BRP WS-22D PILOT TESTING REPORT

Wells 2 & 5 PFAS Removal with Iron and Manganese Pretreatment
Barnstable Fire District Water Department

Transmittal No. X287778

July 2021
File No. 01.0174868.00

PREPARED FOR:
Barnstable Fire District Water Department
1841 Phinney's Lane
Barnstable, MA 02630

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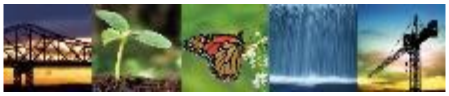

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July 26, 2021
Project No.: 01.0174868.00

James McLaughlin, Chief
Drinking Water Section
Massachusetts Department of Environmental Protection
Southeast Regional Office
20 Riverside Drive
Lakeville, Massachusetts 02347

Re: BRP WS 22D – Pilot Study Report = or > 1 MGD
Per- and Polyfluoroalkyl Substances (PFAS) Removal
with Iron and Manganese Pretreatment
Barnstable, Massachusetts, Transmittal No. X287778

Dear Mr. McLaughlin,

On behalf of the Barnstable Fire District Water Department (BFDWD), GZA GeoEnvironmental Inc. (GZA) is submitting this Pilot Study Report for the Massachusetts Department of Environmental Protection's (MassDEP's) review and approval. A permit application (MassDEP BRP WS 22D-Pilot Study Report = or > 1 MGD) and Transmittal Form No. X287778 is included as cover pages of this report. This report is subject to the Limitations contained in **Appendix A.**

The BFDWD seeks to construct a water treatment plant to remove per- and polyfluoroalkyl substances (PFAS) from groundwater supplied by Well 2 (402000-02G) and Well 5 (4020000-05G), which are both located off Breeds Hill Road in Barnstable, Massachusetts. The pilot test for Wells 2 and evaluated the use of pressure filtration using catalytic media for iron and manganese removal, and granular activated carbon (GAC) and ion exchange resin (IX) for removal of PFAS6[1]. The pilot study was completed using the following technologies:

- Catalytic manganese dioxide coated silica: GreensandPlus™
- Coal-based granular activated carbon: Calgon Carbon FILTRASORB® 400
- Ion Exchange Resin: Purolite Purofine® PFA694E

This Pilot Study Report has been prepared in accordance with MassDEP Policy #90-04 "Pilot Study Requirements for Proposed Treatment". The piloting was completed in accordance with the Pilot Study Proposal approved by the MassDEP in a letter dated January 18, 2021 (Transmittal No. X287110).

Very truly yours,
GZA GEOENVIRONMENTAL, INC.

Thomas C Sexton

Thomas C. Sexton, P.E.
Senior Project Manager

Gregory McNeal

Gregory McNeal EIT
Project Engineer

Chad Cox

Chad H. Cox, P.E.
Principal-in-Charge

Susan J. Bator, LSP
Consultant/Reviewer

cc: Thomas Rooney, Superintendent, Barnstable District Fire Department, via email
Robert Williamson, P.E., Regional Group Leader, Wright-Pierce, via email
Erik Grotton, P.E., President, Blueleaf Inc., via email

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[1] Perfluorooctanoic acid (PFOA), perfluorooctanesulfonic acid (PFOS), perfluorodecanoic acid (PFDA), perfluoroheptanoic acid (PFHpA), perfluorohexanesulfonic acid (PFHxS), and perfluorononanoic acid (PFNA).

Massachusetts Department of Environmental Protection
Bureau of Resource Protection – Drinking Water Program

BRP WS Application

For Drinking Water Program (Water Supply) Permits or Approvals

X287778
Transmittal Number

4020000
Facility ID# (if known)

A. Application

Important: When filling out forms on the computer, use only the tab key to move your cursor - do not use the return key.

1. Is this application for ☒ an Original or ☐ a Resubmittal?

2. Applicant:

Barnstable Fire District Water Department	1841 Phinney's Lane
Name	Address

Barnstable	MA	02630	Thomas J Rooney	508-362-6498
City	State	Zip	Contact	Telephone

3. Consultant:

GZA Geoenvironmental, Inc.	249 Vanderbilt Avenue
Name	Address

Norwood	MA	02062	Thomas C Sexton	215-510-5741
City	State	Zip	Contact	Telephone

B. Permit

Please check the permit or approval for which you are applying:

Zone II Determination for Existing Sources
- ☐ BRP WS 07 Approval to Conduct Pump Test for Zone II Delineation
- ☐ BRP WS 08 Approval of Zone II Delineation

New Technology
- ☐ BRP WS 11 Minor New Technology Approval; where no field test required
  - ☐ Drinking Water Additive
  - ☐ Cross Connection Device
  - ☐ Water Vending Machine
  - ☐ Other (specify):
- ☐ BRP WS 12 Major New Technology Approval: where field testing is required
- ☐ BRP WS 27 New Technology with Third-party Approval
- ☐ BRP WS 28 Vending Site/Source Prototype
- ☐ BRP WS 31 Vending and POU/POE Devices with Third-party Approval

New Source Approvals <70 gpm
- ☐ BRP WS 13 Exploratory Phase, Site Examination, Land Use Survey and Approval to Conduct Pumping Test
- ☐ BRP WS 15 Pumping Test Report Approval and Approval to Construct Source
- ☐ BRP WS 37 Approval of Transient Non-Community Source Less than 7 Gallons per Minute (combines BRP WS 13 and BRP WS 15 submittals)

New Source Approvals = or > 70 gpm
- ☐ BRP WS 17 Exploratory Phase, Site Examination, Land Use Survey, and Conduct Pumping Test
- ☐ BRP WS 19 Pumping Test Report Approval
- ☐ BRP WS 20 To Construct Source

Water Treatment Approvals
- ☐ BRP WS 21A To Conduct Pilot Study < 40,000 gpd
- ☐ BRP WS 21B To Conduct Pilot Study = or > 40,000 gpd and < 200,000 gpd
- ☐ BRP WS 21C To Conduct Pilot Study = or > 200,000 gpd and < 1 mgd
- ☐ BRP WS 21D To Conduct Pilot Study = or > 1 mgd
- ☐ BRP WS 22A Pilot Study Report < 40,000 gpd
- ☐ BRP WS 22B Pilot Study Report = or > 40,000 gpd and < 200,000 gpd
- ☐ BRP WS 22C Pilot Study Report = or > 200,000 gpd and < 1 mgd
- ☒ BRP WS 22D Pilot Study Report = or > 1 mgd
- ☐ BRP WS 23A To Construct Facility <40,000 gpd
- ☐ BRP WS 23B To Construct Facility = or > 40,000 gpd and < 200,000 gpd
- ☐ BRP WS 23C To Construct Facility = or > 200,000 gpd and < 1 mgd
- ☐ BRP WS 24 To Construct Facility = or > 1 mgd
- ☐ BRP WS 25 Treatment Facility Modification
- ☐ BRP WS 29 Water Treatment: Chemical Addition Retrofits of Water Systems > 3,300 people
- ☐ BRP WS 30A Vending Installation Approval
- ☐ BRP WS 30B POU/POE Installation Approval
- ☐ BRP WS 34 Water Treatment: Chemical Addition Retrofits of Water Systems = or < 3,300 people
- ☐ BRP WS 35A Multiple Vending Installation Approval
- ☐ BRP WS 35B Multiple POU/POE Installation Approval

Water Quality Assurance
- ☐ BRP WS 26 Sale or Acquisition of Land for Water Source
- ☐ BRP WS 36 Abandonment of Water Source

Distribution System Modifications
- ☐ BRP WS 32 Systems > 3,300 people
- ☐ BRP WS 33 Systems = or < 3,300 people

Massachusetts Department of Environmental Protection
Bureau of Resource Protection – Drinking Water Program

BRP WS Application

For Drinking Water Program (Water Supply) Permits or Approvals

X287778
Transmittal Number

4020000
Facility ID# (if known)

C. Certification

"I certify, under penalty of law, that this application and all attachments were prepared under my supervision, in accordance with a system designed to ensure that qualified personnel properly gathered and evaluated the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information submitted in this application, the information submitted is, to the best of my knowledge and belief, true, accurate and complete."

Thomas C Sexton	7-23-21
Authorized Signature	Date
Thomas C Sexton	Engineer/Project Manager
Print Name	Position/Title

Enter your transmittal number →

X287778
Transmittal Number

Your unique Transmittal Number can be accessed online:
https://www.mass.gov/service-details/transmittal-form-number-for-massdep-permit-application-payment

Massachusetts Department of Environmental Protection

Transmittal Form for Permit Application and Payment

1. Please type or print. A separate Transmittal Form must be completed for each permit application.

2. Make your check payable to the Commonwealth of Massachusetts and mail it with a copy of this form to: MassDEP, P.O. Box 4062, Boston, MA 02211.

3. Three copies of this form will be needed.

Copy 1 - the original must accompany your permit application.
Copy 2 must accompany your fee payment.
Copy 3 should be retained for your records

4. Both fee-paying and exempt applicants must mail a copy of this transmittal form to:

MassDEP
P.O. Box 4062
Boston, MA
02211

*** Note:**
For BWSC Permits, enter the LSP.

A. Permit Information

BRP WS-22D	Drinking Water Program (Water Supply)
1. Permit Code: 4-to-7-character code from permit instructions	2. Name of Permit Category

Pilot Study Report = or > 1 mgd
3. Type of Project or Activity

B. Applicant Information – Firm or Individual

Barnstable Fire District Water Department PWSID 4020000
1. Name of Firm - Or, if party needing this approval is an individual enter name below:

2. **Last Name** of Individual	3. **First Name** of Individual	4. MI

1841 Phinney's Ln
5. Street Address

Barnstable	MA	02630	508-362-6498	102
6. City/Town	7. State	8. Zip Code	9. Telephone #	10. Ext. #

Thomas J Rooney	bfdwatersupt@barnstablefiredistrict.com
11. Contact Person	12. e-mail address

C. Facility, Site or Individual Requiring Approval

Barnstable Fire District Water Department Wells 2 and 5
1. Name of Facility, Site or Individual

Breeds Hill Rd
2. Street Address

Barnstable	MA	02601		
3. City/Town	4. State	5. Zip Code	6. Telephone #	7. Ext. #

4020000		
8. DEP Facility Number (if Known)	9. Federal I.D. Number (if Known)	10. BWSC Tracking # (if Known)

D. Application Prepared by (if different from Section B)*

GZA GeoEnvironmental, Inc.
1. Name of Firm or Individual

249 Vanderbilt Ave
2. Address

Norwood	MA	02062	215-510-5741	
3. City/Town	4. State	5. Zip Code	6. Telephone #	7. Ext. #

Tom Sexton	
8. Contact Person	9. LSP Number (BWSC Permits only)

E. Permit - Project Coordination

1. Is this project subject to MEPA review? ☒ yes ☐ no
If yes, enter the project's EOEA file number - assigned when an Environmental Notification Form is submitted to the MEPA unit:

EOEA File Number

F. Amount Due

DEP Use Only

Permit No:

Rec'd Date:

Reviewer:

Special Provisions:

1. ☒ **Fee** Exempt: city, town, county, or district of the Commonwealth; federally recognized Indian tribe housing authority; municipal housing authority; the MBTA; or state agency if fee is $100 or less. *There are no fee exemptions for BWSC permits, regardless of applicant status.*
2. ☐ Hardship Request - payment extensions according to 310 CMR 4.04(3)(c).
3. ☐ Alternative Schedule Project (according to 310 CMR 4.05 and 4.10).
4. ☐ Homeowner (according to 310 CMR 4.02).

Check Number	Dollar Amount	Date

EXECUTIVE SUMMARY

The groundwater source providing water to the Barnstable Fire District Water Department (BFDWD) and containing Well 4020000-02G (Well 2) and 4020000-05G (Well 5) has been contaminated by per- and polyfluoroalkyl substances (PFAS) and requires treatment to maintain PFAS6[2] concentrations below the current Massachusetts Maximum Contaminant Level (MCL) of 20 nanograms per liter (ng/L; equivalent to parts per trillion or ppt). A piloting program to support design and permitting of a new PFAS treatment plant for Wells 2 and 5 was conducted by Blueleaf, Incorporated with oversight by GZA between February 15 and March 5, 2021, the results of which are summarized herein.

The pilot testing compared the use of two different PFAS adsorptive media: Granular Activated Carbon (GAC) using FILTRASORB® 400 from Calgon Carbon Corporation and Ion Exchange (IX) using Purofine® PFA694E resin from Purolite. The purpose of the comparison was to evaluate if regulated or unregulated PFAS compounds were more-efficiently removed by either process. Prior to the treatment study, conceptual design of the treatment process considered GAC to be the preferred method of PFAS removal with a potential need for IX for refining the treatment process to treat contaminants not removed by GAC.

Both GAC and IX were found to be equally effective in removing PFAS. Testing the shortest empty bed contact times (EBCT), 10 minutes for GAC and 1.5 minutes for IX, showed both GAC and IX brought detected PFAS compounds to non-detectable limits. The performance observed in PFAS removal using GAC appears to preclude the need for IX. Simulated distribution system testing was completed, and detected concentrations of disinfection byproducts in the effluent of the GAC and IX contactors were found to be significantly below the MCLs.

Calgon Carbon Corporation provided an estimate of GAC backwashing and replacement frequency. This estimate was the result of a propriety model with inputs for water quality data collected during this pilot program.

Historically low to moderate concentrations of iron and manganese, as well as seasonal complaints of discolored water warranted the piloting of iron and manganese removal as pretreatment to the PFAS removal processes. Iron and manganese concentrations detected in the raw water during the pilot test were found to be less than the Secondary Maximum Contaminant Levels (SMCLs) for these metals, except for the manganese concentration in Well 2 which slightly exceeded the SMCL of 0.05 milligrams per liter (mg/L). The iron and manganese piloting trials were conducted using Inversand's catalytic manganese dioxide coated media known as GreensandPlus™ (GSP).

GSP filter influent was pretreated with sodium hypochlorite (NaOCl) to oxidize dissolved iron and manganese and potassium hydroxide (KOH) for raising pH into the target range for GSP filtration. Two pH targets (6.7 and 7.7) were tested to evaluate impact on iron and manganese treatment, and approximate dosages of pretreatment chemicals, for the full-scale plant. An aeration step was piloted on the raw water prior to pretreatment chemical addition and was found to be effective in removing CO2 to increase raw water pH, which decreased the pretreatment KOH dose. Iron and manganese were both removed to non-detectable limits at various filter surface loading rates and chemical pretreatment doses.

The GSP pilot testing also included recycling the settled supernatant of the GSP filter backwash. When settled supernatant was added to the GSP filter influent at a rate of 10 percent of the total influent flow, manganese concentrations in the raw water more than doubled, causing an increase of manganese concentrations and turbidity measured in the effluent in recycle trials. Concentrations in the effluent, however, were below the primary and secondary regulatory limits for iron, manganese, and turbidity, but GSP filter run times were significantly reduced due to increased differential pressure buildup.

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[2] Perfluorooctanoic acid (PFOA), perfluorooctanesulfonic acid (PFOS), perfluorodecanoic acid (PFDA), perfluoroheptanoic acid (PFHpA), perfluorohexanesulfonic acid (PFHxS), and perfluorononanoic acid (PFNA).

GZA, in partnership with Wright-Pierce of Topsham, Maine, recommends construction of a full-scale PFAS removal treatment plant for source water from Wells 2 and 5 utilizing GAC preceded by GSP filtration pretreatment. The GSP pretreatment process will include the use of NaOCl for oxidation of dissolved iron and manganese, and for continuous regeneration of the filtration media. Finished water pH correction will be achieved by a combination of aeration and KOH addition. Based on the recycle trials, it is not recommended to recycle settled supernatant. The BFDWD is recommended to continue use of NaOCl for finished water chlorination and KOH for finished water corrosion control following GSP and GAC treatment.

Wright-Pierce provided a conceptual design of a treatment plant with lockers, bathrooms, mechanical, plumbing, HVAC, fire-protection, electrical, and backwash storage tank. GZA provided an opinion of probable costs for two (2) 100,000-gallon lined lagoons for settling solids from GSP backwash water, two (2) 250,000-gallon sand filters for infiltration of GSP and GAC backwash water supernatant, a tight tank for sanitary wastewater handling, a stormwater infiltration basin and associated catch basins and pipe, and modifications to major utilities (power, water distribution main, and telecommunications). The estimated cost of construction of this facility is approximately $14 million with an annual operating cost of $336,000.

TABLE OF CONTENTS

MASSDEP BRP WS 22D-PILOT STUDY REPORT = OR > 1 MGD APPLICATION

MASSDEP TRANSMITTAL LETTER

EXECUTIVE SUMMARY

TABLE OF CONTENTS

TABLES

APPENDICES

Appendix A	Limitations
Appendix B	Site Locus
Appendix C	Email Correspondence with MassDEP Regarding Well Withdrawal Rates
Appendix D	Blueleaf, Inc. Pilot Study Report
Appendix E	Conceptual Treatment Plant Process Flow Diagram
Appendix F	BFDWD Lead and Copper – 90th Percentile Compliance Report, dated 10/14/2020

1.0 INTRODUCTION

1.1 PURPOSE

This report presents the results of a pilot testing program conducted for Well 2 and Well 5 in Barnstable, Massachusetts for the Barnstable Fire District Water Department (BFDWD). Recommendations for treatment alternatives necessary to remove iron, manganese, and per- and poly-fluoroalkyl substances (PFAS) are presented herein. The pilot study was performed by Blueleaf, Incorporated (Blueleaf) of Charlton, Massachusetts between February 15 and March 5, 2021 under the supervision of GZA GeoEnvironmental, Inc. (GZA).

This report also serves to support the Massachusetts Department of Environmental Protection (MassDEP) Drinking Water Program's (DWP) Bureau of Resource Protection (BRP) WS-22D application. Approval of the BRP WS-22D permit will allow GZA with its partner, Wright-Pierce of Topsham, Maine, to design a full-scale water treatment plant (WTP) including iron and manganese pretreatment and PFAS removal. This facility will serve Well 2 and Well 5 with a planned capacity of 2.16 million gallons per day (MGD), which is equivalent to a combined Well 2 and Well 5 pumping rate of 1,500 gallons per minute (GPM).

1.2 BACKGROUND

The BFDWD serves the whole of the Barnstable Village and Cummaquid neighborhoods within the Town of Barnstable, MA, located on Cape Cod, which consists of approximately 3,500 year-round residents and a summer population of approximately 5,236 [1]. The BFDWD water system consists of three separate groundwater source areas containing five gravel-packed wells, two treatment buildings, and three storage tanks. Well 1 is currently inactive and a new treatment building is currently being constructed under the Drinking Water State Revolving Fund (DWSRF) Project 6929 with substantial completion expected by December 2021. Wells 3 and 4 are manifolded together and Wells 2 and 5 are manifolded together in separate groundwater source areas. Each source is treated with potassium hydroxide (KOH) for corrosion control and sodium hypochlorite (NaOCL) for disinfection. PFAS6 have been detected within Wells 3 and 4 below the Massachusetts Maximum Contaminant Level (MMCL) and has not been detected in Well 1. Construction of a PFAS removal facility for Wells 2 and 5 will reduce the BFDWD's reliance on Wells 3 and 4. A site map showing the locations of Well 2 and 5 and BFDWD property lines is included as **Appendix B**.

The source area containing Wells 2 and 5 is located off Breeds Hill Road, adjacent to the Barnstable Municipal Airport and Barnstable County Fire/Rescue Training Academy, and currently exhibits the highest levels of PFAS6 contamination. The source(s) of PFAS has (have) not been identified, though response actions related to detections of PFAS in soil and groundwater at the adjacent Barnstable Fire Training Academy are ongoing. It is anticipated that PFAS contamination of the groundwater supply area will be a long-term condition.

Of the five BFDWD wells, Wells 3, 4, and 5 are permitted withdrawals through the Water Management Act (WMA) Permit Program. Wells 1 and 2 are registered withdrawals, but not permitted through the WMA, and Well 3 is both registered and permitted. All the wells in the BFDWD system are limited to the combined total of 0.66 MGD, based on an annual average day, or 240.9 MG annually. Wells 1 and 2 are limited to combined 0.34 MGD annual average daily withdrawal, or 124.1 MG annually.

The maximum daily withdrawal limits, annual average daily withdrawal limits, and annual withdrawal limits are presented in **Table 1-1**. These limits for Wells 3 through 5 are set by the WMA permit, and the registered limits for Wells 1 and 2 have been confirmed in email correspondence with MassDEP included as **Appendix C**. In addition to the limits presented in **Table 1-1**, Wells 1 and 2 also have a combined yearly withdrawal limit of 124.1 MG. The planned capacity for the treatment plant is 2.16 MGD, corresponding with the combined maximum daily withdrawal limit of Wells 2 and 5. This will provide BFDWD with the greatest flexibility for meeting peak summertime demands by various combinations of their approved maximum daily withdrawal limits for each well. Wells 2 and 5 would be BFDWD's primary source of water upon construction of the treatment plant.

Table 1-1: BFDWD Registered and Permitted Withdrawal Volumes

Well	PWSID	Maximum Day Withdrawal Limit	Annual Average Daily Withdrawal Limit	Annual Withdrawal Limit	Compliance Regulation
Well 1	4020000-01G	0.396 MG	0.66 MGD (All Wells Combined)	240.9 MGY (All Wells Combined)	WMA Registered
Well 2	4020000-02G	0.864 MG			
Well 3	4020000-03G	0.77 MG			WMA Permitted
Well 4	4020000-04G	0.67 MG			
Well 5	4020000-05G	1.296 MG			

2.0 WATER QUALITY

2.1 HISTORICAL RAW WATER QUALITY

Massachusetts has set maximum contaminant levels and guidance levels for various contaminants that could be found in public drinking water. The Massachusetts Maximum Contaminant Levels (MMCLs) listed in the drinking water regulations (310 CMR 22.00) consist of promulgated US Environmental Protection Agency (EPA) MCLs in addition to MCLs set specifically by Massachusetts. On October 2, 2020, MassDEP published its PFAS MMCL of 20 nanograms per liter (ng/L; equivalent to parts per trillion or ppt) – individually or for the sum of the concentrations of six specific PFAS[3]. This report refers to the sum of the six individual PFAS compounds as "PFAS6"[4]. The EPA has also established secondary maximum contaminant levels (SMCLs) for water quality criteria that generally affect the aesthetic qualities of drinking water. The BFDWD has occasionally received aesthetic water quality complaints possibly due to the iron and manganese content of the source water.

Table 2-1 summarizes the median laboratory analytical concentrations of PFAS6, iron, and manganese from the pilot testing program and from historical data records.

Table 2-1: Historical Median Raw Water Quality in Well 2 and Well 5

Contaminant	Units	Data Source	Well 2	Well 5	Compliance Regulation	Regulatory Level
PFAS6	ng/L	2021 Pilot Study	12.41	20.97	MMCL	20 ng/L
		Historical 2016 - 2020	**7.7**	**24.9**		
Iron	mg/L	2021 Pilot Study	**<0.01**	**0.06**	SMCL	0.3 mg/L
		Historical 1995 - 2016	**0.08**	**0.12**		
Manganese	mg/L	2021 Pilot Study	**0.049**	**0.014**	SMCL	0.05 mg/L
		Historical 1995 - 2016	**0.041**	**0.020**		

Note: **Bold** indicates median value.

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[3] The six specific PFAS compounds regulated by MassDEP are: perfluorooctanoic acid (PFOA), perfluorooctanesulfonic acid (PFOS), perfluorodecanoic acid (PFDA), perfluoroheptanoic acid (PFHpA), perfluorohexanesulfonic acid (PFHxS), and perfluorononanoic acid (PFNA).

[4] PFAS6 is calculated using zero for analytical results that are non-detect and using the Minimum Reporting Level (MRL) for estimated results that are less than the MRL.

Concentrations of PFAS6 detected during the pilot study fall within the range of the historical data. The levels of PFAS6 detected during the pilot study suggests that without treatment, blending and diluting flows from Well 2 and Well 5 is required to provide water below the regulatory level of 20 ng/L. Under this configuration, should an equipment failure, natural disaster, or other event shut down Well 2, the source would be unusable due to concentrations in Well 5 exceeding the MMCL.

Iron concentrations in raw water for both wells was detected at lower levels than the historical records. The historical iron analysis reported concentrations with a Method Detection Limit (MDL) of 0.1 mg/L. Eight of the thirteen historical iron analytical results for water from Well 2 were non-detects, and two of the four results for water from Well 5 were non-detects. Field analysis of raw water completed by Blueleaf were below the detection limit of 0.1 mg/L, and Blueleaf reported estimated concentrations below 0.1 mg/L using a HACH DR890 Colorimeter. The iron concentrations in the raw water for both wells detected during the pilot study are representative of the historical data because both sources of data are consistently below the SMCL and predominantly below the MDL.

Manganese concentrations detected during the pilot study fall within the range of the historical data. Sixteen of twenty-two samples from Well 2 analyzed by Blueleaf exceed the SMCL for manganese, while eight of seventeen historical samples from Well 2 exceed the SMCL. For Well 5, manganese was consistently reported below the SMCL in both historical and recent data. While iron and manganese can increase over time in a supply well, historical iron and manganese levels have remained generally consistent in both wells.

Blueleaf states in their Pilot Study Report: “Review and comparison of the historical iron, manganese, and PFAS data indicates that both wells produced representative water quality during the pilot study.” GZA concurs with this statement based upon our own review of the data collected by Blueleaf and the historical records. The remaining raw water quality parameters required to be collected during pilot study by MassDEP Policy 90-04 “Pilot Study Requirements for Proposed Treatment” are listed in **Table 2-2**: Raw Water Quality Parameters Collected During Pilot Study.

Table 2-2: Raw Water Quality Parameters Collected During Pilot Study

Analyte	Units	Well 2	Well 5	Compliance Regulation	Regulatory Level
Total Coliform	Col/100mL	Absent	Absent	MMCL	Absent
E. Coli	Col/100mL	Absent	Absent	MMCL	Absent
Turbidity	NTU	0.49	0.52	N/A	N/A
Color, True	s.u.	ND	ND	SMCL	15 s.u.
Color, Apparent	s.u.	7.0	6.0	SMCL	15 s.u.
Alkalinity	mg/L	7.50	11.1	N/A	N/A
Carbon Dioxide	mg/L	81	96	N/A	N/A
pH		6.7	6.5	SMCL	6.5 – 8.5
Total Organic Carbon	mg/L	ND	0.579	N/A	N/A
Dissolved Organic Carbon	mg/L	ND	ND	N/A	N/A
Chloride	mg/L	135	55.9	SMCL	250

2.2 WATER QUALITY GOALS

The raw water from Wells 2 and 5 requires treatment for the removal of PFAS for the BFDWD to provide finished water with PFAS6 concentrations below the PFAS6 MMCL. Manganese should be removed to ensure concentrations remain below the SMCL and to reduce the fouling effects on downstream treatment processes. Though iron concentrations in the raw water of Wells 2 and 5 are generally below the SMCL, iron removal is complimentary to manganese removal and can protect against potential increase of iron concentrations in the supply wells over time. Removal of iron and manganese may address aesthetic quality complaints that the BFDWD has received, in lieu of a sequestering program that was previously considered under a separate scope of work.

Pilot tests were conducted to evaluate the effectiveness of each process in achieving these water quality goals. The pilot study was designed to allow direct extrapolation of full-scale filtration plant performance from pilot study data. Each process was piloted through the anticipated range of raw water quality, hydraulic loading rates, chemical feed rates, and operational conditions so that a cost-effective treatment facility may be designed to produce water that meets current State and Federal drinking water standards.

3.0 WATER TREATMENT ALTERNATIVES

3.1 GREENSANDPLUS™ IRON AND MANGANESE REMOVAL PRETREATMENT

Iron and manganese removal was evaluated with a catalytic manganese dioxide coated silica GreensandPlus™ (GSP), manufactured by Inversand. GSP is considered an industry standard for iron and manganese removal. The primary purpose of iron and manganese removal is to maintain iron and manganese levels below the SMCL. This will also provide pretreatment to the PFAS6 removal system for the purpose of extending the service life of granular activated carbon (GAC) or ion exchange (IX) by reducing adsorptive competition for PFAS.

GSP is a filtration media consisting of an adsorptive manganese dioxide coating fused to a silica core. GSP is advantageous compared to typical manganese-coated sand because it is capable of withstanding higher differential pressures without breakdown of the media particles. This allows for operation at filter service loading rates (FSLR) of 8 GPM per square foot (GPM/SF) or greater, compared to 2 to 5 GPM/SF for other manganese-coated filtration media. Increasing FSLR reduces the total filter area required to achieve the treatment goals which translates to potential cost reductions by using smaller filtration vessels and a reduced quantity of media. Another advantage to GSP is the ability to continuously regenerate the filter media using NaOCl instead of potassium permanganate. NaOCl is already used by the BFDWD for disinfection, and GSP relieves the operational burden of sourcing and storing an additional treatment chemical.

The manganese-dioxide coating of the filter media is maintained by feeding a chemical oxidant such as potassium permanganate or NaOCl. Pre-oxidation was implemented in the pilot study as a specific media regeneration procedure using NaOCl. The existing water treatment process includes NaOCl feed for disinfection. However, there is potential for the chemical oxidant to compete with adsorption sites in the GAC filtration process. Therefore, the NaOCL injected for pre-oxidation must then be neutralized, in this case using sodium bisulfite, and the process of NaOCl feed for disinfection would follow GAC filtration.

GSP filters require periodic backwashing. This would be conducted with treated water sourced from a backwashing water supply tank. Filter backwash water can be disposed using a combination of a lined lagoon for settling the solids and a sand filter for infiltrating the supernatant. The backwash water supernatant can also be disposed by recycling into the raw water feed after allowing sufficient setting time for suspended particles of iron and manganese. For reasons discussed below, recycling of the backwash water supernatant is not proposed for this WTP.

The GSP pilot testing included recycling the settled supernatant of the GSP filter backwash. When settled supernatant was added to the GSP filter influent at a rate of 10 percent of the total influent flow, manganese concentrations in the raw water more than doubled, causing an increase of manganese concentrations and turbidity measured in the effluent in recycle trials. Concentrations in the effluent, however, were below the primary and secondary regulatory limits for iron, manganese, and turbidity, but GSP filter run times were significantly reduced due to increased differential pressure buildup. Based on the recycle trials, GZA and WP do not propose to recycle settled supernatant.

3.2 GRANULAR ACTIVATED CARBON FOR PFAS REMOVAL

PFAS removal was evaluated using the coal-based GAC FILTRASORB® 400 (F400), manufactured by Calgon Carbon Corporation (Calgon). GAC is a filter media engineered to have an extremely porous structure that removes PFAS from the water by the process of adsorption. Rather than stay within the liquid phase, PFAS has a preference to concentrate on the surface of the GAC. When the adsorption sites are exhausted the GAC media is replaced with either virgin GAC or reactivated GAC. F400 can either be returned to Calgon to be thermally reactivated for recycling and reused, or disposed of by landfilling or incineration.

GAC media requires conditioning before being placed into service. Conditioning is a two-step process consisting of a backwash cycle to segregate the bed by media size and wash out fine particles, followed by a filter-to-waste cycle. The filter-to-waste cycle is needed to stabilize the pH of the effluent and remove metal byproducts of the media manufacturing process to below MCL and SMCL limits. GAC-filtered effluent can have elevated pH levels for a significant duration (estimated 100 to 300 bed volumes). Calgon supplies a variation of the F400 media that is preconditioned to potentially reduce the volume of rinse required.

GAC filters require periodic backwashing due to media compaction and particulate fouling of the upper layers of finer-grained GAC. Pretreatment using GSP is intended to reduce the frequency of these backwash cycles and extend the life of the GAC. Neutralization of free chlorine with sodium bisulfite upstream of the GAC filters will also help to enhance the longevity of the GAC.

3.3 ION EXCHANGE FOR PFAS REMOVAL

PFAS removal was also evaluated using the ion-exchange resin, PFA694E, engineered by Purolite specifically to remove PFAS from drinking water. PFA694E utilizes both ion-exchange and adsorptive mechanisms to remove PFAS. The anion (negatively-charged) "head" of the PFAS molecule is exchanged for the resin's PFAS-selective functional groups, while the hydrophobic tail end of the PFAS molecule is strongly adsorbed onto the hydrophobic surface of the resins.

IX for PFAS removal requires significantly less contact time than GAC; therefore, it requires less space and has potential for initial capital cost savings. However, due to the exchange of chlorides in the IX process, Chloride-to-Sulfate Mass Ratio (CSMR) can increase which may increase corrosivity of water. The original intent for piloting IX was for it to be considered as a polishing step after GAC, not necessarily to replace GAC as the primary PFAS removal medium.

Similar to the GAC F400 media, IX PFA694E requires conditioning before use. The conditioning process would involve a filter to waste cycle during which chloride anions are released by the resin. Purolite claims that following initial startup and conditioning of the IX beds, the resin no longer exchanges chlorides and there is no long-term impact on the CSMR. IX does not require backwashing, and the media would require periodic changeout.

4.0 PILOT DESCRIPTION

4.1 GENERAL PILOT DESCRIPTION

Blueleaf provided a custom-fabricated, scaled water treatment unit housed within two mobile structures. A detailed description of the pilot equipment is provided by Blueleaf in their pilot study report, included as **Appendix D**. References to tables and figures authored by Blueleaf are also included in **Appendix D**.

Source water for both wells was supplied at a single hydrant located near the Well 2 pumping station. BFDWD operated valves to provide water from each well individually. The hydrant flowed at approximately 350 gpm, of which 6 gpm were used for the pilot. The remainder was discharged to a nearby swale and infiltrated into the ground surface.

The source water was pumped to a 150-gallon tank which provided an air-gap connection between the piloting equipment and BFDWD's distribution system. A booster pump supplied water from the tank to four iron and manganese removal contactors. The water was pre-treated with NaOCl as a chemical oxidant for iron and manganese, and KOH as pH adjustment. Chemical metering pumps with adjustable feed rate controls were used to feed the treatment chemicals in liquid form into the raw water supply. The liquid chemical volume was measured using graduated day tanks, which allowed measurement of daily drawdown rates and calculation of chemical feeds rates and doses. The treated pilot effluent water was dechlorinated prior to discharge on the ground as requested by MassDEP in their conditional approval for conducting the pilot study.

The pilot test evaluated recycling settled backwash water supernatant into the raw water feed at 10 percent of the total influent flow rate. This was completed to evaluate if recycling the backwash water would be a suitable method of disposal.

4.1.1 General Water Quality Sampling Program

Samples were collected of raw water, pretreated water, GSP effluent, GAC effluent, IX effluent, and GSP filter backwash. Raw water analysis included individual samples of each well with and without recycling supernatant at 10 percent of the influent flow rate. Samples for laboratory analysis were collected by Blueleaf and transported under chain-of-custody to state-certified laboratories. Off-site analyses except for Halo Acetic Acids (HAA5) were completed by Alpha Analytical, located in Westborough, MA. HAA5 analysis was completed by Granite State Analytical Services, LLC of Derry, NH. Blueleaf completed frequent field analysis of iron, manganese, chlorine, turbidity, and pH at various locations of the treatment process which is described in the following respective sections.

4.1.2 Raw Water Quality Results

Comprehensive water quality data can be found in the Blueleaf Pilot Report included as **Appendix D**. A summary of select raw water analytical data collected during the pilot study are presented in **Table 4-1**. The pilot was structured to allow for the evaluation of recycling settled supernatant.

Table 4-1: Raw Water Quality Analytical Data

Parameter	Well 2	Well 2 w/ 10% Supernatant Recycle	Well 5	Well 5 w/ 10% Supernatant Recycle
Total PFAS (ng/L)	30.88	24.7	27.97	29.40
PFAS6 (ng/L)	12.41	6.96	20.97	22.36
Unregulated PFAS (ng/L)	18.47	17.74	7.00	7.04
Total Iron (mg/L)	**0.00** (0.00 - 0.03) [21]	ND	**0.03** (0.00 - 0.07) [18]	ND
Dissolved Iron (mg/L)	**0.00** (0.00-0.02) [19]	ND	**0.01** (0.00 - 0.03) [12]	ND
Total Manganese (mg/L)	0.055	0.142	0.013	0.015
Dissolved Manganese (mg/L)	**0.054** (0.034 - 0.068) [22]	0.052	**0.016** (0.002 - 0.028) [12]	0.014
pH	**5.39** (5.27 - 5.50) [19]	6.7	**5.52** (5.47 - 5.65) [11]	6.5
Carbon Dioxide (mg/L)	89	81	80	96
Chloride (mg/L)	NM	135	NM	55.9

Notes: 1) NM = Not Measured.
2) ND = Not Detected.
3) Values in **bold** are median values collected by field analyses, also shown are (min – max) and [count]

Total iron concentrations of the raw well water for both Wells 2 and 5 were found to be minimal, and less than expected based on historical values presented in the pilot proposal. Iron was not detected in Well 2 for both field and laboratory analyses. Well 5 field analysis resulted in a median total iron content of 0.03 mg/L; however, in the laboratory analysis, iron was not detected. With 10 percent recycled supernatant Well 2 was found to have a median of 0.02 mg/L total iron and Well 5 was determined to have a median of 0.04 mg/L total iron. For both Well 2 and Well 5, iron was not detected in the samples of the raw water plus 10 percent recycled supernatant.

Manganese sample results exceeded the SMCL of 0.05 mg/L for Well 2 but Well 5 analytical results were less than the manganese SMCL. Laboratory analysis of Well 2 raw water confirmed a large increase of total manganese when 10 percent supernatant was included. However, Well 5's raw water laboratory analysis only appeared to have a slight increase of 0.002 mg/L manganese when 10 percent supernatant was included.

Both EPA Method 533 and 537.1 were used for PFAS analysis of the raw water. A summary of the PFAS analytical results is provided in Table 3.03 of the Blueleaf Pilot Report in **Appendix D**. For regulated PFAS compounds, analytical results for Well 5 showed PFHxS, PFOS, and PFOA, for a total of 20.97 ng/L PFAS6. For Well 2, analytical results showed PFHpA, PFHxS, PFOS, and PFOA for a total of 12.41 ng/L PFAS6. With 10 percent supernatant recycle, the PFAS6 concentrations of the raw water from Well 5 increased but decreased in the raw water for Well 2. This is may be due to variation of PFAS6 concentrations of the raw water feed, as there is no apparent mechanism by which PFAS6 would increase or decrease in the settled supernatant. Some variation in detected PFAS quantities is expected as a laboratory testing artifact. Quality control data for the PFAS sampling events show no detections in field blanks, while showing matrix spike and laboratory control sample recoveries within acceptance criteria.

Both wells were found to contain unregulated PFAS compounds in addition to the regulated PFAS6 compounds. Unregulated compounds detected in Wells 2 and 5 include: perfluoropentanoic acid (PFPeA), perfluorobutanesulfonic acid (PFBS), perfluorobutanoic acid (PFBA), and perfluorohexanoic acid (PFHxA).

4.2 GREENSANDPLUS™ IRON AND MANGANESE REMOVAL PRETREATMENT

4.2.1 Pilot Description

Four individual filter trials were conducted on both wells for a total of eight filter trials. Pilot tests were conducted over a 1-week period for each of the two wells. The parameters monitored included flow rate, inlet pressure, head loss, turbidity, and chemical feed rates. Four of the eight filter trial runs included recycling of backwash supernatant into the raw water feed as 10 percent of total influent flow. Backwash water was also analyzed to estimate settling characteristics and total suspended solids to estimate the size of backwash and residuals handling systems. Four iron and manganese removal contactors (labeled A, B, C, D) were operated to evaluate two levels of KOH pre-treatment and two FSLRs. GSP filter design process parameters are described in **Table 4-2**.

Table 4-2: GSP Filter Design Process Parameters

Description		Filter A	Filter B	Filter C	Filter D
Filter Diameter		6 inches			
Filter Surface Area		0.20 ft^2			
FSLR		5 gpm/sf	10 gpm/sf	5 gpm/sf	10 gpm/sf
pH		6.7	6.7	7.7	7.7
Media	Anthracite	12-inch depth			
	GSP	24-inch depth			
Duration		11 Days Per Well			
NaOCl Dosage		0.5mg/L to 0.9mg/L			

To evaluate the performance of each filter, Blueleaf recorded the duration, FSLR, clean bed head loss, slope (rate of differential pressure in pounds per square inch (PSI) per hour), unit filter run volume (volume of water treated per unit filter surface area), and turbidity. Blueleaf used these data to provide estimates of runtime to breakthrough and runtime to 10 psi of differential pressure. A bench-scale aeration test was completed to evaluate if the use of aeration in the full-scale plant could reduce the volume of pretreatment chemicals used. Aeration increased the pH by stripping CO_2 from the water and may have also oxidized some dissolved iron and manganese in the process.

Backwashing was completed using raw water on each contactor with a loading rate of 12 gpm/sf for a period of 10 minutes until 24-gallons of backwash water was collected from each filter. Representative sampling of supernatant was achieved by sampling backwash effluent following four hours of settling.

4.2.2 GSP Pilot Water Quality Sampling Program

Raw water from each well was sampled and analyzed separately to evaluate if specific treatment or pretreatment considerations would be required if the plant operated without blending the two sources. A total of four rounds of raw water quality samples were collected from each well. Two of the rounds from each well included the introduction of supernatant at 10 percent of the influent raw water flow rate. The water quality parameters analyzed are presented in **Table 4-3**.

Table 4-3: GSP Raw Water Quality Analysis

GSP Raw Water Quality Laboratory Analyses Without Supernatant Recycle (2 Rounds)	GSP Raw Water Quality Laboratory Analyses With 10% Supernatant Recycle (2 Rounds)
PFAS (1 round)	PFAS (1 round)
Total Iron	Total Iron
Dissolved Iron	Dissolved Iron
Total Manganese	Total Manganese
Dissolved Manganese	Total Coliform
pH	Escherichia Coliform
Temperature	Turbidity
Alkalinity	True Color
Carbon Dioxide	Apparent Color
	Alkalinity
	Carbon Dioxide
	pH
	Total Organic Carbon
	Dissolved Organic Carbon
	Chloride

Raw water was injected with NaOCL and KOH for the purposes described in **Section 3**. This water is referred to as post-oxidated (POX). One round of water quality sampling of the POX influent water was completed for each of the target pH levels. The analyses are shown in **Table 4-4**.

