Northeast Water Solutions, Inc.

FINAL REPORT
PILOT PLANT EVALUATION
SEPTEMBER, 2022

MANGANESE REMOVAL FROM PRE-FILTERED SURFACE WATER USING GREENSAND PLUS FILTRATION

PREPARED FOR

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February 7, 2023

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EXECUTIVE SUMMARY

Housatonic Water Works Company and NWSI conducted a comprehensive pilot plant program to assess and evaluate the ability of the Greensand Plus Filtration treatment process to effectively removal manganese from the source water. Over the 250-hour duration of the pilot plant program the system experienced a particularly high manganese levels in the Long Pond source water were experienced, with the pilot plant experiencing an average total manganese concentration of 0.192 mg/L, with a range of 0.075 mg/L to 0.306 mg/L. Approximately 24% of the influent total manganese was in the dissolved form.

The greensand filtration process demonstrated consistently effective and excellent removal of manganese from the pre-treated water, over the entire 250-hour active duration of the pilot plant program. Fifty-six (56) of 60 total pilot plant effluent samples demonstrated non-detectable manganese (<0.00204 mg/L) and the four (4) samples with detectable manganese were all at least an order of magnitude (10X) less than the USEPA/MassDEP SMCL (0.05 mg/L). Additionally, in all cases, the effluent total manganese was below the HWWC goal of 0.015 mg/L total manganese. Additionally, the pilot plant further demonstrated effective removal of manganese to non
detectable levels at all and hydraulic loading rates (3.7 gpm/ft^{2}to 7.2 gpm/ft^2) tested, achieving an overall >98.9% removal of total manganese and 100% removal of dissolved manganese.

The three (3) pilot filter units all demonstrated a similar free chlorine oxidation demand of approximately 0.53 mg/L. To assure maintenance of full media oxidative capacity, it is recommended the filter effluent contain a minimum chlorine residual of 0.5 mg/L. Therefore, the minimum net influent free chlorine dosage is ~1.0 mg/L.

Operating filter cycle loading on the order of 10,000 to 11,000 gal./ft^{2}resulted in steady-state performance from the standpoint of sustaining consistent pressure drop and hydraulic throughput across the filters, regardless of the hydraulic loading rates. No manganese breakthrough occurred during any operating cycle of the pilot plant run. The greensand filter pilot plant further demonstrated excellent reduction of turbidity demonstrating an average effluent turbidity of 0.126 NTU and a range of <0.100 NTU to a maximum of 0.270 NTU. However, no correlation between effluent turbidity and effluent total manganese was identified and therefore turbidity should not be considered as an operational control metric.

The greensand filter backwash determined effective flushing of the majority of TSS occurred within 6 to 8 minutes on each backwash cycle, after which the backwash water demonstrated an extended "tail" of TSS, regardless of duration. Similarly, the backwash water manganese monitoring determined the majority of the particulate manganese was flushed within 6 to 8 minutes, again with an extended "tail" for the duration of the backwash cycle. The backwash water evaluation provides indication that use of an air-scour assist backwash will beneficially enhance backwash efficiency.

The greensand filtration process had no impact upon the finished water characterization, nor any adverse impact upon the corrosion potential of the finished water. Both the raw and finished water have a very low corrosion potential, that is unaffected by both the existing treatment process and the proposed greensand filtration treatment.

The greensand filtration system performance was unaffected by organic loading, monitored as total organic carbon (TOC), dissolved organic carbon (DOC) and UV254. Additionally, the greensand filtration treatment had no practical impact upon formation of disinfection-by-products.

HWWC successfully tested the Greensand Plus filters under worst-case conditions during a period of high-spiking manganese in the Long Pond source water. MassDEP has required that four (4), discrete, quarterly pilot plant programs be executed. However, manganese has historically not been occurring in the finished water from October/November through May, therefore pilot studies conducted during that time period will be of limited value due to the typically low to non-detectable manganese present in the water supply. Based on the findings in the September, 2022 pilot plant test program, the following recommendations are presented for consideration:

- The greensand filtration process will function effectively over a hydraulic loading range of 3.8 to 7.5 gpm/ft^2;

- It is recommended the full-scale system consist of four (4), 36” Ø x 72: S/S Ht. filter vessels, installed in parallel. During normal operation at 100 gpm, three (3) vessels would be on-line, with a nominal hydraulic load of 4.7 gpm/ft^2;

- The chlorine pre-oxidant dosage should be approximately 1.0 mg/L, to allow a minimum 0.5 mg/L free chlorine residual in the filter effluent;

- A backwash cycle duration of 10 minutes is recommended, at a nominal unit loading rate of 12 gpm per square foot of filter bed area. Use of a low pressure, dry, oil-free air-scour backwash assist is recommended to enhance backwash efficiency, particularly during periods when the water temperature is greater than 60^{o}F. Use of an air scour assist can reduce the backwash water requirement by approximately 60%, to 4.5 gpm per square foot of filter bed area.

- Spent backwash water may be discharged to a settling tank, and then to the on-site lagoon system currently used for disposal of the slow sand filter wash water.

HWWC is prepared to proceed with design of the manganese removal system as soon as MassDEP approves so. Based upon the findings of this pilot plant program no further pilot testing is necessary to demonstrate the performance of this process, for removing manganese from the Long Pond source water. It would be best for the customers if HWWC was allowed to try and complete the installation of the full-scale system before the next likely manganese spike in summer 2023, an admittedly optimistic goal.

INTRODUCTION

Housatonic Water Works Company (HWWC) draws surface supply from Long Pond, treating the raw water via slow rate media depth filtration and chlorination (sodium hypochlorite) disinfection prior to discharge to the nearby 1.1 MG water storage standpipe tank. The finished water is pumped to the water storage tank at flowrates ranging from 50 to 150 gpm, from where it discharges by gravity to the water distribution system. During 2020/2021 the system demonstrated an average daily use of approximately 104,000 to 111,000 gpd.

The finished water is historically compliant with MassDEP/USEPA water quality requirements for pH (6.5 to 8.5 S.U.) and free chlorine residual ($\leq$4.0 mg/L), typically demonstrating pH in the range of 7.0 – 7.5 S.U. and a free chlorine residual ranging from 1.0 – 1.5 mg/L. The finished water at the distribution system point-of-entry is typically within the MassDEP/USEPA

Manganese SMCL (<0.05 mg/L) however seasonal manganese discoloration has occurred, typically from late June to September, demonstrating manganese concentrations on the order of 0.05 – 0.34 mg/L. HWWC is presently under a directive from MassDEP to conduct a pilot plant and implement manganese treatment to meet the USEPA/MassDEP Secondary Water Quality Limit (0.05 mg/l) and MassDEP Advisory Limits. Additionally, the pilot plant program must assess the impact of the manganese treatment upon disinfection by-products (DBP) formation.

HWWC proposes to implement a Greensand Plus filtration system for removal of manganese from the Long Pond source water. Prior studies evaluated a range of treatment process alternatives ultimately determining that the greensand filtration process would likely be the optimum process for the HWWC system, due to specific advantages including: (1) the ability to remove both soluble and particulate manganese, (2) operational flexibility regarding pre-oxidant chemistry, (3) simplicity of operation and (4), the ability to be easily integrated into the existing treatment process. The intent of the pilot plant is to evaluate the effectiveness of the Greensand Plus filtration process, installed following the existing chlorination process, to achieve consistent removal of manganese to ≤0.015 mg/l. This standard is in accordance with good engineering practice and Water Research Foundation guidance for the maximum level of manganese to avoid generating color and consumer complaints. The pilot plant program will evaluate critical operational variables (hydraulic loading, manganese loading, pre-oxidation chlorine dosage, pH, backwash flowrates, organic load, etc.) upon the finished water quality and define the operating criteria for a full-scale system.

HWWC submitted the pilot plant permit application BRP WS 21B to MassDEP to conduct a pilot study using Greensand Plus Filtration on May 20, 2022, subsequently augmented with updated design and operating criteria. MassDEP issued a conditional approval for manganese treatment pilot study on August 1, 2022. The pilot plant must be performed during the summer when manganese is typically experienced in the water supply. However, MassDEP has required that four (4), discrete, quarterly pilot plant programs be executed to demonstrate the effectiveness of the treatment process, over the range of seasonal water characterization conditions experienced by Long Pond and HWWC.

The 1st quarterly pilot plant program was conducted over a 2-week period from September 14th to 28th, 2022. This report presents a summary of the pilot plant program including raw water and

pre-filtered water characterization, greensand filtration performance under a realistic range of operating conditions, finished water quality, filter backwash performance and efficiency, and impact upon chlorine residual and disinfection by-product formation. Finally, this report presents recommendations for full-scale system implementation.

The pilot plant program was performed by Northeast Water Solutions, Inc., under the direct supervision of a Massachusetts Registered Professional Engineer. The day-to-day pilot plant operation was performed by a Massachusetts certified public water system operator (Grade 2T, 3T-OIT). Technical review of the pilot plant operation, data generation and findings, including select text, figures and tables, were provided by Water Compliance Solutions, LLC.

I. **BASIS OF PILOT PLANT TEST PROGRAM**

Housatonic Water Works Company (HWWC) draws surface supply from a gravity intake and pipeline installed in Long Pond. The raw surface water enters the Treatment Building, installed adjacent to Long Pond, where it undergoes slow rate media depth filtration and chlorination (sodium hypochlorite) disinfection. The chlorine contact tank effluent is pumped continuously (24 hrs./day) to the 1.1 MG water storage tank at flowrates ranging from 50 to 100 gpm (150 gpm peak during periodic distribution system flushing), from where it discharges by gravity to the water distribution system. The storage tank effluent is considered the finished water at the point-of-entry (POE) to the distribution system. During 2020/2021 the system demonstrated an average daily use of approximately 104,000 to 111,000 gpd (avg. ≈75 gpm). The process flow diagram for the HWWC treatment facility is presented in Appendix A.

1.1 **Problem Statement**

HWWC's distribution system water exhibits periodic seasonal episodes of discolored water and related customer complaints. The color is believed due to spikes in natural manganese concentrations occurring in the Long Pond source water. Dissolved manganese itself does not impart color to the water. However, dissolved manganese passing through the slow sand filters can be oxidized by chlorine into a particulate form that causes color ranging from light-to-dark yellow, to brown, grey and black.

The manganese spikes and resulting color have recently occurred in the summers of 2018, 2020, 2021, and 2022, but not in 2019, as shown in Figure 1-1 (color monitoring data) for distribution system samples. The discolored water typically occurs between early May to as late as September during the year, but not necessarily for that entire period (Figures 1-1 and 1-3). In between the manganese spikes there is typically little or no color to the water.

