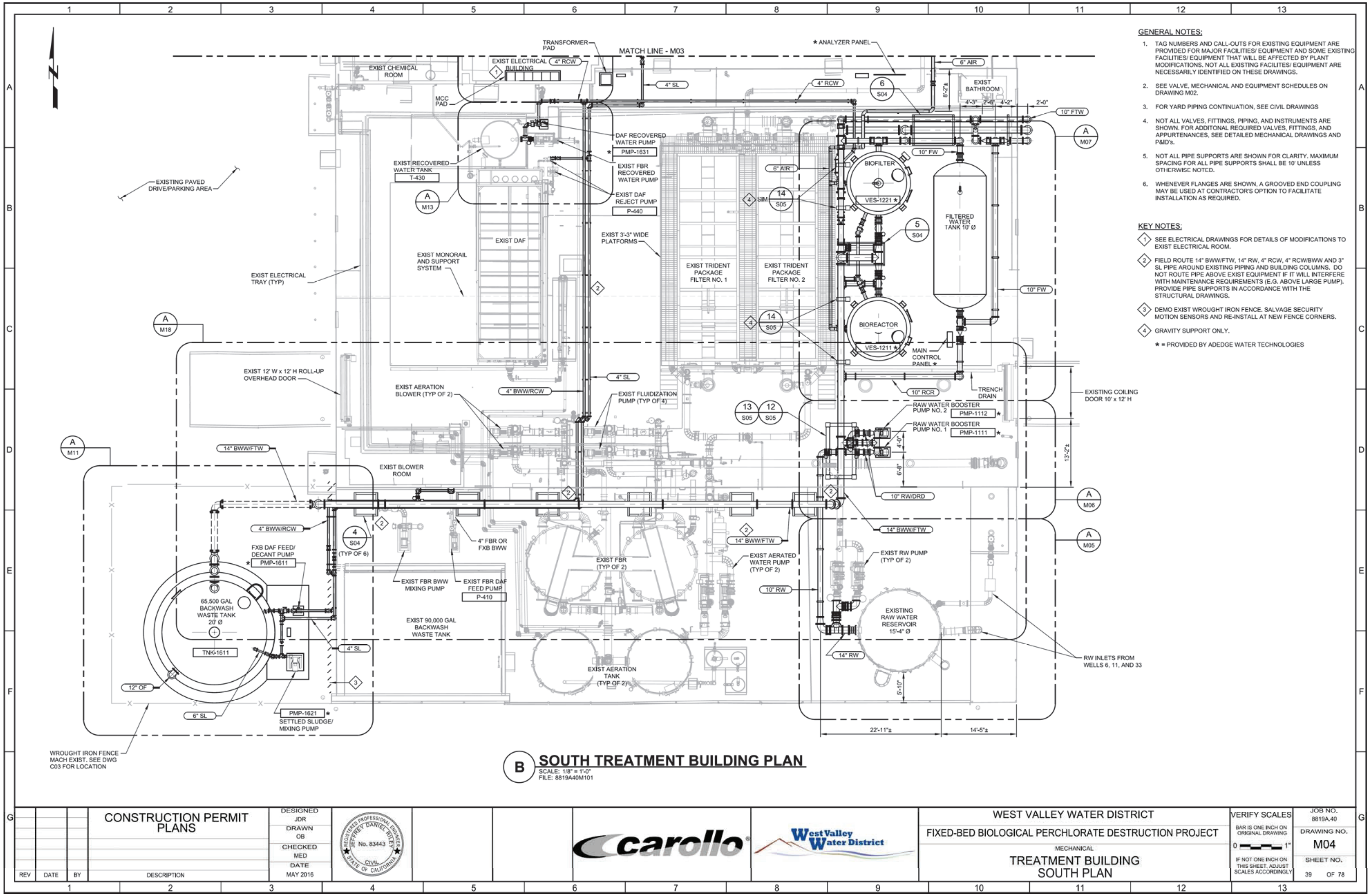


Figure B.1 Layout of the Treatment Plant

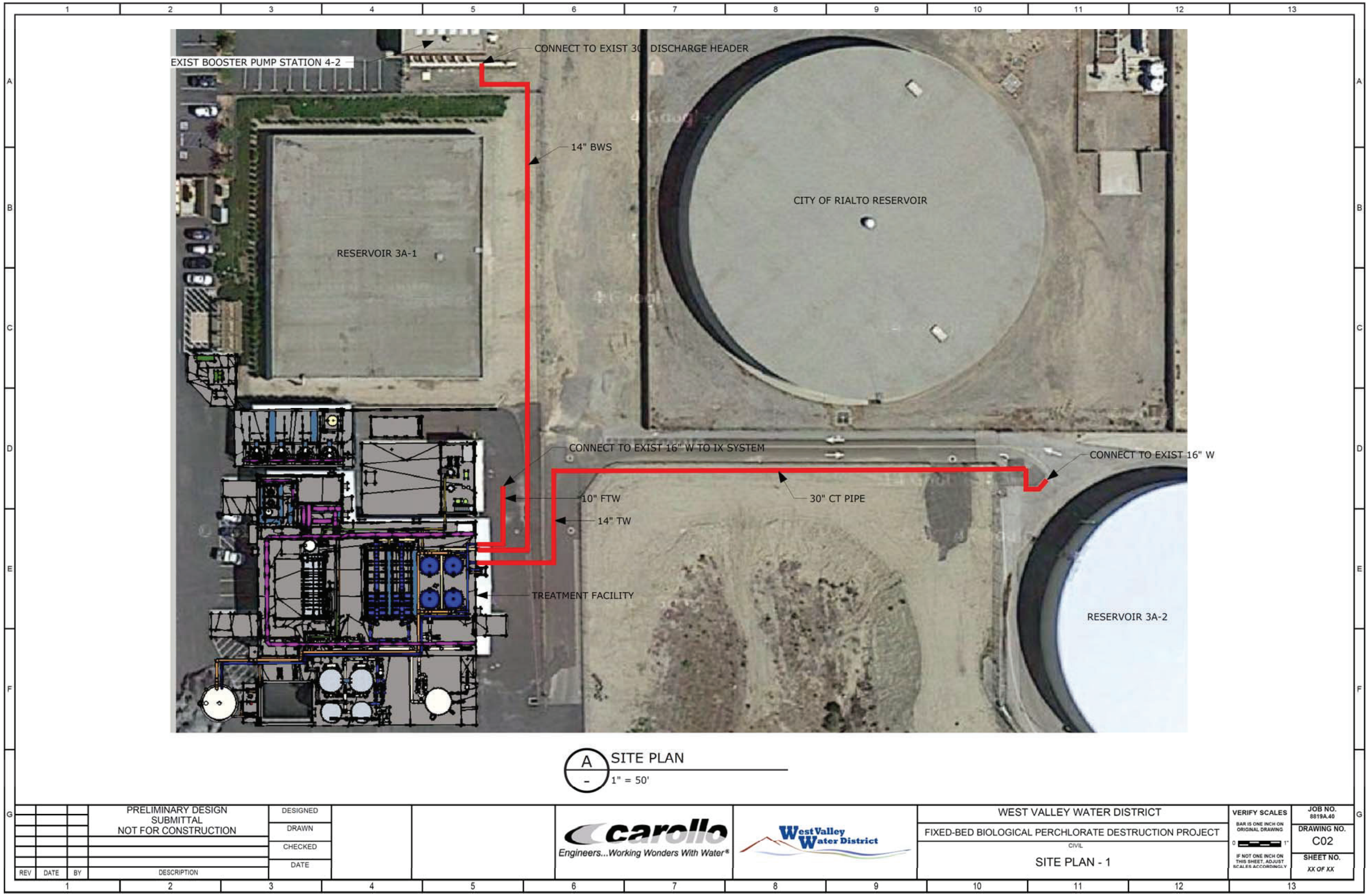


Figure B.2 Site Plan showing location of Booster Pump Station 4-2 relative to the FXB