Table 4-4: POX Influent Water Quality Analyses

POX Influent Water Quality Laboratory Analyses
Free Chlorine
Total Chlorine
Dissolved Iron
Dissolved Manganese
pH

Field and laboratory analysis were completed on the GSP effluent. Simulated distribution system (SDS) testing was completed on the effluent from Filters B and D (low pH and high pH) for both Well 2 and Well 5. Combined GSP backwash from the two sets of filters was analyzed, in addition to the supernatant after four hours of settling. These water quality analyses are presented in **Table 4-5**.

Table 4-5: GSP Effluent Water Quality Analyses

GSP Effluent Water Quality Field Analyses	GSP Effluent Water Quality Laboratory Analyses	Disinfection Byproduct Water Quality Laboratory Analyses (Filters B and D Only, Well 2 and Well 5)	Combined Backwash Water Quality Laboratory Analyses (Filters A + B and Filters C + D)	Supernatant Water Quality Laboratory Analyses (Filters A + B and Filters C + D)
Free Chlorine	Total Iron	Halo Acetic Acids (HAA5)	Total Iron	Total Iron
Total Chlorine	Total Manganese	Total Trihalomethanes (TTHM)	Dissolved Iron	Dissolved Iron
Total Iron	Total Coliform		Total Manganese	Total Manganese
Total Manganese	Eschericia Coliform		Dissolved Manganese	Sodium
pH	Turbidity		Arsenic	Dissolved Solids
	True Color		Barium	Suspended Solids
	Apparent Color		Cadmium	pH
	Odor		Chromium	
	Alkalinity		Lead	
	Carbon Dioxide		Mercury	
	Total Dissolved Solids		Selenium	
	Total Cyanide		Silver	
	Total Residual Chlorine		Sodium	
	Total Residual Free Chlorine		Dissolved Solids	
	pH		Suspended Solids	
	Total Organic Carbon		Total Residual Chlorine	
	Surfactants		Residual Free Chlorine	
	Chloride		pH	
	Fluoride			
	Sulfate			
	Aluminum			
	Antimony			
	Arsenic			
	Barium			
	Beryllium			
	Cadmium			
	Calcium			
	Chromium			
	Copper			
	Mercury			
	Nickel			
	Selenium			
	Silver			
	Sodium			
	Thallium			
	Zinc			
	PFAS			

4.2.3 GSP Pilot Results

An abbreviated summary of the iron and manganese removal results are presented in **Table 4-6**. Complete analytical data is provided in the Blueleaf Pilot Report, Tables 3.11 through 3.14 in **Appendix D**.

Table 4-6: Filtered Water Quality, Iron and Manganese Removal

Filter and Trial	Source	FSLR (gpm/sf)	Median pH (min – max) [count]	Median Effluent Total Manganese (mg/L) (min – max) [count]
A.3	Well 5	5	6.93 (6.90 - 6.98) [10]	0.005 (0.000 - 0.028) [9]
A.3DR (During Recycle)			6.90-6.92 [2]	0.011 (0.000 - 0.028) [3]
A.5	Well 2	5	6.77 (6.60 - 6.99) [22]	0.000 (0.000 - 0.007) [15]
A.5DR (During Recycle)			6.60 - 6.67 [2]	0.000-0.002 [2]
B.3	Well 5	10	6.93 (6.89 - 6.98) [10]	0.000 (0.000 - 0.011) [9]
B.3DR (During Recycle)			6.89 - 6.91 [2]	0.010 (0.000 - 0.011) [3]
B.5	Well 2	10	6.80 (6.68 - 7.04) [22]	0.000 (0.000 - 0.007) [15]
B.5 (During Recycle)			6.70 - 6.77 [2]	0.000 - 0.001 [2]
C.3	Well 5	5	7.47 (7.28 - 7.66) [4]	0.000 (0.000 - 0.009) [9]
C.3DR (During Recycle)			7.33 - 7.43 [2]	0.000 (0.000 - 0.009) [3]
C.5	Well 2	5	7.51 (7.12 - 7.94) [22]	0.000 (0.000 - 0.006) [15]
C.5DR (During Recycle			7.34 - 7.41 [2]	0.000 - 0.000 [2]
D.3	Well 5	10	7.48 (7.28 - 7.70) [10]	0.005 (0.000 - 0.020) [9]
D.3DR (During Recycle)			7.28 - 7.34	0.017 (0.000 - 0.020) [3]
D.5	Well 2	10	7.45 (7.12 - 7.73) [22]	0.000 (0.000 - 0.008) [15]
D.5DR (During Recycle)			7.33 - 7.39 [2]	0.001 - 0.007 [2]

The filter trials performed met the water quality goals of total iron < 0.30 mg/L and total manganese < 0.05 mg/L.

The results of Filters A and B, trials 3 and 5, show that both FSLRs removed manganese to below the SMCL at the lower target pH level. Trials run at higher pH did not exhibit significant differences in the removal of iron and manganese. There was a statistically significant increase in manganese in the filtered effluent during the recycle trials, but the concentrations remained below the SMCL.

Blueleaf estimated the runtime until 10 PSI of differential pressure would develop across the GSP filters using linear regression of the collected differential pressure data. Predicted runtimes for the GSP filters ranged from approximately 200 hours to over 2,000 hours. Filter trials using supernatant recycle generally showed greater differential pressure and represented the low end of predicted filter run time, indicating that recycle would reduce the runtime of the filters before backwashing would be required. Blueleaf completed Imhoff cone tests of the supernatant, shown in Figures 4.07 and 4.08 of the Blueleaf Pilot Report, which showed cloudy water after four hours of settling. This suggests that the manganese was not effectively settling out of the supernatant which may be contributing to the reduced hydraulic performance of the filters when recycling supernatant. Based on these results, recycling of the supernatant is not proposed for the full-scale treatment plant.

Since the GSP filter bed performance is enhanced with the pretreatment oxidation of iron and manganese, the pretreatment oxidant was evaluated at two different pH targets for both wells. Due to the low levels of iron at both wells in comparison to manganese, this evaluation was based on the oxidation of manganese and not iron. For Well 2, at a pH of 6.7, chlorine precipitated an average of 18 percent of raw manganese, whereas 22 percent of raw manganese was precipitated at a pH of 7.7. For Well 5, at a pH of 6.7, chlorine precipitated an average of 12 percent of raw manganese, whereas 35 percent of raw manganese was precipitated at a pH of 7.7. The higher pH was more effective at precipitating manganese, but the results shown in **Table 4-6** indicate that the water quality goal for iron and manganese removal was achieved using the lower pH target. Therefore, the proposed full-scale treatment plant will utilize the lower pH target of 6.7 to reduce KOH cost.

Bench scale titrations were conducted to evaluate the potassium hydroxide dose necessary to raise the raw water pH from ambient to 6.7 and then further to 7.7. The experiment was repeated for both wells and again for post aerated water to evaluate the possible benefits of aeration in reducing chemical usage. The results are summarized in **Table 4-7**. Five minutes of aeration reduced KOH doses by greater than half. The proposed full-scale treatment plant will utilize aeration to reduce KOH cost.

Table 4-7: KOH Dosing

Source	pH Target	KOH Dose (mg/L)	KOH Dose Post Aeration (mg/L)
Well 2	6.7	49	15
	7.7	97	37
Well 5	6.7	28	6
	7.7	56	21

4.3 PFAS REMOVAL USING GAC AND IX

4.3.1 Pilot description

Downstream of the iron and manganese removal system, the effluent water from all contactors was combined in a PFAS feed water storage tank and dechlorinated using LPD-Chlor™ dechlorination tablets. The water was then pumped to four distinct treatment processes. The four treatment configurations evaluated filter performance targeting two different EBCTs. The pilot PFAS removal filter design parameters are presented in **Table 4-8**.

Table 4-8: PFAS Removal Filter Design Parameters

Parameter	GAC 1 and GAC 2				IX1 and IX2
	Vessel 1	Vessel 2	Vessel 3	Total	Total
Media Type	Calgon Filtrasorb 400				Purolite PFA 694E
Adsorptive Media Depth (inch)	40			120	26
Adsorptive Media Volume (gal)	4.9			14.7	1.95
Freeboard Above Filter Surface (inch)	20			60	24
Contactor Vessel Diameter (inch)	6			6	4
Contactor Surface Area (feet^2)	0.2			0.2	0.09
Contractor Vessel Height (feet)	5			15	5
Filter Vessel Empty Volume (gal)	7.34			22	3.26

The GAC PFAS removal contactors were designed as a train of 3 vessels connected in series to simplify the construction and operation of the contactors. The IX PFAS removal contractor process consisted of a single vessel.

The EBCTs of each configuration are presented in **Table 4-9**.

Table 4-9: PFAS Contactors Empty Bed Contact Time

	PFAS Removal Contactors			
	GAC1	GAC2	IX1	IX2
Media	Filtrasorb 400		PFA 694E	
EBCT (min)	10	20	1.5	3

The pilot study was structured in this fashion to evaluate treatment performance across a range of operational parameters. The treated system effluent was discharged to a nearby swale and infiltrated. Ion exchange and GAC were piloted in parallel to evaluate the differences in removal performance down to individual PFAS compounds; however, the original intent of piloting IX was evaluating its suitability as a polishing treatment step following GAC.

To evaluate the performance of each PFAS removal contactor, Blueleaf recorded flow rate, flow totalizer volume, elapsed time, actual flow rates (totalizer volume divided by elapsed time), FSLR, EBCT, and total bed volumes treated. The PFAS removal piloting was completed between February 16 and March 5, 2021.

4.3.2 PFAS Removal Water Quality Sampling Program

Filter effluent from each PFAS removal contactor was sampled and analyzed separately. Laboratory analyses of the treated effluent are presented in **Table 4-10**.

Table 4-10: PFAS Treated Effluent Water Quality Laboratory Analyses

PFAS Treated Effluent Water Quality Laboratory Analyses	
PFAS	Sulfate
Total Iron	Aluminum
Total Manganese	Antimony
Turbidity	Arsenic
True Color	Barium
Apparent Color	Beryllium
Odor	Cadmium
Alkalinity	Calcium
Carbon Dioxide	Chromium
Total Dissolved Solids	Copper
Total Cyanide	Mercury
Total Residual Chlorine	Nickel
Total Residual Free Chlorine	Selenium
pH	Silver
Total Organic Carbon	Sodium
Surfactants	Thallium
Chloride	Zinc
Fluoride	Disinfection Byproducts

Chlorine was added to the GAC and IX contactor effluent for the sampling of disinfection byproducts (DBPs) for the SDS test. GAC1 and IX1 effluent for both Wells 2 and 5 were sampled for DBPs. DBP analysis included HAA5 and total trihalomethanes (TTHM).

4.3.3 PFAS Removal Results

PFAS compounds analyzed by both EPA Methods EPA 533 and 537.1 were reduced to non-detectable limits in the treated effluent for both GAC and IX. A summary of these results is presented in **Table 4-12**, showing the method detection limits achieved for each sampling round.

The high-rate GAC contactor operated at EBCT of 10 minutes treated approximately 2,452 bed volumes of water during the pilot study without indication of contaminant breakthrough above laboratory reporting limits based on the laboratory analysis. The high-rate IX contactor operating at EBCT of 1.5 minutes treated approximately 15,330 bed volumes without indication of contaminant breakthrough above laboratory reporting limits based on the laboratory analysis. Measurements of filter differential pressure showed increases of less than 2 PSI over the course of the pilot for both IX and GAC, indicating full-scale contactors would achieve acceptable runtimes before required backwashing for GAC or media changeout for IX.

A summary of DBP analysis of the treated effluent is presented in **Table 4-13**. SDS testing of the treated PFAS contactor effluent from both GAC and IX show results less than the MCL for the DBPs reported. The results show a higher potential for formation of DBPs using IX instead of GAC.

The hydraulic performance (minimal head loss development) and PFAS6 removal performance (concentrations reduced to non-detectable levels) of the GAC pilot indicate that full-scale GAC contactors would achieve the water quality goal of PFAS6 < 20 µg/L. Calgon and Purolite each provided estimates for GAC and IX media life, respectively, based upon the influent water quality data. Calgon estimated a usable life of 80,000 bed volumes for GAC to remove PFAS6 to non-detectable levels. Purolite estimated 340,000 bed volumes for IX to remove PFAS6 to non-detectable levels.

The results of the pilot study supported development of the conceptual design criteria for a full-scale WTP. The results also support the intent of using GAC as the primary technology for PFAS removal. IX was shown to also be effective at removing PFAS but at greater cost. The performance of the GAC pilot shows that IX is not required as a polishing step following GAC because the PFAS compounds detected in raw water by Methods 533 and 537.1 were removed to non-detectable levels. **Table 4-11** shows concept-level costs, based on assumed filter vessel dimensions and flow rate, and using manufacturer supplied estimates of media life.

Table 4-11: Comparison of GAC vs. IX Media Life and Annual Cost

	GAC	**IX**
Estimated Life (Bed Volumes)	80,000	340,000
Media Per Vessel (lbs GAC or CF IX)	40,000	500
Estimated Media Cost - $/lb GAC or $/CF IX)	$1.80	$275
Cost Per Vessel Changeout	$72,000	$137,500
Bed Volume (Gallons)	9,975	2,641
Flow Rate (GPM)	900	900
Empty Bed Contact Time (minutes)	11.08	2.93
Treatment Rate (Bed Volumes per Hour)	5.41	20.45
Bed Life (Months)	20.52	1.56
Media Changeouts Per Year	0.58	0.52
Annual Media Usage (lbs GAC / CF IX)	23,386	260
Annual Media Cost	$ 42,000	$ 72,000

Table 4-12: PFAS Contactor Effluent Water Quality Laboratory Analyses - PFAS

	PFAS Contactor Effluent Water Quality Laboratory Analyses - PFAS		**Well 2**		**Well 2 with 10% Recycle**		**Well 5**		**Well 5 with 10% Recycle**	
	Analysis	**Units**	**GAC**	**IX**	**GAC**	**IX**	**GAC**	**IX**	**GAC**	**IX**
Method 533	11-Chloroeicosafluoro-3-Oxaundecane-1-Sulfonic Acid (11Cl-PF3OUdS)	ng/L	<1.80	<1.82	<1.90	<1.83	<1.78	<1.82	<1.91	<1.97
	1H,1H,2H,2H-Perfluorodecanesulfonic Acid (8:2FTS)	ng/L	<1.80	<1.82	<1.90	<1.83	<1.78	<1.82	<1.91	<1.97
	1H,1H,2H,2H-Perfluorohexanesulfonic Acid (4:2FTS)	ng/L	<1.80	<1.82	<1.90	<1.83	<1.78	<1.82	<1.91	<1.97
	1H,1H,2H,2H-Perfluorooctanesulfonic Acid (6:2FTS)	ng/L	<1.80	<1.82	<1.90	<1.83	<1.78	<1.82	<1.91	<1.97
	2,3,3,3-Tetrafluoro-2-[1,1,2,2,3,3,3-Heptafluoropropoxy]-Propanoic Acid (HFPO-DA)	ng/L	<1.80	<1.82	<1.90	<1.83	<1.78	<1.82	<1.91	<1.97
	4,8-Dioxa-3h-Perfluorononanoic Acid (ADONA)	ng/L	<1.80	<1.82	<1.90	<1.83	<1.78	<1.82	<1.91	<1.97
	9-Chlorohexadecafluoro-3-Oxanone-1-Sulfonic Acid (9Cl-PF3ONS)	ng/L	<1.80	<1.82	<1.90	<1.83	<1.78	<1.82	<1.91	<1.97
	Nonafluoro-3,6-Dioxaheptanoic Acid (NFDHA)	ng/L	<1.80	<1.82	<1.90	<1.83	<1.78	<1.82	<1.91	<1.97
	Perfluoro(2-Ethoxyethane)Sulfonic Acid (PFEESA)	ng/L	<1.80	<1.82	<1.90	<1.83	<1.78	<1.82	<1.91	<1.97
	Perfluoro-3-Methoxypropanoic Acid (PFMPA)	ng/L	<1.80	<1.82	<1.90	<1.83	<1.78	<1.82	<1.91	<1.97
	Perfluoro-4-Methoxybutanoic Acid (PFMBA)	ng/L	<1.80	<1.82	<1.90	<1.83	<1.78	<1.82	<1.91	<1.97
	Perfluorobutanesulfonic Acid (PFBS)	ng/L	<1.80	<1.82	<1.90	<1.83	<1.78	<1.82	<1.91	<1.97
	Perfluorobutanoic Acid (PFBA)	ng/L	<1.80	<1.82	<1.90	<1.83	<1.78	<1.82	<1.91	<1.97
	Perfluorodecanoic Acid (PFDA)	ng/L	<1.80	<1.82	<1.90	<1.83	<1.78	<1.82	<1.91	<1.97
	Perfluorododecanoic Acid (PFDoA)	ng/L	<1.80	<1.82	<1.90	<1.83	<1.78	<1.82	<1.91	<1.97
	Perfluoroheptanesulfonic Acid (PFHpS)	ng/L	<1.80	<1.82	<1.90	<1.83	<1.78	<1.82	<1.91	<1.97
	Perfluoroheptanoic Acid (PFHpA)	ng/L	<1.80	<1.82	<1.90	<1.83	<1.78	<1.82	<1.91	<1.97
	Perfluorohexanesulfonic Acid (PFHxS)	ng/L	<1.80	<1.82	<1.90	<1.83	<1.78	<1.82	<1.91	<1.97
	Perfluorohexanoic Acid (PFHxA)	ng/L	<1.80	<1.82	<1.90	<1.83	<1.78	<1.82	<1.91	<1.97
	Perfluorononanoic Acid (PFNA)	ng/L	<1.80	<1.82	<1.90	<1.83	<1.78	<1.82	<1.91	<1.97
	Perfluorooctanesulfonic Acid (PFOS)	ng/L	<1.80	<1.82	<1.90	<1.83	<1.78	<1.82	<1.91	<1.97
	Perfluorooctanoic Acid (PFOA)	ng/L	<1.80	<1.82	<1.90	<1.83	<1.78	<1.82	<1.91	<1.97
	Perfluoropentanesulfonic Acid (PFPeS)	ng/L	<1.80	<1.82	<1.90	<1.83	<1.78	<1.82	<1.91	<1.97
	Perfluoropentanoic Acid (PFPeA)	ng/L	<1.80	<1.82	<1.90	<1.83	<1.78	<1.82	<1.91	<1.97
	Perfluoroundecanoic Acid (PFUnA)	ng/L	<1.80	<1.82	<1.90	<1.83	<1.78	<1.82	<1.91	<1.97
Other Analysis Method 537.1	N-Ethyl Perfluorooctanesulfonamidoacetic Acid (NEtFOSAA)	ng/L	<1.80	<1.81	<1.84	<1.86	<1.90	<1.84	<1.91	<1.93
	N-Methyl Perfluorooctanesulfonamidoacetic Acid (NMeFOSAA)	ng/L	<1.80	<1.81	<1.84	<1.86	<1.90	<1.84	<1.91	<1.93
	Perfluorotetradecanoic Acid (PFTA)	ng/L	<1.80	<1.81	<1.84	<1.86	<1.90	<1.84	<1.91	<1.93
	Perfluorotridecanoic Acid (PFTrDA)	ng/L	<1.80	<1.81	<1.84	<1.86	<1.90	<1.84	<1.91	<1.93
	Total PFAS6	ng/L	<1.80	<1.82	<1.90	<1.86	<1.78	<1.84	<1.91	<1.93

Table 4-13: PFAS Contactor Effluent Water Quality Analysis – Disinfection Byproducts

	Initial Chlorine Residual				Final Chlorine Residual			Haloacetic Acids (HAA5) (µg/L) - MMCL = 60 µg/L						Trihalomethanes (TTHM) (µg/L) - MMCL = 80 µg/L				
Source	**Free (mg/L)**	**Total (mg/L)**	**Initial pH**	**Hold Time (hours)**	**Free (mg/L)**	**Total (mg/L)**	**Final pH**	Dibromoacetic	Dichloroacetic	Monobromoacetic	Monochloroacetic	Trichloroacetic	**HAA5**	Chloroform	Bromodichloro-methane	Dibromochloro-methane	Bromoform	**TTHM**
Well 2 – GAC1	0.52	0.59	7.15	168	0.21	0.36	7.42	3.2	1.1	<1	<2	<1	4.3	0.58	3.2	7.8	4.8	16
Well 2 – IX1	0.6	0.61	7.47		0.2	0.3	7.42	3.9	1.2	1.2	2.8	<1	9.1	1.4	6.2	12	5.3	25
Well 5 – GAC1	0.62	0.64	6.95		0.51	0.51	7.37	<1	<1	<1	<2	<1	<1	<0.50	1.1	2.1	1.1	4.3
Well 5 – IX1	0.6	0.68	6.99		0.42	0.42	7.34	2.3	1	<1	<2	<1	3.3	1.4	2.9	5	2.2	12

5.0 RECOMMENDATION

Without any treatment, the groundwater source would not supply drinking water that is below the MCL, since Well 5 PFAS6 exceeded the MCL of 20 ng/L and Well 2 PFAS6 exceeded 10 ng/L. GZA's recommendation is for the BFDWD to pursue the installation of a WTP serving Wells 2 and 5 for PFAS6 removal with iron and manganese pretreatment. A conceptual process flow diagram prepared by Wright-Pierce is included as **Appendix E**.

5.1 GENERAL WATER TREATMENT PLANT CRITERIA AND DESCRIPTION.

Based upon analysis of historical demand and given the maximum facility capacity equal to the maximum combined daily withdrawal limit of Wells 2 and 5, the WTP capacity design criteria have been established as shown in **Table 5-1**.

Table 5-1: WTP Capacity Design Criteria

Criteria	WTP Flow Rate
Minimum Operational Flow	0.43 MGD (300 gpm)
Average Day Operational Flow	0.94 MGD (650 gpm)
Maximum WTP Design Capacity	2.16 MGD (1,500 gpm)

The operational rates in **Table 5-1** have been calculated based on the seasonal variability in demand for this coastal community and varying duration of daily operation throughout the year. Proposed operation would require the plant to operate at the average day demand rate of 650 gpm for 8 to 12 hours per day for most of the year. During peak summer hours, maximum-day plant flows are expected to be 1,000-1,100 gpm and operate for approximately 18 hours per day when accounting for possible short-term grown in demand. Designing around these operational flow rates should provide flexibility and resilience in operations. A water distribution model developed by Stantec, Inc. for BFDWD will be used to confirm that the storage tanks can receive the anticipated flows in the proposed operational timeframes.

The proposed site for the treatment facility off Breeds Hill Road in Barnstable, MA is sufficiently sized with fairly level topography in proximity to Wells 2 and 5. The parcel is entirely owned by BFDWD. There is an existing access road suitable for a construction project of this scale. The site has access to major utilities (power, communications, and water). The building would include a small laboratory for routine water quality analysis. As required by building code regulations, the facility will include two lavatories. It is anticipated that a 10,000-gallon tight tank will be sufficient to handle sanitary wastewater, but an on-site disposal system outside of the Zone I may be a feasible alternative and will be investigated during subsequent phases of design. The building will be oriented as southward as possible for a rooftop solar installation.

There are wetlands present at the site. A Request For Determination of Applicability (RDA) will be filed with the local conservation commission. If required by the Commission, a project Notice of Intent will be filed, and the project will comply with any subsequent Orders of Condition. Inquiry with MassWildlife relative to the Natural Heritage Endangered Species program will be made. BFDWD certified the "Fresh Hole" vernal pool during the Well 5 New Source Approval. An Environmental Notification Form will be prepared, filed with the Massachusetts Environmental Policy Act Office, and published, for the construction of the WTP.

5.2 CONCEPT LEVEL WATER TREATMENT PLANT DESIGN CRITERIA

Based on the maximum proposed capacity of 2.16 MGD, the major components of the WTP are preliminarily anticipated to consist of three (3) 10-foot-diameter GSP vessels, four (4) 12-foot-diameter GAC vessels, NaOCL, KOH, and sodium bisulfite (for dechlorination of GAC influent water) chemical feed systems, a box tower aeration unit, backwash pumps for both GAC and GSP filters, a blower system to provide air for the air/water backwash to the GSP filters, a flow equalization tank, a baffled backwash supply storage tank, transfer pumps, two (2) 100,000-gallon lined lagoons for backwash water, and (2) 250,000-gallon sand filters for backwash water supernatant. Emergency power generation and natural -gas-fuel would also be included.

It is proposed that the existing treatment building located next to Well 2 (“Treatment 2”) will be used for the dosage of pre-aeration chlorine addition when necessary to control biological growth on the filters, as recommended by 10 States Standards. The raw water flow from Wells 2 and 5 would be pumped through Treatment 2 and then through a box-style aerator located inside the new WTP. The aerator will raise pH by removing CO2 from the raw water, reducing chemical costs for pH adjustment. Following aeration, the water will flow into a flow equalization tank. Water pumped from the flow equalization tank will be dosed with NaOCL and KOH (as needed) prior to GSP filtration. This chemical pre-treatment step is for oxidation of iron and manganese, pH adjustment, and catalytic oxidation maintenance of the GSP filter media. Aerated and pre-treated water will be pumped from the flow equalization tank through the GSP and GAC filters, then to the backwash-water-supply tank/clearwell and then pumped to the distribution system. Three (2 duty, 1 standby) high-lift distribution system pumps are anticipated, each matching half the WTP capacity (750 gpm). See **Appendix E.**

As chlorinated and degassed water enters the top of each GSP filter, it will pass through 12 inches of anthracite, followed by 24 inches of GSP media and a final 12-inch graded gravel bed. Upon exiting the GSP filter, the filtered water will be dosed with sodium bisulfite for dechlorination to prevent chlorine entry into the GAC filters. Dechlorination is currently proposed to be performed via inline mixer and lengths of increased diameter pipe to eliminate the need for repumping or a contact tank prior to the GAC filters. The dechlorinated water will split flow and run parallel through two dual vessel GAC systems. Each system will consist of two (2) 12-foot-diameter, 27-foot-tall pressure vessels connected in series (2 systems, 4 vessels total, each system operating in lead-lag configuration). This will allow uninterrupted operations at plant maximum capacity (1,500 gpm) during media change out of a single vessel and minimize the possibility of PFAS entering distribution should the media in the primary vessels reach the end of useful life without detection.

Upon exiting the GAC filters, the water will be dosed again with NaOCL as needed prior to entering distribution or the clearwell/backwash supply tank. The clearwell/backwash supply tank will be designed with space for future baffle installation allowing the tank to meet 4-log virus inactivation if needed in the future. The groundwater source does not currently require 4-log virus inactivation in accordance with the Ground Water Rule. This tank design would facilitate compliance for 4-log virus inactivation in the event it is required in the future. The connection to the distribution system will allow space for a pipe loop will be made, such that additional disinfection contact time could be provided in the future.

A KOH injection for final pH adjustment as required for corrosion control will be provided prior to exiting the facility to increase pH to the existing target level of 8.

The existing wells may require modifications, including but not limited to new pumps, motors and drives to meet the proper head and flow requirements of the new facility. Reprogramming of well pump controls will be required.

The conceptual design criteria for the WTP are summarized in **Table 5-2**. These conceptual design criteria were developed based upon the water filtration performance data collected during the pilot study.

Table 5-2: WTP Conceptual Design Criteria

GreensandPlus™ Filter System	
System Design Capacity	1,500 gpm (2.16 MGD)
No. of Filters	3
Filter Diameter	10 ft
Filter Area (each)	78.5 sq ft
Maximum Loading Rate (three filters in service)	6.40 gpm/sq ft
Maximum Loading Rate (two filters in service during backwash)	9.55 gpm/sq ft
Backwash Loading Rate	12 gpm/sq ft
Backwash Waste Volume (per filter)	20,000 gallons
GAC Filter System	
System Design Capacity	1,500 gpm (2.16 MGD)
No. of Filters	4 (2 per skid)
Filter Diameter	12 ft
Filter Height	27 ft
Minimum EBCT (per vessel, 1 filter skid active, 1 down for maintenance)	13 minutes
Pounds GAC (per vessel)	40,000 lbs
Backwash Loading Rate	8.5 gpm/sf
Backwash Waste Volume (per filter)	35,000 gallons
Chemical Systems	
Potassium Hydroxide (KOH)	
Solution Strength	45%
Dosage	15 mg/L (Pre w/aeration)
Dosage	17 mg/L (Post w/aeration)
Daily Requirements	25 gallons per day (based on 0.50 MGD production)
Day Tank Quantity	2
Day Tank Size	55 gallons
Bulk Tank Quantity	2
Bulk Tank Size	2,550 gallons
Sodium Hypochlorite (NaOCl)	
Solution Strength	12.5%
Dosage	0.9 mg/L (Pre) & 1.0 mg/L (Post)
Daily Requirements	7 gallons per day (based on 0.50 MGD production)
Day Tank Quantity	2
Day Tank Size	30 gallons
Bulk Tank Quantity	2
Bulk Tank Size	685 gallons

Dechlorination: Sodium Bisulfite (NaHSO3)	
Solution Strength	27%
Dosage	1.4 mg/L
Daily Requirements	1.9 gallons per day (based on 0.50 MGD production)
Day Tank Quantity	1
Day Tank Size	30 gallons
Bulk Tank Quantity	1
Bulk Tank Size	400 gallon

Air Wash System	
Blower - Air Flow Rate	51 cfm
Wastewater Handling	
Wastewater Holding Tank Capacity	10,000 gallons
Backwash Waste Handling	
Recommended Lined Lagoon Capacity	200,000 gallons
Recommended Sand Filter Capacity	500,000 gallons
Water Pumping System	
Aerated Water Pumps (3)	750 gpm each
Backwash Pumps (2)	1000 gpm each
Finished Water Pumps (3)	750 gpm each
Backwash Storage	
Backwash Storage Volume Required	55,000 gallons
Design Flow	1,500 gpm
Design Baffling Factor	0.50
Chlorine Residual	0.8 mg/L
pH	6.7
Temperature	10° C
Number of Backwash Storage Tanks	1

5.3 CAPITAL AND OPERATION & MAINTENANCE (O&M) COST ANALYSIS

Based on the conceptual design developed, this section presents the estimated capital and O&M costs for the WTP. The cost of project financing is not included in the estimates. Costs and availability of labor, equipment, and materials may vary and market conditions, regulatory issues, and/or contractor means and methods may affect pricing. GZA has no control over final construction costs and actual costs may vary from these estimates.

The capital cost estimate includes the costs anticipated to build a fully functioning WTP for the conceptual design presented. These costs include site development (utilities, access road improvements, parking, and stormwater management) and backwash handling lagoons. In accordance with industry standards for cost estimates at this stage of the project, the construction estimate includes a 25 percent contingency for unknown conditions or changes to scope of work as well as a 3 percent per year inflation rate for construction cost escalation. It is assumed construction would begin summer of 2022. Engineering, project management costs, resident project representation and fees have not been included.

The O&M cost estimates include estimated chemical usage, major power demand usage, routine operations labor, and general maintenance of the equipment, building, and site.

Tables 5-3 and 5-4 summarize the estimated probable costs for construction and O&M.

Table 5-3: Opinion of Probable Construction Cost

Work Type	Estimate
General Conditions	$ 1,090,000
WTP Building & Support Systems	$ 5,040,000
Process Equipment	$ 4,040,000
Site Development & Lagoons	$ 650,000
Preliminary Construction Opinion:	$ 10,820,000
Construction Contingency (25%)	$ 2,705,000
Construction Budget:	$ 13,525,000
2-year Construction Cost Escalation (3%/year)	$ 825,000
FY2024 Project Funding:	$ 14,350,000

Table 5-4: Opinion of Estimated Annual O&M Cost

O&M Category	Annual Estimate
Chemical	$ 45,000.00
Power	$ 154,000.00
Labor	$ 26,000.00
General Maintenance	$ 21,000.00
GAC Change Out (2 per year)	$ 90,000.00
Total O&M Estimate	$ 336,000.00

The estimated annual O&M costs were based on an average day output of 0.312 MGD. It was assumed the plant would run approximately 8 hours per day for 7 days per week at approximately 650 gpm. Labor was based on one operator present for 20 hours per week at a raw labor rate of $27 per hour. Provisions for a sufficient SCADA system to allow for unmanned operation were included, and MassDEP approval of unmanned operation will be sought in subsequent design phases of the project. Probable costs will be re-evaluated upon design completion and closer to the actual time of construction.

6.0 REGULATORY IMPACTS

6.1 CORROSION CONTROL

The BFDWD has injected KOH into their source waters since the 1990s. After the construction of Treatment Building 1 (Pump Station #4) in the 1990s, discharge from Wells 3 and 4 has been treated with KOH. KOH was injected in Well 2 discharge after the station returned to service in 2007, and Well 5 was treated with KOH after the station went online in 2012. In 2013, a round of water samples put BFDWD in violation of the Lead and Copper Rule (LCR) action level (AL) for copper. In response to this exceedance, MassDEP recommend increasing the finished water pH from at or below 7.0 to 8.0 for corrosion control. Based on a study completed by Fay, Spofford & Thorndike in December 2013, the BFDWD increased its KOH injections to achieve a target pH of 7.7 [1]. Since this operational change, the BFDWD has been in compliance with the LCR.

The BFDWD completed its most recent sampling for lead and copper in the third quarter of 2020. Twenty lead and copper samples were collected. The 90th percentile result for lead was 0.0046mg/L, and the 90th percentile result for copper was 0.21mg/L. None of the results for the analyzed samples exceeded the lead or copper action levels. There are no known lead service lines in the BFDWD water system. A copy of the most recent Lead and Copper Compliance report can be found in **Appendix F**.

Currently, the BFDWD is on a schedule waiver, sampling for lead and copper every 3 years. However, the BRP WS-29 Condition of Approval #6 for the BFDWD's Well 1 pump station rehabilitation project requires "full rounds of semiannual monitoring under the Lead and Copper Rule after granting final approval of the modified treatment facility to go online."[5] Further, the BFDWD is required to "submit a new LCR sampling plan for approval at least thirty (30) days prior to anticipated activation of the modified facility." Semiannual sampling is expected to continue after the PFAS removal treatment plant is operating.

The existing chloride to sulfate mass ratio at all wells of the BFDWD is summarized in the table below

Table 6-1: Chloride-to-Sulfate Mass Ratio and Alkalinity

	Chloride mg/L as Cl^-	**Sulfate mg/L as SO_4^{2-}**	**Alkalinity mg/L as $CaCO_3$**	**CSMR**
Well 2 raw	46.2	8.3	6.9	5.5
Well 5 raw	39.0	10.4	8.8	3.8
Wells 2 and 5 blended after NaOCl and KOH injection	78.1	8.8	62.9	8.8
Well 3 raw	17.9	8.1	10.1	2.2
Well 4 raw	28.1	10.6	15.9	2.7
Wells 3 and 4 blended after NaOCl and KOH injection	36.6	11.0	60.8	3.3
Well 1 raw	74.6	8.4	9.1	8.9

Based on CSMR research conducted at Virginia State Polytechnic Institute, "if a utility has a CSMR greater than 0.5 and an alkalinity of less than 50 mg/L as $CaCO_3$, then the utility could potentially have serious lead problems following treatment changes that increase the CSMR." [4]. Though at all Wells 2, 3, 4, and 5, the CSMR is greater than 0.5, based on the quantity of KOH added, the alkalinity exceeds 50 mg/L as $CaCO_3$. However, there are still significant concerns about increasing CSMR [4]. GAC is preferred over IX due to its lower impact on the corrosivity of the PFAS contactor effluent.

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[5] MassDEP, December 16, 2020. Transmittal No. X286923.

The BFDWD service area contains no known lead services, and the use of KOH has proven effective in managing corrosion control for the BFDWD system. KOH will continue to be used by the proposed WTP. Construction and operation of the proposed WTP has no anticipated regulatory impacts related to corrosion control.

6.2 DISINFECTION

The BFDWD intends on continuing the use of NaOCl for disinfection, maintaining a residual chlorine concentration of approximately 0.5 mg/L. Maintaining this residual chlorine concentration has kept the BFDWD in compliance with the Revised Total Coliform Rule. The SDS results for treated water effluent during the pilot study showed concentrations of TTHMs and HAA5 significantly below the MCLs for the respective DBPs. The BFDWD system was not designed for 4-log virus disinfection, and the BFDWD does not intend on applying for Groundwater Rule Log Credit.

6.3 GROUNDWATER DISCHARGE

A groundwater discharge permit would not be required in accordance with 314 CMR 5.05(17) which states:

[A groundwater discharge permit is not required for] Any discharge from water supply treatment works to a lined lagoon, followed by a discharge of supernatant from the lined lagoon to an unlined lagoon; provided the water supply treatment works, and the discharge design and location, are approved by the Department and remain in compliance with the approval and all applicable requirements of 310 CMR 22.00: Drinking Water.

The conceptual treatment plant presented in this report has been designed with the intention of seeking the above-mentioned approval by MassDEP during the subsequent comprehensive design phases.

6.4 AIR QUALITY COMPLIANCE CERTIFICATION

The facility emergency backup power generators are likely to exceed 37 kilowatts (kw). Compliance certification for a stationary engine must be filed with MassDEP within 60 days of installing the generator.

6.5 MEPA

This project triggers the Massachusetts Environmental Policy Act (MEPA) review threshold for construction of a new drinking water treatment plan with a capacity greater than 1 MGD. An Environmental Notification Form (ENF) must be submitted in accordance with 301 CMR 11.00.

7.0 REFERENCES

[1] Fay, Spofford & Thorndike, "Barnstable Fire District Chemical Addition - pH Increase at Stations, Distribution System Water Quality, Distribution System Sampling," Burlington, MA, December 16, 2013.

[2] Stantec, "Residential Population Estimate in Barnstable Fire District's Water Service Area," Burlington, MA, 2020.

[3] MassDEP, "FINAL Water Management Act Permit 9P242202001," Boston, 2018.

[4] C. K. Nguyen, K. R. Stone and M. A. Edwards, "Chloride-to-sulfate mass ratio: Practical Studies in Galvanic Corrosion of Lead Solder," *Journal AWWA,* pp. 81-92, January 2011.

[5] 314 CMR 5: Ground Water Discharge Permit Program

[6] 310 CMR 22: The Massachusettes Drinking Water Regulations

Appendix A

Limitations

APPENDIX A

1.0 LIMITATIONS

1.1 USE OF REPORT

1. GZA GeoEnvironmental, Inc. (GZA) prepared this Report on behalf of, and for the exclusive use of the Barnstable Fire District Water Department for the stated purpose(s) and location(s) identified in the Report. Use of this report, in whole or in part, at other locations, or for other purposes (except as per the terms and conditions established by the Commonwealth of Massachusetts as part of project funding requirements), may lead to inappropriate conclusions; and we do not accept any responsibility for the consequences of such use(s). Further, reliance by any party not expressly identified in the contract documents, for any use, without our prior written permission, shall be at that party's sole risk, and without any liability to GZA.

1.2 STANDARD OF CARE

2. GZA's findings and conclusions are based on the work conducted as part of the Scope of Services set forth in Proposal for Services and/or Report, and reflect our professional judgment. These findings and conclusions must be considered not as scientific or engineering certainties, but rather as our professional opinions concerning the limited data gathered during the course of our work. If conditions other than those described in this report are found at the subject location(s), or the design has been altered in any way, GZA shall be so notified and afforded the opportunity to revise the report, as appropriate, to reflect the unanticipated changed conditions.

3. GZA's services were performed using the degree of skill and care ordinarily exercised by qualified professionals performing the same type of services, at the same time, under similar conditions, at the same or a similar property. No warranty, expressed or implied, is made.

1.3 GENERAL

4. The observations described in this report were made under the conditions stated therein. The conclusions presented were based solely upon the services described therein, and not on scientific tasks or procedures beyond the scope of described services or the time and budgetary constraints imposed by the Client.

5. In preparing this Report, GZA relied on certain information provided by the Client, state and local officials, and other parties referenced therein which were made available to GZA at the time of our evaluation. GZA did not attempt to independently verify the accuracy or completeness of all information reviewed or received during the course of this evaluation.

1.4 COMPLIANCE WITH CODES AND REGULATIONS

6. We used reasonable care in identifying and interpreting applicable codes and regulations. These codes and regulations are subject to various, and possibly contradictory, interpretations. Compliance with codes and regulations by other parties is beyond our control.

1.5 COST OPINIONS

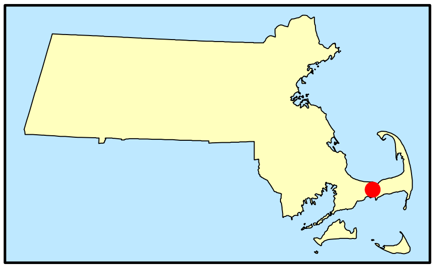
7. Unless otherwise stated, our cost opinions are only for comparative and general planning purposes. These opinions may involve approximate quantity evaluations. Note that these quantity evaluations are not intended to be sufficiently accurate to develop construction bids, or to predict the actual cost of work addressed in this Report. Further, since we have no control over either when the work will take place or the labor and material costs required to plan and execute the anticipated work, our cost opinions were made by relying on our experience, the experience of others, and other sources of readily available information. Actual costs may vary over time and could be significantly more, or less, than stated in the Report.

1.6 ADDITIONAL SERVICES

8. GZA recommends that we be retained to provide services during any future: site observations, design, implementation activities, construction and/or property development/redevelopment. This will allow us the opportunity to: i) observe conditions and compliance with our design concepts and opinions; ii) allow for changes in the event that conditions are other than anticipated; iii) provide modifications to our design; and iv) assess the consequences of changes in technologies and/or regulations.