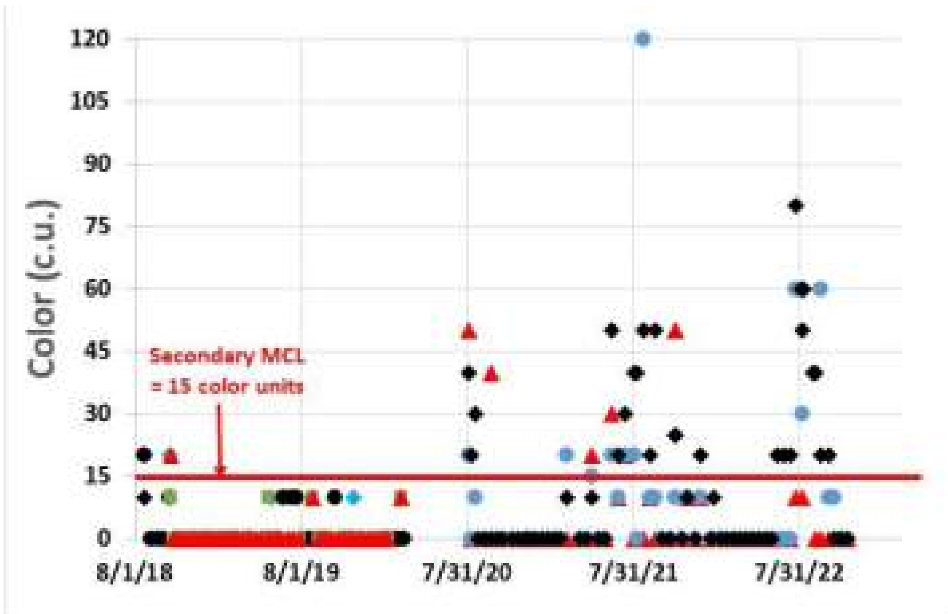


Figure 1-1: Color in Distribution System Samples - 2018 – 2022 (prepared by WCS)

The water color is linearly correlated with the manganese concentration, as exemplified in Figure 1-2 presenting data for samples collected at the request of complaining customers in 2022 (with one datum point outlier). Depending on the extent of manganese oxidation, samples that have the same amount of total manganese could have different ratios of dissolved and particulate manganese and thus different types and shades of color. Iron is typically not detected in the filtered water nor in distribution system water, and thus is not believed contributing to the periodic color episodes.

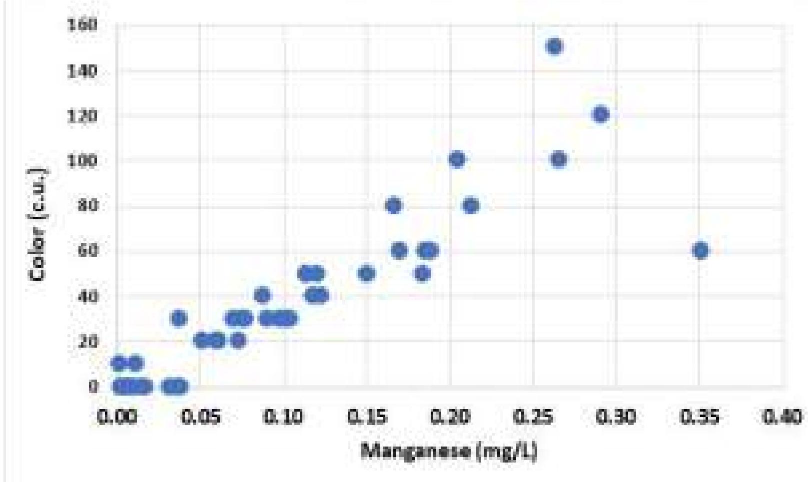


Figure 1-2: Manganese v Color – 2022 Customer Samples (prepared by WCS)

Figure 1-3 presents the raw and finished water total manganese concentrations for the past three years. Manganese is detected year-round in the Long Pond water, with periods of relatively low concentrations however, periodic manganese spikes have reached as high as 0.34 mg/L for both the raw and finished water.

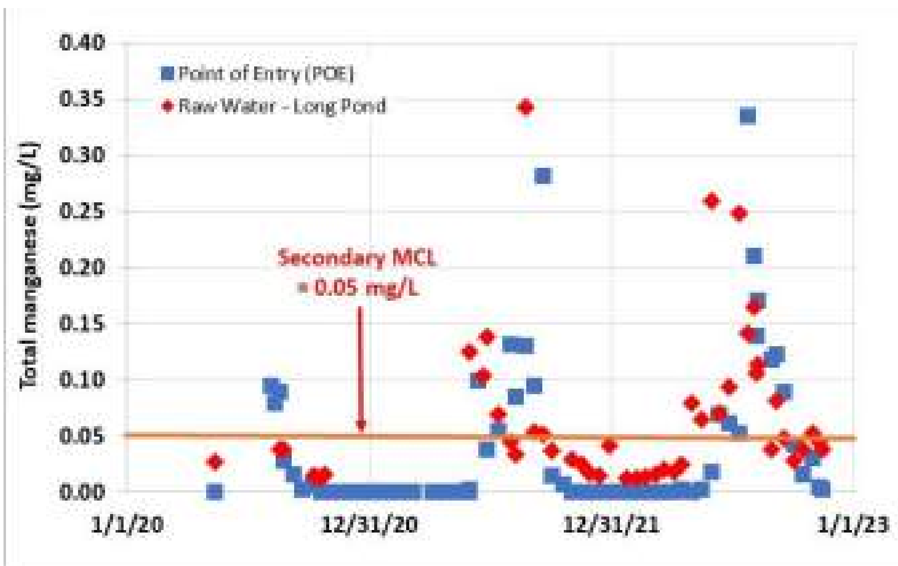


Figure 1-3: Manganese in Raw and Finished Water 2020 – 2022 (prepared by WCS)

Some manganese removal is experienced by the slow sand filters, and when source water manganese is low then manganese is not detected in the treated water. As examples, manganese was not detected in the finished water from October 2020 through May 2021, and then was non detectable again from November 2021 through May 2022 (Figure 1-3). In fall of 2022 there was no color detected after mid-October, and manganese levels were not above the SMCL.

1.2 Regulatory Requirements

The USEPA has not published a Maximum Contaminant Level (MCL) for manganese however, there is a Secondary MCL (SMCL) of 0.050 mg/L based on staining and taste considerations. In order to enhance consumer acceptance of water resources, the USEPA Drinking Water Health

Advisory recommends reducing manganese concentrations ≤ 0.050 mg/L, the SMCL for manganese. The Massachusetts Drinking Water Regulation, 310 CMR 22.07D(1), also identifies the SMCL for manganese as 0.05 mg/L. However, Water Research Foundation guidance indicates ≤ 0.015 mg/L is a more appropriate target to avoid aesthetic issues.

In addition, a lifetime Health Advisory (USEPA) of 0.3 mg/L and a 1-day and 10-day Health Advisory of 1.0 mg/L for acute exposure has been established. However, it is advised that for infants younger than 6 months, the lifetime Health Advisory of 0.3 mg/L be used even for an acute exposure of 10 days, because of the concerns for differences in manganese content in human milk and formula and the possibility of a higher absorption and lower excretion in young infants. MassDEP extended that age to one year due to concerns for formula use up to that age and the potential susceptibility of this early life stage to excessive manganese exposure and potential resultant toxicity

1.3 Water Characterization – Inorganic & Physical Parameters

Northeast Water Solutions Inc. (NWSI) conducted an evaluation of the raw source water and finished water produced by HWWC. Table 1-1 presents a summary of the analytical characterization of the point-of-entry (POE) finished water from a previous evaluation by Cornwell Engineering (July – September, 2020), augmented with raw source water and finished water samples obtained on March 22, 2022. Table 1-2 presents a summary of the analytical characterization of both the source water and POE finished water from August 5, 2020 through March 21, 2022. This table includes a breakout of the "summer" seasonal monitoring during 2020/2021 from June 1st to September 30th, each year.

- Temperature: The Long Pond (surface) source water is subject to a wide temperature range from 0.7°C (33.2°F) to 27.2°C (81°F). During the summer period the range decreases, demonstrating 18°C (64.4°F) to 27.2°C (81°F). The finished water at the point of-entry (POE) is similar, demonstrating an annual range of 2°C (35.6°F) to 25.7°C (78.3°F) and a summer seasonal range of 10°C (50°F) to 25.7°C (78.3°F). At minimum, the temperature variability impacts the dissolved oxygen content in the water and potentially impacts manganese in the raw source water.

- pH: The source water is slightly alkaline demonstrating an annual average pH of 7.5 S.U., with a range of 7.1 to 8.5 S.U. Note: the pH value of 8.5 S.U. is an outlier, with source

water demonstrating a median pH of 7.3 S.U. The finished water (POE) demonstrates an annual average pH of 7.5 S.U, with a range of 7.2 to 7.9 S.U. The pH during the summer season is consistent with the annual average value and range.

- Turbidity: The source water demonstrates turbidity with an annual average value of 0.88 NTU and a range of 0.04 to 3.7 NTU. During the summer season the average turbidity increases to 1.32 NTU, with a similar range. The finished water (POE) is lower and more consistent demonstrating an annual average value of 0.22 NTU with a range of 0.02 to 0.90 NTU. During the summer season the turbidity increases somewhat, to an average of 0.41 NTU.

- Color: The source water demonstrates an annual average apparent color value of 23.3 C.U. and a range of <1 to 50 C.U. During the summer season the average apparent color increases slightly to 25.5 C.U. with a range of 10 to 45 C.U. The finished water (POE) is lower, demonstrating an annual average apparent color of 10.8 C.U. with a range of <1 to 50 C.U. During the summer season the apparent color increases significantly to an average of 26 C.U., with a range of <1 to 50 C.U.

- Total Dissolved Solids (TDS): The source water and finished water (POE) demonstrate moderately low TDS with an annual average of ≈122 mg/L. Eliminating one (1) outlier TDS value for each sampling location determines a source water TDS range of 74 to 162 mg/L and a finished water range of 54 to 168 mg/L. The TDS principally consists of alkalinity (≈80 mg/L, as $CaCO_3$), calcium (≈20 mg/L) and chloride (≈14 mg/L), with lesser quantities of magnesium (≈7 mg/L), sulfate (≈4 mg/L) and potassium (≈1 mg/L). All other inorganic constituents are non-detectable or at trace concentrations in the water.

- Alkalinity: Alkalinity is consistently present at ≈ 80 mg/L (as $CaCO_3$). Based upon the average annual pH of 7.5 S.U., the alkalinity is virtually entirely in the bicarbonate (HCO_3) form and will represent approximately 95% of the total inorganic carbon in the water, with the balance present as carbonic acid (H_2CO_3) or carbon dioxide (CO_2).

- Chloride & Sulfate: Chloride demonstrated an average concentration of 14.2 mg/L in a series of four (4) samples obtained in August 2020. The March 22, 2022 sampling event demonstrated chloride concentrations of 9.2 mg/L and 11.6 mg/L in the raw and finished water, respectively. Concurrent sulfate monitoring demonstrated <5.00 mg/L in all samples, with the March 22, 2022 finished water sample demonstrating 4.4 mg/L.

- Total Iron: The source water demonstrates very low total iron with an annual average concentration of 0.074 mg/L and a range of <0.050 to 0.333 mg/L. The iron concentration increases during the summer season, demonstrating an average of 0.114 mg/L.

  Alternatively, the finished water (POE) consistently demonstrates non-detectable (<0.050 mg/L) total iron. It is believed this is due to the iron being oxidized to a particulate form via "natural" aeration and dissolved oxygen in the water, with the particulate iron being captured in the slow sand filtration system.

- Total Manganese: The source water demonstrates periodic elevated total manganese with an annual average concentration of 0.0530 mg/L, with a range of 0.0128 to 0.343 mg/L. The manganese concentration increases during the summer season, demonstrating an average of 0.095 mg/L, with a range of 0.033 to 0.343 mg/L. The seasonal variability is further demonstrated by the "non-summer" (October 1st to May 31st) monitoring indicating an average concentration of 0.0202 mg/L and a range of 0.0128 to 0.0411 mg/L. As noted above (Section 1.1 – Problem Statement) it is believed the seasonally increased manganese content causes the periodic increase in color.

