Whitney Pond Wells

Iron and Manganese Removal Treatment

Conceptual Design Report

Completed for

Groton Water Department

173 Main St

Groton, MA 01450

Completed by

Comprehensive Environmental, Inc.

45 Main Street

Bolton, MA 01740

September 28, 2020

Report

COMPREHENSIVE
ENVIRONMENTAL
INCORPORATED

www.ceiengineers.com

September 28, 2020

Groton Water Department
173 Main St
Groton, MA 01450

RE: Report on Conceptual Design
Iron and Manganese Removal Treatment Whitney Pond Wells

Dear Board of Water Commissioners:

In accordance with CEI's agreement with the Groton Water Department, this report presents the results of pilot testing and conceptual design development associated with the proposed treatment of the Whitney Pond Wells, specifically for removal of iron and manganese. Ultimately, the Board voted at its July 28, 2020 meeting to proceed with the design and construction of an independent treatment facility at the Whitney Pond Wells, designated as Option 3B in the Manganese Mitigation Alternatives Analysis and Compliance Plan (August 2019).

Please contact us at 508-281-5160 if you should have any questions.

Sincerely,
COMPREHENSIVE ENVIRONMENTAL INC

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Note:

- *The purpose of this conceptual design was to evaluate two potential options for treatment of Mn from the Whitney Pond Wells – 1) Expand existing Baddacook Treatment Facility and 2) Construct New Water Treatment Facility at Whitney Pond Wells.*
- *A decision matrix was prepared to compare these two options to enable GWD to make an informed decision.*
- *The selected option was to Construct a New Water Treatment Facility at the Whitney Pond Wells.*
- *For brevity, the alternative evaluation, conceptual design narrative, and drawings for the Baddacook expansion option have been omitted from the main body of this report; however, they can be viewed as **Appendix E.1**, **Appendix E.2,** and **Appendix E.3** for reference.*

1 Background and Water Quality

1.1 Background

The Groton Water Department (GWD) has approximately 1,953 service connections. All connections are served through one pressure zone with approximately 51 miles of distribution water main. The 1 million gallon (MG) Chestnut Hill Tank (also known as Brooks Orchard Tank) is the system's only active storage tank. The GWD supplies its customers with water from three wells in current operation (Baddacook Pond Well and Whitney Pond Wells #1 and #2).

This project is being completed to address elevated levels of manganese (Mn) at the Whitney Pond Wells. The Town was issued a letter from the Massachusetts Department of Environmental Protection (MassDEP) on February 25, 2019 indicating that Mn test results in Whitney Well #1 and Whitney Well #2 finish water exceed MassDEP's Office of Research and Standards Guidance Level for Mn. Because of these test results, MassDEP required that a draft compliance plan be submitted by September 1, 2019 to reduce the level of Mn to a level "reliably and consistently" below the 0.30 mg/L Health Advisory Level (HAL) at the entry point to the distribution system and "preferably" below the 0.05 mg/L Secondary Maximum Contaminant Level (SMCL).

In response to this letter, GWD retained Comprehensive Environmental, Inc (CEI) to perform an analysis of potential Mn mitigation alternatives, then prepare a proposed Manganese Corrective Action Plan in accordance with MassDEP requirements. The most favorable alternative would have the capacity to replace or exceed the approved maximum daily withdrawal of the Whitney Pond Wells (0.576 mgd) while cost effectively providing treated water below the SMCL. Results from the analysis indicated that the two highest ranked alternatives were to:

- Expand the existing Baddacook Treatment Facility to handle and treat additional flows from the Whitney Pond Wells and construct water main improvements to pipe untreated water from the Whitney Pond Wells to the Baddacook Treatment Facility (Option 3C); or
- Construct an independent treatment facility at the Whitney Pond Wells (Option 3B).

A proposed Manganese Corrective Action Plan was submitted to MassDEP in August 2019. MassDEP issued an Administrative Consent Order (ACO) on February 4, 2020 (copy provided in **Appendix A**) which includes the requirements for GWD to complete pilot testing, conceptual design, final design, and construction of a manganese treatment facility for the Whitney Pond Wells. Key deadlines from the ACO are as follows:

- <u>By September 30, 2021</u>: Address elevated levels of Mn at the Whitney Pond Wells, submit a WS25 permit application with design plans to expand the Baddacook Treatment Facility <u>or</u> submit a W23C permit application with design plans to construct a new Water Treatment Facility.
- <u>By December 31, 2024</u>: Submit confirmation to MassDEP that construction of the selected treatment option is complete and in operation.

1.2 Report Scope

To address requirements of the ACO, GWD retained CEI to develop and compare conceptual designs for the two potential treatment options. A pilot study for Mn removal at Whitney Pond Wells was performed by Blueleaf Inc to inform design of these options. A pilot study summary report was completed in June 2020 (see **Appendix B**). CEI's scope of work for the pilot study and conceptual design phase of this project generally consisted of the following tasks:

1.2.1 Pilot Study Scope

- Prepare and submit pilot test proposal to MassDEP for their review and approval.
- Attend kickoff meeting with the Town and Blueleaf.
- Notify MassDEP of the pilot schedule.
- Check in with Blueleaf during operation of the pilot equipment.
- Review Blueleaf's pilot test report, performance data and water quality data.
- Analyze process performance and make recommendations for facility design including filter loading rates, runtimes, chemical dosages and backwash handling.
- Provide summary of analysis and recommendations to be incorporated into the Conceptual Design Report.

1.2.2 Conceptual Design Phase Scope

- Perform review of the existing Baddacook Treatment Facility and Whitney Well Pump Station and Vault.
- Perform initial process evaluation and sizing based on pilot study results for each option.
- Consider the ability to accommodate the addition of Shattuck Wells and future potential treatment needs (i.e., PFAS removal).
- Develop process flow schematics and conceptual facility layouts for each option.
- Establish design criteria, cost estimates, and project schedules for each option.
- Perform evaluation of each option.
- Prepare draft conceptual design report that documents the preferred/selected alternative.
- Meet with the GWD to present the draft conceptual design report.
- Revise and finalize the conceptual design report per discussions with GWD.

1.3 Summary of Proposed Treatment Option

Conceptual designs were prepared for two options: 1) Expand the existing Baddacook Treatment Facility to handle and treat additional flows from the Whitney Pond Wells or 2) Construct an independent treatment facility at the Whitney Pond Wells. Once conceptual designs were developed for both options, a decision matrix was developed to enable relative scoring of each option. The selected option was to construct an independent treatment facility at the Whitney Pond Wells. Refer to **Appendix E.1** for a summary of the alternative selection process and to **Appendix E.2** / **E.3** for the expanded Baddacook conceptual design.

The proposed treatment option to construct a new iron and manganese treatment facility at the Whitney Pond Wells would include the following primary improvements:

- Construct new WTP and associated systems;
- Connect to existing Whitney Pond Wells;
- Construct backwash residuals handling system;
- Perform site improvements as needed (i.e., access road improvements, etc.)
- Connect new facility to the existing distribution system.

- This option will also include upgrades to Baddacook WTP's existing backwash handling system to improve performance.

1.4 Water Quality Regulatory Limits

The following overview provides a description of the contaminants of focus for this project and their associated regulatory limits. Mn is a mineral in drinking water which when present at elevated levels cause aesthetic and nuisance issues as follows: (1) stain laundry and water use fixtures; (2) clog household water filters; (3) prompt customer complaints; (4) support growth of Mn bacteria, non-health related bacteria that clog strainers/pumps/valves; and (5) may increase the number of coliform "hits" in the distribution system. The USEPA and MassDEP regulate Mn in drinking water as a Secondary Maximum Contaminant Level (SMCL) of 0.05 mg/L to protect public welfare and promote increased customer satisfaction. Levels above SMCLs lead to loss of customer confidence in water quality/health, resulting in customers seeking alternative supplies. The USEPA and MassDEP have also established a Health Advisory Level (HAL) for Mn of 0.3 mg/L. Over a lifetime, the USEPA recommends that people drink water with Mn levels less than 0.3 mg/L and over the short term, the USEPA recommends that people limit their consumption of water with levels over 1 mg/L, primarily due to concerns about possible neurological effects. Additionally, the USEPA recommends that children up to 1 year of age should not be given water with Mn concentrations over 0.3 mg/L.

The MassDEP states in the *Guidelines for Public Water Systems* (Chapter 5): "If the manganese concentrations in raw water exceeds 0.3 mg/L but are less than or equal to 1.0 mg/L, an assessment by MassDEP Office of Research and Standards will be necessary to determine if removal shall be required. If manganese concentrations in raw water exceed 1.0 mg/L, removal is required. If iron, manganese, or a combination thereof exceeds 1.0 mg/L, removal is required."

Note that Mn sequestering can help to mitigate the aesthetic impacts of Mn in drinking water but it does not remove the Mn, so the potential health risks remain.

1.5 Historical Water Quality

Water from the Baddacook Pond Well is treated for iron and manganese removal through pressure filtration (GreensandPlus™). The finished water for manganese is below the SMCL (0.05 mg/L) and HAL (0.3 mg/L). There are currently no Mn removal processes at the Whitney Pond Wells. The remainder of this section therefore focuses on water quality relative to the Whitney Pond Wells.

1.5.1 Manganese

Finish water Mn levels for the Whitney Pond Wells since 2010 as measured by a MassDEP certified laboratory are presented by **Figure 1-1**. Finish water Mn levels at the Whitney Pond Wells were typically below the 0.3 mg/L HAL until 2018 when levels abruptly increased. Mn levels at Whitney Well #1 are typically higher than Whitney Well #2. Blending of each well in an effort to reduce overall concentrations also resulted in levels above the HAL based on sampling results from May 2019 through May 2020.

GWD has been monitoring for Mn at key locations within the distribution system since August 2019. This data has been collected <u>for informational purposes only</u> and is not a MassDEP requirement. As indicated by **Table 1-1**, Mn levels in the distribution system only exceeded the HAL at 777 Boston Road on 10/8/2019.

Table 1-1. Distribution System – Historic Manganese Levels (August 2019 to June 2020)[1]

Sample Date	Chestnut Hill Tank (Orchard Lane)	173 Main Street	270 Farmers Row	777 Boston Road	147 Lowell Road	Skyfields Drive
8/16/2019	0.020	0.030	0.010	0.110	0.040	0.040
9/3/2019	0.080	0.050	0.040	0.260	0.110	0.110
9/3/2019		0.020	0.005	0.217	0.072	0.026
10/8/2019	0.100	0.090	0.080	0.320	0.170	0.090
12/12/2019		0.032	0.024	0.225	0.127	0.027
1/8/2020	0.012	0.023	0.029	0.157	0.015	0.027
2/5/2020	0.000	0.010	0.009	0.186	0.045	0.019
3/5/2020	0.000	0.017	0.005	0.183	0.019	0.000
4/2/2020	0.000	0.014	0.000	0.058	0.020	0.005
5/6/2020	0.010	0.015	0.017	0.107	0.095	0.030
6/1/2020	0.023	0.010	0.007	0.097	0.017	0.027

Table Notes:

1. Highlighted sample exceeded 0.30 mg/L HAL.
2. All Samples were analyzed by a certified laboratory with the exception of samples taken on 9/3/2019. Those samples were analyzed using bench top equipment.

[1] Data Source: Obtained from GWD via email on 6/4/2020,

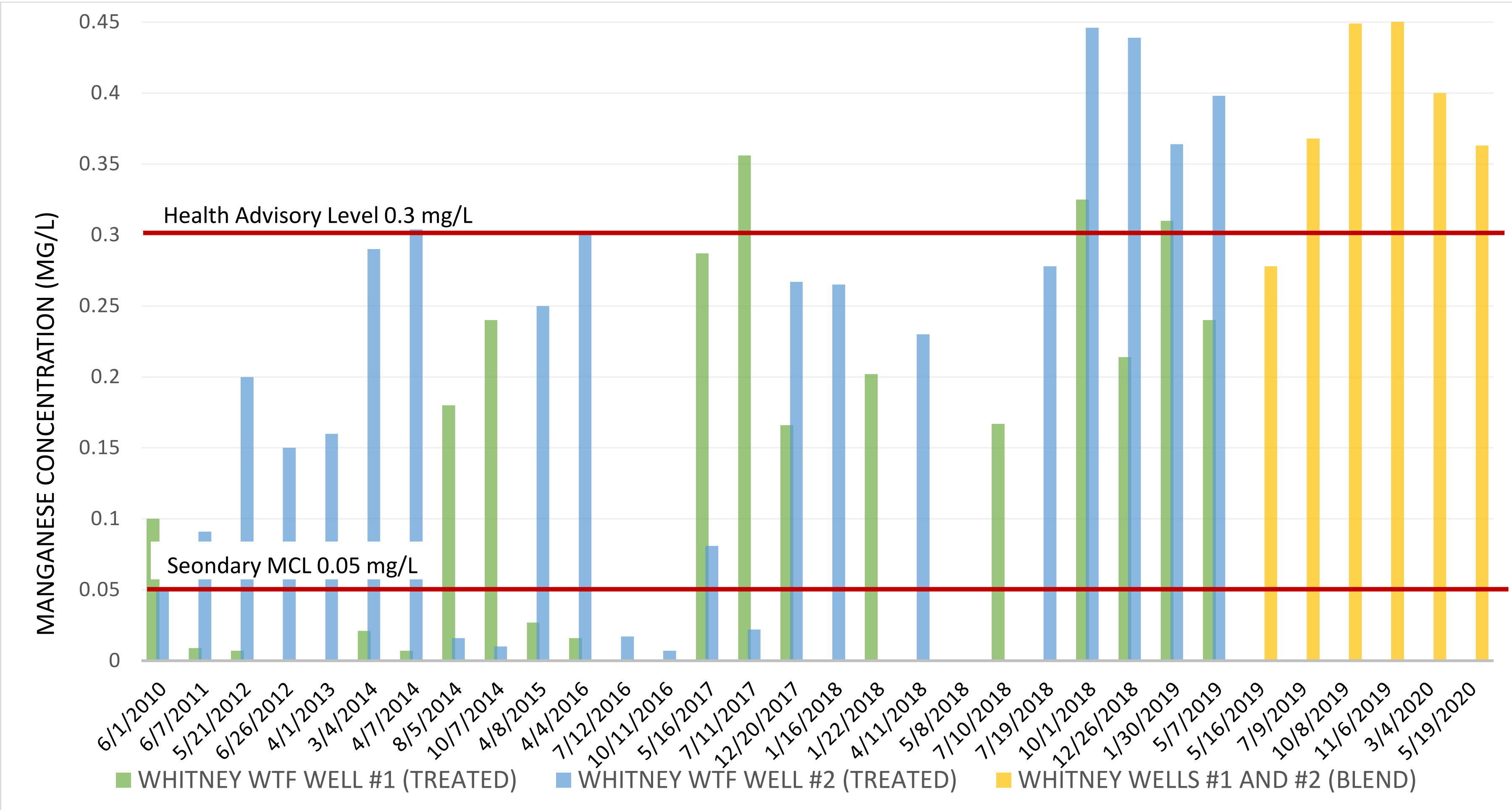

Figure 1-1. Whitney Well #1 and Whitney Well #2 – Historic Manganese Levels[2]

[2] Historic Water Quality Data Source: https://eeaonline.eea.state.ma.us/portal#!/search/drinking-water

1.5.2 Raw Water Quality, pH, and Corrosion Control

A summary of the raw water quality parameters at the blended Whitney Pond Wells as measured during the May 2020 Pilot Study via field analyses is provided by **Table 1**. The target pH leaving the blended Whitney Pond Wells is approximately 7.5-8.0. GWD achieves the pH goal by adding potassium hydroxide (KOH) to the raw well water at the Whitney Pond Wells.

Table 1. Raw Water Quality at Blended Whitney Pond Wells (5/12/2020 through 5/18/2020)

Parameter	Result
pH (Handheld), s.u.	**6.79** (6.41 – 7.18) [21]
Temperature, ^{o}C	**13.8** (11.9 – 16.4) [19]
Alkalinity (mg/L)	(53, 63) [2]
Carbon Dioxide (mg/L)	91 – 111 [2]
Total Organic Carbon (mg/L)	0.45 [1]

Table Notes:

1. *Data Source is* Table 3.01 from Blue Leaf Pilot Report, dated July 9, 2020.
2. Number of measurements are bracketed, e.g., [21]
3. Numbers in parentheses represent range.
4. Bold results represent average of measurements (if greater than 2 measurements taken)

1.6 Summary of Pilot Testing

Pilot testing was completed by Blueleaf Incorporated from May 11 through May 22, 2020 to evaluate the ability to treat Mn in the Blended Whitney Pond Wells using Greensand Filtration. The pilot study also evaluated the potential for blending Whitney Pond Well water with Baddacook Pond Well water; this evaluation was performed in order to determine if the blended water could be treated successfully through the existing Baddacook WTP as a short-term benefit of piping the raw water from the Whitney Wells to the Baddacook WTP, until the expansion of Baddacook WTP could be completed.

The pilot results demonstrated that the GreensandPlus media was successful in treating either the Whitney Wells separately or combined with the Baddacook Well. Ultimately, the decision was made to proceed with an independent treatment facility for the Whitney Wells. Therefore, this summary focuses on treatment of the blended Whitney Pond Wells.

The goals of the pilot study were as follows:

1. Demonstrate the ability of GreensandPlus filtration to remove iron and manganese to concentrations below the SMCL (0.3 mg/L Fe and 0.05 mg/L Mn), and pilot goals of 0.15 mg/L Fe and 0.025 mg/L Mn (50% for the respective SMCL).
2. Quantify the filter runtime to the point of contaminant breakthrough or terminal head loss at various Filter Surface Loading Rates to establish design parameter.
3. Quantify the rate at which pressure losses increase at various filter surface loading rates.
4. Provide chemical dosages for effective treatment conditions.

A copy of the Pilot Test Report prepared by Blueleaf is provided as an attachment (**Appendix B**). A summary of the pilot study is as follows:

1.6.1 Raw Mn Data

Mn concentrations were analyzed via laboratory (Alpha Analytical) and field analyses by Blueleaf. Mn samples analyzed by the laboratory ranged from 0.31 to 0.44 (6 samples). Field analysis results ranged from 0.29 mg/L to 0.41 mg/L with a median of 0.353 mg/L (13 samples). Most samples exceeded the SMCL of 0.05 mg/L and the HAL of 0.3 mg/L.

1.6.2 Pretreatment Water Quality

Pretreatment included pH adjustment with KOH to increase raw pH to approximately 7.2 and sodium hypochlorite to oxidize dissolved iron and manganese such that they could be removed as precipitated particles or adsorbed onto the adsorptive media.

- Oxidation with sodium hypochlorite (NaOCl) required an applied dose of approximately between 3.4 and 4.2 mg/L.
- Oxidation with NaOCl precipitated 75% to 90% of the dissolved raw water iron and 3% to 30% of the dissolved raw water manganese. Low rates of precipitation of manganese are typical for greensand filtration because the primary mode of removal is adsorption.
- Potassium hydroxide doses required to raise the raw water pH to 7.2 ranged from 5.5 to 4.2 mg/L.

Provisions will be made for pre-pH and post-pH adjustment, although the Town may choose to use just post-pH adjustment if iron/manganese removal determined to be acceptable without any pre-pH adjustment.

1.6.3 Filter Performance

The study used four filters to evaluate pretreatment using sodium hypochlorite for pre-oxidation and continuous regeneration of manganese dioxide coated media, and potassium hydroxide for pH adjustment. The pilot filters were operated at loading rates of 3, 5, 7 and 9 gpm/sf.

Filter run times were generally limited by the pilot schedule and were therefore ended prior to reaching terminal head loss (10 psi differential pressure). Estimated runtimes to 10 psi were determined by fitting a linear regression to recorded head loss data. Differential pressure (DP) across the filters increased over time as a function of filter loading rate and raw water quality. Results indicated that there was not a statistically significant difference when comparing filter effluent manganese concentrations from treatment with 18-inches vs. 24-inches of GreensandPlus Media. Results are therefore presented here for trials that utilized an 18-inch media depth. Projected runtimes to 10 psi during trials that used an 18-inch media depth ranged from 434 hours operating at 3 gpm/sf (Trial 1.4) to 125 hours at 9 gpm/sf (Trial 2.4). All filter trials met the Project Goal for total Fe < 0.3 mg/L and total Mn of < 0.05 mg/L.

1.6.4 Pilot Study Conclusions

- Oxidation with sodium hypochlorite (NaOCl) required an applied dose of between 3.4 and 4.2 mg/L.
- Potassium hydroxide doses required to raise the raw water pH to 7.2 ranged from 5.5 to 4.2 mg/L.
- Oxidation with NaOCl precipitated 75% to 90% of the dissolved raw water iron and 3% to 30% of the dissolved raw water manganese.
- All filter trials met the Project Goal for total Fe < 0.3 mg/L and total Mn of < 0.05 mg/L.
- Differential pressure (DP) across the filters increased over time as a function of filter loading rate

and raw water quality.

1.7 Conceptual Design Goals

Conceptual design goals for construction of a new treatment facility at the Whitney Pond Wells are as follows:

- Identify basic design criteria for the process, structure, mechanical and electrical components.
- Provide general facility layout an approximate floor plan.
- Provide preliminary cost estimate.
- Provide evaluation and comparison of options.

2 Existing Treatment Processes

2.1 Overview

Raw water from Whitney Pond Well #1 and Whitney Pond Well #2 is pumped and treated within the existing Whitney Pond Wells Pump Station. The water from these wells receives chemical treatment for disinfection with 12.5% sodium hypochlorite (NaOCL) and corrosion control and pH adjustment with 45% potassium hydroxide (KOH).

2.2 Existing Well Pumps

The Whitney Pond Wells (#1 and #2) are gravel packed with vertical turbine pumps. Pump operation (start/stop) is controlled by the SCADA system. The Whitney Pond Wells are permitted by MassDEP under the Water Management Act (WMA) Program. The Whitney Pond Wells are currently operated simultaneously and have a combined maximum pumping rate of 650 gpm (410 gpm from #1 and 240 gpm from #2). If the wells are pumped simultaneously, the combined pumping rate is not to exceed 0.576 mgd.

2.3 Existing Chemical Feed Systems

There are two chemical feed systems located at the Whitney Well pump station; (1) KOH and (2) NaOCl. These chemicals are stored within a separate containment area within the center of the pump. Both chemicals are stored within a dedicated day tank, with manual transfers from the manufacturer's containers. The injection nozzles for the chemicals are located downstream of the raw water sample tap.

2.4 Building Components

The existing Whitney Well #1 Pump Station structure consists of masonry construction, with standard CMU structural walls and painted exterior. The existing Whitney Well #2 Pump Station structure is entirely below grade, located directly over Whitney Well #2.

Note: Construction of a new treatment facility at the Whitney Pond Wells was selected as the preferred alternative. This option will also include upgrades to Baddacook WTP's existing backwash handling system to improve performance. See **Appendix E.1** and **Appendix E.2** for Baddacook conceptual design information, including existing backwash residuals handling methods.

3 Proposed Treatment Process

The sections below describe proposed process information details for the option to construct a new Whitney Pond Wells Treatment Facility.

3.1 Overview

CEI recommends that the new water treatment facility use GreensandPlus™ filtration as the primary process to consistently and reliably produce drinking water that meets the required regulatory limits. GreensandPlus™ filtration is a generally accepted technology for manganese (Mn) removal and it was successfully piloted for treatment of Whitney Pond Well as discussed in **Section 1.7** of this report. Additionally, the Town is familiar with this established treatment technology, as it is primary treatment process in the existing Baddacook WTP.

Treatment for the removal of Mn is achieved through oxidation, filtration, and adsorption. Mn can be oxidized to solid form, MnO_2(s), using sodium hypochlorite NaOCl. Therefore, the NaOCl will be injected within the new treatment facility before filtration to oxidize the Mn; KOH will also need to be injected before filtration to achieve the optimal pH of approximately 6.8 for manganese removal. Ultimately, chemically pre-treated water will be directed to the filtration system. The primary removal mechanism for any Mn not oxidized by the NaOCl will be through adsorption using an oxide-coated media (GreensandPlus™). After flowing through the new pressure filters, a post injection of NaOCl and KOH will take place before the water is discharged to the distribution system. The general treatment process will be as follows for each option:

- A chemical feed system will pre-treat raw well with KOH for pH adjustment and corrosion control and with NaCl for disinfection.
- Pre-treated water will be pumped to pressure vessels with GreensandPlus™ media for further treatment.
- Filter backwash water will be directed to a settling basin and infiltration lagoon.

3.2 Anticipated Design Flow Rate

The anticipated design flow rate will be 750 gpm to accommodate the capacity of the Whitney Pond Wells. As indicated by **Sections 3.2.1** and **3.3.1**, the pressure filtration systems will be sized conservatively to enable up to 200 gpm of additional capacity should future capacity increase (e.g., if a third Whitney Well is developed) or if Mn levels continue to increase. See **Section 3.3** for more details on filter sizing.

3.3 Proposed Pressure Filtration System

The pressure filtration system will be sized based on the capacity of the Whitney Pond Wells, 750 gpm. Manganese levels in the raw water may increase over time. Therefore, the filtration system will be designed with the capability to reduce elevated Mn levels below threshold levels.

As summarized by **Section 1.6**, pilot testing demonstrated that each of the loading rates examined (3.0, 5.0, 7.0, and 9.0 gpm/sf) were effective in reducing Mn levels in raw Whitney Pond Wells below 0.05 mg/L. Vessels will therefore be sized to handle a "normal" 5 gpm/sf loading rate and up to 7 gpm/sf "temporary" backwash loading rate with one cell offline.

The proposed filter layout for a new Whitney Pond Wells WTP consists of three 10-foot diameter vertical filters. Proposed filters will have a surface area of 78.5 sf. Assuming a designing flow of 750 gpm, the "normal" filter loading rate with both filters in operation will be approximately 3.2 gpm/sf. With one filter out of service for backwash, the "temporary" filter loading rate will be approximately 4.8 gpm/sf. This conservative filter size allows for future increases in flow rate or Mn levels in the well water without compromising the proposed treatment facility operation. For example, if future demands increase, GWD may explore the possibility of permitting and constructing a Whitney Pond Well #3. It is expected that the pressure vessels will be able to handle up to an additional 200 gpm with projected “normal” and “temporary” loading rates of 5 gpm/sf and 7.5 gpm/sf, respectively.

Each filter will contain the following media:

- Gravel support layer 12 inches in depth.
- GreensandPlus™ (media cut sheet provided in **Appendix D**) layer 24 inches in depth.
- Anthracite layer 12 inches in depth.

The interior of the filters will be equipped with an inlet distributor/backwash collector, underdrain system to collect filtered water, and air wash distributors to provide air scour during backwash. All internal piping and materials will be designed to be corrosion resistant.

The filter face piping system will consist of ductile iron pipe and fittings, control valves, manual butterfly valves for isolation, and magnetic flow meters for metering at various process flow locations. Filter face piping and valves for each filter will be designed so as to provide the ability to hydraulically balance the flow provided to each filter. A modulating control valve will be provided on the filter inlets (influent) and backwash supply inlets. Open/close control valves will be provided on the filter outlet (effluent), backwash waste, drain down, filter to waste (rinse), air pressurizing, and air wash control lines. Air supply piping will be stainless steel.

The system will also include air and vacuum valves located at the top of the filters, filter manways for access of the interior of the filters, sample taps, pressure gauges, differential pressure transmitters, a blower unit to introduce air during backwash and a filter control panel. Air release valves on the filters will be vented to the exterior of the building, to avoid release of moisture inside the building during filter operation and backwash.

The filter control panel (FCP) will include the ability to select whether the operator wants equal flow supplied to each filter (inlet valves modulate) or to allow hydraulics to govern and naturally balance filter flows (inlet valve full open). The influent pipe will connect to the filter face piping at the center of the three-vessel arrangement, to provide a hydraulic balance of flows between the three filters as much as possible.

Backwashing will be setup to be initiated automatically or alarmed/signaled as needed by one of three methods: (1) on head loss across the filter (discussed previously), (2) on run time by a timer in the FCP PLC, or (3) on production flow by a flow totalizer in the FCP PLC. The operator will be able to select whether he wants the system to backwash automatically when needed without an operator present or to alarm/signal when a backwash is needed allowing for the operator to go to the facility to trigger a backwash (known as semi-automatic backwash). The setpoints (SPs) for these conditions will be manually adjustable via the FCP Operator Interface Terminal (OIT). Regardless of whether the backwash was initiated automatically or semi-automatically, the actual backwash sequence proceeds “automatically” through prescribed steps. This setup provides the operator with the most flexibility in controlling the system in terms of when a backwash occurs, allowing the operators to manage the timing of backwashes so as to not conflict with backwashing of filters at the Baddacook WTP.

3.4 Backwash Residual Handling Methods

The filter backwash process will generate backwash residuals that require handling and disposal. After a filter has been in operation for a period of time, an accumulation of suspended solids may build up in the filter media. The filters will require periodic cleaning after a certain amount of run time/treated water volume, when the differential pressure reaches about 8 to 10 psi, or when the water quality indicates it is necessary based on an increase in the filtered Mn levels. The filter backwash process involves reversal of flow through the filter.

During the "backwash cycle" the mixed media of a filter is expanded (fluidized) using the pressure of the backwash air and water in a controlled manner. The accumulated solids trapped within the media are released and washed up through the expanded bed and discharged into the backwash waste piping. The backwash includes multiple steps including drain down, air pressurization, air scour, low flow/air scour concurrent wash, high rate water wash and filter to waste.

The backwash waste generated during this process will consist of water with concentrated levels of Mn that were removed from the well water during treatment. The amount of backwash generated depends on the volume of water treated, frequency of backwash, specific settings for backwash cycle, and amount of particulates removed. The required frequency of backwash, volume of backwash waste produced and the quality of the backwash waste are estimated below based upon pilot testing information.

Backwash waste can be handled in several different ways: (1) discharge to residuals-holding basin and local sewer system; (2) discharge to on-site residuals-handling lagoons; (3) discharge to a combination of a residuals-holding basin, infiltration lagoon and local sewer system; (4) mechanical dewatering methods. There is currently no sewerage available adjacent to either treatment option. Mechanical dewatering methods are rarely used for these types of facilities, as it inherently creates an additional level of operational complexity and increases overall costs (capital and operational). Therefore, discharge to on-site residuals-handling lagoons has been selected as the proposed backwash handling method. GWD has adequate space on both sites to accommodate this option.

For this method, backwash waste would be discharged to a residuals-handling settling basin where the Mn solids would settle and collect at the bottom. The settling basin would be rectangular in shape and may include a series of baffles to encourage settling of solids. Clarified supernatant would flow from the settling basin to an unlined infiltration basin for percolation into the ground. Over time the Mn solids collecting at the bottom of the settling basin would form a solids “cake” which would be periodically removed and disposed of legally to an appropriate disposal facility.

The MassDEP has a draft policy entitled “Permit Requirements for the Disposal of Water Treatment Plant Residuals to Lagoon Systems”. The policy states that a Groundwater Discharge Permit is required for new water treatment facilities using unlined lagoons for handling of process residuals. Alternatively, the facility can be constructed with two lined lagoons (or a concrete settling basin) (operated in parallel) for solids settling with the supernatant discharging to a third unlined lagoon for percolation into the ground. With this design, the groundwater standards would be considered as met and a permit would not be required.

Refer to **Section 3.8** for specific design details of each proposed facility’s backwash residual handling configuration and sizing.

3.5 Chemical Feed System

The existing Whitney Pump Station has chemical feed systems KOH and NaOCl. This equipment will be re-purposed and/or modified as follows. The facility design flows used to determine chemical feed requirements are listed below:

- Low Flow of 500 gpm
- Design Flow of 750 gpm
- Max Flow of 750 gpm

3.5.1 Potassium Hydroxide Feed System

The existing KOH feed system at the Whitney Pond Wells provides pH adjustment prior to entering the distribution system. The KOH is delivered to station via tanker trucks at 45% dilution. The KOH is delivered to the system through a metered injection within the station. Pilot testing indicated that the pH of the raw water (6.79) will need to be increased to a target level of 7.2 for the manganese removal processes.

For the proposed facility at Whitney Pond Wells, the intent is for the KOH feed system to be relocated from the existing pump station into the new WTP. This will make the KOH feed system easier to manage and maintain as it will be under the same roof as the rest of the WTP. Trucks performing chemical deliveries will have easier access to the proposed WTP because it will be surrounded by a circular driveway.

Given the existing water quality, the anticipated KOH feed rates based on use of 45% potassium hydroxide are shown in **Table 3-1.** The pre-filter dosages were determined using the RTW model, as confirmed by the pilot testing, using a raw water 6.7 pH and target pre-filtered water 6.8 pH. The post-filter dosages were determined using the RTW model and adjusting from the filtered water pH of 6.8 to a target pH of 7.7 for finished water, to be consistent with the current operations for corrosion control.

Table 3-1. Anticipated Potassium Hydroxide Dosages and Feed Rates

Dosages and Feed Rates	Dosage	Feed Rate[3,4] (gallons per hour)
Pre-Filter Dosages		
Low Dose	3.0 mg/L	0.14 gph
Design Dose	5.0 mg/L	0.35 gph
Maximum Dose	5.5 mg/L	0.39 gph
Post-Filter Dosages		
Low Feed Rate[1]	19.5 mg/L	0.93 gph
Design Feed Rate[2]	20.0 mg/L	1.40 gph
Maximum Feed Rate[2]	20.5 mg/L	1.44 gph

Table Notes:

[1]Low feed rate is based on a facility flow rate of 0.75 mgd (i.e., Appx. 500 gpm) and dose calculated using the RTW Model.

[2]Design and maximum feed rates are based on a facility flow rate of 1.10 mgd (i.e., Appx. 750 gpm) and dose calculated using the RTW Model.

[3]All rates assume 24 hour operation

[4]These design feed rates translate to a combined bulk storage quantity for a month of 650 gallons. To provide 30 hours of chemical storage in day tanks, approximately 55 gallons of combined storage is required.

3.5.2 Sodium Hypochlorite Feed System

NaOCl is used for manganese oxidation and media regeneration. NaOCl is typically dosed based on the levels of Mn in the raw water and the chlorine demand of the oxide-coated media, with a goal to carry approximately 0.2 to 0.5 mg/L residual chlorine in the filter effluent. However, NaOCl does not oxidize the manganese easily. In fact, the pH would need to be adjusted to higher than 8.5 to affect the manganese oxidation reaction using NaOCl. Therefore, the NaOCl dosages are primarily based on the level required for continuous regeneration of the media and any desired residual for the finished water.

The intent is to relocate the existing NaOCl feed system to the proposed facility for improved chemical containment, storage, and pre/post injection.

Given the existing water quality, the anticipated NaOCl feed rates based on use of 12.5% sodium hypochlorite with a 1:1 dilution (6.25% solution) to minimize off-gassing issues are shown in **Table 3-2**.

Table 3-2. Anticipated Sodium Hypochlorite Dosages and Feed Rates

Dosages and Feed Rates	Dosage	Feed Rate (gallons per hour)
Pre-Filter Dosages		
Minimum Dose	0.5 mg/L	0.21 gph
Design Dose	1.0 mg/L	0.61 gph
Maximum Dose	1.5 mg/L	0.91 gph
Post-Filter Dosages		
Minimum Dose	0.8 mg/L	0.33 gph
Design Dose	1.0 mg/L	0.61 gph
Maximum Dose	1.5 mg/L	0.91 gph

These design feed rates translate to use of a 40 gallon day tank with bulk storage accommodated through onsite storage of manufacturer's shipping containers (drums, carboys, buckets). Expected NaOCl consumption is 436 gallons per month.

3.6 Backwash Supply

The Town's potable water distribution system runs closest to the Whitney Pond Wells along Route 40, also known as Lowell St. A connection to the distribution system would be made at this location to supply necessary backwash water.

3.7 Anticipated Backwash Residuals Volume and Quality

Based upon the pilot test results, it is anticipated that each filter will need to be backwashed at least every 2 to 4 days of runtime. For every complete backwash cycle of all three (3) pressure filters, it is anticipated that 4,700 cf of backwash water will be generated.

3.8 Backwash Residuals Handling Methods

As part of the proposed Whitney Pond Wells WTP, the backwash handling system will be configured as follows: Two (2) concrete backwash settling basins will be constructed upgradient of the proposed WTP. The settling basins will be installed in parallel. Each settling basin will be sized to handle backwash from all three (3) filters (4,800 cf) such that one settling basin can be taken offline for maintenance without interrupting operations. Each settling basin will be rectangular and will have a series of baffles to encourage settling of solids. A decanter will be installed at the outlet of each settling basin to draw supernatant into a downstream infiltration lagoon.

Note: Construction of a new treatment facility at the Whitney Pond Wells was selected as the preferred alternative. This option will also include upgrades to Baddacook WTP's existing backwash handling system to improve performance. See **Appendix E.1** and **Appendix E.2** for Baddacook conceptual design information, including proposed backwash residuals handling methods and design criteria.

3.9 Design Criteria

The following is a summary of design criteria for the treatment process equipment needed for removal of Mn:

PROCESS EQUIPMENT

GreensandPlus™ System

Design Flow Rate .... 750 gpm

Filter Configuration.. Vertical Vessels

Number of Vessels.. 3

Surface Area per Filter Cell.. 63.6 ft^2

Dimension of Vessels .... 10 ft diameter

Depth of Anthracite Media.. 12 inches

Depth of GreensandPlus Media .... 24 inches

Depth of Support Gravel .... 12 inches

Filter Service Rate at Design Flow .... 3.9 gpm/ft^2

Filter Service Rate with One Filter in Backwash....................... 5.9 gpm/ft^2

Filter Backwash System.. Air/Water and Water

Filter Backwash Rate (preliminary):

Simultaneous Air/Water Backwash .... 5 gpm/ft^2

Duration .... 12 minutes

Water Only Wash (restratification) .... 12 gpm/ft^2

Duration .... 3 minutes

Filter Vessel Material .... Painted Steel

Piping (Water)... Ductile Iron

Piping (Air).. Stainless Steel

Filter Control Valves............ Hydraulically-Operated Globe Style (Cla-Val)

Modulating Valves .... Filter Influent and Backwash Supply

Open Close ValvesFilter Effluent, Drain Down, Rinse, Air Pressure, Air Control

Manual Isolation valves... Butterfly Valves

Flow Meters .... Magnetic Flow Meters

Air Release Valves.................................... Pipe to Exterior of Facility

Filter Control Panel .... PLC with OIT

Chemical Pumping Equipment Modifications

Chemical.. KOH 45% Solution (Existing System)

Application Point .... Raw and Finished water

ModificationsRelocate chemicals and pre/post injection to the new facility

Chemical................................ NaOCl 12.5% Solution (Existing System)

Application Point .... Raw and Finished water

ModificationsRelocate chemicals and pre/post injection to the new facility

Well Pumps Modifications (to be verified during detailed design phase)

Number of Pumps to Modify... 1

Type of Pumps... Vertical Turbine

Modifications.................................... VFD and adjust for increased TDH

Backwash Supply

Type ....Backwash Supply from Distribution System

Design Backwash Flow Rate for Each Filter ....450 to 1,000 gpm

Surge Protection ....Speed Control and Surge Relief Valve

Backwash Residuals Handling

Method.. Method 2

Settling Basin Volume (each basin) ....4,800 cf

Number of Basins 2

Number of Pumps... 2

Refer to **Appendix C** for Conceptual Design Plans for the New Whitney Pond Wells Treatment Facility, including a site layout, floor layout, and process schematic.

4 Facility Construction

4.1 Overview

Green concept design elements will be evaluated for incorporation into the design where possible and cost effective. These design elements may include but not be limited to the following:

- Pumping systems using variable frequency drive units to reduce energy usage and associated energy costs. Pumps selection for operations at or near to their maximum efficiency points.
- Energy saving instantaneous hot water heating systems for emergency eyewash/shower units required by code for tempered water.
- Separate spaces for areas that require more frequent air changes for health/safety reasons (chemical areas) to improve HVAC efficiency and energy usage.
- Ceiling fans in filter room to better circulate air helping to improve both heating and cooling.
- Use of programmable heating thermostats.
- Storm water handling systems that provide water treatment and cooling to improve overall water quality as it infiltrates to the ground.
- Solar power system for on-site energy use and supplemental electricity to grid. Use of solar power will be evaluated during the design.
- Energy efficient lighting systems including motion sensors and LED lighting.

4.2 Facility Overview

For the option to construct a new WTP at the Whitney Pond Wells, CEI recommends the facility be located in the area northeast of the existing Whitney well pump station, with the exact layout dependent upon site topography and the required treatment layout. The site location is generally flat with relatively no underground utility, and allows for locating the treatment facility and all associated basins (backwash supernatant and stormwater) outside of DCR's Watershed Protection Area boundary.

4.3 Facility Structure

The Filter System addition will be classified as a Type F building occupancy. The proposed structure will be a pre-engineered pre-fabricated metal building. The foundation will be constructed of reinforced concrete, inclusive of any footing walls. The superstructure will have a gable roof (minimal pitch). The proposed structure will have two sets of exterior metal double doors, at opposite ends of the facility.