Appendix B

Site Locus



SOURCE : USGS TOPOGRAPHIC QUADRANGLES SCANNED BY
THE NATIONAL GEOGRAPHIC SOCIETY & I-CUBED, COPYRIGHT 2011

Data Supplied by :
esri

0 500 1,000 2,000 3,000
SCALE IN FEET

N
W E
S

PROJ. MGR.: TCS
DESIGNED BY: GMM
REVIEWED BY: TCS
OPERATOR: GMM

DATE: 06-30-2021

LOCUS MAP - SHOWING BFDWD OWNED PARCEL AND 500 FOOT & 1/2 MILE OFFSETS

BFDWD PILOT STUDY REPORT
BREEDS HILL RD
BARNSTABLE, MASSACHUSETTS

JOB NO.
01.0174868.00

APPENDIX
B

Appendix C

Email Correspondence with MassDEP Regarding Well Withdrawal Rates

From: Thomas Sexton
Sent: Friday, June 4, 2021 1:58 PM
To: Gregory McNeal
Subject: FW: Barnstable Fire District

Haven't found permit yet, but described below

From: LeVangie, Duane (DEP) <duane.levangie@state.ma.us>
Sent: Wednesday, March 18, 2020 10:34 AM
To: Thomas Sexton <Thomas.Sexton@gza.com>; Chen, Shi (DEP) <shi.chen@state.ma.us>
Cc: Tom Rooney <bfdwatersupt@barnstablefiredistrict.com>
Subject: Re: Barnstable Fire District

I'm not sure why we have different registration volumes and can't confirm without file access which may be a while. Yes, they get the 100,000 on the registration volume from the registered sources, so either 0.42 or 0.44 mgd.   They don't get more than the 0.66 md permitted volume system-wide. Also Well #2 is not permitted to my knowledge?

Duane

From: Thomas Sexton <Thomas.Sexton@gza.com>
Sent: Wednesday, March 18, 2020 10:15 AM
To: LeVangie, Duane (DEP); Chen, Shi (DEP)
Cc: Tom Rooney
Subject: RE: Barnstable Fire District

Hi Duane,
You are right, max-day is the potential issue.   Thank you for the explanation and analysis! One thing may be transposed – their 2018 permit indicates that the registration volume is 0.34 for Wells 1 & 2. Would BFDWD have up to 99,900 gpd leeway on the registration volume as well or not so b/c they are already under a permit that includes Well 2?
Thanks!
As always, please contact me if you have any questions on this communication or if I may be of assistance.
Sincerely,
Tom

Thomas C. Sexton, P.E.
Senior Project Manager
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o: 781-278-4826 | f: 781-278-5701 | c: 215-510-5741
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From: LeVangie, Duane (DEP) <duane.levangie@state.ma.us>
Sent: Wednesday, March 18, 2020 9:32 AM
To: Chen, Shi (DEP) <shi.chen@state.ma.us>; Thomas Sexton <Thomas.Sexton@gza.com>
Subject: Re: Barnstable Fire District

Tom,

To put it mildly we are operating a little blindly here but here is what I know about BFD's situation.

BFD is registered for 0.32 MGD/116.8 MG from Wells 1 – 3 and permitted for 0.34 MGD/124.1 MG from Wells 3-5, for a total of 0.66 MGD/240.9 MGY. Because of how BFD chose to permit their water use they are constrained to 0.32 MGD from the registered only Wells 1 & 2. My understanding is BFD is looking for more flexibility on how they can withdraw both the 0.66 MGD total allocation and perhaps the maximum daily approval rates on a few wells (Wells 2 and 3). Registrations were issued for the system and not by source, so provided the well's individual approval rate (Zone II column below) is not exceeded, Well 1 or 2 could in theory pump the full 0.32 registered volume without being in non-compliance with the registration provided the other well wasn't being used.

Based on BFD's recent ASRs, Well #1 has been inactive for many years due to the iron and manganese issues. BFD has been withdrawing 0.13 MGD/46.76 MG from the Well #2 on average over last three years. From Wells 4 & 5 they have been withdrawing a combined average of 0.30 MGD/108.88 MG for the last three years. BFD appears to have the ability to withdraw a lot more (up to 0.32 mgd registered volume or up to 116.8 MG annually) from Well 2, without triggering any WMA filings. The following table is a summary of BFD withdrawals by source in 2016, their highest year of the last 3 years, and how that compares to their maximum daily volumes, their maximum annual volumes and their WMA approvals.

	Well 1	Well 2	Well 3	Well 4	Well 5	Total
Zone II max day (MGD)	0.396	0.86	0.77	0.67	1.296	
2016 Actual (MG)	0	61	39.4	52.5	56.75	209.69
ZII rate annually (MG)	Off line	313.9	281	244.6	473.04	
WMA annual limits (MG)	116.8		240.9			240.9

It would appear on paper that on an annual time-step that BFD wouldn't need to file anything with the WMA program to meet their demands. Between Wells 2 & 3, they would appear to have plenty of capacity to make up for the loss or significant reductions in the use of wells 4 and 5 and still be capable of staying within their registration and permit limits. More likely the problem is peak days, BFD's peak days the last three years were 1.34 mgd in 2018; 1.40 mgd in

2017, and 1.51 mgd in 2016. With a peak day approved capacity of 1.63 mgd combined between wells 2 & 3, that would likely be the place BFD is looking for some flexibility.

None of the above takes into account the water quality issues BFD is now trying to manage. As I mentioned our Lakeville staff is more familiar with those issues and has been evaluating ways to address BFD's need to provide clean water and address regulatory compliance issues. I'm expecting they'll be in contact with BFD soon.

Hope this helps, and I'm happy to discuss.

Duane

From: Chen, Shi (DEP)
Sent: Wednesday, March 18, 2020 7:58 AM
To: Thomas Sexton
Cc: LeVangie, Duane (DEP)
Subject: Re: Barnstable Fire District

Hi Tom,

We start working remotely today. I will get you the information as soon as I have access to my files. At the meantime, please feel free to email me if you have any questions. I apologize for the inconvenience.

Thank you,

Shi

From: Thomas Sexton <Thomas.Sexton@gza.com>
Sent: Tuesday, March 17, 2020 12:15 PM
To: Chen, Shi (DEP)
Subject: Barnstable Fire District

Hi Shi,

I realize you may be working remotely. In case you are, were you able to find the individual registration volumes for Wells 1 and 2, for the Barnstable Fire District Water Department?

Duane called me and said there was some decision making down in the SERO that is pending. I still have the question about permit volumes and temporary use exceedance due to other well(s) having PFAS contamination. In BFDWD's case, we may have an issue depending on the individual registration volumes.

Best of luck with the situation!

Thanks!

As always, please contact me if you have any questions on this communication or if I may be of assistance.

Sincerely,

Tom
Thomas C. Sexton, P.E.
Senior Project Manager
GZA |190 Old Derby Street | Suite 210 | Hingham, MA 02043
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For information about GZA GeoEnvironmental, Inc. and its services, please visit our website at www.gza.com.

Appendix D

Blueleaf, Inc. Pilot Study Report

Blueleaf, Inc.

RESEARCH · INVESTIGATE · EXPERIMENT · SOLVE · AUDIT · ANALYZE · EXPLORE · INSPECT · EVALUATE · CHARACTERIZE · DEMONSTRATE · PILOT

PILOT STUDY REPORT FOR

PFAS REMOVAL BY GAC ADSORPTION AND ION EXCHANGE WITH PRETREATMENT FOR IRON AND MANGANESE REMOVAL BY GREENSANDPLUS^{TM} PRESSURE FILTRATION

WELLS 2 AND 5
BREEDS HILL ROAD
BARNSTABLE, MASSACHUSETTS

FEBRUARY - MARCH 2021

Submitted by: Blueleaf, Inc.
57 Dresser Hill Road
Charlton, MA 01507

For: GZA GeoEnvironmental, Inc.
249 Vanderbilt Avenue
Norwood, MA 02062

Submitted: April 8, 2021
Revised: May 4, 2021

SUMMARY

This report details the methods and results of a pilot study for PFAS removal including pretreatment for iron and manganese removal from two well sources used for municipal drinking water supply by the Barnstable Fire District Water Department (BFDWD). Treatment of Wells 2 and 5 at 223 Breeds Hill Road was evaluated between February 15 and March 5, 2021.

The Project Water Quality Goals for the six PFAS compounds known as PFAS6 was 20 ng/L. The PFAS6 include:

- perfluoroheptanoic acid (PFHpA)
- perfluorohexane sulfonic acid (PFHxS)
- perfluorooctanoic acid (PFOA)
- perfluorononanoic acid (PFNA
- perfluorooctane sulfonic acid (PFOS)
- perfluorodecanoic acid (PFDA)

Additionally, goals for filter effluent iron and manganese were 0.30 mg/L total Fe and 0.05 mg/L total Mn.

Raw water concentrations for the contaminants of concern as measured during the pilot study were:

- Well 2 PFAS6 = 6.96 and 12.41 ng/L   < 20 ng/L MCL
- Well 5 PFAS6 = 20.97 and 22.36 ng/L   > 20 ng/L MCL
- Well 2 Median Fe = 0.00 mg/L   < 0.30 mg/L SMCL
- Well 5 Median Fe = 0.03 mg/L   < 0.30 mg/L SMCL
- Well 2 Median Mn = 0.057 mg/L   > 0.050 mg/L SMCL
- Well 5 Median Mn = 0.018 mg/L   < 0.050 mg/L SMCL

This pilot study evaluated the performance of GAC and ion exchange (IX) for the removal of PFAS compounds as well as pretreatment with GreensandPlus™ adsorptive media filtration for removal of iron and manganese.

The pretreatment for iron and manganese removal evaluated adsorptive pressure filtration with four identical filters in parallel, all containing 24” of GreensandPlus$^{\text{TM}}$ media and 12” of anthracite. 20 individual filter runs were completed at the two sources. Greensand pilot filter effluent effectively met the project goals for iron and manganese at both sources.

There was very little headloss development during the trials due to the low contaminant concentrations. Trial runs were operated as long as 145 hours and were always terminated due to pilot schedule and not because of differential pressure greater than 10 psi or contaminant breakthrough. Fourteen of sixteen representative filter runs were projected to exceed 1000 hours. It is unknown if or when turbidity breakthrough may have occurred.

Backwashing was completed at a rate of 12 gpm/sf for 10 minutes without air scour to maintain effective filter operations during the study. Settled supernatant was observed to be gray with minimal accumulation of recovered solids. Lab samples of settled supernatant had total manganese concentrations of just less than 1.0 mg/L in three out of four samples.

The introduction of 10% recycle more than doubled the influent manganese concentrations during the recycle periods for both wells. All other influent water quality parameters remained similar. During the Well 5 recycle period filtered turbidity increased in all four filters and was greater than 0.1 NTU in the two high-rate filters. Effluent manganese concentrations also increased by a statistically significant amount but remained below the SMCL Mn of 0.050 mg/L. All other operational and water quality parameters remained consistent during the recycle period. During the Well 2 recycle period filtered turbidity and effluent manganese remained at acceptable levels without any obvious impact from the introduction of recycle supernatant.

Downstream of Greensand filtration the high-rate GAC contactor operating at an Empty Bed Contact Time (EBCT) of 10 minutes reduced total PFAS6 concentrations to non-detectable levels in all four lab sampling events. Similarly, the high-rate ion exchange contactor operating at an Empty Bed Contact Time (EBCT) of 1.5 minutes reduced total PFAS6 concentrations to non-detectable levels in all four lab sampling events.

Two episodes of headloss development in the GAC and the IX contactors occurred during the pilot study due to breakdown of the dechlorination tabs upstream of the contactors. These events were pilot artifacts and would not occur in a full-scale application. There was no other detectable trend of increasing headloss development during the study.

It appeared that Manganese Greensand Filtration with pretreatment using sodium hypochlorite and pH adjustment to 6.7 or 7.7 was effective for removal of manganese at both Well 2 and 5. PFAS was removed to below the laboratory detection limits in all Granular Activated Carbon and Anionic Exchange Resins tested.

TABLE OF CONTENTS

APPENDICES

LIST OF TABLES

LIST OF FIGURES

LIMITATIONS

This pilot test report was prepared for GZA GeoEnvironmental, Inc. (GZA) for the purpose of evaluating treatment of PFAS in water supplied from the Barnstable Fire District Water Department. The findings provided in this report are based solely on the information contained and referenced herein. All field operations, field analyses, data compilation, data analysis and reporting were completed in a fair and impartial manner and are intended to be an accurate representation of treatment performance. Additional quantitative information regarding the raw water, or other treatment goals and concerns that were not available to Blueleaf, Inc. at the time of the pilot study may result in modification of the stated findings. Note that bench and/or pilot scale studies may not identify issues arising from long-term changes to source water quality, nor predict long-term performance of the treatment processes tested.

RESPONSIBILITIES

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ABBREVIATIONS

11Cl-PF3OUds	11-Chloroeicosafluoro-3-Oxaundecane-1-Sulfonic Acid
9Cl-PF3ONs	9-Chlorohexadecafluoro-3-Oxanone-1-Sulfonic Acid
ADONA	4,8-Dioxa-3h-Perfluorononanoic Acid
ANOVA	Analysis of Variance
AER	Anionic Exchange Resin
AWD	Acton Water District
BDL	Below Detection Limit
BW	Backwash
CBW	Composite Backwash
cf	Cubic Foot
CFU	Colony-Forming Unit
DBP	Disinfection By-Product
DOC	Dissolved Organic Carbon
DP	Differential Pressure
EBCT	Empty Bed Contact Time
EPA	Environmental Protection Agency
FSLR	Filter Surface Loading Rate
GAC	Granular Activated Carbon
gal	Gallon
gpm	Gallons per minute
gpm/sf	Gallons per Minute per Square Foot (of surface area)
gr	Gram
HA	Health Advisory
HAA5	Haloacetic Acids
HFPO-DA	Hexafluoropropylene Oxide Dimer Acid
HP	Horsepower
HPC	Heterotrophic Plate Count
IX	Ion Exchange
L	Liter
MA ORSG	Massachusetts Office of Research and Standards Guidelines
MaDEP	Massachusetts Department of Environmental Protection
MBAS	Methylene BlueActive Substances
MCL	Maximum Contaminant Level
mg	Milligram
µg/L	Micrograms per Liter (equivalent to ppb)
mg/L	Milligrams per Liter (equivalent to ppm)
min	Minutes
mV	Millivolt
MGD	Million Gallons per Day
MTBE	Methyl Tertiary Butyl Ether

NTU	nephalometric turbidity units
N/A	Not Applicable
ND	Not Detected
NEtFOSAA	N-Ethyl Perfluorooctanesulfonamidoacetic Acid
ng	Nanogram
NMeFOSAA	N-Methyl Perfluorooctanesulfonamidoacetic Acid
PFAS	Per- and Poly- Fluoroalkyl Substances
PFAS6	Per- and Poly- Fluoroalkyl Substances (regulated by MaDEP)
PFBS	Perfluorobutanesulfonic Acid
PFDA	Perfluorodecanoic Acid
PFDoA	Perfluorododecanoic Acid
PFHpA	Perfluoroheptanoic Acid
PFHxA	Perfluorohexanoic Acid
PFHxS	Perfluorohexanesulfonic Acid
PFNA	Perfluorononanoic Acid
PFOA	Perfluorooctanoic Acid
PFOS	Perfluorooctanesulfonic Acid
PFTA	Perfluorotetradecanoic Acid
PTFE	Polytetrafluoroethylene
PFTrDA	Perfluorotridecanoic Acid
PFUnA	Perfluoroundecanoic Acid
PID	Proportional Integral Derivative
ppb	Parts per Billion
ppm	Parts per Million
ppt	Parts per Trillion
psi	Pounds per Square Inch
PVC	Polyvinyl Chloride
RSSCT	Rapid Small Scale Column Test
SDS	Simulated Distribution System
SE	Sample Event
sf	Square Foot
SM	Standard Methods
su	Standard Units
TDS	Total Dissolved Solids
TOC	Total Organic Carbon
TSS	Total Suspended Solids
TTHM	Total Trihalomethanes
µg	Micrograms
UV	Ultraviolet
VOC	Volatile Organic Compound
WMA	Water Management Act
WTP	Water Treatment Plant

1 INTRODUCTION

1.1 BACKGROUND

The Barnstable Fire District Water Department (BFDWD) services Barnstable Village and Cummaquid within the Town of Barnstable, Massachusetts. The department utilizes a groundwater supply consisting of 5 gravel packed wells. The department seeks to construct a water filtration treatment plant to remove Per- and Poly- Fluoroalkyl Substances (PFAS) from the water supplied by Wells 2 and 5, which are both located off Breeds Hill Road in Barnstable. This pilot study evaluated the performance of GAC and ion exchange (IX) for the removal of PFAS compounds as well as pretreatment with GreensandPlus™ adsorptive media filtration for removal of iron and manganese.

Table 1.01 is a summary of historical data provided to GZA by the BFDWD. Data for secondary samples collected at Well 2 are from 1995 to 2016 and the Well 5 data is from 2012 to 2016. PFAS samples were collected from 2016 to 2020.

Table 1.01: Historical Raw Water Quality

	Median (Min – Max) [Count]	
	Well 2	**Well 5**
Total Fe (mg/L)	**<0.1** (<0.1 – 2.1*) [13]	**0.06** (<0.1 – 0.24) [4]
Total Mn (mg/L)	**0.049** (<0.003 – 0.060) [12]	**0.014** (0.013 – 0.040) [4]
pH (s.u.)	**5.8** (5.2 – 7.4) [17]	**6.3** (5.7 – 7.1) [4]
PFAS (6)	**9.5** (ND - 16.2) [8]	**23.1** (9.4 - 45.6) [10]

* Eight of the 13 Well 2 total iron samples were reported as non-detect (<0.1 mg/L). The result of 2.1 mg/L is an outlier and appears to be a spreadsheet data entry error.

The Barnstable Fire District Water Department contracted with the consulting engineer, GZA Geoenvironmental, Inc. (GZA), to evaluate treatment options for PFAS removal at Wells 2 and 5. GZA contracted Blueleaf, Inc. to conduct a pilot study evaluating PFAS removal with pretreatment for iron and manganese removal by GreensandPlus™ media filtration. Blueleaf conducted the pilot study from February 15 through March 5, 2021. GZA has also contracted with Wright Pierce, Inc. as a subconsultant for the project.

1.2 REGULATORY REQUIREMENTS

1.2.1 PFAS

In May 2016, the United State Environmental Protection Agency (EPA) issued a lifetime Health Advisory (HA) of 70 parts per trillion (0.07 µg/L) for the combination of two PFAS chemicals, PFOS and PFOA, in drinking water. In June 2018, MassDEP established an ORSG of 70 parts per trillion (ppt) for drinking water for a subgroup of five closely related PFAS compounds. This subgroup included perfluorooctanoic acid (PFOA), perfluorooctanesulfonic acid (PFOS), perfluorononanoic acid (PFNA), perfluorohexanesulfonic acid (PFHxS), and perfluoroheptanoic acid (PFHpA).

On October 2, 2020, MassDEP published its PFAS public drinking water standard or maximum contaminant level (MCL) of 20 nanograms per liter (ng/L) or parts-per-trillion (ppt). Individually or for the sum of the concentrations of six specific PFAS. These PFAS are perfluorooctane sulfonic acid (PFOS), perfluorooctanoic acid (PFOA), perfluorohexane sulfonic acid (PFHxS), perfluorononanoic acid (PFNA), perfluoroheptanoic acid (PFHpA), and perfluorodecanoic acid (PFDA). These six PFAS compounds are often referred to by the MassDEP as “PFAS6”. If any PFAS concentrations are reported below the report limit then they are totaled using “0 ng/L” in the PFAS6 calculation. Below is an example of the PFAS6 calculation with concentrations below the reporting limit:

PFHpA = 5.09 ng/L
PFHxS = 2.97 ng/L
PFOA = 13.5 ng/L
PFNA = ND (< 1.79 ng/L)
PFOS = 5.70 ng/L
PFDA = ND (< 1.79 ng/L)

$$Total\ PFAS6\ Concentration\ \left(\frac{\mathrm{ng}}{\mathrm{L}}\right) = \mathrm{PFHpA} + \mathrm{PFHxS} + \mathrm{PFOA} + \mathrm{PFNA} + \mathrm{PFOS} + \mathrm{PFDA}$$

$$Total\ PFAS6\ Concentration\ \left(\frac{\mathrm{ng}}{\mathrm{L}}\right) = 5.09 + 2.97 + 13.5 + 0 + 5.70 + 0$$

$$Total\ PFAS6\ Concentration\ \left(\frac{\mathrm{ng}}{\mathrm{L}}\right) = 27.26\ \frac{\mathrm{ng}}{\mathrm{L}}$$

1.2.2 Iron and Manganese

The Secondary Maximum Contaminant Level (SMCL) is 0.05 mg/L for manganese and 0.3 mg/L for iron per the secondary standards of the National Secondary Drinking Water Regulations (NSDWR). The current Massachusetts Office of Research and Standards Guidelines (ORSG) has established a maximum concentration of 0.3 mg/L for manganese.

1.3 PILOT STUDY GOALS

The goals of the pilot study were as follows:

1. Demonstrate the ability of GAC (Filtrasorb F400) to reduce PFAS concentrations below the PFAS6 regulatory limit of 20 ng/L.
2. Demonstrate the ability of an anionic exchange resin (Purofine PSA694E) to reduce PFAS concentrations below the PFAS6 regulatory limit of 20 ng/L.
    a. Evaluate potential for headloss development in the contactors.
    b. Evaluate operational or treatment issues (media fouling, etc).
3. Demonstrate the ability of adsorptive media (GreensandPlus™,) filtration to remove iron and manganese to concentrations below the respective SMCL (0.3 mg/L Fe and 0.05 mg/L Mn).
    a. Quantify the filter runtime to the point of contaminant breakthrough or terminal headloss at various filter surface loading rates.
    b. Identify effective pretreatment chemicals and chemical doses for effective treatment to meet the WQ goals.
    c. Collect and analyze composite backwash to provide data that will be used to evaluate various disposal options. Filter backwash solids will be quantified for the sizing of full-scale plant holding tanks or ponds.
    d. Evaluate the effects of recycling settled backwash supernatant at a 10% rate.

2 METHODS AND MATERIALS

Section 2 - Methods and Materials describes the equipment, procedures, and analytical methods utilized during the pilot testing effort. Results are included in this Section only when discussing the precision and accuracy of field methods used.

The pilot equipment was delivered and installed to the pump station site at 223 Breeds Hill Road on February 12, 2021. Formal filter trials began on February 15th. The pilot systems were operated on Well 5 from February 15th to the 24th and on Well 2 from February 24th to March 5th.

2.1 PILOT EQUIPMENT DESCRIPTION

2.1.1 Raw Water Connections

The pilot equipment was supplied with raw water from a hydrant connection as seen in Figure 2.01. Raw water was supplied to the hydrant without chemical pretreatment during the pilot study. The same hydrant was used for each of the two wells. The hydrant expelled close to 350 gpm into a nearby swale while Blueleaf utilized approximately 6 gpm for pilot operations.

Figure 2.01: Well #5 and #2 Raw Water Connection

Raw water was discharged into a 150-gallon hydraulic break tank (Figure 2.02) which provided an air gap (Figure 2.03) between the supply connection at the top of the tank and the tank overflow which regulated the operating elevation in the tank at approximately 1 foot lower. A 1-inch hose connection at the base of the tank supplied a ½ HP booster pump which fed the Greensand pilot system and maintained between 30 and 35 psi of influent pressure.

Figure 2.02: Raw Water Break Tank

Figure 2.03: Air Gap on Raw Water Break Tank

2.1.2 Greensand Pilot Filtration System

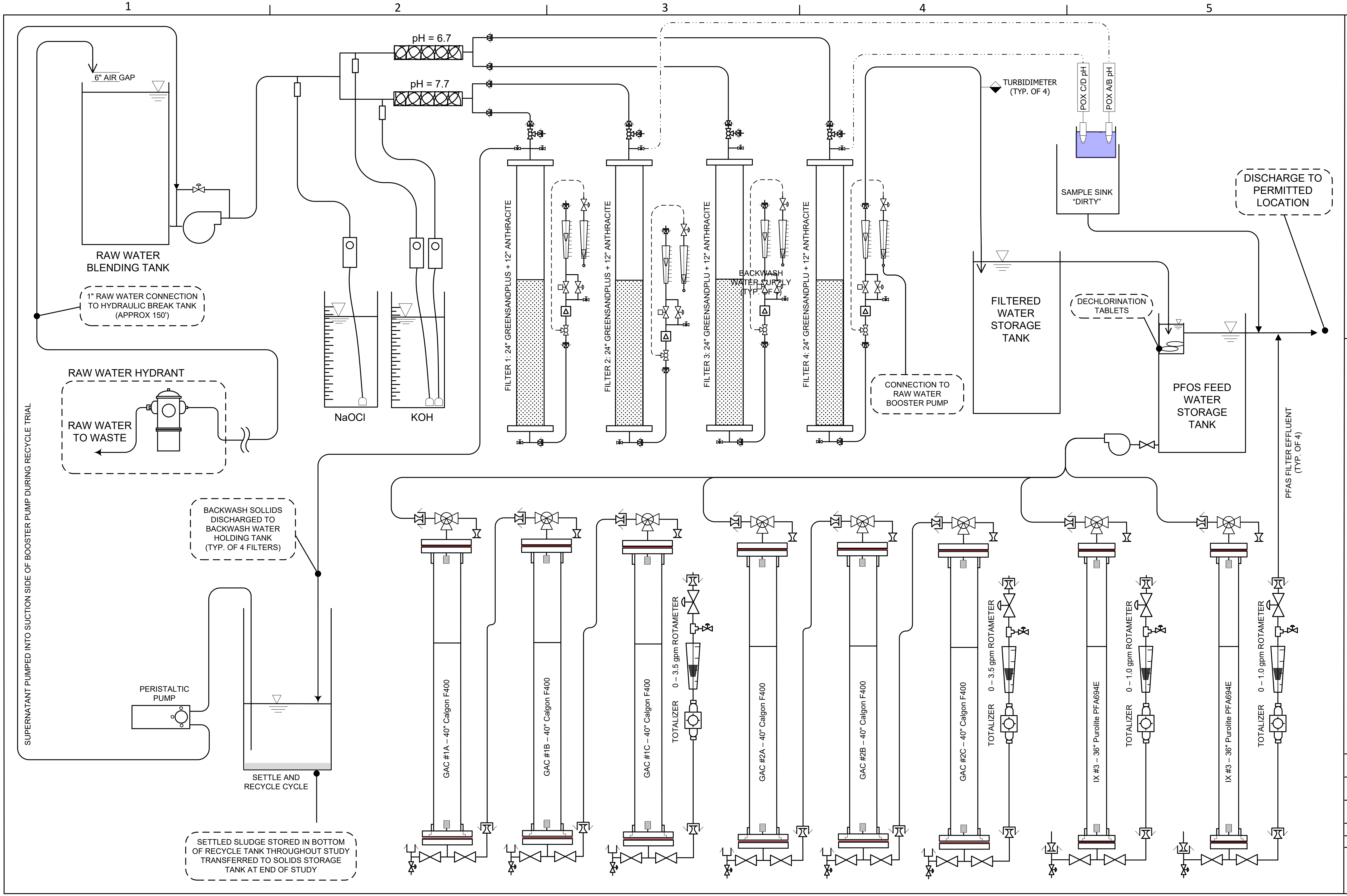
The greensand pilot filtration system and field laboratory were contained in a cargo style trailer. The greensand pilot filtration system removed iron and manganese from the raw water and supplied the treated water to the downstream GAC and IX contactors. Figure 2.04 shows the pilot trailer which contained the Greensand filtration system and the 20’ shipping container which contained the raw water break tank as well as the GAC and IX contractors.

Figure 2.04: Pilot Trailer and Conex at the Well sites

Figure 2.05 shows the interior of the greensand pilot trailer.

Figure 2.05: Interior of Pilot Filtration Trailer

The pilot filtration system included equipment for chemical pretreatment, flow control, four pressure filters operating in parallel, a data acquisition system, and sample points for all relevant sample streams. A process flow diagram of the greensand pilot system and the downstream PFAS removal contactors is in shown in Figure 2.06.



PROJECT:
PFAS AND IRON AND MANGANESE REMOVAL PILOT STUDY

FIGURE 2.06: PROCESS FLOW DIAGRAM OF PROPOSED PILOT SYSTEM AT BARNSTABLE FIRE DISTRICT

BLUELEAF, INC
PILOT TESTING FOR WATER AND WASTEWATER TREATMENT
57 DRESSER HILL ROAD, CHARLTON, MA 01507
(508) 248-7094

DRAWN BY
E. GROTTON
FILE NAME
07202_06
DATE
07APR2021
SIZE: 11' X 17"
SCALE: NONE'
DWG NO
FIG. 2.06

2.1.2.1 *Chemical Pretreatment*

The greensand pilot system influent was pretreated using sodium hypochlorite (NaOCl) for oxidation and media regeneration, and potassium hydroxide (KOH) for pH adjustment.

Each of the four pilot filters were supplied with chemically pretreated water via 3/4-inch nylon braided hose. NaOCl was injected into the common supply for all four filters. The common NaOCl injection location is indicated by the blue circle in Figure 2.07. KOH was injected downstream of a tee which split raw water flow into two trains to allow for the evaluation of two different pH levels. The two KOH injection locations are indicated by the yellow circles. The direction of flow is indicated by the two orange arrows.

Figure 2.07: Pilot Trailer Chemical Feed Area

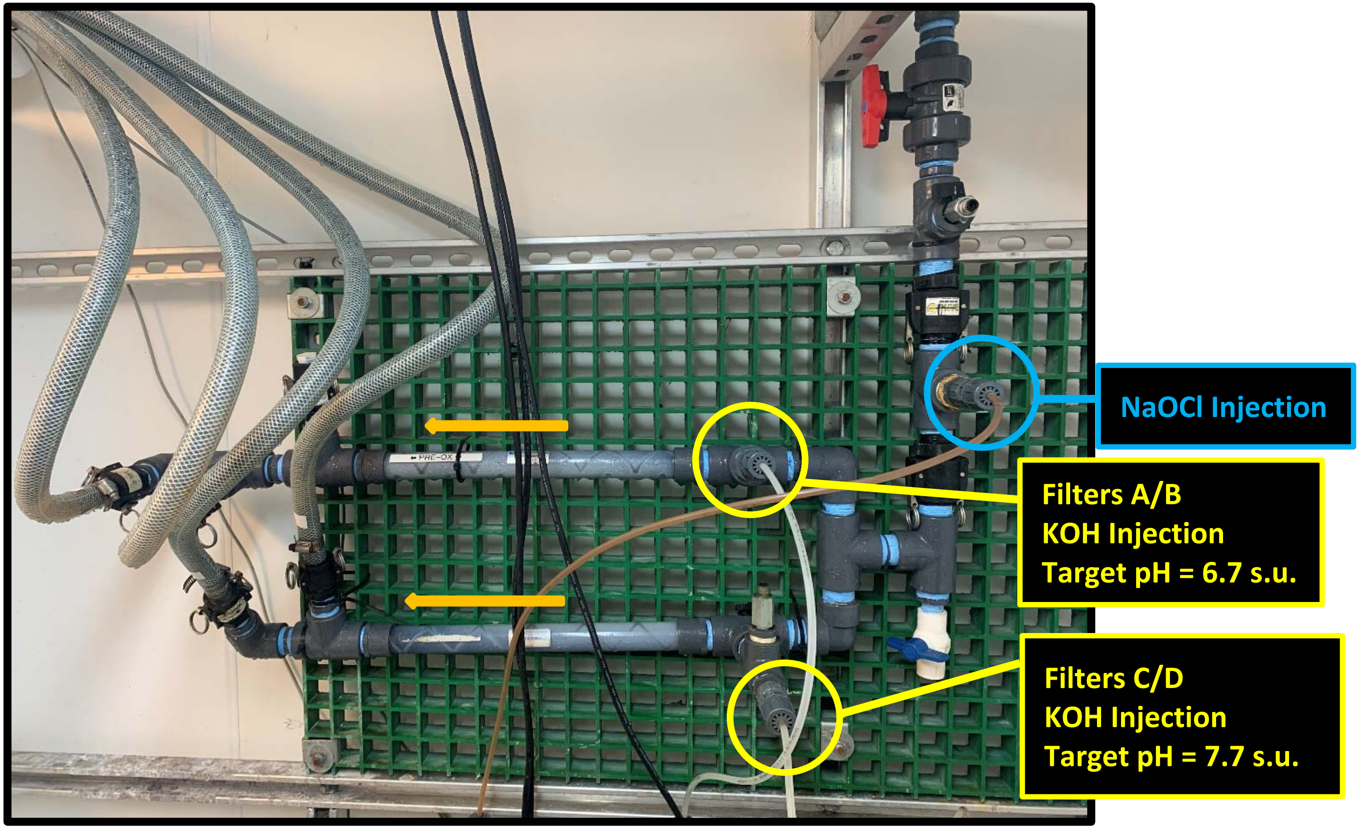


Figure 2.08 shows the sodium hypochlorite (NaOCl) feed pump as well as the two KOH feed pumps. The chemical feed pumps were Grundfos DDA diaphragm pumps. The suction tubing from the pumps withdrew diluted NaOCl and KOH stock stored in 55-liter day tanks located below the pumps.

The pumps had a maximum capacity of 7.5 lph (liters per hour) and a minimum capacity of 2.5 mL/hour (milliliters per hour). Typical feed rates were 125 to 250 mL/hr. The feed rates were calibrated by recording the drawdown versus elapsed time in the graduated day tank. The feed pumps injected into the 1-inch PVC raw water supply line via an injection quill.

The oxidant feed rate for NaOCl was manually set by the operator to obtain the desired residual chlorine concentration in the filter effluents.

The feed rates for the two KOH feed pumps were controlled by a Hach SC200 two-channel controller to maintain the setpoint pH levels in the filter influent to Filters A&B (low-pH) and Filters C&D (high-pH). The pH was monitored in each stream of pretreated filter influent water, referred to herein as "POX" samples (acronym for Post-OXidized). Each of the two POX sample flows ran continuously into a sample cup with a dedicated Hach online pH probe connected to the SC200 controller. The controller sent a separate 4-20 milliamp signal to each KOH feed pump, and the feed pump trimmed the feed rate to maintain the setpoint pH (either low or high) per a PID (Proportional Integral Derivative) control algorithm.

Figure 2.08: Sodium Hypochlorite and Potassium Hydroxide Feed Pumps

Pretreated water was sampled via ¼-inch POX sample lines connected to the filter inlets of Filter A, B, C, D. The pretreated sample line was used to monitor various water quality parameters, including chlorine (free and total), iron (total and dissolved), manganese (total and dissolved), and pH.

2.1.2.2 *GreensandPlus™ Adsorptive Media*

The pilot filter utilized GreensandPlus™ (GSP) media which is a non-proprietary filtration media with the same adsorptive coating and treatment performance as standard manganese greensand, but the adsorptive coating is fused to a silica core. This allows GreensandPlus™ to withstand higher differential pressures than standard greensand without breakdown of the particles, and without stripping the adsorptive coating from the substrate. GreensandPlus™ can operate at filter loading rates 8 gpm/sf or greater, depending upon water quality, compared to 2 to 5 gpm/sf for standard manganese greensand.

GreensandPlus™ has a manganese dioxide coating that both catalyzes the oxidation/reduction of manganese and is adsorptive to manganese. The manganese dioxide coating is maintained by feeding an oxidant, typically either permanganate or chlorine. Pre-oxidation for contaminant removal or disinfection can provide sufficient oxidant to also maintain the adsorptive qualities of the media, but it is sometimes necessary to perform specific media regeneration procedures.

GreensandPlus™ filters are typically backwashed at 12 gpm/sf minutes, with or without air scour. A terminal differential pressure (DP) of 10 psi is often used to trigger backwash, but the manufacturer claims GreensandPlus™ is capable of withstanding DPs substantially greater than 10 psi.

Table 2.01 summarizes the pilot filter configurations.

Table 2.01: Pilot Filter Configurations

Parameter	Filters A, B, C, D
Adsorptive filtration media	GreensandPlus^{TM} with Anthracite
Adsorptive media depth	24 inches (61 cm)
Anthracite filter cap	12 inches (30 cm)
Total filter bed depth	36 inches (91 cm)
Filtration media volume	0.4 ft^3 (11.3 L)
Anthracite volume	0.2 ft^3 (5.7 L)
Total media volume	0.6 ft^3 (17.0 L)
Freeboard above filter surface	24 inches (61 cm)
Filter vessel diameter	6 inches (15 cm)
Filter surface area	0.20 ft^2 (182 cm^2)
Filter vessel height	60 inches (1.52 m)
Filter vessel empty volume	27.6 gallons (104.5 L)

2.1.2.3 *Flow Control and Instrumentation*

There were four parallel flow control assemblies, one per filter. Each flow control assembly included separate components for filtration and backwash operations. Forward flow had automated control capability. A flow meter controlled an automatic modulating valve via a PC-based PLC program with a PID loop. The PLC continuously monitored and logged filter flow rates, filter inlet and outlet pressures, filter effluent turbidities, and filter influent pH. The flow rate to the turbidimeters was manually adjusted and periodically measured.

Four pilot filters were operated in parallel during all trials. Each pilot filter was 6 inches in diameter by 60 inches high. Pilot filters were constructed from 6-inch clear PVC schedule 40 pipe. Each filter had an underdrain consisting of a 2" stainless steel slotted media-retention nozzle with No. 8-12 garnet surrounding the nozzle. All four filters contained 24 inches of GreensandPlus^{TM} (GSP) filtration media, with a 12" anthracite coal filter cap.

Figure 2.09 shows the flow control assembly for the pilot filters.

Figure 2.09: Pilot Filter with Flow Control Panel

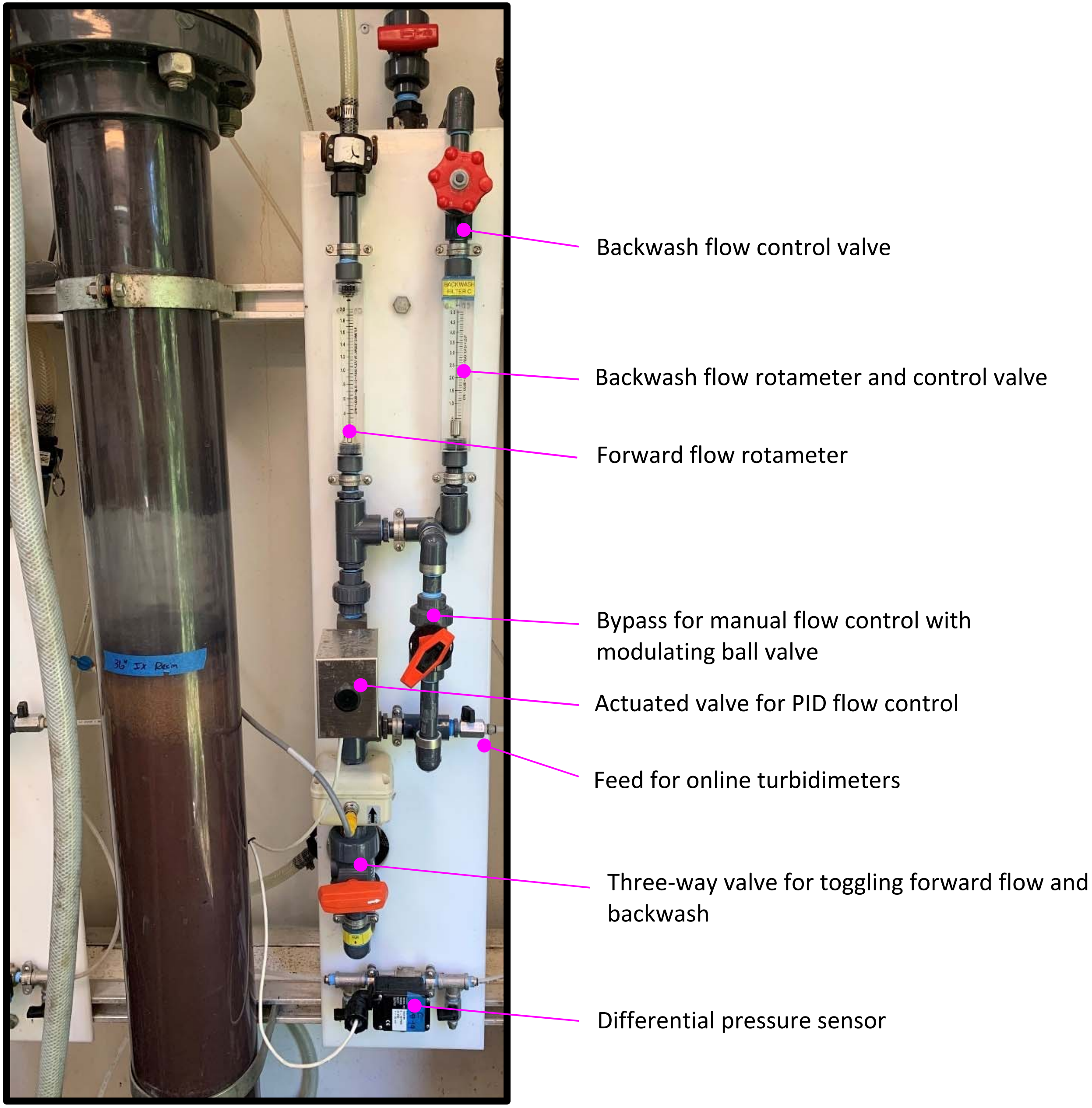


Figure 2.10 shows the sample sink, with ½" hoses for pilot filter effluent, 3/8" lines for discharge from the four Hach 1720e flow-through turbidimeters, and the 1/4" sample lines for untreated raw water, and pretreated filter influent. The pretreated filter influent sample lines flowed into a common sample cup with an online pH meter, connected to a Hach SC200 controller. The pH controller provided automated control of the potassium hydroxide feed pump to maintain the target filter influent pH.

Figure 2.10: Pilot Trailer Sample Sink

The four ½" filter effluent hoses are shown grouped together and discharging into a 2" standpipe which collected the combined flow. The combined Greensand filter effluent then flowed by gravity to the filter effluent storage tank in the adjacent storage container as the source water for the PFAS treatment system.

Each filter effluent flow had a dedicated flow-through Hach 1720E low range turbidimeter. The four effluent turbidimeters were connected to two Hach SC200 2-channel controllers. Filter effluent turbidimeters and SC200 controllers are shown in Figure 2.11. Filter effluent grab samples were collected from the individual filter effluent streams at the points of discharge into the sample sink.