Figure B.3 Location of WVWD relative to Well 6 and Well 11

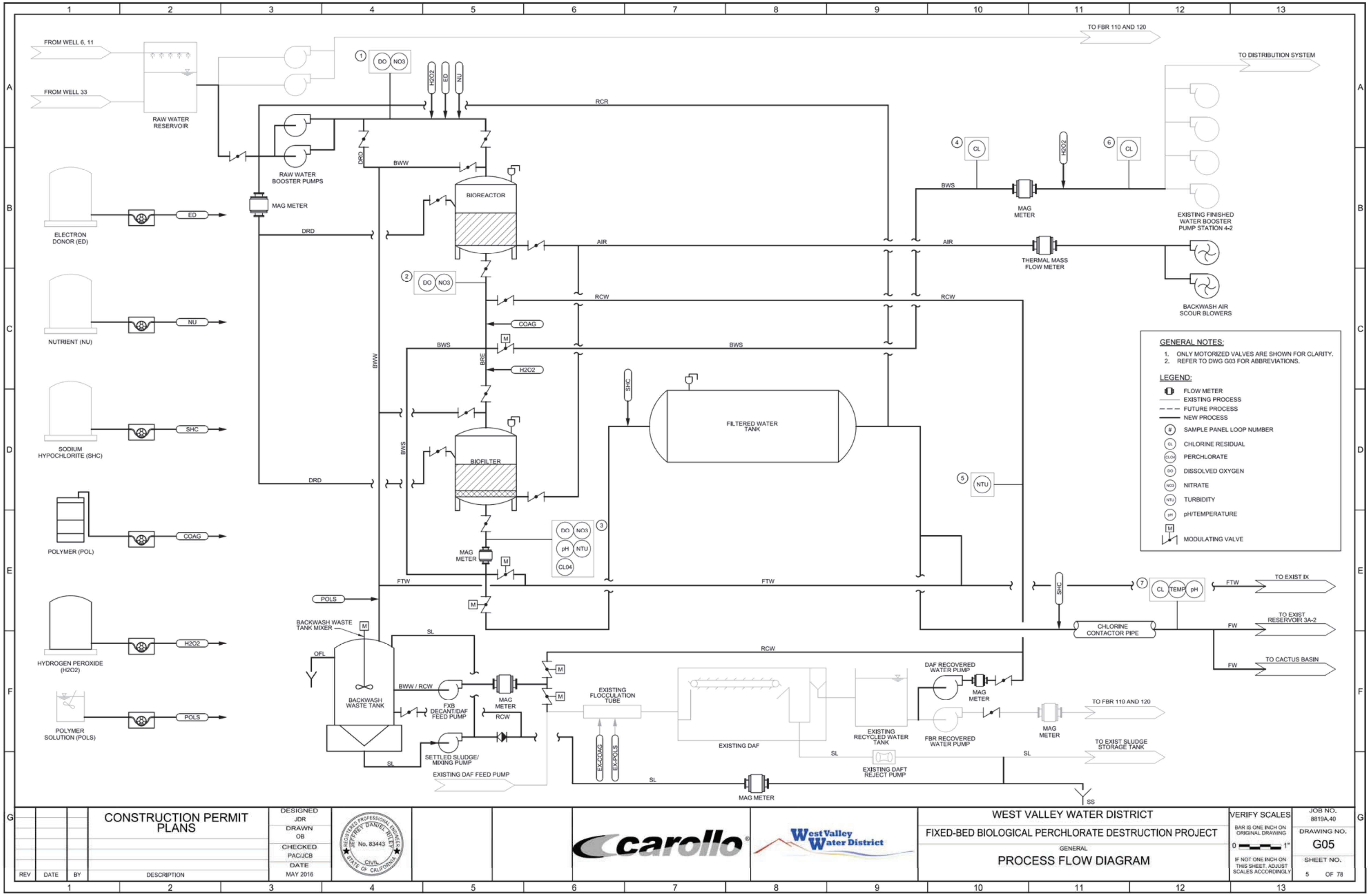


Figure B.4 FXB Process Flow Diagram

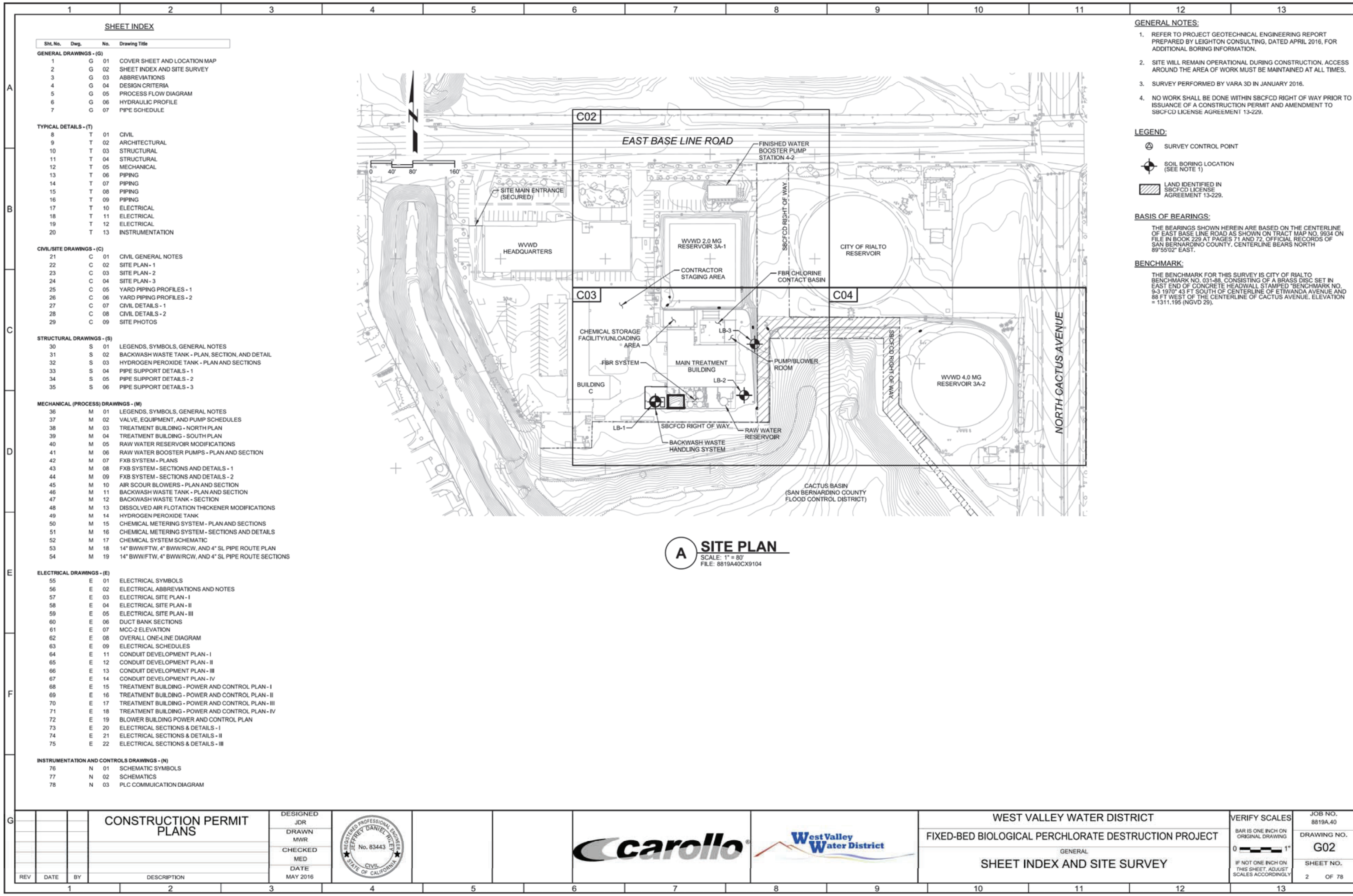


Figure B.5 Site Overview

Appendix C

# PROPOSED DRAINDOWN MODIFICATIONS

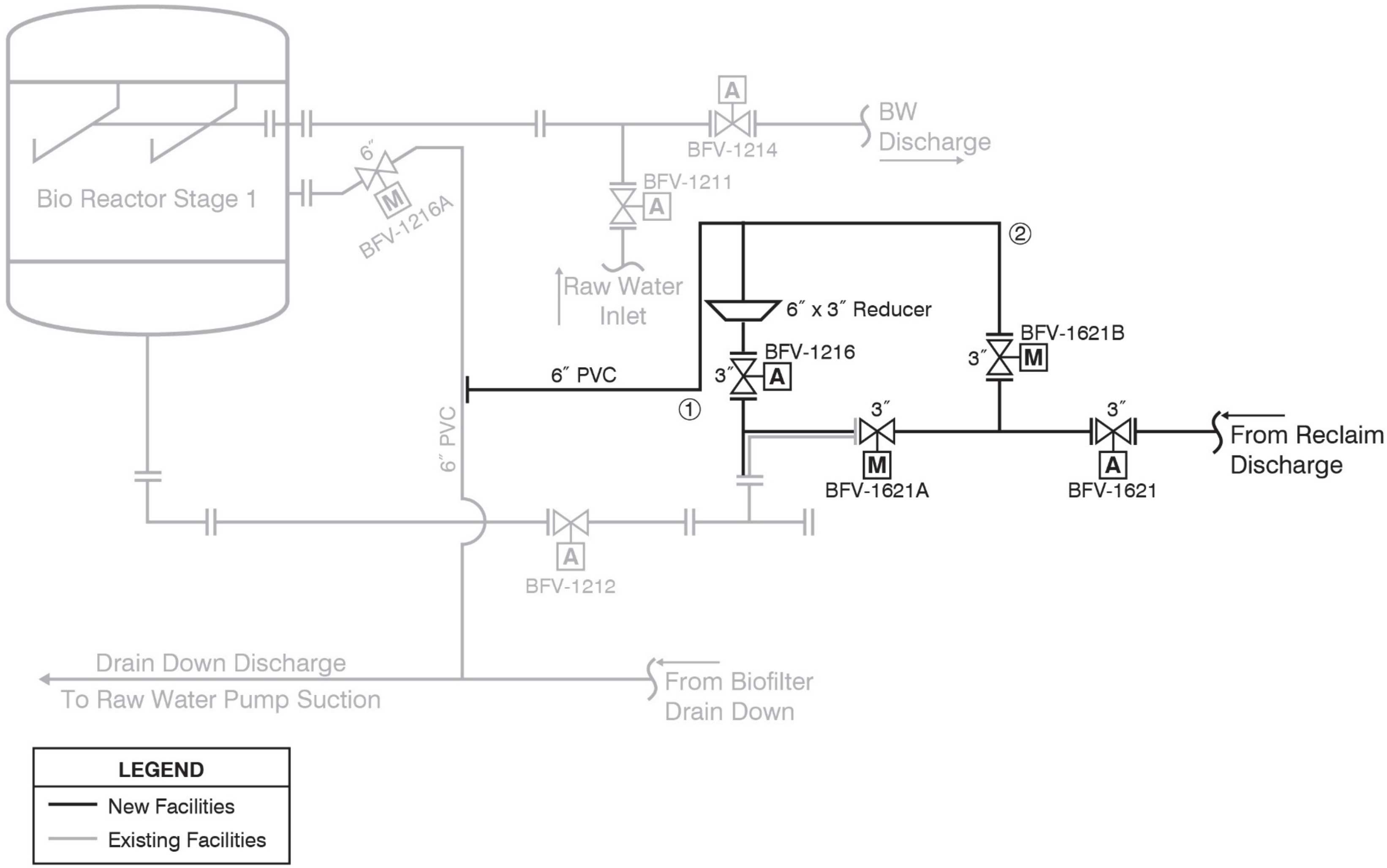


Figure C.1 Draindown Modifications

Appendix D

# CONCEPTUAL COST ESTIMATE

March 14, 2017

Jess Brown, Ph.D., P.E.
Chief Technologist
Carollo Engineers
(714) 593-5100
jbrown@carollo.com

**Subject: Perchlorate Removal Treatment Plant for West Valley Water District, CA**
**Well 11 - biottta® Two Stage – Fixed Bed Biotreatment**

Dear Dr. Brown,

AdEdge Water thanks your involvement with the biottta® treatment plant for West Valley Water District, CA. Attached you will find the updated proposal documents for a plant design based on West Valley installed plant for perchlorate removal, given the advancement in technology gained from this project.

The design and scope consider the results of the full scale demonstration of the two-stage, fixed-bed treatment process at West Valley. The reduction of perchlorate from 0.061 mg/L to less than 0.001 mg/L proving the full scale viability to utilize biological treatment for groundwater applications.

The biottta plant includes bioreactor, biofilter, operator interface, water quality monitoring, chemical delivery, and backwash blower. The unit is a modular unit, flexible to multiple site layouts. Further details of the equipment are included in the scope of supply.

As an applied technology provider in the drinking water market AdEdge offers solid, deliverable, scalable, scientifically proven technology with experience addressing inorganic and organic contamination of groundwater. Our extensive experience in packaging water technologies to provide a simple solution has led to over 750 operating water plants in the last 15 years.

The biottta® treatment systems offer several key advantages.