  The finished water (POE) demonstrates an annual average total manganese concentration of 0.0028 mg/L. However, the "non-summer" monitoring demonstrates an average concentration **<0.0006 mg/L, with only 3 of 28 samples having detectable manganese (0.0061 to 0.0141 mg/L)**. The "summer season" monitoring demonstrates an average total manganese concentration of **0.082 mg/L, with a range of <0.002 to 0.282 mg/L**. This indicates the manganese is seasonally generated in Long Pond. Additionally, a comparison of the summer season average total manganese in the source (0.095 mg/L) and POE (0.082 mg/L) samples indicates that an average of only **14% of the manganese is being removed through the treatment facility, during the summer season**. This is believed due to manganese being much more difficult to oxidize and precipitate, compared to iron, with the soluble manganese passing through the slow sand filtration process. Therefore, to achieve effective removal of manganese it is necessary to **consistently oxidize and precipitate the soluble manganese in the raw water supply**.

- Chlorine Residual: The HWWC treatment process includes chlorination of the slow sand filtration effluent. The free chlorine residual in monitored in two (2) locations including at the outlet of the chlorine contact chamber ("Segment #1") and at the finished water "point-of-entry" (POE – Segment #2). The finished water demonstrates an annual average chlorine residual of 1.58 mg/L with a range of 0.56 to 2.80 mg/L. During the summer season the average chlorine residual declines somewhat to an average of 1.37 mg/L with a range of 0.56 to 1.74 mg/L. It is believed this slight decline at the POE is due to seasonally increased chlorine demand related to increases of manganese, natural organic matter, etc.

Table 1-1
HWWC Water Characterization

Sample Date/Parameter	**03/22/22**	**03/22/22**	**Cornwell Report 2018 - 2020**
Location	**Raw Water**	**Finished Water**	**Finished Water**
Temperature – Field	5.0°C	14.6°C	-----
pH – Laboratory	7.3 S.U.	7.4 S.U.	7.3 S.U.
Turbidity	0.75 NTU	0.15 NTU	-----
Apparent Color	8 C.U.	2 C.U.	20 C.U.
UV 254	0.055	-----	-----
Total Organic Carbon	2.86 mg/L	1.66 mg/L	-----
Total Solids	-----	105 mg/L	-----
Total Dissolved Solids	-----	99 mg/L	107 mg/L
Conductivity (umhos/cm)	191	206	-----

Alkalinity ($CaCO_3$)	80 mg/L	83 mg/L	80 mg/L
Chloride	9.2 mg/L	11.6 mg/L	14.2 mg/L
Sulfate	-----	4.4 mg/L	<5 mg/L
Fluoride	<0.02 mg/L	<0.02 mg/L	-----
Nitrate – N	<0.002 mg/L	0.047 mg/L	-----
Nitrite-N	<0.002 mg/L	<0.002 mg/L	-----
Silica	-----	1.6 mg/L	-----
Arsenic	<0.0005 mg/L	<0.0005 mg/L	-----
Barium	0.005 mg/L	0.005 mg/L	-----
Beryllium	-----	<0.003 mg/L	-----
Calcium	-----	21.7 mg/L	19.2 mg/L
Copper	<0.01 mg/L	<0.01 mg/L	
Iron	0.03 mg/L	<0.01 mg/L	<0.05 mg/L
Lead	<0.001 mg/L	<0.001 mg/L	
Magnesium	-----	7.90 mg/L	0.086 mg/L
Manganese	0.02 mg/L	<0.01 mg/L	-----
Potassium	-----	0.79 mg/L	-----
T. Phosphate	ND	<0.007 mg/L	-----
Selenium	<0.001 mg/L	<0.001 mg/L	-----
Sodium	5.0 mg/L	6.8 mg/L	-----
Zinc	<0.01 mg/L	,0.01 mg/L	-----
Total Hardness ($CaCO_3$)	-----	86.6 mg/L	-----
Corrosion/Scale Indices:			
Langelier Saturation Index – pK	-1.53	-1.18	-----
Langelier Saturation Index –A+B	-1.26	-0.97	
Larson Skold Index	0.22	0.25	-----
CSMR	-----	2.63	-----
Alkalinity-to-Chloride Ratio	8.69	7.16	-----

Table 1-2
HWWC Source & Point-of-Entry Water Quality Monitoring (08/03/2020 – 03/21/2022)[1]

Parameter	Units	Long Pond Source Monitoring				Point-of-Entry Finished Water			
		# Samples	Avg	Min.	Max.	# Samples	Avg	Min.	Max.
Temperature:									
All Samples	^0C	21	14.1	0.7	27.2	43	13.0	2.0	25.7
Summer	^0C	9	21.4	18.0	27.2	14	19.2	10.6	25.7
pH:									
All Samples	SU	22	7.5	7.09	8.5	43	7.50	7.2	7.90
Summer	SU	10	7.46	7.09	8.5	15	7.42	7.21	7.71
Tot. Diss. Solids									
All Samples	mg/L	24	122	74	325	44	121	54	436
Summer	mg/L	10	129	74	325	15	118	98	168
Alkalinity ($CaCO_3$)									
All Samples	mg/L	20	83.5	75.0	95.0	44	83.2	67.5	95.0
Summer	mg/L	10	80.8	75.0	87.5	15	82.0	75.0	87.5
Total Iron									
All Samples	mg/L	21	0.074	<0.050	0.333	40	<0.0500	<0.0500	<0.0500
Summer	mg/L	11	0.114	<0.050	0.333	15	<0.0500	<0.0500	<0.0500
Total Manganese									
All Samples	mg/L	25	0.0530	0.0128	0.343	43	0.0028	<0.020	0.282
Summer	mg/L	11	0.095	0.033	0.343	15	0.082	<0.002	0.282
Non-Summer	mg/L	14	0.0202	0.0128	0.0411	28	<0.0006	<0.002	0.0072
Color									
All Samples	C.U.	18	23.3	<1	45	43	10.8	<1	50
Summer	C.U.	10	25.5	10	45	15	26	<1	50
Turbidity									
All Samples	NTU	22	0.88	0.04	3.7	41	0.22	0.02	0.90
Summer	NTU	10	1.32	0.04	3.7	15	0.41	0.02	0.90
Cl_2 Residual									
All Samples	mg/L	-----	-----	-----	-----	43	1.58	0.56	2.80
Summer	mg/L	-----	-----	-----	-----	15	1.37	0.56	1.74

Note 1: Summer Samples are from June 1st to September 30th, each year.

In response to customer complaints of colored water, MassDEP has required HWWC to conduct a bi-weekly water quality monitoring program for select sites in the distribution system since August 2018. In August 2020 the raw source water and finished water (POE) were added to that monitoring, and those results are summarized below.

Table 1-3
HWWC Source and Finished Water Quality Monitoring (Aug. 2020 – Nov. 2022)
(data from HWWC's biweekly distribution system water quality monitoring program)

Parameter	Units	Long Pond Source Water				Point-of-Entry Finished Water			
		# Samples	Avg	Min.	Max.	# Samples	Avg	Min.	Max.
Color	c.u.	44	19	< 1	45	64	14	< 1	80
Total Manganese	mg/L	46	0.067	0.013	0.34	67	0.042	<0.020	0.34
Total Iron	mg/L	41	0.074	< 0.050	0.33	66	0.013	<0.050	0.22
Temperature	^{0}C	41	16.0	0.72	28.9	63	14.5	2.0	27.1
pH	s.u.	42	7.6	7.1	8.5	63	7.5	7.2	7.9
Total Dissolved Solids	mg/L	44	118	74	325	64	120	54	436
Alkalinity (as $CaCO_3$)	mg/L	40	85	75	95	44	85	68	95
Turbidity	NTU	42	0.98	0.04	3.7	62	0.32	0.01	3.2
Cl_2 Residual	mg/L	NA	-----	-----	-----	61	1.5	0.56	2.8

1.4 Pilot Study Objectives and Goals

HWWC desires to implement a manganese treatment system to produce water consistently in compliance with the MassDEP Secondary Maximum Contaminant Level (0.05 mg/L), using a target **water quality goal of 0.015 mg/L** for manganese. Prior studies evaluated a range of treatment process alternatives ultimately determining that the GreensandPlus filtration process would likely be the optimum process for the HWWC system, due to specific advantages including: (1) the ability to remove both soluble and particulate manganese, (2) operational flexibility regarding pre-oxidant chemistry, (3) simplicity of operation and (4), the ability to be easily integrated into the existing treatment process. The greensand (Greensand Plus) filtration process would be installed following the existing chlorination system.

To facilitate this objective, HWWC submitted permit application BRP WS 21B to MassDEP to conduct a pilot study using Greensand Plus Filtration on May 20, 2022, subsequently augmented on May 26, 2022 with additional design and operating criteria. MassDEP issued a conditional approval for manganese treatment pilot study on August 1, 2022 (Appendix B). **This conditional approval is based on a pilot plant for Mn treatment only**, with appropriate consideration of simultaneous compliance with the Surface Water Treatment Rule (SWTR), Lead and Copper Rule (LCR) and Disinfection Byproducts Rule (DBPR). The pilot plant must be performed during the summer when manganese is typically experienced in the water supply. However, MassDEP has also required that four (4) discrete, quarterly pilot plant programs be executed.

HWWC and NWSI installed the pilot treatment system in early September (2022) and MassDEP conducted a final inspection on September 9, 2022. NWSI conducted the first quarterly pilot testing program between September 14, 2022 and September 28, 2022.

II. PILOT PLANT DESIGN & INSTALLATION

The greensand filtration pilot plant was installed within the HWWC facility, to accept a side stream of the filtered/chlorinated water discharged to the 1.1 MG water storage standpipe tank, as illustrated in Figure 2-1.

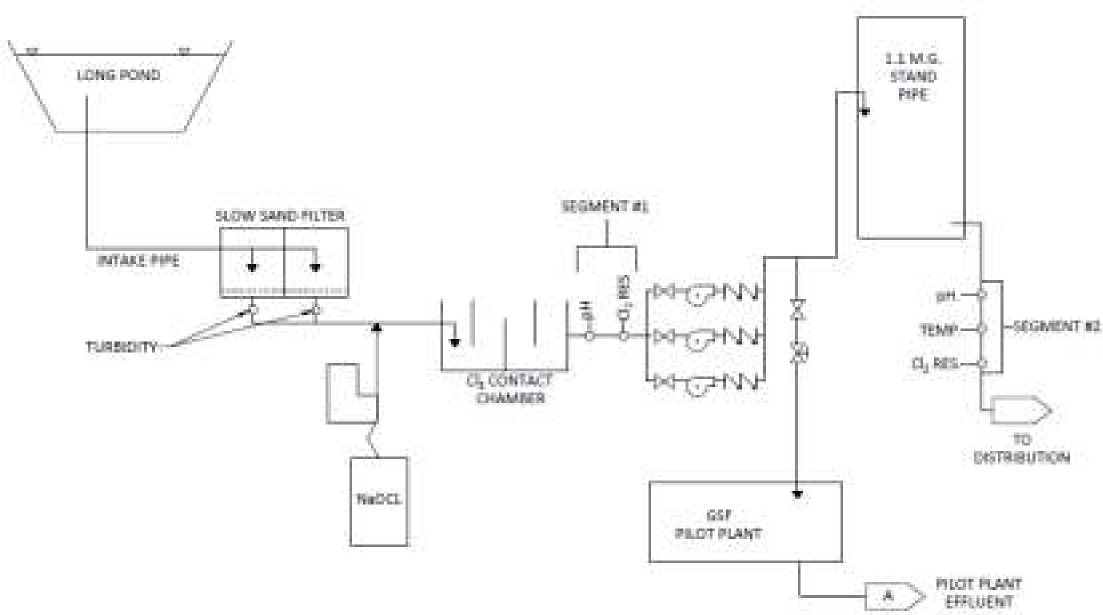


Figure 2-1: Process Flow Diagram

2.1 Pilot Plant Design

The pilot plant system includes three (3) greensand (GS) media filter vessels (10" Ø x 54" Ht.) installed in parallel. The pilot plant is supplied from a single pre-treated water source, with the vessels operating in parallel to assess alternative hydraulic loading and operating conditions.