The reinforced concrete design will be in accordance with ACI 318, Building Code Requirements for Structural Concrete, and ACI 350, Code Requirements for Environmental Engineering Concrete Structures, as applicable. ACI 350 defines more stringent design criteria resulting in a more impermeable structure where crack control and resistance to chemical attack are especially important. Concrete design strength will be 4,500 psi and reinforcement will conform to American Society of Testing and Materials (ASTM) A615 grade 60 deformed bars. Design live loads will meet the latest edition of the Massachusetts Building Code and operational requirements. Design conditions include floor, snow, wind, earthquake, earth pressure and operational loads including fluid pressures and equipment loads.

The structure will have a straight wall height of 16 feet to accommodate the filters. The peak of the roof will be centered in the building (standard for pre-engineered pre-fabricated metal buildings).

4.4 Mechanical and Electrical Systems

4.4.1 Plumbing

The treatment facility will have emergency eyewash stations that are supplied with tempered water from an instantaneous electric water heater. Hose bibs will be distributed around the facility.

A condensation collection area encompassing the filters and filter face piping will be provided, using sloped floors surfaces. Condensation discharge will be piped to the onsite stormwater handling basin.

Propane piping shall be installed and will be connected to the new HVAC propane fired unit heaters with unions, dirt legs, full-size shut-off valves, and an exhaust flume.

Stormwater run-off from the roof will be collected by gutters and transported through downspouts to downspout boots that will connect below grade to the onsite stormwater handling basin.

An automatic fire sprinkler system is not expected to be required to be installed, since the floor area is well below the threshold that would require fire sprinklers and there will be limited chemical storage within the new facility. The Massachusetts Building Code 780 CMR 8th Edition Chapter 9, table 903.2 indicates only Type F building occupancy classification over 12,000 sq/ft are required to have an automatic sprinkler system. However, this will be evaluated further during the detailed design phase, since specific quantities of chemical storage may require an automatic fire sprinkler system.

4.4.2 HVAC

It is standard procedure to heat treatment facilities using propane-fire unit heaters supplemented by a heat pump for in-office air conditioning. Since the Town has its own Electric Light Department, GWD is subject to low electrical rates. During the final design, an evaluation will be performed to look into alternative heating options that utilize electrical components given this unique situation.

The heating system will be designed for up to 70-degrees inside temperature. Each unit heater in the Filter Room will have a remote-mounted two-stage thermostat. A 5-kW electric unit heater with a remote-mounted thermostat is planned for the separate rooms, although the potential use of a wall mounted propane fired unit heater or split ductless heat pump should be considered during the final design (especially for the Control Room). A split-system dehumidifier designed for low temperature application (50-degrees) will provide dehumidification for the Filter Room. The basis of design will be Desert Aire model LT-1500. The packaged system includes a remote-mounted temperature and humidity controller.

The Filter Room will be ventilated by a wall-mounted propeller exhaust fan and a gravity outdoor air intake. Intake and exhaust openings will be protected by automatic control dampers that have low-leakage weather seals. The fans and interlocked dampers will be initiated by a remote-mounted cooling thermostat. The systems will be designed to provide six air changes per hour of outdoor air.

4.4.3 Electrical

The proposed facility may require a new service, separate from the existing Whitney Wells Pump Station. A new 480V, 3-phase panelboard shall provide power to the new dehumidifier, electric unit heaters, condenser, process blower and backwash residuals handling pumps. A new 30KVA transformer shall provide 120/208V, 3-phase power to a new 100A branch circuit panelboard for power to lighting, receptacle, gas unit heaters, exhaust fans, louvers and the filter control panel.

The proposed facility will be provided with emergency power using an emergency standby power generator that provides power to the entire facility during a loss of utility power via an automatic transfer switch. Emergency battery lighting units will be provided throughout the facility and at the exit doors to provide code required emergency egress lighting. Exit signs with integral battery backup units shall be mounted over exit doors.

5 Planning Cost Estimate

5.1 Funding

GWD is currently considering options to fund construction of the selected alternative. Potential options include: 1) the State Revolving Fund (SRF) administered through the Massachusetts Water Pollution Abatement Trust and the Massachusetts Department of Environmental Protection (MassDEP) or 2) obtain private loan.

5.2 Capital Costs

The American Association of Cost Engineers (per ANSI Standard Z94.0-1989) has defined levels of accuracy that are commonly used by professional cost estimators. Three categories of accuracy include: (1) order-of- magnitude, (2) budget, and (3) definitive estimates. The estimates of comparative cost presented in this report are considered order-of-magnitude, and were developed with limited engineering detail for comparison purposes. Cost estimates reflect historical construction costs scaled forward to 2022 (anticipated bid date) and are based on work of a similar nature. If construction occurs beyond this time frame, then the cost estimating will need to be re-evaluated. To estimate the future cost in 2022, the Real Discount Rate (3%) from the United States Office of Management and Budget was implemented to extrapolate beyond the current ENR index. Actual project costs may vary from this preliminary estimate as a result of additional engineering detail and other cost-related variables.

In addition to the traditional engineering and construction costs associated with capital projects of this nature, Massachusetts has additional requirements for an Owner's Project Manager (OPM). Per Massachusetts General Law (M.G.L. c.149 §44½), for public building contracts that are estimated to cost $1.5 million or more, the jurisdiction must contract with or assign a qualified OPM to serve as the jurisdiction's agent during the planning, design and implementation of the contract. The OPM must be independent of the project designer, general contractor or any subcontractor. The District may elect to assign the role of the OPM to a qualified in-house individual or hire an outside OPM. For the purposes of this report, we have assumed that the District will use qualified staff in-house for the role of OPM.

An order-of-magnitude cost estimates is shown by **Table 5-1**

Table 5-1. Whitney Pond Wells WTP Order-of-Magnitude Project Costs

Item	Unit of Measure	Quantity	Unit Cost	Total
Treatment				
Pilot Testing	LS	1	$ 39,500	$ 39,500
Engineering Design and Permitting	LS	1	$ 250,000	$ 250,000
OPM Design Phase	LS	1	$ 70,000	$ 70,000
Engineering Bid and Construction Phase	LS	1	$ 200,000	$ 200,000
Engineering Field - Resident Services	LS	1	$ 190,000	$ 190,000
OPM Construction Phase	LS	1	$ 70,000	$ 70,000
Materials Testing	LS	1	$ 20,000	$ 20,000
Electrical Services Cost	LS	1	$ 20,000	$ 20,000
Construction of the Project[1]	LS	1	$ 4,230,000	$ 4,230,000
			Subtotal	$ 5,089,500
			15% Contingency	$ 763,425
			Total	$ 5,852,925
			Total with inflation (2019-2022)	**$ 6,590,000**

[1] Design phase costs are not typically eligible for funding through the State Revolving Fund (SRF) program. Design phase costs include permitting. Permits anticipated include MassDEP Treatment Facility Construction, DCR Watershed Protection Area and Conservation Commission Notice of Intent.

[2] Construction cost estimate for Whitney Wells WTP includes allowance of $350,000 for improvements to the backwash waste handling system at the Baddacook WTP.

[3] Cost as submitted in SRF Project Evaluation Form (PEF) August 2019.

6 Anticipated Project Schedule

A detailed anticipated project schedule is provided by **Table 6-1**. The Project Schedule has been configured to meet key deadlines from the **Appendix A** MassDEP ACO. Key deadlines from the ACO are as follows:

- By September 30, 2021: Prepare and submit a W23C permit application to MassDEP with design plans to construct a new Water Treatment Facility.
- By December 31, 2024: Submit confirmation to MassDEP that construction of the selected treatment option is complete and in operation.

Table 6-1. Anticipated Project Schedule

Year	Quarter	Months
2019	Q3	July, August, September
2019	Q4	October, November, December
2020	Q1	January, February, March
2020	Q2	April, May, June
2020	Q3	July, August, September
2020	Q4	October, November, December
2021	Q1	January, February, March
2021	Q2	April, May, June
2021	Q3	July, August, September
2021	Q4	October, November, December
2022	Q1	January, February, March
2022	Q2	April, May, June
2022	Q3	July, August, September
2022	Q4	October, November, December
2023	Q1	January, February, March
2023	Q2	April, May, June
2023	Q3	July, August, September
2023	Q4	October, November, December
2024	Q1	January, February, March
2024	Q2	April, May, June
2024	Q3	July, August, September
2024	Q4	October, November, December

Activity	Completion Date
Coordination with MassDEP on Mnaganese Compliance	
Prep./submit prop. Manganese Compliance Plan to MassDEP	9/1/2019
MassDEP Review of Compliance Plan	12/31/2019
Prepare/submit Final Manganese Compliance Plan to MassDEP	2/1/2020
Manganese Removal Treatment Facility at Whitney Wells	
Prepare Pilot Protocol and Submit to DEP **(Permit WS 21)**	3/31/2019
Conduct Pilot Testing **(Permit WS 22)**	7/31/2020
Complete Pilot Study Report and Conceptual Design	10/31/2020
Approval of Appropriation at Annual Town Meeting	6/30/2021
Deadline for decision to pursue SRF Funding	8/15/2021
Design and Preparation of Bid Documents **(Permit WS 23C)**	9/30/2021
Pre-qualification	3/31/2022
Bid Period (Filed Sub-bids and General Bids)	6/30/2022
Review/Evaluate of General Bids	7/31/2022
DWSRF Program Review & Approval to Award	12/31/2022
Project Award / Execution of Construction Contract	3/31/2023
Construction of Manganese Removal Treatment Facility	9/31/2024
Facility Startup and Testing	11/30/2024
Final Inspection (Building Inspector and MassDEP)	12/31/2024
Manganese Treatment Facility Online	12/31/2024

Appendix A. MassDEP Groton-ACO

COMMONWEALTH OF MASSACHUSETTS
EXECUTIVE OFFICE OF ENERGY AND ENVIRONMENTAL AFFAIRS
DEPARTMENT OF ENVIRONMENTAL PROTECTION

In the matter of:

Town of Groton

Enforcement Document Number:
ACO-CE-20-5D00008483
Issuing Bureau: BWR
Issuing Region/Office: CERO
Issuing Program: DWP
Primary Program Cited: DWP
Program ID # 2115000

ADMINISTRATIVE CONSENT ORDER

I. THE PARTIES

1. The Department of Environmental Protection ("Department" or "MassDEP") is a duly constituted agency of the Commonwealth of Massachusetts established pursuant to M.G.L. c. 21A, § 7. MassDEP maintains its principal office at One Winter Street, Boston, Massachusetts 02108, and its Central Regional Office at 8 New Bond Street, Worcester, MA 01606.

2. Town of Groton ("Respondent") is a municipality with its principal offices located at 173 Main Street, Groton, MA 01450. Respondent's mailing address for purposes of this Consent Order is 173 Main Street, Groton, MA 01450.

II. STATEMENT OF FACTS AND LAW

3. MassDEP has primary enforcement responsibility for the requirements of the Federal Safe Drinking Water Act, 42 U.S.C. §300f et seq. and the regulations promulgated there under. MassDEP implements and enforces statutes and regulations of the Commonwealth of Massachusetts for the protection of the public drinking water supply, including, without limitation, M.G.L. c. 111, §5G and §160 and the Drinking Water Regulations at 310 CMR 22.00; the Cross Connections, Distribution System Protection Regulations at 310 CMR 22.22; and the Underground Injection Control Regulations at 310 CMR 27.00. MassDEP, pursuant to M.G.L. c. 111, §160, may issue such orders as it deems necessary to ensure the delivery of fit and pure drinking water by public water systems to all consumers. MassDEP, pursuant to M.G.L. c. 111, §5G, may require by order the provision and operation of such treatment facilities as it deems necessary to ensure the delivery of a safe water supply to all consumers.

MassDEP's Drinking Water Regulations at 310 CMR 22.02 define a public water system as a system for the provision to the public of water for human consumption, through pipes or other constructed conveyances, if such system has at least 15 service connections or regularly serves an

average of at least 25 individuals daily at least 60 days of the year. 310 CMR 22.02 also defines a supplier of water as "any person who owns or operates a public water system."
MassDEP has authority under M.G.L. c. 21A, § 16 and the Administrative Penalty Regulations at 310 CMR 5.00 to assess civil administrative penalties to persons in noncompliance with the laws and regulations set forth above.

4. Respondent, a supplier of water, owns and operates a Community Public Water System ("PWS"), referred to as the Groton Water Department ("GWD") serving a population of 5,529 persons per day from a three gravel packed wells (Baddacook Pond Well - "Well 02G", Whitney Pond Well #1 – "Well 03G" and Whitney Pond Well #2 – "Well 04G") under identification number PWS ID# 2115000.

5. The following facts and allegations have led MassDEP to issue this Consent Order:

A. In October 2013, MassDEP's Office of Research and Standards established health advisory guidelines for manganese in Massachusetts drinking waters (ORSG). The ORSG includes a lifetime health advisory value of 0.3 mg/L to protect against concerns of potential neurological effects and a 10-day health advisory of 1 mg/L for acute exposure. MassDEP recommends that infants up to 1 year of age should not be given water with manganese concentrations greater than 0.3 mg/L for more than a total of 10 days in a year, nor should the water be used to make formula for more than a total of 10 days in a year.

B. On February 25, 2019, MassDEP issued a letter to Respondent informing it of manganese levels in Respondent's water above the health advisory limit of 0.3 mg/l and requiring a public notice and submittal of a corrective action plan (CAP) by September 1, 2019 and a final plan by February 1, 2020.

C. On August 15, 2019, Respondent submitted a proposed manganese compliance plan and requested a technical assistance meeting with MassDEP.

D. On September 25, 2019, MassDEP met with Respondent to discuss the submitted compliance plan.

III. DISPOSITION AND ORDER

For the reasons set forth above, MassDEP hereby issues, and Respondent hereby consents to, this Order:

6. The parties have agreed to enter into this Consent Order because they agree that it is in their own interests, and in the public interest, to proceed promptly with the actions called for herein rather than to expend additional time and resources litigating the matters set forth above. Respondent enters into this Consent Order without admitting or denying the facts or allegations

set forth herein. However, Respondent agrees not to contest such facts and allegations for purposes of the issuance or enforcement of this Consent Order.

7. MassDEP's authority to issue this Consent Order is conferred by the statutes and regulations cited in Part II of this Consent Order.

8. Respondent shall perform the following actions:

A. On or before March 31, 2020, submit to MassDEP a BRP WS21 Approval to Conduct Pilot Study permit application to evaluate treatment for manganese at Well-03G and Well-04G ("the Whitney Wells").

B. On or before December 31, 2020, submit to MassDEP a BRP WS22 Approval of Pilot Study permit application with conceptual design for a water treatment plant or plant improvements to address the elevated = levels of manganese at the Whitney Wells.

C. On or before September 30, 2021, submit to MassDEP a BRP WS25 Modification of Treatment Facility permit application to make modifications to the Baddacook Water Treatment Plant ("WTP") or a BRP W23C Approval to Construct a Water Treatment Facility application to address the elevated levels of manganese at the Whitney Wells.

D. On or before March 31, 2023, submit confirmation to MassDEP that construction of the MassDEP approved water treatment plant or plant improvements at the has commenced.

E. On or before December 31, 2024, submit confirmation to MassDEP that the modified Baddacook WTP or new treatment plant to address elevated levels of for manganese at the Whitney Wells is complete and in operation.

F. Until manganese levels are below the ORSG at all entry points to the distribution system, Respondent shall continue to provide public notice in accordance with 310 CMR 22.16 and 22.16A, about the elevated levels of manganese consumers and new billing units.

9. Unless submitted via eDEP or except as otherwise provided herein, all notices, submittals and other communications required by this Consent Order shall be directed to:

Robert Bostwick, Drinking Water Section Chief
MassDEP
8 New Bond Street
Worcester, MA 01606

Such notices, submittals and other communications shall be considered delivered by Respondent upon receipt by MassDEP.

10. Actions required by this Consent Order shall be taken in accordance with all applicable federal, state, and local laws, regulations and approvals. This Consent Order shall not be construed as, nor operate as, relieving Respondent or any other person of the necessity of complying with all applicable federal, state, and local laws, regulations and approvals.

11. <u>Force Majeure - General</u>

A. MassDEP agrees to extend the time for performance of any requirement of this Consent Order if MassDEP determines that such failure to perform is caused by a Force Majeure event. The failure to perform a requirement of this Consent Order shall be considered to have been caused by a Force Majeure event if the following criteria are met: (1) an event delays performance of a requirement of this Consent Order beyond the deadline established herein; (2) such event is beyond the control and without the fault of Respondent and Respondent's employees, agents, consultants, and contractors; and (3) such delay could not have been prevented, avoided or minimized by the exercise of due care by Respondent or Respondent's employees, agents, consultants, and contractors.

B. Financial inability and unanticipated or increased costs and expenses associated with the performance of any requirement of this Consent Order shall not be considered a Force Majeure Event.

C. If any event occurs that delays or may delay the performance of any requirement of this Consent Order, Respondent shall immediately, but in no event later than 5 days after obtaining knowledge of such event, notify MassDEP in writing of such event. The notice shall describe in detail: (i) the reason for and the anticipated length of the delay or potential delay; (ii) the measures taken and to be taken to prevent, avoid, or minimize the delay or potential delay; and (iii) the timetable for taking such measures. If Respondent intends to attribute such delay or potential delay to a Force Majeure event, such notice shall also include the rationale for attributing such delay or potential delay to a Force Majeure event and shall include all available documentation supporting a claim of Force Majeure for the event. Failure to comply with the notice requirements set forth herein shall constitute a waiver of Respondent's right to request an extension based on the event.

D. If MassDEP determines that Respondent's failure to perform a requirement of this Consent Order is caused by a Force Majeure event, and Respondent otherwise complies with the notice provisions set forth in paragraph C above, MassDEP agrees to extend in writing the time for performance of such requirement. The duration of this extension shall be equal to the period of time the failure to perform is caused by the Force Majeure event. No extension shall be provided for any period of time that

Respondent's failure to perform could have been prevented, avoided or minimized by the exercise of due care. No penalties shall become due for Respondent's failure to perform a requirement of this Consent Order during the extension of the time for performance resulting from a Force Majeure event.

E. A delay in the performance of a requirement of this Consent Order caused by a Force Majeure event shall not, of itself, extend the time for performance of any other requirement of this Consent Order.

12. Respondent understands, and hereby waives, its right to an adjudicatory hearing before MassDEP on, and judicial review of, the issuance and terms of this Consent Order and to notice of any such rights of review. This waiver does not extend to any other order issued by the MassDEP.

13. This Consent Order may be modified only by written agreement of the parties hereto.

14. MassDEP hereby determines, and Respondent hereby agrees, that any deadlines set forth in this Consent Order constitute reasonable periods of time for Respondent to take the actions described.

15. The provisions of this Consent Order are severable, and if any provision of this Consent Order or the application thereof is held invalid, such invalidity shall not affect the validity of other provisions of this Consent Order, or the application of such other provisions, which can be given effect without the invalid provision or application, provided however, that MassDEP shall have the discretion to void this Consent Order in the event of any such invalidity.

16. Nothing in this Consent Order shall be construed or operate as barring, diminishing, adjudicating or in any way affecting (i) any legal or equitable right of MassDEP to issue any additional order or to seek any other relief with respect to the subject matter covered by this Consent Order, or (ii) any legal or equitable right of MassDEP to pursue any other claim, action, suit, cause of action, or demand which MassDEP may have with respect to the subject matter covered by this Consent Order, including, without limitation, any action to enforce this Consent Order in an administrative or judicial proceeding.

17. This Consent Order shall not be construed or operate as barring, diminishing, adjudicating, or in any way affecting, any legal or equitable right of MassDEP or Respondent with respect to any subject matter not covered by this Consent Order.

18. This Consent Order shall be binding upon Respondent and upon Respondent's employees, agents, contractors or consultants to violate this Consent Order. Until Respondent has fully complied with this Consent Order, Respondent shall provide a copy of this Consent Order to each successor or assignee at such time that any succession or assignment occurs.

19. If Respondent violates, any provision of the Consent Order, Respondent shall pay stipulated civil administrative penalties to the Commonwealth in the amount of $1,000.00 per day for each day, or portion thereof, each such violation continues.

Stipulated civil administrative penalties shall begin to accrue on the day a violation occurs and shall continue to accrue until the day Respondent corrects the violation or completes performance, whichever is applicable. Stipulated civil administrative penalties shall accrue regardless of whether MassDEP has notified Respondent of a violation or act of noncompliance. All stipulated civil administrative penalties accruing under this Consent Order shall be paid within thirty (30) days of the date MassDEP issues Respondent a written demand for payment. If simultaneous violations occur, separate penalties shall accrue for separate violations of this Consent Order. The payment of stipulated civil administrative penalties shall not alter in any way Respondent's obligation to complete performance as required by this Consent Order. MassDEP reserves its right to elect to pursue alternative remedies and alternative civil and criminal penalties which may be available by reason of Respondent's failure to comply with the requirements of this Consent Order. In the event MassDEP collects alternative civil administrative penalties, Respondent shall not be required to pay stipulated civil administrative penalties pursuant to this Consent Order for the same violations.

Respondent reserves whatever rights it may have to contest MassDEP's determination that Respondent failed to comply with the Consent Order and/or to contest the accuracy of MassDEP's calculation of the amount of the stipulated civil administrative penalty. Upon exhaustion of such rights, if any, Respondent agrees to assent to the entry of a court judgment if such court judgment is necessary to execute a claim for stipulated penalties under this Consent Order.

20. Failure on the part of MassDEP to complain of any action or inaction on the part of Respondent shall not constitute a waiver by MassDEP of any of its rights under this Consent Order. Further, no waiver by MassDEP of any provision of this Consent Order shall be construed as a waiver of any other provision of this Consent Order.

21. Respondent agrees to provide MassDEP, and MassDEP's employees, representatives and contractors, access at all reasonable times to the PWS for purposes of conducting any activity related to its oversight of this Consent Order. Notwithstanding any provision of this Consent Order, MassDEP retains all of its access authorities and rights under applicable state and federal law.

22. The undersigned certify that they are full authorized to enter into the terms and conditions of this Consent Order and to legally bind the party on whose behalf they are signing this Consent Order.

23. This Consent Order shall become effective on the date that it is executed by MassDEP.

SPECIAL INSTRUCTIONS:

Your two **signed copies of the** Administrative **Consent Orders** (ACO) must be delivered, for execution (signature) by MassDEP, to the following address:

Robert A. Bostwick, Drinking Water Section Chief
MassDEP
8 New Bond Street
Worcester, Massachusetts 01606

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Appendix B. Blue Leaf Pilot Study Report

Blueleaf, Inc.

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

PILOT STUDY REPORT FOR

IRON AND MANGANESE REMOVAL BY GREENSANDPLUS™ PRESSURE FILTRATION

WHITNEY AND BADDACOOK WELLS
GROTON WATER DEPARTMENT
GROTON MASSACHUSETTS

MAY 2020

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Submitted: July 02, 2019
July 09, 2020 (revision 1)

SUMMARY

This report details the methods and results of a pilot study for iron and manganese removal from three sources utilized by the Groton Water Department. Testing was completed at the Baddacook Water Treatment Plant Site, located off Route 40 in Groton MA, and used water from Whitney Well 1, Whitney Well 2, and the Baddacook Well. All pilot work was conducted at the Baddacook WTP site and Whitney Well water was brought to the Baddacook site in a 10,000 gallon tanker truck and stored in a 20,000 gallon onsite storage tank. The field component of the pilot study was conducted from May 11, 2020 through May 22, 2020.

The pilot study evaluated two alternative media configuration of GreensandPlus™ media and anthracite to compare two alternatives: (1) filtration of Whitney Wells with the Baddacook Well at the existing Baddacook WTP, or (2) filtration of the Whitney Wells at a new treatment facility with deeper media depths. Trials conducted using only Whitney Well water for the source used both shallow media depth (18" to match the existing Baddacook media profile) and deep media (24" GreensandPlus with 12" anthracite to match a media profile at a new WTP) . Trials conducted with Baddacook as part of the source water used only the shallow media configuration.

The raw water iron and manganese concentrations were higher during the pilot study than were reported as the 10-year average in the Pilot Study Protocol. The difference may be due to a gradual increase in the iron and manganese from the wells, from a recent cleaning of the Baddacook Well or from seasonal variations in contaminant concentrations.

The GreensandPlus™ portion of the study used the four filters to evaluate pretreatment using sodium hypochlorite for pre-oxidation and continuous regeneration of manganese dioxide coated media, and potassium hydroxide for pH adjustment. The pilot filters were operated at loading rates of 3, 5, 7 and 9 gpm/sf.

A total of 22 individual filter runs were completed. All pilot filters effectively removed metal contaminants to meet the SMCL for iron (Fe <0.30 mg/L) and manganese (Mn <0.05 mg/L) at all sources and with both media depths. Differential pressure (DP) across the filters increased over time as a function of filter loading rate and raw water quality. Pilot filters receiving Baddacook raw water had shorter runtimes either due to differential pressure (low rate filters), or contaminant breakthrough (high rate filters). Filter run times are expected to increase with the addition of water from the Whitney source.

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LIMITATIONS

This pilot test report was prepared for CEI Incorporated and the Town of Groton for the purpose of evaluating treatment of iron and manganese in water supplied from the Whitney Wells and Baddacook Wells in Groton MA. 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.

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ABBREVIATIONS

ANOVA	Analysis of Variance
BDL	Below Detection Limit
FSLR	Filter Surface Loading Rate
gpm	Gallons per Minute
gpm/sf	Gallons per Minute per Square Foot (of surface area)
gpd	Gallons per Day
gr	Gram
HP	Horsepower
L	Liter
mg	Milligram
MG	Million Gallons
MGD	Million Gallons per Day
µg/L	Micrograms per Liter (equivalent to ppb)
mg/L	Milligrams per Liter (equivalent to ppm)
min	Minutes
mV	Millivolt
NTU	nephalometric turbidity units
N/A	Not Available / Not Applicable
ND	Not Detected
PID	Proportional Integral Derivative
ppb	Parts per Billion
ppm	Parts per Million
SM	Standard Methods
S.U.	Standard Units
TSS	Total Suspended Solids

1 INTRODUCTION

1.1 BACKGROUND

The Groton Water Department operates the Baddacook Water Treatment Plant to remove iron and manganese from the Baddacook Well, a brick lined shallow well constructed in the late 1800's . The Baddacook WTP includes horizontal pressure vessels with 18" of manganese GreensandPlus™ media and 12" of anthracite. The Groton Water Department also operates Whitney Well #1 and Whitney Well #2 to augment the supply of drinking water. The Whitney wells contain low concentrations of iron, but manganese that exceeds the Secondary Maximum Contaminant Limit of 0.05 mg/L (50 µg/L). Historical iron and manganese concentrations that were reported in the Pilot Study Protocol (Table 1) are shown in Table 1.01.

Table 1.01: Well Capacities and Historical Raw Water Iron and Manganese Data from Groton Wells

Well #	**Average** [Count]	
	Total Iron, mg/L	**Total Manganese, mg/L**
Baddacook	1.0 mg/L Average, 1.4 mg/L Max	0.75 mg/L Average, 1.2 mg/L Max
Whitney No. 1	0.004 mg/L Average, 0.03 mg/L Max	0.24 mg/L Average, 0.51 mg/L Max
Whitney No. 2	0.11 mg/L Average, 1.0 mg/L Max	0.29 mg/L Average, 0.60 mg/L Max

*Highlighted median values exceed the EPA SMCL (Fe > 0.3 mg/L, Mn > 0.05 mg/L)

The Groton Water Department is considering options for the treatment of the Whitney Wells raw water. Options include constructing a new water treatment plant at or near the Whitney Wells or installing a new raw water pipeline to convey raw water from the Whitney Wells to the existing Baddacook WTP for filtration. The Groton Water Department has retained the services of Comprehensive Environmental Inc (CEI) to assist in planning, design, permitting and construction of an iron and manganese treatment facility. CEI contracted Blueleaf, Inc. to conduct a pilot study for evaluation of two alternatives: treating the Whitney Wells in a new stand-alone water treatment plant with vertical pressure vessels (vertical vessels would allow the media depths to be increased), or Whitney Well water blended Baddacook Well water in the existing Baddacook WTP.

1.2 REGULATORY REQUIREMENTS

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 standard 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 GreensandPlus filtration and biological filtration to remove iron and manganese to concentrations below the SMCL (0.3 mg/L Fe and 0.05 mg/L Mn), and pilot goals of 0.15 mg/L Fe and 0.025 mg/L Mn.
2. Quantify the filter runtime to the point of contaminant breakthrough or terminal headloss at various Filter Surface Loading Rates.
3. Quantify the rate at which pressure losses increase at various Filter Surface Loading Rates.
4. Provide chemical dosages for effective treatment conditions.

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 Greensand pilot system was delivered to the Baddacook site on May 8th, 2020. Formal filter trials began on May 12th and concluded on May 22nd, 2020.

2.1 PILOT EQUIPMENT DESCRIPTION

2.1.1 Raw Water Connections

Raw water from the Whitney Wells was delivered to the site with a 9,000 tanker "pool-water" tanker truck operated by Z. Taylor Trucking (Leominster, MA). The Groton Water Department operated the Whitney Wells at flow rates that matched the typical blended ratio of the Whitney #1 and Whitney #2 Wells from the wellfield. A gate valve was shut to isolate the Whitney Wells from the distribution system and all chemical feed pumps were shut off. Raw water was pumped through a fire hydrant located immediately outside the Whitney Well Pump Station to the tanker truck. Figure 2.01 shows the hydrant, filling hose and tanker truck at the Whitney Well site.

Figure 2.01: Tanker Filling at Whitney Wellfield

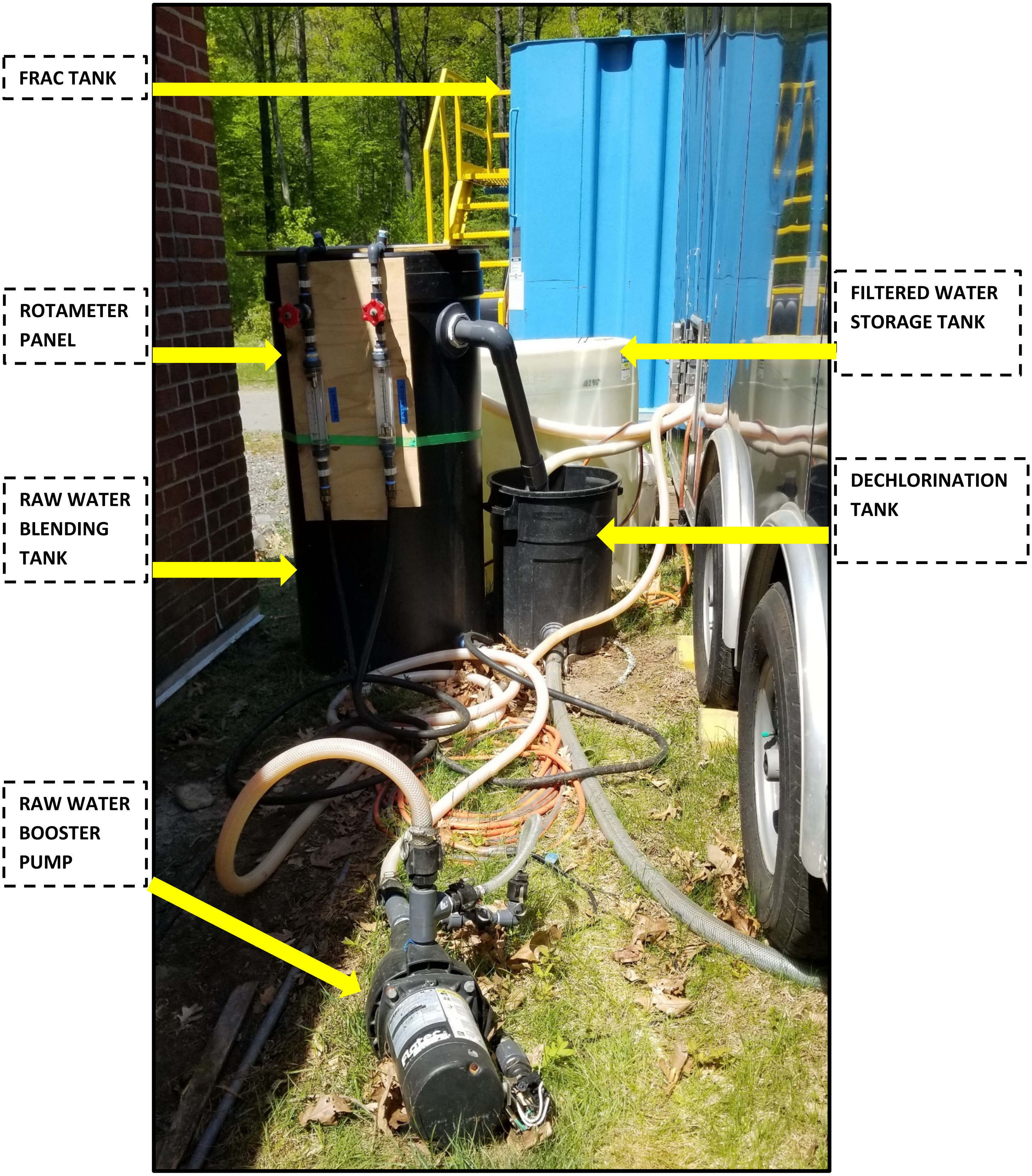
The tanker filled a 20,000-gallon epoxy-lined Fractionalization ("Frac") Tank provided by Rain 4 Rent (Charlton MA) through a 3" cam fitting installed in the front of the tank. The tank was filled with two loads of water on Tuesday May 12, and then single loads on May 13, 14, and 15. The following week, two loads were delivered on Monday May 18, then single loads on May 19 and 20. Whitney blended water was pumped from the Frac tank to a blending tank with a 1/2 HP sump pump.

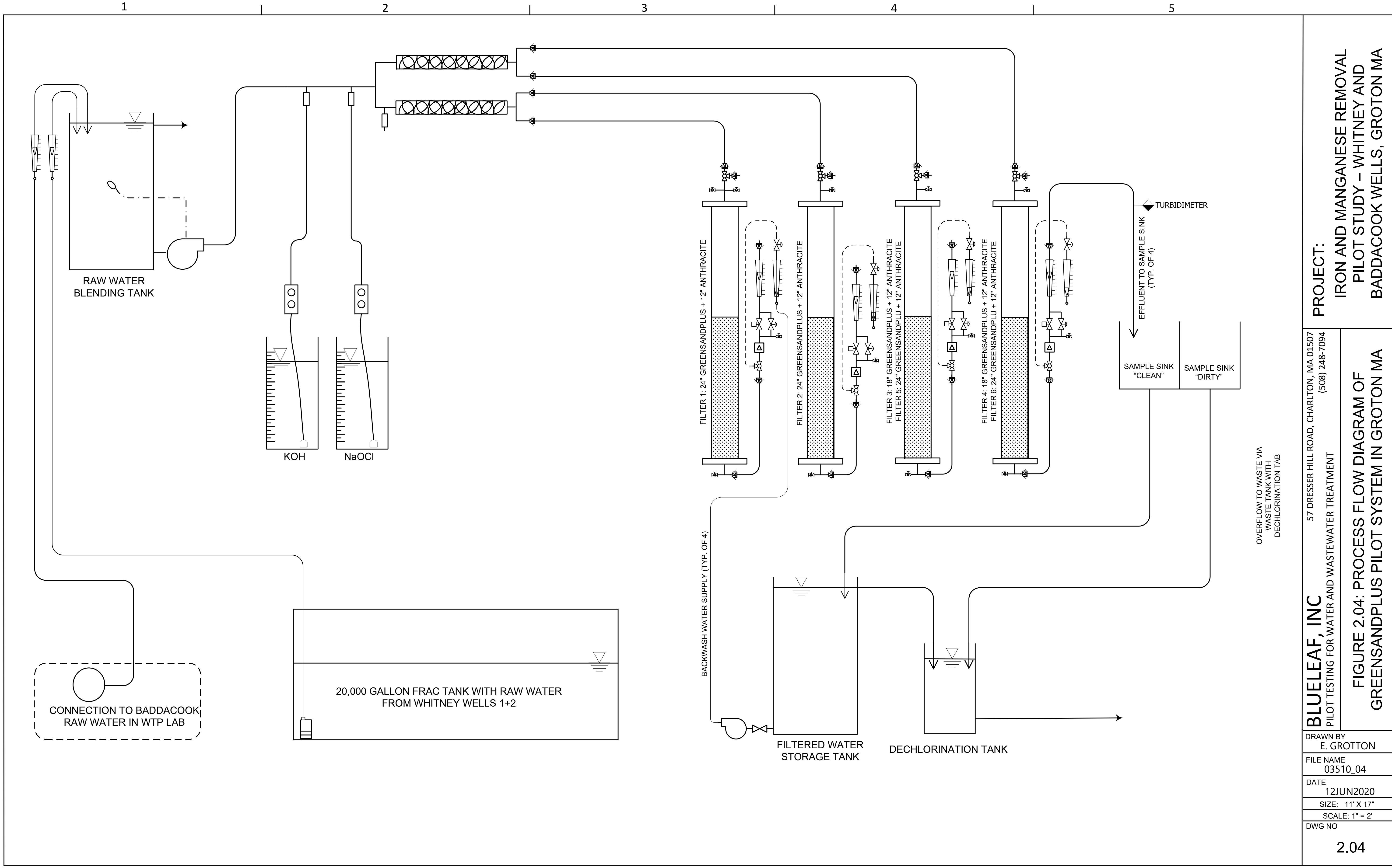
Water from the Baddacook Well was provided through a connection inside the Baddacook WTP lab. The connection was upstream of all chemical addition. Figure 2.02 shows the connection location prior to connection of a 5/8" diameter garden hose by the Groton WTP operators.

Figure 2.02: Baddacook Raw Water Connection

The flow rate from both raw water sources were measured and controlled on a rotameter panel mounted to the side of the blending tank (Figure 2.03). For trials with Whitney as the only source, the rotameter was set to be slightly higher than the total pilot flowrate so the blending tank had a continuous small overflow. For trials with a Whitney and Baddacook blend, the two rotameters were set to provide equal flows from Whitney and Baddacook at a total flow slightly higher than the total pilot flowrate. Blended raw water was pumped into the pilot trailer with a 3/4 HP booster pump (shown in the foreground of Figure 2.03). The overall setup of the pilot study is shown in Figure 2.04.

Figure 2.03: Blending and Waste Tanks outside of Pilot Trailer




RAW WATER BLENDING TANK
KOH
NaOCl
CONNECTION TO BADDACOOK RAW WATER IN WTP LAB
20,000 GALLON FRAC TANK WITH RAW WATER FROM WHITNEY WELLS 1+2
FILTER 1: 24" GREENSANDPLUS + 12" ANTHRACITE
FILTER 2: 24" GREENSANDPLUS + 12" ANTHRACITE
FILTER 3: 18" GREENSANDPLUS + 12" ANTHRACITE
FILTER 5: 24" GREENSANDPLUS + 12" ANTHRACITE
FILTER 4: 18" GREENSANDPLUS + 12" ANTHRACITE
FILTER 6: 24" GREENSANDPLU + 12" ANTHRACITE
TURBIDIMETER
EFFLUENT TO SAMPLE SINK (TYP. OF 4)
SAMPLE SINK "CLEAN"
SAMPLE SINK "DIRTY"
BACKWASH WATER SUPPLY (TYP. OF 4)
FILTERED WATER STORAGE TANK
DECHLORINATION TANK
OVERFLOW TO WASTE VIA WASTE TANK WITH DECHLORINATION TAB
PROJECT:
IRON AND MANGANESE REMOVAL PILOT STUDY – WHITNEY AND BADDACOOK WELLS, GROTON MA
BLUELEAF, INC
PILOT TESTING FOR WATER AND WASTEWATER TREATMENT
57 DRESSER HILL ROAD, CHARLTON, MA 01507
(508) 248-7094
FIGURE 2.04: PROCESS FLOW DIAGRAM OF GREENSANDPLUS PILOT SYSTEM IN GROTON MA
DRAWN BY
E. GROTTON
FILE NAME
03510_04
DATE
12JUN2020
SIZE: 11' X 17"
SCALE: 1" = 2'
DWG NO
2.04

2.1.2 Greensand Pilot System

The pilot filtration system and field laboratory were contained in a cargo style trailer. Figure 2.05 shows the interior of the Greensand pilot trailer.

Figure 2.05: Interior of Pilot Trailer at Groton MA Baddacook Site

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.

2.1.2.1 GreensandPlus™ Pretreatment

GreensandPlus™ pilot influent was pretreated using potassium hydroxide (KOH) for pH adjustment, and sodium hypochlorite for oxidation and media regeneration.

Figure 2.06 shows the chemical feed area, with three Grundfos chemical feed pumps, and two chemical day tanks located to the left of the pumps. The day tanks were 6-inch diameter clear PVC graduated in 0.1 L intervals, with a measured volume of 17 liters. Additional 12-inch diameter day tanks with a volume of 55 liters each were available if needed for longer periods of operation. Each of the four pilot filters were supplied with chemically pretreated water via 3/4-inch nylon braided hose, seen above the feed pumps. There were two branches that allowed two different chemical pretreatment scenarios to be tested side-by-side, but these were not used during the pilot study. KOH and NaOCl were injected into the common supply for all four filters, indicated by the yellow circles. The direction of flow is indicated by the two yellow arrows.

Figure 2.06 shows the sodium hypochlorite (NaOCl) feed pump, which was identical to the KOH pump. The NaOCl feed pump was connected on the suction side to one of the 17-liter clear PVC day tanks via 1/4" tubing. The pump 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 100 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.