- Enriches natural processes to create a sustainable solution with indigenous microbes;
- Biologically reduced / destroyed contaminants produce no hazardous liquid waste streams;
- The absence of brine shrinks the imprint of treatment on Salinity Management Plans;
- 15 years of practical application including the first operating biological denitrification plant in North America for a potable water;
- Patented process with conventional water treatment equipment;
- Pre-engineered package plants offer increased reliability and quality;
- The integrated controls provide refined remote operation and historical trending;
- Increased dependability with guaranteed performance;

Thank you for the evaluation of the AdEdge proposed treatment solution for West Valley Water District Well 11.

Sincerely,

Christopher E. Clark, P.E.
Manager of Engineering Services

Cc: Douglas Craver, Western Regional Sales

# West Valley Water District, Well 6 & 11

## 470 gpm Two Stage Fixed Bed Biological for Perchlorate Removal

## CONTACT INFORMATION

| | | | |
|---|---|---|---|
| **Customer / Utility:** | West Valley Water District - California - Well 18A | **Date:** | 8/27/2018 |
| **Well Identity / Location:** | Well 6, 11 | **Project Contact:** | Carollo Engineers - Jess Brown |
| **Local Engineer / Firm:** | Carollo Engineers | **Contact Phone:** | (714) 593-5101 |
| **Other Pertinent Notes:** | | **Contact Email:** | Jbrown@carollo.com |
| **Operator:** | | **Rep Contact:** | |
| **Target Date for Installation:** | Installed 2016 | **Rep Phone/Email:** | |
| **Treatment Goals:** | Perchlorate < 6 µg/L-ClO4, Trichlorethene < 5 µg/L-TCE, Nitrate + Nitrite < 1 mg/L-N | | |

## WATER SYSTEM DESCRIPTION

| | | |
|---|---|---|
| **System Type / Application:** | Municipal | (municipal, industry, remediation, etc) |
| **Population Served:** | | (potable water application) |
| **Number of Connections:** | | (potable water application) |
| **Number of Wells to be treated:** | 2 | (# wells to be treated) |
| **Water Supply Flow (GPM):** | 470 | |
| **Bypass Flow (GPM):** | 0 | |
| **Design Treatment Flow (GPM):** | **470** | |
| **Water Supply (MGD):** | 0.6 | (average daily over 12 months) |
| **Treatment (MGD):** | 0.6 | (average daily over 12 months) |
| **Water Supply (ANNUAL, MGY):** | 242 | |
| **Treatment (ANNUAL, MGY):** | 242 | |
| **Existing Treatment:** | | |
| **Pump Operation / Pressure:** | Variable / 26-30 psi | |
| **Site Electrical Power:** | 3ph/480v/60hz | |
| **Atm Storage Tank Volume:** | 4,000,000 gallons | |
| **Hydropneumatic Tank Size:** | N/A | |
| **New or Existing Construction:** | Existing | |
| **Discharge Options available:** | Recycle, POTW limit 20k gallons/day, Ion Exchange plant | |

**APPLICATION NOTES:**

Site CAPEX, OPEX, and design re-evaluated after installation and completion of the grant program.

**FACILITY ADDRESS:**

855 W. Base Line Rd, Rialto, CA 92376

**PREPARED BY:**

BM; reviewed GG

## WATER ANALYSIS

| | PARAMETER | | | PARAMETER | |
|---|---|---|---|---|---|
| **pH** | 7.40 | units | **Sodium** | 10.0 | mg/L Na |
| **Dissolved Oxygen** | 13.5 | mg/L DO | **Nitrate** | 4.0 | mg/L as N |
| **Iron** | <0.1 | mg/L Fe | **Chloride** | 6.7 | mg/L Cl |
| **Manganese** | 0.00 | mg/L Mn | **Bicarbonate** | 190.0 | mg/L (as CaCO3) |
| **Sulfides** | No Data | mg/L (total sulfides) | **Alkalinity** | 150.0 | mg/L (as CaCO3) |
| **Calcium** | 54.0 | mg/L Ca | **Arsenic** | 0.001 | mg/L As |
| **Magnesium** | 7.0 | mg/L Mg | **Sulfate** | 18.5 | mg/L as SO4 |
| **Radium** | <1 | pCi/L Ra 226/228 | **Conductivity** | 361.0 | µmho/cm |
| **Gross Alpha** | 4.3 | pCi/L | **Phosphate** | 0.40 | mg/L P04 |
| **Suspended Solids** | No Data | mg/L TSS | **Uranium** | 0.004 | mg/L U 238 |
| **Turbidity** | 0.2 | NTU | **Trichloroethene** | 3.8 | µg/L TCE |
| **TOC** | <0.3 | mg/L TOC | **Perchlorate** | 291 | µg/L ClO4 |
| **Temperature** | 63.0 | degrees F | **Chrome (VI)** | 2.20 | µg/L CrVI |

020917rev

## biottta™ DESIGN

| | | | | |
|---|---|---|---|---|
| **System Model:** | biottta 12-1 | | **Design Flow Rate:** | 470 |
| **Number of Trains:** | 1 | | **HLR (gpm/ft²):** | 4.2 |
| **Water Recovery Rate:** | 99.6% | | **EBCT (Minutes):** | 9.0 |
| **Approximate System Footprint:** | See Attached | LxWxH | **Avg GPD Treated:** | 648,600 |
| | | | **Utilization %:** | 98% |