Each filter vessel provides a discrete treatment, with dedicated, programmable controls, as well as the capability for individual influent and effluent monitoring using dedicated sample taps. The treated effluent produced by the pilot plant system is completely segregated from the HWWC finished water and was discharged to the "lagoon" system via a dedicated pump station.

2.1.1 Design Criteria:

The pilot plant is designed to simulate the operation of the full-scale greensand filtration system, based upon the following critical design and operating criteria:

- Greensand filtration operates optimally when the water pH is in the range of 6.2 to 8.5 S.U. The existing system is provided continuous pH monitoring upstream of the pilot plant. Based upon historic raw and finished water pH monitoring, no pH adjustment of the water is required to facilitate the pilot plant operation. In the absence of iron in the pilot plant feedwater, with the pH typically ≈7.3 S.U., formation of colloidal iron is not a concern.

- Because iron is a non-factor and this application principally involves removal of manganese, the "Continuous Regeneration" mode of operation is used. The greensand filtration system installed downstream from the chlorine contact chamber with the free chlorine residual continuously monitored (Segment #1) to provide an accurate record of the pre-oxidation condition of the influent to the pilot plant system.

- The free chlorine residual remaining after oxidation of the soluble manganese will maintain the filtration media in a continuously regenerated, oxidative condition. The recommended filter effluent chlorine residual is 0.5 to 1.0 mg/L to maintain optimum media oxidative capacity. The greensand filter effluent underwent periodic free chlorine residual monitoring, to assess the chlorine demand through the system and for comparison to the on-line chlorine residual monitoring data.

- The pilot plant greensand filters utilize a dual media configuration including anthracite and greensand, with periodic backwash to flush accumulated particulate iron and manganese from the filter bed, to restore the filter to full service.

- The greensand filters operate under pressure and will directly accept the discharge from the transfer pumps to the water storage standpipe tank.

- The pilot plant includes three (3) greensand filters (10" Ø x 54" Ht.) installed in parallel (Figure 2-2). Each filter vessel is provided a control valve head and will be operated at different flowrate loading to assess a range of hydraulic loading conditions, all within the effective operating range established by the media manufacturer (Inversand).

- Greensand Plus media has a nominal capacity of 700 – 1200 grains per square foot (gr./ft^2) of oxidized iron and manganese. Based upon a filter cross-sectional area of 0.545 ft^2 and an assumed capacity (as manganese) of 1,000 gr./ft^2, each filter has an anticipated gross manganese capacity of 545 grains. Using an assumed maximum manganese concentration of 0.39 mg/L results in a loading rate of 0.0456 grains per gallon of water, and a gross filter bed capacity of 11,952 gallons.

The pilot plant will operate under similar hydraulic and loading conditions, chemical pre treatment and pressure, as the full-scale treatment system, therefore the pilot plant operating data and findings require only scale-up to the full-scale treatment system operation. The specifications for the pilot plant system are summarized in Table 2-1, and the installation is presented in Figure 2-2.

Table 2-1
HWWC Greensand Filter Pilot Plant
Design & Operating Criteria (Updated 09-07-22)

Vessel ID	GSF #1	GSF #2	GSF #3
Process Type	Catalytic Oxidation	Catalytic Oxidation	Catalytic Oxidation
Operating Configuration	Parallel, Continuous	Parallel, Continuous	Parallel, Continuous
Vessel Dimensions	10” ϕ x 54” Ht.	10” ϕ x 54” Ht.	10” ϕ x 54” Ht.
X-Section Surface Area	0.545 ft^2	0.545 ft^2	0.545 ft^2
Design Flowrate per Vessel	2 gpm	3 gpm	4 gpm
Hydraulic Loading	3.7 gpm/ft^2	5.5 gpm/ft^2	7.3 gpm/ft^2
Pre-Oxidation Chemistry	Sodium Hypochlorite	Sodium Hypochlorite	Sodium Hypochlorite
Avg. Oxidant Dosage[1]	0.21 mg/l	0.21 mg/l	0.21 mg/l
Oxidant Feed Control	Flow Proportional	Flow Proportional	Flow Proportional
Minimum Chlorine Residual[1]	0.5 mg/l	0.5 mg/l	0.5 mg/l
Media Configuration:	Dual Bed	Dual Bed	Dual Bed
Anthracite – Bed Depth	15”	15”	15”
Greensand Plus – Bed Depth	24”	24”	24”
Unit Capacity	1,000 $gr./ft^2$	1,000 $gr./ft^2$	1,000 $gr./ft^2$
Filter Bed Capacity	545 gr.	545 gr.	545 gr.
Max. Loading (gr./gal.)	0.0456 gr./gal.	0.0456 gr./gal.	0.0456 gr./gal.
Vessel Capacity	11,952 gallons	11,952 gallons	11,952 gallons
Operating Cycle Duration	99 hours	66 hours	50 hours
Freeboard	15”	15”	15”
Backwash Flowrate	6.5 gpm	6.5 gpm	6.5 gpm

Backwash Hydraulic Loading	12 gpm/ft^2	12 gpm/ft^2	12 gpm/ft^2
Backwash Bed Expansion	40%	40%	40%
Backwash Duration	10 minutes	10 minutes	10 minutes
Backwash Volume	65 gallons	65 gallons	65 gallons
Final Rinse Flowrate	2 gpm	3 gpm	4 gpm
Final Rinse Duration	3 minutes	3 minutes	3 minutes
Final Rinse Volume	6 gallons	9 gallons	12 gallons

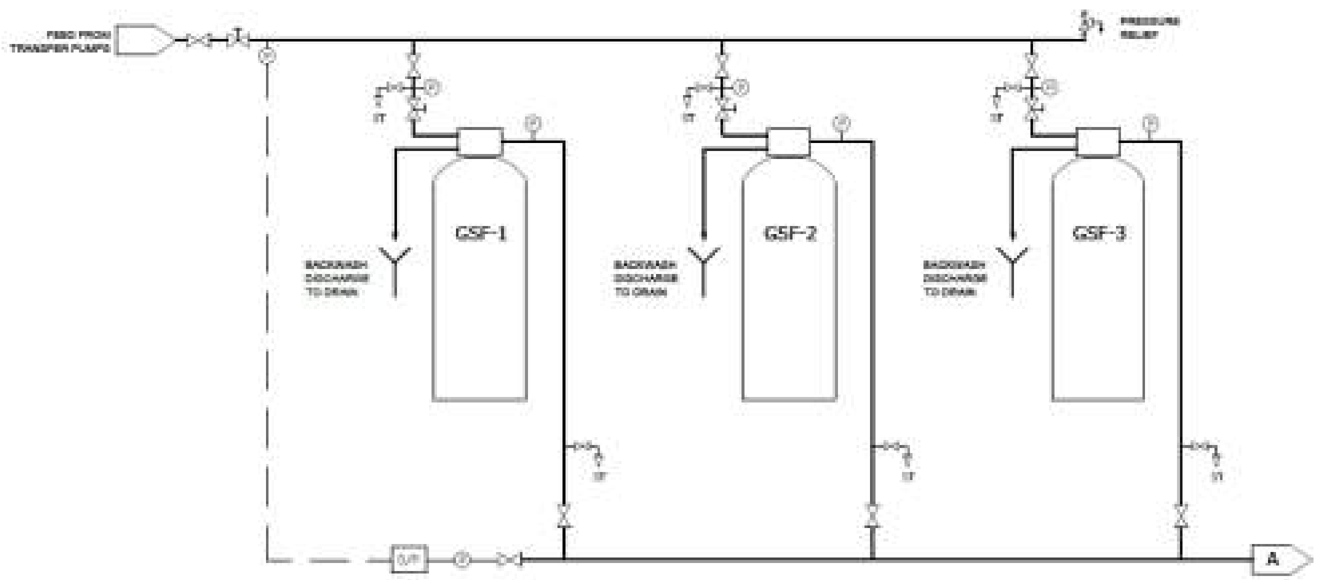


Figure 2-2 Diagram of the Pilot GSF Treatment System

2.1.2 Greensand Plus Filtration Media:

The pilot plant greensand filters utilize a dual media configuration including anthracite (15”) and GreensandPlus™ media (24”) for each vessel. The anthracite and GreensandPlus™ media specifications are presented in Table 2-2.

Table 2-2
Greensand Filter System Media Specification

	Anthracite	**Greensand Plus**
Acid Solubility (AWWA B100-89)	<1%	NA
Caustic Solubility (1% @ 190°F)	<1%	NA
Specific Gravity	1.65	2.40
Effective Size	0.65 to 0.90 mm	0.30 to 0.35 mm
Screen Grading	NA	18 x 60 Mesh

Sphericity (Loose)	0.61	NA
Sphericity (Packed)	0.60	NA
Hardness (Mohs Scale)	3.0 to 3.8	NA
Ignition Point	950°F	NA
Porosity	NA	0.45
Uniformity Coefficient	NA	<1.60
pH Range	NA	6.2 to 8.5
Bed Depth in GSF #1	15"	24"
Bed Depth in GSF #2	15"	24"
Bed Depth in GSF #3	15"	24"

The greensand media manufacturer (Inversand) product specification states the following:

> *"Inversand 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. GreensandPlus™ has a manganese dioxide coating which creates a highly oxidative environment. When a strong oxidant is injected in the raw water stream ahead of a GreensandPlus™ filter, soluble iron and manganese are easily oxidized and the precipitates are trapped by the media (which acts as a catalyst and does not participate in the reaction). The filter is subsequently backwashed and reused, therefore it is not sacrificed in this process."*

Anthracite media is a hard, brittle, and black lustrous coal which has long been a medium-weight filter for sediment reduction, widely used in multi-media depth filtration of both surface and groundwater for removal of suspended solids.

2.2 <u>Pilot Plant Installation</u>

The inlet to the pilot plant system is installed downstream of all treatment process including the slow sand filter, the chlorine contact chamber, and transfer pumps (Figure 2-1). The pilot plant system includes three (3) greensand (GS) media vessels (10" Ø x 54" Ht.) installed in parallel. The pilot plant effluent is discharged to the waste lagoon and not discharged to the water storage standpipe tank or distribution system.

Each Filter Vessel Provided a Dedicated Control Valve Head and OIT. (typical of all 3)

GSF Filter Vessels (left to right) #1, #2 & #3.

Photo 2-1: View of Installed Pilot Plant System

2.2.1 Raw Water Sampling Tap:

Raw water samples are obtained from the existing intake line from Long Pond (Photo 2-2), inside the treatment facility. Raw water samples have been collected and analyzed for pH, Fe/Mn, TOC, DOC and UV254.

Raw Water Sample Tap (supply from Long Pond).