Figure 2.06: Pilot Trailer Chemical Feed Area

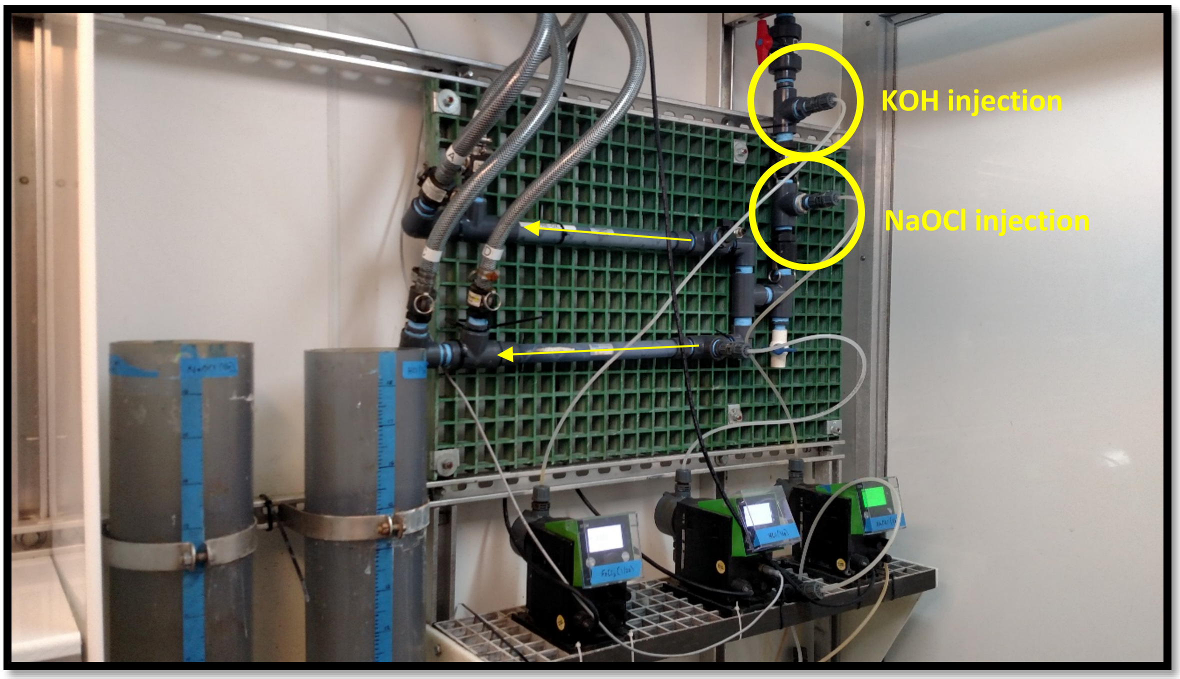


Figure 2.07: Sodium Hypochlorite Feed Pump

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

2.1.2.2 GreensandPlus™ Filters

GreensandPlus™ (GSP) 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. Regeneration can be performed continuously by feeding permanganate or chlorine during filter service (continuous regeneration, CR), or intermittently by occasionally backwashing or soaking with permanganate (intermittent regeneration, IR).

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 1, 2, 5, 6	3, 4
Adsorptive filtration media	GreensandPlus™ with Anthracite	
Adsorptive media depth	24 inches (61 cm)	18 inches (48 cm)
Anthracite filter cap	12 inches (30 cm)	12 inches (30 cm)
Total filter bed depth	36 inches (91 cm)	30 inches (76 cm)
Filtration media volume	0.4 ft^3 (11.3 L)	0.3 ft^3 (8.5 L)
Anthracite volume	0.2 ft^3 (5.7 L)	0.2 ft^3 (5.7 L)
Total media volume	0.6 ft^3 (17.0 L)	0.5 ft^3 (14.1 L)
Freeboard above filter surface	24 inches (61 cm)	30 inches (76 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 GreensandPlus™ 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™ (GSP) filtration media, with a 12” anthracite coal filter cap.

Figure 2.08 shows the flow control for the pilot filters.

Figure 2.08: Pilot Filter with Flow Control Panel

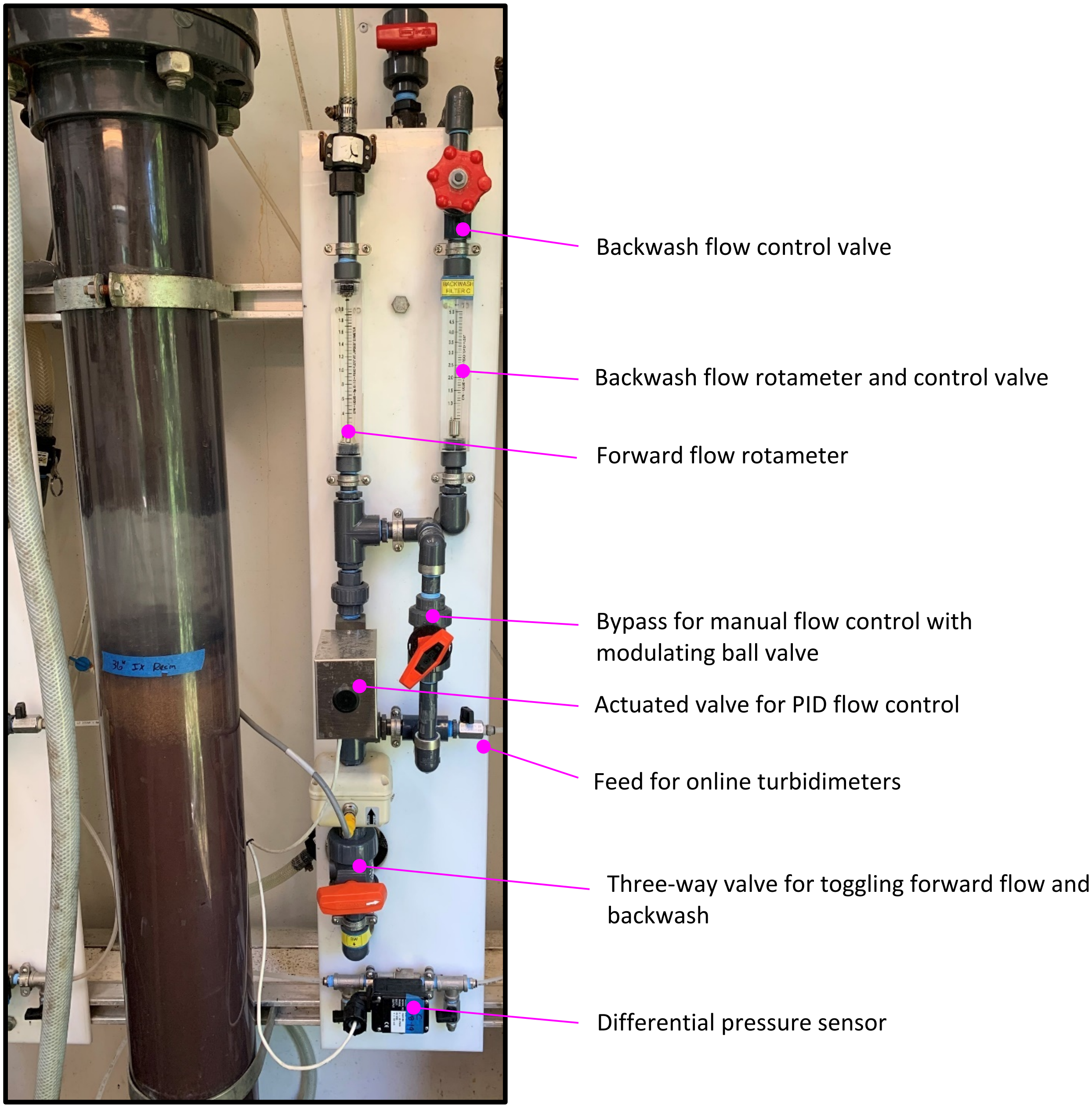
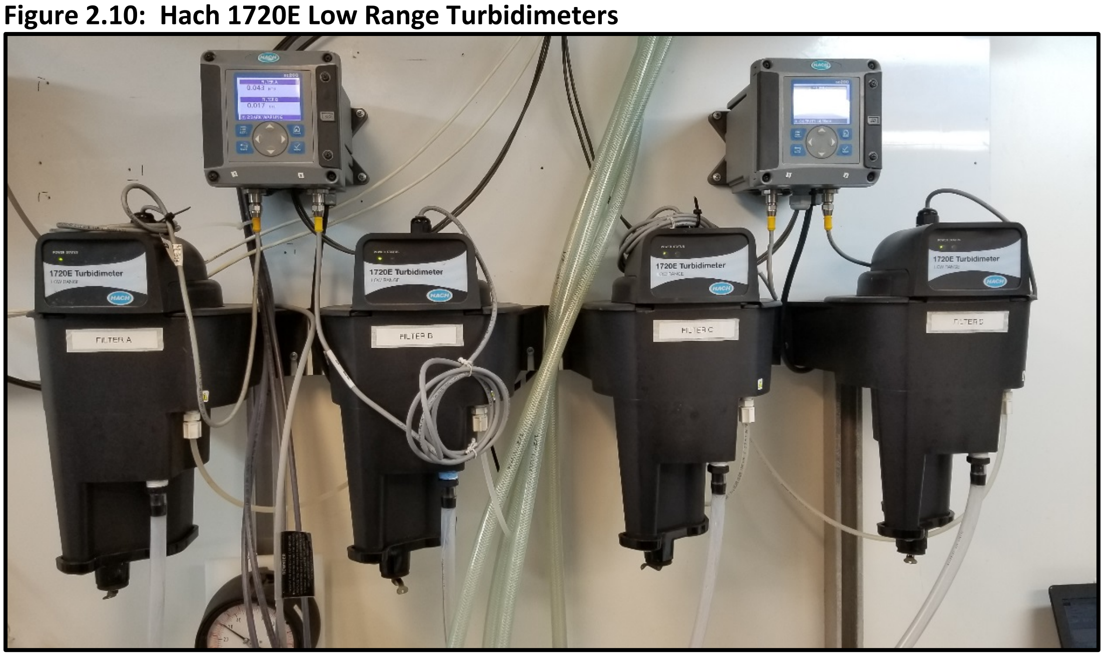


Figure 2.09 shows the sample sink, with ½" hoses for pilot filter effluent, 3/8" lines for discharge from the four Hach 1720e flow-through turbidimeters, and the 1/4" sample lines for untreated raw water, and pretreated filter influent. The pretreated filter influent sample lines flowed into a common sample cup with an online pH meters, 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 2.09: Pilot Trailer Sample Sink

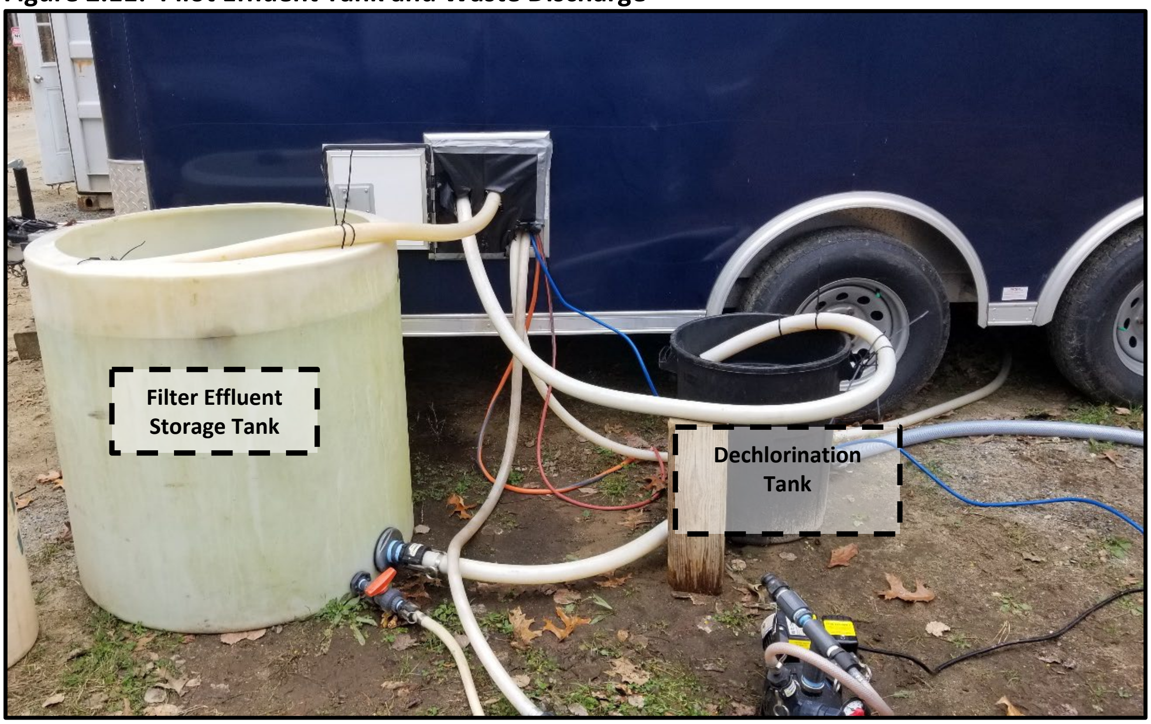
Each filter effluent flow had a dedicated flow-through Hach 1720E low range turbidimeter. The four effluent turbidimeters were connected to two Hach SC200 2-channel controllers. Filter effluent turbidimeters and SC200 controllers are shown in Figure 2.10. Filter effluent grab samples were collected from the individual filter effluent streams at the points of discharge into the sample sink.

Figure 2.10: Hach 1720E Low Range Turbidimeters



"Clean" water, consisting of filter effluent and turbidimeter drains, from the right side of the sample sink was discharged conveyed into a 150-gallon tank. The filters were backwashed using filter effluent stored in the 150-gallon effluent tank. The effluent tank was equipped with an overflow which discharged by to a dechlorination tank containing dechlor tablets. "Dirty" water, consisting of raw water and pretreated water from the left side of the sample sink was discharged into a separate dechlorination tank that bypassed the filter effluent storage tank. The filter effluent and bypass drain tanks are shown set up at a previous pilot site in Figure 2.11 for clarity. At the Baddacook site, tanks were located between the pilot trailer and the Baddacook WTP, and they were shown and marked in Figure 2.03.

Figure 2.11: Pilot Effluent Tank and Waste Discharge



2.1.2.4 GreensandPlus™ Backwash Water Feed Tank, Pump, and Connections

During backwashes a booster pump supplied backwash water from the effluent storage tank to the pilot system. 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. The collected bulk backwash sample was typically sampled to characterize the backwash water and settleability. After sampling, the backwash water was either discharged to waste or transferred to a 150-gallon storage tank for eventual use as supernatant recycle.

The settled supernatant was then recycled into the raw water at a rate of 10% of the total forward feed flow during supernatant recycle trials. A Masterflex peristatic pump fed the supernatant into the raw water at a rate calibrated to equal 10% of the total pilot system influent flow rate. The intake for the supernatant pump was suspended above the sludge layer in the backwash settling tank to avoid the withdrawal of solids.

2.1.3 Field Laboratory and Analytical Testing Equipment

The pilot trailer was equipped with a field laboratory to provide an area to complete field analyses (Figure 2.11). Glassware, reagents, and analytical equipment necessary to complete the analyses described in Section 2.3 were included in the field laboratory.

Figure 2.11: Greensand Pilot Trailer Field Laboratory

The following sample locations were used during the pilot study:

- Whitney – Raw water sample from the combined Whitney #1 and Whitney #2 wells.
- Baddacook – Raw water sample from Well #3 collected from pilot influent tap.
- POX – Pretreated influent to the Greensand Filters A/B 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.

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 a an oxidative environment for media regeneration.

Table 2.02 summarizes the pretreatment chemical properties.

Table 2.02: Pretreatment Chemical Properties

Product	Formula	Function	Stock Strength	Specific Gravity
Sodium Hypochlorite	NaOCl	Oxidant/Disinfection	~6.0%	1.10
Potassium Hydroxide	KOH	pH Adjustment	45%	1.45

The liquid chemicals were added to graduated day tanks, 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 25% (1/4). The diluted KOH was placed in a 6" diameter day tank with a volume of 17 L, with graduations at 0.1 L (100 mL) intervals.
- NaOCl was used at a dilution of the stock by 10% (1/10) and 20% (1/5). The diluted NaOCl was placed in a 6" diameter day tank with a volume of 17 L, with graduations at 0.1 L (100 mL) intervals.

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:

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

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 6%. For determining the mass based NaOCl dose, the stock solution is assumed to have a free chlorine concentration of 6% by weight and a specific gravity of 1.10. The NaOCl dose based on mass was determined using the following formula:

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

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)
6% = 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 measureable 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. The 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 Iron – Ferrozine

Iron samples for pilot effluent were occasionally analyzed in accordance with Hach (Loveland, CO) Ferrozine® method #8147 in order to provide increased precision and accuracy for low range concentration of total iron. Samples were distributed to 25 ml sample vials. Ferrozine iron reagent was added, mixed, and 5 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 using a blank from the appropriate sample site.

2.3.3 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.

2.3.4 Manganese - Graphite Furnace Analysis

Manganese samples were collected during the pilot study to be analyzed using Blueleaf's Perkin Elmer 900Z graphite furnace. The analyses were completed in accordance with EPA Method 200.9 using a wavelength of 279.5, a sample volume of 20 µL and a calibration range of 0 to 50 µg/L.

The method detection limit for the graphite furnace method was calculated in accordance to Method 200.9 by measuring 7 replicate analyses of a single filter effluent sample collected during the study. Results are shown in Table 2.03.

Table 2.03: Estimation of Method Detection Limit for GF Method - Manganese

	First Analysis (ug/L)	Second Analysis (ug/L)	**Average (ug/L)**
Replicate 1	1.0	0.8	**0.9**
Replicate 2	3.2	3.0	**3.1**
Replicate 3	-0.1	0.0	**-0.1**
Replicate 4	1.6	1.6	**1.6**
Replicate 5	0.0	0.0	**0.0**
Replicate 6	0.5	0.5	**0.5**
Replicate 7	0.6	0.5	**0.5**
Standard Deviation			1.10
t-statistic for 1-tailed , 6 degrees of freedom, α=0.01			3.14
MDL (ug/L)			**3.5**

The estimated detection limit for the method was 3.5 ug/L, or 0.0035 mg/L.

2.3.5 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:

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

2.3.6 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.

2.3.7 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. Turbidity was not monitored in the Biological Treatment system.

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. The chlorine residual and pH were not altered after collection of the sample. The pilot free chlorine residual target was 1.0 mg/L during collection. Free/total residual chlorine and pH were analyzed in the field by Blueleaf prior to incubation of the sample. The sample collected was 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 Granite State Analytical. The final free/total residual chlorine and pH from the incubated sample were analyzed 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 0.100 (10%) for all ANOVAs herein. If the p-value is greater than alpha (p>0.10) then there was greater than 10% probability that the population means were the same (or alternatively less than 90% probability that the means were different) and the null hypothesis cannot be rejected. If the p-value is less than alpha (p<α), 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 >90%.

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 90% confidence intervals. For each data set (Levels 1 and 2) the asterisk (*) indicates the mean value, and 9 out of 10 data fall within the 90% 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.

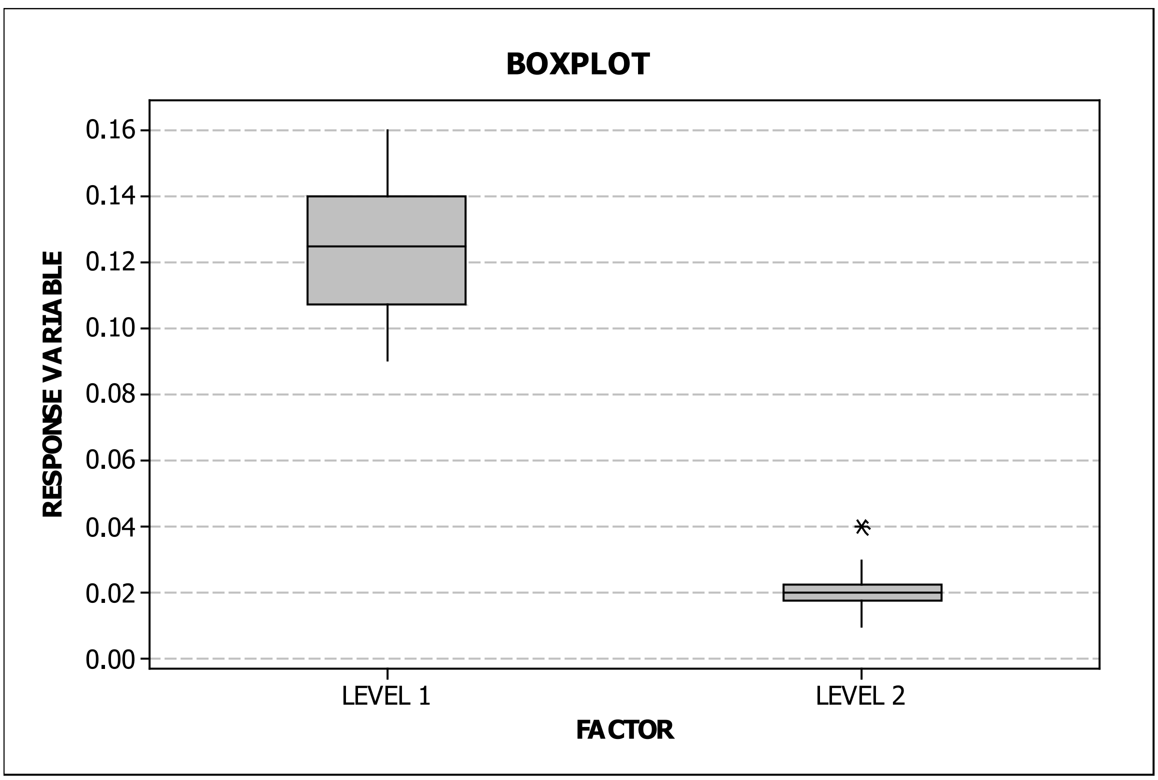
2.5.2.4 *Mean and Standard Deviation*

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 2.20 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 2.20: 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 (Whitney Wells 1 and 2) and Table 3.03 (Whitney + Baddacook).

Table 3.01: Raw Water Quality by Field Analyses

Parameter	Whitney Blend	Baddacook Well	Whitney + Baddacook Blend
Total Iron, mg/L	**0.22** (0.10 – 0.48) [13]	1.54, 1.70 [2]	**0.87** (0.78 – 0.99) [6]
Dissolved Iron, mg/L	**0.07** (0.03 – 0.22) [12]	1.51 [1]	**0.73** (0.64 – 0.75) [5]
Total Manganese, mg/L	**0.353** (0.29 – 0.41) [13]	1.06 [2]	**0.653** (0.63 – 0.68) [6]
Dissolved Manganese, mg/L	**0.334** (0.28 – 0.36) [12]	0.982 [1]	**0.639** (0.61 – 0.66) [5]
pH (Handheld), s.u.	**6.79** (6.41 – 7.18) [21]	No Data [0]	**6.70** (6.19 – 7.02) [6]
Temperature, °C	**13.8** (11.9 – 16.4) [19]	No Data [0]	**14.1** (12.6 – 15.4) [7]
Alkalinity (mg/L)	(53, 63) [2]	No Data [0]	59 [1]
Carbon Dioxide (mg/L)	91 – 111 [2]	No Data [0]	110 [1]
Total Organic Carbon (mg/L)	0.45 [1]	No Data [0]	0.92 [1]

Note that the water from the Whitney wells had been transferred to the site in a tanker and stored in a Frac tank. It is likely that the precipitated dissolved fraction of iron increased during transport and storage.

Table 3.02: Raw Water Quality for Whitney Wells by Laboratory Analysis

	Analysis	Units	Laboratory Report #					
			L2020091	L2020094	L2020587	L2020589	L2020591	L2021199
			Sample Date and Time					
			5/13/20 11:33	5/14/20 9:00	5/15/20 8:45	5/18/20 10:30	5/19/20 8:45	5/20/19 8:35
Laboratory Analyses by Alpha Analytical	Total Iron	mg/L	0.208	0.326	0.207	0.188	0.088	0.093
	Dissolved Iron	mg/L		<0.050			<0.050	
	Total Manganese	mg/L	0.3090	0.4421	0.3971	0.3943	0.3145	0.3511
	Dissolved Manganese	mg/L		0.4126			0.3002	
	Total Coliform	Col/100mL					Negative	
	Escherichia Coliform	Col/100mL					Negative	
	Turbidity	NTU						
	Color, True	s.u.						
	Color, Apparent	s.u.						
	pH	s.u.						
	Alkalinity	mg/L						
	Carbon Dioxide	mg/L					420	
	Calcium	mg/L		26.2				
	UV Absorbance	/cm						
	Total Organic Carbon	mg/L					0.670	

Table 3.03: Raw Water Quality for Whitney + Baddacook Blend by Laboratory Analysis

	Analysis	Units	Laboratory Report #					
			L2021196	L2021195	L2021331			
			Sample Date and Time					
			5/20/20 12:43	5/21/20 10:37	5/22/20 8:35			
Laboratory Analyses by Alpha Analytical	Total Iron	mg/L	0.744	0.862	0.811			
	Dissolved Iron	mg/L		0.721				
	Total Manganese	mg/L	0.6698	0.7620	0.7500			
	Dissolved Manganese	mg/L		0.7058				
	Total Coliform	Col/100mL		Positive				
	Escherichia Coliform	Col/100mL		Negative				
	Turbidity	NTU		1.5				
	Color, True	s.u.		11				
	Color, Apparent	s.u.		160				
	pH	s.u.		6.5				
	Alkalinity	mg/L						
	Carbon Dioxide	mg/L		430				
	Calcium	mg/L						
	UV Absorbance	/cm		0.038				
	Total Organic Carbon	mg/L		1.06				

3.2 PRETREATMENT CONDITIONS

3.2.1 Pilot Chemical Doses

3.2.1.1 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- GreensandPlus™ Filtration

Source	NaOCl Dose*1 (mg/L)
Whitney Blend	3.4
Whitney +Baddacook Blend	4.2

*1 - The reported stock concentration of a typical bottle of bleach is 6%.

3.2.1.2 KOH Doses

KOH doses are calculated as described in Section 2.2.3. The doses used during the pilot study are summarized in Tables 3.05.

Table 3.05: Pretreatment KOH Doses – Greensand Filtration

Source	KOH Doses (mg/L)
Whitney Blend	5.5
Whitney + Baddacook Blend	6.2

3.2.2 Pretreated Water Quality

Pretreatment included pH adjustment with KOH to increase raw pH to approximately 7.2 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 Table 3.06.

The percentage of iron that was precipitated was 86% from the Whitney Wells (0.19 mg/L of 0.22 mg/L), and 71% from the Whitney + Baddacook Blend (62 mg/L of 0.87 mg/L). The slightly higher rate of precipitation may be due to the transport and storage of raw water from the Whitney Wells to the Baddacook site.

The percentage of manganese that was precipitated was 13% from the Whitney Wells (0.046 mg/L of 0.353 mg/L), and 27% from the Whitney + Baddacook Blend (0.175 mg/L of 0.653 mg/L). Low rates of precipitation of manganese are typical for greensand filtration because the primary mode of removal is adsorption.

Table 3.06: Greensand Pilot – Pretreated Water Quality Data from Field Analyses

Trial	Free Chlorine (mg/L)	Total Chlorine (mg/L)	Dissolved Iron (mg/L)	Dissolved Manganese (mg/L)	Benchtop pH (s.u.)
1	No Data [0]	No Data [0]	No Data [0]	No Data [0]	No Data [0]
2	0.67 (0.15-1.16) [6]	1.10 (0.17-1.67) [6]	0.05 (0.03-0.12) [6]	0.32 (0.29-0.35) [6]	7.28 (6.48-7.71) [12]
3	No Data [0]	No Data [0]	No Data [0]	No Data [0]	No Data [0]
4	0.33 (0.05-1.66) [5]	1.53 (0.17-1.81) [5]	0.02 (0.02-0.02) [3]	0.24 (0.23-0.31) [3]	7.30 (7.06-7.72) [9]
5	0.21-0.34 [2]	0.67-1.16 [2]	0.25 (0.09-0.26) [4]	0.50 (0.48-0.54) [4]	7.19 (6.45-7.53) [6]
6	0.66 [1]	1.48 [1]	No Data [0]	0.39 [1]	6.87-7.38 [2]

3.3 FILTER PERFORMANCE

Pilot filters were operated using the Whitney Wells from May 12 through May 20. Two pilot filters (F1 and F2) had a media depth of 18" GreensandPlus with 12" Anthracite to match the media depths at the existing Baddacook WTP. Two other filters (F5 and F6) had a media depth of 24" GreensandPlus with 12" Anthracite to evaluate the impact of deeper media at a new WTP. Filters were operated at Filer Surface Loading Rates of 3, 5, 7 and 9 gpm/sf.

The Baddacook Well was added to the source water blending tank on May 20 at a 1:1 ratio with the Whitney Wells. At the same time, Filters F5 and F6 were replaced with two additional pilot filters with 18" GreensandPlus with 12" Anthracite (F3 and F4) so all filters matched the media depths at the existing Baddacook WTP (there is no proposed scenario to replace the filters at the existing Baddacook WTP). Filters were operated at Filer Surface Loading Rates of 3 and 9 gpm/sf. The two filters that operated at 9 gpm/sf reached contaminant breakthrough within 24 hours and were backwashed and restarted to replicate the trial.

3.3.1 Pilot Filter Hydraulic Performance

For each filter run, online data was logged every 3 minutes by the PLC, and grab samples were collected and analyzed periodically throughout the day.

Figures 3.01 through 3.22 show important operating conditions and effluent iron and manganese concentrations for each filter run. 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 red triangles in units of mg/L and represent results of field analyses of grab samples. The data are plotted using the right y-axis. In Figure 3.10, the iron concentration increases between 18 hours and 21 hours because the Filter Surface Loading Rate and influent iron concentration are relatively high, and the filter reaches contaminant breakthrough.
3. Field data for effluent manganese concentrations are presented as hollow purple triangles in units of mg/L and represent results of field analyses of grab samples. Grab samples collected from filter effluent and later analyzed by Blueleaf’s graphite furnace for manganese concentrations are presented as solid purple triangles in units of mg/L. Laboratory data for effluent manganese concentrations are presented as yellow squares with black outline in units of mg/L and represent results of laboratory analyses of grab samples. The data are plotted using the right y-axis.
4. Filter effluent manganese goal is presented as a purple 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).
5. 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.

6. 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.
7. Filter effluent turbidity breakthrough is presented as a hollow red square. Criteria for turbidity breakthrough is a turbidity that exceeds 0.10. Turbidity breakthrough preceded iron and manganese breakthrough during this study.
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.
11. Terminal headloss is shown as a hollow red triangle, at 10 psi.

The Clean Bed Headloss and Terminal Headloss were used to determine the rate of headloss development.