## COST ESTIMATE

| | CAPITAL | | OPERATING EXPENSES | |
|---|---|---|---|---|
| **Raw Water Supply Pumps:** | Included | **Chemical** | **Annual Volume** | |
| **BioReactor and BioFilter:** | Included | **Electron Donor:** | 9,274 | gallons |
| **Backwash Reclaim System:** | Included | **Phosphoric Acid:** | 488 | gallons |
| **Chemical Feed System:** | Included | **H2O2:** | 12,118 | gallons |
| **Air Scour Blower:** | Included | **Coagulant:** | 916 | gallons |
| **Remote Monitoring:** | Included | | **Annual Cost** | |
| **1 Year Service Plan:** | Included | **Power:** | $18,667 | USD |
| **Installation:** | Not Included | **Chemicals:** | $134,452 | USD |
| **Taxes:** | Not Included | **Estimated Annual Total:** | $153,119 | USD |
| **Freight:** | Not Included | **Treatment Cost:** | **$0.63** | USD/kgal Treated |
| **Total Capital for biottta 12-1:** | **$1,200,000** | | **$206** | USD/acre-ft |

## AdEdge Scope of Supply

### *biottta* ® Drinking Water Treatment Plant

**AdEdge Water Technologies, LLC**

**678-730-6511**

| Model |
|---|
| biottta 12-1 |

| Item | Qty | Detail | Design | Supply | Install |
|---|---|---|---|---|---|
| A | | ***Vessel System - biottta ® 12-1*** **One Train Anaerobic BioReactors and Aerobic BioFilters** | AdEdge | AdEdge | Others |
| | | 12' O.D. x 8' Side Shell x 100 PSI Carbon Steel Vertical Pressure Vessels | | | |
| | 1 | - Stage 1 BioReactors | | | |
| | 1 | - Stage 2 BioFilters | | | |
| | | - NSF 61 Epoxy Coatings | | | |
| | | - Orthos Poly Nozzle Underdrain System | | | |
| | 2 | High Flow Combination - Air / Vacuum Valve (one per vessel) | | | |
| | 4 | Analog Pressure Transmitters & Pressure Gauges (Inlet & Outlet Pressure of each vessel) | | | |
| | 10 | 10" Electric Actuated Butterfly Valves with Position Feedback (on each train valve tree) | | | |
| | 1 | 10" Automated Flow Control Butterfly Valves | | | |
| | 1 | 10" Electromagnetic Flow Meters - Endress Hauser - (Stage 2 effluent of each train) | | | |
| | 1 | Stage 1 BioReactor Media - Biologically Tailored GAC - 60" Bed Depth | | | |
| | 1 | Stage 2 BioFilter Media - Biologically Tailored GAC | | | |
| | 1 | Stage 2 BioFilter Filtration Media - Silica Sand | | | |
| B | | **Raw Water Supply System** | AdEdge | AdEdge | Others |
| | 2 | 15 hp Centrifugal pump | | | |
| | 2 | Pressure Switch (Raw Water Pump Suction) | | | |
| C | | **Backwash Water Supply System** | AdEdge | AdEdge | Others |
| | 1 | Automated Modulating Butterfly Flow Control Valve | | | |
| | 1 | 10" Electromagnetic Flow Meter - Endress Hauser | | | |
| | 1 | Analog Pressure Transmitter & Pressure Gauges | | | |
| D | | **Backwash Air Supply System** | AdEdge | AdEdge | Others |
| | 2 | Regenerative Air Blower - Floor mount | | | |
| | | - High efficiency TEFC motor | | | |
| | 2 | Manual Butterfly Isolation Valve (one per blower) | | | |
| | 2 | 3" Pressure Relief Valve (one per blower) | | | |
| | 2 | 3" Check Valves | | | |
| | 1 | Analog Pressure Transmitter & Pressure Gauges (on air supply header) | | | |
| E | | **WQ Monitor Integration System** | AdEdge | AdEdge | Others |
| | 1 | NEMA 12 Fiberglass Local Control Panel for indoor installation with ethernet communication | | | |
| | 1 | Stainless Steel Skid Frame with Electrical and Mechanical tie points | | | |
| | | - Mounted sample analyzers pre-installed, pre-wired, and factory tested | | | |
| | | - Panel mounted analyzer calibration and display module | | | |
| | 2 | Dissolved Oxygen Analyzers - Endress Hauser | | | |
| | | *- Stage 1 Effluent* | | | |
| | | *- Stage 2 Effluent* | | | |
| | | *- Blended Water - Dedicated Analyzer post pH Readjustment* | | | |
| | 1 | NO3-N UV Optical Analyzer - Hach | | | |
| | | *- Stage 1 Effluent* | | | |
| | 1 | Turbidity, Compact White Light Analyzer - Endress Hauser | | | |
| | | *- Stage 2 Effluent* | | | |
| | 1 | pH Analyzer - Endress Hauser | | | |
| | | *- Stage 2 Effluent* | | | |
| | 1 | Chlorine Analyzer - Endress Hauser | | | |
| | | *- Dechlorinated Backwash Supply* | | | |
| F | | **Chemical Feed System** | AdEdge | AdEdge | Others |
| | 1 | NEMA 12 Fiberglass Local Control Panel for indoor installation with ethernet communication | | | |
| | 5 | Primary Chemical Feed Modules (ACA, PHA, Service/BW H202, Service/BW ACH, NaOCl) | | | |
| | | - Diaphragm SMART Metering Pumps with built in flow feedback | | | |
| | | - One Duty Pump | | | |
| | | - Chemical Feed Components (Injection Quill, Valves, Dampeners, Cal Columns, Gauges, etc) | | | |
| | 1 | Chemical Feed Module for Maintenance | | | |
| | | - Diaphragm SMART Metering Pump with built in flow feedback | | | |
| | | - One Duty Pump | | | |
| | 4 | 10" Inline Mixer (Raw Water, Interstage, BW Dechlor, & BW Effluent) | | | |
| G | | **Control Systems - Indoor Installation** | AdEdge | AdEdge | Others |
| | 1 | 21" HMI Color Touch Screen | | | |
| | | - Point I/O communication via ethernet to all panels | | | |
| | 1 | Main Control Panel - NEMA 12 Fiberglass PLC Enclosure, Wall Mount | | | |
| | 2 | Local Control Panel - NEMA 12 PLC Enclosure, Wall Mount (Stage 2, Reclaim System) | | | |
| | | - Point I/O communication via ethernet to all panels | | | |
| | | - Eternet Communications to Plant SCADA | | | |
| | | - Remote Access via LAN Connection | | | |