Photo 2-2: View of The Raw Water Sampling Tap

2.2.2 Water Supply Connection (Photo 2-3):

The pilot plant receives pre-treated water from a connection installed downstream of the transfer pump discharge to the 1.1 MG Water Storage Tank. A 1” tap and isolation ball valve and reinforced hose were installed to supply the pilot plant. A 2nd connection into this branch connection was installed to supply filter backwash water to the pilot plant – by having a 2nd, … ilot plant filters could continue to operate while one filter was

1” Isolation ball valve and supply service to Pilot Plant

¾” Isolation ball valve and backwash service to Pilot Plant

Photo 2-3: View of Service and Backwash Water Feed to Pilot Plant

2.2.3 Pilot Plant Control and Monitoring:

Monitoring of the pilot plant operation included a combination of: (1) existing on-line instrumentation (pH, turbidity, chlorine residual, pressure – Figures 2-1, 2-2; Photos 2-4, 2-5, 2-6); (2) filter vessel control head instrumentation (filter flowrate, volume treated, gallons

remaining per cycle, etc.); (3) field analytical instruments (pH, DO, ORP, TDS, Conductivity); (4) field analyses including manganese, chlorine residual, etc.) and (5) laboratory wet chemistry analysis (all water characterization parameters in scope of monitoring).

- The Segment #1 chlorine residual analyzer provides automatic monitoring upstream of the pilot plant;

• The existing turbidity analyzers are installed on the effluent of each slow sand filter bed, providing indication of the performance of the slow sand filters and the influent turbidity to the pilot plant;

• The existing pH monitor provided indication of the influent pH to the pilot plant;

• The schedule of field and laboratory monitoring conducted during the pilot plant is presented in Appendix C.

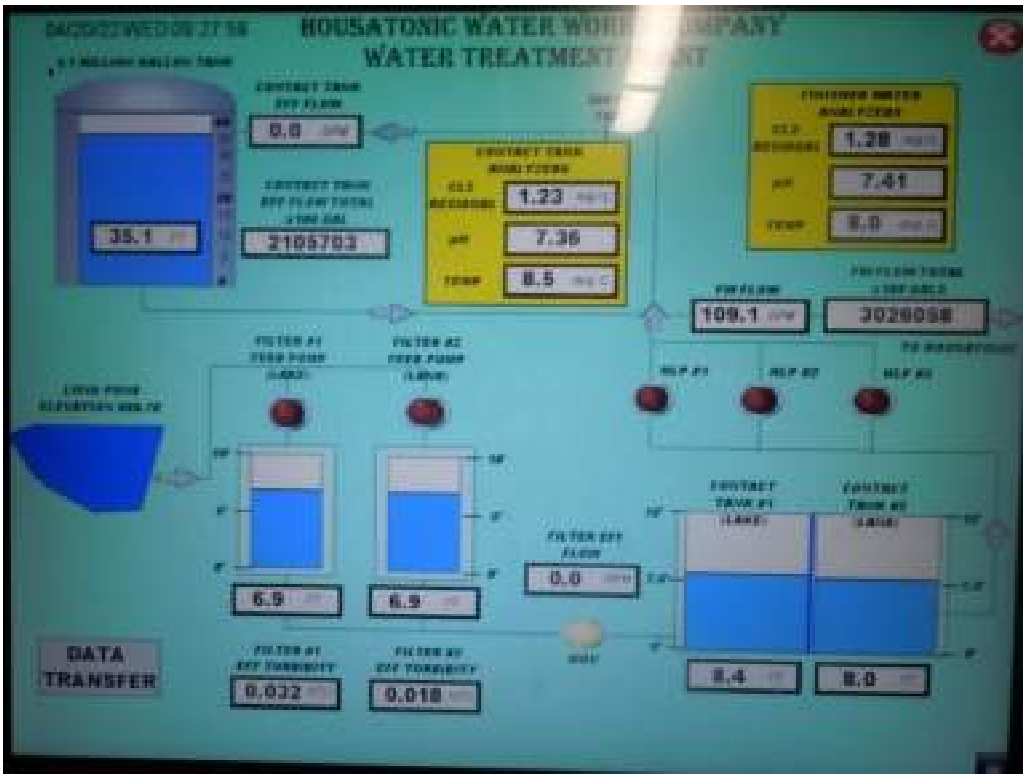


Photo 2-4: HWWC Master On-Line Monitoring System

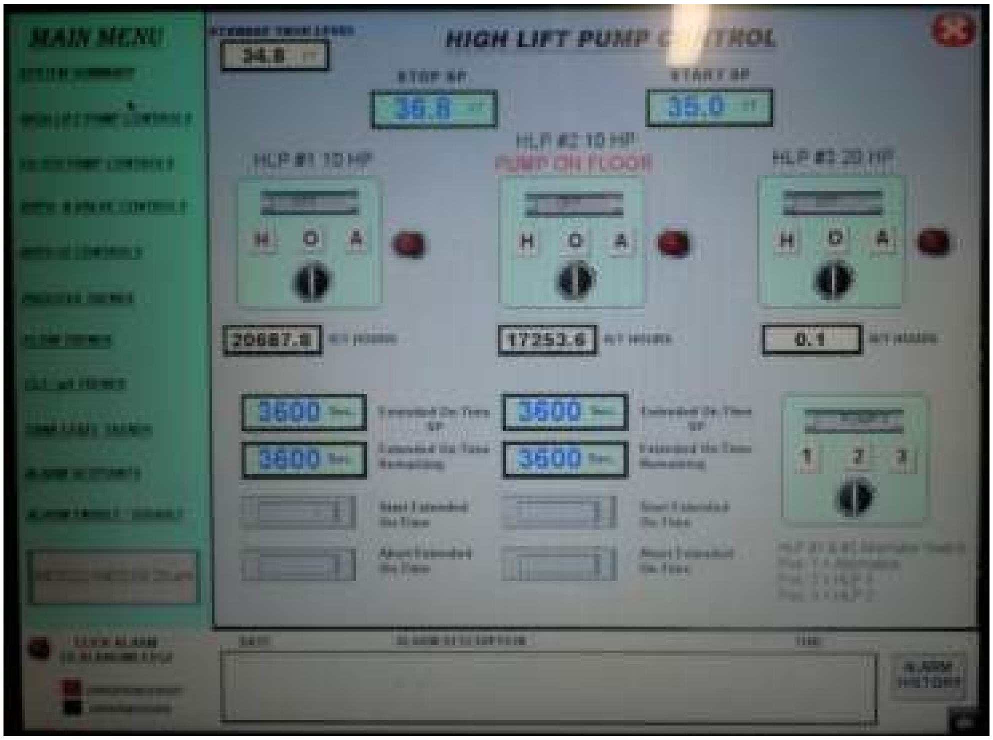


Photo 2-5: HWWC Master On-Line Monitoring System

Photo 2-6: View of On-Line pH & Free Cl Residual Monitoring Analyzer

2.3 <u>Pilot Plant Test and Monitoring Protocols</u>

Following installation of the triplex filter vessels and associated piping, the Greensand Plus media was installed into the vessels in accordance with the specifications and the written protocol provided by the manufacturer (Inversand). The Greensand Plus media were backwashed and preconditioned (sodium hypochlorite) in accordance with the Inversand approved protocol, after which the anthracite media was installed to the specified bed thickness. Each filter vessel then underwent a full backwash and rinse, to prepare the filter vessels for operation.

2.3.1 Pilot Plant Operating Period:

To assess and validate the performance of the Greensand Plus filtration process for this application, the Pilot Plant vessels were each operated through 3 to 5 cycles, using the specified loading condition for each vessel. The Pilot Plant was operated for 250 hours from September 14^{th} to 23^{rd} and September 26^{th} to 28th, 2022. During the pilot plant operation critical operating variables and performance to be assessed includes, but not be limited to, the following:

- Hydraulic Loading;
- Manganese Loading and Removal Efficiency;
- Effective System Capacity – gallons;
- Effective System Capacity – manganese mass load;
- Chlorine Pre-Oxidant Dosage and Oxidation Efficiency;
- Chlorine Pre-Oxidant Dosage and Oxidation Efficiency;
- Backwash Flowrate, Volume, and Manganese Concentration;
- Evaluation of Field Monitoring v Laboratory Monitoring Results (Manganese);

2.3.2 Hydraulic Loading:

The pilot plant supply manifold was provided a master isolation valve and throttling valve, and each filter vessel was provided dedicated inlet/outlet isolation ball valves. The dedicated filter inlet ball valves were used to provide vessel-specific throttling capability for flow control. The feedwater flowrate was monitored at each filter control head, and was manually adjusted, as needed to maintain the specified operating flowrate (2, 3, 4 gpm). Each filter vessel control head water meter provided indication of the water flowrate continuously during operation, and also indication of the gallons of raw water treated on each filter operating cycle. The operating cycle volume for each filter was specified and programmed into the control head. Manual logging of the pilot plant pressure, flowrate, treated water volume and water quality parameters augmented the electronic monitoring and logging to assess the following, for each operating cycle:

- Instantaneous Filter Bed Hydraulic Loading (gpm/ft^2);
- Filter Bed Total Volumetric Loading (gallons/ft^2);
- Filter Bed Mn Mass Load (Grains/ft^2);
- Filter vessel pressure (psig);
- Turbidity leakage vs effluent manganese;

2.3.3 Chlorine Pre-Oxidant Load and Oxidation Efficiency:

The pilot plant influent free chlorine residual was automatically monitored and data logged, providing a continuous data base to assess the pilot plant chlorine demand and performance. Field monitoring of filter influent/effluent free chlorine concentration was used to: (1) validate accuracy vs the calibrated on-line instrumentation, (2) quantify the pre-oxidation chlorine demand and mass load, and (3) quantify the filter effluent chlorine residual and chlorine demand to maintain the media in an oxidized condition.

2.3.4 pH Monitoring – Raw Source Water, Pilot Plant Influent/Effluent:

The historic pre-treated water pH (average 7.5 s.u.) indicates that pH adjustment upstream of the greensand filtration system is not needed. The GSF filter influent iron monitoring consistently demonstrated "non-detectable", indicating no concern regarding formation of colloidal iron that could impact turbidity or finished water quality. Field monitoring of filter influent/effluent pH was used to: (1) validate accuracy vs the calibrated on-line instrumentation, (2) determine if the manganese oxidation and filtration process impacted pH, (3) determine if pH had any limiting impact upon the manganese oxidation process, and (4) validate the finished water pH relative to the historic system operation.

2.3.5 Manganese Loading and Removal Efficiency:

The raw source water and pilot plant influent water underwent manganese (and other parameter) monitoring using both field and laboratory wet chemistry analyses to: (1) assess the baseline source water characterization, and (2) assess the performance of the slow sand filtration system to provide effective pre-filtration of the source water. The monitoring data were accumulated over each operating cycle and be used to assess the total and unit mass load of total manganese and total Mn mass captured in each filter bed. This data is critical to the overall pilot plant performance evaluation and is also used to assess the effective filter cycle time/volume relative to Mn mass loading and chlorine residual. Ultimately, this data will be used to develop baseline performance curves to be incorporated into the system O&M Manual and be used as a diagnostic tool for system operational monitoring.