Figure 3.01: Filter 1, Trial 1 Filter Performance Plot

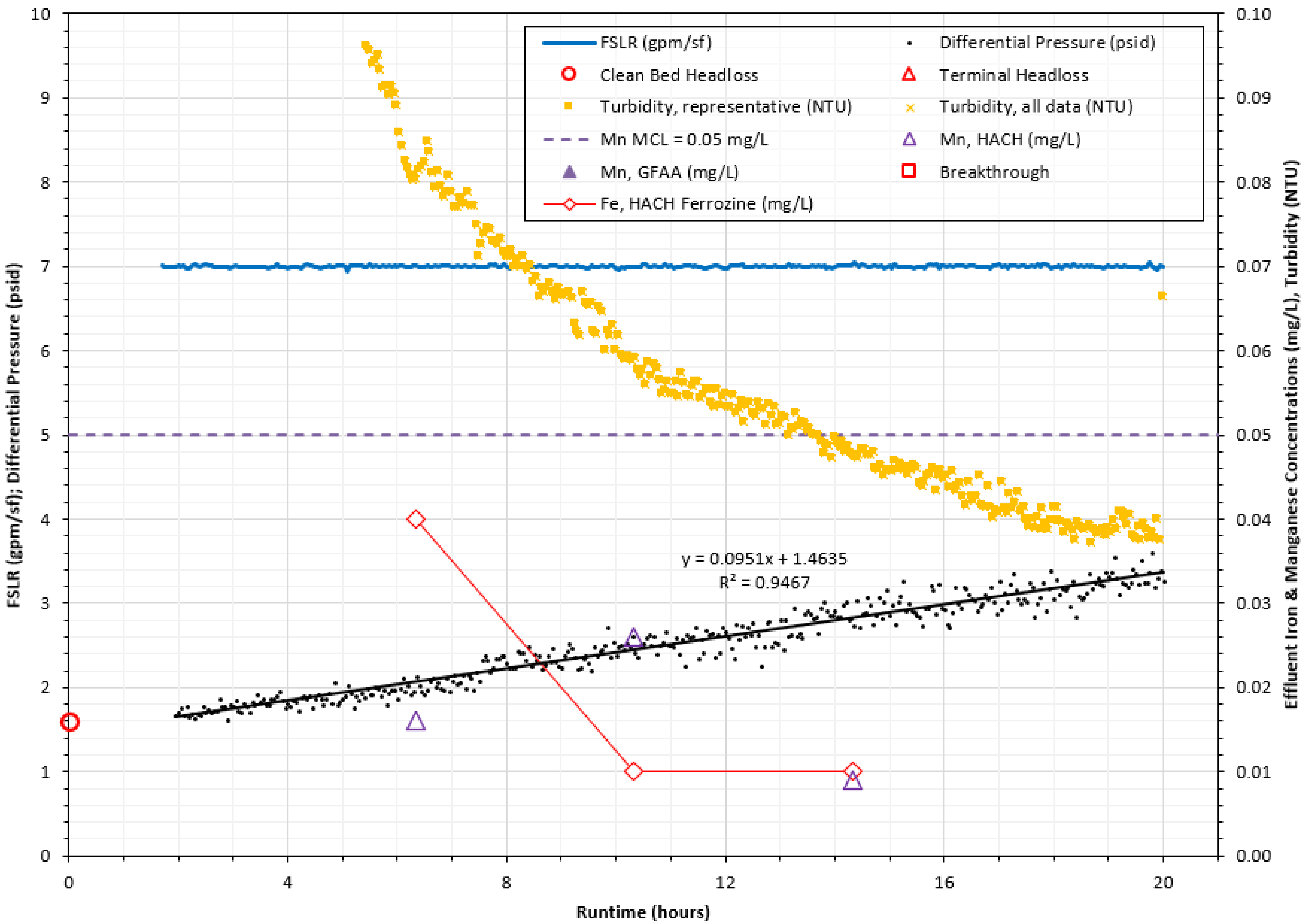


Figure 3.02: Filter 1, Trial 2 Filter Performance Plot

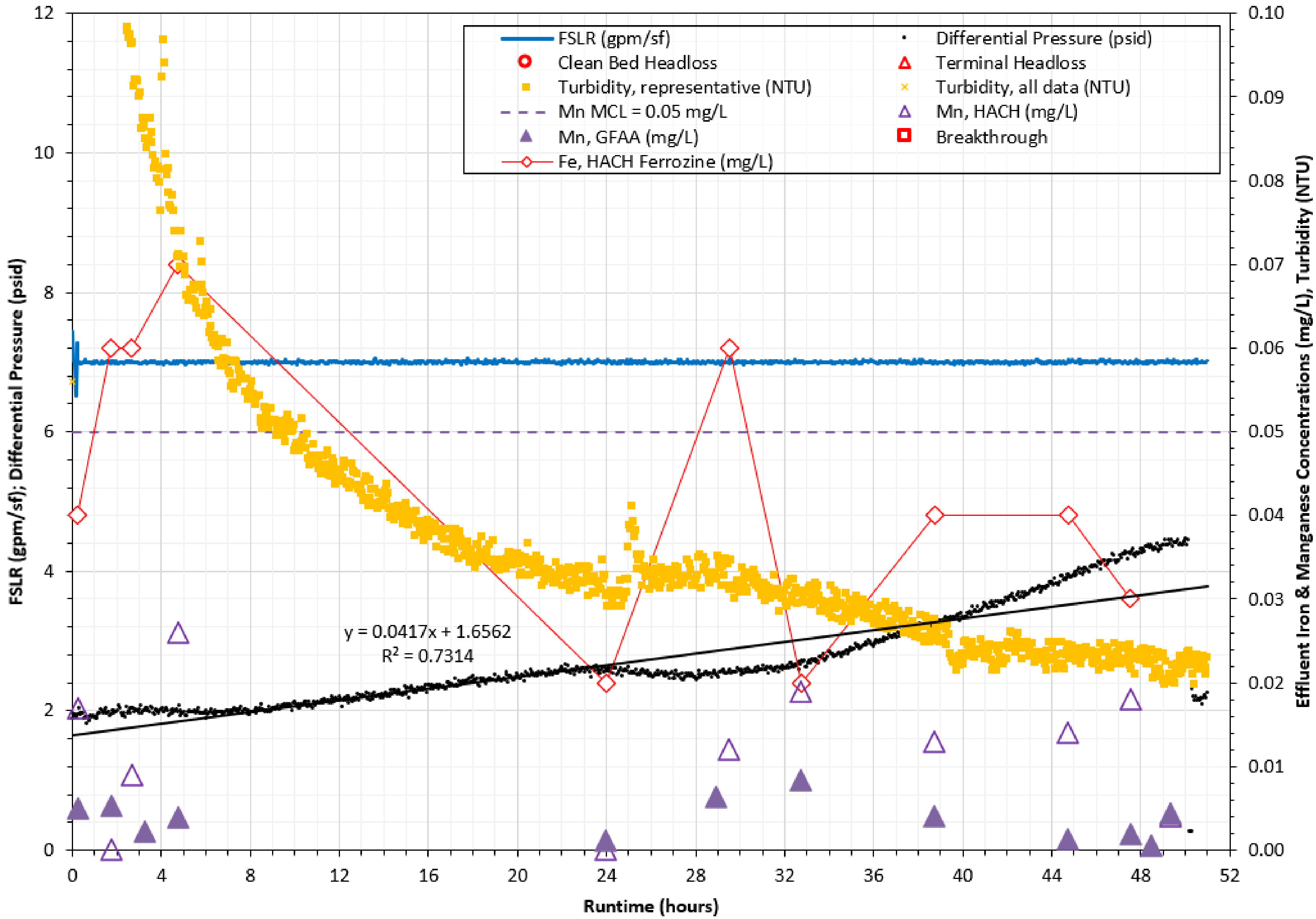


Figure 3.03: Filter 1, Trial 3 Filter Performance Plot

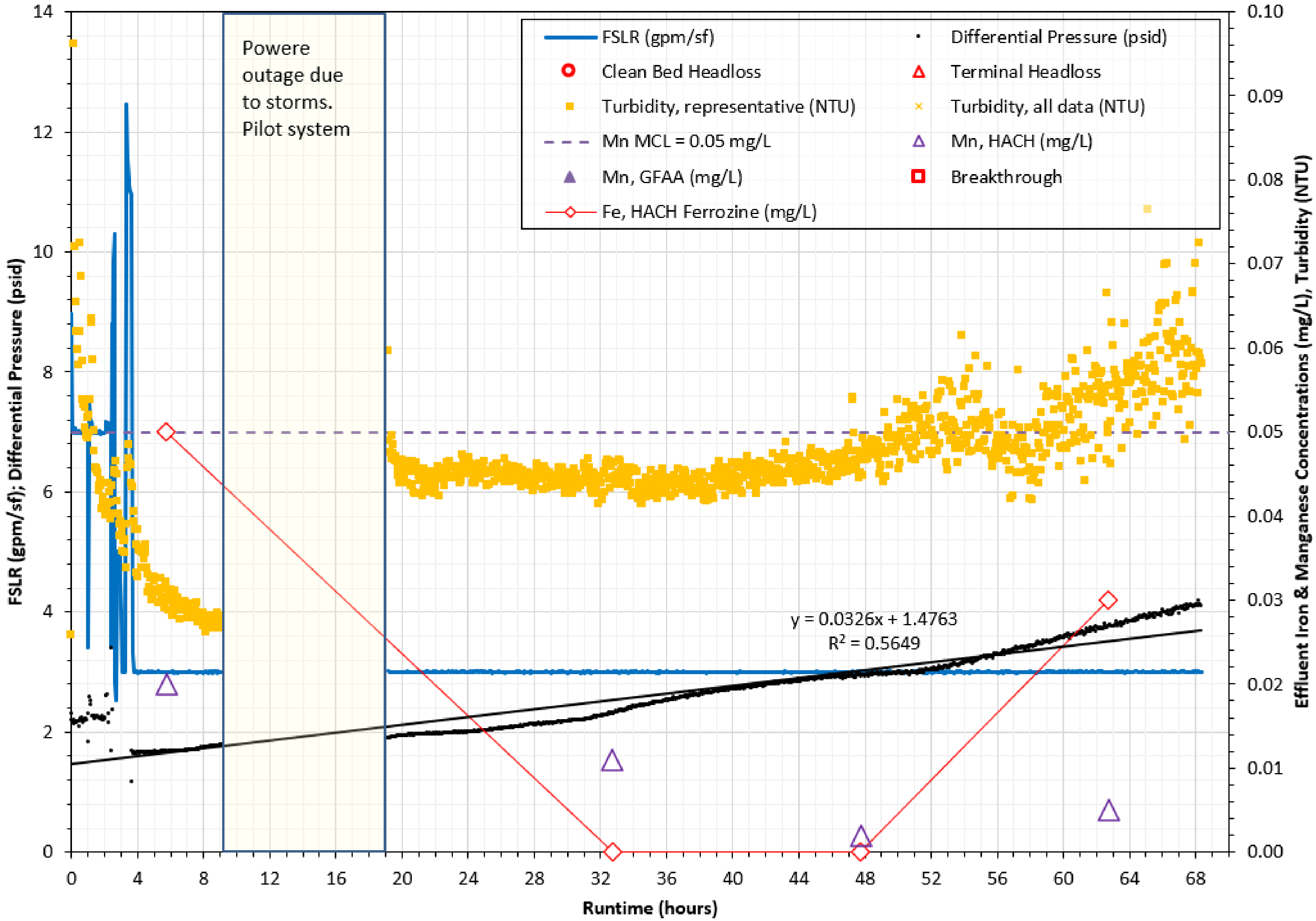


Figure 3.04: Filter 1, Trial 4 Filter Performance Plot

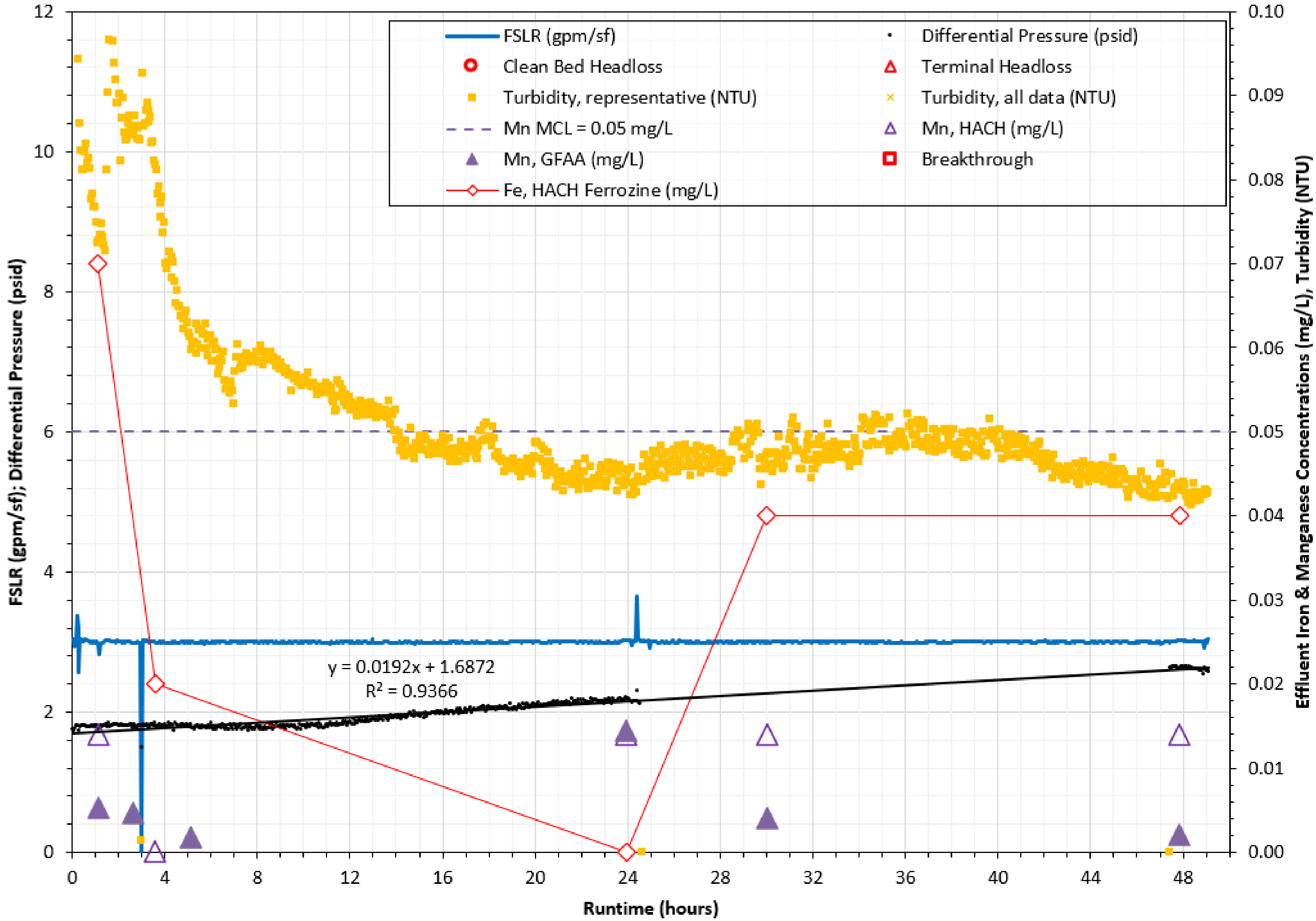


Figure 3.05: Filter 1, Trial 5 Filter Performance Plot

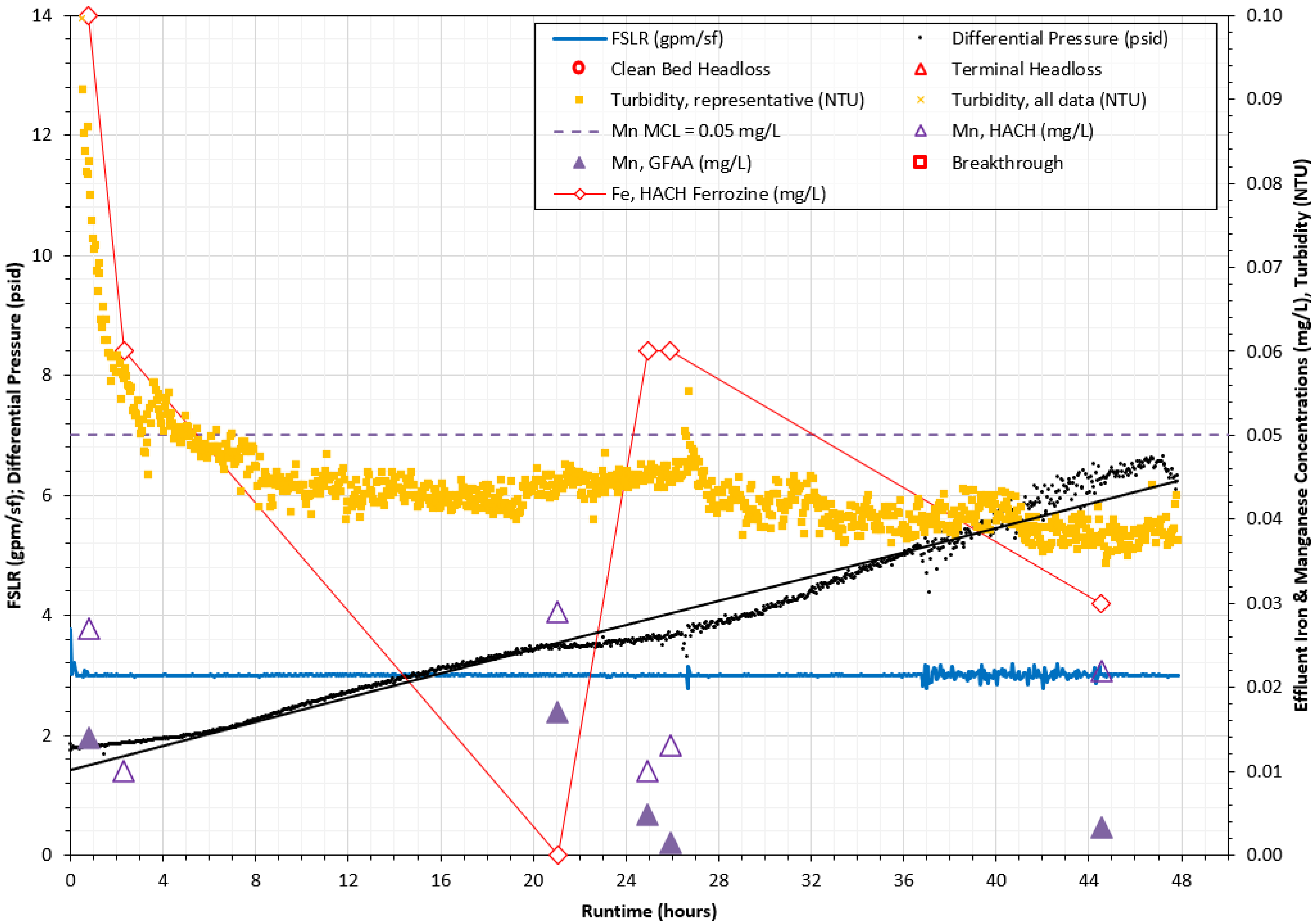


Figure 3.06: Filter 2, Trial 1 Filter Performance Plot

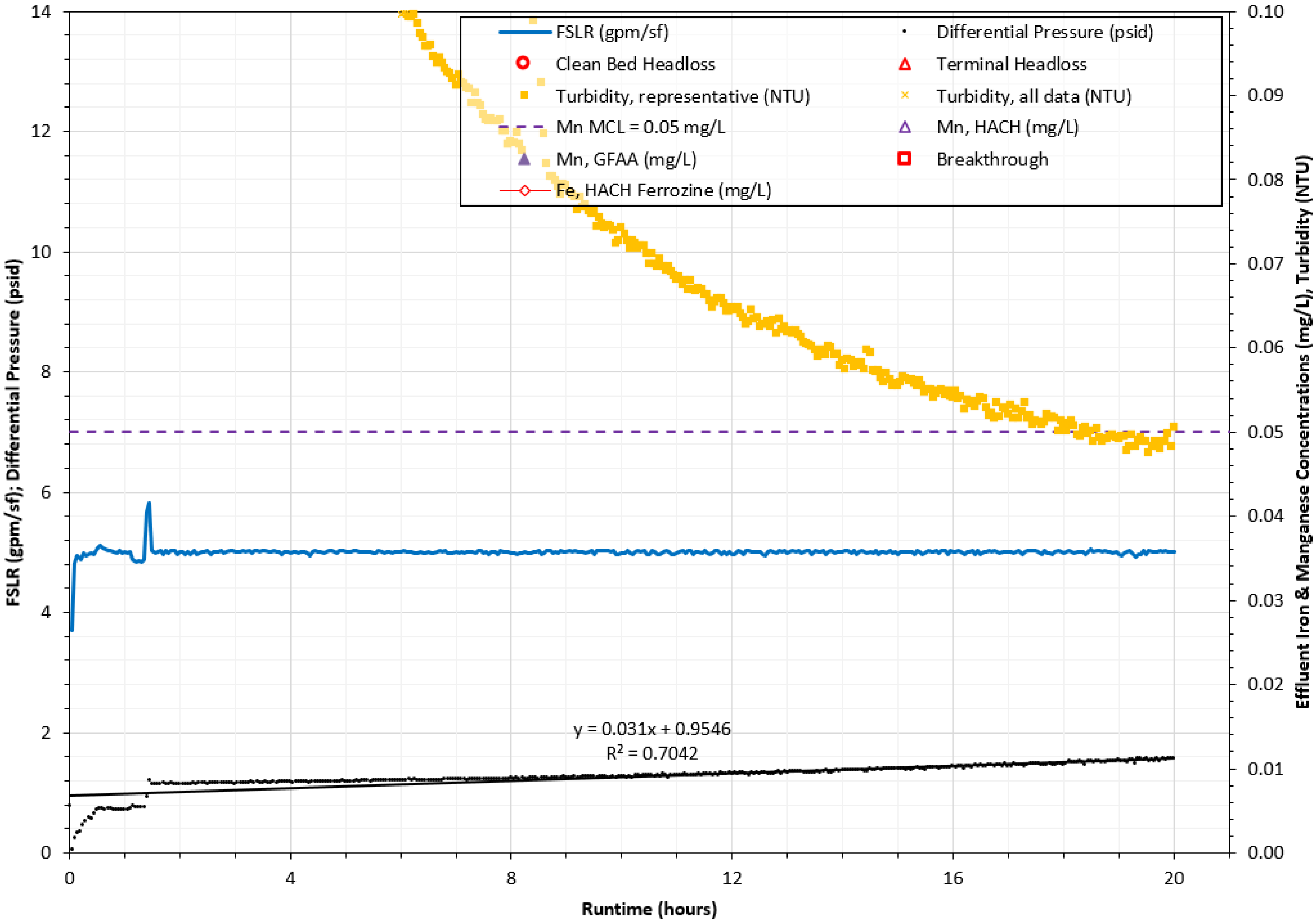


Figure 3.07: Filter 2, Trial 2 Filter Performance Plot

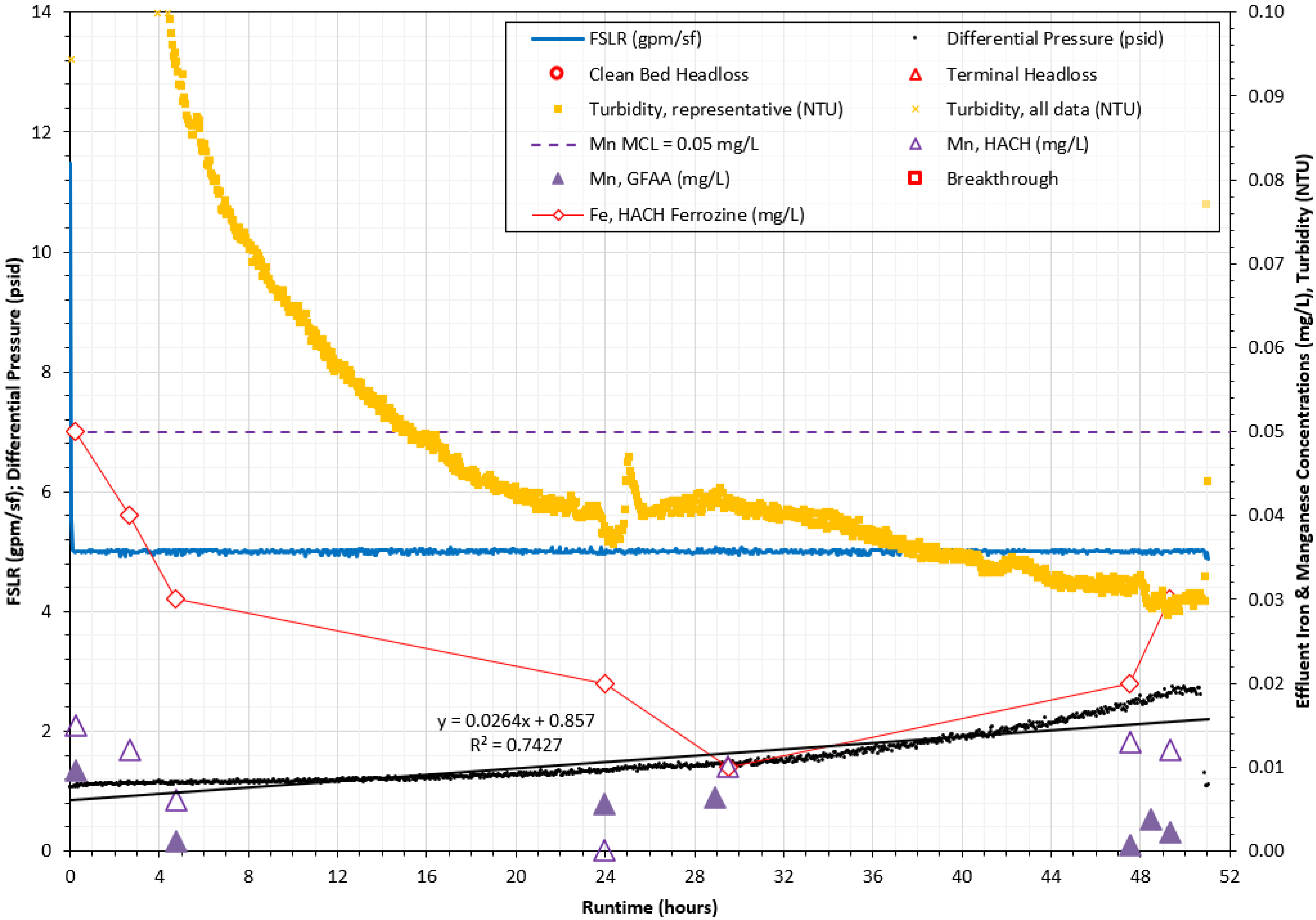


Figure 3.08: Filter 2, Trial 3 Filter Performance Plot

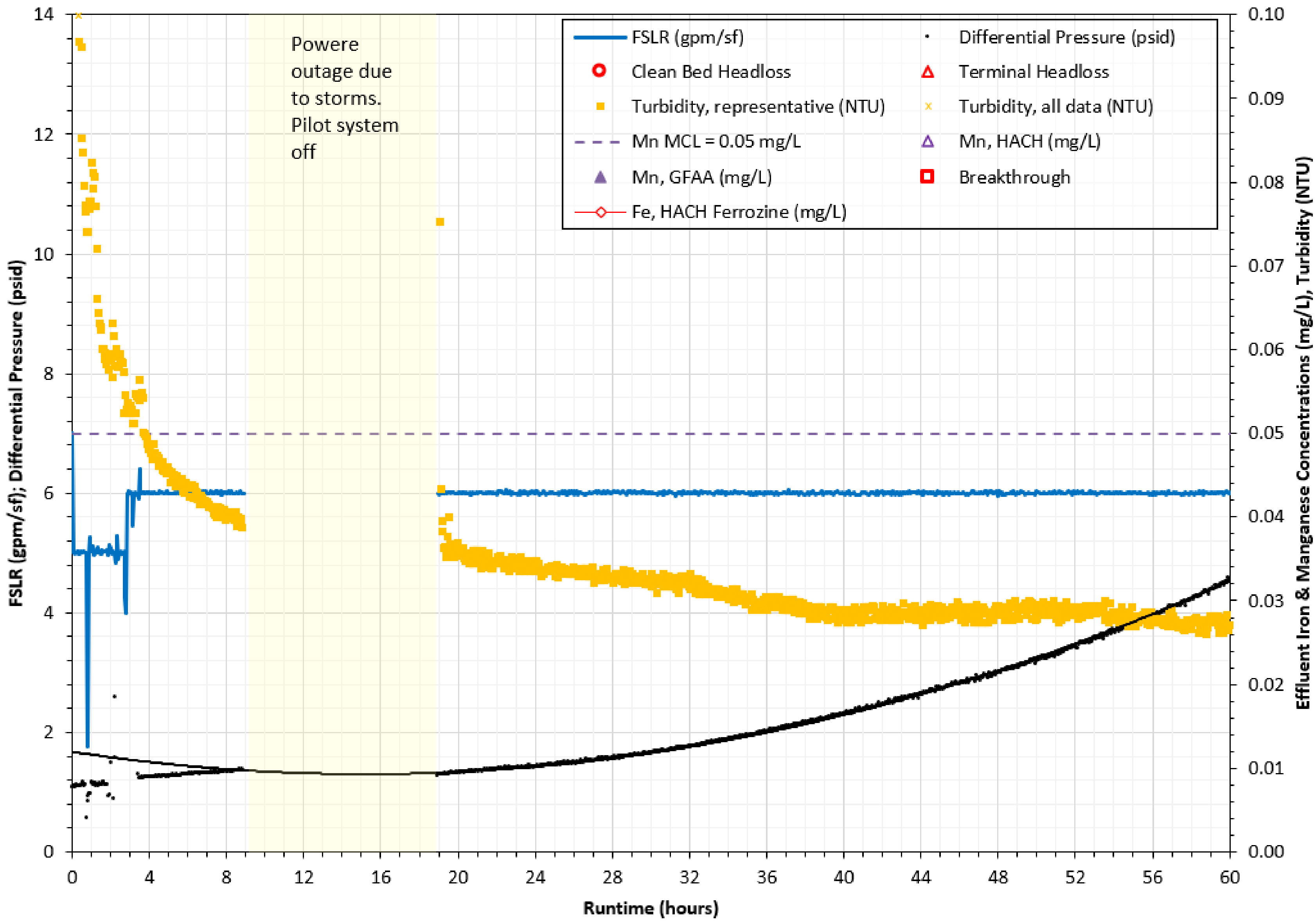


Figure 3.09: Filter 2, Trial 4 Filter Performance Plot

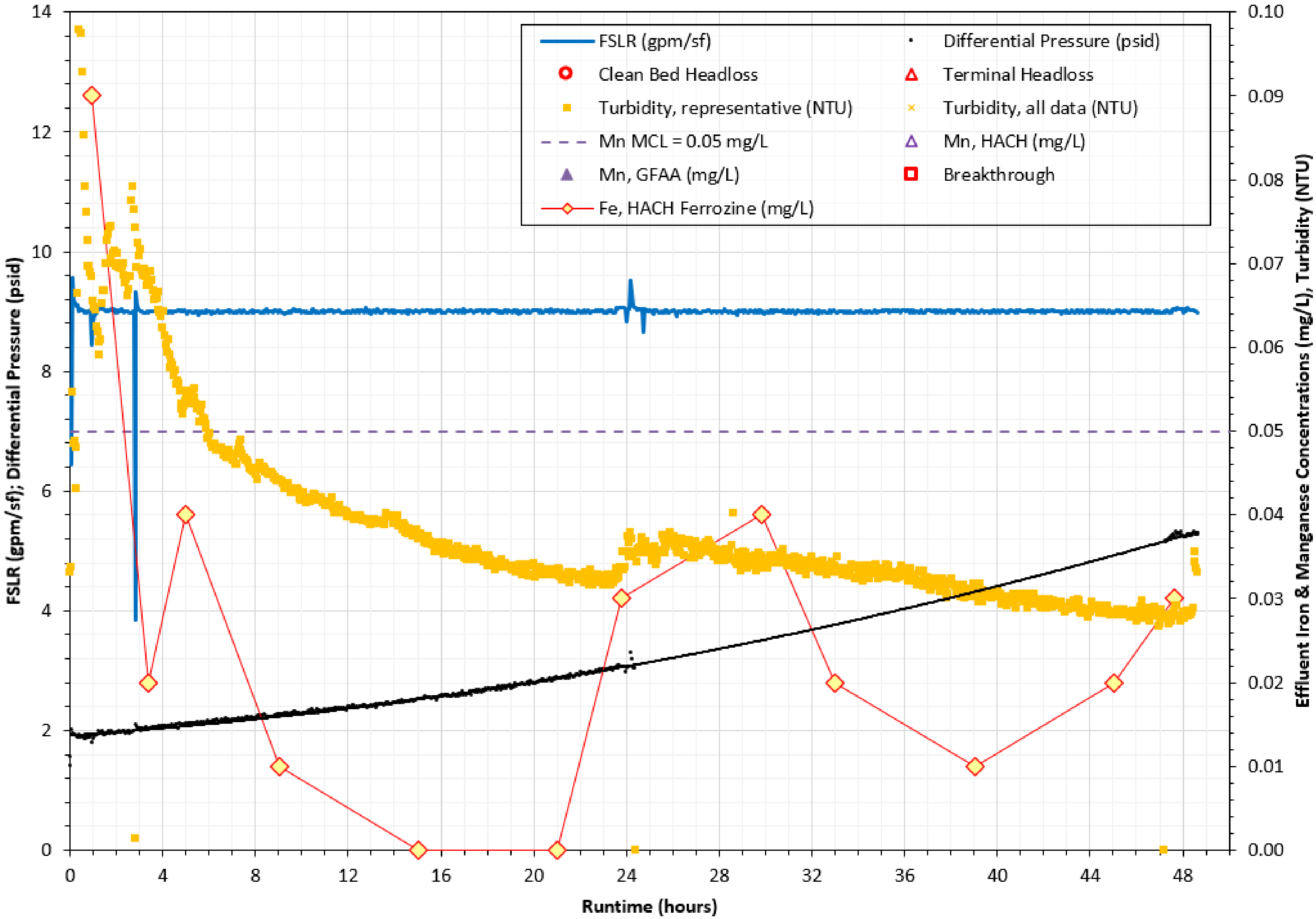


Figure 3.10: Filter 2, Trial 5 Filter Performance Plot

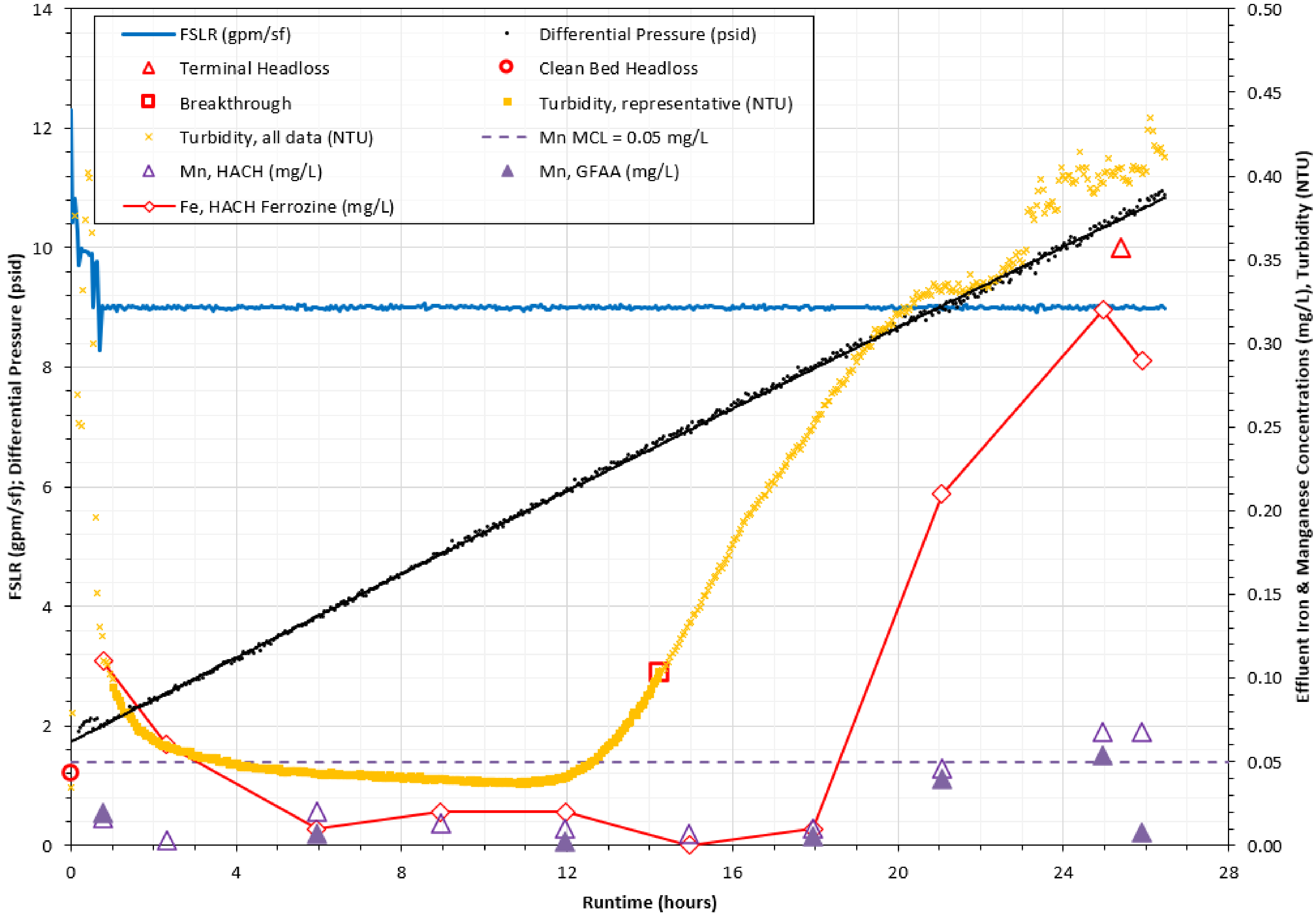


Figure 3.11: Filter 2, Trial 6 Filter Performance Plot

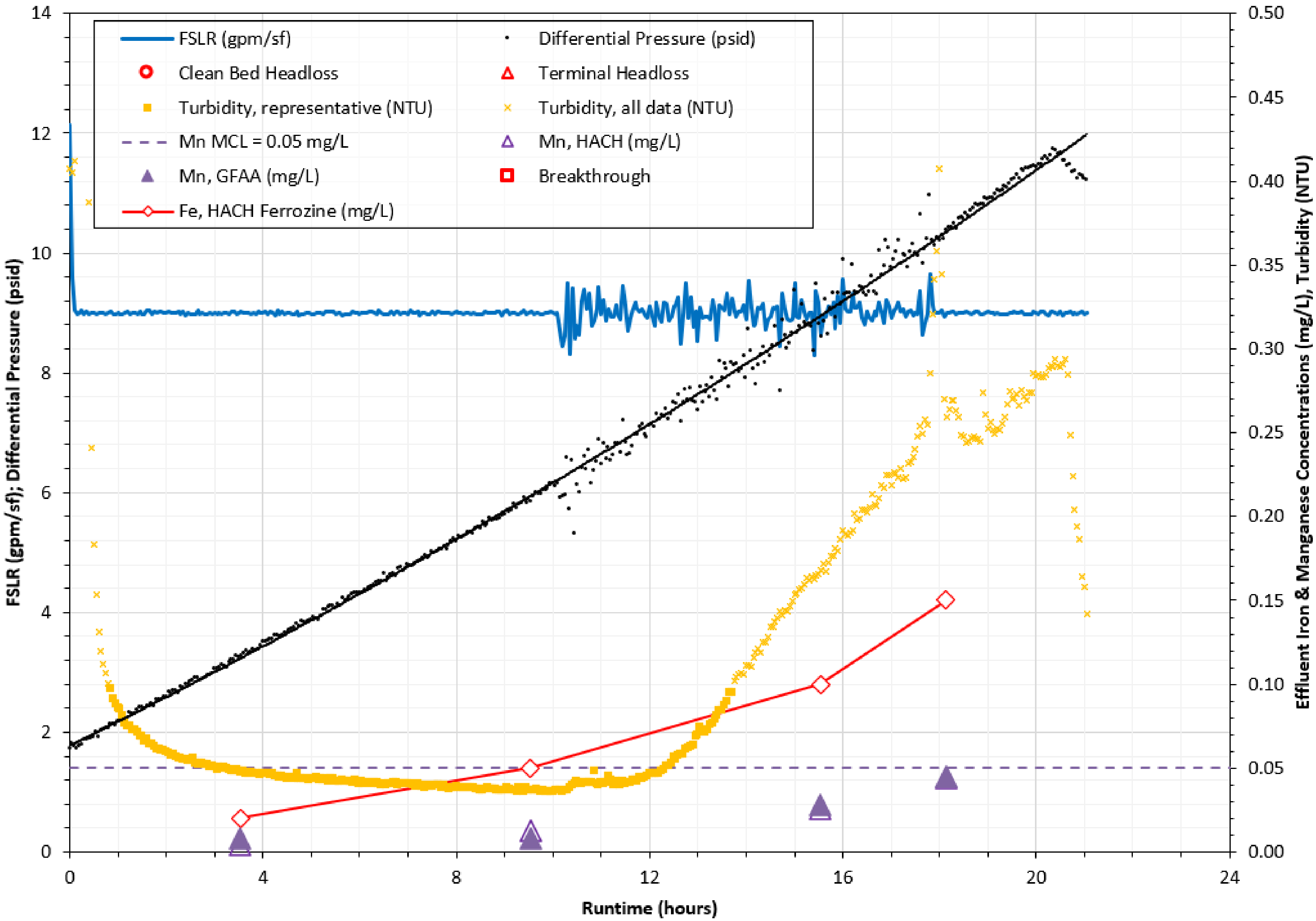


Figure 3.12: Filter 5, Trial 1 Filter Performance Plot

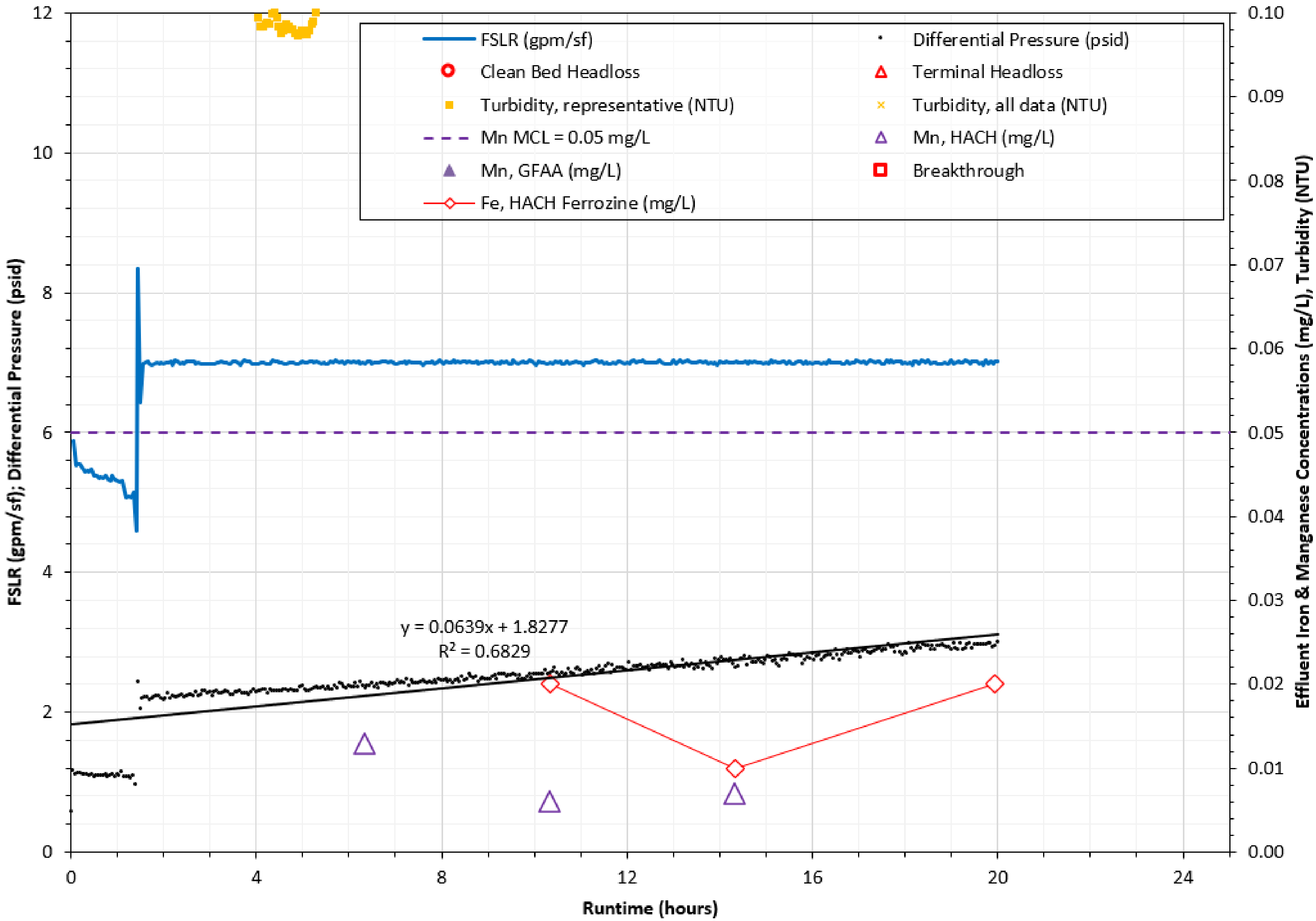


Figure 3.13: Filter 5, Trial 2 Filter Performance Plot

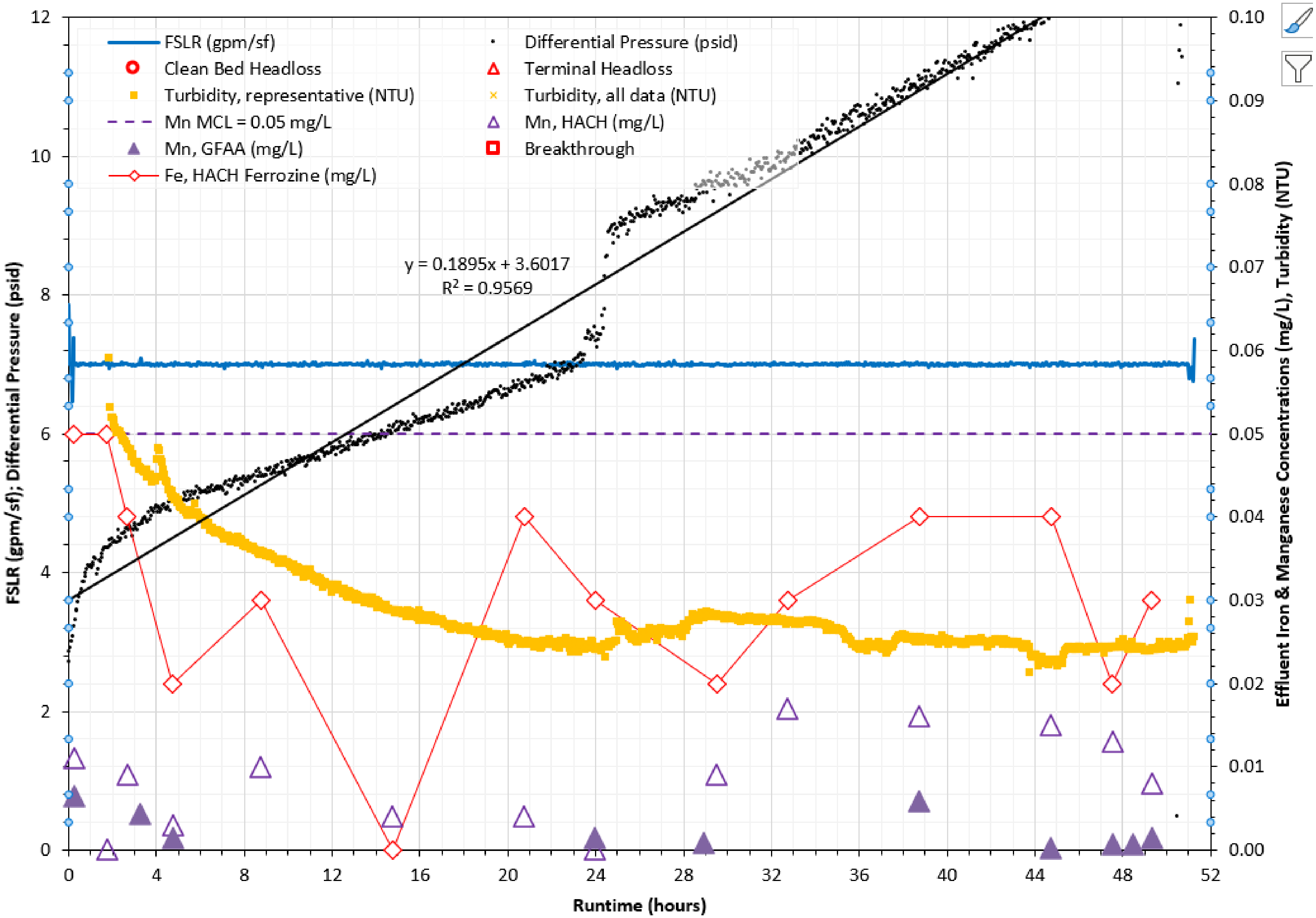


Figure 3.14: Filter 5, Trial 3 Filter Performance Plot

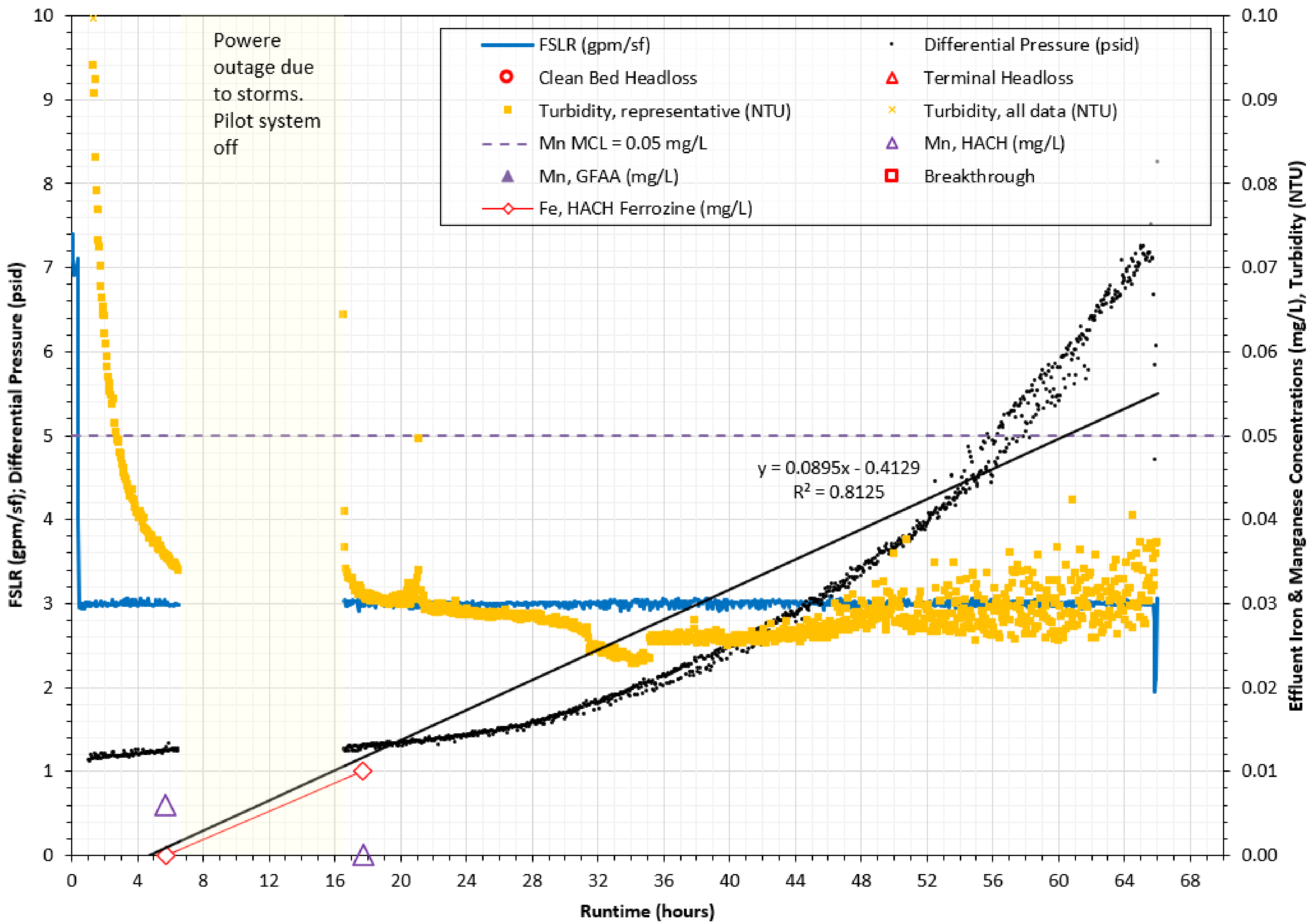


Figure 3.15: Filter 5, Trial 4 Filter Performance Plot

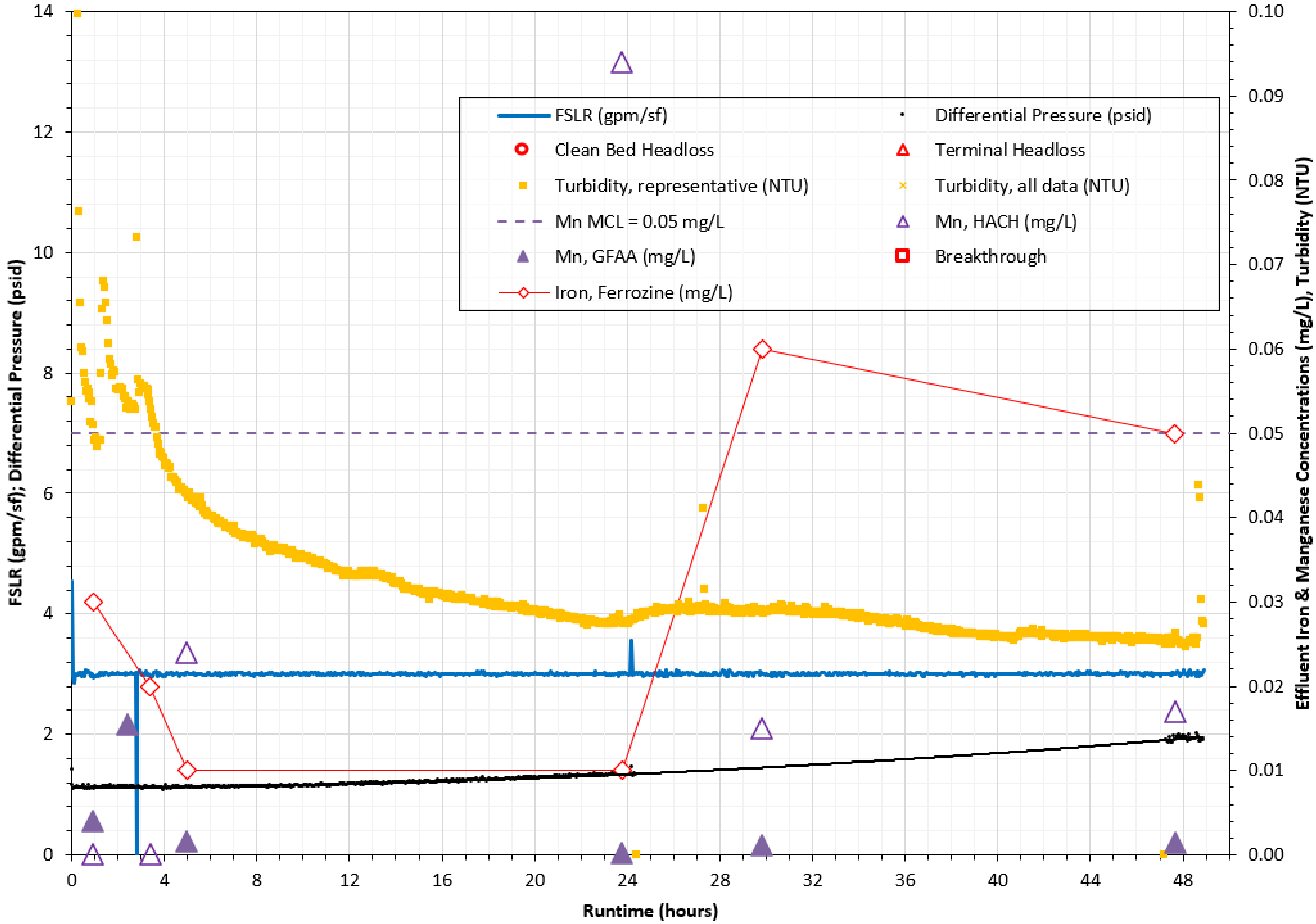


Figure 3.16: Filter 3, Trial 1 Filter Performance Plot

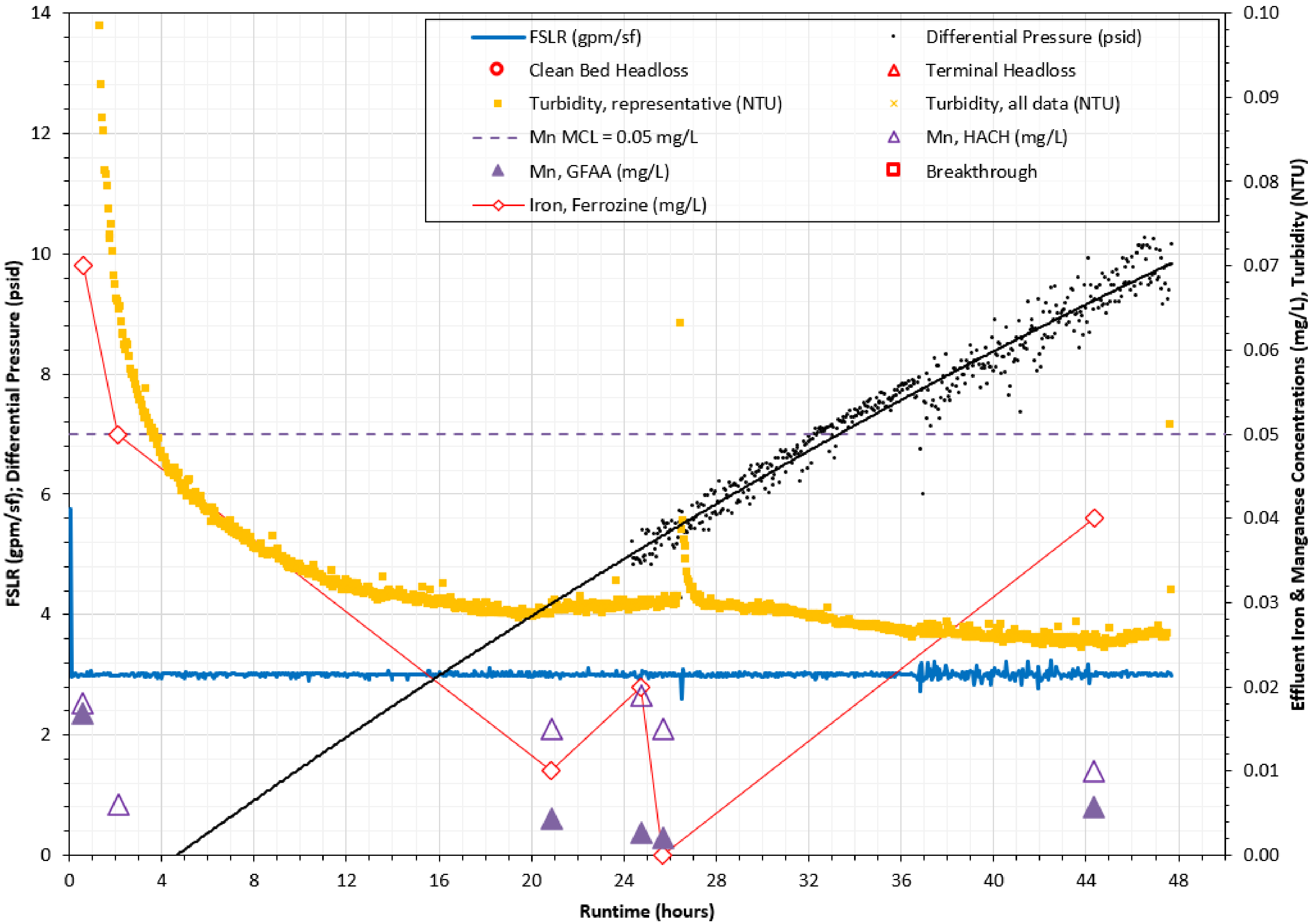


Figure 3.17: Filter 6, Trial 1 Filter Performance Plot

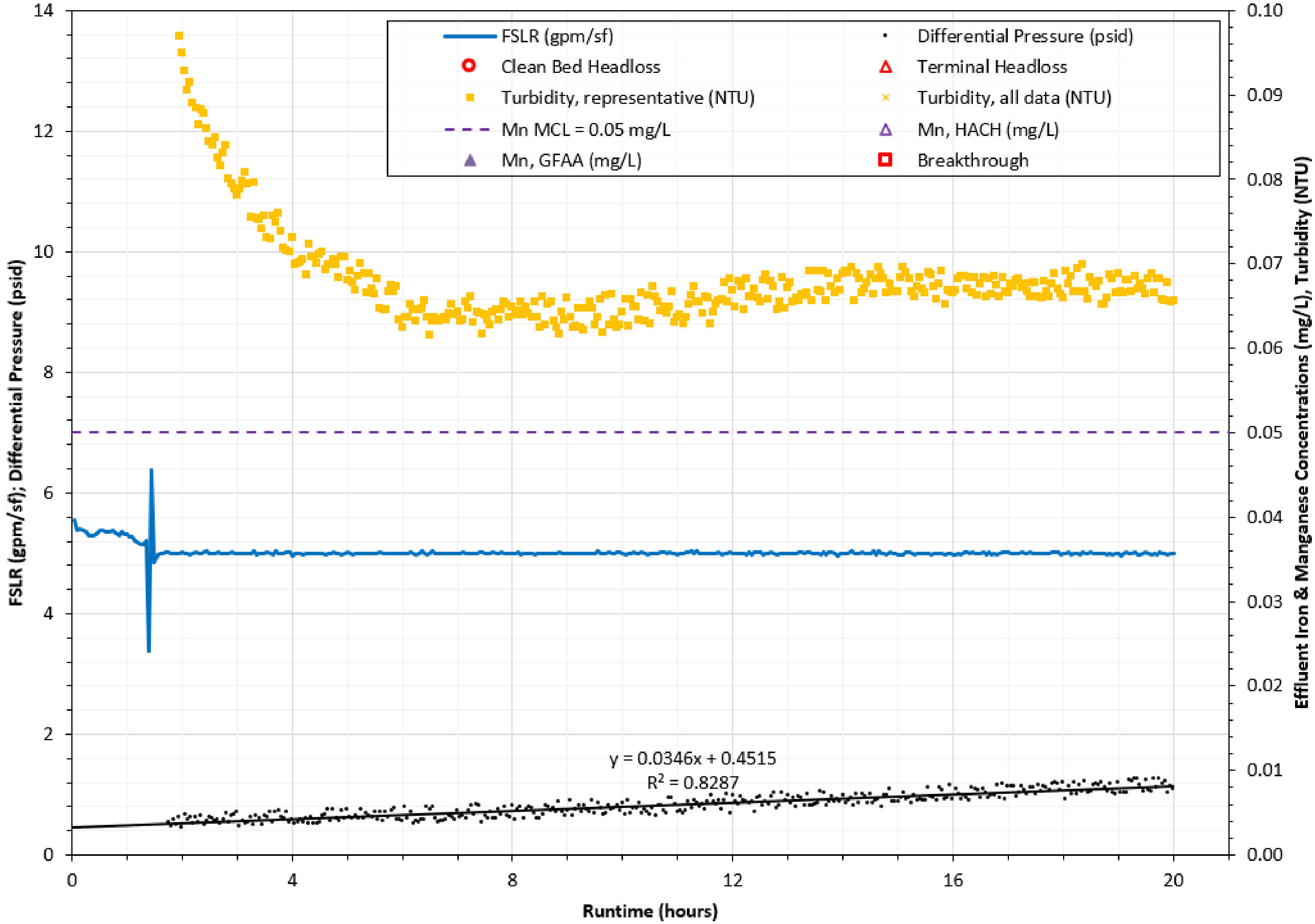


Figure 3.18: Filter 6, Trial 2 Filter Performance Plot

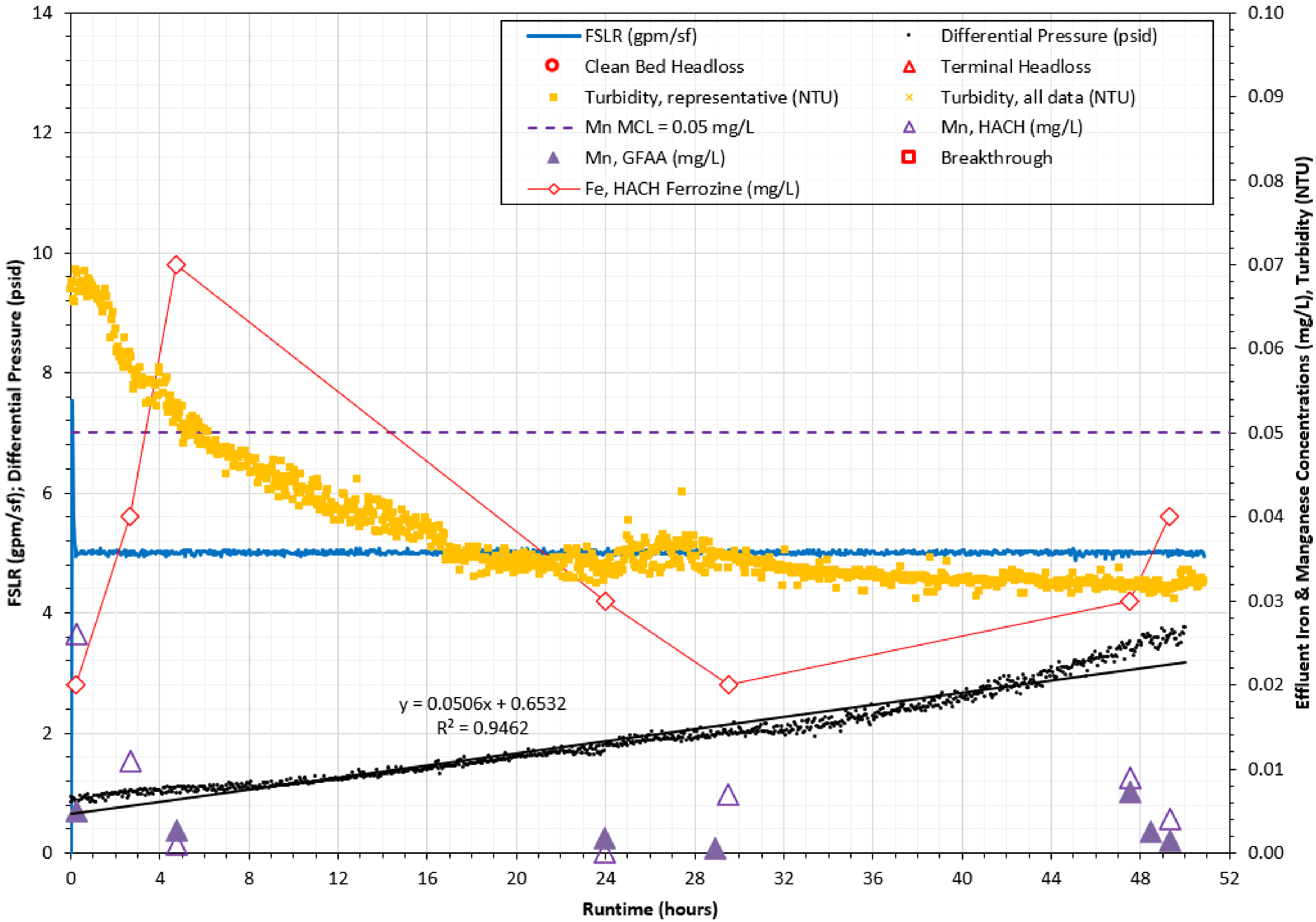


Figure 3.19: Filter 6, Trial 3 Filter Performance Plot

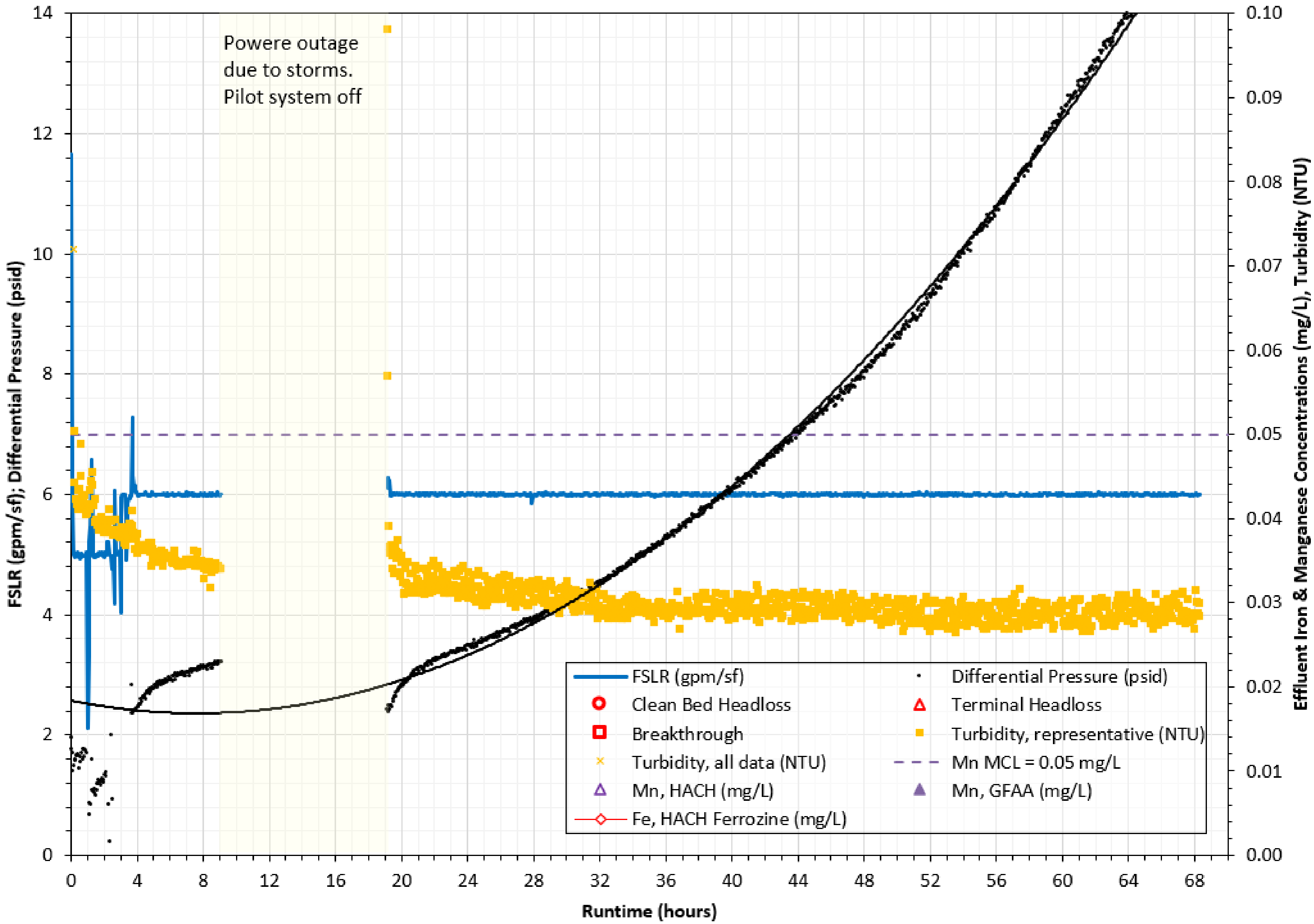


Figure 3.20: Filter 6, Trial 4 Filter Performance Plot

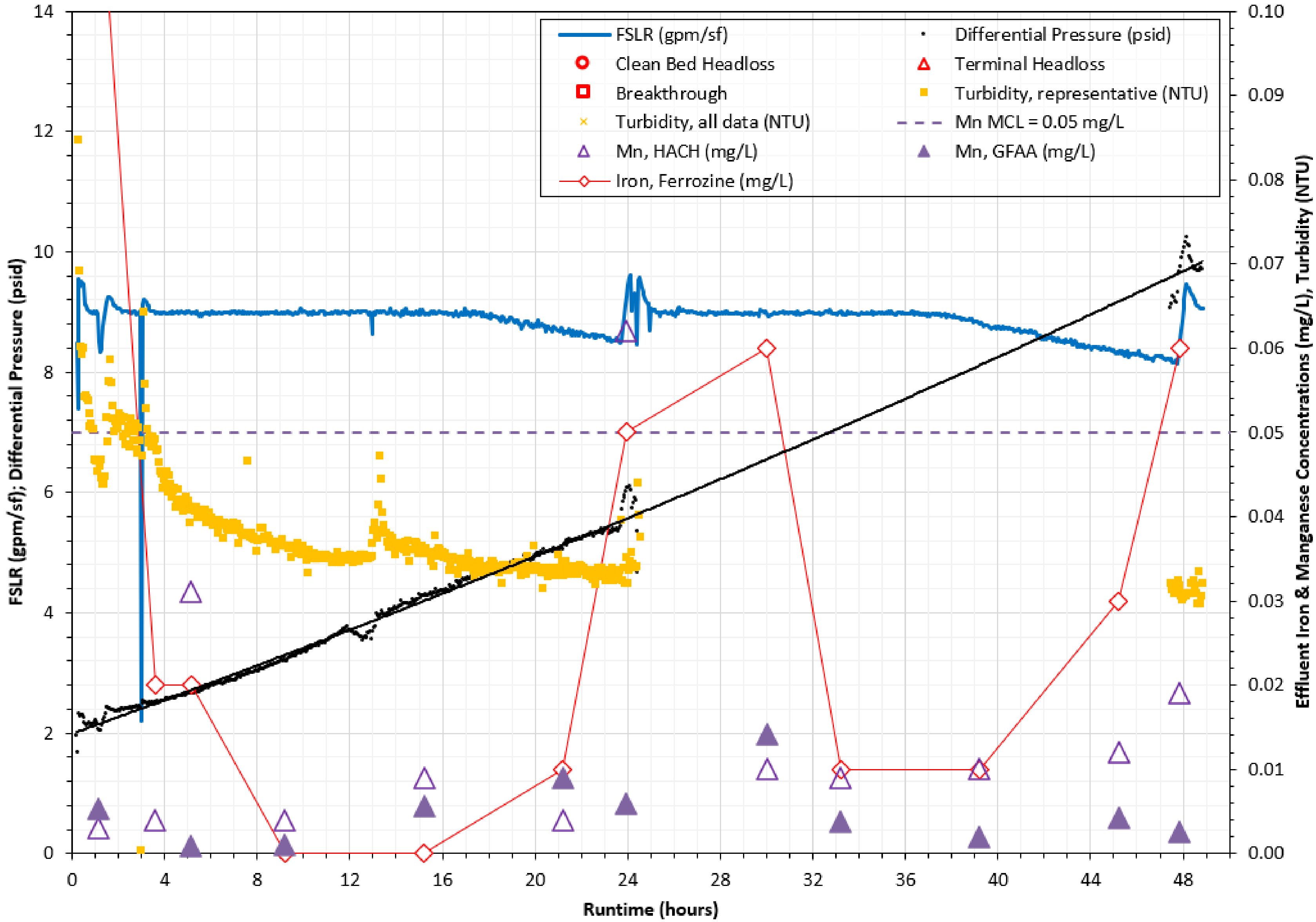


Figure 3.21: Filter 4, Trial 1 Filter Performance Plot

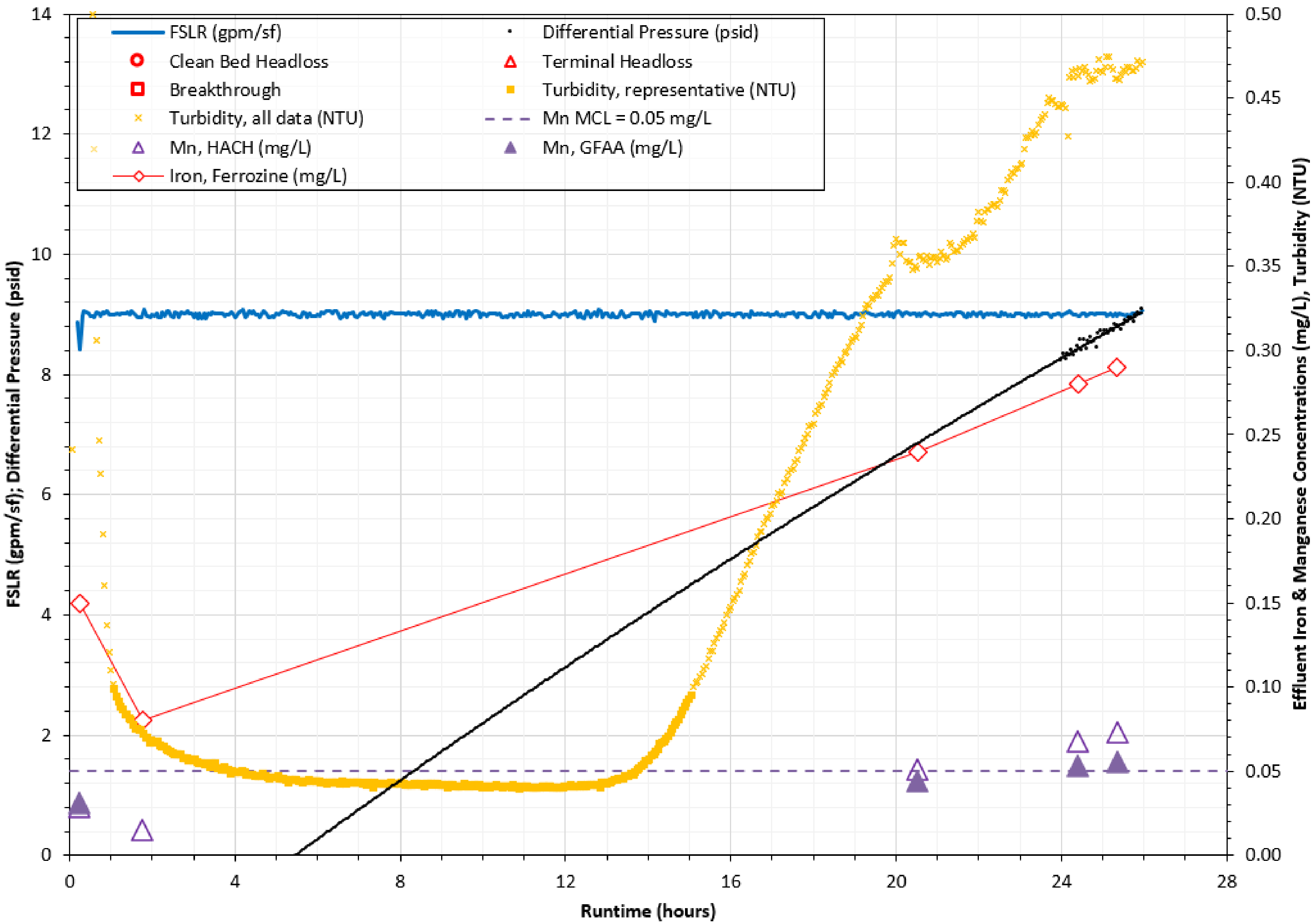
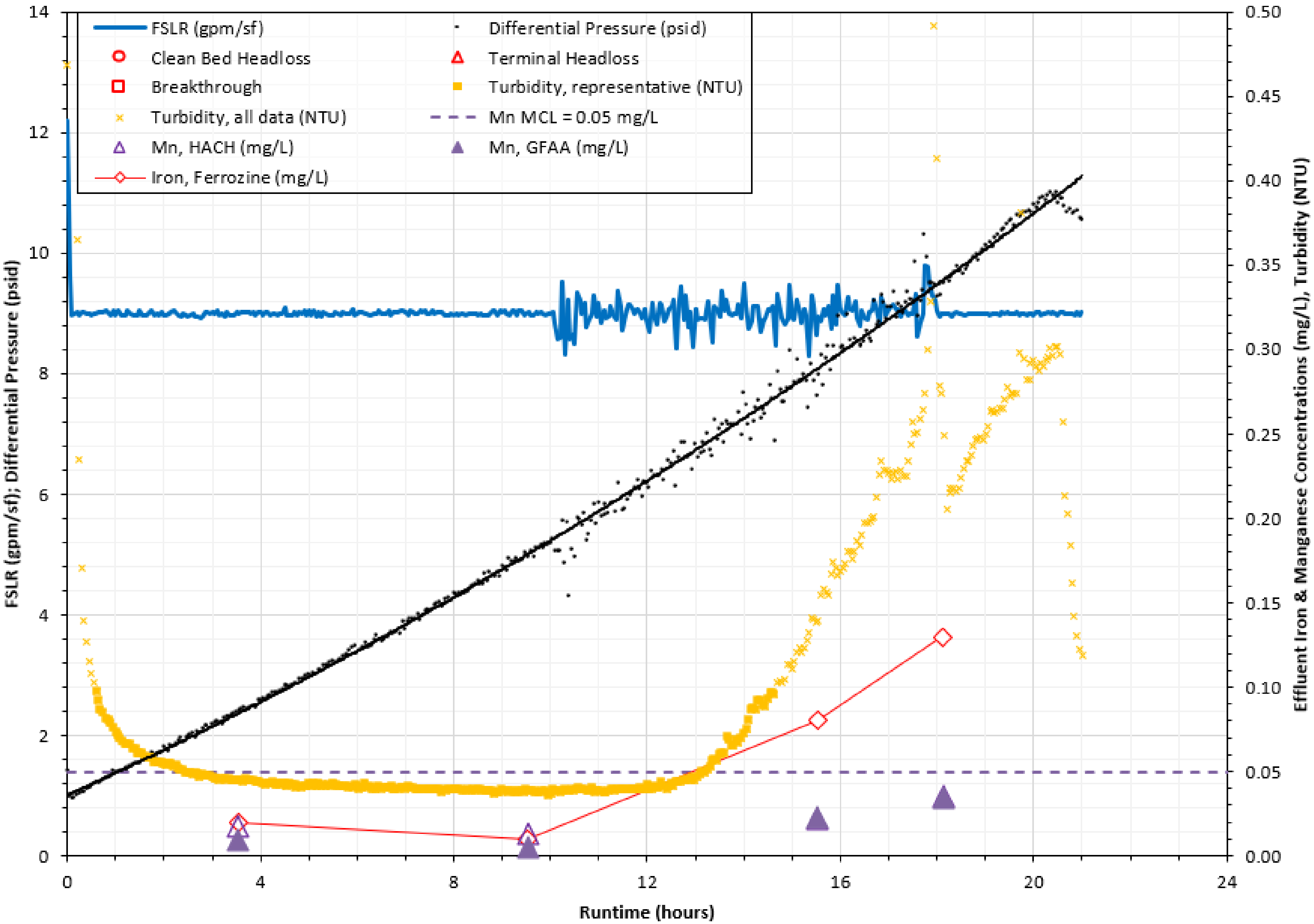


Figure 3.22: Filter 4, Trial 2 Filter Performance Plot



3.3.2 Filter Performance Summary Tables

Table 3.12 summarizes 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 1.3 indicates that it is the third trial using Filter 1. Filters were backwashed and restarted between trials.
B. "Start" and "End" represent the start and end date and time of the filter trial.
C. "Duration" is the total length of the filter trial in hours.
D. "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]."
E. "Slope" is the slope of the regression equation for DP versus runtime (coefficient "m" in the equation y = mx + b). Slope is reported in psid/hour.
F. "Intercept" is the y-intercept of the line of the regression equation for DP versus runtime ("b" in the equation y = mx + b). The intercept is reported in psid.
G. "R^2" is the coefficient of multiple determination for multiple regression of the line of the regression equation for DP versus runtime.
H. "Runtime to 10 psi (hrs)" – The projected runtime (in hours) to develop a DP of 10 psi. Projected runtimes were calculated when a DP of 10 psi was not observed during the Filter Trial.
I. "Runtime to Breakthrough (hrs)" – The runtime (in hours) until the turbidity increased to 0.1 NTU. Breakthrough of iron and manganese often occurred after the effluent turbidity reached 0.1 NTU, so the breakthrough estimates are conservative.
J. "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.
K. "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.
L. "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 Shallow Media Filters (18" GreensandPlus + 12" Anthracite)

Filter and Trial #	Description	Start Date and Time	End Date and Time	Duration (hours)	Filter Surface Loading Rate (gpm/sf)	Headloss VS. Loading Rate			Runtime to 10 psi(hours)	Runtime to 0.10 NTU (hours)	UFRV (gal/sf)	All Turbidity (NTU)	Representative Turbidity (NTU)
						Slope (psi/hr)	Intercept	R-sq					
1.1	Whitney 1+2, Acclimation Trial	05/12/20 11:52	05/13/20 07:51	20.0	7.00 ± 0.01 [367]	0.107	1.295	0.9132	81.0	-	42,821	0.186 ± 0.460 [401]	0.056 ± 0.015 [292]