Figure 2.11: Hach 1720E Low Range Turbidimeters

2.1.2.4 *Backwash Water Feed Tank, Pump, and Connections*

During backwashes the raw water was used to backwash each greensand filter one by one. Each filter was backwashed one after the other so that the feed to the PFAS removal system would not be interrupted by shutting all four filters at the same time. Backwash flows were controlled on the upstream, clean-water side of the filters while in reverse flow mode. Each filter had a dedicated 0-5 gpm rotameter and flow control valve.

All filters were backwashed at a nominal flow rate of 2.4 gpm (12 gpm/sf) for a period of 10 minutes. For each filter, the entire backwash volume was collected in a 30-gallon tank, and backwashing continued until a volume of 24-gallons was collected. A bulk backwash sample was typically collected to evaluate settling and characterize the backwash water. After sampling, the backwash water was discharged either to a backwash tank for future recycle trials or to waste.

2.1.3 PFAS Pilot Filtration System

The PFAS removal pilot equipment was fabricated at the Blueleaf workshop in Charlton, MA and installed inside a 20’ shipping container. The PFAS pilot equipment was delivered and installed at the same time as the greensand filtration system on February 12th and then operated concurrently from February 15th to March 5th, 2021. Most of the pipe and fittings were purchased new for this study to avoid any PFAS contamination. All plumbing connections were made using *Gasoila Non-PTFE* pipe thread sealant. Teflon based thread sealant tape is produced from a polytetrafluoroethylene (PTFE) formula which can contribute to false positive PFAS results. Figure 2.12 shows the shipping container setup at the Breeds Hill Road site in Barnstable, MA.

Figure 2.12: Shipping Container Housing PFAS Removal Pilot Equipment at the Barnstable Site

2.1.3.1 *Pilot Feed Configuration*

The combined filter effluent from the four iron and manganese removal filters flowed by gravity from the greensand filtration pilot trailer through 2-inch hose into a 250-gallon storage tank in the shipping container. The effluent tank was equipped with an overflow which discharged to a dechlorination tank containing dechlorination tablets. Dechlorinated water was used to feed the GAC and IX contactors to avoid taking up sites within the media or breaking down the IX resin. Figure 2.13 shows the side-by-side filter effluent and dechlorination tanks.

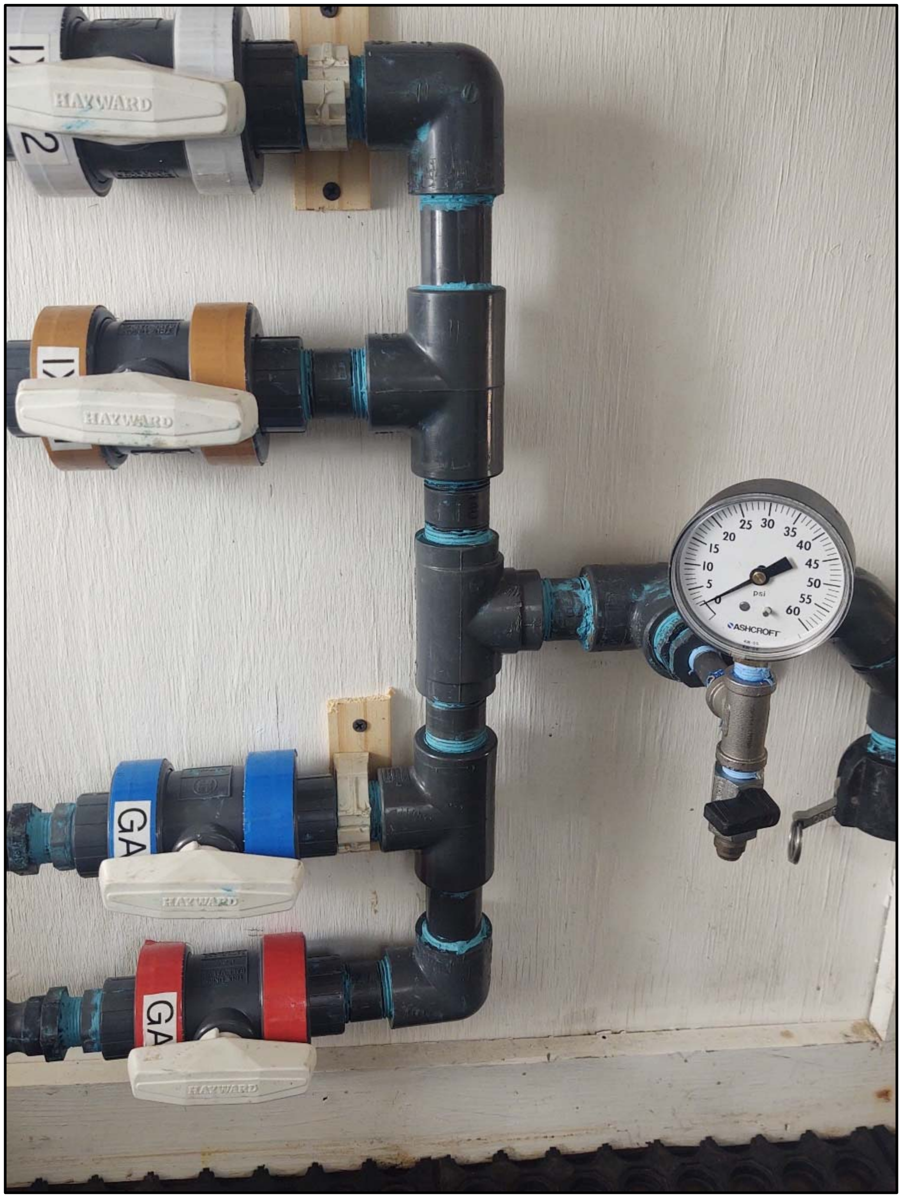
Figure 2.13: Pilot Effluent Tank and Dechlorination Feed Tank

A ½ HP booster pump supplied water to two GAC contactors and two IX contactors via a 4-way header (Figure 2.14) equipped with 1” ball valves which allowed individual trains to be turned on or off for backwashing if necessary.

Treatment trains were configured and color coded as follows:

- GAC1: Calgon F-400 High Flow Rate/Low EBCT Contactor – Blue Labeling
- GAC2: Calgon F-400 Low Flow Rate/High EBCT Contactor – Red Labeling
- IX1: Purolite Purofine PFA694E) High Flow Rate/Low EBCT Contactor – Brown Labeling
- IX2: Purolite Purofine PFA694E Low Flow Rate/High EBCT Contactor – White Labeling

Figure 2.14: Pilot Feed Header



2.1.3.2 *Pilot Contactors*

Four contactors were constructed and installed for the pilot study.

- The GAC contactors (GAC1 and GAC2) each contained a total depth of 10-feet of GAC media. The two contactor trains were constructed as a series of three 5-foot-tall vessels containing 40 inches GAC media each and were operated to function as a single contactor. Each vessel was constructed of 6-inch diameter clear PVC.
- The IX contactors (IX1 and IX2) were each constructed as a single 5-foot-tall vessel. Each vessel was constructed of 4-inch diameter clear PVC. The IX contactors contained 36 inches of anionic exchange resin.

All eight vessels had an underdrain consisting of a 2-inch stainless steel slotted media-retention nozzle. Each of the vessels had top and bottom flanges equipped with a ¾-inch bulkhead fitting. Each top flange was connected to a ¾-inch three-way valve, where one position was forward flow (feed) and the other was reverse flow (backwash). The contactor bottoms had two ¾-inch connections, each equipped with ¾-inch ball valves. One connection was used as the discharge of the contactor (forward flow) and the other for backwashing (reverse flow). Figures 2.15 and 2.16 show the contactor top and bottom configurations.

Figure 2.15: Contactor Inlet

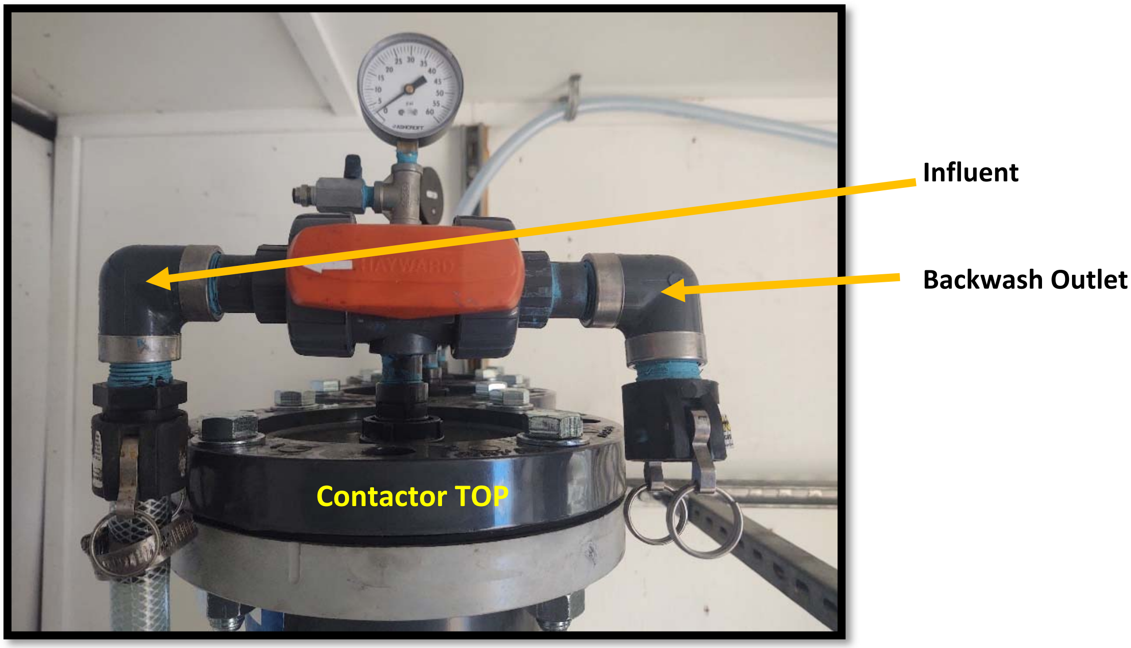
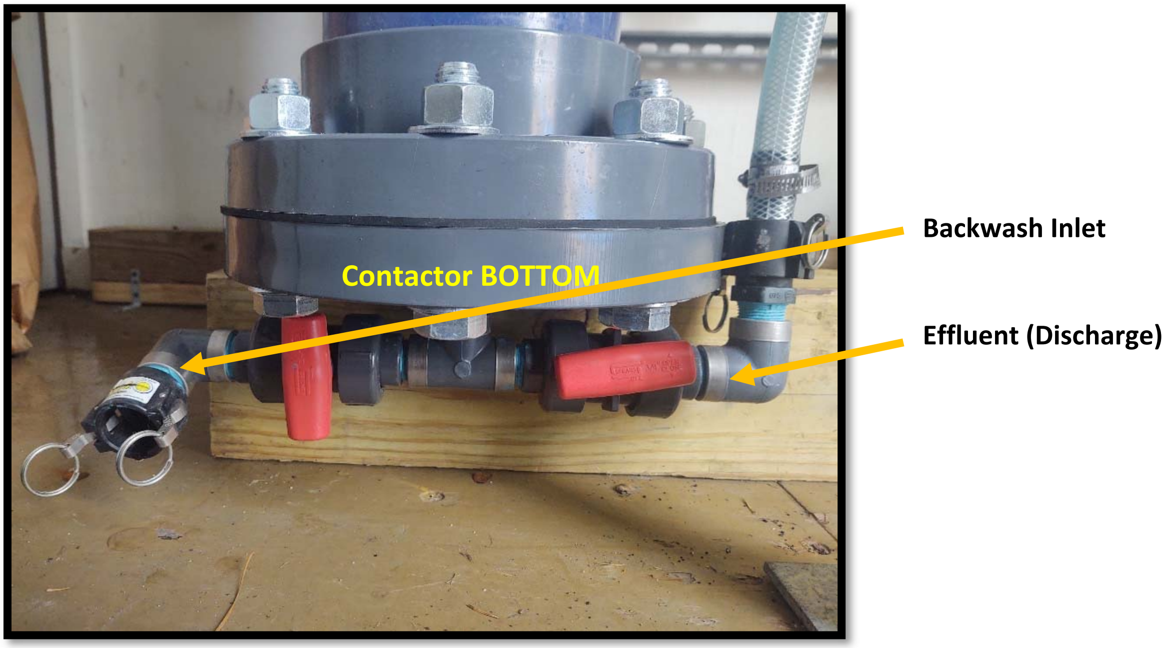


Figure 2.16: Contactor Outlet



The four treatment trains are discussed below.

GAC 1 - Calgon F-400 GAC at Low EBCT
Three identical 5-foot tall 6-inch diameter contactors each containing 40"' of Calgon GAC were operated in series. The first GAC vessel (GAC #1A) received greensand filter effluent and the second and third GAC vessels (GAC #1B, GAC #1C) received effluent from the previous GAC vessel (GAC #1A). All three GAC vessels were hydraulically connected and operated at the same flow rate to function as a single contactor with a total depth of 10’ of media. Separate GAC contactors were constructed as opposed to one taller GAC contactor to provide sufficient headspace for backwashing the GAC and due to height restrictions, and ease of construction/installation. The total volume of media was approximately 2.0 cubic feet, or 14.7 gallons, and the contactor operated at 10 minutes EBCT at a flow rate of 1.5 gallons/minute.

GAC 2 - Calgon F-400 GAC at High EBCT
The construction and operation of the GAC 2 contactor was identical to GAC 1 with the exception that GAC 2 operated at 20 minutes EBCT at a flow rate of 0.75 gallons/minute.

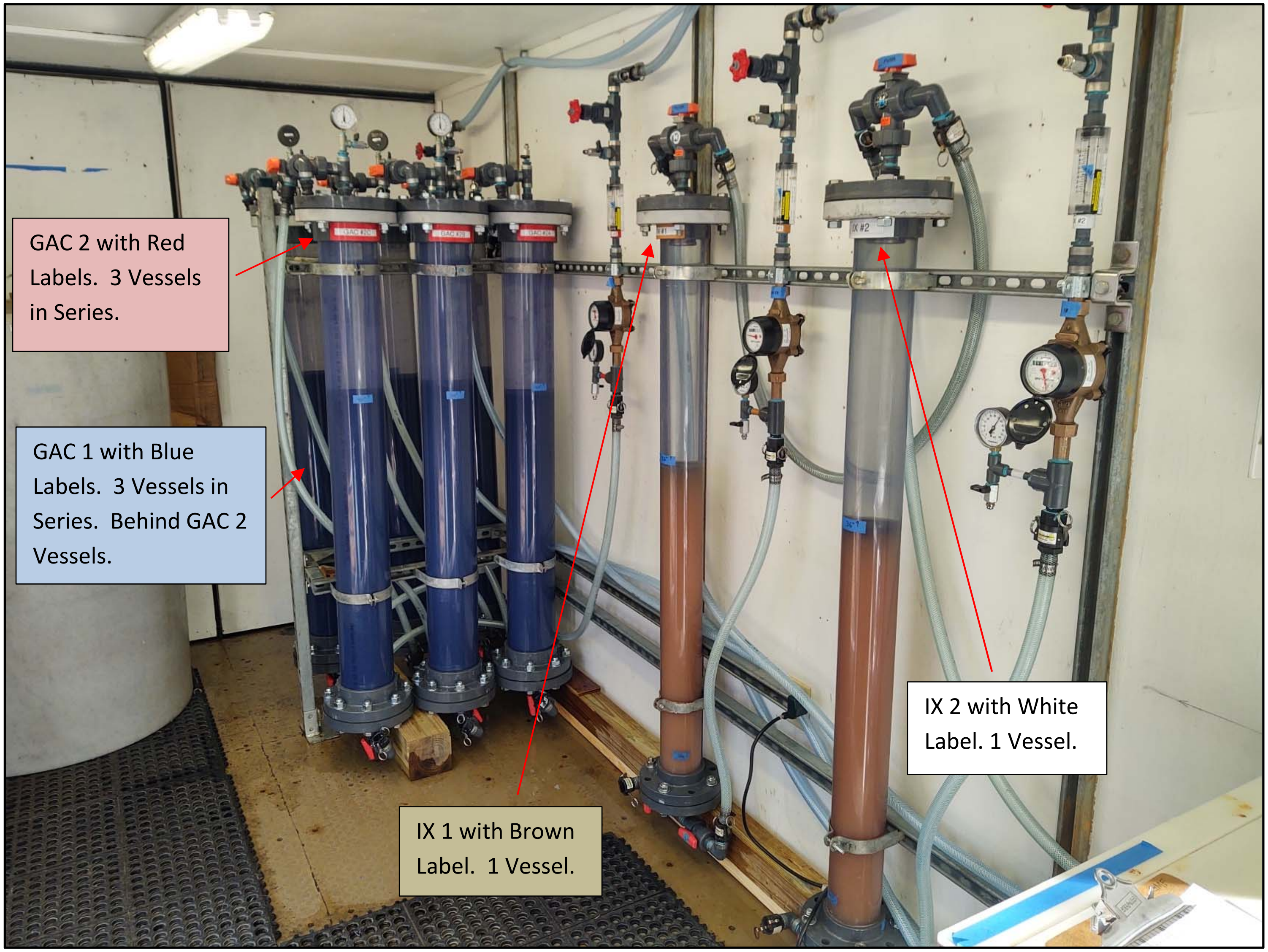
IX 1 – Purolite Purofine PFA694E IX at Low EBCT
One 5-foot tall 4-inch diameter contactor containing 36" Purolite Purofine PFA694E ion exchange resin which received greensand filter effluent. Effluent from the IX contactor passed through a flow control assembly prior to discharging to the drain. The total volume of media was 0.26 cubic feet, or 1.95 gallons, and operated at 1.5 minutes EBCT at a flow rate of 1.3 gallons/minute.

IX 2 – Purolite Purofine PFA694E IX at High EBCT
The construction and operation of IX 2 was identical to IX 1 with the exception that IX 2 operated at 3.0 minutes EBCT at a flow rate of 0.65 gallons/minute.

The process flow diagram of the PFAS removal pilot system is shown in Figure 2.06.

Figure 2.18 shows the pilot contactor layout. Greensand filter effluent was fed from right to left through the hoses at the bottom of the photo which then swept up to the tops of the contactor vessels. The contactor vessels operated in downward flow. All contactor effluent was discharged at the bottom of the contactor vessels and then flowed upward through the vertical flow control assemblies and then left to right through the hoses at the top of the photo eventually discharging into a sample sink shown in Figure 2.20.

Figure 2.18: PFAS Contactor Layout



The granular activated carbon (GAC) utilized for the pilot study was Calgon's F-400. The GAC media was soaked and backwashed prior to pilot operation to remove media fines.

The ion exchange (IX) resin utilized for the pilot study was Purolite's Purofine PFA 694E anionic exchange resin (AER). The IX media was soaked prior to pilot operation to saturate the media and reduce buoyancy.

Manufacturer media descriptions are included in Appendix D.

Table 2.02 summarizes the pilot contactor configurations.

Table 2.02: Pilot Contactor Configurations

Parameter	**Train 1 and 2**				**Trains 2 and 3**
	Vessel 1	**Vessel 2**	**Vessel 3**	**Total**	**Total**
Media Type	Calgon Filtrasorb 400				Purolite PFA 694E
Adsorptive media depth	40" (3'4")			120" (10')	36" (3')
Adsorptive media volume	4.9 gal			14.7 gal	1.95 gal
Freeboard above filter surface	20" (1'8")			60" (5')	24" (2')
Contactor vessel diameter	6"			6"	4"
Contactor surface area	0.2 ft^2			0.2 ft^2	0.09 ft^2
Contactor vessel height	5'			15'	5'
Filter vessel empty volume	7.34 gal			22 gal	3.26 gal

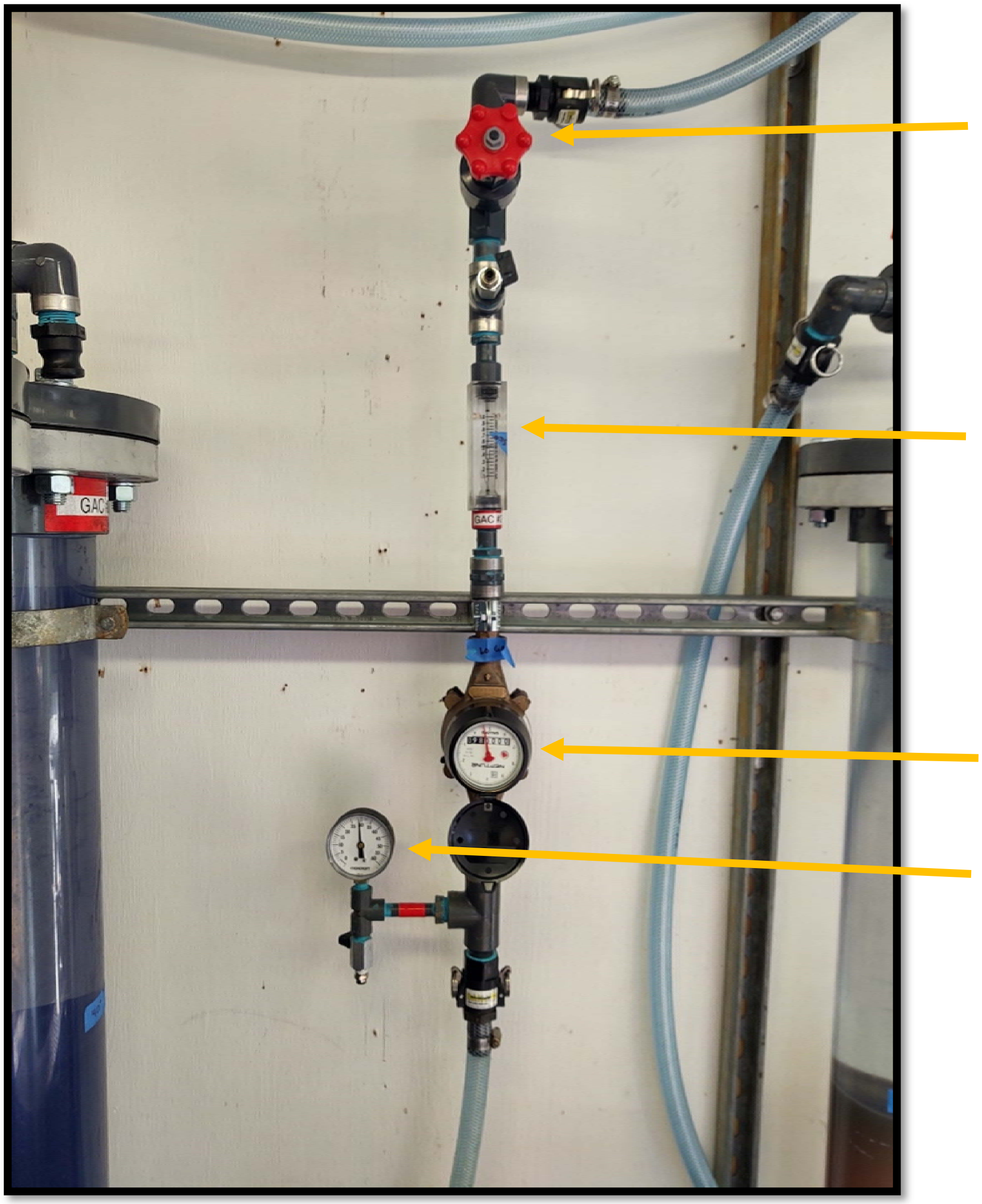
2.1.3.3 *Flow Control, Pressure Monitoring, and Drain*

There were four flow control and monitoring assemblies installed for the four treatment trains. Each flow control and monitoring assembly consisted of a globe valve for flow control, a rotameter for manual flow readings, and a totalizer for quantifying the total volume of water treated.

0-60 psi pressure gauges were used to monitor differential pressure (headloss) development for each of the pilot scale contactors. All eight pilot vessels had differential pressure monitoring capability. A common inlet pressure gauge was used to log the inlet pressure for all contactors. Each contactor had a dedicated outlet pressure tap connected to a pressure gauge. Contactor differential pressures (DPs) were calculated using the inlet and outlet pressures for each contactor. DPs for first vessel in the GAC trains and both IX contactors were calculated using the common inlet pressure and that contactors outlet pressure. DPs for the second and third contactors in the GAC trains were calculated using the outlet pressure for the contactor upstream and the outlet pressure for the contactor of interest.

Figure 2.19 shows the contactor flow control assembly. Important components such as globe valve, rotameter, totalizer (water meter), and pressure tap are identified.

Figure 2.19: PFAS Contactor Flow Control Assembly



Globe Valve

Rotameter

Totalizer

Effluent Pressure Gauge

All contactor effluent discharged into a sample sink where the final PFAS contactor effluent could be sampled. The sample sink drained by gravity to ground outside the container. Figure 2.20 shows the final sample sink and effluent discharge hoses.

Figure 2.20: PFAS Pilot System Drain

2.1.4 Field Laboratory and Analytical Testing Equipment

The greensand pilot trailer was equipped with a field laboratory to provide an area to complete field analyses (Figure 2.21). Glassware, reagents, and analytical equipment necessary to complete the analyses described in Section 2.3 were included in the field laboratory.

Figure 2.21: Greensand Pilot Trailer Field Laboratory

The following sample locations were used during the pilot study:

- RAW – Raw water sample from the well source depending on which well was being treated.
- POX AB – Post Oxidized influent to the Greensand Filters A/B collected from filter influent tap.
- POX CD – Post Oxidized influent to the Greensand Filters C/D collected from filter influent tap.
- FILTER A – Filter Effluent from Filter A collected at the point of discharge to the sample sink.
- FILTER B – Filter Effluent from Filter B collected at the point of discharge to the sample sink.
- FILTER C – Filter Effluent from Filter C collected at the point of discharge to the sample sink.
- FILTER D – Filter Effluent from Filter D collected at the point of discharge to the sample sink.
- CBW A – Combined Backwash Filter A collected from homogenized backwash.
- CBW B – Combined Backwash Filter B collected from homogenized backwash.
- CBW C – Combined Backwash Filter C collected from homogenized backwash.
- CBW D – Combined Backwash Filter D collected from homogenized backwash.
- SSN A – Settled Supernatant Filter A collected from top of settled CBW A.
- SSN B – Settled Supernatant Filter B collected from top of settled CBW B.
- SSN C – Settled Supernatant Filter C collected from top of settled CBW C.
- SSN D – Settled Supernatant Filter D collected from top of settled CBW D.
- GAC 1 – Filter Effluent from GAC Contactor 1

- GAC 2 – Filter Effluent from GAC Contactor 2
- AER 1 – Filter Effluent from Ion Exchange Contactor 1
- AER 2 – Filter Effluent from Ion Exchange Contactor 2

2.2 PRETREATMENT

Liquid pretreatment chemicals were diluted with filtered water at measured volumetric ratios to produce feed stocks with the desired concentrations. The objective was to maintain chemical feed rates within the mid-range of the feed pumps to allow for dose adjustments up or down as required.

- Potassium hydroxide (KOH) was used to achieve the target pH of each filtration process.
- Sodium hypochlorite (NaOCl) was used for oxidation of dissolved iron and maintenance of an oxidative environment for media regeneration.

Table 2.03 summarizes the pretreatment chemical properties.

Table 2.03: Pretreatment Chemical Properties

Product	Formula	Function	Stock Strength	Specific Gravity
Sodium Hypochlorite	NaOCl	Oxidant/Disinfection	7.5%	1.10
Potassium Hydroxide	KOH	pH Adjustment	45%	1.45

The liquid chemicals were added to graduated day tanks shown in Figure 2.22, which allowed measurement of daily drawdown rates. The drawdown rates were used to calculate chemical feed rates and doses. Field dilutions were as follows:

- KOH was used at a dilution of the stock KOH by 33% (1/3). The diluted KOH was placed in a day tank with a volume of up to 60 L, with graduations at 1 L (1000 mL) intervals.
- NaOCl was used at a dilution of the stock by 10% (1/10). The diluted NaOCl was placed in a day tank with a volume of up to 60 L, with graduations at 1 L (1000 mL) intervals.

Figure 2.22: Chemical Day Tanks

2.2.1 Dose Calculation for NaOCl

NaOCl doses were calculated based on the stock concentration of the product, the dilution of the stock product with make-up water, the chemical feed rate, and the flow rate of the process water. The NaOCl dose based on volume of product was determined using the following formula:

$$Cl_2\ Dose\ (\mathrm{ppm}) = \left[\frac{(R)(D)(10^6\ ppm)}{(Q)(3{,}785\ mL/gal)(60\ min/hr)}\right]$$

Where:
R = chemical feed rate (mL/hour) per day tank drawdown measurements
Q = process water flow rate (gpm)
D = dilution factor of chemical in day dank (dimensionless ratio)

The concentration of free available chlorine in sodium hypochlorite stock solution was not determined during the pilot study. Typical store-bought sodium hypochlorite stock solution is assumed to have an available chlorine concentration of 7.5%. For determining the mass based NaOCl dose, the stock solution is assumed to have a free chlorine concentration of 7.5% by weight and a specific gravity of 1.10. The NaOCl dose based on mass was determined using the following formula:

$$Cl_2\ Dose\ (mg/L) = \left[\frac{(R)(D)(1.10)(7.5\%)(10^6\ mg/L)}{(Q)(3{,}785\ mL/gal)(60\ min/hr)}\right]$$

Where:
R = chemical feed rate (mL/hour) per day tank drawdown measurements
Q = process water flow rate (gpm)
1.10 = specific gravity of the product (dimensionless)
7.5% = weight percentage of the product (% NaOCl)
D = dilution factor of chemical in day dank (dimensionless ratio)

2.2.2 Dose Calculation for KOH

KOH doses were calculated based on the specific gravity and stock concentration of the product, the dilution of the stock product with make-up water, the chemical feed rate, and the flow rate of the process water. The doses were calculated in terms of mg/L as KOH. The product had a weight percentage of 45%, a specific gravity of 1.45, and a normality of 11.7 N. Doses were calculated as:

$$KOH\ Dose\ (mg/L) = \left[\frac{(R)(D)(1.45)(45\%)(10^6\ mg/L)}{(Q)(3{,}785\ mL/gal)(60\ min/hr)}\right]$$

Where: *R* = chemical feed rate (mL/hour) per day tank drawdown measurements
Q = process water flow rate (gpm)
1.45 = specific gravity of the product (dimensionless)
45% = weight percentage of the product (% KOH)
D = dilution factor of chemical in day dank (dimensionless ratio)

2.3 FIELD ANALYTICAL METHODS

2.3.1 Iron - FerroVer

Iron samples for raw water, pilot influent and intermediate filtrations steps were analyzed in accordance with Hach (Loveland CO) FerroVer® method #8008. Samples with iron concentrations above 3.3 mg/L were diluted with distilled water by a ratio appropriate to bring them into a measurable range. Samples were distributed to 25 ml sample vials. FerroVer iron reagent was added to each sample vial and mixed, and 3 minutes were allowed for reaction. Te samples were read using a Hach DR 5000, or DR 890 colorimeter. The colorimeter was zeroed with each set of readings using a blank from the appropriate sample site. The estimated detection limit for the method was 0.04 mg/L.

2.3.2 Manganese – PAN Method (Field Method)

Manganese samples were analyzed using the PAN (1-(2 Pyridylazo)-2 Napthol) method in accordance with Hach method #8149. 10 mL samples were measured into 25 ml sample vials. Ascorbic acid, alkaline cyanide and 0.1% PAN indicator solution were added using autoburettes set to dispense 0.5 mLs of ascorbic acid, 0.4 mLs of alkaline cyanide, and 0.4 mLs of PAN reagent. The vials were mixed and 2 minutes were allowed for reaction. The samples were read using a Hach DR 5000 or DR 890 colorimeter. The colorimeter was zeroed with each set of readings with a blank of DI water, prepared identically to the samples according to the PAN method. A new blank was prepared with each set of manganese samples that were analyzed. The results were displayed in mg/L of total manganese.

2.3.3 Alkalinity

Alkalinity was analyzed in accordance with the Standard Methods 2320 Titration Method. Either 100 or 200 mL samples were titrated using 0.020N H_2SO_4. The endpoint of the titration was a pH of 4.5 SU.

For alkalinity samples of 30 mg/L or greater, the total alkalinity was determined as follows:

$$Total\ Alkalinity\ (mg/L\ CaCO_3) = \frac{A \times N \times 50{,}000}{mL\ Sample}$$

Where:

A = mL titrant to recorded pH (4.5 SU), and
N = Normality of Titrant (0.02 N)

For alkalinity samples less than 30 mg/L, the total alkalinity was determined as follows:

$$Total\ Alkalinity\ (mg/L\ CaCO_3) = \frac{(2B - C) \times N \times 50{,}000}{mL\ Sample}$$

Where:

B = mL titrant to first recorded pH (4.5 SU)
C = total mL titrant to reach pH 0.3 unit lower, and
N = Normality of Titrant (0.02 N)

Results were expressed as mg/L of calcium carbonate per liter (mg $CaCO_3$/L).

2.3.4 Carbon Dioxide

Carbon dioxide was determined in accordance with Standard Method 4500-CO_2 and an Orion 3-star pH meter. A titration was performed on 100 mL samples using 0.02 N NaOH while pH was continously monitored. The titration was complete when the pH reached approximately 8.3. The volume of titrant added was then used to calculate the concentration of carbon dioxide using the following formula:

$$\frac{mg\ CO_2}{L} = \frac{Volume\ of\ Titrant\ (mL)\ x\ 0.02\ N\ NaOH\ x\ 44{,}000}{100\ mL}$$

2.3.5 pH Measurements

Manual pH measurements were made in accordance with Standard Methods 4500-H+B using an Orion glass pH Triode with temperature compensation, and an Orion 3-Star pH meter. A two-point calibration was performed using standard buffer solutions of pH 4.00 SU and pH 7.00 SU, or pH 7.00 SU and pH 10.00 SU.

Online pH probes were HACH pHd differential pH (HACH #DRC1R5N) sensors connected to a SC200 controller. Online pH was monitored by placing the probe in a sample container in the sample sink; the sample container was continuously filling with fresh sample and overflowing at a constant level.

2.3.6 Turbidity

Turbidity was monitored by Hach Model 1720D turbidimeters installed in the pilot trailer. The turbidimeters were connected to pressurized sample ports via ¼" OD tubing, and flow rates were controlled by ¼" ball valves. Sample flow rates were periodically checked and maintained at 100-450 ml/minute. The turbidimeter controllers displayed instantaneous turbidities in Nephelometric Turbidity Units (NTU). The controllers provided a signal to a PC based data acquisition system that recorded data continuously for all turbidimeters.

2.4 LABORATORY METHODS

Alpha Analytical (Westborough, MA) was utilized as the certified laboratory for off-site analyses. Samples were collected by Blueleaf personnel by filling laboratory-prepared bottles, which were delivered to Alpha with a Chain of Custody (COC) that identified the sample field ID, the data and time of sample collection, the bottle size and type, the preservative, and the required analysis.

2.4.1 SDS Setup and Sampling Procedure

Blueleaf personnel collected a one-liter sample in a one-liter amber bottle. For greensand filter effluent the chlorine residual and pH were not altered after collection of the sample. The pilot free chlorine residual target was 0.6 mg/L during collection and pH was targeted to either 6.7 or 7.7 depending on filter. For PFAS contactor effluent samples it was necessary to add diluted NaOCl to the jar in order to reestablish a chlorine residual of 0.6 mg/L.

Free and total residual chlorine and pH were analyzed in the field by Blueleaf prior to incubation of the samples. The samples were kept in a water bath onsite for 172 hours. At the end of the incubation period, TTHM and HAA5 samples were collected from the incubated sample volume and submitted to Alpha Analytical. The final free/total residual chlorine and pH from the incubated sample were analyzed and recorded in the field by Blueleaf.

2.5 STATISTICAL METHODS

2.5.1 Paired t-test

The paired t-test procedure is used to analyze the differences between paired observations. The procedures are used to determine if the mean difference for the population is likely to be different from zero. The paired t-procedure is used to compare two opposing hypotheses:

H_o (the null hypothesis): That the mean of the differences in the population is equal to zero
- or -
H_1 (the alternative hypothesis): That the mean of the differences in the population is not equal to zero.

The paired t test results are normally displayed as a confidence interval, which is a range of likely values for the difference between the two sample sets. Confidence intervals that contain zero normally indicate that the null hypothesis has not been disproven, i.e. that there was not a significant difference in paired values.

The t-test results also provide two statistics to test of the mean difference: a t-value and a p-value. The t-value is not very informative by itself, but it is used to determine the p-value. The p-value indicates how likely it is that H_o is true. High p-values suggest that there is no difference between paired values, while low p-values suggest that there is a statistically significant difference between paired values.

2.5.2 Analysis Of Variance (ANOVA)

When appropriate, Minitab software was used to perform an Analysis Of Variance (ANOVA) to compare the effects of two or more factors upon a specific response. For example, an ANOVA might be used to compare effluent iron concentrations (the response) at different surface loading rates (the factor). The following explanation was adapted from the software documentation.

An ANOVA tests the hypothesis that the means of two or more populations are equal. The procedure uses variances to determine whether the means are different, by comparing the variance between group means versus the variance within groups. In this way the ANOVA determines whether the different groups are all part of one larger population, or can be statistically distinguished as separate populations with different characteristics. An ANOVA requires data from normally distributed populations with roughly equal variances between factor levels.

An example of the output from an ANOVA is shown below on Table 2.04. The ANOVA tested a data set to determine whether the Factor had a statistically significant affect upon the Response. The Factor had two levels. Level 1 included 22 data points, and Level 2 included 10 data points.

Table 2.04: Example of One-Way ANOVA Response versus Factor with Two Levels

```
Source  DF        SS        MS        F      P
Trial    1  0.071783  0.071783  234.91  0.000
Error   30  0.009167  0.000306
Total   31  0.080950

S = 0.01748   R-Sq = 88.68%   R-Sq(adj) = 88.30%

                             Individual 90% CIs For Mean Based on
                             Pooled StDev
Level   N     Mean    StDev  ------+---------+---------+---------+---
1      22  0.12318  0.02009                                   (-*-)
2      10  0.02100  0.00876  (--*--)
                             ------+---------+---------+---------+---
                                 0.030     0.060     0.090     0.120

Pooled StDev = 0.01748
```

The most important aspects of the ANOVA are described below.

2.5.2.1 *Null Hypothesis*

The ANOVA determines whether the null hypothesis should be accepted or rejected. For all ANOVAs herein, the null hypothesis and its alternative hypothesis were as follows:

- The Null Hypothesis (Ho) states that all population means are equal.
- The Alternative Hypothesis (H_1) states that at least one population mean is different.

If the null hypothesis is rejected, it indicates that the population means were different, and it follows that the Factor had a statistically significant affect upon the Response. If the null hypothesis is accepted, then it follows that the factor did not have a significant effect upon the response.

2.5.2.2 *Probability Value*

The probability value (p-value) reports the probability that the null hypothesis can be accepted. The p-value is tested against an alpha value (α), often called the level of significance. Alpha was chosen to be 0.05 (5%) for all ANOVAs herein. If the p-value is greater than alpha ($p>0.05$) then there was greater than 5% probability that the population means were the same (or alternatively less than 95% probability that the means were different) and the null hypothesis cannot be rejected. If the p-value is less than alpha ($p<\alpha$), then the null hypothesis can be rejected, and it can be concluded that at least one mean is different than the others to a certainty of >95%.

In the example above, the p-value was 0.000, which indicates <0.1% probability that the null hypothesis is correct, or conversely >99.9% probability that the null hypothesis can confidently be rejected.

2.5.2.3 *Confidence Intervals*

A confidence level of 90% was chosen for all ANOVAs herein. The ANOVA output includes a plot of the 95% confidence intervals. For each data set (Levels 1 and 2) the asterisk (*) indicates the mean value, and 95 out of 100 data fall within the 95% confidence interval indicated between the parentheses.

In the example above, there is no overlap of the confidence intervals. The data sets corresponding to Level 1 and Level 2 are clearly different. This indicates that the Factor at Levels 1 and 2 had a significant effect upon the response.

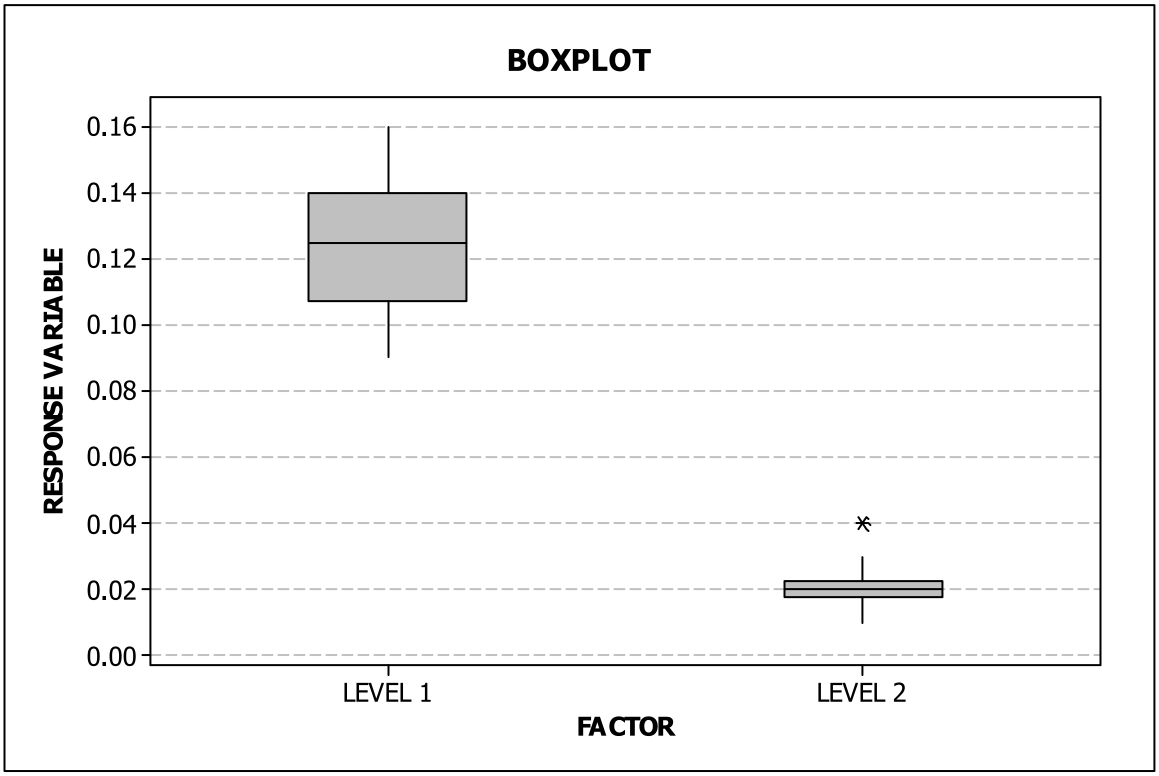
2.5.2.4 *Mean and Standard Deviation*

The ANOVA reports the mean, standard deviation, and sample count (N) for each data set. In the example above, Level 1 had a mean of 0.123 and a standard deviation of 0.020, while Level 2 had a mean of 0.021 and a standard deviation of 0.009. Level 2 had a lower mean and a smaller standard deviation than Level 1.