2.3.6 Backwash Water Flowrate, Volume, and Manganese Concentration:

Upon completion of each operating cycle the filter vessel undergoes a proscribed backwash protocol that is programmed into the filter control head. The backwash flowrate, hydraulic loading rate (gpm/ft^2), duration and volume were monitored. During backwash events the backwash discharge is sampled at 2-minute intervals for analysis. Field testing included turbidity and manganese content and laboratory analyses included TSS, turbidity and total manganese content. The intent of the backwash water monitoring was to assess the repeatability of the system performance and also develop a profile of the backwash water characterization over time. This in turn will be used to develop a baseline curve of volume v [TSS] and volume v [Mn] to assess the effectiveness of the backwashing, and determine if the backwash flowrate and duration is acceptable or must be modified to optimize the system performance. The backwash curves will be incorporated into the system O&M Manual and be used as a diagnostic tool for operational

monitoring, in conjunction with other critical parameters including chlorine residual, manganese concentrations, pH and hydraulic loading.

2.3.7 Evaluation of Field Monitoring v Laboratory Monitoring Results (Manganese):

A comparison of the results of field and laboratory analysis of iron and manganese were conducted to assess the accuracy and correlation of the field test results to laboratory wet chemistry results. This is critical to assess because the field test kits will be used for routine, daily operational monitoring of the full-scale system, augmented by periodic laboratory wet chemistry analysis.

2.3.8 Disinfection-by-Products Evaluation:

The raw source water and pilot plant influent/effluent water underwent periodic analyses for Disinfection By-Products (DBPs), to assess whether the greensand filtration process has any impact upon DBP formation. Samples of pilot plant effluent water were also obtained to conduct an evaluation of water age upon DBP formation using a range of: 0 to 15 days. The raw source water and pilot plant influent water also underwent periodic analyses for Total Organic Carbon (TOC), Dissolved Organic Carbon (DOC) and UV 254.

III. PILOT PLANT DAILY OPERATIONS SUMMARY AND OBSERVATIONS

The greensand filtration pilot plant was activated on September 14, 2022, operating for 250 hours from September 14th to 23rd and September 26th to 28th, 2022. A brief descriptive summary of the operation each day is presented below.

Wednesday September 14, 2022:

The pilot plant operation was initiated at 11:30 A.M.

- The flow rates for each of the three (3) filter vessels was monitored by the control head flow meter and field checked with manual measurements. Filter influent flowrates, measured for each filter unit flowmeter were the following:

    - ➢ GSF #1 – 2.1 gpm (3.85 gpm/ft^2);
    - ➢ GSF #2 – 3.1 gpm (5.7 gpm/ft^2);
    - ➢ GSF #3 – 4.1 gpm (7.5 gpm/ft^2);

- Pilot plant influent/effluent Manganese were field monitored using the Hach DR 900 Analytical Instrument. Influent manganese demonstrated a concentration of 0.22 mg/L, consistent with expectations based upon historic monitoring results. Pilot Plant effluent samples demonstrated non-detectable manganese for all three (3) filters, indicating effective performance at all hydraulic loading rates. (Note: subsequent laboratory analysis of ALL filter effluent samples demonstrated non-detectable (<0.00204 mg/L) manganese.

- Turbidity was monitored using the existing on-line instrumentation, demonstrating average GSF influent turbidity of 0.109 NTU (higher value). This indicates effective operation of the Slow Sand Filtration system to remove suspended material from the water supply.

- The pilot plant influent chlorine residual averaged between 1.5-1.7 mg/L throughout the day, based upon the on-line instrument monitoring, consistent with field tests using field analytical instruments. However, pilot plant effluent chlorine residuals ranged from 0.17-0.79 mg/L indicating a substantial chlorine demand through the greensand filters. This is attributed to the fact the pilot plant was stagnant for six (6) days following loading and initial conditioning of the greensand media. Therefore, the greensand plus media required regeneration to restore full oxidative capacity, which occurred over the course of the initial 24 to 48 hours of operation as the feed of fresh chlorinated water was being introduced to the filter media. The need for media regeneration and the capability of the chlorination process to effectively regenerate the media is demonstrated by the following findings:

  - ➢ The three (3) pilot plant filters attained full oxidative capacity in a sequence of GSF #3, GSF #2 and GSF #1, consistent with their respective hydraulic loading rates of 4 gpm, 3 gpm and 2 gpm.

  - ➢ The influent free chlorine residual was the same for all three (3) filters therefore chlorine mass load to each filter was a function of the hydraulic loading rate and total gallons passing through the filter bed.

  - ➢ The attainment of full media oxidative capacity is demonstrated by the increasing filter effluent chlorine residual and decreasing Δ [Cl_2 res.] across each filter bed, over the initial 48-hour operating period. At full media regeneration the greensand filter effluent demonstrated a free chlorine residual on the order of 1.4 to 1.7 mg/L, and a Δ [Cl_2 residual] across the filter bed of 0.2 to 0.4 mg/L.

- The pre-filtered greensand filter influent demonstrated an average pH of 7.33 S.U. GSFs #1 and #2 demonstrated average effluent pH values of 7.2 S.U. and 7.05 S.U. respectively.

Thursday September 15, 2022:

The pilot plant operated continuously overnight without any problems.

- The flow rates for each of the three (3) filter vessels was monitored by the control head flow meter and field checked with manual measurements. From 8:00 PM the prior evening through 8:00 PM on September 15th the filter influent flowrates, as indicated by the individual filter unit flowmeter were the following:

- ➢ GSF #1 – 2.14 gpm (3.93 gpm/ft^2);
- ➢ GSF #2 – 3.22 gpm (5.91 gpm/ft^2);
- ➢ GSF #3 – 4.03 gpm (7.40 gpm/ft^2);

• Pilot plant influent/effluent Manganese were field monitored using the Hach DR 900 Analytical Instrument. Influent manganese demonstrated a concentration of 0.24 mg/L. Pilot Plant effluent samples demonstrated non-detectable manganese for GSF #1 and #2 and 0.002 mg/L for GSF #3, indicating effective performance at all hydraulic loading rates.

• Turbidity was monitored using the existing on-line instrumentation, demonstrating average GSF influent turbidity of 0.155 NTU, a slight increase from the prior day, but continuing to indicate effective operation of the Slow Sand Filtration system to remove suspended material from the water supply.

• The pilot plant influent free chlorine residual ranged between 1.5-1.7 mg/L The pilot plant effluent chlorine residuals ranged continued to increase as the media regenerated:

- ➢ GSF #1 demonstrated an increase in effluent free chlorine residual to 0.93 mg/L;
- ➢ GSF #2 demonstrated an increase in effluent free chlorine residual to 0.90 mg/L;
- ➢ GSF #3 demonstrated an increase in effluent free chlorine residual to 1.05 mg/L;

By 8:00 PM the chlorine demand through the filters (Δ [Cl_2 res.]) was reduced to 0.7 mg/L indicating the greensand media was approaching full regeneration and optimal conditions for manganese removal.

Friday September 16, 2022:

The pilot plant operated continuously overnight without any problems.

• The flow rates for each of the three (3) filter vessels was monitored by the control head flow meter and field checked with manual measurements. From 8:00 PM the prior evening through 7:15 AM on September 16th the filter influent flowrates, as indicated by the individual filter unit flowmeters were the following:

- ➢ GSF #1 – 2.09 gpm (3.83 gpm/ft^2);
- ➢ GSF #2 – 2.73 gpm (5.01 gpm/ft^2);
- ➢ GSF #3 – 3.97 gpm (7.28 gpm/ft^2);

• GSF #3 initiated a backwash cycle at 9:55 AM. Backwash water samples were obtained at 2:00 minute intervals for laboratory analysis.

• Pilot plant influent/effluent Manganese were field monitored using the Hach DR 900 Analytical Instrument. Influent manganese demonstrated a concentration of 0.029 mg/L (Note: laboratory analysis demonstrated influent Mn = 0.194 mg/L). Pilot Plant effluent samples demonstrated non-detectable manganese for GSF #1. GSF #2 demonstrated effluent manganese of 0.03 mg/L and GSF #3 at 0.018 mg/L. (Note: subsequent laboratory analysis of ALL filter effluent samples demonstrated non-detectable

(<0.00204 mg/L) for manganese).

- Turbidity was monitored using the existing on-line instrumentation, demonstrating average GSF influent turbidity of 0.226 NTU, again an increase from the prior day, but continuing to indicate effective operation of the Slow Sand Filtration system to remove suspended material from the water supply.

- The pilot plant influent free chlorine residual ranged between 1.5-1.8 mg/L All three (3) greensand filter units demonstrated effluent free chlorine residual in the range of 0.69 to 0.93 mg/L.

- The greensand filter influent demonstrated an average pH of 7.32 S.U. The three (3) GSFs demonstrated effluent pH values ranging from 7.15 to 7.2 S.U.

Periodic GSF influent and effluent water samples were taken in white Styrofoam cups to provide a visual indication of performance (see typical photo, below).

Photo 3-1: GSF Influent and Effluent Water Samples
Left: GSF #3 Influent - 9:30 A.M.
Right: GSF #3 Effluent- 9:30 A.M.

<u>Saturday/Sunday, September 17 & 18, 2022</u>:

Greensand filter GSF #2 underwent automated backwash on September 17th and GSF #1 on September 18th. Samples of both backwash events were obtained at 2-minute intervals and submitted for laboratory analysis. Following backwash and rinsing, the filter units were returned to service.

<u>Monday September 19, 2022</u>:

The pilot plant operated continuously through the weekend without any problems.

- Filter Unit Flowrates: From 8:00 AM (September 19, 2022) through 7:15 AM on September 20th the filter influent flowrates, as indicated by the individual filter unit flowmeters were the following:
    - ➢ GSF #1 – 1.98 gpm (3.64 gpm/ft^2);
    - ➢ GSF #2 – 2.90 gpm (5.32 gpm/ft^2);
    - ➢ GSF #3 – 3.89 gpm (7.14 gpm/ft^2);

- GSF #2 initiated a backwash cycle at 3:15 PM. Backwash water samples were obtained at 2:00 minute intervals for laboratory analysis.

- Pilot plant influent/effluent Manganese were <u>field monitored</u> using the Hach DR 900 Analytical Instrument. Influent manganese demonstrated a concentration of 0.301 mg/L. Pilot Plant effluent samples demonstrated non-detectable manganese for GSF #1. GSF #2 demonstrated effluent manganese of 0.004 mg/L and GSF #3 at 0.003 mg/L. (Note: subsequent laboratory analysis of ALL filter effluent samples demonstrated non-detectable (<0.00204 mg/L) for manganese).

    Note: At 7:00 PM the pumping discharge rate was increased by cycling to a larger transfer pump. Field testing demonstrated a significant increase in influent manganese to 0.64 mg/L This "spike" was monitored, and manganese levels did not return to "normal" range for approximately 1-hour. This is believed potentially due to solids scouring in the clearwell.

- Turbidity was monitored using the existing on-line instrumentation, demonstrating average GSF influent turbidity of 0.198 NTU indicating effective operation of the Slow Sand Filtration system to remove suspended material from the water supply.

- The pilot plant influent free chlorine residual ranged between 1.8-2.0 mg/L All three (3) greensand filter units demonstrated effluent free chlorine residual in the range of 1.34 to 1.8 mg/L.

- The pre-filtered greensand filter influent demonstrated an average pH of 7.33 s.u.

<u>Tuesday September 20, 2022</u>:

The pilot plant operated continuously overnight without any problems.

- Filter Unit Flowrate: From 7:15 AM on September 20th through 8:30 AM on September 21st the filter influent flowrates, as indicated by the individual filter unit flowmeters were the following:

  - ➢ GSF #1 – 2.74 gpm (3.83 gpm/ft^2);
  - ➢ GSF #2 – 2.66 gpm (5.01 gpm/ft^2);
  - ➢ GSF #3 – 4.01 gpm (7.36 gpm/ft^2);

- GSF #3 initiated a backwash cycle at 7:40 AM. Backwash water samples were obtained at 2:00 minute intervals for laboratory analysis.