1.2	Whitney 1+2	05/13/20 08:03	05/15/20 11:03	51.0	7.00 ± 0.03 [1021]	0.046	1.551	0.8699	185.3	-	109,286	0.045 ± 0.080 [1021]	0.037 ± 0.015 [972]
1.3	Whitney 1+2	05/15/20 11:15	05/18/20 07:36	68.3	3.25 ± 1.10 [1168]	0.033	1.476	0.5649	261.8	-	66,955	0.047 ± 0.018 [1168]	0.046 ± 0.008 [1166]
1.4	Whitney 1+2	05/18/20 07:54	05/20/20 08:57	49.0	3.00 ± 0.10 [982]	0.019	1.687	0.9366	433.8	-	45,046	0.052 ± 0.016 [980]	0.052 ± 0.011 [977]
1.5	Whitney + Baddacook	05/20/20 11:03	05/22/20 10:54	47.9	3.00 ± 0.04 [958]	0.101	1.424	0.9729	85.2	-	43,944	0.047 ± 0.036 [958]	0.044 ± 0.006 [947]
2.1	Whitney 1+2	05/12/20 11:52	05/13/20 07:51	20.0	5.00 ± 0.09 [400]	0.031	0.955	0.7042	291.8	-	30,587	0.227 ± 0.725 [401]	0.066 ± 0.015 [278]
2.2	Whitney 1+2	05/13/20 08:12	05/15/20 11:15	51.0	5.01 ± 0.20 [1022]	0.028	0.825	0.8406	331.2	-	78,138	0.054 ± 0.044 [1022]	0.045 ± 0.014 [932]
2.3	Whitney 1+2	05/15/20 11:30	05/18/20 07:51	68.3	5.95 ± 0.26 [1168]	0.064	0.287	0.5816	152.2	-	123,448	0.035 ± 0.028 [1168]	0.034 ± 0.017 [1160]
2.4	Whitney 1+2	05/18/20 08:03	05/20/20 08:42	48.7	8.99 ± 0.19 [974]	0.067	1.634	0.9459	125.7	-	132,546	0.038 ± 0.011 [972]	0.038 ± 0.011 [974]
2.5	Whitney + Baddacook	05/20/20 11:03	05/21/20 13:30	26.4	9.03 ± 0.22 [530]	0.344	1.780	0.9995	23.9	14.2	72,872	0.171 ± 0.140 [530]	0.049 ± 0.015 [265]
2.6	Whitney + Baddacook	05/21/20 13:42	05/22/20 10:45	21.0	9.01 ± 0.21 [422]	0.484	1.472	0.9941	17.6	13.7	57,995	0.119 ± 0.108 [422]	0.049 ± 0.014 [258]
3.1	Whitney + Baddacook	05/20/20 11:15	05/22/20 10:54	47.7	3.01 ± 0.10 [954]	0.207	0.059	0.9613	48.0	-	43,760	0.066 ± 0.309 [954]	0.032 ± 0.011 [928]
4.1	Whitney + Baddacook	05/20/20 11:36	05/21/20 13:30	25.9	9.00 ± 0.04 [516]	0.391	2.000	0.9435	20.5	15.4	71,357	0.203 ± 0.313 [519]	0.050 ± 0.013 [280]
4.2	Whitney + Baddacook	05/21/20 13:45	05/22/20 10:45	21.0	9.01 ± 0.22 [421]	0.488	0.569	0.9920	19.3	14.6	57,857	0.110 ± 0.116 [421]	0.048 ± 0.014 [282]

Table 3.08: Filter Performance Table for Deep Media Filters (24" GreensandPlus + 12" Anthracite)

Filter and Trial #	Description	Start Date and Time	End Date and Time	Duration (hours)	Filter Surface Loading Rate (gpm/sf)	Headloss VS. Loading Rate			Runtime to 10 psi(hours)	Runtime to 0.10 NTU (hours)	UFRV (gal/sf)	All Turbidity (NTU)	Representative Turbidity (NTU)
						Slope (psi/hr)	Intercept	R-sq					
5.1	Whitney 1+2, Acclimation Trial	05/12/20 11:52	05/13/20 07:51	20.0	6.89 ± 0.44 [400]	0.064	1.828	0.6829	127.8	-	41,598	0.321 ± 0.319 [401]	0.323 ± 0.226 [321]
5.2	Whitney 1+2	05/13/20 08:03	05/15/20 11:18	51.2	7.00 ± 0.31 [1026]	0.190	3.507	0.9569	34.3	-	109,821	0.036 ± 0.040 [1026]	0.029 ± 0.006 [989]
5.3	Whitney 1+2	05/15/20 13:51	05/18/20 07:51	66.0	3.03 ± 0.35 [1121]	0.090	-0.413	0.8125	116.3	-	60,612	0.038 ± 0.094 [1121]	0.030 ± 0.007 [1094]
5.4	Whitney 1+2	05/18/20 08:03	05/20/20 08:57	48.9	3.00 ± 0.11 [979]	0.016	1.008	0.8897	548.5	-	44,908	0.037 ± 0.098 [977]	0.032 ± 0.013 [974]
6.1	Whitney 1+2, Acclimation Trial	05/12/20 11:52	05/13/20 07:51	20.0	5.02 ± 0.14 [400]	0.035	0.452	0.8287	276.4	-	30,587	0.105 ± 0.258 [401]	0.068 ± 0.006 [362]
6.2	Whitney 1+2	05/13/20 08:12	05/15/20 11:03	50.9	5.00 ± 0.18 [1018]	0.051	0.613	0.9462	185.5	-	77,832	0.039 ± 0.012 [1018]	0.039 ± 0.012 [1018]
6.3	Whitney 1+2,	05/15/20 11:15	05/18/20 07:36	68.3	5.95 ± 0.31 [1168]	0.197	-0.491	0.8695	53.3	-	123,448	0.032 ± 0.017 [1168]	0.031 ± 0.004 [1164]
6.4	Whitney 1+2,	05/18/20 07:54	05/20/20 08:42	48.8	8.85 ± 0.36 [977]	0.159	1.830	0.9909	51.3	-	131,461	0.041 ± 0.033 [520]	0.038 ± 0.007 [515]

3.3.3 Filter Effluent Water Quality

Water quality results from field analyses are shown in Table 3.09 (filters with 18" of GreensandPlus media) and 3.10 (filters with 24" of GreensandPlus media).

Note that four trial operated past contaminant breakthrough when operating with the Whitney + Baddacook blend, and the iron concentrations associated with contaminant breakthrough are highlighted in Table 3.07. Water quality from the filters met treatment goals prior to contaminant breakthrough.

Laboratory data is reported in Tables 3.11 through 3.16.

Simulated Distribution System (SDS) field and laboratory data from Filter 2 are reported in Table 3.17.