2.5.3 Boxplots

Boxplots are used to provide a graphical summary of the distribution of a sample. Minitab can include a boxplot as part of the output of an ANOVA. A boxplot shows the shape, central tendency, and variability of the sample. Figure 2.14 was from the same data used for the ANOVA example, above. One factor was tested at two levels. The boxplot shown here suggests that Level 2 resulted in a lower median response than Level 1, and also had a narrower range of variation than Level 1.

Figure 2.23: Boxplot Example



The important aspects of the boxplot are described below:

1. The upper whisker extends to the maximum data point within 1.5 box heights from the top of the box.
2. The interquartile range box contains the middle 50% of the data.

   a. The top line indicates the third quartile (Q3). 75% of the data are less than or equal to this value.
   b. The middle line indicates the median (Q2). 50% of the data are less than or equal to this value, and 50% of the data are greater than this value.
   c. The bottom line indicates the first quartile (Q1). 25% of the data are less than or equal to this value.
3. The lower whisker extends to the minimum data point within 1.5 box heights from the bottom of the box.
4. An asterisk (*) denotes an outlier, an observation that is beyond the upper or lower.

3 RESULTS

Section 3 – Results, presents the data and results collected during the pilot testing effort.

Data in this section are reported as follows:

1. Analytical data from continuously logged online instrumentation are typically reported as:
   Mean ± standard deviation [N = number of data]
2. Analytical data from grab samples or manually recorded data:
   a. Three or more data are reported as:
      Median (minimum – maximum) [N]
   b. Two or fewer data are reported as:
      Two data: (minimum – maximum) [N]
      One data: **Value** [1]
      Zero data: **No Data** [0]

3.1 RAW WATER QUALITY

Table 3.01 summarizes the raw water quality analyzed by field analyses during the pilot study. Laboratory results are shown in Tables 3.02 and 3.03.

Table 3.01: Raw Water Quality by Field Analyses

Parameter	Well 2	Well 2 w/ 10% Recycle*	Well 5	Well 5 w/ 10% Recycle*
Total Iron, mg/L	**0.00** (0.00 – 0.03) [21]	**0.02** (0.00 – 0.02) [3]	**0.03** (0.00 – 0.07) [18]	**0.04** (0.04 – 0.05) [3]
Dissolved Iron, mg/L	**0.00** (0.00 – 0.02) [19]	**0.00** (0.00 – 0.00) [3]	**0.01** (0.00 – 0.03) [12]	**0.00** (0.00 – 0.01) [3]
Total Manganese, mg/L	**0.057** (0.046 – 0.094) [22]	**0.133** (0.112– 0.154) [3]	**0.018** (0.003– 0.054) [18]	**0.111** (0.104– 0.138) [3]
Dissolved Manganese, mg/L	**0.054** (0.034 – 0.068) [22]	**0.045** (0.044 – 0.059) [12]	**0.016** (0.002 – 0.028) [12]	**0.017** (0.006 – 0.022) [12]
pH (Handheld), s.u.	**5.39** (5.27 – 5.50) [19]	**5.52** [1]	**5.52** (5.47 – 5.65) [11]	**5.75** [1]
Temperature, °C	**12.3** (11.8 – 12.8) [19]	**11.9** [1]	**11.5** (11.4 – 11.7) [7]	No Data [0]
Alkalinity (mg/L)	7 [1]	No Data [0]	No Data [0]	No Data [0]
Carbon Dioxide (mg/L)	89 [1]	No Data [0]	80 [1]	No Data [0]

* Note: Greensand pilot influent water quality during recycle periods is included in this table to be consistent with the following Table 3.02 presenting certified laboratory data. Two of the raw water laboratory sample events were conducted during the recycle periods.

Table 3.02: Raw Water Quality by Laboratory Analyses - General Analyses

	Analysis	Units	Laboratory Report #					
			L2108104	L2108761	L2108761	L2110175	L2110175	L2110984
			Sample Date					
			02/18/21	02/23/21	02/23/21	03/02/21	03/02/21	03/04/21
			Well 5	Well 5	Well 5 w/ recycle	Well 2	Well 2 w/ recycle	Well 2
Laboratory Analyses by Alpha Analytical	Total Iron	mg/L		ND	ND	ND	ND	
	Dissolved Iron	mg/L			ND		ND	
	Total Manganese	mg/L		0.013	0.015	0.055	0.142	
	Dissolved Manganese	mg/L			0.014		0.052	
	Total Coliform	Col/100mL			Negative		Negative	
	Escherichia Coliform	Col/100mL			Negative		Negative	
	Turbidity	NTU			0.52		0.49	
	Color, True	s.u.			ND		ND	
	Color, Apparent	s.u.			6.0		7.0	
	Alkalinity	mg/L			11.1		7.50	
	Carbon Dioxide	mg/L			96		81	
	pH	s.u.			6.5		6.7	
	Total Organic Carbon	mg/L			0.579		ND	
	Dissolved Organic Carbon	mg/L			ND		ND	
	Chloride	mg/L			55.9		135	

Table 3.03: Raw Water Quality by Laboratory Analyses - PFAS Compounds – Method 533 and 537.1

	Analysis	Units	Laboratory Report #					
			L2108104	L2108761	L2108761	L2110175	L2110175	L2110984
			Sample Date					
			02/18/21	02/23/21	02/23/21	03/02/21	03/02/21	03/04/21
			Well 5	Well 5	Well 5 w/ recycle	Well 2	Well 2 w/ recycle	Well 2
Method 533	11-Chloroeicosafluoro-3-Oxaundecane-1-Sulfonic Acid (11Cl-PF3OUdS)	ng/L	<1.89		<1.85		<1.86	<1.93
	1H,1H,2H,2H-Perfluorodecanesulfonic Acid (8:2FTS)	ng/L	<1.89		<1.85		<1.86	<1.93
	1H,1H,2H,2H-Perfluorohexanesulfonic Acid (4:2FTS)	ng/L	<1.89		<1.85		<1.86	<1.93
	1H,1H,2H,2H-Perfluorooctanesulfonic Acid (6:2FTS)	ng/L	<1.89		<1.85		<1.86	<1.93
	2,3,3,3-Tetrafluoro-2-[1,1,2,2,3,3,3-Heptafluoropropoxy]-Propanoic Acid (HFPO-DA)	ng/L	<1.89		<1.85		<1.86	<1.93
	4,8-Dioxa-3h-Perfluorononanoic Acid (ADONA)	ng/L	<1.89		<1.85		<1.86	<1.93
	9-Chlorohexadecafluoro-3-Oxanone-1-Sulfonic Acid (9Cl-PF3ONS)	ng/L	<1.89		<1.85		<1.86	<1.93
	Nonafluoro-3,6-Dioxaheptanoic Acid (NFDHA)	ng/L	<1.89		<1.85		<1.86	<1.93
	Perfluoro(2-Ethoxyethane)Sulfonic Acid (PFEESA)	ng/L	<1.89		<1.85		<1.86	<1.93
	Perfluoro-3-Methoxypropanoic Acid (PFMPA)	ng/L	<1.89		<1.85		<1.86	<1.93
	Perfluoro-4-Methoxybutanoic Acid (PFMBA)	ng/L	<1.89		<1.85		<1.86	<1.93
	Perfluorobutanesulfonic Acid (PFBS)	ng/L	1.89		2.11		7.9	8.21
	Perfluorobutanoic Acid (PFBA)	ng/L	<1.89		<1.85		2.46	2.62
	Perfluorodecanoic Acid (PFDA)	ng/L	<1.89		<1.85		<1.86	<1.93
	Perfluorododecanoic Acid (PFDoA)	ng/L	<1.89		<1.85		<1.86	<1.93
	Perfluoroheptanesulfonic Acid (PFHpS)	ng/L	<1.89		<1.85		<1.86	<1.93
	Perfluoroheptanoic Acid (PFHpA)	ng/L	<1.89		<1.85		<1.86	2.31
	Perfluorohexanesulfonic Acid (PFHxS)	ng/L	5.53		6.34		<1.86	2.43
	Perfluorohexanoic Acid (PFHxA)	ng/L	2.35		2.37		2.98	3.24-06
	Perfluorononanoic Acid (PFNA)	ng/L	<1.89		<1.85		<1.86	<1.93
	Perfluorooctanesulfonic Acid (PFOS)	ng/L	11.2		11.8		3.46	3.89
	Perfluorooctanoic Acid (PFOA)	ng/L	4.24		4.22		3.5	3.78
	Perfluoropentanesulfonic Acid (PFPeS)	ng/L	<1.89		<1.85		<1.86	<1.93
	Perfluoropentanoic Acid (PFPeA)	ng/L	2.76		2.56		4.4	4.4-06
	Perfluoroundecanoic Acid (PFUnA)	ng/L	<1.89		<1.85		<1.86	<1.93
Addition Analytes in Method 537.1	N-Ethyl Perfluorooctanesulfonamidoacetic Acid (NEtFOSAA)	ng/L	<1.89		<1.87		<1.86	<1.93
	N-Methyl Perfluorooctanesulfonamidoacetic Acid (NMeFOSAA)	ng/L	<1.89		<1.87		<1.86	<1.93
	Perfluorotetradecanoic Acid (PFTA)	ng/L	<1.89		<1.87		<1.86	<1.93
	Perfluorotridecanoic Acid (PFTrDA)	ng/L	<1.89		<1.87		<1.86	<1.93
	Total PFAS6	ng/L	**20.97**		**22.36**		**6.96**	**12.41**

3.2 PRETREATMENT CONDITIONS

3.2.1 NaOCl Doses

Sodium hypochlorite doses were calculated as described in Section 2.2.1. The doses utilized during the pilot are summarized in Table 3.04. The chlorine dose is provided in mg/L and ppm due to the inconsistency in the percentage of active chlorine in commercial bleach (stock sodium hypochlorite used during the pilot study). Bleach is utilized as a source of sodium hypochlorite due to its accessibility.

Table 3.04: Pretreatment Sodium Hypochlorite Doses- Greensand Filtration

Source	NaOCl Dose*1 (mg/L)	Bleach Dose as Product (ppm)
Trial 2 - Well 5	0.9	12.2
Trial 3 - Well 5	0.9	11.8
Trial 4 - Well 2	0.5	6.5
Trial 5 - Well 2	0.7	9.9

*1 - The labelled stock concentration of the bleach used during the pilot was 7.5%.

3.2.2 Bench Scale pH Titrations

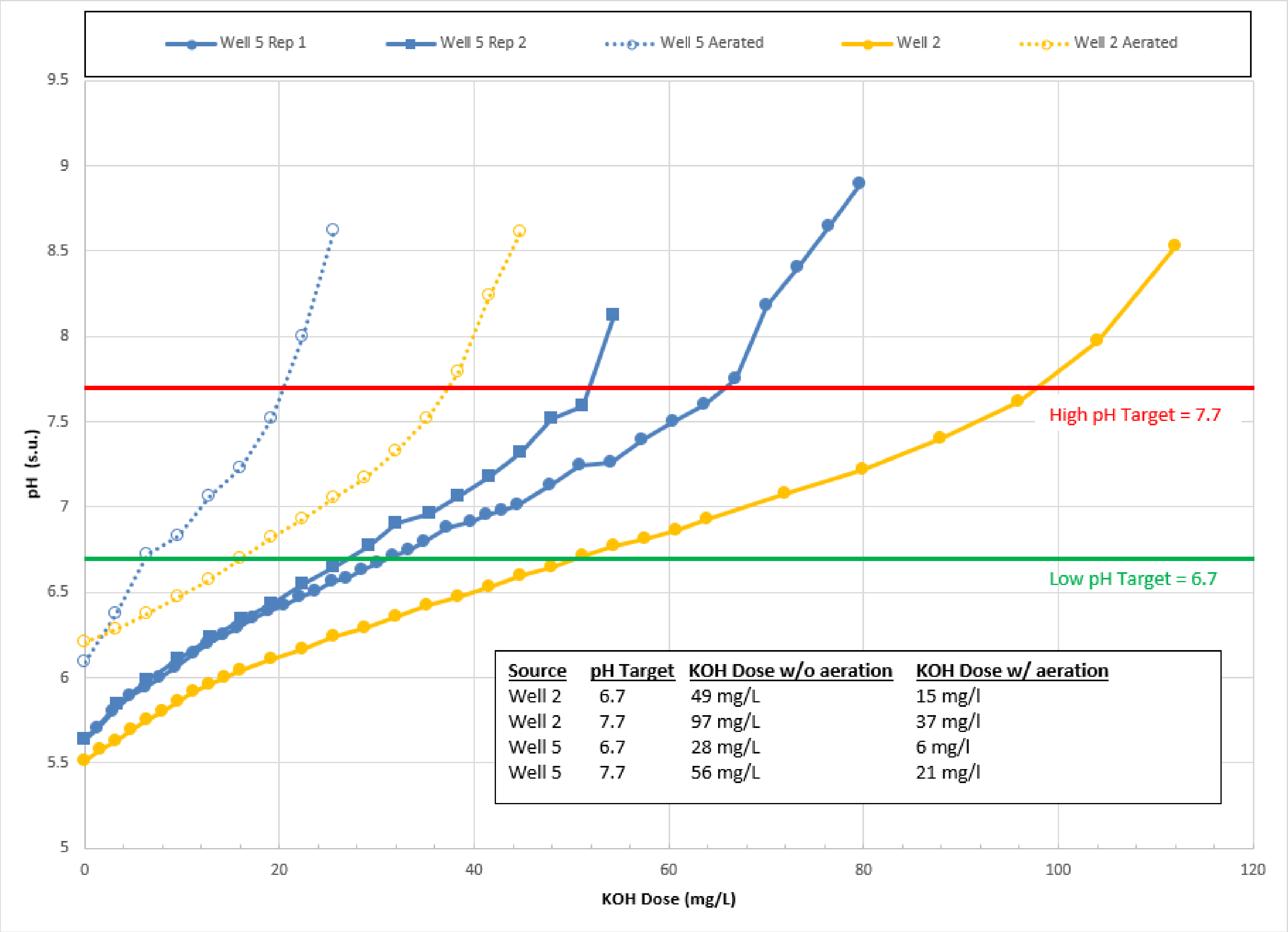
The dose of KOH required for pH control was evaluated by bench titration. A 0.02N NaOH standard was titrated into 500 mL of raw water sample from each source while the pH was continuously monitored. A second experiment was conducted at each source to evaluate whether the KOH dose for pH adjustment could be reduced by aeration to strip dissolved carbon dioxide (CO2) from the raw water prior to KOH injection; a 500 mL sample of raw water was first aerated for 5 minutes and then titrated with the 0.02N NaOH standard. Figure 3.01 shows the results (adjusted pH vs. NaOH dose in mg/L) of the NaOH titrations.

- Solid data points (circles) and solid lines indicate titration data for un-aerated raw water samples.
- Open data points and dashed lines indicate titration data for samples after 5 minutes of aeration.
- The red line indicates the High-pH target (7.7 s.u.) and the green line indicates the Low-pH target (6.7 s.u.).

The doses required for the target pH levels are summarized in the table within the figure.

Stock titrant is available only as NaOH, and was used to complete the bench studies. Since the (OH^-) hydroxide ion is common between KOH and NaOH and responsible for the pH increase, the KOH dose and NaOH dose are expected to be similar.

Figure 3.01: Raw Water KOH Titration from Wells 2 and 5 with and without Aeration (5 min)



Source	pH Target	KOH Dose w/o aeration	KOH Dose w/ aeration
Well 2	6.7	49 mg/L	15 mg/l
Well 2	7.7	97 mg/L	37 mg/l
Well 5	6.7	28 mg/L	6 mg/l
Well 5	7.7	56 mg/L	21 mg/l

3.2.3 Pretreated Water Quality

Pretreatment included pH adjustment with KOH to increase raw pH to targets of 6.7 and 7.7 and sodium hypochlorite to oxidize dissolved iron and manganese such that they could be removed as precipitated particles or adsorbed onto the adsorptive media. The pretreated water quality by field analyses is summarized by trial in Tables 3.05 and 3.06.

Table 3.05: Pretreated Water Quality Data for Low pH (6.7) Conditions (POX AB) from Field Analyses

Source	Free Chlorine (mg/L)	Total Chlorine (mg/L)	Dissolved Iron (mg/L)	Dissolved Manganese (mg/L)	Benchtop pH (s.u.)
Well 2	**0.62** (0.31-0.89) [17]	**0.65** (0.35-0.94) [17]	**0.00** (0.00-0.03) [15]	**0.047** (0.036-0.064) [17]	**6.84** (6.69-7.03) [17]
Well 5	**0.54** (0.34-0.84) [12]	**0.64** (0.50-0.92) [11]	**0.01** (0.00-0.02) [13]	**0.016** (0.000-0.024) [13]	**6.87** (6.18-6.95) [14]

Table 3.06: Pretreated Water Quality Data for High pH (7.7) Conditions (POX CD) from Field Analyses

Source	Free Chlorine (mg/L)	Total Chlorine (mg/L)	Dissolved Iron (mg/L)	Dissolved Manganese (mg/L)	Benchtop pH (s.u.)
Well 2	**0.62** (0.31-0.79) [17]	**0.69** (0.35-0.88) [17]	**0.00** (0.00-0.02) [15]	**0.044** (0.029-0.060) [17]	**7.74** (7.07-8.09) [17]
Well 5	**0.56** (0.35-0.81) [12]	**0.62** (0.46-0.92) [11]	**0.01** (0.00-0.03) [13]	**0.009** (0.000-0.031) [13]	**7.64** (6.72-8.06) [15]

3.3 FILTER PERFORMANCE

3.3.1 Filter Performance Summary Tables

Tables 3.07 through 3.10 summarize the operating conditions, and performance of each filter trial. The following information is included for each filter trial:

A. "Trial" is the Trial number indicating the Filter number and sequential trial. For example, Trial A.3 indicates that it is the third trial using Filter A. Filters were backwashed and restarted between trials.
B. Fig No. is the associated Filter Performance Figure for the Filter Trial.
C. "Source" identified the water source being treated.
D. "Start Time" and "End Time" represent the start and end date and time of the filter trial.
E. "Duration" is the total length of the filter trial in hours.
F. "FSLR" is the actual filter loading rate processed through the filters, in gallons per minute per square foot (gpm/sf). The FSLR was calculated using recorded online flowrate (gpm) and dividing by the surface area of the pilot filter (0.2 ft^2). Data is presented as "average ± standard deviation [count]."
G. "Clean Bed Headloss" is the stabilized differential pressure (in psi) at the start of a filter trial after backwash.
H. "Slope" is the rate of differential pressure accumulation throughout the filter trial in units psi/hr. The rate is calculated based on the time elapsed between the clean bed headloss and the time terminal headloss was either observed or projected. The absence of a calculated slope indicates the trial was not long enough to sufficiently project the time terminal headloss would occur.
I. "Runtime to 10 psi" is the runtime (in hours) terminal headloss was either observed or projected. Observed runtimes to terminal headloss are in **bold**.
J. "Runtime to Breakthrough (hrs)" – The runtime (in hours) until the turbidity shows an increase or an "inflection point". Breakthrough of iron and manganese often occurs after the effluent turbidity reaches 0.1 NTU, so the breakthrough estimates are conservative, measuring at the inflection point.
K. "UFRV at Termination Criterion" – The unit filter run volume (UFRV) is the volume of water treated per unit filter surface area at termination (gal/sf). UFRV was calculated based on the observed runtime until 10 psi or contaminant breakthrough, whichever came first. If contaminant breakthrough was not observed and the trial ended prior to the projected runtime to 10 psi, the trial duration was used and was indicated by a ">" greater than symbol.
L. "All Turbidity Data" includes all the logged turbidity data, including non-representative data from post-breakthrough operation, turbidity spikes, etc. Turbidity data are presented as Mean ± standard deviation [sample count] in units of NTU.

- "Representative Turbidity Data" includes only representative turbidity data, excluding non-representative data from post-breakthrough operations, short-term turbidity spikes caused by operational upsets, the presumed filter-to-waste period following backwashing, etc. Turbidity data are presented as Mean ± standard deviation [sample count] in units of NTU.

Table 3.07: Filter Performance Table for Filter A (Low pH)

Trial*	Fig. No.	Source	Start Time	End Time	Duration (hrs)	FSLR (gpm/sf)	Headloss vs. Runtime			Runtime to Breakthrough (hrs)	UFRV (gal/sf)	All Turbidity Data (NTU)	Representative Turbidity Data (NTU)
							Clean Bed Headloss (psi)	Slope (psi/hr)	Runtime to 10 psi (hrs)				
A.1	C-1	Well 5	02/15/21 12:45	02/16/21 14:00	25.3	10.35 ± 0.38 [299]	3.40	0.041	160.0	>25.3	489,933	0.090 ± 0.411 [304]	0.033 ± 0.025 [284]
A.2	C-5	Well 5	02/16/21 14:50	02/22/21 11:35	140.8	5.51 ± 0.08 [1687]	0.20	0.008	1218.9	>140.8	2,052,149	0.026 ± 0.072 [1690]	0.026 ± 0.072 [1690]
A.3	C-9	Well 5	02/22/21 11:50	02/24/21 10:00	46.2	5.51 ± 0.04 [554]	1.15	0.005	1654.4	>46.2	2,785,481	0.028 ± 0.011 [555]	0.028 ± 0.007 [553]
A.3BR	C-9	Well 5	02/22/21 11:50	02/23/21 11:15	23.4	5.51 ± 0.05 [282]	1.15	0.006	1439.5	>23.4	N/A	0.028 ± 0.013 [282]	0.027 ± 0.003 [281]
A.3DR	C-9	Well 5	02/23/21 11:20	02/23/21 13:05	1.8	5.52 ± 0.03 [22]	N/A	0.062	166.2	>1.8	N/A	0.059 ± 0.013 [22]	0.059 ± 0.011 [22]
A.3AR	C-9	Well 5	02/23/21 13:10	02/24/21 10:00	20.8	5.51 ± 0.01 [250]	N/A	0.003	3004.8	>20.8	N/A	0.027 ± 0.002 [251]	0.027 ± 0.002 [250]
A.4	C-13	Well 2	02/24/21 11:40	03/01/21 08:40	117.0	5.51 ± 0.01 [1405]	1.45	0.008	1075.5	>117.0	1,810,740	0.026 ± 0.010 [1406]	0.026 ± 0.002 [1405]
A.5	C-17	Well 2	03/01/21 08:55	03/05/21 08:20	95.4	5.04 ± 0.28 [1146]	2.00	0.001	10725.3	>95.4	16,416,330	0.026 ± 0.008 [1146]	0.026 ± 0.002 [1146]
A.5BR	C-17	Well 2	03/01/21 08:55	03/02/21 09:05	24.2	5.11 ± 0.20 [291]	2.00	-0.012	-645.3	>24.2	N/A	0.026 ± 0.003 [291]	0.026 ± 0.003 [291]
A.5DR	C-17	Well 2	03/02/21 09:05	03/02/21 10:45	1.7	5.02 ± 0.06 [21]	N/A	0.019	449.7	>1.7	N/A	0.026 ± 0.001 [21]	0.026 ± 0.001 [21]
A.5AR	C-17	Well 2	03/02/21 10:45	03/05/21 08:20	69.6	5.01 ± 0.30 [836]	N/A	0.001	6896.7	>69.6	N/A	0.026 ± 0.009 [836]	0.026 ± 0.001 [836]

* Trial Abbreviations: BR = Before Recycle, DR = During Recycle, AR = After Recyle

Table 3.08: Filter Performance Table for Filter B (Low pH)

Trial*	Fig. No.	Source	Start Time	End Time	Duration (hrs)	FSLR (gpm/sf)	Headloss vs. Runtime			Runtime to Breakthrough (hrs)	UFRV (gal/sf)	All Turbidity Data (NTU)	Representative Turbidity Data (NTU)
							Clean Bed Headloss (psi)	Slope (psi/hr)	Runtime to 10 psi (hrs)				
B.1	C-2	Well 5	02/15/21 12:45	02/16/21 12:55	24.2	4.69 ± 0.24 [290]	0.00	0.001	7890.1	>24.2	11,110,528	0.030 ± 0.243 [291]	0.014 ± 0.016 [284]
B.2	C-6	Well 5	02/16/21 13:05	02/22/21 13:15	144.2	9.41 ± 0.25 [1730]	2.20	0.000	131705.2	>144.2	378,988,332	0.015 ± 0.038 [1731]	0.014 ± 0.005 [1725]
B.3	C-10	Well 5	02/22/21 13:30	02/24/21 10:00	44.5	9.44 ± 0.04 [533]	2.30	0.001	7128.2	>44.5	20,511,893	0.019 ± 0.028 [535]	0.018 ± 0.015 [533]
B.3BR	C-10	Well 5	02/22/21 13:30	02/23/21 11:15	21.8	9.44 ± 0.04 [261]	2.30	0.001	10002.1	>21.8	N/A	0.017 ± 0.036 [262]	0.015 ± 0.006 [261]
B.3DR	C-10	Well 5	02/23/21 11:20	02/23/21 13:05	1.8	9.44 ± 0.04 [22]	N/A	0.064	142.4	>1.8	N/A	0.083 ± 0.029 [22]	0.083 ± 0.025 [22]
B.3AR	C-10	Well 5	02/23/21 13:10	02/24/21 10:00	20.8	9.44 ± 0.03 [250]	N/A	-0.003	-2430.7	>20.8	N/A	0.015 ± 0.002 [251]	0.015 ± 0.002 [250]
B.4	C-14	Well 2	02/24/21 11:40	03/01/21 08:50	117.2	9.44 ± 0.02 [1407]	2.15	0.005	1487.0	>117.2	4,279,004	0.017 ± 0.010 [1408]	0.016 ± 0.001 [1407]
B.5	C-18	Well 2	03/01/21 09:05	03/05/21 08:20	95.3	9.98 ± 0.12 [1144]	2.30	0.006	1376.6	>95.3	4,171,887	0.017 ± 0.003 [1144]	0.017 ± 0.001 [1143]
B.5BR	C-18	Well 2	03/01/21 09:05	03/02/21 09:05	24.0	9.91 ± 0.21 [289]	2.30	-0.001	-8124.1	>24.0	N/A	0.017 ± 0.005 [289]	0.017 ± 0.002 [288]
B.5DR	C-18	Well 2	03/02/21 09:05	03/02/21 10:45	1.7	10.01 ± 0.02 [21]	N/A	0.041	207.6	>1.7	N/A	0.017 ± 0.001 [21]	0.017 ± 0.001 [21]
B.5AR	C-18	Well 2	03/02/21 10:45	03/05/21 08:20	69.6	10.00 ± 0.04 [836]	N/A	0.006	1279.3	>69.6	N/A	0.017 ± 0.001 [836]	0.017 ± 0.001 [836]

* Trial Abbreviations: BR = Before Recycle, DR = During Recycle, AR = After Recyle

Table 3.09: Filter Performance Table for Filter C (High pH)

Trial*	Fig. No.	Source	Start Time	End Time	Duration (hrs)	FSLR (gpm/sf)	Headloss vs. Runtime			Runtime to Breakthrough (hrs)	UFRV (gal/sf)	All Turbidity Data (NTU)	Representative Turbidity Data (NTU)
							Clean Bed Headloss (psi)	Slope (psi/hr)	Runtime to 10 psi (hrs)				
C.1	C-3	Well 5	02/15/21 12:45	02/16/21 13:15	24.5	11.08 ± 0.56 [290]	0.00	No Data	>24.5	>24.5	82,500	0.044 ± 0.222 [295]	0.020 ± 0.018 [282]
C.2	C-7	Well 5	02/16/21 13:55	02/22/21 13:35	143.7	5.56 ± 0.11 [1724]	2.50	0.007	1041.7	>143.7	1,753,967	0.016 ± 0.014 [1725]	0.016 ± 0.001 [1724]
C.3	C-11	Well 5	02/22/21 13:50	02/24/21 10:00	44.2	5.57 ± 0.02 [530]	3.15	0.002	3792.9	>44.2	6,385,932	0.020 ± 0.026 [531]	0.019 ± 0.009 [528]
C.3BR	C-11	Well 5	02/22/21 13:50	02/23/21 11:15	21.4	5.57 ± 0.03 [258]	3.15	0.027	257.0	>21.4	N/A	0.019 ± 0.035 [258]	0.017 ± 0.003 [256]
C.3DR	C-11	Well 5	02/23/21 11:20	02/23/21 13:05	1.8	5.58 ± 0.03 [22]	N/A	No Data	>1.8	>1.8	N/A	0.059 ± 0.017 [22]	0.059 ± 0.014 [22]
C.3AR	C-11	Well 5	02/23/21 13:10	02/24/21 10:00	20.8	5.57 ± 0.01 [250]	N/A	No Data	>20.8	>20.8	N/A	0.017 ± 0.002 [251]	0.017 ± 0.002 [250]
C.4	C-15	Well 2	02/24/21 11:40	03/01/21 09:00	117.3	5.57 ± 0.02 [1409]	3.30	0.003	1922.7	>117.3	3,237,278	0.018 ± 0.013 [1410]	0.017 ± 0.001 [1409]
C.5	C-19	Well 2	03/01/21 09:15	03/05/21 08:20	95.1	5.04 ± 0.12 [1142]	4.00	-0.010	-597.2	>95.1	145,536	0.017 ± 0.005 [1142]	0.017 ± 0.001 [1141]
C.5BR	C-19	Well 2	03/01/21 09:15	03/02/21 09:05	23.8	5.11 ± 0.22 [287]	4.00	-0.037	-159.9	>23.8	N/A	0.018 ± 0.009 [287]	0.017 ± 0.001 [286]
C.5DR	C-19	Well 2	03/02/21 09:05	03/02/21 10:45	1.7	5.02 ± 0.03 [21]	N/A	No Data	>1.7	>1.7	N/A	0.018 ± 0.001 [21]	0.018 ± 0.001 [21]
C.5AR	C-19	Well 2	03/02/21 10:45	03/05/21 08:20	69.6	5.02 ± 0.04 [836]	N/A	0.002	3290.9	>69.6	N/A	0.017 ± 0.001 [836]	0.017 ± 0.001 [836]

* Trial Abbreviations: BR = Before Recycle, DR = During Recycle, AR = After Recyle

Table 3.10: Filter Performance Table for Filter D (High pH)

Trial*	Fig. No.	Source	Start Time	End Time	Duration (hrs)	FSLR (gpm/sf)	Headloss vs. Runtime			Runtime to Breakthrough (hrs)	UFRV (gal/sf)	All Turbidity Data (NTU)	Representative Turbidity Data (NTU)
							Clean Bed Headloss (psi)	Slope (psi/hr)	Runtime to 10 psi (hrs)				
D.1	C-4	Well 5	02/15/21 12:45	02/16/21 13:00	24.2	4.63 ± 0.99 [291]	2.75	0.001	5870.7	>24.2	8,266,887	0.064 ± 0.320 [292]	0.033 ± 0.006 [277]
D.2	C-8	Well 5	02/16/21 13:20	02/22/21 13:55	144.6	11.13 ± 0.29 [1735]	2.65	0.001	5892.2	>144.6	19,841,081	0.029 ± 0.020 [1736]	0.029 ± 0.002 [1735]
D.3	C-12	Well 5	02/22/21 14:10	02/24/21 10:00	43.8	11.17 ± 0.02 [526]	2.70	0.003	2549.9	>43.8	8,586,418	0.035 ± 0.026 [527]	0.035 ± 0.019 [525]
D.3BR	C-12	Well 5-BR	02/22/21 14:10	02/23/21 11:15	21.1	11.17 ± 0.02 [254]	2.70	0.004	1634.4	>21.1	N/A	0.032 ± 0.028 [254]	0.031 ± 0.006 [253]
D.3DR	C-12	Well 5-DR	02/23/21 11:20	02/23/21 13:05	1.8	11.18 ± 0.04 [22]	N/A	-0.027	>1.8	>1.8	N/A	0.123 ± 0.038 [22]	0.123 ± 0.033 [22]
D.3AR	C-12	Well 5-AR	02/23/21 13:10	02/24/21 10:00	20.8	11.17 ± 0.02 [250]	N/A	0.008	952.3	>20.8	N/A	0.031 ± 0.005 [251]	0.031 ± 0.003 [250]
D.4	C-16	Well 2	02/24/21 11:40	03/01/21 09:10	117.5	11.17 ± 0.04 [1410]	2.70	0.010	719.8	>117.5	2,423,785	0.032 ± 0.025 [1412]	0.031 ± 0.002 [1410]
D.5	C-20	Well 2	03/01/21 09:30	03/05/21 08:20	94.8	10.06 ± 0.24 [1139]	2.50	0.008	939.4	>94.8	2,875,840	0.031 ± 0.004 [1139]	0.031 ± 0.001 [1138]
D.5BR	C-20	Well 2-BR	03/01/21 09:30	03/02/21 09:05	23.6	10.21 ± 0.43 [284]	2.50	-0.007	>23.6	>23.6	N/A	0.032 ± 0.008 [284]	0.032 ± 0.002 [283]
D.5DR	C-20	Well 2-DR	03/02/21 09:05	03/02/21 10:45	1.7	10.02 ± 0.05 [21]	N/A	0.078	117.3	>1.7	N/A	0.032 ± 0.001 [21]	0.032 ± 0.001 [21]
D.5AR	C-20	Well 2-AR	03/02/21 10:45	03/05/21 08:20	69.6	10.01 ± 0.07 [836]	N/A	0.010	743.9	>69.6	N/A	0.031 ± 0.001 [836]	0.031 ± 0.001 [836]

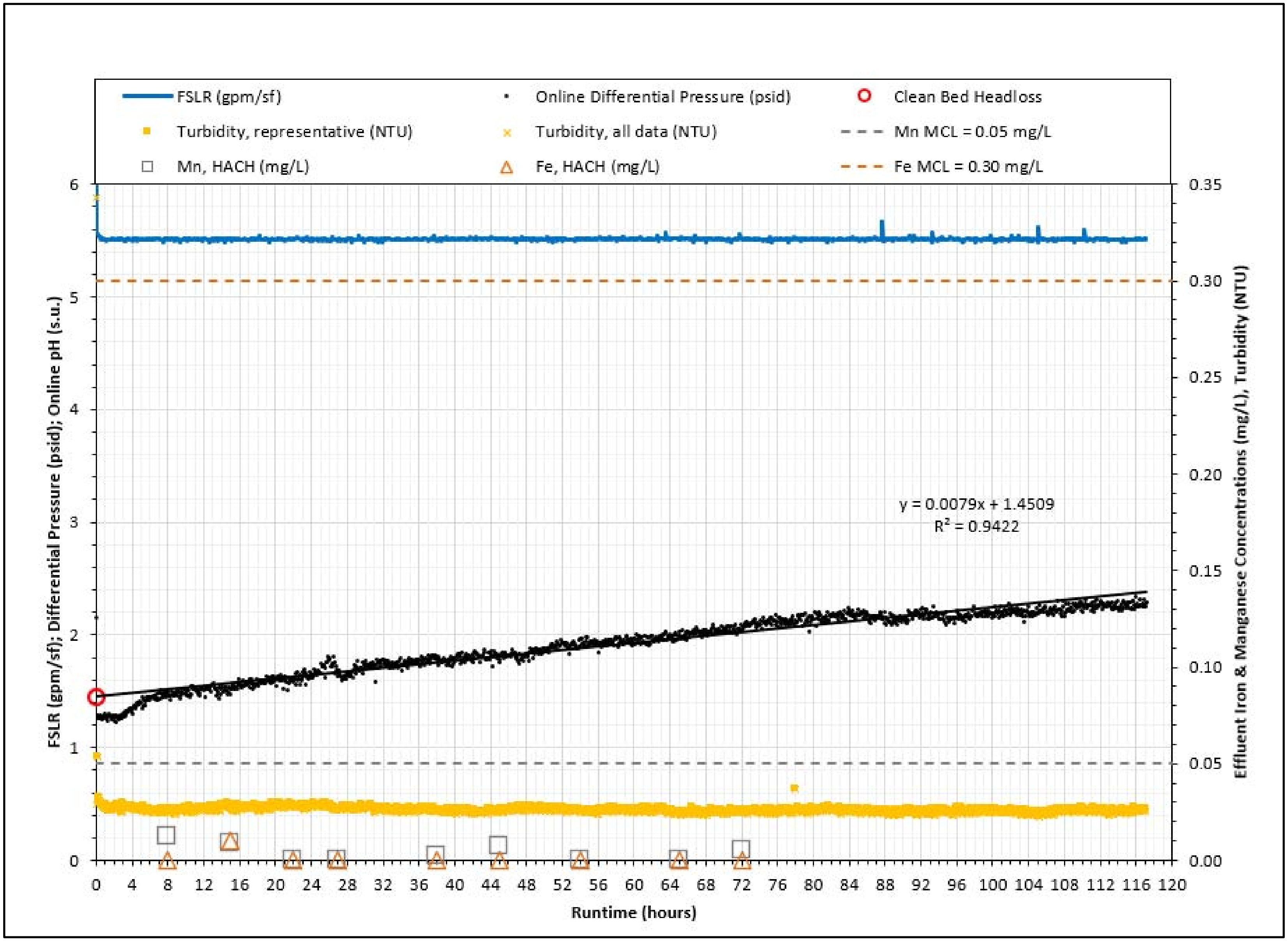
* Trial Abbreviations: BR = Before Recycle, DR = During Recycle, AR = After Recyle

3.3.2 Pilot Filter Hydraulic Performance

For each filter run, online data was logged every 5 minutes by the PLC, and grab samples were collected and analyzed periodically throughout the day. A figure was prepared for each filter trial, showing important operating conditions and effluent iron and manganese concentrations for the filter run. An example Filter Performance Figure is shown in Figure 3.03, and all figures are included in Appendix C. Information included in each figure is described below:

1. X-axis is presented in units of hours of filter run time, with 0 hours set at the time the filter was placed online.
2. Field data for effluent iron concentrations are presented as orange triangles in units of mg/L and represent results of field analyses of grab samples. The data are plotted using the right y-axis.
3. Field data for effluent manganese concentrations are presented as gray triangles in units of mg/L and represent results of field analyses of grab samples.
4. Filter effluent iron goal is presented as a orange dashed line plotted in units of mg/L using the right y-axis. The effluent iron goal was set to 0.30 mg/L to match the Mn SMCL (<0.30 mg/L Mn).
5. Filter effluent manganese goal is presented as a gray dashed line plotted in units of mg/L using the right y-axis. The effluent manganese goal was set to 0.050 mg/L to match the Mn SMCL (<0.05 mg/L Mn).
6. All recorded filter effluent turbidity data are presented as orange "x". These are all the turbidity data logged by the PLC during the filter trial in units of NTUs. The data are plotted using the right y-axis.
7. Representative filter effluent turbidity data are presented as orange squares. These are the turbidity recorded after the filter-to-waste period, and prior to breakthrough in units of NTUs. The data are plotted using the right y-axis.
8. The filter surface loading rate (FSLR) is shown as a blue line. Loading rate was calculated from the effluent flow rate and the surface area of the filters (0.2 ft^2). The FSLR is included in the figures to show when flow rates were stable, when flow rate adjustments were made, and when the filter experienced declining rate conditions. The FLSR is presented in gpm/sf and is plotted using the left y-axis.
9. Differential pressure (DP) is shown as solid black circles in units of psid and is plotted using the left y-axis. DP was calculated from the differential pressure transducer connected to the inlet and outlet of the filter.
10. The Clean Bed Headloss is shown as a hollow red circle on the left-most y-axis.

Figure 3.02: Filter A, Trial 4 Filter Performance Plot



3.3.3 Filter Effluent Water Quality

Water quality results from field analyses for each Filter are shown in Tables 3.11 to 3.14.

Laboratory data is reported in Tables 3.15 to 3.17.

Simulated Distribution System (SDS) field and laboratory data are reported in Table 3.18.