- Pilot plant influent/effluent Manganese were <u>field monitored</u> using the Hach DR 900 Analytical Instrument. Influent manganese demonstrated a concentration of 0.293 mg/L. Pilot Plant effluent manganese monitoring: GSF #1 demonstrated 0.001 mg/L, GSF #2 demonstrated 0.006 mg/L and GSF #3 demonstrated 0.006 mg/L. (Note: subsequent laboratory analysis of ALL filter effluent samples demonstrated non-detectable (<0.00204 mg/L) for manganese).

- Turbidity was monitored using the existing on-line instrumentation, demonstrating average GSF influent turbidity of 0.222 NTU indicating effective operation of the Slow Sand Filtration system to remove suspended material from the water supply.

- The pilot plant influent free chlorine residual ranged between 2.2 to 2.4 mg/L All three (3) greensand filter units demonstrated effluent free chlorine residual in the range of 1.4 to 1.8 mg/L.

- The pre-filtered greensand filter influent demonstrated an average pH of 7.31 S.U. Greensand filter effluent samples demonstrated pH of 7.2 S.U.

Based upon backwash sample observations the determination was made to increase the filter backwash duration time from 12 minutes to 16 minutes.

<u>Wednesday September 21, 2022</u>:

The pilot plant operated continuously overnight without any problems.

- Filter Unit Flowrate: From 8:30 AM on September 21st through 5:30 AM on September 22nd the filter influent flowrates, as indicated by the individual filter unit flowmeters were the following:

  - ➢ GSF #1 – 1.95 gpm (3.58 gpm/ft^2);
  - ➢ GSF #2 – 2.79 gpm (5.12 gpm/ft^2);
  - ➢ GSF #3 – 3.67 gpm (6.73 gpm/ft^2);

- Pilot plant influent/effluent Manganese were <u>field monitored</u> using the Hach DR 900 Analytical Instrument. Influent manganese demonstrated a concentration of 0.291 mg/L. Pilot Plant effluent manganese monitoring: GSF #1 demonstrated 0.005 mg/L, GSF #2 demonstrated 0.012 mg/L and GSF #3 demonstrated 0.001 mg/L. (Note: subsequent laboratory analysis of ALL filter effluent samples demonstrated non-detectable (<0.00204 mg/L) for manganese). (Note: Raw Long Pond source water was field monitored, demonstrating manganese at 0.032 mg/L)

- Turbidity was monitored using the existing on-line instrumentation, demonstrating average GSF influent turbidity of 0.275 NTU indicating effective operation of the Slow Sand Filtration system to remove suspended material from the water supply.

- The pilot plant influent free chlorine residual ranged between 2.2 to 2.6 mg/L All three (3) greensand filter units demonstrated effluent free chlorine residual in the range of 1.55 to 1.74 mg/L.

- The pre-filtered greensand filter influent demonstrated an average pH of 7.34 S.U. Greensand filter effluent samples demonstrated pH of 7.17 S.U.

<u>Thursday September 22, 2022</u>:

The pilot plant operated continuously overnight without any problems.

- Filter Unit Flowrate: From 5:30 AM through 8:00 PM on September 22nd the filter influent flowrates, as indicated by the individual filter unit flowmeters were the following:

  - GSF #1 – 1.95 gpm (3.58 gpm/ft^2);
  - GSF #2 – 2.79 gpm (5.12 gpm/ft^2);
  - GSF #3 – 3.67 gpm (6.73 gpm/ft^2);

- Pilot plant influent/effluent Manganese were <u>field monitored</u> using the Hach DR 900 Analytical Instrument. Influent manganese demonstrated a concentration of 0.454 mg/L, with a maximum sample exceeding 0.8 mg/L. Pilot Plant effluent manganese monitoring: GSF #1 demonstrated 0.0126 mg/L, GSF #2 demonstrated 0.008 mg/L and GSF #3 demonstrated 0.019 mg/L. (Note: subsequent laboratory analysis of ALL filter effluent samples demonstrated non-detectable (<0.00204 mg/L) for manganese).

  Note: Another large increase of filter influent manganese was observed at ≈5:00 P.M., exceeding the detectable level of the field instrument (>0.8 mg/L). Effluent manganese levels were closely monitored for a 2-hour period, with GSF #3 producing the highest effluent manganese at 0.015. GSF #1 and #2 effluent manganese remained <0.01 mg/L.

- Turbidity was monitored using the existing on-line instrumentation, demonstrating average GSF influent turbidity of 0.261 NTU indicating effective operation of the Slow Sand Filtration system to remove suspended material from the water supply.

- The pilot plant influent free chlorine residual ranged between 1.49 to 1.93 mg/L All three (3) greensand filter units demonstrated effluent free chlorine residual in the range of 1.15 to 1.79 mg/L.

- The pre-filtered greensand filter influent demonstrated an average pH of 7.29 S.U.

Based upon backwash sample observations the determination was made to increase the filter backwash duration time from 16 minutes to 20 minutes.

Friday September 23, 2022:

Overnight the HWWC plant's chlorine feed pump malfunctioned and upon arrival at the water treatment facility (6:15 A.M) the GSF influent (Disinfection Segment #1) chlorine residual was 0.2 mg/L, and the GSF effluent demonstrated <0.1 mg/L free chlorine residual. The decision was made to temporarily suspend the pilot filter runs and activate backwash of all 3 greensand filters. The full pilot plant operation was restored over the weekend, including regeneration of the greensand media. Note: the chlorination pump was replaced that morning and there was no adverse impact regarding primary disinfection compliance (4-log chlorination) of the water discharged to

the distribution POE, evidenced by a review of the on-line free chlorine (Segment #2) monitoring data.

Monday September 26, 2022:

Following the temporary suspension of testing on September 23rd, the pilot plant filters were backwashed and placed back into service at 10:00 AM. Flowrates for all three (3) filters was confirmed and the pilot plant operated continuously from that point, without any problems.

- Filter Unit Flowrate: From 10:00 AM on September 26th through 8:00 AM on September 27th the filter influent flowrates, as indicated by the individual filter unit flowmeters were the following:

  - GSF #1 – 2.08 gpm (3.81 gpm/ft^2);
  - GSF #2 – 3.17 gpm (5.81 gpm/ft^2);
  - GSF #3 – 4.14 gpm (7.60 gpm/ft^2);

- Pilot plant influent/effluent Manganese were field monitored using the Hach DR 900 Analytical Instrument. Influent manganese demonstrated a concentration of 0.21 mg/L. Pilot Plant effluent manganese monitoring: GSF #1 demonstrated 0.0126 mg/L, GSF #2 demonstrated 0.008 mg/L and GSF #3 demonstrated 0.019 mg/L. (Note: subsequent laboratory analysis of filter effluent samples demonstrated GSF#1 and GSF#2 effluent at non-detectable (<0.00204 mg/L) for manganese, and GSF#3 at 0.00207 mg/L total manganese.)

- Turbidity was monitored using the existing on-line instrumentation, demonstrating average GSF influent turbidity of 0.230 NTU indicating effective operation of the Slow Sand Filtration system to remove suspended material from the water supply.

- The pilot plant influent chlorine residual ranged between 2.4 to 2.5 mg/L All three (3) greensand filter units demonstrated effluent free chlorine residual in the range of 1.9 to 2.2 mg/L. The chlorine demand through the greensand filters is ≈0.5 mg/L, indicating the filter media has been fully regenerated.

- The pre-filtered greensand filter influent demonstrated an average pH of 7.36 S.U.

Tuesday September 27, 2022:

The pilot plant operated continuously overnight without any problems.

- Filter Unit Flowrate: From 8:00 AM on September 27th through 7:30 AM on September 28th the filter influent flowrates, as indicated by the individual filter unit flowmeters were the following:

  - ➢ GSF #1 – 1.97 gpm (3.62 gpm/ft^2);
  - ➢ GSF #2 – 3.09 gpm (5.67 gpm/ft^2);

  - ➢ GSF #3 – 3.97 gpm (7.28 gpm/ft^2);

- Pilot plant influent/effluent Manganese were field monitored using the Hach DR 900 Analytical Instrument. Influent manganese demonstrated a concentration of 0.148 mg/L. Pilot Plant effluent manganese monitoring: GSF #1 demonstrated 0.003 mg/L, GSF #2 demonstrated 0.01 mg/L and GSF #3 demonstrated 0.005 mg/L. (Note: subsequent laboratory analysis of ALL filter effluent samples demonstrated non-detectable (<0.00204 mg/L) for total manganese).

- Turbidity was monitored using the existing on-line instrumentation, demonstrating average GSF influent turbidity of 0.238 NTU indicating effective operation of the Slow Sand Filtration system to remove suspended material from the water supply.

- The pilot plant influent free chlorine residual ranged between 2.2 to 2.6 mg/L All three (3) greensand filter units demonstrated effluent free chlorine residual in the range of 1.6 to 2.14 mg/L.

- The pre-filtered greensand filter influent demonstrated an average pH of 7.38 s.u.

Wednesday September 28, 2022:

The pilot plant operated continuously overnight without any problems. Final operational readings were obtained at 7:30 AM. A final round of water samples was obtained for laboratory analysis. Additional water samples were obtained for the disinfection by-products evaluations. Each greensand filter unit underwent a final backwash cycle, including sampling at 2-minute intervals, after which the pilot plant was shut down and taken off-line.

IV. PILOT PLANT RESULTS AND EVALUATION

The Greensand Filter (GSF) pilot plant was operated for 250 hours from September 14th to 23rd and September 26th to 28th, 2022. The test program was temporarily suspended on September 23rd due to a malfunction of the treatment plant's chlorine feed pump. The chlorine pump was replaced that morning, and there was no adverse impact regarding primary disinfection compliance (4-log chlorination) of the water discharged to the distribution POE, evidenced by a review of the on-line free chlorine (Segment #2) monitoring data. Critical operating variables monitored during the pilot plant operation include, but not be limited to, the following:

• Raw Source Water & Greensand Filter Influent Water Characterization; • Hydraulic Loading;
• Manganese Loading and Removal Efficiency;
• Evaluation of Field Monitoring (Mn) v Laboratory Monitoring Results; • Effective System Capacity – gallons;
• Effective System Capacity – manganese mass load;
• Chlorine Pre-Oxidant Dosage;
• Backwash Flowrate, Volume, and Manganese Concentration;
• Disinfection By-Products Formation

Pilot plant operating/performance and backwash data are presented in Appendix F including tabular and graphic outputs of hydraulic loading; manganese removal efficiency, mass loading and maximum load capacity; effluent quality; optimum effluent chlorine residual; pH; backwash loading and efficiency, DBP evaluation, etc.

4.1 Raw Source Water & Greensand Filter Influent Water Characterization

4.1.1 Raw Source Water Characterization:

Table 4-1 present the result of weekly pH, TOC, DOC and UV254 analyses of the raw source water during the Q1 pilot study period.

Table 4-1
Raw Water Analytical Results

Sampling Date	9/15/2022	9/21/2022	9/28/2022
pH, S.U.	-----	7.93	7.93
UV254 (absorbance) /cm	-----	0.087	0.077
TOC, mg/L	3.43	3.56	3.30
DOC, mg/L	3.51	3.51	3.44
DOC % of TOC	102.3%	98.6%	104.2%

- The raw water pH was 7.93 S.U., slightly higher than historic monitoring (Tables 1-3, 1- 4) indicting an annual average pH of 7.5 S.U., although within the range of 7.1 to 8.5 S.U.