Table 3.09: Filtered Water Quality of Shallow Media Pilot Filters (18" GreensandPlus + 12" Anthracite) from Field Analysis

Trial	Source	Cl2 (f) (mg/L)	Cl2 (t) (mg/L)	Fe(t) (mg/L)	Mn(t) by Field Analyses (HACH PAN) (mg/L)	Mn(t) by EPA Method 200.9 Graphite Furnace (mg/L)	pH (s.u.)	Temp (°C)	Alkalinity (mg/L)	Carbon Dioxide (mg/L)	TOC (mg/L)
1.1	Whitney Wells 1 and 2	0.64-1.27 [2]	No Data [0]	**0.010** (0.010-0.040) [3]	**0.016** (0.009-0.026) [3]	No Data [0]	No Data [0]	No Data [0]	No Data [0]	No Data [0]	No Data [0]
1.2		**0.90** (0.19-1.36) [7]	**1.15** (0.63-1.41) [6]	**0.040** (0.020-0.070) [11]	**0.013** (0.000-0.026) [11]	**0.004** (0.001-0.008) [12]	**7.16** (6.75-7.63) [12]	**14.6** (11.8-16.3) [10]	68 [1]	51 [1]	0.69 [1]
1.3		No Data [0]	No Data [0]	**0.015** (0.000-0.050) [4]	**0.008** (0.002-0.020) [4]	No Data [0]	No Data [0]	No Data [0]	No Data [0]	No Data [0]	No Data [0]
1.4		**0.42** (0.04-1.01) [5]	**0.83** (0.06-1.53) [5]	**0.040** (0.000-0.070) [5]	**0.014** (0.000-0.014) [5]	**0.004** (0.002-0.015) [6]	**7.35** (7.00-7.55) [9]	**14.2** (11.8-16.8) [8]	76 [1]	68 [1]	0.55 [1]
1.5	Whitney + Baddacook	**0.28** (0.11-0.55) [4]	**0.50** (0.10-0.66) [4]	**0.060** (0.000-0.100) [6]	**0.018** (0.010-0.029) [6]	**0.005** (0.001-0.017) [5]	**7.31** (6.77-7.56) [8]	**14.9** (13.4-17.0) [8]	71 [1]	52 [1]	1.18 [1]
2.1	Whitney Wells 1 and 2	0.51-1.15 [2]	No Data [0]	No Data [0]	No Data [0]	No Data [0]	No Data [0]	No Data [0]	No Data [0]	No Data [0]	No Data [0]
2.2		**0.59** (0.16-1.01) [7]	**0.96** (0.43-1.08) [6]	**0.030** (0.010-0.050) [7]	**0.012** (0.000-0.015) [7]	**0.004** (0.001-0.010) [7]	**7.12** (6.73-7.51) [12]	**14.8** (11.8-16.4) [9]	66 [1]	66 [1]	0.92 [1]
2.3		No Data [0]	No Data [0]	No Data [0]	No Data [0]	No Data [0]	No Data [0]	No Data [0]	No Data [0]	No Data [0]	No Data [0]
2.4		**0.30** (0.02-1.67) [6]	**0.19** (0.05-1.27) [5]	**0.020** (0.000-0.090) [12]	**0.013** (0.000-0.024) [12]	**0.004** (0.001-0.010) [12]	**7.28** (6.54-7.55) [10]	**14.2** (11.9-16.3) [9]	73 [1]	70 [1]	0.67 [1]
2.5	Whitney + Baddacook	**0.39** (0.06-0.69) [11]	**0.77** (0.57-1.02) [4]	**0.040** (0.000-0.320) [10]	**0.015** (0.003-0.068) [10]	**0.008** (0.002-0.053) [7]	**7.34** (6.59-7.49) [7]	**15.1** (13.7-16.9) [7]	76 [1]	65 [1]	1.04 [1]
2.6		0.11 [1]	1.02 [1]	**0.075** (0.020-0.150) [4]	**0.020** (0.004-0.044) [4]	**0.018** (0.008-0.045) [4]	6.83-7.34 [2]	14.3-14.7 [2]	No Data [0]	No Data [0]	No Data [0]
3.1		**0.09** (0.06-0.15) [4]	**0.37** (0.30-0.45) [4]	**0.030** (0.000-0.070) [6]	**0.015** (0.006-0.019) [6]	**0.004** (0.002-0.017) [5]	**7.27** (6.77-7.54) [8]	**16.4** (13.9-18.2) [7]	72 [1]	63 [1]	1.14 [1]
4.1		**0.08** (0.02-0.29) [3]	**0.54** (0.02-0.86) [3]	**0.240** (0.080-0.290) [5]	**0.051** (0.015-0.073) [5]	**0.049** (0.031-0.056) [4]	**7.49** (7.05-7.83) [6]	**16.7** (14.3-18.3) [6]	72 [1]	54 [1]	1.06 [1]
4.2		0.36 [1]	0.69 [1]	**0.050** (0.010-0.130) [4]	**0.020** (0.013-0.036) [4]	**0.016** (0.005-0.035) [4]	6.94-7.56 [2]	14.8-15.2 [2]	No Data [0]	No Data [0]	No Data [0]

* highlighted values reflect data from filter trials during breakthrough events.

Table 3.10: Filtered Water Quality of Deep Media Pilot Filters (24" GreensandPlus + 12" Anthracite) from Field Analysis

Trial	Source	Cl2 (f) (mg/L)	Cl2 (t) (mg/L)	Fe(t) (mg/L)	Mn(t) by Field Analyses (HACH PAN) (mg/L)	Mn(t) by EPA Method 200.9 Graphite Furnace (mg/L)	pH (s.u.)	Temp (°C)	Alkalinity (mg/L)	Carbon Dioxide (mg/L)	TOC (mg/L)
5.1	Whitney Wells 1 and 2	No Data [0]	No Data [0]	**0.020** (0.010-0.020) [3]	**0.007** (0.006-0.013) [3]	No Data [0]	No Data [0]	No Data [0]	No Data [0]	No Data [0]	No Data [0]
5.2		**0.60** (0.08-1.23) [6]	**1.04** (0.81-1.44) [6]	**0.030** (0.000-0.050) [14]	**0.009** (0.000-0.017) [14]	**0.001** (0.000-0.007) [10]	**7.18** (6.71-7.53) [12]	**14.9** (12.0-16.5) [9]	67 [1]	63 [1]	0.62 [1]
5.3		No Data [0]	No Data [0]	0.000-0.010 [2]	0.006 [1]	No Data [0]	No Data [0]	No Data [0]	No Data [0]	No Data [0]	No Data [0]
5.4		**0.23** (0.00-0.65) [5]	**0.57** (0.04-1.28) [5]	**0.025** (0.010-0.060) [6]	**0.016** (0.000-0.094) [6]	**0.002** (0.000-0.015) [6]	**7.25** (6.69-7.50) [10]	**14.5** (12.0-17.2) [9]	No Data [0]	No Data [0]	0.51 [1]
6.1		No Data [0]	No Data [0]	No Data [0]	No Data [0]	No Data [0]	No Data [0]	No Data [0]	No Data [0]	No Data [0]	No Data [0]
6.2		**1.07** (0.07-1.41) [6]	**1.17** (0.05-1.48) [6]	**0.030** (0.020-0.070) [7]	**0.007** (0.000-0.026) [7]	**0.003** (0.001-0.007) [7]	**7.24** (6.77-7.65) [12]	**15.2** (12.0-17.2) [10]	72 [1]	53 [1]	0.84 [1]
6.3		No Data [0]	No Data [0]	No Data [0]	No Data [0]	No Data [0]	No Data [0]	No Data [0]	No Data [0]	No Data [0]	No Data [0]
6.4		**0.41** (0.07-0.87) [5]	**1.21** (0.08-1.45) [5]	**0.020** (0.000-0.120) [12]	**0.010** (0.003-0.062) [12]	**0.004** (0.001-0.014) [11]	**7.40** (6.80-7.79) [10]	**14.7** (12.0-16.9) [9]	No Data [0]	No Data [0]	0.72 [1]

Table 3.11: Filtered Water Quality for Filter F1 by Laboratory Analysis

Analysis	Units	Laboratory Report #								
		L2020091	L2020094	L2020587	L2020589	L2020591	L2021199	L2021196	L2021195	L2022331
		Whitney Wells						Whitney + Baddacook		
		5/13/20 11:47	5/14/20 9:00	5/15/20 8:45	5/18/20 10:30	5/19/20 8:45	5/20/19 8:35	5/20/19 12:43	5/21/20 10:45	5/22/20 8:35
Total Iron	mg/L	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Dissolved Iron	mg/L		<0.050			<0.050			<0.050	
Total Manganese	mg/L	0.0016	0.0037	<0.0010	0.0016	<0.0010	<0.0010	0.0043	<0.0010	<0.0010
Dissolved Manganese	mg/L		0.0087			0.0020			<0.0010	
Total Coliform	Col/100mL					Negative			Negative	
Escherichia Coliform	Col/100mL					Negative			Negative	
Turbidity	NTU								<0.20	
Color, True	s.u.								<5	
Color, Apparent	s.u.								5	
pH	s.u.								7.2	
Alkalinity	mg/L		67.1			75.2			72.3	
Carbon Dioxide	mg/L		370			440			470	
Chloride	mg/L		55.3			55.4			43.4	
Sulfate	mg/L		8.74			15.7			8.71	
Calcium	mg/L		26			28.2			23.6	
Hardness	mg/L		79.3			86.9			70.6	
Total Dissolved Solids	mg/L		190			200			160	
UV Absorbance	/cm									
Total Organic Carbon	mg/L					0.78			0.950	

Table 3.12: Filtered Water Quality for Filter F2 by Laboratory Analysis

Analysis	Units	Laboratory Report #								
		L2020091	L2020094	L2020587	L2020589	L2020591	L2021199	L2021196	L2021195	L2022331
		Whitney Wells						Whitney + Baddacook		
		5/13/20 11:47	5/14/20 9:20	5/15/20 8:45	5/18/20 10:30	5/19/20 8:45	5/20/19 8:35	5/20/19 12:43	5/21/20 10:55	5/22/20 8:35
Total Iron	mg/L	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	0.259	0.139
Dissolved Iron	mg/L		<0.050			0.111			0.0558	
Total Manganese	mg/L	0.0014	0.0035	<0.0010	0.0029	<0.0010	<0.0010	0.0088	<0.050	0.0504
Dissolved Manganese	mg/L		0.0041			<0.0010			0.0018	
Total Coliform	Col/100mL					Negative			Negative	
Escherichia Coliform	Col/100mL					Negative			Negative	
Turbidity	NTU								0.48	
Color, True	s.u.								10	
Color, Apparent	s.u.								18	
pH	s.u.								7.0	
Alkalinity	mg/L		65.7			73.2			70.8	
Carbon Dioxide	mg/L		350			430			460	
Chloride	mg/L		55.1			54.3			43.1	
Sulfate	mg/L		7.91			14.3			8.75	
Calcium	mg/L		26.1			27.8			22.9	
Hardness	mg/L		79.5			85.8			68.8	
Total Dissolved Solids	mg/L		180			230			160	
UV Absorbance	/cm								0.024	
Total Organic Carbon	mg/L					0.690			0.94	

Table 3.13: Filtered Water Quality for Filter F3 by Laboratory Analysis

Analysis	Units	Laboratory Report #								
		L2020091	L2020094	L2020587	L2020589	L2020591	L2021199	L2021196	L2021195	L2022331
		Whitney Wells						Baddacook + Whitney		
								5/20/19 12:43	5/21/20 11:02	5/22/20 8:35
Total Iron	mg/L							<0.050	0.062	<0.050
Dissolved Iron	mg/L								<0.050	
Total Manganese	mg/L							0.0086	0.0054	<0.0010
Dissolved Manganese	mg/L								<0.0010	
Total Coliform	Col/100mL								Negative	
Escherichia Coliform	Col/100mL								Negative	
Turbidity	NTU								<0.20	
Color, True	s.u.								10	
Color, Apparent	s.u.								9	
pH	s.u.								7.1	
Alkalinity	mg/L								69.6	
Carbon Dioxide	mg/L								450	
Chloride	mg/L								43.2	
Sulfate	mg/L								8.68	
Calcium	mg/L								24.2	
Hardness	mg/L								72.2	
Total Dissolved Solids	mg/L								160	
UV Absorbance	/cm									
Total Organic Carbon	mg/L								0.96	

Table 3.14: Filtered Water Quality for Filter F4 by Laboratory Analysis

Analysis	Units	Laboratory Report #								
		L2020091	L2020094	L2020587	L2020589	L2020591	L2021199	L2021196	L2021195	L2022331
		Whitney Wells						Whitney + Baddacook		
								5/20/19 12:43	5/21/20 11:19	5/22/20 8:35
Total Iron	mg/L							<0.050	0.259	0.127
Dissolved Iron	mg/L								<0.050	
Total Manganese	mg/L							0.0132	0.0609	0.0604
Dissolved Manganese	mg/L								0.0013	
Total Coliform	Col/100mL								Negative	
Escherichia Coliform	Col/100mL								Negative	
Turbidity	NTU								0.47	
Color, True	s.u.								9	
Color, Apparent	s.u.								15	
pH	s.u.								7.2	
Alkalinity	mg/L								72	
Carbon Dioxide	mg/L								450	
Chloride	mg/L								42.6	
Sulfate	mg/L								8.68	
Calcium	mg/L								23.2	
Hardness	mg/L								69.5	
Total Dissolved Solids	mg/L								160	
UV Absorbance	/cm									
Total Organic Carbon	mg/L								0.94	

Table 3.15: Filtered Water Quality for Filter F5 by Laboratory Analysis

Analysis	Units	Laboratory Report #								
		L2020091	L2020094	L2020587	L2020589	L2020591	L2021199	L2021196	L2021195	L2022331
		Whitney Wells						Baddacook + Whitney		
		5/13/20 11:48	5/14/20 9:20	5/15/20 8:45	5/18/20 10:30	5/19/20 8:45	5/20/19 8:35			
Total Iron	mg/L	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050			
Dissolved Iron	mg/L		<0.050			<0.050				
Total Manganese	mg/L	<0.0010	0.0013	<0.0010	0.0014	<0.0010	<0.0010			
Dissolved Manganese	mg/L		0.0025			<0.0010				
Total Coliform	Col/100mL					Negative				
Escherichia Coliform	Col/100mL					Negative				
Turbidity	NTU									
Color, True	s.u.									
Color, Apparent	s.u.									
pH	s.u.									
Alkalinity	mg/L		65.4			72.7				
Carbon Dioxide	mg/L		350			430				
Chloride	mg/L		56.8			54.2				
Sulfate	mg/L		7.67			14				
Calcium	mg/L		26.5			28.5				
Hardness	mg/L		80.7			88.1				
Total Dissolved Solids	mg/L		170			230				
UV Absorbance	/cm									
Total Organic Carbon	mg/L					0.700				

Table 3.16: Filtered Water Quality for Filter F6 by Laboratory Analysis

Analysis	Units	Laboratory Report #								
		L2020091	L2020094	L2020587	L2020589	L2020591	L2021199	L2021196	L2021195	L2022331
		Whitney Wells						Whitney + Baddacook		
		5/13/20 11:49	5/14/20 9:30	5/15/20 8:45	5/18/20 10:30	5/19/20 8:45	5/20/19 8:35			
Total Iron	mg/L	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050			
Dissolved Iron	mg/L		<0.050			<0.050				
Total Manganese	mg/L	<0.0010	0.0022	<0.0010	<0.0010	<0.0010	<0.0010			
Dissolved Manganese	mg/L		<0.0010			<0.0010				
Total Coliform	Col/100mL					Negative				
Escherichia Coliform	Col/100mL					Negative				
Turbidity	NTU									
Color, True	s.u.									
Color, Apparent	s.u.									
pH	s.u.									
Alkalinity	mg/L		68			74.4				
Carbon Dioxide	mg/L		360			400				
Chloride	mg/L		57.4			55.2				
Sulfate	mg/L		7.82			13.4				
Calcium	mg/L		26.8			28				
Hardness	mg/L		81.3			86.6				
Total Dissolved Solids	mg/L		190			220				
UV Absorbance	/cm									
Total Organic Carbon	mg/L					0.690				

Table 3.17: Simulated Distribution System Results

Conditions	Units	Whitney Wells 5/19/20 10:56 Filter 2	Whitney + Baddacook 5/21/20 10:24 Filter 2
pH, Initial	s.u.	7.47	7.34
Residual Free Chlorine, Initial	mg/L	1.42	0.69
Residual Total Chlorine, Initial	mg/L	1.56	1.02
Incubation Time	hours	240	240
pH, Final	SU	7.28	7.31
Residual Free Chlorine, Final	mg/L	1.13	0.29
Residual Total Chlorine, Final	mg/L	1.24	0.40
Bromodichloromethane	µg/l	4.2	7.0
Bromoform	µg/l	0.52	ND (<0.5)
Chloroform	µg/l	3.9	16
Dibromochloromethane	µg/l	3.5	2.4
THMs, Total	**µg/l**	**12**	**25**
Dibromoacetic Acid	µg/l	1.4	<1
Dichloroacetic Acid	µg/l	2.2	7.8
Monobromoacetic Acid	µg/l	<1	<1
Monochloroacetic Acid	µg/l	<2	<2
Trichloroacetic Acid	µg/l	1.7	10
HAA5, Total	**µg/l**	**5.3**	**18**

3.4 SPENT BACKWASH WATER ANALYSES

Table 3.18 shows the laboratory results from filter composite backwash (CBW) and settled supernatant (SSN) concentrations from a sample collected at the end of Trial 2.6. Samples were also left onsite at the request of CEI.

Table 3.18: Backwash Water Quality from Field Analysis

Trial	TSS (mg/L)		pH (s.u.)	
	CBW	SSN	CBW	SSN
2.6	380	Not sampled	7.6	7.7

4 DATA ANALYSIS

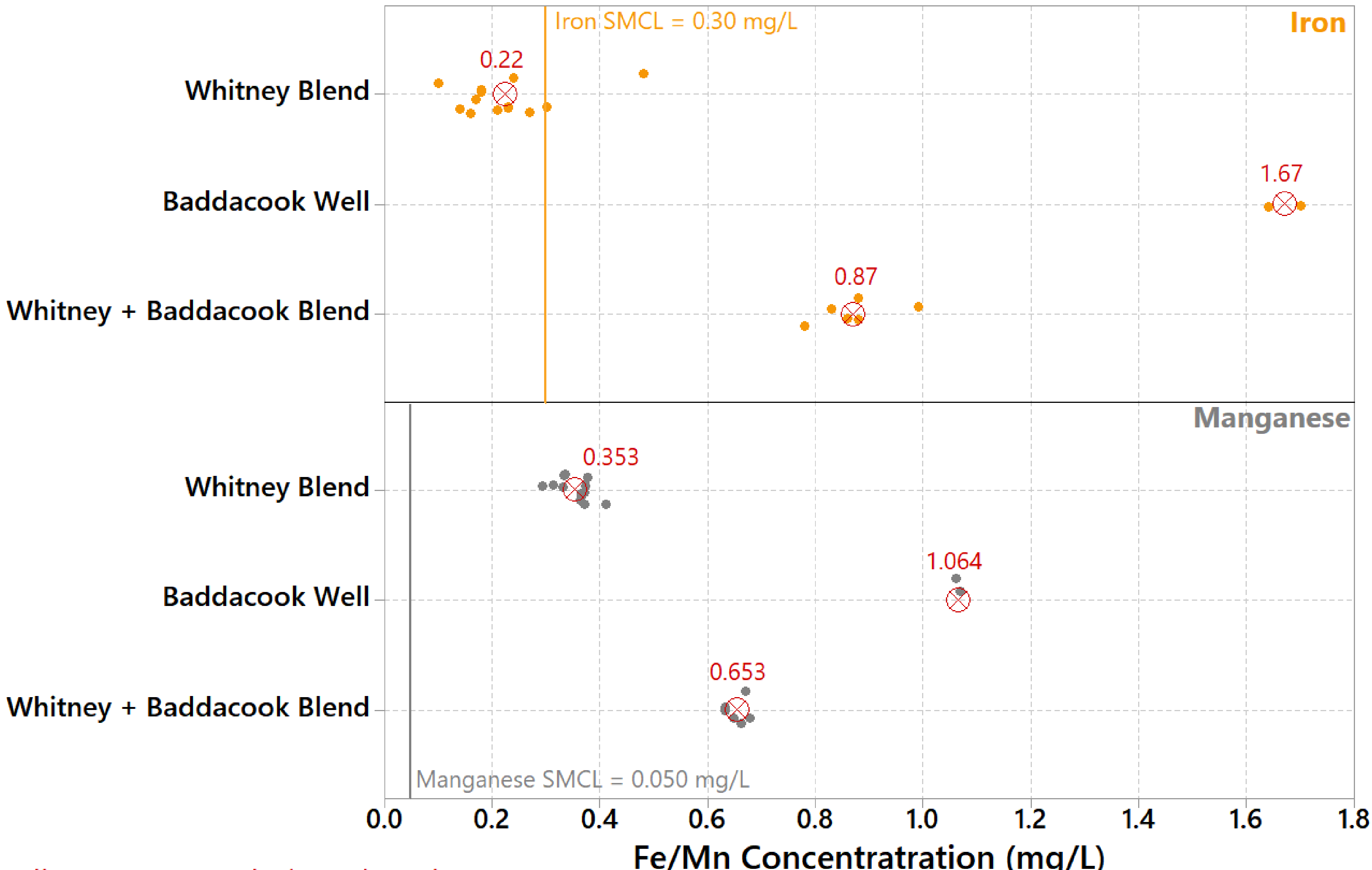
Section 4 – Data Analysis provides analysis and discussion of the data presented in Section 3. This Section contains comparisons of Filter Trials and discussion of data from separate parts of Section 3. Issues and questions that are addressed in this Section were developed by the pilot operators to answer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

4.1 RAW WATER QUALITY

4.1.1 Comparison of Raw Water Quality by Source

To compare the pilot results of each raw water source, the raw iron and manganese concentration from the three evaluated raw water sources was plotted in Figure 4.01. Figure 4.01 shows an individual value plot of all raw iron and manganese concentrations during the study and are shown in orange and grey, respectively. The average of the data collected during the pilot study is shown in red. Solid lines showing the secondary maximum contaminant limit (SMCL) for both iron and manganese are also shown on the figure.

Figure 4.01: Raw Iron and Manganese Concentrations from all well sources



Pilot Data Average is shown in Red

Figure 4.01 shows that only 2 of the 10 raw water iron concentrations from Whitney Blend exceeded the iron SMCL, and the average iron concentration was 0.22 mg/L. All samples from the Baddacook Well and the Whitney + Baddacook Blend exceeded the iron SMCL.

Figure 4.01 also shows that the average raw manganese concentrations from all three well sources tested during the pilot study exceed the Mn SMCL. The figure also shows the Baddacook Well has a raw manganese concentration that is much greater than the Whitney Blend. The average of the two sources, Whitney Blend (Average Mn = 0.353 mg/L) and Baddacook Well (Average Mn = 1.064 mg/L), is equal to 0.709 mg/L which is similar to the detected average from the blended source, Whitney + Baddacook Blend (average Mn = 0.653 mg/L), which suggests the pilot treated an equal blend of both well sources.

4.1.2 Comparison of Raw Water Quality to Historical Data

The maximum and average raw iron and manganese concentrations reported in the Pilot Study Protocol prepared by CEI were used to compare field measurements collected during the pilot study. The average iron and manganese from Whitney 1 and 2 were averaged together to obtain a historical Whitney Blend average. Similarly, the average iron and manganese detected historically from the Whiney Blend were averaged with the Baddacook Well average to obtain a historical Whitney + Baddacook Blend average.

Figure 4.02 shows raw iron and manganese concentrations detected during the pilot study from all three sources summarized in an individual value plot next to the historical average of the data set. The individual data points of raw iron and manganese concentrations detected during the pilot study are shown in orange and grey, respectively. The average of the data collected during the pilot study is shown in red while the average of the historical data is shown in blue. Solid lines showing the secondary maximum contaminant limit (SMCL) for both iron and manganese are also shown on the figure.

Figure 4.02: Raw Iron and Manganese Concentrations from all well sources compared to Historic Data

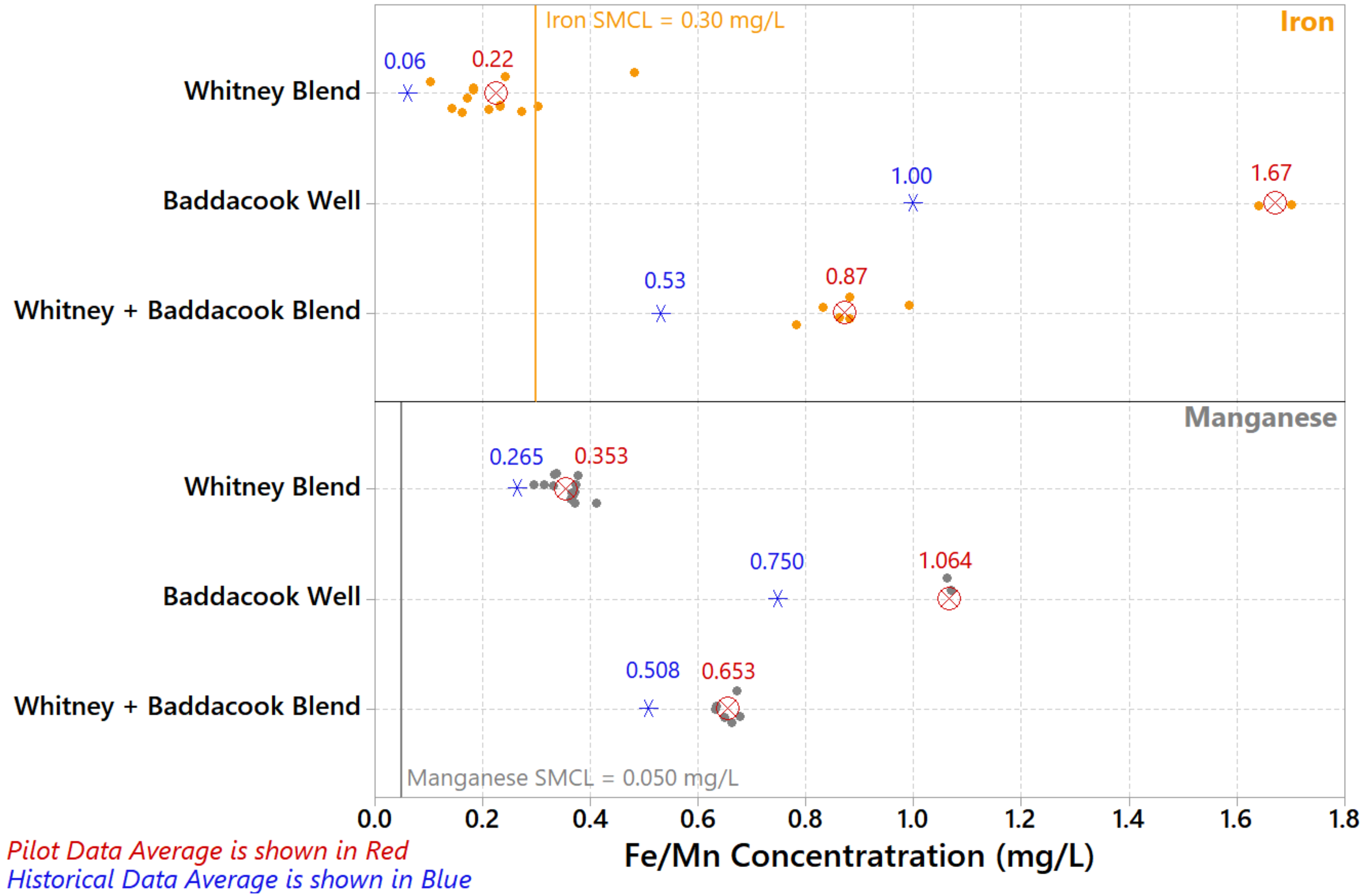


Figure 4.03 shows the concentrations measured during the pilot study exceed the historical concentrations reported in the protocol for each source and each contaminant. The difference in concentrations may suggest an increase in concentrations over time, or a seasonal difference. Not also that the Baddacoook Well had been cleaned just one week prior to the pilot study, so the Baddacook concentrations may reflect the result of the disturbance caused by cleaning or the result of a short duration stagnation period.

4.2 GREENSANDPLUS PILOT

4.2.1 GreensandPlus™ Filtration Effectiveness for Fe and Mn Removal

This section compares the effectiveness of GreensandPlus™ filtration for the removal of raw iron and manganese by operational variables such as well source (Whitney Blend or Whitney + Baddacook Blend), media depth (18" GSP + 12" Anthracite or 24" GSP + 12" Anthracite), and filter surface loading rate (3, 5, 7, 9 gpm/sf). Filter effluent data was omitted from this section if the data collected was determined unrepresentative of typical filter effluent due to mechanical errors, the filter had broken through, the filter was sampled too soon after a backwash, etc. The following data was omitted from graphs and statistical analyses herein:

- Filter 2 Effluent, Trial 2.5 (Fe =0.11 mg/L, GF Mn = 0.019 mg/L). Filter 2 runtime <1 hr (ripening).
- Filter 2 Effluent, Trial 2.5 (Fe = 0.21 mg/L, GF Mn = 0.040 mg/L). Filter 2 past breakthrough.
- Filter 2 Effluent, Trial 2.5 (Fe = 0.32 mg/L, GF Mn = 0.054 mg/L). Filter 2 past breakthrough.
- Filter 2 Effluent, Trial 2.5 (Fe = 0.29 mg/L, PAN Mn = 0.068 mg/L). Filter 2 past breakthrough.
- Filter 2 Effluent, Trial 2.6 (Fe = 0.10 mg/L, GF Mn = 0.028 mg/L). Filter 2 past breakthrough.
- Filter 2 Effluent, Trial 2.6 (Fe = 0.15 mg/L, GF Mn = 0.045 mg/L). Filter 2 past breakthrough.
- Filter 4 Effluent, Trial 4.1 (Fe = 0.15 mg/L, GF Mn = 0.031 mg/L). Filter 4 runtime <1 hr (ripening).
- Filter 4 Effluent, Trial 4.1 (Fe = 0.24 mg/L, GF Mn = 0.051 mg/L). Filter 4 past breakthrough.
- Filter 4 Effluent, Trial 4.1 (Fe = 0.28 mg/L, GF Mn = 0.044 mg/L). Filter 4 past breakthrough.
- Filter 4 Effluent, Trial 4.1 (Fe = 0.29 mg/L, PAN Mn = 0.073 mg/L). Filter 4 past breakthrough.
- Filter 4 Effluent, Trial 4.2 (Fe = 0.13 mg/L, GF Mn = 0.035 mg/L). Filter 4 past breakthrough.

Only effluent manganese concentrations determined by the Graphite Furnace (GF) method were used for graphs and statistical analyses.

To determine if the GreensandPlus™ pilot filters met the SMCL for Mn (Mn < 0.050 mg/L), a t-test was performed. Inputs for the t-test were labeled as " #" GSP, (Filter Surface Loading Rate) ", for example " 18" GSP (3 gpm/sf) " indicates that the data was collected from the effluent of a filter with 18-inches of GreensandPlus™ operating at a filter surface loading rate of 3 gpm/sf.

The results of the t-test for filter effluent iron concentrations analyzed by the Field Method when treating raw water from the Whitney Blend and Whitney + Baddacook Blend are shown in Tables 4.01 and 4.02, respectively. The results of the t-test for filter effluent manganese concentrations analyzed by the GF method when treating raw water from the Whitney Blend and Whitney + Baddacook Blend are shown in Tables 4.03 and 4.04, respectively.

Table 4.01: Results of t-test for Effluent Fe by Field Method versus Project Goal – Whitney Blend

Test of μ = 0.30 vs < 0.30

Variable	N	Mean	StDev	SE Mean	95% Upper Bound	T	P
18″ GSP (3 gpm/sf)	9	0.03	0.02	0.01	0.04	-32.81	0.000
18″ GSP (5 gpm/sf)	7	0.03	0.01	0.01	0.04	-53.39	0.000
18″ GSP (7 gpm/sf)	14	0.04	0.02	0.01	0.05	-51.06	0.000
18″ GSP (9 gpm/sf)	10	0.03	0.03	0.01	0.04	-32.39	0.000
24″ GSP (3 gpm/sf)	8	0.02	0.02	0.01	0.04	-36.62	0.000
24″ GSP (5 gpm/sf)	7	0.04	0.02	0.01	0.05	-40.69	0.000
24″ GSP (7 gpm/sf)	17	0.03	0.01	0.00	0.03	-81.98	0.000
24″ GSP (9 gpm/sf)	12	0.03	0.04	0.01	0.05	-26.52	0.000

Table 4.02: Results of t-test for Effluent Fe by Field Method versus Project Goal – Whitney Baddacook Blend

Test of μ = 0.3 vs < 0.30

Variable	N	Mean	StDev	SE Mean	95% Upper Bound	T	P
18″ GSP (3 gpm/sf)	12	0.04	0.03	0.01	0.06	-29.15	0.000
18″ GSP (9 gpm/sf)	14	0.03	0.03	0.01	0.04	-38.52	0.000

Table 4.03: Results of t-test for Effluent Mn by GF versus Project Goal – Whitney Blend

Test of μ = 0.050 vs < 0.050

Variable	N	Mean	StDev	SE Mean	95% Upper Bound	T	P
18″ GSP (3 gpm/sf)	6	0.005	0.005	0.002	0.009	-23.39	0.000
18″ GSP (5 gpm/sf)	7	0.004	0.003	0.001	0.007	-37.88	0.000
18″ GSP (7 gpm/sf)	12	0.004	0.002	0.001	0.005	-68.42	0.000
18″ GSP (9 gpm/sf)	10	0.004	0.003	0.001	0.006	-51.68	0.000
24″ GSP (3 gpm/sf)	6	0.004	0.006	0.002	0.009	-19.70	0.000
24″ GSP (5 gpm/sf)	7	0.003	0.002	0.001	0.005	-53.65	0.000
24″ GSP (7 gpm/sf)	10	0.002	0.002	0.001	0.004	-65.31	0.000
24″ GSP (9 gpm/sf)	11	0.005	0.004	0.001	0.007	-38.59	0.000

Table 4.04: Results of t-test for Effluent Mn by GF versus Project Goal – Whitney Baddacook Blend

Test of μ = 0.05 vs < 0.05

Variable	N	Mean	StDev	SE Mean	95% Upper Bound	T	P
18″ GSP (3 gpm/sf)	10	0.007	0.006	0.002	0.011	-21.80	0.000
18″ GSP (9 gpm/sf)	10	0.008	0.006	0.002	0.011	-22.51	0.000

Tables 4.01 and 4.02 show the upper bound for the 95% confidence interval for iron concentrations were generally below 0.06 mg/L (highlighted in green in Tables 4.01 and 4.02), and the upper bound for the 95% confidence interval for manganese concentrations were generally below 0.012 mg/L (highlighted in green in Tables 4.03 and 4.04). All concentrations were well-below the respective SMCLs. The p-values for each of the data sets (highlighted in yellow) were all zero, suggesting that there is a

very high likelihood that the greensand filters met the goals at all Filter Surface Loading Rates with all blends.

To determine if a statistically significant difference in effluent iron and manganese concentrations existed when treating either of the two raw water sources or GreensandPlus™ media depth (18-inches or 24-inches), two ANOVAs were performed. Table 4.05 shows the results of the ANOVA comparing iron concentrations analyzed by the field method and Table 4.06 shows the results of the ANOVA comparing manganese concentrations analyzed by the GF method.

Table 4.05: Results of ANOVA for Effluent Fe by Field Method – Raw Water Source and Media Depth

Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Variable	2	0.00	0.00	0.66	0.520
Error	107	0.06	0.00		
Total	109	0.06			

Variable	**N**	**Mean**	**StDev**	**95% CI**
Whitney Blend_18” GSP	42	0.03	0.02	(0.02, 0.04)
Whitney Blend_24” GSP	44	0.03	0.02	(0.02, 0.04)
Whitney Baddacook Blend_18” GSP	24	0.04	0.03	(0.03, 0.05)

Grouping Information Using the Tukey Method and 95% Confidence

Variable	N	Mean	Grouping
Whitney Blend_24” GSP	42	0.03	A
Whitney Blend_18” GSP	44	0.03	A
Whitney Baddacook Blend_18” GSP	24	0.04	A

Means that do not share a letter are significantly different.

Table 4.06: Results of ANOVA for Effluent Mn by GF – Raw Water Source and Media Depth

Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Variable	2	0.000	0.000	6.97	0.002
Error	86	0.001	0.000		
Total	88	0.002			

Variable	**N**	**Mean**	**StDev**	**95% CI**
Whitney Blend_18” GSP	37	0.004	0.003	(0.003, 0.005)
Whitney Blend_24” GSP	34	0.004	0.004	(0.002, 0.005)
Whitney Baddacook Blend_18” GSP	18	0.008	0.006	(0.006, 0.010)

Grouping Information Using the Tukey Method and 95% Confidence

Variable	N	Mean	Grouping	
Whitney Blend_18” GSP	37	0.004		B
Whitney Blend_24” GSP	34	0.004		B
Whitney Baddacook Blend_18” GSP	18	0.008	A	

Means that do not share a letter are significantly different.

The ANOVA shown in Table 4.05 resulted in a p-value of 0.520 (highlighted in yellow) when comparing the filter effluent iron concentrations while treating either of the two raw water sources and with either of the two adsorptive media depths. This p-value is greater than the alpha (0.05) indicating there was not a statistically significant difference in effluent iron concentrations when treating either of the two raw water sources with 18-inches of GreensandPlus™ and treating the Whitney Blend raw water source with 24-inches of GreensandPlus™. The mean effluent iron concentrations are highlighted in teal on Table 4.05.

The ANOVA shown in Table 4.06 resulted in a p-value of 0.002 (highlighted in yellow) when comparing the filter effluent manganese concentrations while treating either of the two raw water sources and the with either of the two adsorptive media depths. This p-value is less than the alpha (0.05) indicating there was a statistically significant difference in effluent manganese concentrations when treating either of the two raw water sources with 18-inches of GreensandPlus™ and treating the Whitney Blend raw water source with 24-inches of GreensandPlus™. The Tukey Method results (highlighted in pink) determined no statistically significant difference in effluent manganese concentrations when treating the Whitney Blend raw water source with either 18-inches or 24-inches of GreensandPlus™, but did determine statistically significant difference when treating the Whitney Baddacook Blend raw water source with 18-inches of GreensandPlus™. While this statistically significant difference was determined, the mean value of each data set (highlighted in teal) show the difference is not practically significant, since the difference in effluent manganese concentration is only 0.004 mg/L.

Figure 4.03 shows a boxplot of the iron and manganese concentrations detected in filter effluent by raw water source and adsorptive media depth. All filter effluent manganese concentrations were analyzed by the GF method. The orange and grey boxes summarize iron and manganese concentrations, respectively. Mean values are shown in red. The solid line indicates the SMCL for manganese and the dash line indicates the detection limit of the GF method (Mn < 0.0035). A solid line indicates the SMCL for iron was not included because the SMCL is much greater than the range of the figure.

Figure 4.03: Boxplot of GreensandPlus™ Filter Effluent Iron and Manganese Concentrations by Well Source and Media Depth

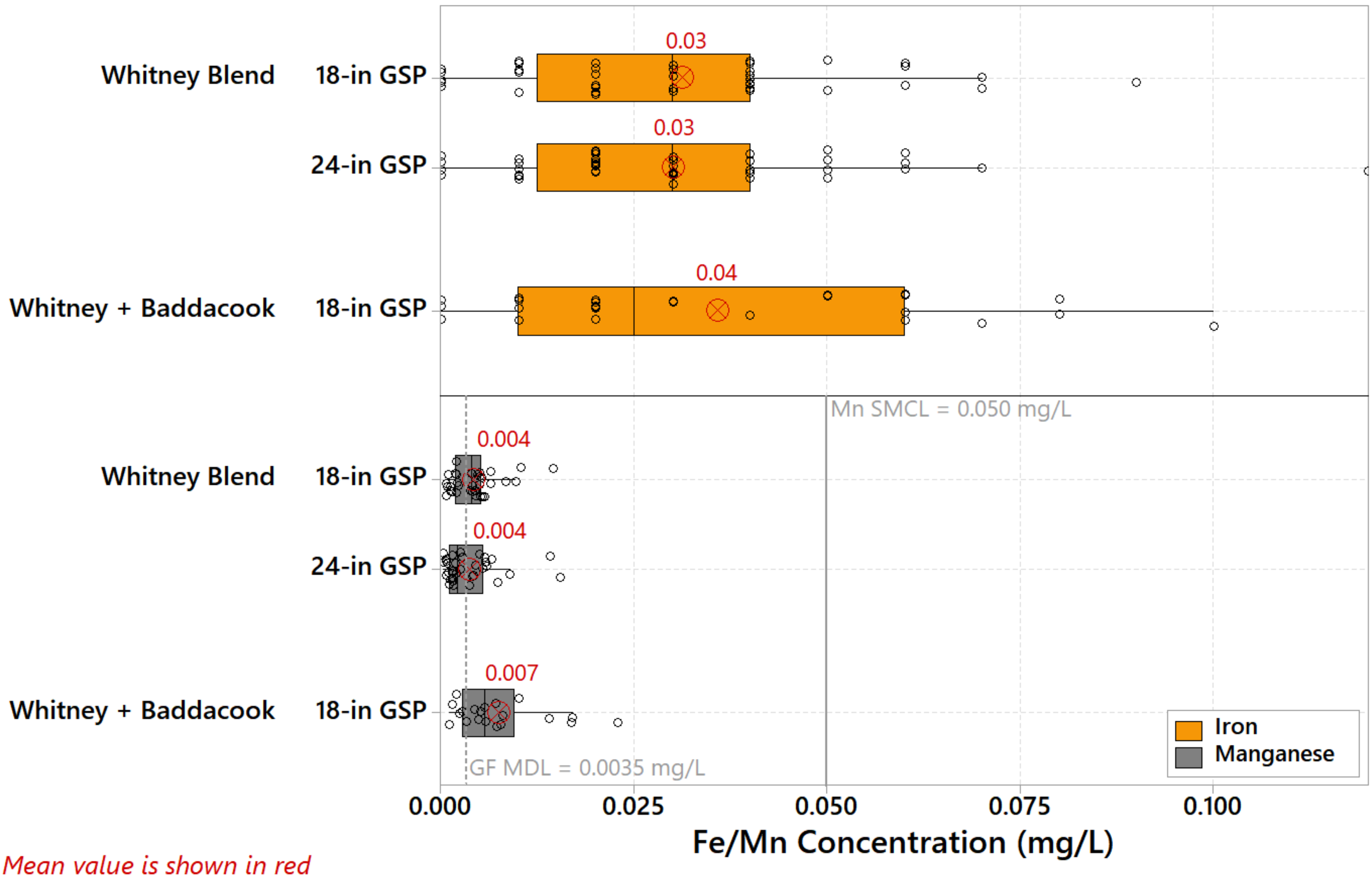


Figure 4.05 shows that all filter effluent iron concentrations were far below the SMCL (Fe SMCL = 0.30 mg/L). The mean value and distribution of effluent iron concentrations while treating either the Whitney Blend or Whitney + Baddacook Blend with 18-inches of GreensandPlus™ appears to be similar. The mean value and distribution of effluent iron concentrations while treating the Whitney Blend with 18-inches or 24-inches of GreensandPlus™ also appear to be similar.