| | | | | | |
|---|---|---|---|---|---|
| **H** | | **Backwash Reclaim System** | **AdEdge** | **AdEdge** | **Others** |
| | 1 | 60,000-gallon Backwash Reclaim Steel Bolted Tank -Concrete conical bottom by others | | | |
| | 1 | Variable Speed Tank Flocculator Mixer (BW Waste Tank) | | | |
| | 2 | 4" Electromagnetic Flow Meter - Endress Hauser (Settled Sludge & Reclaim) | | | |
| | 1 | Variable Speed 10 hp Centrifugal Pump and check valve (Backwash Reclaim) | | | |
| | 2 | Variable Speed 5 hp Centrifugal Pump and check valve (Settled Sludge) | | | |
| | 3 | Analog Pressure Transmitter & Pressure Gauges (Sludge Pump & Reclaim Pump, BW Tanks) | | | |

**Notes, Clarifications and Exceptions**

**1** AdEdge will coordinate closely with Installer and the Engineer on all equipment and design related items

**2** System will be shipped on a flatbed trailer for offloading by personnel other than AdEdge personnel with appropriate equipment and trained operator

**3** Media will be shipped in bags on pallets for offloading by forklift - By Others

**5** Costs of metal components, especially steel, in our system are subject to change due to the volatilities of market pricing and imposed taxes and tariffs, therefore AdEdge reserves the right to adjust pricing to pass along any such increases.

**Items Supplied By Others / Contractor**

**A** Non-AdEdge system related site, civil, or structural engineering or support costs from Owner

**B** Safety equipment as required for media loading, startup/commissioning

**C** Offloading, storage and placement of all equipment and media

**D** Site work and any building structure / facility or shade structure to be provided; HVAC

**E** Construction of structural concrete pad as necessary for treatment equipment provided by AdEdge

**F** Anchoring Equipment, tanks and other equipment to the building's foundation/structural pads

**G** Dedicated power supply to AdEdge equipment; Interconnecting control and instrumentation wiring to control panel

**H** Labor for Media loading with AdEdge Supervision

**I** Regulator Interfacing & Permitting

**J** All Chemical Supply for Start-Up & Commissioning

**K** Chemical Storage & Containment

**WVWD - OPEX Update**
**biottta®**
**9/25/2018**

| | | | **biottta ® 12-1** |
|---|---|---|---|
| **Energy Cost Assumptions (Motors > 1 HP)** | | | |
| Energy Cost - Power | $/KWH | $ | 0.14 |
| **Raw Water Feed Pumps** | | | |
| Hours Operating per Day | Hrs | | 23.50 |
| Load | HP | | 15.0 |
| Energy Consumption | kW | | 11.2 |
| Annual Energy Cost (BW Pump) | $/Annual | $ | 13,432 |
| **Backwash Air Blowers** | | | |
| Hours Operating per Day | hrs/day | | 0.13 |
| Load | hp | | 18.8 |
| Energy Consumption | kW | | 14.0 |
| Annual Energy Cost | $/year | $ | 95 |
| **Backwash Reclaim Pump** | | | |
| Hours Operating per Day | hrs/day | | 13.33 |
| Load | hp | | 10.0 |
| Energy Consumption | kW | | 7.5 |
| Annual Energy Cost | $/year | $ | 5,081 |
| **Backwash Sludge Pump** | | | |
| Hours Operating per Day | hrs/day | | 0.22 |
| Load | hp | | 5.0 |
| Energy Consumption | kW | | 3.7 |
| Annual Energy Cost | $/year | $ | 42 |
| **Backwash Tank Mixer** | | | |
| Hours Operating per Day | hrs/day | | 0.22 |
| Load | hp | | 2.0 |
| Energy Consumption | kW | | 1.5 |
| Annual Energy Cost | $/year | $ | 17 |
| **Combined Annual Energy Cost** | **$/Year** | **$** | **18,667** |