Table 3.11: Filtered Water Quality – Low pH Filter A, Field Analyses

Trial	Source	Nominal FSLR (gpm/sf)	Cl2 (f) (mg/L)	Cl2 (t) (mg/L)	Fe(t) (mg/L)	Mn(t) (mg/L)	pH (s.u.)
A.1	Well 5	**8**	0.61-0.68 [2]	0.73-0.97 [2]	0.00-0.01 [2]	0.000-0.003 [2]	6.65 [1]
A.2		**5**	**0.44** (0.42-0.58) [6]	**0.47** (0.43-0.56) [5]	**0.01** (0.00-0.02) [9]	**0.006** (0.000-0.009) [9]	**6.77** (6.23-6.88) [12]
A.3		**5**	**0.49** (0.32-0.66) [5]	**0.62** (0.36-0.72) [5]	**0.01** (0.00-0.01) [9]	**0.005** (0.000-0.028) [9]	**6.93** (6.90-6.98) [10]
A.3BR		**5**	0.32-0.42 [2]	0.36-0.45 [2]	**0.01** (0.01-0.01) [3]	**0.006** (0.005-0.008) [3]	**6.94** (6.91-6.95) [4]
A.3DR		**5**	0.49 [1]	0.62 [1]	**0.01** (0.00-0.01) [3]	**0.011** (0.000-0.028) [3]	6.90-6.92 [2]
A.3AR		**5**	0.64-0.66 [2]	0.71-0.72 [2]	**0.00** (0.00-0.01) [3]	**0.002** (0.000-0.002) [3]	**6.94** (6.91-6.98) [4]
A.4	Well 2	**5**	**0.58** (0.47-0.72) [12]	**0.63** (0.44-0.79) [9]	**0.00** (0.00-0.01) [9]	**0.002** (0.000-0.012) [9]	**6.82** (6.63-7.06) [18]
A.5		**5**	**0.52** (0.26-0.71) [14]	**0.58** (0.29-0.84) [11]	**0.00** (0.00-0.00) [13]	**0.000** (0.000-0.007) [15]	**6.77** (6.60-6.99) [22]
A.5BR		**5**	**0.64** (0.26-0.71) [5]	**0.79** (0.43-0.84) [5]	**0.00** (0.00-0.00) [4]	**0.002** (0.000-0.005) [4]	**6.77** (6.60-6.95) [6]
A.5DR		**5**	0.57 [1]	No Data [0]	0.00-0.00 [2]	0.000-0.002 [2]	6.60-6.77 [2]
A.5AR		**5**	**0.49** (0.29-0.55) [8]	**0.56** (0.29-0.59) [6]	**0.00** (0.00-0.00) [7]	**0.000** (0.000-0.007) [9]	**6.81** (6.60-6.99) [14]

Table 3.12: Filtered Water Quality – Low pH Filter B, Field Analyses

Trial	**Source**	**Nominal FSLR (gpm/sf)**	**Cl2 (f) (mg/L)**	**Cl2 (t) (mg/L)**	**Fe(t) (mg/L)**	**Mn(t) (mg/L)**	**pH (s.u.)**
B.1	Well 5	**4**	0.48-0.66 [2]	0.56-0.96 [2]	0.00-0.01 [2]	0.001-0.006 [2]	6.81 [1]
B.2		**10**	**0.49** (0.46-0.66) [6]	**0.55** (0.49-0.63) [5]	**0.00** (0.00-0.01) [9]	**0.000** (0.000-0.004) [9]	**6.78** (6.22-6.90) [12]
B.3		**10**	**0.49** (0.33-0.75) [5]	**0.67** (0.47-0.79) [5]	**0.01** (0.00-0.02) [9]	**0.000** (0.000-0.011) [9]	**6.93** (6.89-6.98) [10]
B.3BR		**10**	0.33-0.41 [2]	0.47-0.50 [2]	**0.00** (0.00-0.01) [3]	**0.000** (0.000-0.000) [3]	**6.93** (6.91-6.96) [4]
B.3DR		**10**	0.49 [1]	0.67 [1]	**0.01** (0.01-0.02) [3]	**0.010** (0.000-0.011) [3]	6.89-6.91 [2]
B.3AR		**10**	0.71-0.75 [2]	0.78-0.79 [2]	**0.01** (0.00-0.02) [3]	**0.000** (0.000-0.009) [3]	**6.93** (6.91-6.98) [4]
B.4	Well 2	**10**	**0.63** (0.52-0.78) [12]	**0.61** (0.43-0.84) [9]	**0.00** (0.00-0.01) [9]	**0.001** (0.000-0.006) [9]	**6.86** (6.65-7.05) [18]
B.5		**10**	**0.57** (0.29-0.75) [14]	**0.63** (0.26-0.90) [11]	**0.00** (0.00-0.00) [13]	**0.000** (0.000-0.007) [15]	**6.80** (6.68-7.04) [22]
B.5BR		**10**	**0.72** (0.38-0.75) [5]	**0.72** (0.48-0.90) [5]	**0.00** (0.00-0.00) [4]	**0.003** (0.000-0.007) [4]	**6.80** (6.74-6.96) [6]
B.5DR		**10**	0.59 [1]	No Data [0]	0.00-0.00 [2]	0.000-0.001 [2]	6.70-6.77 [2]
B.5AR		**10**	**0.51** (0.29-0.60) [8]	**0.59** (0.26-0.64) [6]	**0.00** (0.00-0.00) [7]	**0.000** (0.000-0.007) [9]	**6.82** (6.68-7.04) [14]

Table 3.13: Filtered Water Quality – High pH Filter C, Field Analyses

Trial	Source	Nominal FSLR (gpm/sf)	Cl2 (f) (mg/L)	Cl2 (t) (mg/L)	Fe(t) (mg/L)	Mn(t) (mg/L)	pH (s.u.)
C.1	Well 5	**8**	0.35-0.81 [2]	0.80-1.14 [2]	0.00-0.01 [2]	0.000-0.004 [2]	7.68 [1]
C.2		**5**	**0.48** (0.35-0.58) [6]	**0.54** (0.47-0.60) [5]	**0.00** (0.00-0.02) [9]	**0.000** (0.000-0.004) [9]	**7.62** (6.91-7.91) [12]
C.3		**5**	**0.55** (0.29-0.72) [5]	**0.67** (0.25-0.78) [5]	**0.00** (0.00-0.02) [9]	**0.000** (0.000-0.009) [9]	**7.47** (7.28-7.66) [10]
C.3BR		**5**	0.29-0.42 [2]	0.25-0.43 [2]	**0.01** (0.00-0.02) [3]	**0.000** (0.000-0.000) [3]	**7.50** (7.47-7.66) [4]
C.3DR		**5**	0.55 [1]	0.67 [1]	**0.00** (0.00-0.01) [3]	**0.000** (0.000-0.009) [3]	7.33-7.43 [2]
C.3AR		**5**	0.72-0.72 [2]	0.72-0.78 [2]	**0.00** (0.00-0.01) [3]	**0.000** (0.000-0.001) [3]	**7.45** (7.28-7.66) [4]
C.4	Well 2	**5**	**0.61** (0.52-0.73) [12]	**0.66** (0.49-0.80) [9]	**0.00** (0.00-0.01) [9]	**0.000** (0.000-0.007) [9]	**7.56** (7.29-8.00) [18]
C.5		**5**	**0.52** (0.23-0.73) [14]	**0.59** (0.27-0.80) [11]	**0.00** (0.00-0.00) [13]	**0.000** (0.000-0.006) [15]	**7.51** (7.12-7.94) [22]
C.5BR		**5**	**0.69** (0.39-0.73) [5]	**0.74** (0.46-0.80) [5]	**0.00** (0.00-0.00) [4]	**0.000** (0.000-0.006) [4]	**7.48** (7.26-7.94) [6]
C.5DR		**5**	0.51 [1]	No Data [0]	0.00-0.00 [2]	0.000-0.000 [2]	7.34-7.41 [2]
C.5AR		**5**	**0.51** (0.23-0.62) [8]	**0.58** (0.27-0.73) [6]	**0.00** (0.00-0.00) [7]	**0.000** (0.000-0.006) [9]	**7.54** (7.12-7.87) [14]

Table 3.14: Filtered Water Quality – High pH Filter D, Field Analyses

Trial	Source	Nominal FSLR (gpm/sf)	Cl2 (f) (mg/L)	Cl2 (t) (mg/L)	Fe(t) (mg/L)	Mn(t) (mg/L)	pH (s.u.)
D.1	Well 5	**4**	0.36-0.41 [2]	0.63-0.81 [2]	0.00-0.02 [2]	0.000-0.001 [2]	7.70 [1]
D.2		**10**	**0.55** (0.36-0.67) [6]	**0.62** (0.51-0.65) [5]	**0.00** (0.00-0.02) [9]	**0.001** (0.000-0.008) [9]	**7.61** (7.04-7.83) [12]
D.3		**10**	**0.64** (0.37-0.77) [5]	**0.70** (0.50-0.78) [5]	**0.00** (0.00-0.02) [9]	**0.005** (0.000-0.020) [9]	**7.48** (7.28-7.70) [10]
D.3BR		**10**	0.37-0.51 [2]	0.50-0.52 [2]	**0.00** (0.00-0.00) [3]	**0.004** (0.001-0.010) [3]	**7.59** (7.49-7.70) [4]
D.3DR		**10**	0.64 [1]	0.70 [1]	**0.00** (0.00-0.01) [3]	**0.017** (0.000-0.020) [3]	7.28-7.34 [2]
D.3AR		**10**	0.76-0.77 [2]	0.76-0.78 [2]	**0.01** (0.00-0.02) [3]	**0.005** (0.000-0.005) [3]	**7.44** (7.29-7.54) [4]
D.4	Well 2	**10**	**0.68** (0.57-0.79) [12]	**0.69** (0.49-0.85) [9]	**0.00** (0.00-0.01) [9]	**0.000** (0.000-0.005) [9]	**7.55** (7.18-7.98) [18]
D.5		**10**	**0.59** (0.24-0.88) [14]	**0.63** (0.29-0.89) [11]	**0.00** (0.00-0.00) [13]	**0.000** (0.000-0.008) [15]	**7.45** (7.12-7.73) [22]
D.5BR		**10**	**0.75** (0.40-0.88) [5]	**0.78** (0.48-0.89) [5]	**0.00** (0.00-0.00) [4]	**0.000** (0.000-0.006) [4]	**7.47** (7.24-7.59) [6]
D.5DR		**10**	0.54 [1]	No Data [0]	0.00-0.00 [2]	0.001-0.007 [2]	7.33-7.39 [2]
D.5AR		**10**	**0.57** (0.24-0.60) [8]	**0.63** (0.29-0.66) [6]	**0.00** (0.00-0.00) [7]	**0.000** (0.000-0.008) [9]	**7.46** (7.12-7.73) [15]

Table 3.15: Filtered Water Quality by Laboratory Analyses - General Analyses

	Analysis	Units	Laboratory Report #							
			L2108104		L2108761		L2110175		L2110984	
			02/18/21		02/23/21		03/02/21		03/04/21	
			Well 2		Well 2 with 10% Recycle		Well 5		Well 5 with 10% Recycle	
			No Filter B Samples	No Filter D Samples	Filter B Low pH	Filter D High pH	Filter B Low pH	Filter D High pH	No Filter B Samples	No Filter D Samples
Laboratory Analyses by Alpha Analytical	Total Iron	mg/L			<0.050	<0.050	<0.050	<0.050		
	Total Manganese	mg/L			<0.010	<0.010	<0.010	<0.010		
	Total Coliform	Col/100mL			Negative	Negative	Negative	Negative		
	Escherichia Coliform	Col/100mL			Negative	Negative	Negative	Negative		
	Turbidity	NTU			<0.20	<0.20	<0.20	<0.20		
	Color, True	s.u.			6.0	<5.0	<5.0	<5.0		
	Color, Apparent	s.u.			6.0	6.0	6.0	6.0		
	Odor	TON			No Odor	No Odor	No Odor	No Oder		
	Alkalinity	mg/L			60.3	80.9	46.3	57.7		
	Carbon Dioxide	mg/L			200	200	190	200		
	Total Dissolved Solids	mg/L			170	210	270	270		
	Total Cyanide	mg/L			<0.005	<0.005	<0.005	<0.005		
	Total Residual Chlorine	mg/L			0.68	0.80	0.51	0.79		
	Total Residual Free Chlorine	mg/L			<0.05	<0.05	<0.05	<0.05		
	pH	s.u.			7.3	7.8	7.3	7.4		
	Total Organic Carbon	mg/L			0.562	0.554	<0.500	<0.500		
	Dissolved Organic Carbon	mg/L			<1.0	<1.0	<1.0	<1.0		
	Surfactants, MBAS	mg/L			<0.050	<0.050	<0.050	<0.050		
	Chloride	mg/L			56.2	56.7	135	139		
	Fluoride	mg/L			0.053	<0.050	<0.050	0.058		
	Sulfate	mg/L			9.13	9.07	8.83	8.87		

Table 3.16: Filtered Water Quality by Laboratory Analyses – Additional Metals

	Analysis	Units	Laboratory Report #							
			L2108104		L2108761		L2110175		L2110984	
			Well 2		Well 2 with 10% Recycle		Well 5		Well 5 with 10% Recycle	
			02/18/21		02/23/21		03/02/21		03/04/21	
			No Filter B Samples	No Filter D Samples	Filter B Low pH	Filter D High pH	Filter B Low pH	Filter D High pH	No Filter B Samples	No Filter D Samples
Laboratory Analyses by Alpha Analytical	Total Aluminum	mg/L			<0.100	<0.100	<0.100	<0.100		
	Total Antimony	mg/L			<0.0040	<0.0040	<0.0040	<0.0040		
	Total Arsenic	mg/L			<0.0010	<0.0010	<0.0010	<0.0010		
	Total Barium	mg/L			0.0092	0.0076	0.0445	0.0460		
	Total Beryllium	mg/L			<0.0010	<0.0010	<0.0010	<0.0010		
	Total Cadmium	mg/L			<0.0002	<0.0002	<0.0002	<0.0002		
	Total Calcium	mg/L			4.98	4.83	6.61	6.61		
	Total Chromium	mg/L			<0.0010	<0.0010	<0.0010	<0.0010		
	Total Copper	mg/L			0.0014	<0.0010	0.0012	<0.0010		
	Total Mercury	mg/L			<0.0002	<0.0002	<0.0002	<0.0002		
	Total Nickel	mg/L			<0.0020	<0.0020	<0.0020	<0.0020		
	Total Selenium	mg/L			<0.0050	<0.0050	<0.0050	<0.0050		
	Total Silver	mg/L			<0.0004	<0.0004	<0.0004	<0.0004		
	Total Sodium	mg/L			31.2	31.9	84.3	83.6		
	Total Thalium	mg/L			<0.0010	<0.0010	<0.0010	<0.0010		
	Total Zinc	mg/L			<0.0100	<0.0100	<0.0100	<0.0100		

Table 3.17: Filtered Water Quality by Laboratory Analyses - PFAS Compounds – Method 533 and 537.1

Method	Analysis	Units	Laboratory Report #							
			L2108104		L2108761		L2110175		L2110984	
			Well 2		Well 2 with 10% Recycle		Well 5		Well 5 with 10% Recycle	
			02/18/21		02/23/21		03/02/21		03/04/21	
			No Filter B Samples	No Filter D Samples	Filter B Low pH	Filter D High pH	Filter B Low pH	Filter D High pH	No Filter B Samples	No Filter D Samples
Method 533	11-Chloroeicosafluoro-3-Oxaundecane-1-Sulfonic Acid (11Cl-PF3OUdS)	ng/L			<1.86	<1.84	<1.83	<1.85		
	1H,1H,2H,2H-Perfluorodecanesulfonic Acid (8:2FTS)	ng/L			<1.86	<1.84	<1.83	<1.85		
	1H,1H,2H,2H-Perfluorohexanesulfonic Acid (4:2FTS)	ng/L			<1.86	<1.84	<1.83	<1.85		
	1H,1H,2H,2H-Perfluorooctanesulfonic Acid (6:2FTS)	ng/L			<1.86	<1.84	<1.83	<1.85		
	2,3,3,3-Tetrafluoro-2-[1,1,2,2,3,3,3-Heptafluoropropoxy]-Propanoic Acid (HFPO-DA)	ng/L			<1.86	<1.84	<1.83	<1.85		
	4,8-Dioxa-3h-Perfluorononanoic Acid (ADONA)	ng/L			<1.86	<1.84	<1.83	<1.85		
	9-Chlorohexadecafluoro-3-Oxanone-1-Sulfonic Acid (9Cl-PF3ONS)	ng/L			<1.86	<1.84	<1.83	<1.85		
	Nonafluoro-3,6-Dioxaheptanoic Acid (NFDHA)	ng/L			<1.86	<1.84	<1.83	<1.85		
	Perfluoro(2-Ethoxyethane)Sulfonic Acid (PFEESA)	ng/L			<1.86	<1.84	<1.83	<1.85		
	Perfluoro-3-Methoxypropanoic Acid (PFMPA)	ng/L			<1.86	<1.84	<1.83	<1.85		
	Perfluoro-4-Methoxybutanoic Acid (PFMBA)	ng/L			<1.86	<1.84	<1.83	<1.85		
	Perfluorobutanesulfonic Acid (PFBS)	ng/L			1.98	1.94	9.35	8.43		
	Perfluorobutanoic Acid (PFBA)	ng/L			<1.86	<1.84	2.52	2.44		
	Perfluorodecanoic Acid (PFDA)	ng/L			<1.86	<1.84	<1.83	<1.85		
	Perfluorododecanoic Acid (PFDoA)	ng/L			<1.86	<1.84	<1.83	<1.85		
	Perfluoroheptanesulfonic Acid (PFHpS)	ng/L			<1.86	<1.84	<1.83	<1.85		
	Perfluoroheptanoic Acid (PFHpA)	ng/L			<1.86	<1.84	2.01	2.33		
	Perfluorohexanesulfonic Acid (PFHxS)	ng/L			5.7	6.24	<1.83	2.18		
	Perfluorohexanoic Acid (PFHxA)	ng/L			2.16	2.24	2.85	3.66		
	Perfluorononanoic Acid (PFNA)	ng/L			<1.86	<1.84	<1.83	<1.85		
	Perfluorooctanesulfonic Acid (PFOS)	ng/L			10.2	9.58	3.5	3.47		
	Perfluorooctanoic Acid (PFOA)	ng/L			4.44	4.4	3.18	3.7		
	Perfluoropentanesulfonic Acid (PFPeS)	ng/L			<1.86	<1.84	<1.83	<1.85		
	Perfluoropentanoic Acid (PFPeA)	ng/L			2.61	2.61	4.46	4.47		
	Perfluoroundecanoic Acid (PFUnA)	ng/L			<1.86	<1.84	<1.83	<1.85		
Other Analytes Method 537.1	N-Ethyl Perfluorooctanesulfonamidoacetic Acid (NEtFOSAA)	ng/L			<1.82	<1.82	<1.89	<1.84		
	N-Methyl Perfluorooctanesulfonamidoacetic Acid (NMeFOSAA)	ng/L			<1.82	<1.82	<1.89	<1.84		
	Perfluorotetradecanoic Acid (PFTA)	ng/L			<1.82	<1.82	<1.89	<1.84		
	Perfluorotridecanoic Acid (PFTrDA)	ng/L			<1.82	<1.82	<1.89	<1.84		
	Total PFAS6	ng/L			**20.32**	**20.22**	**8.69**	**11.68**		

Table 3.18: Filtered Water Quality by Laboratory Analyses – Disinfection Byproducts

Source	**SDS Set Date**	**Initial Chlorine Residual**		**Initial pH (s.u.)**	**Hold Time (hrs)**	**Final Chlorine Residual**		**Final pH (s.u.)**	**Laboratory Report**	**HAA5 (µg/L)**						**TTHM (µg/L) - Alpha Analytical**				
		Free (mg/L)	**Total (mg/L)**			**Free (mg/L)**	**Total (mg/L)**			Dibromoacetic	Dichloroacetic	Monobromoacetic	Monochloracetic	Trichloroacetic	**HAA5**	Chloroform	Bromodichloro-methane	Dibromochloro-methane	Bromoform	**TTHM**
Well 2 – Filter B	2/23/2021 12:00	0.49	0.62	6.89	168	0.60	0.66	6.74	L2110175	1.2	<1	<1	<2	<1	**1.2**	0.96	1.4	2.8	1.4	**6.6**
Well 2 – Filter D	2/23/2021 12:00	0.64	0.70	7.31		0.55	0.64	7.51		1.5	<1	<1	<2	<1	**1.5**	1.3	2.6	4.8	3.0	**12**
Well 5 – Filter B	3/02/2021 10:30	0.52	0.53	6.96		0.32	0.4	6.84	L2111596	<1	<1	<1	<2	<1	**<1**	1.2	1.1	1.9	0.94	**5.1**
Well 5 – Filter D	3/02/2021 10:30	0.49	0.55	7.21		0.49	0.49	7.50		1.1	<1	<1	<2	<1	**1.1**	1.3	1.4	2.4	1.4	**6.5**

3.3.4 Spent Backwash Water Analyses

Table 3.19 shows the laboratory results from filter composite backwash (CBW) and Figure 3.20 for settled supernatant (SSN) concentrations after four hours of settling.

Table 3.19: Combined Backwash Water Quality by Laboratory Analysis

	Analysis	Units	Laboratory Report #			
			L2109064		L2110005	
			2/24/21		3/01/21	
			Filter B Low pH	Filter D High pH	Filter B Low pH	Filter D High pH
Laboratory Analyses by Alpha Analytical	Total Iron	mg/L	1.54	2.18	1.54	1.41
	Dissolved Iron	mg/L	<0.050	<0.050	<0.050	<0.050
	Total Manganese	mg/L	1.73	2.34	1.61	5.58
	Dissolved Manganese	mg/L	<0.010	<0.010	0.024	<0.010
	Total Arsenic	mg/L	0.0021	0.0023	0.0016	0.001
	Total Barium	mg/L	0.0438	0.0988	0.0883	0.3683
	Total Cadmium	mg/L	0.0015	0.0042	0.0013	0.0291
	Total Chromium	mg/L	0.0013	0.0015	0.0074	0.0137
	Total Lead	mg/L	0.0029	0.0045	0.0051	0.0134
	Total Mercury	mg/L	<0.0002	<0.0002	<0.0002	<0.0002
	Total Selenium	mg/L	<0.0050	<0.0050	<0.0050	<0.0050
	Total Silver	mg/L	<0.0004	<0.0004	<0.0004	<0.0004
	Total Sodium	mg/L	29.1	29.1	70.2	57.1
	Total Solids	mg/L	180	150	290	320
	Total Dissolved Solids	mg/L	120	120	260	280
	Total Suspended Solids	mg/L	14	19	19	49
	Chlorine, Total Residual	mg/L	0.72	1.6	0.33	2.5
	Chlorine, Residual Free	mg/L	<0.05	<0.05	0.10	<0.20
	pH	S.U.	6.7	6.4	6.8	7.0

Table 3.20: Suspended Supernatant Water Quality by Laboratory Analysis

Laboratory Analyses by Alpha Analytical	Analysis	Units	Laboratory Report #			
			L2109064		L2110005	
			Well 5 2/24/21		Well 2 3/01/21	
			Filter B Low pH	Filter D High pH	Filter B Low pH	Filter D High pH
	Total Iron	mg/L	0.349	0.307	0.269	0.171
	Dissolved Iron	mg/L	<0.050	<0.050	<0.050	<0.050
	Total Manganese	mg/L	0.826	0.992	0.332	0.907
	Dissolved Manganese	mg/L	<0.010	<0.010	<0.010	<0.010
	Total Sodium	mg/L	29.2	29.4	74.4	73.8
	Total Solids	mg/L	160	140	270	280
	Total Dissolved Solids	mg/L	120	100	290	270
	Total Suspended Solids	mg/L	5.3	<5.0	<5.0	<5.0
	pH	S.U.	6.2	6.0	6.7	7.0

3.4 CONTACTOR PERFORMANCE

3.4.1 Contactor Operations Summary Table

Table 3.21 summarizes the operating conditions for the pilot contactors during the pilot study. The following information is included for each filter trial:

A. “Recorded Flow Rate” is the flow rate in gallons per minute as read on the rotometer style flow meter. This data was manually recorded on a data log each data.
B. “Recorded Totalizer Volume” is the total volume of water in gallons registered by the totalizing residential style flow meter. This data was manually recorded on a data log each data.
C. “Elapsed Time” is the calculated elapsed time in minutes from the startup of the pilot contactor.
D. “Actual Flow Rates” is the calculated flow rate in gallons per minute. The recorded totalizer volume (gal) was divided by the elapsed time (min).
E. “FSLR” is the actual filter loading rate processed through the filters, in gallons per minute per square foot (gpm/sf). The FSLR was calculated using recorded online flowrate (gpm) and dividing by the surface area of the pilot filter (0.2 ft^2). Data is presented as “average ± standard deviation [count].”
F. “EBCT” is the empty bed contact time in minutes. Empty bed contact time is calculated as the empty bed volume (gal) divided by the actual flow rate (gal/min).
G. “Total Bed Volumes Treated” is the number of empty bed volumes (BV) treated through the contactor as calculated by dividing the total volume of water treated (gal) by the empty bed volume (gal).

Table 3.21: PFAS Contactor Flows, EBCTs, and Bed Volumes

Date/Time	Recorded Flowrates (gpm)				Recorded Totalizer Volumes (gal)				Elapsed Time (min)				Actual Flow Rates (gpm)				EBCT (min)				Total Bed Volumes (BV) Treated			
	GAC #1	GAC #2	IX #1	IX #2	GAC #1	GAC #2	IX #1	IX #2	GAC #1	GAC #2	IX #1	IX #2	GAC #1	GAC #2	IX #1	IX #2	GAC #1	GAC #2	IX #1	IX #2	GAC #1	GAC #2	IX #1	IX #2
2/16/2021 13:13	1.5				56				0															
2/16/2021 13:22	1.5	0.75				62			9	0														
2/16/2021 15:02	1.5	0.75	1.3				30		109	100	0													
2/16/2021 15:04	1.5	0.75	1.3	0.65				31	111	102	2	0												
2/17/2021 10:30	1	0.75	1.3	0.65	1213	927	923	652	1277	1268	1168	1166	0.95	0.73	0.79	0.56	15.5	20.1	2.5	3.5	83	63	470	332
2/17/2021 10:50	0	0	0	0					1297	1288	1188	1186												
2/17/2021 13:52	1.5	0.75	1.3	0.65					1479	1470	1370	1368												
2/18/2021 11:00	1.5	0.75	1.3	0.65	2834	1811	2286	1446	2747	2738	2638	2636	1.03	0.66	0.87	0.55	14.2	22.2	2.3	3.6	193	123	1164	736
2/19/2021 11:00	1.5	0.75	1.3	0.65	5084	2966	4190	2655	4187	4178	4078	4076	1.21	0.71	1.03	0.65	12.1	20.7	1.9	3.0	346	202	2132	1351
2/22/2021 10:15	1.5	0.75	1.3	0.65	11798	6363	9294	5210	8462	8453	8353	8351	1.39	0.75	1.11	0.62	10.5	19.5	1.8	3.1	803	433	4730	2652
2/23/2021 11:25	1.5	0.75	1.3	0.65	14118	7606	11340	6330	9972	9963	9863	9861	1.42	0.76	1.15	0.64	10.4	19.3	1.7	3.1	960	517	5771	3221
2/24/2021 8:55	1.5	0.75	1.3	0.65	16117	8668	13073	7200	11262	11253	11153	11151	1.43	0.77	1.17	0.65	10.3	19.1	1.7	3.0	1096	590	6653	3664
2/24/2021 9:23	0	0	0	0					11290	11281	11181	11179												
2/24/2021 12:20	1.5	0.75	1.3	0.65					11467	11458	11358	11356												
2/24/2021 12:55	1.5	0.75	1.3	0.65	16218	8721	13160	7243	11502	11493	11393	11391	1.41	0.76	1.16	0.64	10.4	19.4	1.7	3.1	1103	593	6697	3686
2/25/2021 13:00	1.5	0.75	1.3	0.65	18546	9941	15160	8253	12947	12938	12838	12836	1.43	0.77	1.18	0.64	10.3	19.1	1.7	3.1	1262	676	7715	4200
2/26/2021 7:05	1.5	0.75	1.3	0.65	20286	10832	16629	9034	14032	14023	13923	13921	1.45	0.77	1.19	0.65	10.2	19.0	1.6	3.0	1380	737	8463	4597
3/1/2021 8:20	1.5	0.75	1.3	0.65	27124	14381	22527	12044	18427	18418	18318	18316	1.47	0.78	1.23	0.66	10.0	18.8	1.6	3.0	1845	978	11464	6129
3/2/2021 11:00	1.5	0.75	1.3	0.65	29601	15676	24678	13138	20027	20018	19918	19916	1.48	0.78	1.24	0.66	9.9	18.8	1.6	3.0	2014	1066	12559	6686
3/3/2021 13:00	1.5	0.75	1.3	0.65	32015	16937	26721	14222	21587	21578	21478	21476	1.48	0.78	1.24	0.66	9.9	18.7	1.6	3.0	2178	1152	13598	7238
3/4/2021 9:50	1.5	0.75	1.3	0.65	33947	17931	28382	15067	22837	22828	22728	22726	1.49	0.79	1.25	0.66	9.9	18.7	1.6	3.0	2309	1220	14444	7668
3/5/2021 8:20	1.5	0.75	1.3	0.65	36038	18995	30123	15966	24187	24178	24078	24076	1.49	0.79	1.25	0.66	9.9	18.7	1.6	3.0	2452	1292	15330	8125
Final Rates and Volumes at Pilot Completion													**1.49**	**0.79**	**1.25**	**0.66**	**9.9**	**18.7**	**1.6**	**3.0**	**2452**	**1292**	**15330**	**8125**

3.4.2 Contactor Hydraulic Performance Summary Table

Table 3.22 summarizes the recorded pressure data and calculated differential pressure through the contactor vessels. 0-60 psi pressure gauges were used to monitor differential pressure (headloss) development for each of the pilot scale contactors. All eight pilot vessels had differential pressure monitoring capability. A common inlet pressure gauge was used to log the inlet pressure for all contactors. Each contactor had a dedicated outlet pressure tap connected to a pressure gauge. Contactor differential pressures (DPs) were calculated using the inlet and outlet pressures for each contactor. DPs for first vessel in the GAC trains and both IX contactors were calculated using the common inlet pressure and that contactors outlet pressure. DPs for the second and third contactors in the GAC trains were calculated using the outlet pressure for the upstream contactor and the outlet pressure for the contactor of interest.

Table 3.22: PFAS Contactor Pressures and Differential Pressures

Date/Time	Recorded Pressures (PSI)									Differential Pressures (PSI)								
	Pilot Inlet	GAC #1			GAC #2			IX #1	IX #2	GAC #1			GAC #2			IX #1	IX #2
		Vessel 1	Vessel 2	Vessel 3	Vessel 1	Vessel 2	Vessel 3			Vessel 1	Vessel 2	Vessel 3	Vessel 1	Vessel 2	Vessel 3		
2/16/2021 15:04	47	41	39	39	43.5	43	43	38.5	42.5	6.0	2.0	0.0	3.5	0.5	0.0	8.5	4.5
2/17/2021 10:30	50	3	3	0	19	18	19	8	28	47.0	0.0	3.0	31.0	1.0	-1.0	42.0	22.0
2/17/2021 10:50																	
2/17/2021 13:52	48	45	43	43	45	44.5	45	41.5	45	3.0	2.0	0.0	3.0	0.5	-0.5	6.5	3.0
2/18/2021 11:00	48	45	43	43	45	44.5	45	42	45	3.0	2.0	0.0	3.0	0.5	-0.5	6.0	3.0
2/19/2021 11:00	47	43.5	42	41.5	43.7	43.5	43.2	38.3	43.5	3.5	1.5	0.5	3.3	0.2	0.3	8.7	3.5
2/22/2021 10:15	44	44	42	42.5	44	43.5	43.8	39	43.5	0.0	2.0	-0.5	0.0	0.5	-0.3	5.0	0.5
2/23/2021 11:25	47.5	44	42	42.1	43.8	42.9	43.7	37.5	43.5	3.5	2.0	-0.1	3.7	0.9	-0.8	10.0	4.0
2/24/2021 8:55	47.8	44	42.2	42.2	44	43.1	44.1	37.2	44.1	3.8	1.8	0.0	3.8	0.9	-1.0	10.6	3.7
2/24/2021 9:23																	
2/24/2021 12:20																	
2/24/2021 12:55	42.8	39.1	37.8	37.5	39.1	38.5	38.9	36.1	39.1	3.7	1.3	0.3	3.7	0.6	-0.4	6.7	3.7
2/25/2021 13:00	43.7	39.9	38.1	38.4	39.9	39.6	39.9	37	40	3.8	1.8	-0.3	3.8	0.3	-0.3	6.7	3.7
2/26/2021 7:05	43.2	39.2	37.8	37.9	39.6	39	39.4	36.1	39.5	4.0	1.4	-0.1	3.6	0.6	-0.4	7.1	3.7
3/1/2021 8:20	44	40.1	38.6	38.3	40.4	39.9	40.1	36.9	40.5	3.9	1.5	0.3	3.6	0.5	-0.2	7.1	3.5
3/2/2021 11:00	44.5	40.5	39	38.9	40.6	40.5	40.5	37.5	40.7	4.0	1.5	0.1	3.9	0.1	0.0	7.0	3.8
3/3/2021 13:00	44.2	40.1	38.3	38.1	40.6	40.5	40.5	37.1	40.6	4.1	1.8	0.2	3.6	0.1	0.0	7.1	3.6
3/4/2021 9:50	44.9	40.1	38.7	38.7	40.8	40.8	40.8	37.1	40.6	4.8	1.4	0.0	4.1	0.0	0.0	7.8	4.3
3/5/2021 8:20	45.1	40.1	38.6	38.6	40.9	40.8	40.8	37	40.8	5.0	1.5	0.0	4.2	0.1	0.0	8.1	4.3

3.4.3 Contactor Effluent Water Quality

Laboratory data is reported in Tables 3.23 to 3.25.

Simulated Distribution System (SDS) field and laboratory data are reported in Table 3.26.

Table 3.23: PFAS Contactor Effluent Water Quality by Laboratory Analyses - General Analyses

	Analysis	Units	Laboratory Report #							
			L2108104		L2108761		L2110175		L2110984	
			Well 2		Well 2 with 10% Recycle		Well 5		Well 5 with 10% Recycle	
			02/18/21		02/23/21		03/02/21		03/04/21	
			No GAC1 Samples	No AER1 Samples	GAC1	AER1	GAC1	AER1	No GAC1 Samples	No AER1 Samples
Laboratory Analyses by Alpha Analytical	Total Iron	mg/L			<0.050	<0.050	<0.050	<0.050		
	Total Manganese	mg/L			<0.010	<0.010	<0.010	<0.010		
	Turbidity	NTU			<0.20	<0.20	<0.20	<0.20		
	Color, True	s.u.			<5.0	<5.0	<5.0	<5.0		
	Color, Apparent	s.u.			7.0	<5.0	5.0	6.0		
	Odor	TON			No Odor	No Odor	No Odor	No Oder		
	Alkalinity	mg/L			71.3	71.1	53.2	52.5		
	Carbon Dioxide	mg/L			230	220	200	210		
	Total Dissolved Solids	mg/L			220	210	280	270		
	Total Cyanide	mg/L			<0.005	<0.005	<0.005	<0.005		
	Total Residual Chlorine	mg/L			<0.05	<0.05	<0.05	<0.05		
	Total Residual Free Chlorine	mg/L			<0.05	<0.05	<0.05	<0.05		
	pH	s.u.			7.7	7.7	7.2	7.1		
	Total Organic Carbon	mg/L			<0.500	0.586	<0.500	<0.500		
	Dissolved Organic Carbon	mg/L			<1.0	<1.0	<1.0	<1.0		
	Surfactants, MBAS	mg/L			<0.050	<0.050	<0.050	<0.050		
	Chloride	mg/L			59.0	59.3	138	136		
	Fluoride	mg/L			0.059	0.051	<0.050	<0.050		
	Sulfate	mg/L			14.9	13.0	10.7	9.87		

Table 3.24: PFAS Contactor Effluent Quality by Laboratory Analyses – Additional Metals

	Analysis	Units	Laboratory Report #							
			L2108104		L2108761		L2110175		L2110984	
			Well 2		Well 2 with 10% Recycle		Well 5		Well 5 with 10% Recycle	
			02/18/21		02/23/21		03/02/21		03/04/21	
			No GAC1 Samples	No AER1 Samples	GAC1	AER1	GAC1	AER1	No GAC1 Samples	No AER1 Samples
Laboratory Analyses by Alpha Analytical	Total Aluminum	mg/L			<0.100	<0.100	<0.100	<0.100		
	Total Antimony	mg/L			<0.0040	<0.0040	<0.0040	<0.0040		
	Total Arsenic	mg/L			<0.0010	<0.0010	<0.0010	<0.0010		
	Total Barium	mg/L			0.0094	0.0080	0.0418	0.0417		
	Total Beryllium	mg/L			<0.0010	<0.0010	<0.0010	<0.0010		
	Total Cadmium	mg/L			<0.0002	<0.0002	<0.0002	<0.0002		
	Total Calcium	mg/L			4.62	4.78	6.35	6.42		
	Total Chromium	mg/L			<0.0010	<0.0010	<0.0010	<0.0010		
	Total Copper	mg/L			0.0011	0.0022	<0.0010	0.0018		
	Total Mercury	mg/L			<0.0002	<0.0002	<0.0002	<0.0002		
	Total Nickel	mg/L			<0.0020	<0.0020	<0.0020	<0.0020		
	Total Selenium	mg/L			<0.0050	<0.0050	<0.0050	<0.0050		
	Total Silver	mg/L			<0.0004	<0.0004	<0.0004	<0.0004		
	Total Sodium	mg/L			36.3	36.0	83.7	84.1		
	Total Thalium	mg/L			<0.0010	<0.0010	<0.0010	<0.0010		
	Total Zinc	mg/L			<0.0100	<0.0100	<0.0100	<0.0100		

Table 3.25: PFAS Contactor Effluent Water Quality by Laboratory Analyses - PFAS Compounds – Method 533 and 537.1

Method	Analysis	Units	Laboratory Report #							
			L2108104		L2108761		L2110175		L2110984	
			Well 2		Well 2 with 10% Recycle		Well 5		Well 5 with 10% Recycle	
			02/18/21		02/23/21		03/02/21		03/04/21	
			GAC1	AER1	GAC1	AER1	GAC1	AER1	GAC1	AER1
Method 533	11-Chloroeicosafluoro-3-Oxaundecane-1-Sulfonic Acid (11Cl-PF3OUdS)	ng/L	<1.80	<1.82	<1.90	<1.83	<1.78	<1.82	<1.91	<1.97
	1H,1H,2H,2H-Perfluorodecanesulfonic Acid (8:2FTS)	ng/L	<1.80	<1.82	<1.90	<1.83	<1.78	<1.82	<1.91	<1.97
	1H,1H,2H,2H-Perfluorohexanesulfonic Acid (4:2FTS)	ng/L	<1.80	<1.82	<1.90	<1.83	<1.78	<1.82	<1.91	<1.97
	1H,1H,2H,2H-Perfluorooctanesulfonic Acid (6:2FTS)	ng/L	<1.80	<1.82	<1.90	<1.83	<1.78	<1.82	<1.91	<1.97
	2,3,3,3-Tetrafluoro-2-[1,1,2,2,3,3,3-Heptafluoropropoxy]-Propanoic Acid (HFPO-DA)	ng/L	<1.80	<1.82	<1.90	<1.83	<1.78	<1.82	<1.91	<1.97
	4,8-Dioxa-3h-Perfluorononanoic Acid (ADONA)	ng/L	<1.80	<1.82	<1.90	<1.83	<1.78	<1.82	<1.91	<1.97
	9-Chlorohexadecafluoro-3-Oxanone-1-Sulfonic Acid (9Cl-PF3ONS)	ng/L	<1.80	<1.82	<1.90	<1.83	<1.78	<1.82	<1.91	<1.97
	Nonafluoro-3,6-Dioxaheptanoic Acid (NFDHA)	ng/L	<1.80	<1.82	<1.90	<1.83	<1.78	<1.82	<1.91	<1.97
	Perfluoro(2-Ethoxyethane)Sulfonic Acid (PFEESA)	ng/L	<1.80	<1.82	<1.90	<1.83	<1.78	<1.82	<1.91	<1.97
	Perfluoro-3-Methoxypropanoic Acid (PFMPA)	ng/L	<1.80	<1.82	<1.90	<1.83	<1.78	<1.82	<1.91	<1.97
	Perfluoro-4-Methoxybutanoic Acid (PFMBA)	ng/L	<1.80	<1.82	<1.90	<1.83	<1.78	<1.82	<1.91	<1.97
	Perfluorobutanesulfonic Acid (PFBS)	ng/L	<1.80	<1.82	<1.90	<1.83	<1.78	<1.82	<1.91	<1.97
	Perfluorobutanoic Acid (PFBA)	ng/L	<1.80	<1.82	<1.90	<1.83	<1.78	<1.82	<1.91	<1.97
	Perfluorodecanoic Acid (PFDA)	ng/L	<1.80	<1.82	<1.90	<1.83	<1.78	<1.82	<1.91	<1.97
	Perfluorododecanoic Acid (PFDoA)	ng/L	<1.80	<1.82	<1.90	<1.83	<1.78	<1.82	<1.91	<1.97
	Perfluoroheptanesulfonic Acid (PFHpS)	ng/L	<1.80	<1.82	<1.90	<1.83	<1.78	<1.82	<1.91	<1.97
	Perfluoroheptanoic Acid (PFHpA)	ng/L	<1.80	<1.82	<1.90	<1.83	<1.78	<1.82	<1.91	<1.97
	Perfluorohexanesulfonic Acid (PFHxS)	ng/L	<1.80	<1.82	<1.90	<1.83	<1.78	<1.82	<1.91	<1.97
	Perfluorohexanoic Acid (PFHxA)	ng/L	<1.80	<1.82	<1.90	<1.83	<1.78	<1.82	<1.91	<1.97
	Perfluorononanoic Acid (PFNA)	ng/L	<1.80	<1.82	<1.90	<1.83	<1.78	<1.82	<1.91	<1.97
	Perfluorooctanesulfonic Acid (PFOS)	ng/L	<1.80	<1.82	<1.90	<1.83	<1.78	<1.82	<1.91	<1.97
	Perfluorooctanoic Acid (PFOA)	ng/L	<1.80	<1.82	<1.90	<1.83	<1.78	<1.82	<1.91	<1.97
	Perfluoropentanesulfonic Acid (PFPeS)	ng/L	<1.80	<1.82	<1.90	<1.83	<1.78	<1.82	<1.91	<1.97
	Perfluoropentanoic Acid (PFPeA)	ng/L	<1.80	<1.82	<1.90	<1.83	<1.78	<1.82	<1.91	<1.97
	Perfluoroundecanoic Acid (PFUnA)	ng/L	<1.80	<1.82	<1.90	<1.83	<1.78	<1.82	<1.91	<1.97
Other Analytes Method 537.1	N-Ethyl Perfluorooctanesulfonamidoacetic Acid (NEtFOSAA)	ng/L	<1.80	<1.81	<1.84	<1.86	<1.90	<1.84	<1.91	<1.93
	N-Methyl Perfluorooctanesulfonamidoacetic Acid (NMeFOSAA)	ng/L	<1.80	<1.81	<1.84	<1.86	<1.90	<1.84	<1.91	<1.93
	Perfluorotetradecanoic Acid (PFTA)	ng/L	<1.80	<1.81	<1.84	<1.86	<1.90	<1.84	<1.91	<1.93
	Perfluorotridecanoic Acid (PFTrDA)	ng/L	<1.80	<1.81	<1.84	<1.86	<1.90	<1.84	<1.91	<1.93
	Total PFAS6	ng/L	**<1.80**	**<1.82**	**<1.90**	**<1.86**	**<1.78**	**<1.84**	**<1.91**	**<1.93**

Table 3.26: PFAS Contactor Effluent Water Quality by Laboratory Analyses – Disinfection Byproducts

Source	**SDS Set Date**	**Initial Chlorine Residual**		**Initial pH (s.u.)**	**Hold Time (hrs)**	**Final Chlorine Residual**		**Final pH (s.u.)**	**Laboratory Report**	**HAA5 (µg/L)**						**TTHM (µg/L) - Alpha Analytical**				
		Free (mg/L)	**Total (mg/L)**			**Free (mg/L)**	**Total (mg/L)**			Dibromoacetic	Dichloroacetic	Monobromoacetic	Monochloracetic	Trichloroacetic	**HAA5**	Chloroform	Bromodichloro-methane	Dibromochloro-methane	Bromoform	**TTHM**
Well 2 – GAC1	2/24/2021 8:00	0.52	0.59	7.15	168	0.21	0.36	7.42	L2110984	3.2	1.1	<1	<2	<1	**4.3**	0.58	3.2	7.8	4.8	**16**
Well 2 – AER1	2/24/2021 8:00	0.60	0.61	7.47		0.20	0.30	7.42		3.9	1.2	1.2	2.8	<1	**9.1**	1.4	6.2	12	5.3	**25**
Well 5 – GAC1	3/02/2021 11:10	0.62	0.64	6.95		0.51	0.51	7.37	L2111596	<1	<1	<1	<2	<1	**<1**	<0.50	1.1	2.1	1.1	**4.3**
Well 5 – AER1	3/02/2021 11:10	0.60	0.68	6.99		0.42	0.42	7.34		2.3	1.0	<1	<2	<1	**3.3**	1.4	2.9	5.0	2.2	**12**

3.5 PFAS LABORATORY FIELD BLANK RESULTS

Each round of PFAS analyses requires that a field blank of DI water be transferred onsite to a preserved lab bottle provided by the lab. Table 3.27 summarizes the results of the field blank testing.