Figure 4.05 shows that all filter effluent manganese concentrations were below the SMCL (Mn SMCL = 0.050 mg/L). The mean value and distribution of effluent manganese concentrations while treating either the Whitney Blend or Whitney + Baddacook Blend with 18" of GreensandPlus™ appears to be similar. The mean value and distribution of effluent manganese concentrations while treating the Whitney Blend with 18-inches or 24-inches of GreensandPlus™ also appear to be similar.

4.2.2 Filter Runtimes

Figure 4.04 plots the projected filter runtime of filter trials detailed in Section 3.3.2 to a differential pressure of 10 psi. Blue markers represent trials treating the Whitney Blend raw water source and red markers represent trials treating the Whitney + Baddacook Blend raw water source. Solid lines on the figure are linear regressions fitted to the data of the same color and the dashed lines are the upper bound and lower bound of the linear regression with 95% confidence. Circle makers indicate the filter contained 18-inches of GreensandPlus™ and square markers indicate the filter contained 24-inches of GreensandPlus™. During the study, breakthrough was observed with four trials while treating the Whitney + Baddacook Blend and is shown on the figure in green. Runtime to breakthrough was not included in the data set used to create the linear regression.

Some trials while treating the Whitney Blend were omitted from the figure. These trials include Trials 1.3, 2.3, 5.3, and 6.3 which were conducted simultaneously. These trials were omitted because during the trials the pilot trailer lost power due to a storm. After power was restored, the trial continued as normal, however the rate of headloss accumulation and effluent turbidity data appeared to have been affected by the outage and was considered unrepresentative of typical filter hydraulic performance.

Figure 4.04: Filter Surface Loading Rate versus Runtime by Well Source and Media Depth

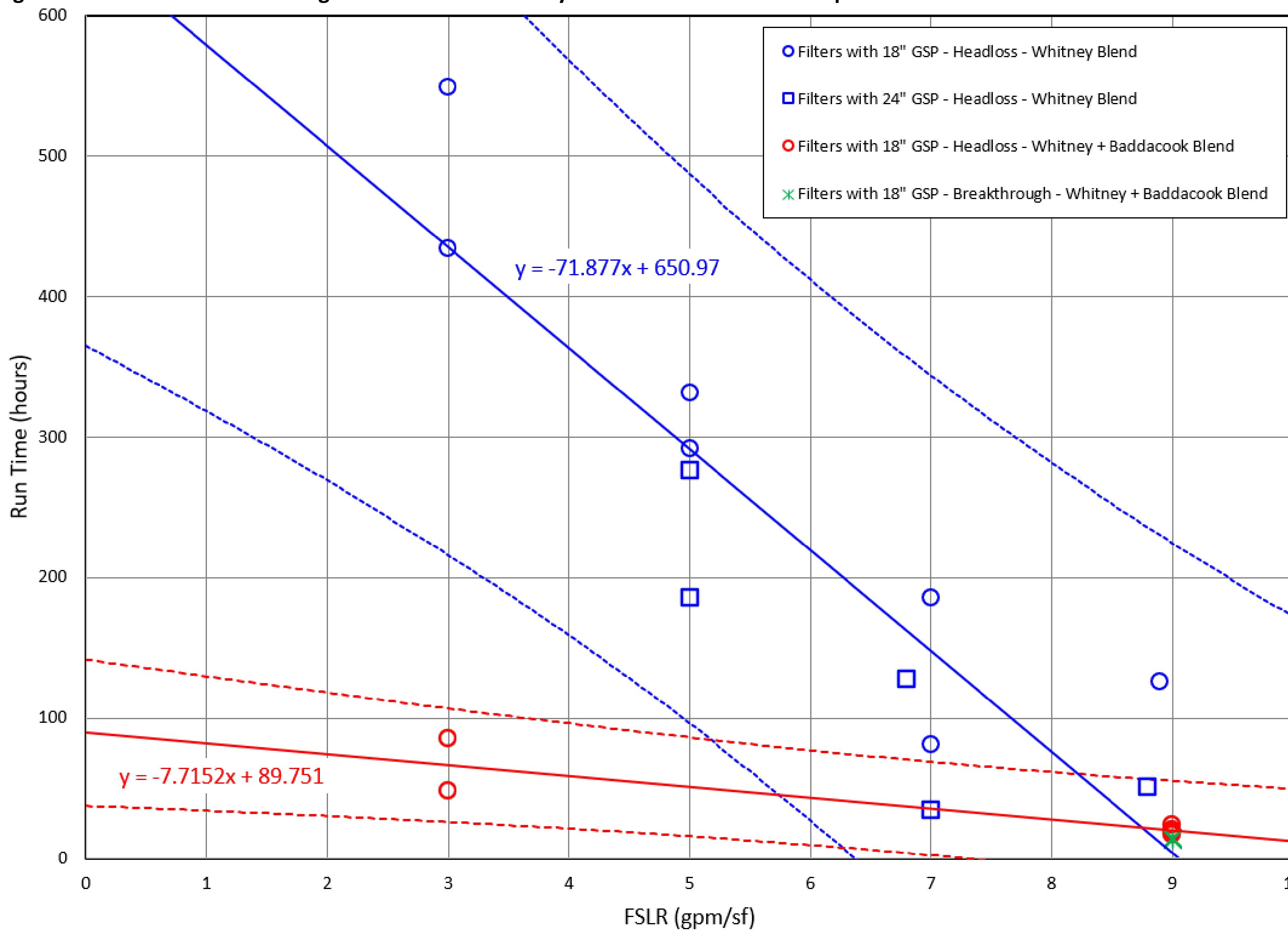


Figure 4.04 shows the runtimes while treating the Whitney Blend raw water source were significantly longer than runtimes while treating the Whitney + Baddacook Blend. This is likely due to the significant raw iron concentration detected from the Baddacook Well (Raw Fe = 1.54 mg/L, 1.70 mg/L). Figure 4.06 also shows when treating the Whitney Blend raw water source, filters containing 18-inches GreensandPlus™ had runtimes slightly longer than filters containing 24-inches GreensandPlus™, but this difference does not appear significant.

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)

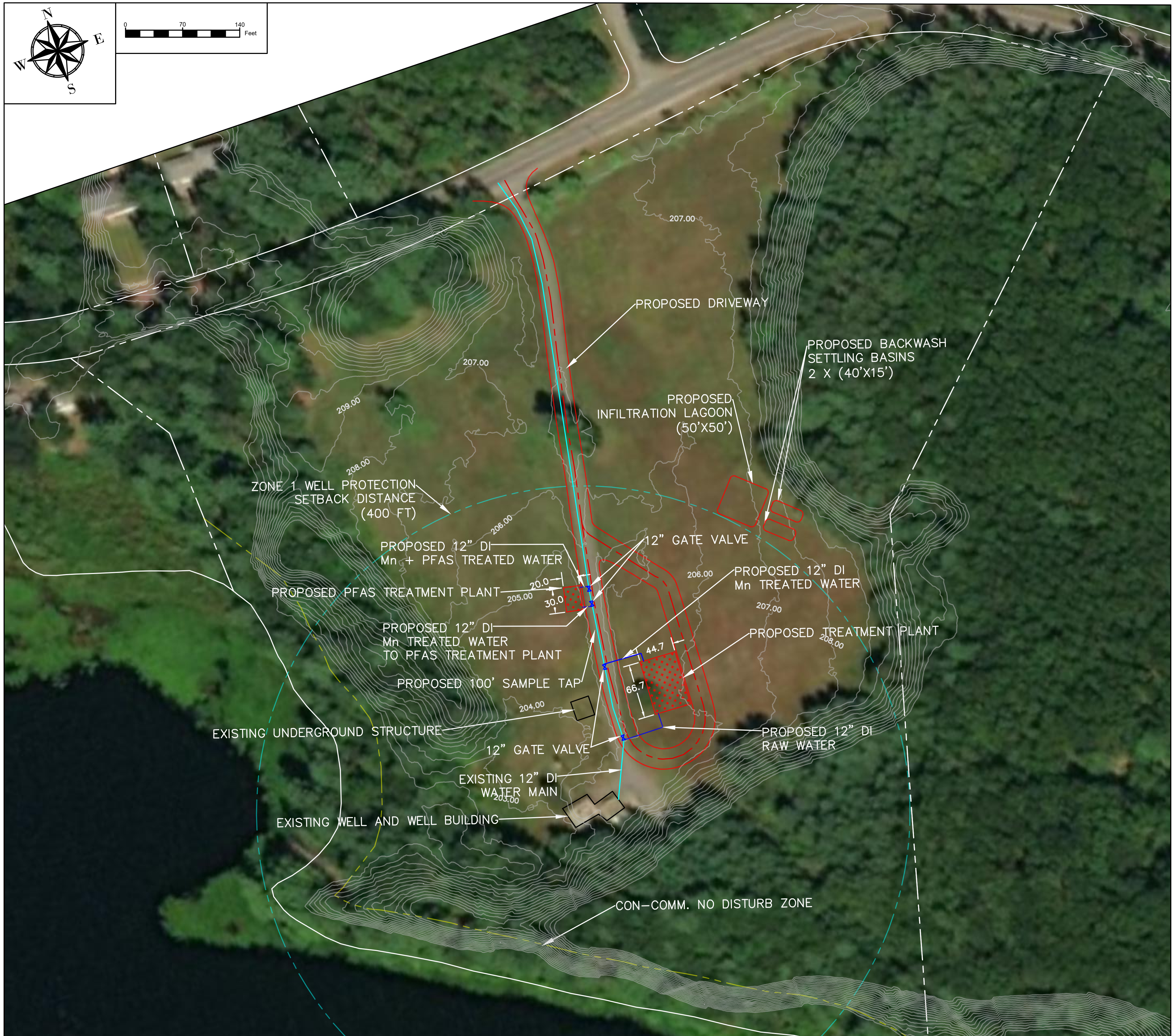
Parameter	Whitney Blend	Baddacook Well	Whitney + Baddacook Blend
Total Iron, mg/L	**0.22** (0.10 – 0.48) [13]	1.54, 1.70 [2]	**0.87** (0.78 – 0.99) [6]
Dissolved Iron, mg/L	**0.07** (0.03 – 0.22) [12]	1.51 [1]	**0.73** (0.64 – 0.75) [5]
Total Manganese, mg/L	**0.353** (0.29 – 0.41) [13]	1.06 [2]	**0.653** (0.63 – 0.68) [6]
Dissolved Manganese, mg/L	**0.334** (0.28 – 0.36) [12]	0.982 [1]	**0.639** (0.61 – 0.66) [5]
pH (Handheld), s.u.	**6.79** (6.41 – 7.18) [21]	No Data [0]	**6.70** (6.19 – 7.02) [6]
Temperature, °C	**13.8** (11.9 – 16.4) [19]	No Data [0]	**14.1** (12.6 – 15.4) [7]
Alkalinity (mg/L)	(53, 63) [2]	No Data [0]	59 [1]
Carbon Dioxide (mg/L)	91 – 111 [2]	No Data [0]	110 [1]
Total Organic Carbon (mg/L)	0.45 [1]	No Data [0]	0.92 [1]

2. The iron and manganese concentrations in all sources was higher than the 10-year average concentrations reported in protocol.

5.2 GREENSAND PILOT CONCLUSIONS

3. Oxidation with sodium hypochlorite (NaOCl) required an applied dose of between 3.4 and 4.2 mg/L.
4. Potassium hydroxide doses required to raise the raw water pH from ambient to 7.2 ranged from 5.5 to 4.2 mg/L.
5. Oxidation with NaOCl precipitated 75% to 90% of the dissolved raw water iron and 3% to 30% of the dissolved raw water manganese.
6. All filter trials met the Project Goal for total Fe < 0.300 mg/L and total Mn of < 0.050 mg/L.
7. Filter run times were shortened when Baddacook Well was added to the influent raw water, likely due to the loading of iron. Adding Whitney raw water to the Baddacook WTP will increase the filter times for a given Filter Surface Loading Rate, or will allow for an increased Filter Surface Loading Rate with a given backwash frequency.

Appendix C. Whitney Conceptual Plans



General Notes

No.	Revision/Issue	Date

COMPREHENSIVE ENVIRONMENTAL INCORPORATED

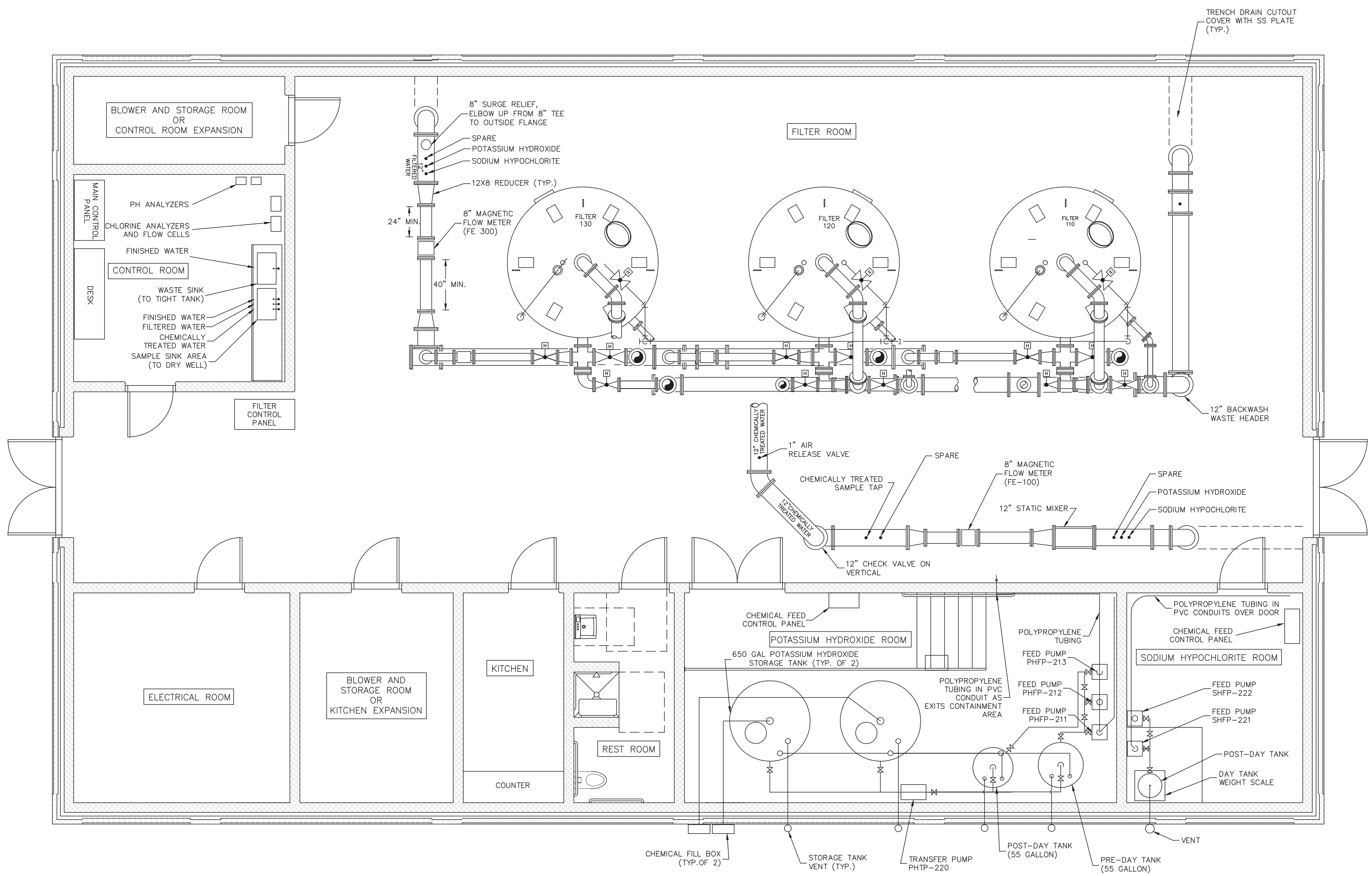
41 MAIN STREET
BOLTON, MA 01740

CONCEPTUAL SITE PLAN

TOWN OF GROTON
WATER DEPARTMENT

Project No.: 239-13
JULY 2020
Drawn By: SS
Checked By:
Scale: AS SHOWN

Sheet
C-1



FLOOR PLAN

NOT TO SCALE

General Notes

No.	Revision/Issue	Date

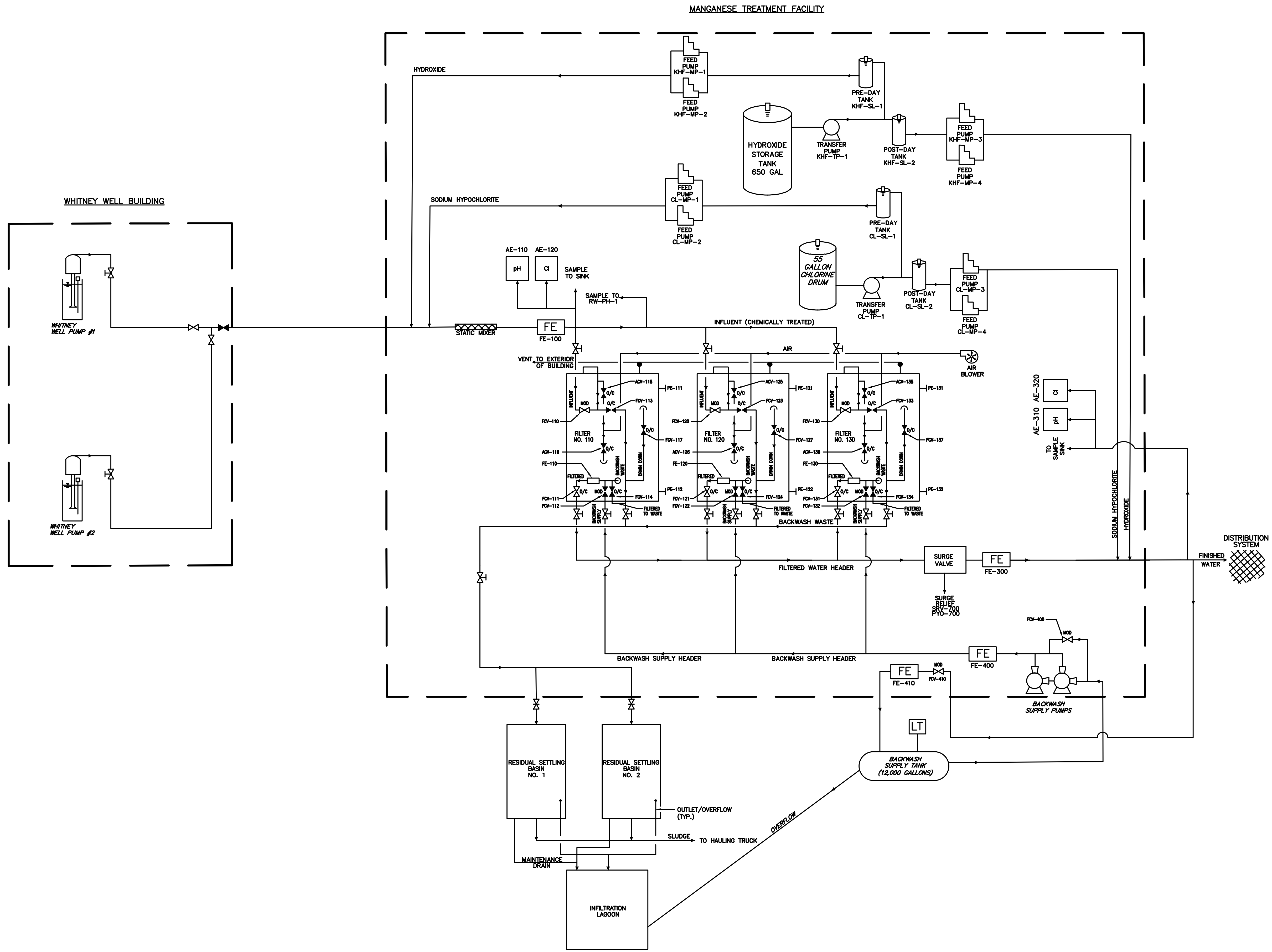
COMPREHENSIVE ENVIRONMENTAL INCORPORATED
41 MAIN STREET
BOLTON, MA 01740

CONCEPTUAL FLOOR PLAN

TOWN OF GROTON WATER DEPARTMENT

Project No.: 239-13
JULY 2020
Drawn By: SS
Checked By:
Scale: AS SHOWN

Sheet
C-2



General Notes

LEGEND

- NORMALLY OPEN
- NORMALLY CLOSED
- HYDRAULIC GLOBE VALVE
- GATE VALVE
- MANUAL BUTTERFLY VALVE
- MOD. MODULATING VALVE
- O/C OPEN / CLOSE VALVE
- Cl CHLORINE ANALYZER
- pH pH ANALYZER
- T TURBIDIMETER (FUTURE)
- FE FLOW ELEMENT
- PROPOSED (THIS CONTRACT)
- LT LEVEL TRANSMITTER

No.	Revision/Issue	Date

COMPREHENSIVE ENVIRONMENTAL INCORPORATED
41 MAIN STREET
BOLTON, MA 01740

PROCESS FLOW SCHEMATIC

TOWN OF GROTON
WATER DEPARTMENT

Project No.: 239-17
AUGUST, 2020
Drawn By: SS
Checked By:
Scale: NOT TO SCALE

Sheet G-1

Appendix D. Greensand Technical Data

Inversand Company
SINCE 1925

226 Atlantic Avenue, P.O. 650 • Clayton, NJ 08312
Phone 856-881-2345 Fax 856-881-6859
Email: info@inversand.com • www.inversand.com

GREENSANDplus™

Performance Media for Water Filtration

Removes iron, manganese, hydrogen sulfide, arsenic and radium.

GreensandPlus™ is a black filter media used for removing soluble iron, manganese, hydrogen sulfide, arsenic and radium from groundwater supplies.

The manganese dioxide coated surface of GreensandPlus acts as a catalyst in the oxidation reduction reaction of iron and manganese.

The silica sand core of GreensandPlus allows it to withstand waters that are low in silica, TDS and hardness without breakdown.

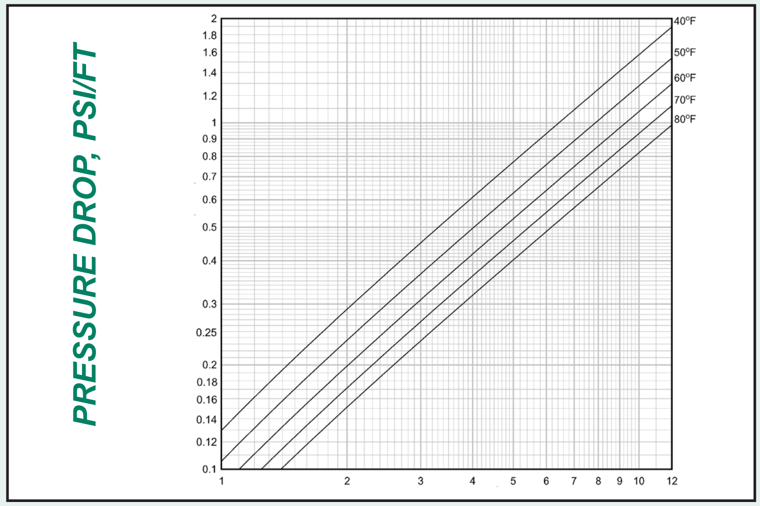
GreensandPlus is effective at higher operating temperatures and higher differential pressures than standard manganese greensand. Tolerance to higher differential pressure can provide for longer run times between backwashes and a greater margin of safety.

Systems may be designed using either vertical or horizontal pressure filters, as well as gravity filters.

GreensandPlus is a proven technology for iron, manganese, hydrogen sulfide, arsenic and radium removal. Unlike other media, there is no need for extensive preconditioning of filter media or lengthy startup periods during which required water quality may not be met.

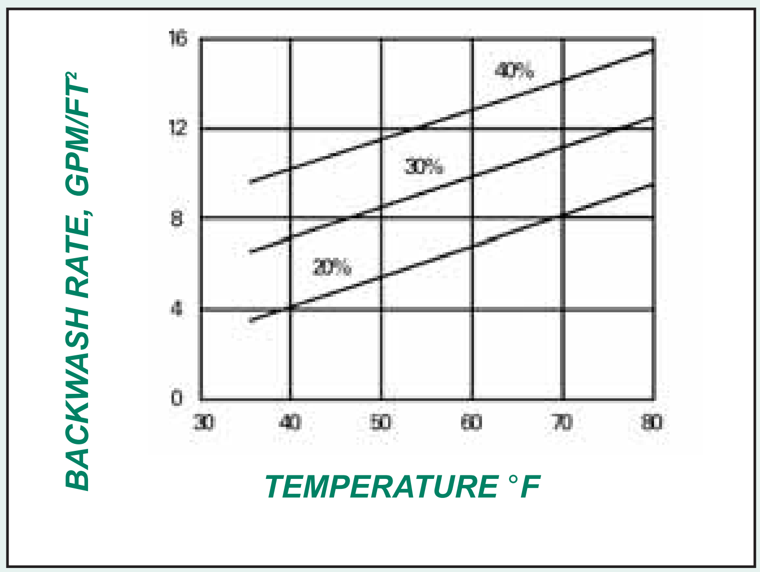
GreensandPlus is an exact replacement for manganese greensand. It can be used in CO or IR applications and requires no changes in backwash rate or times or chemical feeds.

GREENSANDPLUS PRESSURE DROP (CLEAN BED)



FLOW RATE (GPM/FT²)

BED EXPANSION DURING BACKWASHING



GreensandPlus has the WQA Gold Seal Certification for compliance with NSF/ANSI 61.

REACH Registration 01-2119452801-43-0020 for import to the EU.

Packaging is available in 1/2 cubic foot bags or 1 metric ton (2,205 lbs) bulk sacks.

PHYSICAL CHARACTERISTICS

Physical Form
Black, nodular granules shipped in a dry form

Apparent Density
88 pounds per cubic foot net (1410.26 kg/m3)

Shipping Weight
90 pounds per cubic foot gross (1442.31 kg/m3)

Specific Gravity
Approximately 2.4

Porosity
Approximately 0.45

Screen Grading (dry)
18 X 60 mesh

Effective Size
0.30 to 0.35 mm

Uniformity Coefficient
Less than 1.60

pH Range
6.2-8.5 (see General Notes)

MaximumT emperature
No limit

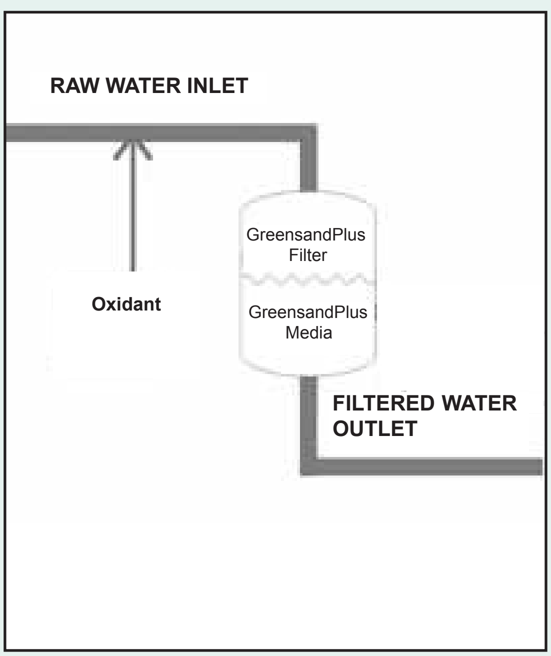
Backwash Rate
Minimum 12 gpm/sq. ft. at 55°F (29.4 m/hr @ 12.78°C) (see expansion chart)

Service Flow Rate
2 -12 gpm/sq. ft (4.9m/hr - 29.4 m/hr)

Minimum Bed Depth
15 inches (381 mm) of each media for dual media beds or 30 inches minimum (762 mm) of GreensandPlus alone.

METHOD OF OPERATION CO

GreensandPlus: Catalytic Oxidation (CO)



Catalytic Oxidation (CO) operation is recommended in applications where iron removal is the main objective in well waters with or without the presence of manganese. This method involves the feeding of a predetermined amount of chlorine (Cl_2) or other strong oxidant directly to the raw water before the GreensandPlus Filter.

Chlorine should be fed at least 10-20 seconds upstream of the filter, or as far upstream of the filter as possible to insure adequate contact time. A free chlorine residual carried through the filter will maintain GreensandPlus in a continuously regenerated condition.

For operation using chlorine, the demand can be estimated as follows:

mg/L Cl_2 = (1 x mg/L Fe) + (3 x mg/L Mn) + (6x mg/L H_2S) + (8 x mg/L NH_3)

SUGGESTED OPERATING CONDITIONS

Bed Type

Dual media: anthracite 15-18 in. (381 mm - 457 mm) and GreensandPlus 15-24 in. (381 mm - 610 mm)

Capacity

700-1200 grains of oxidized iron and manganese/sq.ft. of bed area based on oxidant demand and operation to iron break through or dp limitations.

Backwash

Sufficient rate using treated water to produce 40% bed expansion until waste water is clear, or for 10 minutes, whichever occurs first.

Air/Water Scour

Optional using 0.8-2.0 cfm/sq. ft. (15 m/hr - 7 m/hr) with a simultaneous treated water backwash at 4.0-4.5 gpm/sq. ft. (9.8 m/hr - 11.03 m/hr).

Raw Water Rinse

At normal service flow rate for 3 minutes or until effluent is acceptable.

Flow Rate

Recommended flow rates with CO operation are 2-12 gpm/sq. ft. (4.9 m/hr - 29.4 m/hr). High concentrations of iron and manganese usually require lower flow rates for equivalent run lengths. Higher flow rates can be considered with very low concentrations of iron and manganese. For optimizing design parameters, pilot plant testing is recommended.The run length between backwashes can be estimated as follows:

What is the run length for a water containing 1.7 mg/L iron and 0.3 mg/L manganese at a 4 gpm/sq. ft. service rate:

Contaminant loading

= (1 x mg/L Fe) + (2 x mg/L Mn)
= (1 x 1.7) + (2 x 0.3)
= (2.3 mg/L or 2.3/17.1 = 0.13 grains/gal. (gpg)

At 1,200 grains / sq. ft. loading ÷ 0.13 gpg = 9,230 gal./sq. ft.

At 4 gpm / sq. ft. service rate 9,230/4 = 2,307 min.

The backwash frequency is approximately every 32-38 hours of actual operation.

The Intermittent regeneration (IR) operation is available for certain applications. Contact your Inversand representative for additional information.

GENERAL NOTES

pH

Raw waters having natural pH of 6.2 or above can be filtered through GreensandPlus without pH correction. Raw waters with a pH lower than 6.2 should be pH-corrected to 6.5-6.8 before filtration. Additional alkali should be added following the filters if a pH higher than 6.5-6.8 is desired in the treated water. This prevents the possible adverse reaction and formation of a colloidal precipitate that sometimes occurs with iron and alkali at a pH above 6.8.

Initial Conditioning of GreensandPlus

GreensandPlus media must be backwashed prior to adding the anthracite cap. The GreensandPlus backwash rate must be a minimum of 12 gpm/sq. ft. @ 55 °F.

After backwashing is complete, the GreensandPlus must be conditioned. Mix 0.5 gal. (1.9 L) of 6% household bleach or 0.2 gal (0.75 L) of 12% sodium hypochlorite for

Initial Conditioning of GreensandPlus

every 1 cu. ft. (28.3 L cu. m) of GreensandPlus into 6.5 gallons (25 L) of water.

Drain the filter enough to add the diluted chlorine mix. Apply the diluted chlorine to the filter being sure to allow the solution to contact the GreensandPlus media. Let soak for a minimum of 4 hours, then rinse to waste until the "free" chlorine residual is less than 0.2 mg/L. The GreensandPlus is now ready for service.

REFERENCES

USA

American Water Company, CA
San Jacinto, CA
City of Tallahassee, FL
Adedge Technologies, Inc., Buford, GA
City of Mason City, IL
City of Goshen, IN
City of Hutchinson, KS
City of Burlington, MA
Dedham Water Co., MA
Raynham Center, MA
Northbrook Farms, MD
Sykesville, MD
Tonka Equipment Company, Plymouth, MN
City of New Bern, NC
Onslow County, NC
Hungerford & Terry, Inc., Clayton, NJ
Fort Dix, NJ
Jackson Twsp. MUA, NJ

Radium and Arsenic Removal Using GreensandPlus

The GreensandPlus CO process has been found to be successful in removing radium and arsenic from well water. This occurs via adsorption onto the manganese and/or iron precipitates that are formed. For radium removal, soluble manganese must be present in or added to the raw water for removal to occur. Arsenic removal requires iron to be present in or added to the raw water to accomplish removal. Pilot plant testing is recommended in either case.

USA

Churchill County, NV
Suffolk County Water Authority, NY
City of Urbana, OH
Roberts Filter Group, Darby, PA

International

Watergroup, Saskatoon, SK Canada
BI Pure Water, Surrey, BC Canada
Sydney, Nova Scotia, Canada
PT Beta Pramesta, Jakarta, Indonesia
PT Besflo Prima, Jakarta, Indonesia
Eurotrol, Milanese, Italy
Gargon Industrial, Mexico City, Mexico
River Sands Pty. Ltd., Queensland, Australia
Filtration Tech, Auckland, New Zealand
Alamo Water Poland, Izabeln, Poland
Aquatrol Company, Moscow, Russia
Impulse Group, St. Petersburg, Russia
Brenntag Nordic, Taby, Sweden
EcoFilter Technology, Liechtenstein

The manufacturing of GreensandPlus is an ongoing, 24/7 process to ensure the highest quality water treatment media.

REACH Registration
01-2119452801-43-0020
for import to the EU.

Distributed by:

C USA

Inversand Company
SINCE 1925
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Clayton, NJ 08312 USA
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Appendix E.1 Alternatives Analysis Findings

1 Selection of Preferred Alternative

As indicated in the main text of the conceptual design report, the purpose of the conceptual design was to prepare conceptual designs for two potential options for treatment of Mn from the Whitney Pond Wells to enable GWD to make an informed decision on which option to select for further design and implementation.

The top two options were: 1) Expand the existing Baddacook Treatment Facility to handle and treat additional flows from the Whitney Pond Wells or 2) Construct an independent treatment facility at the Whitney Pond Wells.

Once conceptual designs were developed for both options, a decision matrix was developed to enable relative scoring of each option. The decision matrix included the following factors weighted by priority:

- Capital Costs (High Priority): How much debt burden will the option provide to GWD over an extended period of time?
- Resilience (High Priority): How resilient is the option to potential future unforeseen events?
- Operations and Maintenance (Moderate Priority): How much of an increase in O&M will the option cause?
- Ease of Future Expansion (Lower Priority): Will the option enable future expansion if future demands increase?
- Miscellaneous (Lower Priority): Six additional lower priority factors were evaluated, including: potential for future treatment implementation, hydraulic improvements to the distribution system, distribution system performance during backwash, construction schedule, and potential construction disruptions.

Based on evaluation of these factors, construction of a new WTP at the Whitney Pond Wells resulted in the highest score. The completed decision matrix was presented to the Groton Water Commissioners at a public meeting on July 28, 2020. The Commissioners voted unanimously for design and construction of a new WTP at the Whitney Pond Wells. The primary factors that resulted in selection of this option were: 1) Lower overall capital cost and annual debt burden on GWD; and 2) Greatest potential for overall system resilience.

Refer to **Table G.1-1** for the completed decision matrix. This option will also include upgrades to Baddacook WTP's existing backwash handling system to improve performance. The remaining sections of this report focus on the selected alternative to construct a new WTP at the Whitney Pond Wells.

Table G.1 -1. Decision Matrix of Top Two Potential Treatment Options.

Option 3B: Construct New Treatment Facility at Whitney Pond Wells
Option 3C: Expand Baddacook WTP and Construct Water Main Improvements

Factor	Weight	Rationale	Relative Scoring (1 = Poor/NA, 2 = Fair, 3 = Good)	
			Option 3B	Option 3C
Capital Costs[1,2] *(High Priority)*				
Estimated Debt Service on Construction Cost	15%	***Option 3B:*** *Estimated Capital Cost: $6.6M; Estimated Total Financing over 20 years: $9M | Average Annual Debt Payment of $429k.* ***Option 3C:*** *Estimated Capital Cost: $7.3M (Water Main: $2.4M, Treatment: $4.9M); Estimated Total Financing over 30 years: $10.4M | Average Annual Debt Payments for 20 years: $435k, remaining 10 yrs: $93k.*	3	2
Estimated Cumulative Gain / Shortfall over Time	10%	***Option 3B*** *: Expected cumulative gain/shortfall relative to FY2020 debt load and $20/yr capital charge: by 2032 = $-264k; by 2043 = $1.3M* ***Option 3C*** *: Expected cumulative gain/shortfall relative to FY2020 debt load and $20/yr capital charge: by 2032 = $-604k; by 2043 = $836k; by 2052: $4.9M*	3	2
Resilience *(High Priority)*				
Treatment Redundancy	*15%*	***Option 3B*** *: Two independent facilities provides redundancy in the event of a prolonged outage or other issue.* ***Option 3C*** *: All Mn treatment would be at Baddacook facility; in an emergency, water could be routed from one facility to the other (and vice versa).*	3	2
Filtration Operational Buffer	*10%*	***Option 3B*** *: Vertical vessels provide operational buffer. Less susceptible to losing media. Can backwash more aggressively.* ***Option 3C*** *: N/A - No operational buffer anticipated from horizontal vessels.*	3	1
Operations and Maintenance *(Moderate Priority)*				
Annual O&M Cost Increase (2022)[3]	*10%*	***Option 3B:*** *Estimated increase of $150,000 / yr associated with new operator, electricity, and misc. costs to operate new facility.* ***Option 3C:*** *Estimated increase of $100,000 / yr associated with new operator, electricity, and misc. costs to operate expanded facility.*	2	3
Increase in Required Labor / Logistics	10%	***Option 3B:*** *New operator and may require additional 8-16 hrs of labor/week for logistics and coordination for O&M of two WTPs.* ***Option 3C*** *: New operator required.*	2	3
Ease of Future Expansion & Misc. Factors *(Lower Priority)*				
Future Supply Expansion (Whitney Well #3)[4,5,6]	*5%*	***Option 3B:*** *Vertical vessels are sized to handle normal 5 gpm/sf loading rate and up to 7 gpm/sf temp. backwash loading rate with one filter offline. Proposed building includes capacity for future filter should future demands increase more than anticipated.* ***Option 3C*** *: Horizontal vessels are sized to handle normal 5 gpm/sf loading rate and up to 7 gpm/sf temp. backwash loading rate with one cell offline.*	3	2
Future Treatment Implementation	*5%*	***Option 3B:*** *Adequate space for future PFAS or other treatment.* ***Option 3C:*** *Adequate space for future PFAS or other treatment. If PFAS shows up at both sources, treatment would only be required at Baddacook.*	2	3
Distribution System Hydraulic Improvements	*5%*	***Option 3B*** *: 8-in water main will be upgraded to 12-in along Lowell Road between Allen's Trail and Hemlock Park Drive.* ***Option 3C*** *: N/A - no anticipated hydraulic improvements will be made.*	1	3
Distribution System Performance During Backwash[7,8]	*5%*	***Option 3B*** *: Potential low pressure areas are slightly more pronounced, likely because Whitney is pulling water for a longer distance along Lowell Road.* ***Option 3C*** *: Potential low pressure areas are slightly less pronounced.*	1	2
Accelerated Temporary Treatment	*5%*	***Option 3B*** *: N/A - Construction completion anticipated December 2024.* ***Option 3C:*** *Potential temporary treatment of all water demand for 9 months of the year by 2022 compared to 6 moths currently (pending DEP approval)*	1	3
Construction Disruptions Off-Site[9]	*5%*	***Option 3B*** *: N/A - No anticipated disruptions.* ***Option 3C*** *: Water main installation will cause disruptions along Lowell Road. Estimated duration of 3-4 months.*	3	1
Sum of Weights:	**100%**	**Relative Score (Out of 3):**	**2.5**	**2.2**

Notes:

1. Cost estimates are for planning purposes only (i.e., order-of-magnitude) and have been adjusted for potential inflation from 2019 to 2022 assuming 3% annual inflation.
2. Financing cost estimates obtained from GWD via email on June 25, 2020. Assume equal payment scenario for comparison of each option. Assume water main pipes in ground by 2021. FY 2020 baseline debt load is 400.4k; estimated $20 capital charge income is 140k/yr.
3. See supplemental Tables for increases to current O&M costs
4. Assume that potential Whitney Well #3 will have capacity of appx. 200 gpm. Order of magnitude cost estimates is < $1M for development of new Whitney Well #3 from Manganese Mitigation Alternatives Analysis Report (CEI, August 2019).
5. Whitney Well #1, #2, and potential #3 design flow of 950 gpm. Option 3B proposed filters are two (2) horizontal filters with 7' dia. And 15' length split into two cells. Option 3C proposed filters are three (3) 10' dia. vertical filters.
6. Per July 2020 Blue Leaf Pilot Report (Table 3.07), pilot filters for Whitney Wells #1 and #2 were effective at loading rates of 5 gpm/sf to 7 gpm/sf (18" media depth). Estimated run time to 10 psi filter differential pressure ranged from 185 to 331 hours.
7. GWD's existing WaterCAD model was used to simulate potential capacity limitations from typical backwashing operations based on analysis of pressure contours.
8. Backwash (demand) of 975 gpm and 1,300 gpm was applied to new Whitney Facility (3B) and Baddacook Expansion, respectively. Analysis assumes that backwash will not be performed simulataneously (e.g., Whitney vs. Baddacook Filters will be backwashed at seperate times)
7. Construction duration for appx. 10,900 linear feet of water main estimated based on installation of 100 to 200 linear feet per day.