| Chemical Cost Assumptions | | | |
|---|---|---|---|
| *Phosphoric Acid* | | 75% CONC. | |
| Unit Cost | $/gal | $ | 8.30 |
| Annual Volume | gal/yr | | 488 |
| Annual Cost | $/year | $ | 4,051 |
| *Acetic Acid* | | 80% CONC. | |
| Unit Cost | $/gal | $ | 8.33 |
| Annual Volume | gal/yr | | 9,274 |
| Annual Cost | $/year | $ | 77,227 |
| *Hydrogen Peroxide* | | 27.5% CONC. | |
| Unit Cost | $/gal | $ | 3.94 |
| Annual Volume | gal/yr | | 12,118 |
| Annual Cost | $/year | $ | 47,802 |
| *Coagulant* | | 50% CONC. | |
| Unit Cost | $/gal | $ | 5.59 |
| Annual Volume | gal/yr | | 961 |
| Annual Cost | $/year | $ | 5,372 |
| *Sodium Hypochlorite* | | 12.5% CONC. | |
| Unit Cost | $/gal | $ | 2.50 |
| Annual Volume | gal/yr | | - |
| Annual Cost | $/year | $ | - |
| *Sodium Hydroxide* | | 0% CONC. | |
| Unit Cost | $/gal | $ | - |
| Annual Volume | gal/yr | | - |
| Annual Cost | $/year | $ | - |
| Sludge Disposal | | | |
| Unit Cost | $/gal | $ | - |
| Maximum Sludge Waste | % of BW | 0.36% | |
| | gal/Day | | 2,400 |
| Annual Volume | gal/yr | | 876,000 |
| Annual Cost | $/year | $ | - |
| **Combined Annual Chem & Waste Costs** | **$/year** | **$** | **134,452** |

| OPEX Per Production Unit | | | |
|---|---|---|---|
| Annual Energy + Chemical OPEX | $/Annual | **$** | **153,120** |
| Annual Water Production | MG/year | | 241.9 |
| **Cost per Thousand** | **$/kgal** | **$** | **0.63** |
| **Cost per Acre-Foot** | **$/acre-ft** | **$** | **206** |

Appendix E

# FLUIDIZED-BED BIOREACTOR – FIXED-BED BIOREACTOR TREATMENT SYSTEM COMPARISON

**Fluidized-Bed Bioreactor Treatment System Description**

- Single-stage, upflow fluidized-bed process with recycle line to maintain high feed pumping rate.
- Treatment vessel open to the atmosphere.
- Proprietary coconut-based GAC used; Bed depth is 10 feet
- Acetic acid addition for electron donor and carbon source.
- Phosphoric acid addition for nutrient balance.
- Uses an in-bed media cleaning system for biomass control.
- Typically uses aeration for reoxygenation.
- Uses multi-media Trident filters for solids removal, with coagulant dosed upstream.
- A dissolved air floatation system is used to remove biosolids from the Trident filter backwash wastewater.
- Overall treatment system is multiple unit processes added together.
- Uses in-line nitrate and perchlorate analyzers to control acid dosing.

**Fixed-Bed Bioreactor Treatment System Description**

- Downflow fixed-bed bioreactor followed by a downflow aerobic biofilter; uses pressure vessels and GAC.
- Second stage biofilter is designed for acetic acid polishing, turbidity removal, and the removal of any reduced contaminants like hydrogen sulfide.
- Relatively shallow bed depth (4-5 feet).
- Acetic acid addition for electron donor and carbon source.
- Trace phosphoric acid addition for nutrient balance.
- Hydrogen peroxide for oxygen addition and biomass control.
- Trace coagulant addition for turbidity control.
- Backwash wastewater solids are removed through settling in a backwash wastewater tank.
- Entire treatment system is integrated into a single treatment system.
- Fixed-beds typically backwashed every 18-72 hours to remove excess biomass.

### Main FBR and FXB Performance Similarities

- Both plants removed nitrate, perchlorate, and TCE effectively.
- Performance of both plants was negligibly impacted by short-term phosphorus feed shut-downs.
- Performance of both plants was negligibly impacted by short-term system shut-downs.
- Both systems require approximately the same dose of acetic acid and phosphoric acid.
- Both systems responded similarly to short-term acetic acid feed failures, with perchlorate breaking through the FBR and Bioreactor within approximately 30 minutes to an hour and perchlorate breaking through to system effluent within approximately 2 hours.

### Main Differences Between the FBR and FXB Systems

- FBR system is open to the atmosphere so repumping is required between each unit process. FXB is a closed system under pressure, so a single set of feed pumps drives water across the entire system.
- The open nature of the FBR also means that any volatile compounds like hydrogen sulfide or VOCs can volatilize at the top of the FBR or in the aeration tank. GAC scrubbers were added to the aeration tanks to account for this. Hydrogen sulfide and VOCs do not have access to the atmosphere in the FXB system and are taken out biologically across the system.
- There is no aerobic biological process downstream of the FBR, which means that any acetic acid carry-over causes unintended biological regrowth within the aeration tanks and the Trident filters. The second-stage biofilter in the FXB system is designed to biologically oxidize any acetic acid carryover from the first-stage bioreactor.
- The biomass (i.e., bed height) control system for the FBR was intended to operate in-line (i.e., biomass removal takes place while the system is in operation). However, in practice, the FBR sometimes is taken off-line to clean the beds with water jets and eductor pumps. The FXB system biomass control strategy is to take the pressure vessels out of service for a short period, and backwash the beds with air, water, and occasionally hydrogen peroxide.