Table 3.27: Field Blank Results by Laboratory Analyses - PFAS Compounds – Method 533 and 537.1

Method	Analysis	Units	Laboratory Report #			
			L2108104	L2108761	L2110175	L2110984
			02/18/21	02/23/21	03/02/21	03/04/21
			Field Blank	Field Blank	Field Blank	Field Blank
Method 533	11-Chloroeicosafluoro-3-Oxaundecane-1-Sulfonic Acid (11Cl-PF3OUdS)	ng/L	<1.84	<1.89	<1.86	<1.95
	1H,1H,2H,2H-Perfluorodecanesulfonic Acid (8:2FTS)	ng/L	<1.84	<1.89	<1.86	<1.95
	1H,1H,2H,2H-Perfluorohexanesulfonic Acid (4:2FTS)	ng/L	<1.84	<1.89	<1.86	<1.95
	1H,1H,2H,2H-Perfluorooctanesulfonic Acid (6:2FTS)	ng/L	<1.84	<1.89	<1.86	<1.95
	2,3,3,3-Tetrafluoro-2-[1,1,2,2,3,3,3-Heptafluoropropoxy]-Propanoic Acid (HFPO-DA)	ng/L	<1.84	<1.89	<1.86	<1.95
	4,8-Dioxa-3h-Perfluorononanoic Acid (ADONA)	ng/L	<1.84	<1.89	<1.86	<1.95
	9-Chlorohexadecafluoro-3-Oxanone-1-Sulfonic Acid (9Cl-PF3ONS)	ng/L	<1.84	<1.89	<1.86	<1.95
	Nonafluoro-3,6-Dioxaheptanoic Acid (NFDHA)	ng/L	<1.84	<1.89	<1.86	<1.95
	Perfluoro(2-Ethoxyethane)Sulfonic Acid (PFEESA)	ng/L	<1.84	<1.89	<1.86	<1.95
	Perfluoro-3-Methoxypropanoic Acid (PFMPA)	ng/L	<1.84	<1.89	<1.86	<1.95
	Perfluoro-4-Methoxybutanoic Acid (PFMBA)	ng/L	<1.84	<1.89	<1.86	<1.95
	Perfluorobutanesulfonic Acid (PFBS)	ng/L	<1.84	<1.89	<1.86	<1.95
	Perfluorobutanoic Acid (PFBA)	ng/L	<1.84	<1.89	<1.86	<1.95
	Perfluorodecanoic Acid (PFDA)	ng/L	<1.84	<1.89	<1.86	<1.95
	Perfluorododecanoic Acid (PFDoA)	ng/L	<1.84	<1.89	<1.86	<1.95
	Perfluoroheptanesulfonic Acid (PFHpS)	ng/L	<1.84	<1.89	<1.86	<1.95
	Perfluoroheptanoic Acid (PFHpA)	ng/L	<1.84	<1.89	<1.86	<1.95
	Perfluorohexanesulfonic Acid (PFHxS)	ng/L	<1.84	<1.89	<1.86	<1.95
	Perfluorohexanoic Acid (PFHxA)	ng/L	<1.84	<1.89	<1.86	<1.95
	Perfluorononanoic Acid (PFNA)	ng/L	<1.84	<1.89	<1.86	<1.95
	Perfluorooctanesulfonic Acid (PFOS)	ng/L	<1.84	<1.89	<1.86	<1.95
	Perfluorooctanoic Acid (PFOA)	ng/L	<1.84	<1.89	<1.86	<1.95
	Perfluoropentanesulfonic Acid (PFPeS)	ng/L	<1.84	<1.89	<1.86	<1.95
	Perfluoropentanoic Acid (PFPeA)	ng/L	<1.84	<1.89	<1.86	<1.95
	Perfluoroundecanoic Acid (PFUnA)	ng/L	<1.84	<1.89	<1.86	<1.95
Other Analytes Method 537.1	N-Ethyl Perfluorooctanesulfonamidoacetic Acid (NEtFOSAA)	ng/L	<1.76	<1.87	<1.87	<1.93
	N-Methyl Perfluorooctanesulfonamidoacetic Acid (NMeFOSAA)	ng/L	<1.76	<1.87	<1.87	<1.93
	Perfluorotetradecanoic Acid (PFTA)	ng/L	<1.76	<1.87	<1.87	<1.93
	Perfluorotridecanoic Acid (PFTrDA)	ng/L	<1.76	<1.87	<1.87	<1.93
	Total PFAS6	ng/L	**<1.84**	**<1.89**	**<1.87**	**<1.95**

4 DATA ANALYSIS

Section 4 – Data Analysis provides analysis and discussion of the data presented in Section 3. This Section contains comparisons of Filter Trials and discussion of data from separate parts of Section 3. Issues and questions that are addressed in this Section were developed by the pilot operators to answer questions that are generally of interest when testing PFAS, iron and manganese removal in general.

4.1 RAW WATER QUALITY

4.1.1 Comparison of Raw Water Quality to Historical Data

Raw water iron and manganese concentrations collected during the pilot study, and analyzed by field methods, were compared to the historical data provided by GZA. Similarly, raw water PFAS6 concentrations for samples collected during the pilot study and measured by a certified laboratory were compared to the historical data provided.

Figures 4.01 to 4.03 are box plots which show raw iron (Figure 4.01), raw manganese (Figure 4.02), and raw PFAS6 concentrations measured during the pilot study from both well sources compared with historical data. The respective secondary maximum contaminant limits (SMCLs) for iron and manganese and the MCL for PFAS6 are also displayed on the figures.

Figure 4.01: Raw Iron Concentrations Compared to Historical Data

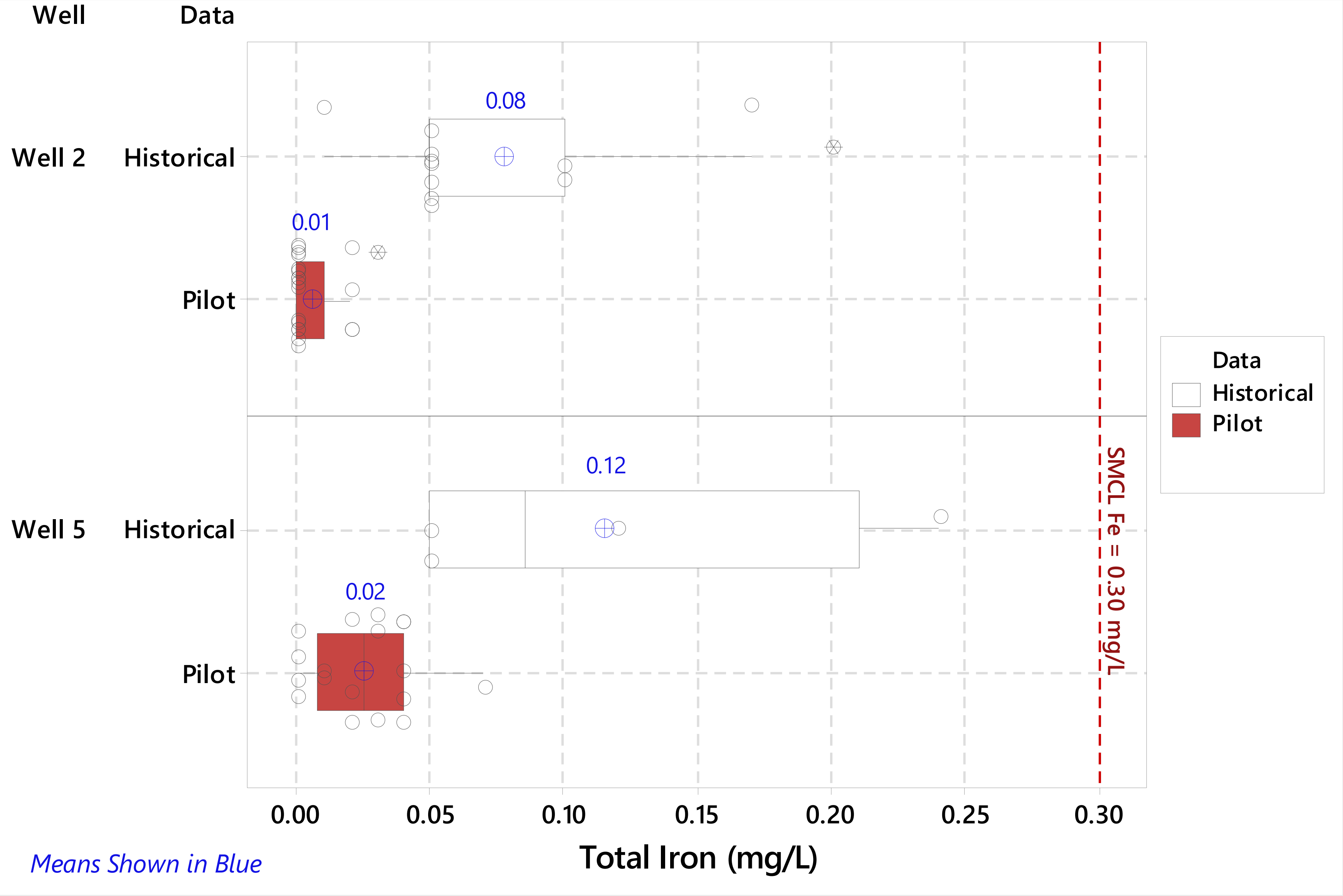


Figure 4.02: Raw Manganese Concentrations Compared to Historical Data

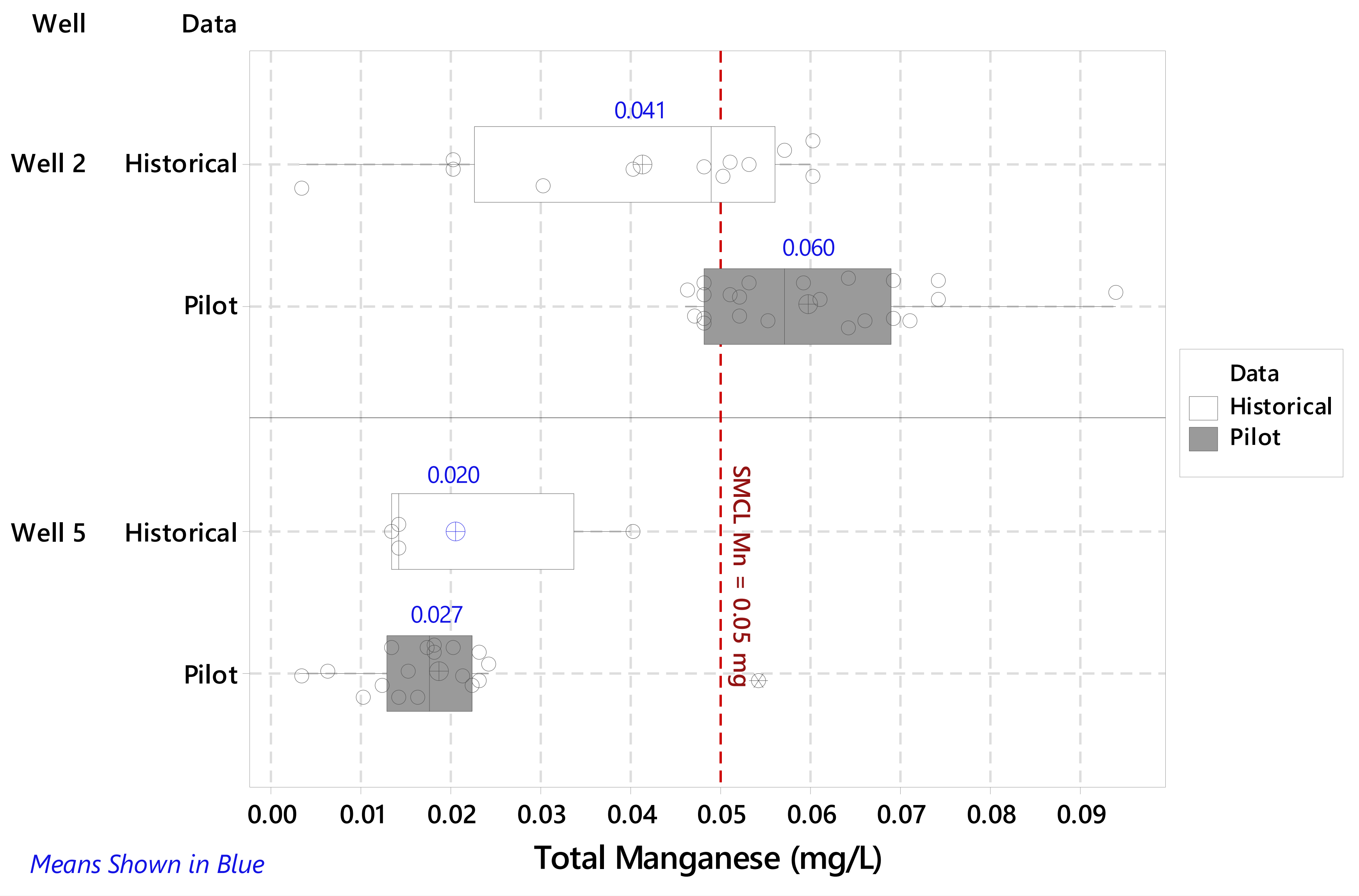


Figure 4.03: Raw PFAS6 Concentrations Compared to Historical Data

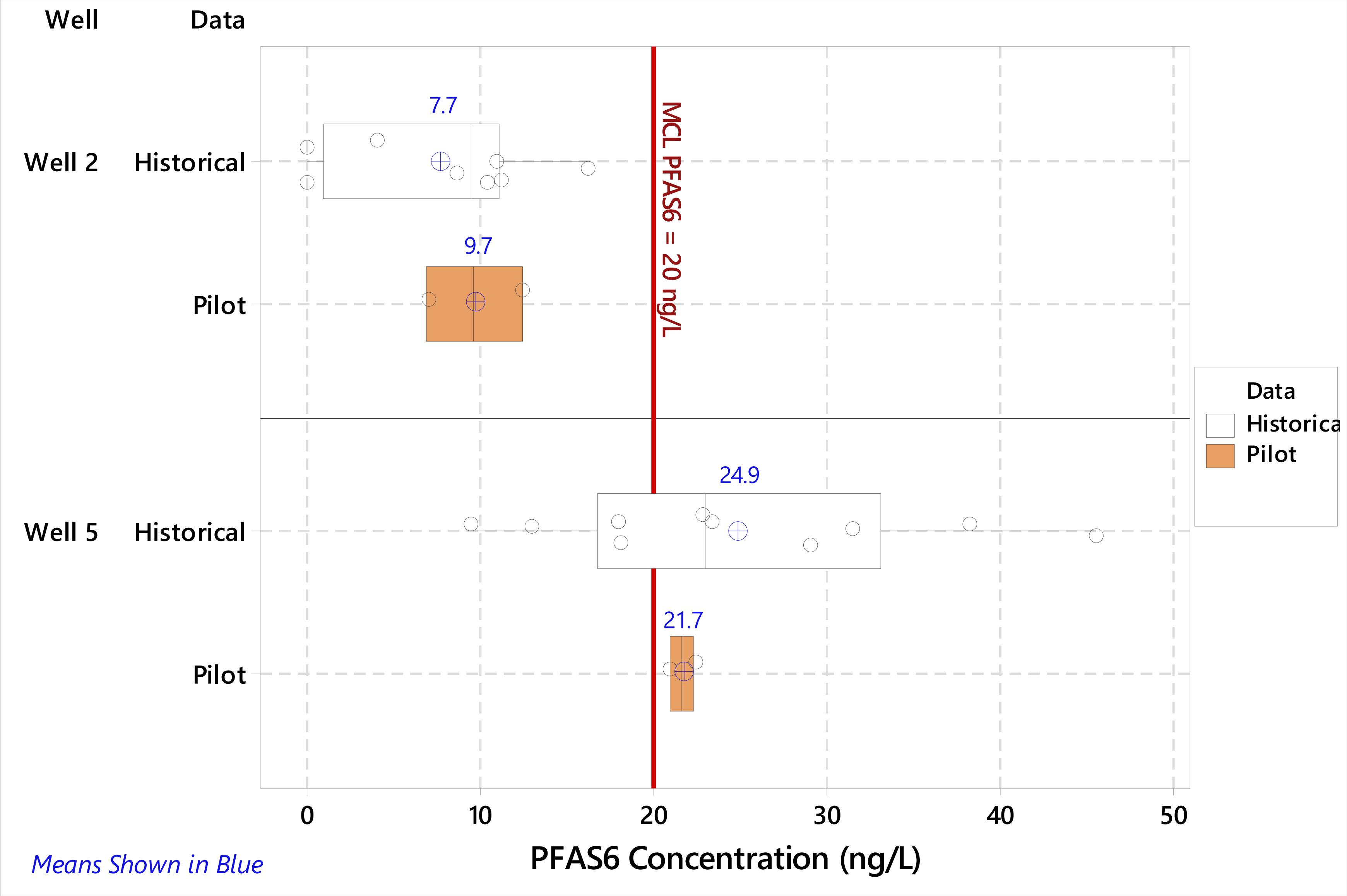


Figure 4.01 shows the box plots for raw iron concentrations measured during the pilot study were lower than historical concentrations for both wells. It should be noted, however, that the predominance of data for both historical and pilot study data are below detection limits. Eight out of the thirteen historical data for Well 2 and two of the four historical data for Well 5 were reported as below the detection limit of 0.1 mg/L. Similarly, the HACH FerroVer® method used for the pilot field analyses also has an estimated detection limit of 0.1 mg/l though HACH DR890 Colorimeter used during the project will report estimated concentrations as low as 0.01 mg/L. All field analyses for raw water were reported below this detection limit and only four of the historical data were reported above 0.1 mg/L. An anomalous data point from 5/7/98 was recorded as 2.1 mg/L in a spreadsheet and appears to have been a typo and was not used for this comparison. The conclusion is that the raw iron concentrations during the pilot study were representative of historical data in that both sources of data are consistently below the regulatory limit and predominantly below detection limits.

Figure 4.02 shows that the manganese concentrations measured during the pilot study were similar when compared to historical data. Data for both wells show that at least half of the data points overlap and the raw manganese concentrations for both wells should be considered representative of concentrations observed in the past.

Figure 4.03 shows that the raw PFAS6 concentrations from samples collected during the pilot study were within the range of historical data.

Review and comparison of the historical iron, manganese and PFAS data indicates that both wells produced representative water quality during the pilot study.

4.2 PRETREATMENT EFFECTIVENESS

4.2.1 Comparison of the Precipitated Fraction of Fe and Mn by pH

To evaluate the effectiveness of the chemical pretreatment for the oxidation and precipitation of iron and manganese, the fraction of raw iron and manganese is evaluated. Because iron was commonly below detection limits in the raw water for both wells this comparison is being made for manganese only.

Figure 4.04 shows the precipitated fraction of manganese in the pretreated water (downstream of chemical addition, but upstream of filtration) for both the low and the high pH trains. The pretreated water to Filters A and B targeted a pH of 6.7 while the pretreated water to Filters C and D targeted a pH of 7.7.

Figure 4.04: Precipitated Fraction of Mn in Pretreated Water by Target pH

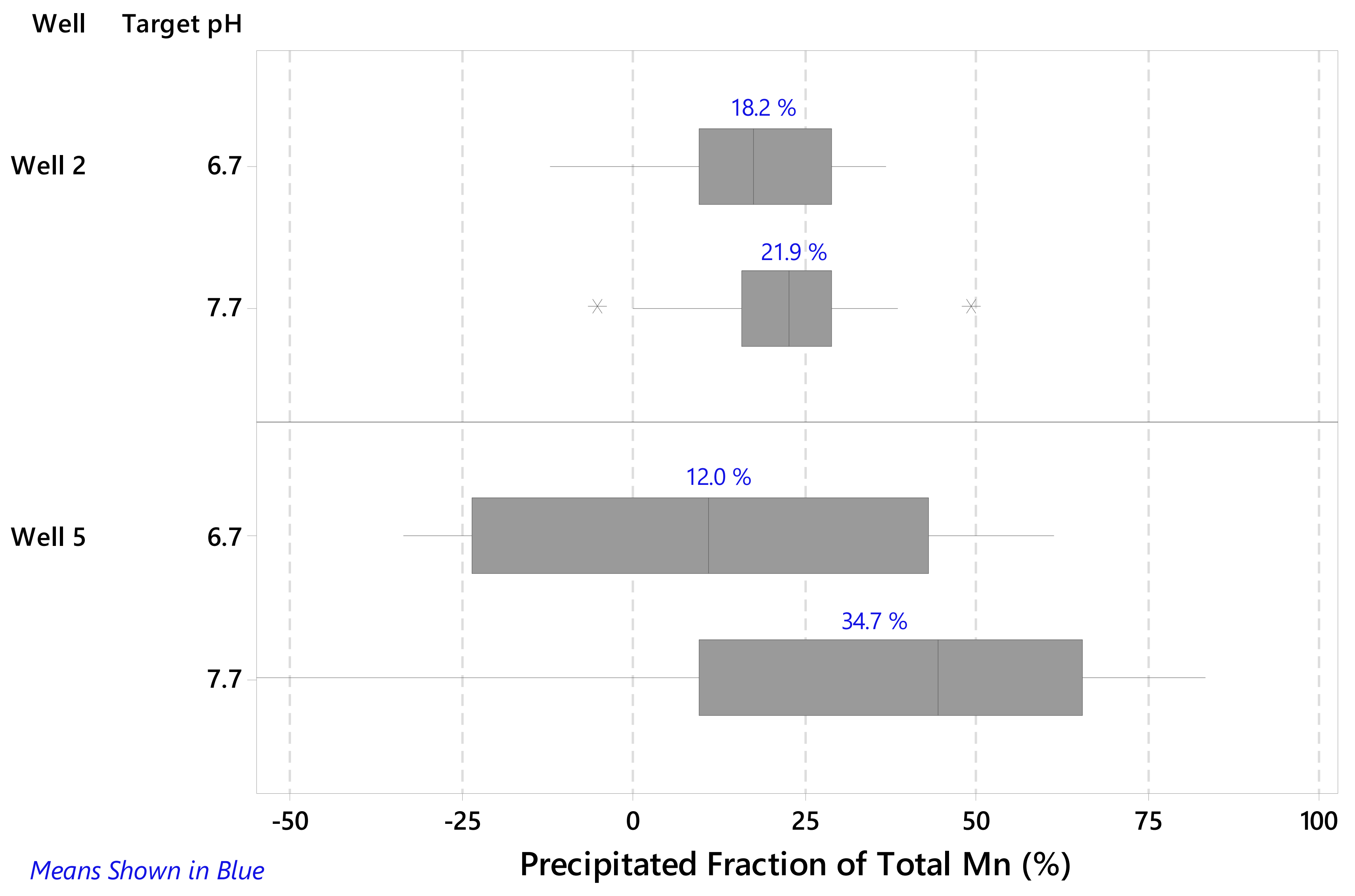


Figure 4.04 shows:

- When treating Well 2 chlorine precipitated an average of 18% of raw manganese at the lower operating pH of 6.7 compared to 22% at the higher pH of 7.7.
- When treating Well 5 chlorine precipitated an average of 12% of raw manganese at the lower operating pH of 6.7 compared to 35% at the higher pH of 7.7.

The mean precipitated fraction of manganese was less than 50% for all four well and pH combinations, a condition not uncommon for manganese. While a high fraction of dissolved iron is oxidized into a filterable particle during pretreatment with chlorine it is acceptable and expected for a significant fraction of dissolved (unprecipitated manganese) to enter an adsorptive media filter since the predominant mechanism for manganese removal is adsorption. There appeared to be no practical differences between the precipitation of manganese at the two pH levels tested.

4.3 TREATMENT EFFECTIVENESS

4.3.1 Effectiveness of Adsorptive Media Filtration for Mn Removal

This section compares the effectiveness of adsorptive media filtration for the removal of raw iron and manganese by operational variables such as well source, filter surface loading rate (5, 10 gpm/sf) and pH setting (6.7, 7.7).

In this report the comparison was made only for manganese removal at Well 2, because the raw iron was lower than the SMCL at both wells, and raw manganese was lower than the SMCL at Well 5.

- Median Raw Iron @ Well 2 = 0.00 mg/L < 0.30 mg/L SMCL
- Median Raw Iron @ Well 5 = 0.03 mg/L < 0.30 mg/L SMCL
- Median Raw Manganese @ Well 5 = 0.018 mg/L < 0.050 mg/L SMCL

To determine if the pilot filters met the SMCL for Mn (Mn< 0.05 mg/L), a t-test was performed comparing effluent manganese by field analysis to the SMCL. The variable inputs for the t-test were labeled as “Well 2”, “-Filter Surface Loading Rate-”, “pH” for example “Well 2-10-Hi pH” indicates that the data was collected from the effluent of a filter from Well 2 operating at a target filter surface loading rate of 10 gpm/sf at the high pH target of 7.7. The results of the t-test are presented in Table 4.01.

Table 4.01: Results of t-test for Effluent Mn (PAN Method) versus Project Goal

```
Test of μ = 0.050 vs < 0.050

Variable            N   Mean      StDev     SE Mean   95% Upper Bound    T       P
Well 2- 5 -Lo pH    23  0.002304  0.002899  0.000604      0.003342     -78.91  0.000
Well 2- 10 -Lo pH   24  0.001792  0.002413  0.000493      0.002636     -97.86  0.000
Well 2- 5 -Hi pH    24  0.001667  0.002548  0.000520      0.002558     -92.93  0.000
Well 2- 10 -Hi pH   24  0.001792  0.002670  0.000545      0.002726     -88.46  0.000
```

Results show the upper bound of the 95% confidence limit (the average is 95% likely to be less than the concentrations shown highlighted in green in Table 4.01). The p-values for each condition indicate the likelihood that the concentrations are less than the SMCL. All p-values are shown in yellow and all five were less than 0.05, indicating a greater than 95% likelihood that the condition met the Mn removal goal.

The t-test shows that the Well 2 median raw manganese of 0.057 mg/L was effectively reduced to less than the SMCL when operating at both loading rates and both pH conditions evaluated. All four combinations produced mean concentrations of 0.002 mg/L Mn or less in the filter effluent. Because the effluent manganese concentrations were comparatively low and practically similar further statistical analysis to evaluate significant differences in treatment by loading rate or pH are not necessary.

4.3.2 Filter Surface Loading Rates versus Filter Runtimes

Wells 2 and 5 had iron concentrations that were below the Secondary MCL and below detection limits in all four lab samples. Low iron concentrations make it difficult to predict filter runtimes because without the removal of precipitated iron particles there is a low rate of headloss development. The manganese removal mechanism is adsorption which also does not contribute significantly to headloss development.

Figure 4.05 plots runtime estimates to 10 psi of differential pressure for filter trials treating Wells 2 and 5. Each of the plots includes data from the media capacity model produced by Inversand. The shaded regions represent the expected range of filter runtimes based on the raw iron and manganese concentrations from each well.

After completion of the acclimation trial (Trial 1) to acclimate the media to the water source and optimize chemical pretreatment two sets of filter trials were completed at each well site. Trials 2 and 3 were conducted using Well 5 and Trials 4 and 5 used Well 2. Therefore, there were eight individual representative filter runs for each well or a total of 16 estimated filter runtime points to plot on Figure 4.05.

Figure 4.05: Filter Surface Loading Rate versus Runtimes – Well 2 and 5

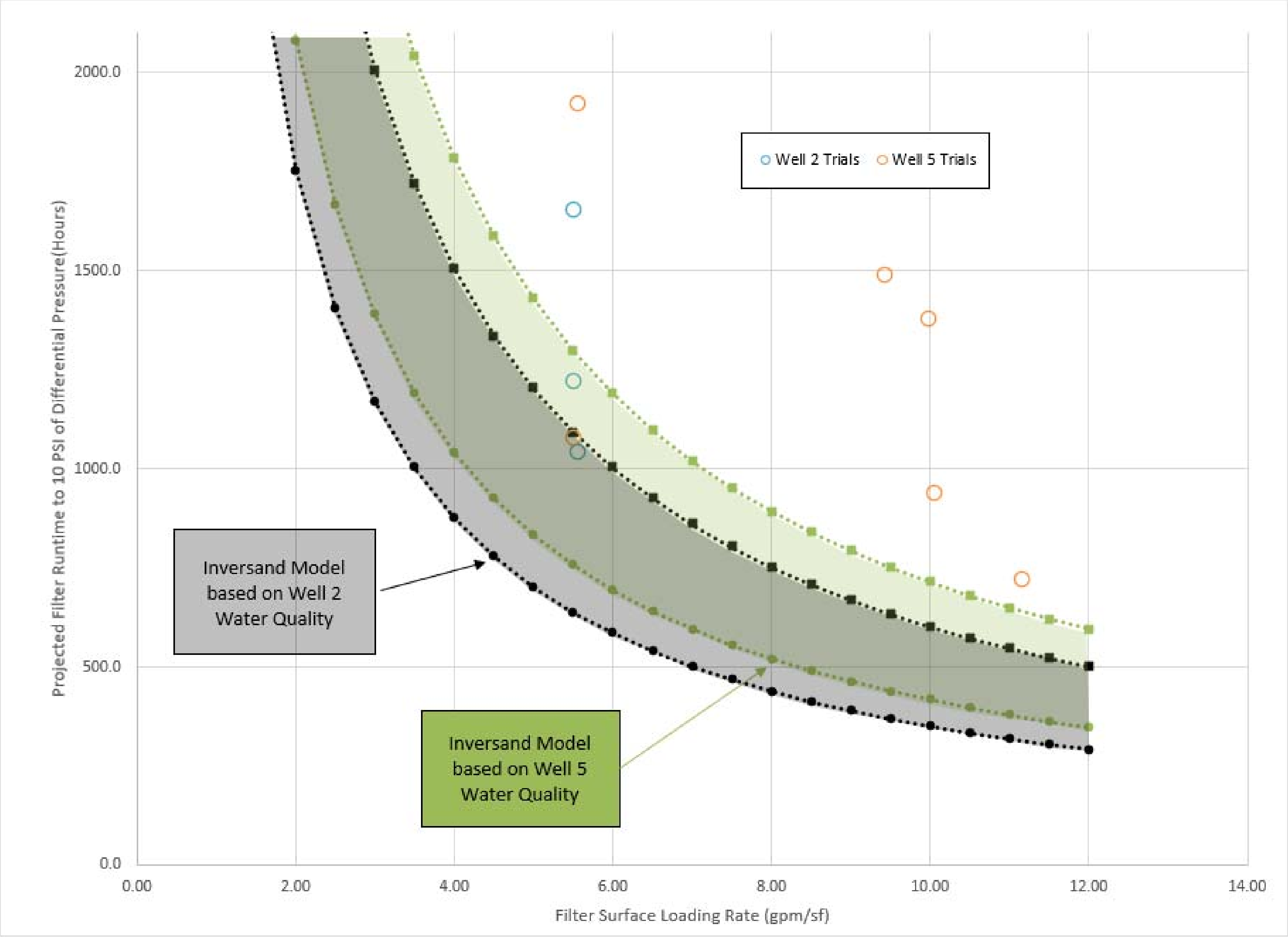


Figure 4.05 shows that a single filter run from each well source fell within the predicted runtime range for its respective model. All other filter runtimes exceeded the model. Nine of the sixteen total data points can be seen on the figure while the other seven data points had runtimes which were predicted at greater than 2,000 hours and were off the scale of the figure.

The pilot filter trials were operated for durations of 44 to 145 hours and always terminated based on the pilot schedule and not due to high differential pressure or turbidity breakthrough. The predicted runtimes plotted in Figure 4.05 are based on headloss development and it is unknown if or when turbidity breakthrough may have occurred.

4.3.3 Supernatant Recycle Performance

The second set of trials for each well included a supernatant recycle period which utilized the settled supernatant from the stored backwash of the previous trial. Settled supernatant was pumped into the raw water feed of the pilot filters for approximately 2 hours during Trial 3 at Well 5 and Trial 5 at Well 2. Recycle flow ended when the supernatant volume had reached a low level to avoid disturbing solids settled at the bottom of the supernatant storage tank. The performance data for the Well 5 recycle period are shown in Appendix C in Figures C.09 – C.12. The performance data for the Well 2 recycle period are shown in Figures C.17 – C.20. The period of supernatant recycle is highlighted in blue in those figures.

The figures show that most operating parameters were unchanged during and after the supernatant recycle was added with the exception that there was an increase in filter turbidity during the Well 5 recycle period. All four filters display an obvious turbidity increase with the two high-rate filters exceeding effluent turbidity of 0.1 NTU during this period. Filtered turbidity recovered after completion of the recycle feed period. Filtered turbidity remained consistent during the Well 2 recycle period.

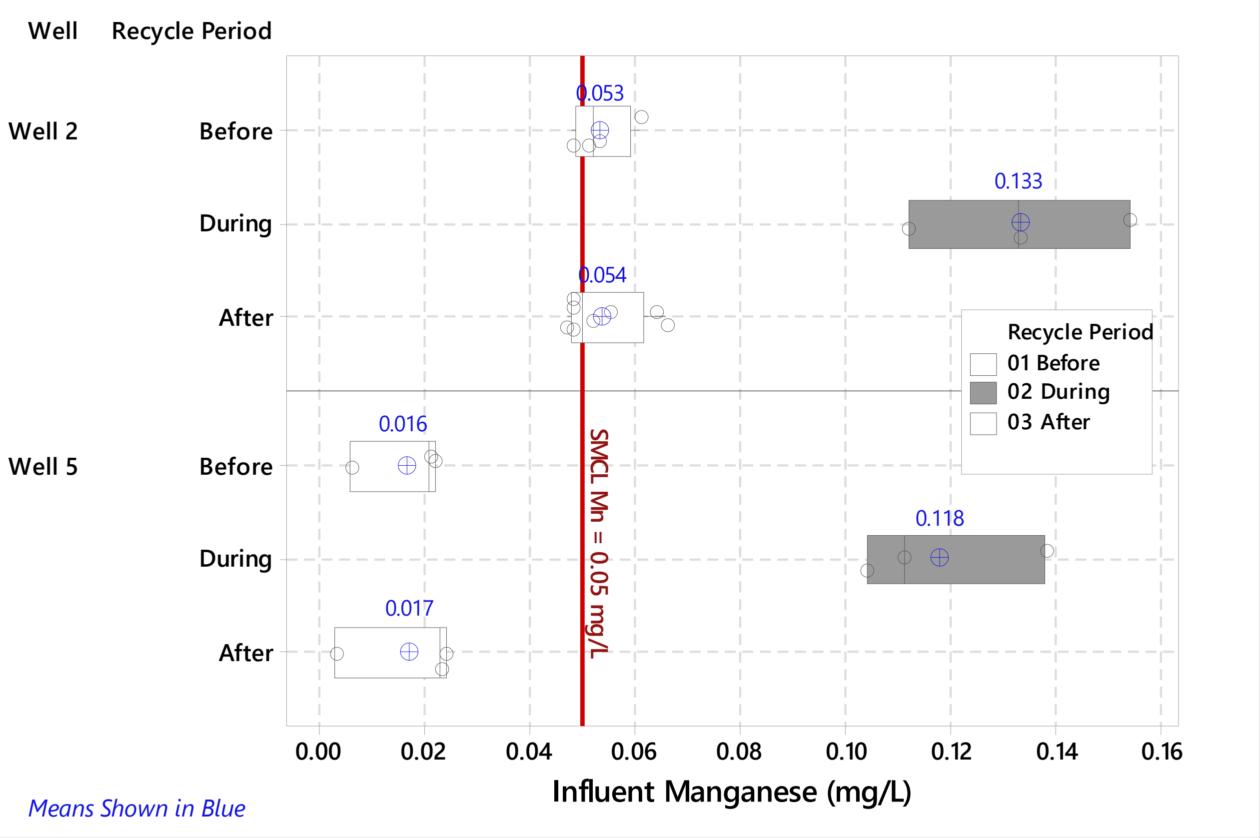
The influent water quality also deviated during the recycle periods. Table 4.02 presents the raw water quality for the two recycle trials and organizes the data into “before”, “during” and “after” the recycle period. Figure 4.06 is a box plot of the influent manganese concentration similarly organized. Influent manganese was more than twice the typical raw manganese during both recycle periods as shown in the red shaded cells in Table 4.02 and the “during” box plots in Figure 4.06 . This was due to the presence of high manganese concentrations in the settled supernatant. This is suspected to be a product of poor settling in the backwash which was observed during the study. The lab samples for the settled supernatant produced elevated manganese concentrations of just under 1.0 mg/L in three of four samples. With ideal settling, supernatant water quality is often similar to raw water quality.

Improved settling and clearer supernatant was later observed in the residual contents of the backwash storage tank but only after days of settling time. The lab samples for settled supernatant were collected after 4 hours of settling and the recycle trials were conducted after 24 hours of settling.

Table 4.02: Raw Water Quality by Field Analyses - Before – During – After - Recycle Periods

Parameter	Well 2			Well 5		
	Before Recycle	**During Recycle**	**After Recycle**	**Before Recycle**	**During Recycle**	**After Recycle**
Total Iron, mg/L	**0.00** (0.00-0.00) [4]	**0.02** (0.00-0.02) [3]	**0.00** (0.00-0.00) [8]	**0.01** (0.00-0.01) [3]	**0.04** (0.04-0.05) [3]	**0.00** (0.00-0.00) [3]
Dissolved Iron, mg/L	**0.00** (0.00-0.00) [4]	**0.00** (0.00-0.00) [3]	**0.00** (0.00-0.00) [7]	0.01-0.03 [2]	**0.00** (0.00-0.01) [3]	**0.00** (0.00-0.01) [3]
Total Manganese, mg/L	**0.052** (0.048-0.061) [4]	**0.133** (0.112-0.154) [3]	**0.052** (0.047-0.066) [9]	**0.021** (0.006-0.022) [3]	**0.111** (0.104-0.138) [3]	**0.023** (0.003-0.024) [3]
Dissolved Manganese, mg/L	**0.050** (0.048-0.060) [4]	**0.045** (0.044-0.059) [3]	**0.049** (0.043-0.058) [9]	0.008-0.017 [2]	**0.017** (0.006-0.022) [3]	**0.011** (0.002-0.025) [3]
pH (Handheld), s.u.	**5.35** (5.27-5.51) [6]	5.52-5.64 [2]	**5.39** (5.34-5.49) [14]	**5.56** (5.48-5.81) [4]	5.75-5.99 [2]	5.49-5.60 [2]

Figure 4.06: Influent Manganese Concentrations Before, During and After Recycle Periods



Figures 4.07 and 4.08 show the four Imhoff cones, each containing a representative sample of homogenized backwash and allowed to settle for approximately 4 hours after Trial 2 using Well 5 and Trial 4 using Well 2 respectively.

There is very little accumulation of manganese solids which is not uncommon for source waters that contain manganese but not iron. Iron removal occurs after the pretreatment oxidant produces a filterable particle that is readily shed during backwash and settles easily. However, manganese removal occurs by adsorption to the media after oxidation. Low contaminant loading (especially low iron) produces colloidal manganese particles that do not settle well. In Figure 4.08 there are increased solids visible in the cone representing Filter D which was the high rate, high pH filter. A greater portion of manganese is precipitated at higher pH when compared to low pH as discussed in Section 4.2.1.