Appendix E.2 Baddacook Conceptual Design Narrative

1 Introduction

The purpose of this Appendix is to describe the potential option to expand the Baddacook Water Treatment Facility to treat water from the Whitney Pond Wells. This option was not selected by the Groton Water Department. Refer to the Main Body of the Conceptual Design Report for project details, a description of the alternatives selection process, and conceptual design information for the selected option to construct a new water treatment plant at the Whitney Pond Wells.

1.1 Summary of Option to Expand Baddacook Treatment Facility

This alternative would involve construction of a raw water transmission main from the Whitney Pond Wells to the existing Baddacook Water Treatment Facility ("Baddacook WTP") and expansion of the WTP's capacity to accommodate treatment of raw water from the Whitney Pond Wells. This alternative would include the following work:

- Install approximately 6,800 feet of 8-in raw water distribution main.
- Install approximately 4,100 feet of 12-inch finished water distribution main.
- Convert approximately 5,500 feet of 12-inch and 1,600 feet of 8-inch water distribution main into finished and raw water distribution main, respectively.
- Expand the existing Baddacook WTP to handle and treat additional flows from the Whitney Pond Wells

The existing pressure vessels at the Baddacook WTP have reserve capacity to handling potential future flows from the permitted but yet to be constructed Shattuck Road Wells. Therefore, expansion of the WTP will require construction of independent treatment to handle flows from the Whitney Pond Wells. Anticipated improvements include:

- Construct expansion to existing building to accommodate existing process equipment.
- Install new horizontal pressure filters and associated chemical feed systems.
- Construct new backwash residuals handling system to accommodate increased flows.

2 Existing Treatment Processes

2.1 Overview

Raw water from the Baddacook Pond Well is pumped and treated within the existing Baddacook treatment facility (aka Baddacook WTP). The existing Baddacook WTP was designed with reserve capacity to handle potential future flows from the permitted but yet to be constructed Shattuck Road Wells (#1 and #2). The existing Baddacook WTP treatment processes include the following:

- 45% Potassium hydroxide (KOH) is added for pH adjustment for corrosion control.
- 15% Sodium hypochlorite (NaOCl) is added for disinfection.
- Iron and Manganese are removed through two horizontal pressure vessels with GreensandPlus™ media.

2.2 Well Pumps

The Baddacook Pond Well has a submersible pump. Pump operation (start/stop) is controlled by the SCADA system. The Baddacook Pond Well is a registered well with a withdrawal limit of 0.217 mgd. The permitted but yet to be constructed Shattuck Road wells are approved under the WMA for a combined maximum daily withdrawal of 0.324 mgd.

2.3 Chemical Feed Systems

There are two chemical feed systems located at the Baddacook WTP: (1) KOH and (2) NaOCl. KOH is stored in a 500-gallon bulk tank within a containment area and is equipped with a fill station and vent which is connected to the tank from the exterior of the Baddacook WTP. The KOH bulk tank is connected to a day tank within the containment area. NaOCL is stored within a day tank within the containment area, with manual transfers from the manufacturer's containers.

2.4 Filtration System and Backwash Operations

The Baddacook WTP includes two (2) horizontal pressure vessels with an 18-in layer of manganese GreensandPlus™ media and a 12-in layer of anthracite. Each vessel is comprised of two cells with a 7.5 ft diameter and total 15 ft length (7.5 ft length per cell). Based on discussions with GWD operators, the pressure vessels are typically operated at a loading rate of approximately 3-4 gpm/sf, which is characteristic of WTP designs for the original greensand media. Filters are typically run for up to 60 hours before backwashing, at which point the entire filter (both cells) is removed from service for backwashing. Filter backwashing typically occurs once per week at rates of up to 1250 gpm. Backwash water is supplied from GWD's potable water distribution system.

2.5 Backwash Residuals Handling

The filter backwash process generates residuals that require handling and disposal. The backwash waste generated during this process consists of water with concentrated levels of Mn that were removed from the well water during treatment. Backwash is pumped to a holding/settling tank located outside of the WTP underneath the parking lot. The holding/settling tank can hold enough water for one backwash cycle. Settled solids (i.e., Mn oxides) are transferred to an adjacent holding tank from which they are preidodically pumped out of the tank and hauled away. Supernatant is pumped out of the holding/settling tank to two gravel lined lagoons for infiltration. Based on discussion with GWD operators, the current system historically performs poorly – backwash can short circuit the holding/settling tank and lead to clogging of the infiltration lagoons. Recently, the operators have focused on improved management of the backwash handling system which has decreased the risk of Mn solids being transferred to the infiltration lagoons.

2.6 Building Components

The existing Baddacook WTP is an addition onto the historical pump station structure of masonry construction. An expansion was completed circa 2002 with standard CMU structural walls and brick veneer. The roof of the expansion has a flat roof (slightly sloped for drainage) with an EPDM roof, intentionally kept below the roofline of the historic pump station . The structure is separated into multiple rooms. The original structure houses an office area, mechanical room (i.e., HVAC), and chemical room with chemical storage and feed equipment. The expansion contains pumping equipment and controls, filters, and a finish water meter pit.

There is an existing propane tank located behind the building. An emergency generator is located on the east side of the building.

3 Proposed Treatment Processes

The sections below describe proposed process information details for the option to expand the existing Baddacook Treament Facility. Refer to **Appendix G.2** for Conceptual Design Plans for this option.

3.1 Overview

CEI recommends that the new water treatment facility use GreensandPlus™ filtration as the primary process to consistently and reliably produce drinking water that meets the required regulatory limits. GreensandPlus™ filtration is a generally accepted technology for manganese (Mn) removal and it was successfully piloted for treatment of Whitney Pond Well as discussed in Main Body of the conceptual design report. Additionally, the Town is familiar with this established treatment technology, as it is primary treatment process in the existing Baddacook WTP.

Treatment for the removal of Mn is achieved through oxidation, filtration, and adsorption. Mn can be oxidized to solid form, MnO_2(s), using sodium hypochlorite NaOCl. Therefore, the NaOCl will be injected within the new treatment facility before filtration to oxidize the Mn; KOH will also need to be injected before filtration to achieve the optimal pH of approximately 6.8 for manganese removal. Ultimately, chemically pre-treated water will be directed to the filtration system. The primary removal mechanism for any Mn not oxidized by the NaOCl will be through adsorption using an oxide-coated media (GreensandPlus™). After flowing through the new pressure filters, a post injection of NaOCl and KOH will take place before the water is discharged to the distribution system. The general treatment process will be as follows for each option:

- A chemical feed system will pre-treat raw well with KOH for pH adjustment and corrosion control and with NaCl for disinfection.
- Pre-treated water will be pumped to pressure vessels with GreensandPlus™ media for further treatment.
- Filter backwash water will be directed to a settling basin and infiltration lagoon.

3.2 Anticipated Design Flow Rate

The anticipated design flow rate will be 750 gpm to accommodate the capacity of the Whitney Pond Wells. The pressure filtration systems will be sized conservatively to enable up to 200 gpm of additional capacity should future capacity increase (e.g., if a third Whitney Well is developed) or if Mn levels continue to increase. See Section 3.3 for more details on filter sizing.

3.3 Proposed Pressure Filtration System

The pressure filtration system will be sized based on the capacity of the Whitney Pond Wells #1 and #2 which is 750 gpm. Manganese levels in the raw water may increase over time. Therefore, the filtration system will be designed with the capability to reduce elevated Mn levels below threshold levels.

As summarized by the Main Body of the report, pilot testing demonstrated that each of the loading rates examined (3.0, 5.0, 7.0, and 9.0 gpm/sf) were effective in reducing Mn levels in raw Whitney Pond Wells below 0.05 mg/L. Vessels will therefore be sized to handle a "normal" 5 gpm/sf loading rate and up to 7 gpm/sf "temporary" backwash loading rate with one cell offline.

The proposed filter layout for an expansion of the Baddacook WTP consists of two additional 7 ft diameter horizontal filters that are each 15 ft in length, containing two cells per filter. Both proposed filters will have a surface area of approximately 52.5 sf per cell (2 cells per filter). Assuming a design flow of 750 gpm, the "normal" filter loading rate with both filters online will be approximately 3.6 gpm/sf. With one filter cell out of service for backwash, the "temporary" filter loading rate will be approximately 4.8 gpm/sf. This conservative filter sizing allows for future increases in Mn levels in the well water or increase in future capacity without compromising the proposed treatment facility operation. For example, if future demands increase, GWD may explore the possibility of permitting and constructing a Whitney Pond Well #3. It is expected that the pressure vessels will be able to handle up to an additional 200 gpm without exceeding allowable “normal” and “temporary” loading rates of 5 gpm/sf and 7 gpm/sf, respectively.

Each filter will contain the following media:

- Gravel support layer 12 inches in depth.
- GreensandPlus™ (media cut sheet provided in Appendix E) layer 18 inches in depth.
- Anthracite layer 12 inches in depth.

The interior of the filters will be equipped with an inlet distributor/backwash collector, underdrain system to collect filtered water, and air wash distributors to provide air scour during backwash. All internal piping and materials will be designed to be corrosion resistant.

The filter face piping system will consist of ductile iron pipe and fittings, electrically operated control valves, manual butterfly valves for isolation, and magnetic flow meters for metering at various process flow locations. Filter face piping and valves for each filter will be designed so as to provide the ability to hydraulically balance the flow provided to each filter. A modulating control valve will be provided on the filter inlets (influent) and backwash supply inlets. Open/close control valves will be provided on the filter outlet (effluent), backwash waste, drain down, filter to waste (rinse), air pressurizing, and air wash control lines. Air supply piping will be stainless steel.

The system will also include air and vacuum valves located at the top of the filters, filter manways for access of the interior of the filters, sample taps, pressure gauges, differential pressure transmitters, a blower unit to introduce air during backwash and a filter control panel. Air release valves on the filters will be vented to the exterior of the building, to avoid release of moisture inside the building during filter operation and backwash.

The filter control panel (FCP) will include the ability to select whether the operator wants equal flow supplied to each filter (inlet valves modulate) or to allow hydraulics to govern and naturally balance filter flows (inlet valve full open). The influent pipe will connect to the filter face piping at the center of each two cell vessel and the two vessel arrangement, to provide a hydraulic balance of flows between the various cells and filters as much as possible.

Backwashing will be setup to be initiated automatically or alarmed/signaled as needed by one of three methods: (1) on head loss across the filter (discussed previously), (2) on run time by a timer in the FCP PLC, or (3) on production flow by a flow totalizer in the FCP PLC. The operator will be able to select whether he wants the system to backwash automatically when needed without an operator present or to alarm/signal when a backwash is needed allowing for the operator to go to the facility to trigger a backwash (known as semi-automatic backwash). The setpoints (SPs) for these conditions will be manually adjustable via the FCP Operator Interface Terminal (OIT). Regardless of whether the backwash was initiated automatically or semi-automatically, the actual backwash sequence proceeds “automatically” through prescribed steps. This setup provides the operator with the most flexibility in controlling the system in terms of when a backwash occurs, allowing the operators to manage the timing of backwashes.

3.4 Backwash Residual Handling Methods

The filter backwash process will generate backwash residuals that require handling and disposal. After a filter has been in operation for a period of time, an accumulation of suspended solids may build up in the filter media. The filters will require periodic cleaning after a certain amount of run time/treated water volume, when the differential pressure reaches about 8 to 10 psi, or when the water quality indicates it is necessary based on an increase in the filtered Mn levels. The filter backwash process involves reversal of flow through the filter.

During the "backwash cycle" the mixed media of a filter is expanded (fluidized) using the pressure of the backwash air and water in a controlled manner. The accumulated solids trapped within the media are released and washed up through the expanded bed and discharged into the backwash waste piping. The backwash includes multiple steps including drain down, air pressurization, air scour, low flow/air scour concurrent wash, high rate water wash and filter to waste.

The backwash waste generated during this process will consist of water with concentrated levels of Mn that were removed from the well water during treatment. The amount of backwash generated depends on the volume of water treated, frequency of backwash, specific settings for backwash cycle, and amount of particulates removed. The required frequency of backwash, volume of backwash waste produced and the quality of the backwash waste are estimated below based upon pilot testing information.

Backwash waste can be handled in several different ways: (1) discharge to residuals-holding basin and local sewer system; (2) discharge to on-site residuals-handling lagoons; (3) discharge to a combination of a residuals-holding basin, infiltration lagoon and local sewer system; (4) mechanical dewatering methods. There is currently no sewerage available adjacent to either treatment option. Mechanical dewatering methods are rarely used for thee types of facilities, as it ineherently creates an additional level of operational complexity and increases overall costs (capital and operational). Therefore, discharge to on-site residuals-handling lagoons has been selected as the proposed backwash handling method. GWD has adequate space on both sites to accommodate this option.

For this method, backwash waste would be discharged to a residuals-handling settling basin where the Mn solids would settle and collect at the bottom. The settling basin would be rectangular in shape and may include a series of baffles to encourage settling of solids. Clarified supernatant would flow from the settling basin to an unlined infiltration basin for percolation into the ground. Over time the Mn solids collecting at the bottom of the settling basin would form a solids "cake" which would be periodically removed and disposed of legally to an appropriate disposal facility.

The MassDEP has a draft policy entitled "Permit Requirements for the Disposal of Water Treatment Plant Residuals to Lagoon Systems". The policy states that a Groundwater Discharge Permit is required for new water treatment facilities using unlined lagoons for handling of process residuals. Alternatively, the facility can be constructed with two lined lagoons (or a concrete settling basin) (operated in parallel) for solids settling with the supernatant discharging to a third unlined lagoon for percolation into the ground. With this design, the groundwater standards would be considered as met and a permit would not be required.

Refer to **Section 3.8** for specific design details of the facility's backwash residual handling configuration and sizing.

3.5 Chemical Feed System Modifications

The existing Baddacook Treatment Facility has chemical feed systems for KOH and NaOCl. This equipment will be re-purposed and/or modified as follows. The facility design flows used to determine chemical feed requirements are as follows:

- Low Flow of 500 gpm
- Design Flow of 750 gpm
- Max Flow of 750 gpm

3.5.1 Potassium Hydroxide Feed System

The existing KOH feed system at the Baddacook Treatment Facility provides pH adjustment prior to filtration. The KOH is delivered to station via tanker trucks at 45% dilution. The KOH is delivered to the system through a metered injection within the facility. Water quality testing indicated that the pH of the raw water (6.7) will need to be increased to a target level of 6.8 for the manganese removal processes.

The intent of the proposed Baddacook expansion is to add new KOH feed equipment to enable it to treat the water coming from the Whitney Pond Wells. This will involve adding additional day tanks, bulk storage, and a new set of chemical injection equipment for the additional filters.

Given the existing water quality, the anticipated KOH feed rates based on use of 45% potassium hydroxide are shown in **Table G-1.** The pre-filter dosages were determined using the RTW model, as confirmed by the pilot testing, using a raw water 6.7 pH and target pre-filtered water 6.8 pH. The post-filter dosages were determined using the RTW model and adjusting from the filtered water pH of 6.8 to a target pH of 7.7 for finished water, to be consistent with the current operations for corrosion control.

Table G-1. Anticipated Potassium Hydroxide Dosages and Feed Rates

Dosages and Feed Rates	Dosage	Feed Rate[3,4] (gallons per hour)
Pre-Filter Dosages		
Low Dose	3.0 mg/L	0.14 gph
Design Dose	5.0 mg/L	0.35 gph
Maximum Dose	5.5 mg/L	0.39 gph
Post-Filter Dosages		
Low Feed Rate[1]	19.5 mg/L	0.93 gph
Design Feed Rate[2]	20.0 mg/L	1.40 gph
Maximum Feed Rate[2]	20.5 mg/L	1.44 gph

Table Notes:

[1]Low feed rate is based on a facility flow rate of 0.75 mgd (i.e., Appx. 500 gpm) and dose calculated using the RTW Model.

[2]Design and maximum feed rates are based on a facility flow rate of 1.10 mgd (i.e., Appx. 750 gpm) and dose calculated using the RTW Model.

[3]All rates assume 24 hour operation

[4]These design feed rates translate to a combined bulk storage quantity for a month of 650 gallons. To provide 30 hours of chemical storage in day tanks, approximately 55 gallons of combined storage is required.

3.5.2 Sodium Hypochlorite Feed System

NaOCl is used for manganese oxidation and media regeneration. NaOCl is typically dosed based on the levels of Mn in the raw water and the chlorine demand of the oxide-coated media, with a goal to carry approximately 0.2 to 0.5 mg/L residual chlorine in the filter effluent. However, NaOCl does not oxidize the manganese easily. In fact, the pH would need to be adjusted to higher than 8.5 to affect the manganese oxidation reaction using NaOCl. Therefore, the NaOCl dosages are primarily based on the level required for continuous regeneration of the media and any desired residual for the finished water.

The intent of the proposed Baddacook expansion is to add new NaOCl feed equipment to enable it to treat the water coming from the Whitney Pond Wells. This will involve adding additional day tanks, bulk storage, and a new set of chemical injection equipment for the additional filters.

Given the existing water quality, the anticipated NaOCl feed rates based on use of 12.5% sodium hypochlorite with a 1:1 dilution (6.25% solution) to minimize off-gassing issues are shown in **Table G-2**.

Table G-2. Anticipated Sodium Hypochlorite Dosages and Feed Rates

Dosages and Feed Rates	Dosage	Feed Rate (gallons per hour)
Pre-Filter Dosages		
Minimum Dose	0.5 mg/L	0.21 gph
Design Dose	1.0 mg/L	0.61 gph
Maximum Dose	1.5 mg/L	0.91 gph
Post-Filter Dosages		
Minimum Dose	0.8 mg/L	0.33 gph
Design Dose	1.0 mg/L	0.61 gph
Maximum Dose	1.5 mg/L	0.91 gph

These design feed rates translate to use of a 40 gallon day tank with bulk storage accommodated through onsite storage of manufacturer's shipping containers (drums, carboys, buckets). Expected NaOCl consumption is 436 gallons per month.

3.6 Backwash Supply

The existing Baddacook WTP has a full pressure filtration system complete with a backwash water supply from the Town's potable water distribution system. Expanding the Baddacook facility to handle flows from the Whitney Pond Wells would involve using the already present water connection for backwash water.

3.7 Anticipated Backwash Residuals Volume and Quality

For every complete backwash cycle of the existing Baddacook WTP and the proposed Whitney Pond Well Filters, it is anticipated that approximately 3,200 cf of backwash water will be generated. To backwash all the existing filters at Baddacook, and the proposed expansion, it is anticipated that approximately 8,400 cf of backwash water will be generated.

3.8 Backwash Residuals Handling Methods

Backwash from the existing Baddacook WTP is pumped to a holding/settling tank located outside of the WTP underneath the parking lot. The holding/settling tank can hold enough water for one backwash cycle. Settled solids (i.e., Mn oxides) are transferred periodically to the adjacent holding tank and then pumped out of the tank and hauled away. Supernatant is pumped upstream to two gravel lined lagoons for infiltration. Based on discussion with GWD operators, the current system historically performs poorly – backwash can short circuit the holding tank and lead to clogging of the infiltration lagoons. Recently, the operators have focused on improved management of the backwash handling system which has decreased the risk of Mn solids being transferred to the infiltration lagoons.

As part of either the proposed expansion to the Baddacook WTP or a new WTP at the Whitney Pond Wells, the backwash handling system at the Baddacook WTP (i.e., holding tank and infiltraton lagoon) will be re-designed and constructed to remedy existing performance issues. It is anticipated that two (2) concrete backwash settling basins will be constructed upstream of the existing Baddacook WTP, near the existing infiltraton lagoons. The settling basins will be installed in parallel. Each settling basin will be sized to handle backwash from all filters such that one settling basin can be taken offline for maintenance without interrupting operatons. Each settling basin will be rectangular and may have a series of baffles to encourage settling of solids. A decanter will be installed at the outlet of each settling basin to allow supernatant to flow into a downstream infiltration lagoon.

3.9 Design Criteria

The following is a summary of design criteria for the treatment process equipment:

PROCESS EQUIPMENT

GreensandPlus™ System

Design Flow Rate	750 gpm
Filter Configuration	Horizontal Vessels
Number of Vessels	2
Number of Cells per Vessel	2
Surface Area per Filter Cell	52.5 ft^2
Dimension of Vessels	7 ft diameter and 15 ft long
Depth of Anthracite Media	12 inches
Depth of GreensandPlus Media	18 inches
Depth of Support Gravel	12 inches
Filter Service Rate at Design Flow	3.6 gpm/ft^2
Filter Service Rate with One Filter in Backwash	4.8 gpm/ft^2
Filter Backwash System	Air/Water and Water
Filter Backwash Rate (preliminary):	
Simultaneous Air/Water Backwash	5 gpm/ft^2
Duration	12 minutes
Water Only Wash (restratification)	12 gpm/ft^2
Duration	3 minutes

Filter Vessel Material .... Painted Steel
Piping (Water).. Ductile Iron
Piping (Air)..Stainless Steel
Filter Control Valves............. Hydraulically-Operated Globe Style (Cla-Val)
Modulating Valves .... Filter Influent and Backwash Supply
Open Close ValvesFilter Effluent, Drain Down, Rinse, Air Pressure, Air Control
Manual Isolation valves...Butterfly Valves
Flow Meters ....Magnetic Flow Meters
Air Release Valves.. Pipe to Exterior of Facility
Filter Control Panel .... PLC with OIT

Chemical Pumping Equipment Modifications

Chemical... KOH 45% Solution (Existing System)
Application Point .... Raw and Finished water
Modifications.....expanded bulk storage, day storage, and injection point
Chemical................................... NaOCl 12.5% Solution (Existing System)
Application Point .... Raw and Finished water
Modifications.....expanded bulk storage, day storage, and injection point

Well Pumps Modifications (to be verified during detailed design phase)

Number of Pumps to Modify... 1
Type of Pumps.. Vertical Turbine
Modifications.................................... VFD and adjust for increased TDH

Backwash Supply

Type ....Backwash Supply from Distribution System
Design Backwash Flow Rate for Each Filter Cell ....300 to 750 gpm
Surge Protection ....Speed Control and Surge Relief Valve

Backwash Residuals Handling

Method..............Discharge to on-site settling basins and infiltration lagoon
Settling Basin Volume (each basin) ....10,000 cf
Number of Basins 2
Number of Pumps... 2

4 Facility Construction

4.1 Overview

Green concept design elements will be evaluated for incorporation into the design of each option where possible and cost effective. These design elements may include but not be limited to the following:

- Pumping systems using variable frequency drive units to reduce energy usage and associated energy costs. Pumps selection for operations at or near to their maximum efficiency points.
- Energy saving instantaneous hot water heating systems for emergency eyewash/shower units required by code for tempered water.
- Separate spaces for areas that require more frequent air changes for health/safety reasons (chemical areas) to improve HVAC efficiency and energy usage.
- Ceiling fans in filter room to better circulate air helping to improve both heating and cooling.
- Use of programmable heating thermostats.
- Storm water handling systems that provide water treatment and cooling to improve overall water quality as it infiltrates to the ground.
- Solar power system for on-site energy use and supplemental electricity to grid. Use of solar power will be evaluated during the design.
- Energy efficient lighting systems including motion sensors and LED lighting.

4.2 Facility Overview

CEI recommends that the Baddacook facility expansion have a filter room located to the North of the existing filters, with a new bathroom and kitchen installed on the Eastern wall of the operator room. Facility expansion will be constructed from concrete masonry units and be covered by an EPDM roof that is slightly sloped for drainage. A new propane tank and backup power generator will also be furnished to accomidate the expansion's heat and backup power requirements.

4.3 Facility Structure

The Filter System addition will be classified as a Type F building occupancy. The proposed structure will be constructed of masonry block with brick veneer to match these existing structures (original pump station and treatment addition). The foundation will be constructed of reinforced concrete, inclusive any footing walls. The superstructure will have a flat, EPDM covered, roof. The proposed structure will have one set of exterior metal double doors, facing the driveway.

The reinforced concrete design will be in accordance with ACI 318, Building Code Requirements for Structural Concrete, and ACI 350, Code Requirements for Environmental Engineering Concrete Structures, as applicable. ACI 350 defines more stringent design criteria resulting in a more impermeable structure where crack control and resistance to chemical attack are especially important. Concrete design strength will be 4,500 psi and reinforcement will conform to American Society of Testing and Materials (ASTM) A615 grade 60 deformed bars. Design live loads will meet the latest edition of the Massachusetts Building Code and operational requirements. Design conditions include floor, snow, wind, earthquake, earth pressure and operational loads including fluid pressures and equipment loads.

The structure will have a straight wall height that matches the existing filter room, approximately 9.5 feet tall. Also matching the existing filter room's roof, the proposed expansion will have a slightly sloped EPDM roof for drainage.

4.4 Mechanical and Electrical Systems

4.4.1 Plumbing

The treatment facility will have emergency eyewash stations that are supplied with tempered water from an instantaneous electric water heater. Hose bibs will be distributed around the facility.

A condensation collection area encompassing the filters and filter face piping will be provided, using sloped floors surfaces. Condensation discharge will be piped to the onsite stormwater handling basin.

Propane piping shall be installed and will be connected to the new HVAC propane fired unit heaters with unions, dirt legs, full-size shut-off valves, and an exhaust flume.

Stormwater run-off from the roof will be collected by gutters and transported through downspouts to downspout boots that will connect below grade to the onsite stormwater handling basin.

An automatic fire sprinkler system shall not be required to be installed, since the floor area is well below the threshold that would require fire sprinklers and there will be limited chemical storage within the new facility. The Massachusetts Building Code 780 CMR 8^{th} Edition Chapter 9, table 903.2 indicates only Type F building occupancy classification over 12,000 sq/ft are required to have an automatic sprinkler system.

4.4.2 HVAC

The facility will be heated directly using propane-fire unit heaters, designed for up to 70-degrees inside temperature. Each unit heater in the Filter Room will have a remote-mounted two-stage thermostat. A 5-kW electric unit heater with a remote-mounted thermostat is planned for the separate rooms, although the potential use of a wall mounted propane fired unit heater or split ductless heat pump should be considered during the final design (especially for the Control Room).

A split-system dehumidifier designed for low temperature application (50-degrees) will provide dehumidification for the Filter Room. The basis of design will be Desert Aire model LT-1500. The packaged system includes a remote-mounted temperature and humidity controller.

The Filter Room will be ventilated by a wall-mounted propeller exhaust fan and a gravity outdoor air intake. Intake and exhaust openings will be protected by automatic control dampers that have low-leakage weather seals. The fans and interlocked dampers will be initiated by a remote-mounted cooling thermostat. The systems will be designed to provide six air changes per hour of outdoor air.

4.4.3 Electrical

The proposed facility may require upgrdades to the existing service for the existing Baddacook WTP. A new 480V, 3-phase panelboard shall provide power to the new dehumidifier, electric unit heaters, condenser, process blower and backwash residuals handling pumps. A new 30KVA transformer shall provide 120/208V, 3-phase power to a new 100A branch circuit panelboard for power to lighting, receptacle, gas unit heaters, exhaust fans, louvers and the filter control panel.

The expanded Baddacook WTP will be provided with emergency power using an emergency standby power generator that provides power to the entire facility during a loss of utility power via an automatic transfer switch.

Emergency battery lighting units will be provided throughout the expanded facility and at the exit doors to provide code required emergency egress lighting. Exit signs with integral battery backup units shall be mounted over exit doors.

New lighting fixture and controls will be installed throughout the facility. The new light fixtures shall be controlled by local switches. The lighting fixtures will mainly consist of T-8 linear and compact fluorescent fixtures. Green lighting alternatives (LED fixtures) will be evaluated during the design.

Both the proposed Baddacook expansion and proposed Whitney well facilities will be equipped with a combined fire/intrusion detection system.

5 Planning Cost Estimate

5.1 Funding

GWD is currently considering options to fund construction of the selected alternative. Potential options include: 1) the State Revolving Fund (SRF) administered through the Massachusetts Water Pollution Abatement Trust and the Massachusetts Department of Environmental Protection (MassDEP) or 2) obtain private loan.

5.2 Capital Costs

The American Association of Cost Engineers (per ANSI Standard Z94.0-1989) has defined levels of accuracy that are commonly used by professional cost estimators. Three categories of accuracy include: (1) order-of- magnitude, (2) budget, and (3) definitive estimates. The estimates of comparative cost presented in this report are considered order-of-magnitude, and were developed with limited engineering detail for comparison purposes. Cost estimates reflect historical construction costs scaled forward to 2022 (anticipated bid date) and are based on work of a similar nature. If construction occurs beyond this time frame, then the cost estimating will need to be re-evaluated. To estimate the future cost in 2022, the Real Discount Rate (3%) from the United States Office of Management and Budget was implemented to extrapolate beyond the current ENR index. Actual project costs may vary from this preliminary estimate as a result of additional engineering detail and other cost-related variables.

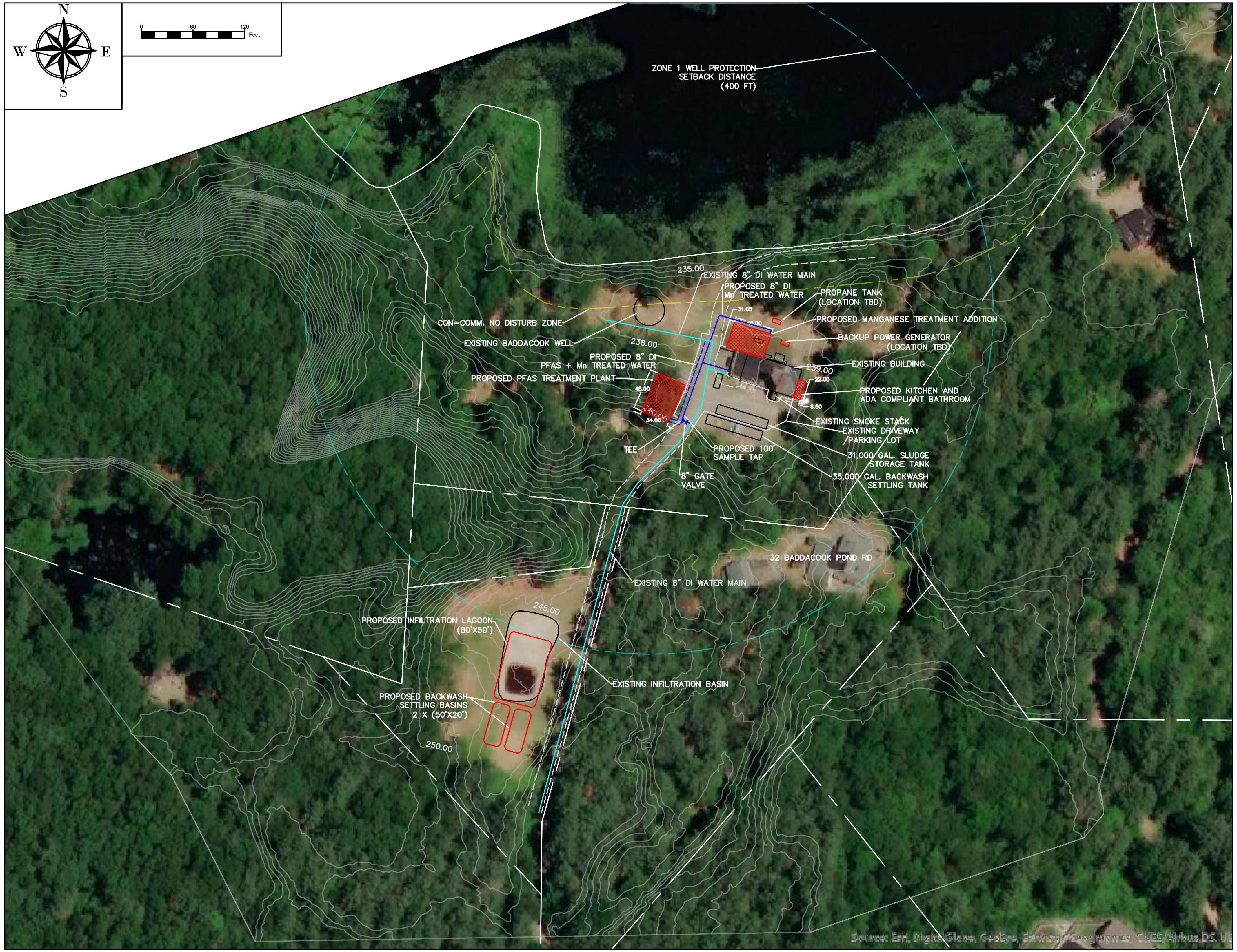
In addition to the traditional engineering and construction costs associated with capital projects of this nature, Massachusetts has additional requirements for an Owner's Project Manager (OPM). Per Massachusetts General Law (M.G.L. c.149 §44½), for public building contracts that are estimated to cost $1.5 million or more, the jurisdiction must contract with or assign a qualified OPM to serve as the jurisdiction's agent during the planning, design and implementation of the contract. The OPM must be independent of the project designer, general contractor or any subcontractor. The District may elect to assign the role of the OPM to a qualified in-house individual or hire an outside OPM. For the purposes of this report, we have assumed that the District will use qualified staff in-house for the role of OPM.

Order-of-magnitude cost estimates ofor each option are shown in **Table G-3**.

Table G-3. Baddacook WTP Order-of-Magnitude Project Costs

Item	Unit of Measure	Est. Quantity	Unit Cost	Total
Water Main				
Engineering for WM (design, bid, field)	LS	1	$ 225,000	$ 225,000
Environmental Permitting	LS	1	$ 80,000	$ 80,000
Install 12-inch DI Water Main	LF	4100	$ 145	$ 595,000
Install 8-inch DI water Main	LF	5600	$ 135	$ 756,000
Bridge Crossings	EA	3	$ 25,000	$ 75,000
			Subtotal	$ 1,730,000
			15% Contingency	$ 260,000
			Total	$ 1,990,000
			Water Main Total with inflation (2019-2022)	**$ 2,240,000**
Treatment				
Pilot Testing	LS	1	$ 39,500.00	$ 39,500
Engineering Design[1]	LS	1	$ 250,000	$ 250,000
OPM Design Phase	LS	1	$ 70,000	$ 70,000
Engineering Bid and Construction Phase	LS	1	$ 200,000	$ 200,000
Engineering Field - Resident Services	LS	1	$ 190,000	$ 190,000
OPM Construction Phase	LS	1	$ 70,000	$ 70,000
Materials Testing	LS	1	$ 20,000	$ 20,000
Electrical Services Cost	LS	1	$ 10,000	$ 10,000
Construction of the Project[2]	LS	1	$ 2,900,000	$ 2,900,000
			Subtotal	$ 3,749,500
			15% Contingency	$ 560,000
			Total	$ 4,309,500
			Sub-Total with inflation (2019-2022)	**$ 4,850,000**
			Complete Project Total:	**$ 7,090,000**

Appendix E.3 Baddacook Conceptual Plans



General Notes

No.	Revision/Issue	Date

COMPREHENSIVE ENVIRONMENTAL INCORPORATED

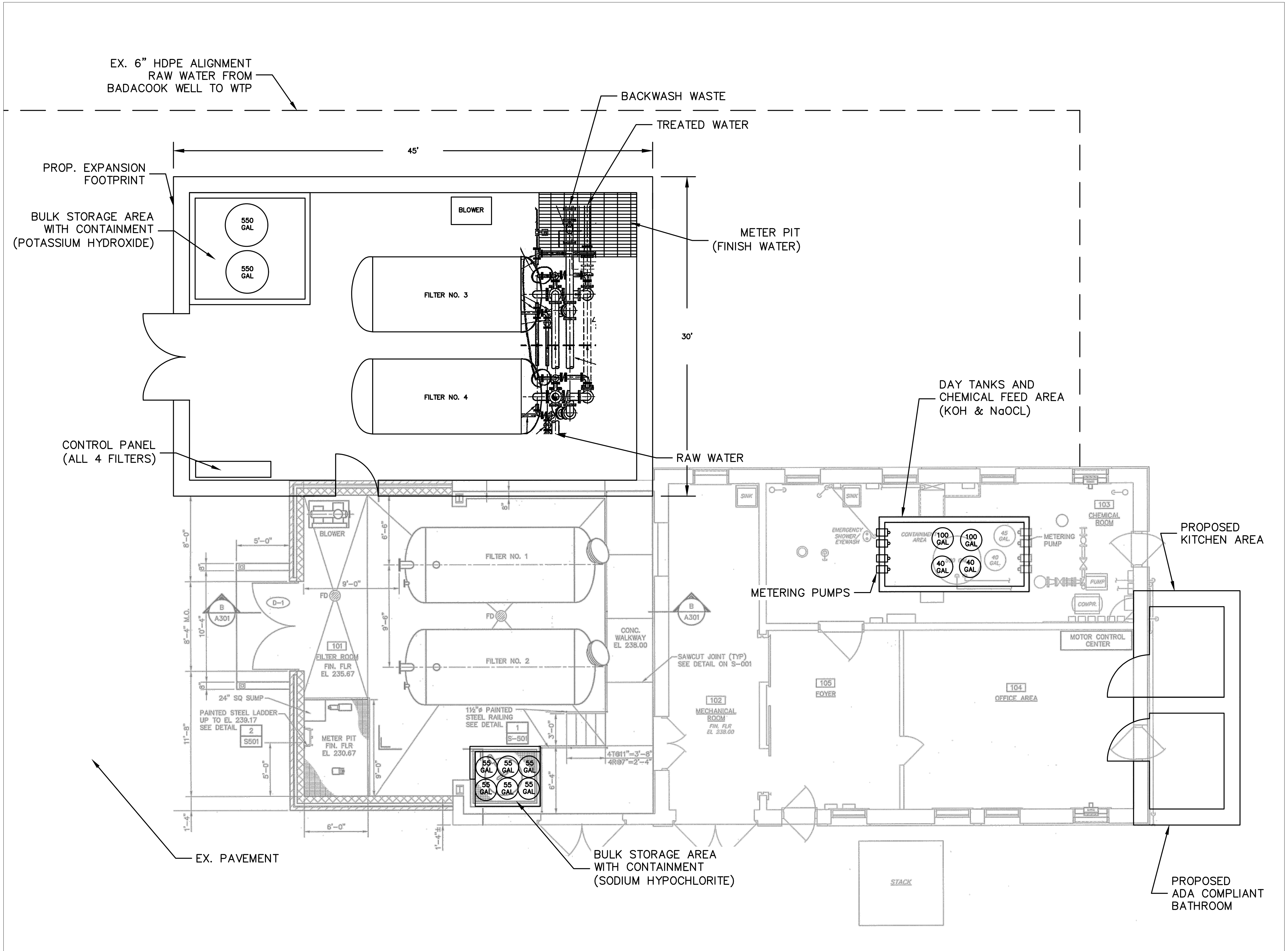
41 MAIN STREET
BOLTON, MA 01740

CONCEPTUAL EXPANSION LAYOUT

TOWN OF GROTON
WATER DEPARTMENT

Project No.: 239-13
JULY 2020
Drawn By: SS
Checked By:
Scale: AS SHOWN

Sheet
C-1



General Notes

No.	Revision/Issue	Date

COMPREHENSIVE ENVIRONMENTAL INCORPORATED
41 MAIN STREET
BOLTON, MA 01740

CONCEPTUAL EXPANSION LAYOUT

TOWN OF GROTON
WATER DEPARTMENT

Project No.: 230-13
JULY 2020
Drawn By: SS
Checked By:
Scale: AS SHOWN

Sheet
C-2