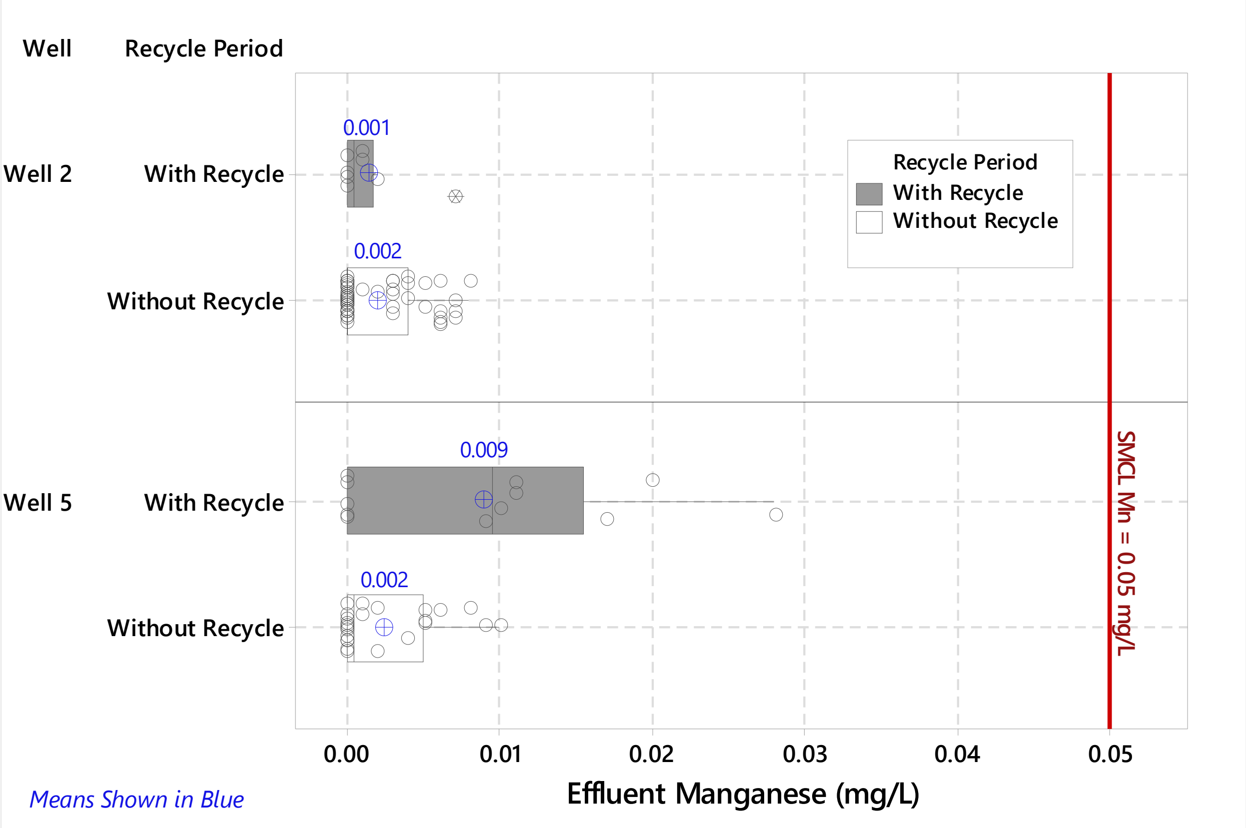
Figure 4.07: Backwash Settling in Imhoff Cones for Well 5 – Trial 2

Figure 4.08: Backwash Settling in Imhoff Cones for Well 2 – Trial 4

Total

Figure 4.09 is a box plot of effluent manganese concentrations comparing the periods with and without recycle during each of the two recycle trials.

Figure 4.09: Effluent Manganese Concentrations With and Without Recycle



An analysis of variance (ANOVA) was performed on the effluent manganese data sets to compare the data with and without recycle for each Well. Table 4.03 presents the ANOVA for the Well 2 recycle trial and Table 4.04 presents the ANOVA for Well 5.

Table 4.03: One-way ANOVA: Mn versus Recycle Period for Well 2

```
Null hypothesis         All means are equal
Alternative hypothesis  At least one mean is different
Significance level      α = 0.05
Rows unused             18

Equal variances were assumed for the analysis.

Factor          Levels  Values
Recycle Period       2  With Recycle, Without Recycle

Analysis of Variance

Source          DF    Adj SS    Adj MS  F-Value  P-Value
Recycle Period   1  0.000002  0.000002     0.36    0.553
Error           58  0.000388  0.000007
Total           59  0.000390

Model Summary

        S   R-sq  R-sq(adj)  R-sq(pred)
0.0025858  0.61%      0.00%       0.00%

Means:
Recycle Period    N      Mean     StDev           95% CI
With Recycle      8  0.001375  0.002387  (-0.000455, 0.003205)
Without Recycle  52  0.001962  0.002612  ( 0.001244, 0.002679)

Pooled StDev = 0.00258576
```

Table 4.04: One-way ANOVA: Mn versus Recycle Period for Well 5

```
Null hypothesis         All means are equal
Alternative hypothesis  At least one mean is different
Significance level      α = 0.05

Equal variances were assumed for the analysis.

Factor          Levels  Values
Recycle Period       2  With Recycle, Without Recycle

Analysis of Variance

Source          DF    Adj SS    Adj MS  F-Value  P-Value
Recycle Period   1  0.000329  0.000329     9.32    0.004
Error           34  0.001201  0.000035
Total           35  0.001531

Model Summary

        S    R-sq  R-sq(adj)  R-sq(pred)
0.0059446  21.52%     19.21%       8.20%

Means:
Recycle Period    N      Mean     StDev           95% CI
With Recycle     12   0.00883   0.00934  (  0.00535,   0.01232)
Without Recycle  24  0.002417  0.003243  (-0.000049, 0.004883)

Pooled StDev = 0.00594460
```

The results of the Well 2 ANOVA shown in Table 4.03 determined a p-value of 0.553 which concluded a statistical similarity between the two data sets. This result concludes there is no statistically significant difference in effluent manganese concentration during the recycle period when compared to the data from before and after the recycle period.

The results of the Well 5 ANOVA shown in Table 4.04 determined a p-value of 0.004 which indicated that the two data sets were statistically different, and the alternative hypothesis is accepted (0.004 < 0.050). This indicated that the introduction of 10% recycle while piloting Well 5 produced effluent manganese results which were statistically different from the effluent manganese results from before and after the recycle period. While the data was statistically different it was not practically different as the treated water quality remained below regulatory limits during the recycle period.

Summarizing the observations in this section:

- The introduction of 10% recycle more than doubled the influent manganese concentrations during the recycle periods for both wells. All other influent water quality parameters remained similar.
- During the Well 5 recycle period filtered turbidity increased in all four filters and was greater than 0.1 NTU in the two high-rate filters. Effluent manganese concentrations also increased by a statistically significant amount but remained below the SMCL Mn of 0.050 mg/L. All other operational and water quality parameters remained consistent during the recycle period.
- During the Well 2 recycle period filtered turbidity and effluent manganese remained at acceptable levels without any obvious impact from the introduction of recycle supernatant.

4.3.4 Were GAC Adsorption and Ion Exchange Effective for PFAS Removal

Figures 4.10 and 4.11 are individual values plots which plot each of the certified lab results for the PFAS6 compounds for the raw water and each process effluent. Figure 4.10 presents PFAS removal while operating on Well 2 and Figure 4.11 for Well 5. The sample sites were:

- Raw (Well 2 or Well 5)
- Filter B Effluent (High Loading Rate - Low pH Greensand Filter)
- Filter D Effluent (High Loading Rate - High pH Greensand Filter)
- GAC1 Effluent (High Rate GAC Contactor)
- IX1 Effluent (High Rate Ion Exchange Contactor)

MaDEP has a PFAS public drinking water standard or maximum contaminate level (MCL) of 20 nanograms per liter (ng/L) or parts-per-trillion (ppt) for the sum of six specific PFAS. These six specific PFAS are often referred to as the PFAS6. The PFAS6 include:

- perfluoroheptanoic acid (PFHpA)
- perfluorohexane sulfonic acid (PFHxS)
- perfluorooctanoic acid (PFOA)
- perfluorononanoic acid (PFNA
- perfluorooctane sulfonic acid (PFOS)
- perfluorodecanoic acid (PFDA)

The total PFAS6 concentration is plotted at the top of the figures then followed by each of the individual six compounds.

There were two lab sampling events for PFAS while operating at each well. Greensand filter effluent was only sampled during one of those events as it is not expected to contribute to PFAS removal. The 20 ng/L regulatory limit is plotted on the figures as a red line. Lab results reported as non-detect (ND) are plotted at their respective minimum detection limits and not as zero (i.e. <1.89 ng/L is plotted at 1.89).

Raw PFAS6 concentrations in the two samples for Well 2 were 6.96 and 12.41 ng/L and below the MCL limit of 20 ng/L. Raw PFAS6 concentrations for Well 5 were 20.97 and 22.36 ng/L and were slightly above the limit. PFAS concentrations in Greensand filter effluent samples were similar to raw as expected. Treatment by GAC adsorption reduced all PFAS6 compounds to non-detectable concentrations in all effluent samples. Treatment by ion exchange with anionic exchange resin also reduced all PFAS6 compounds to non-detectable concentrations in all effluent samples.

Figure 4.10: PFAS Concentration Through Treatment Processes for Well 2

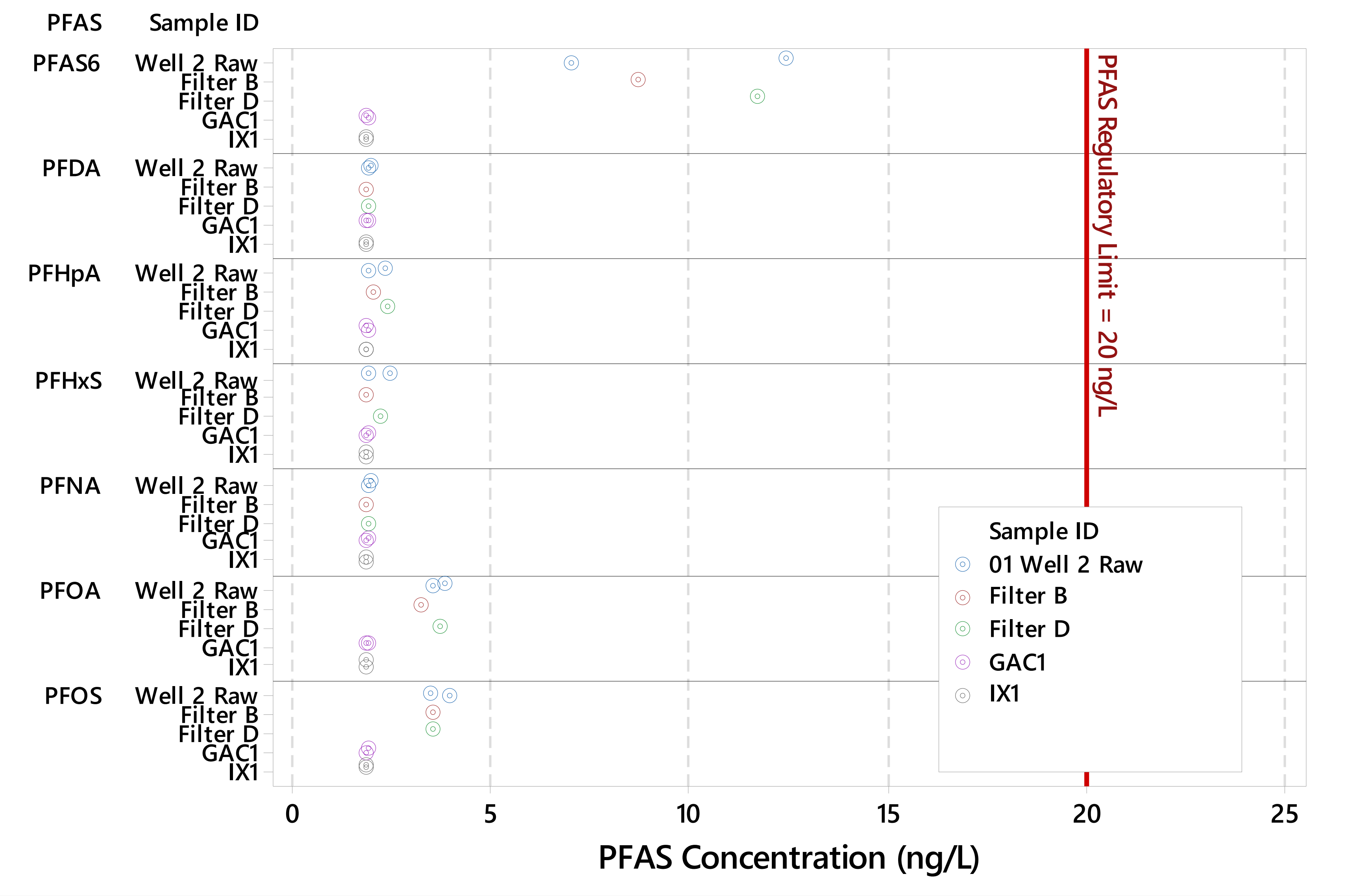
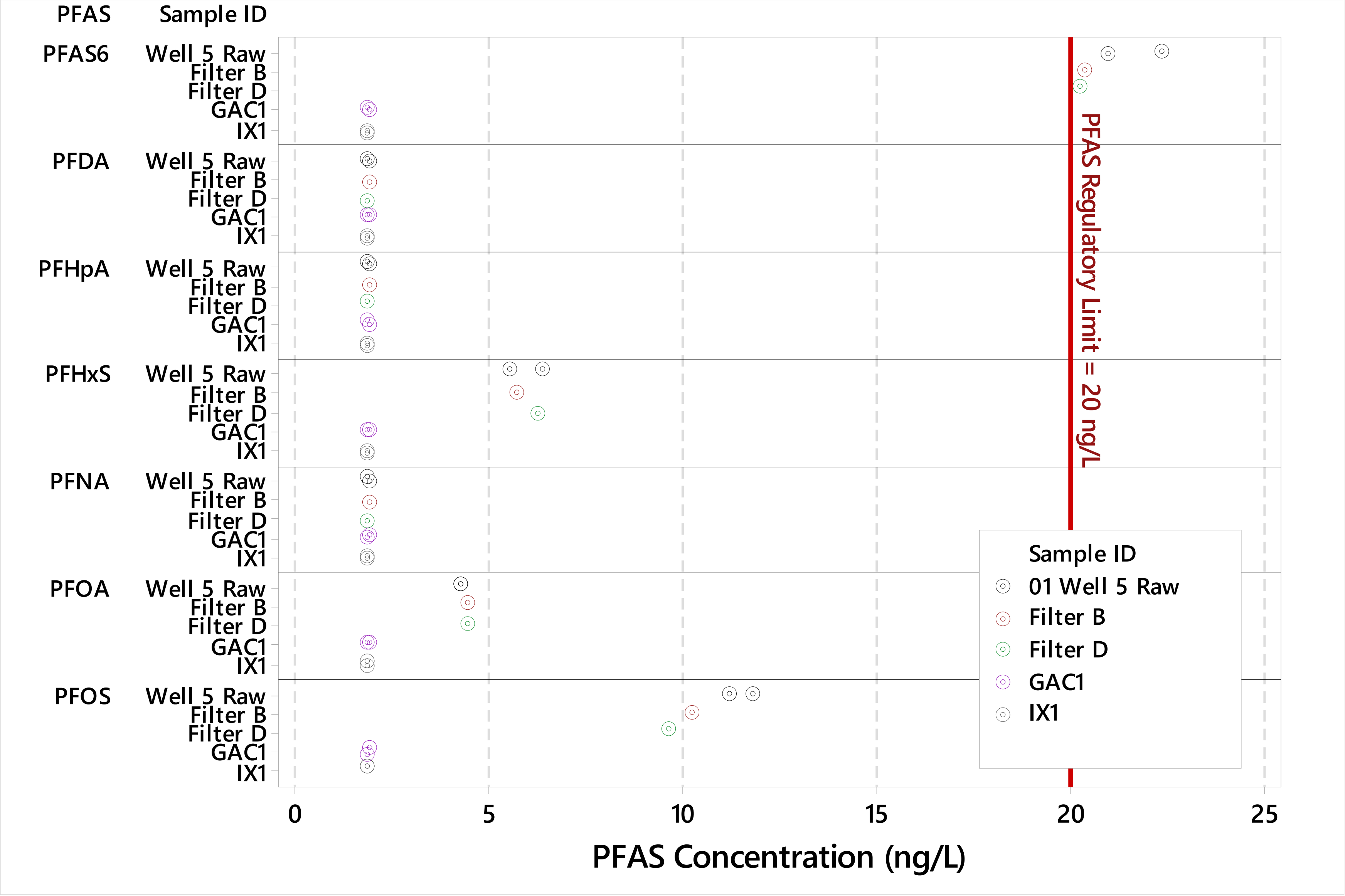


Figure 4.11: PFAS Concentration Through Treatment Processes for Well 5

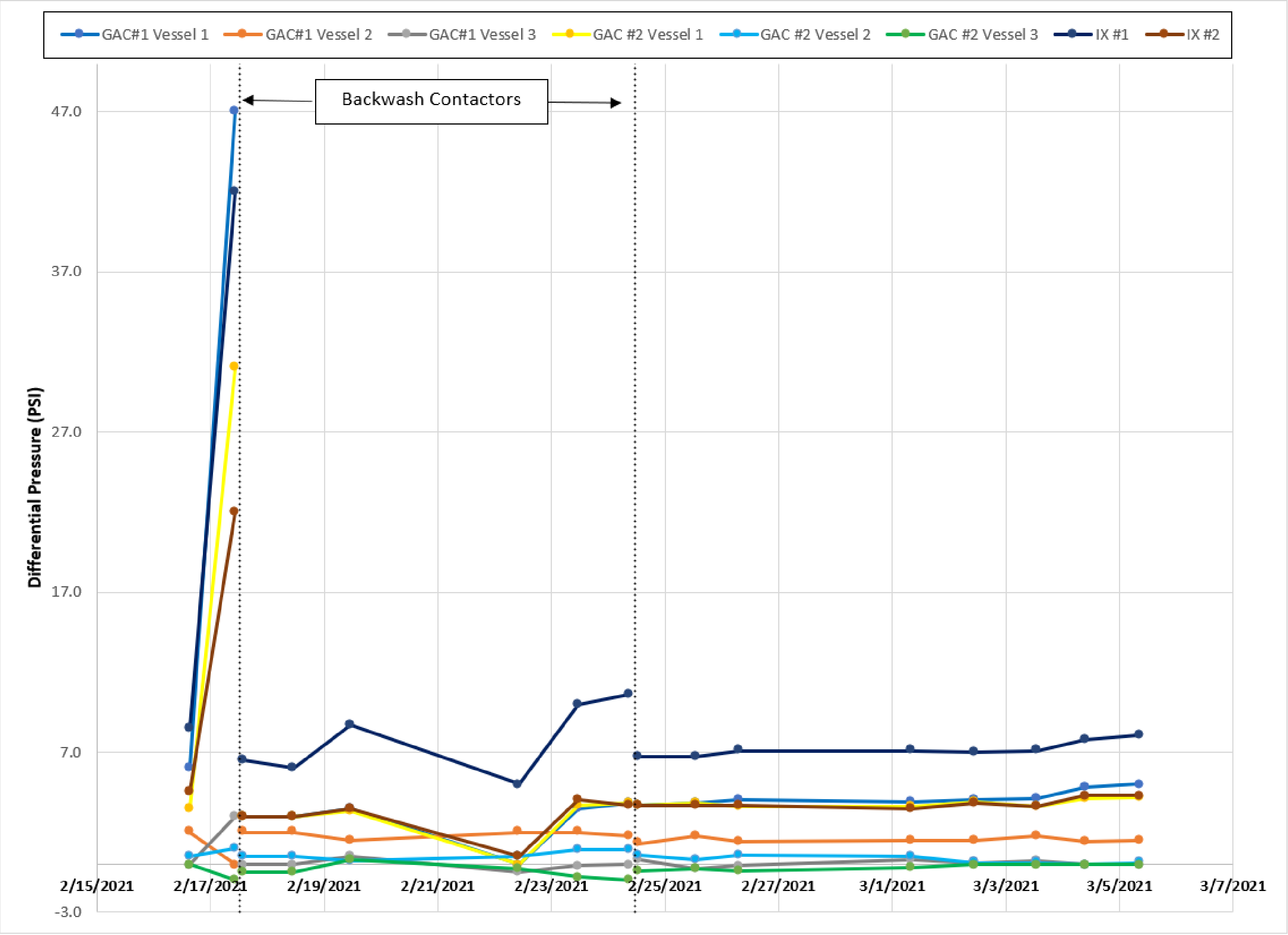


4.3.5 Was GAC and Ion Exchange Hydraulic Performance Acceptable

The pressure loss data summarized in Table 3.22 in Section 3.4.2 is plotted in the following Figure 4.12. The differential pressure is plotted for each contactor vessel for the full duration of the pilot study. There were two occasions after startup of the GAC and IX contactors that the contactors were shut down and backwashed due to differential pressure increase. On both occasions the pressure increase was due to carryover of the particulate from the dechlorination tabs as they broke down in the contactor feed tank.

The first episode occurred over the first night of operation. Differential pressure as high as 47 psi had developed overnight significantly reducing flow through the contactors. It was observed by the operator that particulate from the breakdown of the dechlorination tabs had accumulated on the surface of the media blinding the first column in the GAC trains and both IX contactors. The contactors were backwashed to remove the accumulated particulate and then restarted. The dechlorination tabs were then bound in a cloth wrap to contain the particulate as the tabs dissolved and broke down. This was effective until some of the particulate passed through to the contactors during the tab exchange process. The pressure increase was less pronounced, but the contactors were again backwashed. There was little to no differential pressure development observed the remainder of the pilot study.

Figure 4.12: Differential Pressures for PFAS Contactors During Pilot Study



5 Conclusions and Discussion

5.1 RAW WATER QUALITY CONCLUSIONS

1. Raw water quality from field analyses was summarized in Table 3.01 (reproduced as Table 5.01 to preserve Table numbering format)

Table 5.01: Raw Water Quality by Field Analyses (presented in Section 3.1 as Table 3.01)

Parameter	**Well 2**	**Well 2 w/ 10% Recycle***	**Well 5**	**Well 5 w/ 10% Recycle***
Total Iron, mg/L	**0.00** (0.00 – 0.03) [21]	**0.02** (0.00 – 0.02) [3]	**0.03** (0.00 – 0.07) [18]	**0.04** (0.04 – 0.05) [3]
Dissolved Iron, mg/L	**0.00** (0.00 – 0.02) [19]	**0.00** (0.00 – 0.00) [3]	**0.01** (0.00 – 0.03) [12]	**0.00** (0.00 – 0.01) [3]
Total Manganese, mg/L	**0.057** (0.046 – 0.094) [22]	**0.133** (0.112– 0.154) [3]	**0.018** (0.003– 0.054) [18]	**0.111** (0.104– 0.138) [3]
Dissolved Manganese, mg/L	**0.054** (0.034 – 0.068) [22]	**0.045** (0.044 – 0.059) [12]	**0.016** (0.002 – 0.028) [12]	**0.017** (0.006 – 0.022) [12]
pH (Handheld), s.u.	**5.39** (5.27 – 5.50) [19]	**5.52** [1]	**5.52** (5.47 – 5.65) [11]	**5.75** [1]
Temperature, °C	**12.3** (11.8 – 12.8) [19]	**11.9** [1]	**11.5** (11.4 – 11.7) [7]	No Data [0]
Alkalinity (mg/L)	7 [1]	No Data [0]	No Data [0]	No Data [0]
Carbon Dioxide (mg/L)	89 [1]	No Data [0]	80 [1]	No Data [0]

2. Raw PFAS6 concentrations were measured by certified laboratory. The results for two samples for Well 2 were reported as 6.96 and 12.41 ng/L and below the MCL limit of 20 ng/L. Raw PFAS6 concentrations for Well 5 were reported as 20.97 and 22.36 ng/L and were slightly above the limit.
3. Raw iron, manganese and PFAS6 concentrations were compared to historical data for both wells and were determined to be representative of concentrations observed in the past.

5.2 IRON AND MANGANESE REMOVAL BY PRESSURE FILTRATION CONCLUSIONS

4. Oxidation with sodium hypochlorite (NaOCl) required an applied dose of between 0.5 and 0.9 mg/L.
5. Bench scale titrations were conducted to determine the potassium hydroxide dose necessary to raise the raw water pH from ambient to 6.7 and then further to 7.7. The experiment was repeated for both wells and again for post aerated water to determine the possible benefits of aeration in reduced chemical costs. The results are summarized in Table 5.02:

Table 5.02: KOH Doses

Source	pH Target	KOH Dose (mg/L)	KOH Dose Post Aeration (mg/L)
Well 2	6.7	49	15
	7.7	97	37
Well 5	6.7	28	6
	7.7	56	21

6. Five minutes of aeration reduced KOH doses by greater than half.
7. All filter trials met the Project Goal for total Fe < 0.30 mg/L and total Mn of < 0.050 mg/L at both FSLR evaluated (5 and 10) and at both pH settings (6.7 and 7.7).
8. Filter runs operated as long as 6 days but were always terminated by pilot schedule and not due to headloss greater than 10 psi or turbidity breakthrough. Filter runtimes exceeded the range of the Inversand models for the wells due to the low iron and manganese concentrations and lack of contaminant loading.
9. Fourteen out of 16 representative filter trials were predicted to exceed 1000 hours based on the rate of headloss development. It is unknown if or when turbidity breakthrough may have occurred.
10. SDS analysis of Greensand filtered effluent produced TTHM and HAA5 concentrations significantly below the respective MCLs of 80 and 60 µg/L.
11. The introduction of 10% recycle more than doubled the influent manganese concentrations during the recycle periods for both wells. All other influent water quality parameters remained similar.
12. During the Well 5 recycle period filtered turbidity increased in all four filters and was greater than 0.1 NTU in the two high-rate filters. Effluent manganese concentrations also increased by a statistically significant amount but remained below the SMCL Mn of 0.050 mg/L. All other operational and water quality parameters remained consistent during the recycle period.
13. During the Well 2 recycle period filtered turbidity and effluent manganese remained at acceptable levels without any obvious impact from the introduction of recycle supernatant.

5.3 PFAS REMOVAL CONCLUSIONS

14. The high-rate GAC contactor operating at an Empty Bed Contact Time (EBCT) of 10 minutes reduced total PFAS6 concentrations to non-detectable levels in all four lab sampling events.
15. The high-rate GAC contactor treated 2,452 bed volumes of water during the pilot study without any indication of contaminant breakthrough based on the lab testing.

16. The high-rate ion exchange contactor operating at an Empty Bed Contact Time (EBCT) of 1.5 minutes reduced total PFAS6 concentrations to non-detectable levels in all four lab sampling events.
17. The high-rate ion exchange contactor treated 15,330 bed volumes of water during the pilot study without any indication of contaminant breakthrough based on the lab testing.
18. Two episodes of headloss development in the GAC and the IX contactors occurred during the pilot study due to breakdown of the dechlorination tablets upstream of the contactors. These events were pilot artifacts and would not occur in a full-scale application. There was no detectable trend of increasing headloss development for the remainder of the study.
19. SDS analysis of GAC and IX contactor effluent produced TTHM and HAA5 concentrations significantly below the respective MCLs of 80 and 60 µg/L.

Appendix E

Conceptual Treatment Plant Process Flow Diagram

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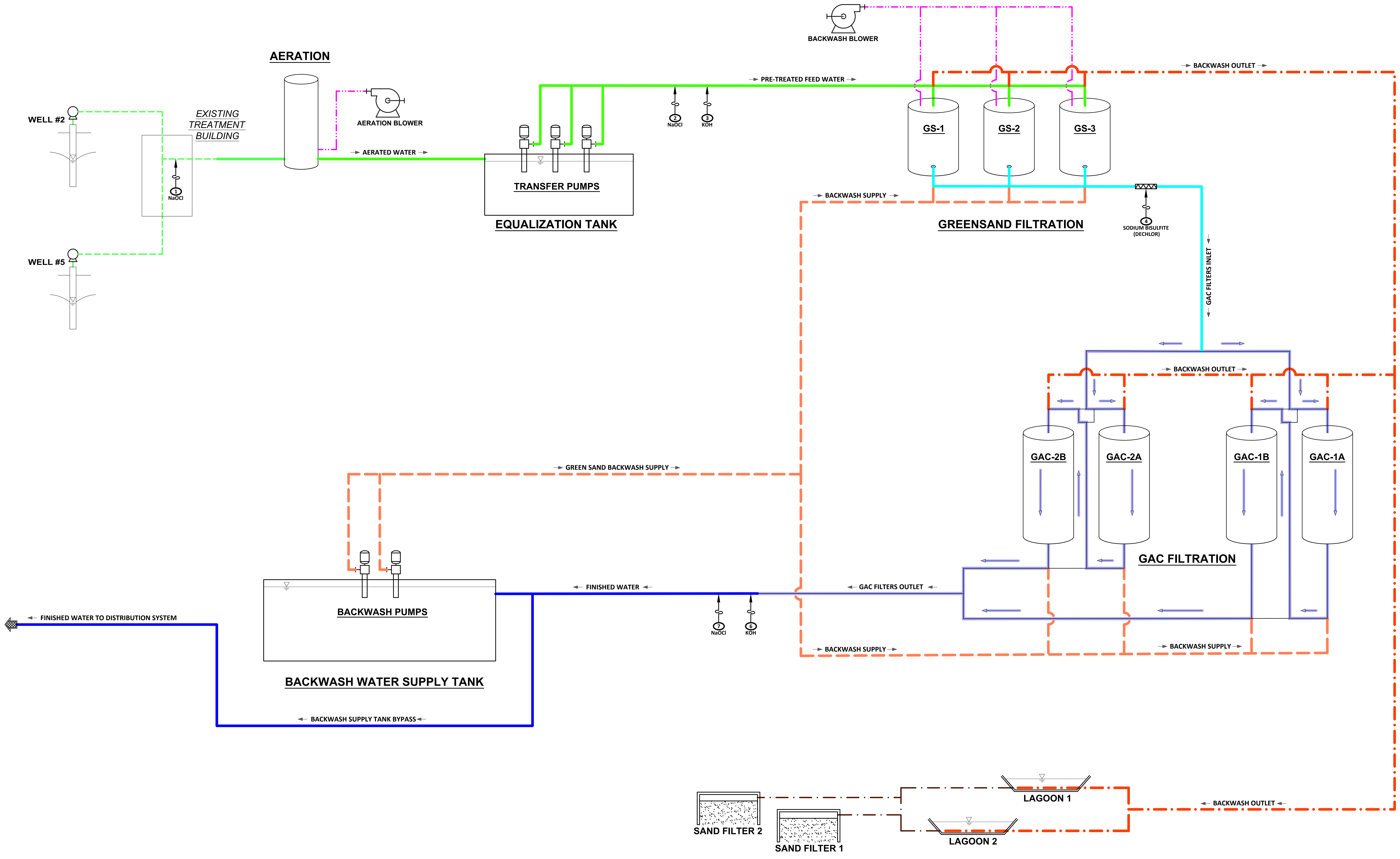
LEGEND

- EXISTING RAW WATER
- RAW WATER
- PRE-TREATED WATER
- GREENSAND FILTRATE
- BACKWASH SUPPLY
- BACKWASH OUTLET
- GAC FILTER PIPING
- GAC FILTER FLOW - LEAD LAG PARALLEL PAIRS
- FINISHED WATER
- RESIDUALS FILTRATE
- BLOWER AIR



NO	REVISIONS	APP'D	DATE
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PROJECT NO: 20521A
DESIGNED:
CAD COORD: W.BAILEY
CAD:
CHECKED:
DATE:
APPROVED:
DATE:
SUBMISSION: PDR

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BARNSTABLE FIRE DISTRICT WATER DEPT
WELL 2&5 WATER TREATMENT PLANT
BARNSTABLE, MASSACHUSETTS

PROCESS FLOW DIAGRAM

DRAWING
PR-1

Appendix F

BFDWD Lead and Copper – 90th Percentile Compliance Report, dated 10/14/2020

Massachusetts Department of Environmental Protection - Drinking Water Program **LCR-D**

Lead and Copper - 90th PERCENTILE COMPLIANCE Report

(For Systems Required to Collect More Than 5 Samples)

I. PWS INFORMATION: Please refer to your DEP Lead & Copper sampling plan for approved sampling locations.

PWS ID #: 4020000 **City / Town:** BARNSTABLE

PWS Name: BARNSTABLE FIRE DISTRICT WATER DEPARTMENT **PWS Class:** COM ☒ NTNC ☐

Sampling Frequency: (choose one)

☐ FIRST SEMI-ANNUAL SAMPLING PERIOD
☒ REDUCED - EVERY THREE YEARS
☐ SECOND SEMI-ANNUAL SAMPLING PERIOD
☐ LEAD SERVICE LINE (LSL) REPLACEMENT PROGRAM
☐ REDUCED – ANNUAL
☐ DEMONSTRATION

Step 1: Place lead results in ascending order (from lowest to highest value) with lowest value at # 1, in the table below. Repeat for *copper* results. Please report results that are ND or less than (<) the laboratory's reported detection limit (MDL) as zero. Results at or above the laboratory's detection limit (MDL) but below 0.005 mg/L for lead or 0.05 mg/L for copper shall be reported as measured or may be reported as 0.0025 mg/L for lead or 0.025 mg/L for copper.

Step 2: Multiply the total number of samples collected by 0.9 (this is your 90th percentile sample number). Round to the nearest whole number, if necessary.

Step 3: Compare the sample result at the 90th percentile sample number against the corresponding action level. If the 90th percentile value is higher than the action level, then you have an exceedance and are required to contact MassDEP as soon as possible for information on compliance actions.

Note: Do not include school results on this form unless the PWS is a school. Remember, within 30 days of receipt, you must send individual results to the persons served at each sampled location as per 310 CMR 22.06B(6)(c)[1]

LEAD RESULTS (mg/L)

#	Results	#	Results	#	Results	#	Results
1*	0	16	.0034	31		46	
2	0	17	.0034	32		47	
3	0	18	.0046	33		48	
4	0	19	.0054	34		49	
5	0	20	.0098	35		50	
6	.0010	21		36		51	
7	.0012	22		37		52	
8	.0013	23		38		53	
9	.0014	24		39		54	
10	.0018	25		40		55	
11	.0021	26		41		56	
12	.0021	27		42		57	
13	.0024	28		43		58	
14	.0025	29		44		59	
15	.0030	30		45		60	

COPPER RESULTS (mg/L)

#	Results	#	Results	#	Results	#	Results
1*	.015	16	0.19	31		46	
2	.024	17	0.20	32		47	
3	.025	18	0.21	33		48	
4	.030	19	0.24	34		49	
5	.030	20	0.51	35		50	
6	.030	21		36		51	
7	0.04	22		37		52	
8	0.12	23		38		53	
9	0.12	24		39		54	
10	0.12	25		40		55	
11	0.16	26		41		56	
12	0.16	27		42		57	
13	0.17	28		43		58	
14	0.18	29		44		59	
15	0.18	30		45		60	

***Lowest Value**

My system was required to collect: 20 lead and copper samples. My system collected: 20 lead and copper samples.

Total # of samples collected: 20 x 0.9 = 18 This number is my system's 90th percentile sample #.

Circle the 90th percentile sample # for both lead and copper in the table above, and enter the results in the appropriate spaces below.

.0046	Compared to **0.015 mg/L**	0.21	Compared to **1.3 mg/L**
(Lead result at 90th percentile sample#)	(The lead action level)	(Copper result at 90th percentile sample#)	(The copper action level)

II. CERTIFICATION:

Check and complete the correct statement for lead as determined by the above results. If you have an exceedance and you are a community system you must comply with the Consumer Confidence Rule (CCR) reporting requirements in accordance with 310 CMR 22.16A(4)(i)6.

☒ My system was **at or below** the lead action level.
☐ My system **exceeded** the lead action level and ________ sampling sites **exceeded** the lead action level.
(Insert # of samples)

Check and complete the correct statement for copper as determined from the above results. If you have an exceedance and you are a community system you must comply with the Consumer Confidence Rule (CCR) reporting requirements in accordance with 310 CMR 22.16A(4)(i)6.

☒ My system was **at or below** the copper action level.
☐ My system **exceeded** the copper action level and ________ sampling sites **exceeded** the copper action level.
(Insert # of samples)

My signature below indicates that all sampling sites on this report have been previously approved in writing by the DEP, and both the sites and sampling procedures used comply with 310 CMR 22.06B(7). I certify under penalty of law that I am the person authorized to fill out this form and the information contained herein is true, accurate and complete to the best of my knowledge and belief.

SUPERINTENDENT	Thomas J. Rooney	10/14/20
Title	Signature of PWS or Owner's Representative	Date

Please submit Form LCR-C along with this form. Rev. 02- 2019 Page 1 of 2

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[1] The Consumer notification form template is available at: https://www.mass.gov/lists/lead-and-copper-forms-and-templates#lead-and-copper-rule-lcr-

Massachusetts Department of Environmental Protection - Drinking Water Program **LCR-C**

Lead and Copper Analysis Report

I. PWS INFORMATION: Please refer to your MassDEP Lead & Copper sampling plan for approved sampling locations.

PWS ID #: 4020000 **City / Town:** BARNSTABLE

PWS Name: Barnstable Fire District Water Dept **PWS Class:** COM ☒ NTNC ☐ TNC ☐

Routine or Special Samples	Original, Resubmitted or Confirmation Report	If Resubmitted Report, list below: (1) Reason for Resubmission	(2) Collection Date of Original Sample
☒ RS ☐ SS	☒ Original ☐ Resubmitted ☐ Confirmation	☐ Resample ☐ Reanalysis ☐ Report Correction	

SAMPLE NOTES – (Such as, if a Manifold/Multiple sample, list the sources that were on-line during sample collection)

II. ANALYTICAL LABORATORY INFORMATION:

Primary Lab MA Cert. #: 009 **Primary Lab Name:** Barnstable County Health Lab **Subcontracted? (Y/N)** N

Analyte	Action Level (mg/L)	Lab Method	MDL (mg/L)	Analysis Lab MA Cert.#	Analysis Lab Name
Lead:	0.015	EPA200.8	0.0010	009	Barnstable County Health Lab
Copper:	1.3	EPA200.8	0.0010	009	Barnstable County Health lab

LAB SAMPLE NOTES

	MassDEP Approved Sample Location (See MassDEP approved LCR plan for sampling locations)	Collection Date	LEAD		COPPER		Lab Sample ID#
			Result (mg/L)	Date Analyzed	Result (mg/L)	Date Analyzed	
1	Bfd001 #145 Pine Lane	9/15/2020	0.0012	9/22/2020	0.17	9/22/2020	20122346-01
2	Bfd002 #91 Cobblestone Road	9/15/2020	0.0046	9/22/2020	0.51	9/22/2020	20122346-02
3	Bfd003 #59 Cypress Point Rd.	9/15/2020	0.0021	9/22/2020	0.21	9/22/2020	20122346-03
4	Bfd004 #58 Otter Lane	9/15/2020	0.0014	9/22/2020	0.030	9/22/2020	20122346-04
5	Bfd005 #256 Indian Trail	9/17/2020	0.00	9/23/2020	0.12	9/23/2020	20122397-01
6	Bfd007 115 Harrbor Point Road	9/17/2020	0.00	9/23/2020	0.034	9/23/2020	20122397-02
7	Bfd008 #78 Maushop Avenue	9/23/2020	0.0018	9/23/2020	0.12	9/23/2020	20122397-03
8	Bfd009 #28 Surgis Lane	9/17/2020	0.0098	9/23/2020	0.24	9/23/2020	20122397-04
9	Bfd010 #205 Palomino Drive	9/17/2020	0.0024	9/23/2020	0.19	9/23/2020	20122415-01
10	Bfd011 #27 Colonial Way	9/17/2020	0.0034	9/23/2020	0.030	9/22/2020	20122346-05
11	Bfd012 #84 Braggs Lane	9/16/2020	0.0034	9/18/2020	0.25	9/18/2020	20122375-01
12	Bfd013 #65 Cindy Lane	9/16/2020	0.0054	9/18/2020	0.18	9/18/2020	20122375-02
13	Bfd014 #56 Chickadee Lane	9/15/2020	0.0021	9/22/2020	.024	9/22/2020	20122346-06
14	Bfd 015 #293 Carriage Lane	9/16/2020	0.0030	9/18/2020	0.16	9/18/2020	20122375-03
15	Bfd016 #187 Keveny Lane	9/15/2020	0.00	9/22/2020	0.16	9/22/2020	20122346-07
16	Bfd 017 #21 Surrey Lane	9/16/2020	0.00	9/18/2020	0.04	9/18/2020	20122375-04
17	Bfd0018 1 Captain Murphy Way	9/15/2020	0.0025	9/22/2020	0.18	9/22/2020	20122346-08
18	Bfd019 #51 Boulder Road	9/16/2020	0.00	9/18/2020	0.12	9/18/2020	20122375-05
19	Bfd 020 #158 Dromoland Road	9/15/2020	0.0010	9/29/2020	0.15	9/2/2020	2012266-08
20	Bfd025 45 Congressional Drive	9/18/2020	0.0013	9/23/2020	0.20	9/23/2020	20122415-02
	Report SCHOOL RESULTS collected in accordance with 310 CMR 22.06B (7)(a)9 below. Do not use these school results in 90th percentile calculations.						
1	Bfd022 Bwb Sink Room #8	9/16/2020	0.00	10/2/2020	0.20	10/2/2020	20122373.02
2	Bfd027 Bwb Fountain	10/7/2020	0.00	10/8/2020	0.0048	10/8/2020	20122659-02
3	Bfd023 Trintiy School	9/16/2020	0.0014	9/18/2020	0.24	9/18/2020	20122372-01
4	Bfd024 Trinity School	9/16/2020	0.0021	9/18/2020	0.34	9/18/2020	20122372-02

I certify under penalties of law that I am the person authorized to fill out this form and the information contained herein is true, accurate and complete to the best extent of my knowledge

Primary Lab Director Signature:

Date: 19Oct20

If not submitting these results electronically, mail ONE copy of this report to your MassDEP Regional Office no later than 10 days after the end of the month in which you received this report or no later than 10 days after the end of the reporting period, whichever is sooner.

COM & NTNC public water suppliers must submit forms **LCR-D or LCR-E** with this form to the appropriate MassDEP Regional Office.

MassDEP REVIEW STATUS (Initial & Date)		Review Comments	
☐ Accepted	☐ Disapproved		

Rev.Oct 2016

Page _______ of _______

GZA GeoEnvironmental, Inc.