- Total organic carbon (TOC) demonstrated a range of 3.30 to 3.56 mg/L compared to dissolved organic carbon (DOC) of 3.44 to 3.51 mg/L, indicating virtually all of the organic

carbon in the raw water is in the dissolved form. Historic monitoring data (Table 4-2) indicates the source water TOC content is consistent with prior monitoring.

Table 4-2
Raw & Finished Water TOC Monitoring

Sample Date	Long Pond (raw water) (mg/L TOC)	Finished Water (POE) (mg/L TOC)	% decrease
10/08/20	4.24	-----	-----
10/13/20	3.06	-----	-----
10/19/20	2.88	-----	-----
10/26/20	2.94	-----	-----
09/07/21	3.80	1.72	55%
09/20/21	3.74	1.68	55%
02/09/22	3.34	2.22	34%

- The raw source water demonstrated UV254 (absorbance/cm) values of 0.077 and 0.087 in the two (2) samples obtained. UV254 is an indication of the concentration of organic matter containing aromatic rings or unsaturated bonds in their molecular structures. Naturally occurring organic compounds such as Humic acids/materials are aromatic and exist in high concentrations in surface water and are known to be a common and potentially significant precursor of DBP formation. UV254 values in the Long Pond source water appear to be within a "typical" range. A study by the MWRA found UV254 of 0.03 to 0.1 - so the order of magnitude is consistent with surface waters in general.

  The SUVA value (UV/DOC in L/mg-m) is ≈2.3 for the raw water. Elevated SUVA (≥ 4) indicates more hydrophobic, aromatic, high molecular weight organic matter, which is more easily removed by coagulation. Low SUVA (≤ 3) indicates more non-humic, hydrophilic, and low molecular weight with coagulation typically removing <30%. Therefore, this water is considered to be "low SUVA".

- Manganese (avg. 0.039 mg/L) demonstrated a range of 0.02 to 0.09 mg/L, consistent with historic monitoring (0.0128 to 0.343 mg/L). A single laboratory analysis determined dissolved manganese of 0.00837 mg/L, compared to total manganese of 0.0451 mg/L, indicating <20% of the source water manganese in that sample was in the dissolved form.

Table 4-3
Raw Water Iron and Manganese (mg/L)

	Fe (T)	Mn (T)	Mn (D)
9/14/2022	0.03**	0.092**	
9/15/2022	<0.05*	0.0451*	0.00837*
9/20/2022		0.037**	
9/21/2022		0.032**	
9/22/2022		0.021**	
9/26/2022		0.02**	
9/27/2022		0.024**	

Note: *lab analytical results, ** field testing results

- Iron was monitored by a combination of field and laboratory analyses, determined to be essentially non-detectible.

4.1.2 Greensand Filter Influent Water Characterization:

Table 4-4 presents a summary of the three (3) rounds of comprehensive laboratory analysis of the greensand filter influent (post filtration & Segment #1 chlorination). Review comments include the following:

- pH: The GSF influent water is similar to the raw water, demonstrating a pH range of 7.53 to 7.95 S.U. also consistent with the historic finished water range of 7.2 to 7.9 S.U.

- Turbidity: The GSF influent water demonstrates somewhat elevated turbidity with values of 0.83 to 1.72 NTU. This level of turbidity is higher than is presented by the on-line instrumentation for the slow sand filter effluent that demonstrates an order of magnitude lower turbidity. This discrepancy is believed due to oxidation and precipitation of soluble manganese in the water, and potentially to differences in the analytical methodology used for field vs laboratory analysis.

- Color: The GSF influent water demonstrates apparent color on the order of 30 to 60 C.U., somewhat higher than historic monitoring demonstrating an annual range of <1 to 50 C.U. and a summer season range of 10 to 45 C.U. The finished water is lower, demonstrating an annual average apparent color of 10.8 C.U. with a range of <1 to 50 C.U. During the summer season the apparent color increases significantly to an average of 26 C.U., with a range of <1 to 50 C.U.

- Total & Dissolved Organic Carbon: The GSF influent water demonstrated TOC of 1.51 to 1.72 mg/L, and DOC of 1.52 to 1.88 mg/L. Allowing for analytical method variability these results indicate: (1) consistency with historic analyses of the "finished" water (Table 4-2), (2) the TOC is virtually 100% in the dissolved form, (3) the HWWC continues to achieve ≈50% reduction of TOC across the treatment system (Table 4-5) and (4) there may be a correlation to reduction of UV254 across the system.

Table 4-5
Raw Water & GSF Influent TOC, DOC & UV154

Sampling Date	**9/15/2022**	**9/21/2022**	**9/28/2022**
Source Water TOC, mg/L	3.43	3.56	3.30
GSF Influent TOC, mg/L	1.72	1.70	1.51
% Reduction Through Treatment Plant	49.8%	52.2%	54.2%
Source Water DOC, mg/L	3.51	3.51	3.44
GSF Influent DOC, mg/L	1.88	1.59	1.52
% Reduction Through Treatment Plant	46.43%	54.7%	55.8%
Source Water UV254 (absorbance/cm)	-----	0.087	0.077
GSF Influent UV254 (absorbance/cm)	0.028	0.032	0.029
% Reduction Through Treatment Plant	-----	63.2%	62.3%

- UV254: The GSF influent water demonstrated very low UV254 values, significantly reduced following treatment via slow sand filtration and chlorination. The SUVA value (UV/DOC in L/mg-m) is ≈1.7 for the pre-treated water (Slow Sand Filter + chlorination) compared to 2.3 for the raw water.

- Total Dissolved Solids (TDS) and Specific Conductance: The GSF influent water contains moderately low TDS, demonstrating 133 to 153 mg/L consistent with the historic source water TDS range of 74 to 162 mg/L and a finished water range of 54 to 168 mg/L. The TDS principally consists of alkalinity (≈90 mg/L, as $CaCO_3$), calcium (≈23 mg/L) and chloride (≈12 – 16 mg/L), with lesser quantities of magnesium (≈9 mg/L), sodium 10 mg/L), potassium (<1 mg/L) and manganese (0.075 to 0.255 mg/L). All other inorganic constituents are non-detectable or at trace concentrations in the water. The GSF influent water demonstrates consistent specific conductance of 225 – 233 umhos/cm, closely correlating with TDS with a conductivity-to-TDS ratio of 1.52 to 1.74.

- Alkalinity: Alkalinity is consistently present at ≈ 90 mg/L (as $CaCO_3$). Based upon the pH of 7.5 to 7.95 S.U., the alkalinity is ≈99% in the bicarbonate (HCO_3) form and represents 95% to 97% of the total inorganic carbon in the water, with the balance present as carbonic acid (H_2CO_3) or carbon dioxide (CO_2).

- Total Iron: The GSF influent water demonstrates non-detectable (<0.050 mg/L) total iron compared to the raw source water demonstrating an annual average concentration of 0.074 mg/L and a range of <0.050 to 0.333 mg/L. The results indicate that iron in the source water is naturally oxidized to the particulate form and is being removed in the slow sand filtration system.

- Total & Dissolved Manganese: The GSF influent water samples demonstrate elevated total manganese of 0.203 mg/L, 0.255 mg/L and 0.075 mg/L. The manganese concentration is consistent with or higher than the historic summer season monitoring demonstrating an average of 0.095 mg/l, with a range of 0.033 to 0.343 mg/l. However, as noted in Table 4-3, over the duration of the pilot plant the source water demonstrated an average manganese concentration of 0.039 mg/L and a range of 0.02 to 0.09 mg/L.

Table 4-6
GSF Influent Manganese (mg/L)

	Mn (T)	Mn (D)	% Dissolved
9/15/2022	0.203	0.0974	48%
9/21/2022	0.255	0.020	8%
9/28/2022	0.075	0.00813	11%

The GSF influent water demonstrates dissolved manganese at concentrations of 0.020 to 0.0974 mg/L, indicating the majority of the manganese in the influent stream is in the particulate form. However, as evidenced by the September 15, 2022 sample, a significant portion can be present as soluble manganese, at levels exceeding the USEPA SMCL.

Table 4-4
Greensand Filter Influent Water Characterization
(mg/L, unless noted)

Sample Date/Parameter	09/15/22	09/21/22	09/28/22
Temperature – Field (°C)	21.3 – 21.7	20.7 – 20.9	17.8
pH – Laboratory (s.u.)	7.75	7.53	7.95
pH – Field Analysis (s.u.)	7.3 – 7.32	7.3 – 7.34	7.4
Dissolved Oxygen - Field	4.87 – 5.80	N/A	N/A
Carbon Dioxide	10	8.00	8.00
Turbidity (NTU)	1.22	1.72	0.83
Apparent Color (C.U.)	50	60	30

True Color (C.U.)	0	0	0
UV 254 (absorbance/cm)	0.028	0.032	0.029
Total Organic Carbon	1.72	1.70	1.51
Dissolved Organic Carbon	1.88	1.59	1.52
Total Suspended Solids	<2.50	<2.78	<3.13
Total Dissolved Solids	139	153	133
Conductivity (umhos/cm)	225	233	231
Free Chlorine Residual – Field	1.64 – 1.75	2.41 – 2.49	3.0
Alkalinity (as $CaCO_3$)	90	92.5	90
Chloride	12.6	14.7	16.0
Sulfate	<0.500	<5.0	<5.0
Nitrate – N	0.0852	0.0988	0.107
Nitrite-N	<0.0100	<0.0100	<0.0100
Aluminum	<0.051	<0.01	<0.01
Arsenic	<0.0040	<0.0040	<0.0400
Beryllium	<0.0010	<0.0010	<0.0010
Cadmium	<0.0010	<0.0010	<0.0010
Calcium	23.4	23.2	22.3
Chromium	<0.0010	<0.0010	<0.0010
Copper	0.0103	0.0144	0.0146
Iron	<0.050	<0.050	<0.050
Lead	<0.0010	<0.0010	<0.0010
Magnesium	9.67	9.27	9.14
Manganese (T)	0.203	0.255	0.075
Manganese (D)	0.0974	0.020	0.00813
Mercury	<0.00020	<0.00020	<0.00020
Potassium	0.559	0.601	0.595
Sodium	9.38	10.3	10.1
Zinc	0.0253	0.0230	0.0184
Total Hardness (as $CaCO_3$)	98.1	96.0	93.2
Corrosion/Scale Indices:			
Langelier Saturation Index (50°F)	-0.87	-1.08	-0.69
Larson Skold Index	0.20	0.22	0.25

CSMR	<25	<2.94	<3.2
Alkalinity-to-Chloride Ratio	7.14	6.29	5.63

- Copper, Lead and Zinc: Copper (0.0103 mg/L to 0.0146 mg/L) and zinc (0.0184 mg/L to 0.0253 mg/L) were present at trace concentrations in the GSF influent. Lead was non detectable (<0.0010 mg/L) in all samples. The copper and zinc are believed to be sourced from wetted materials of construction in the treatment facility.

- Total Hardness: The GSF influent demonstrated moderately elevated total hardness (93 to 98 mg/L, as $CaCO_3$), which is comprised of calcium (55.8 to 58.5 mg/L, as $CaCO_3$) and magnesium (37.5 to 39.6 mg/L, as $CaCO_3$).

Over the duration of the pilot plant the raw source water and the greensand filter influent demonstrated a very consistent baseline characterization for all parameters.

4.2 Hydraulic Loading

The manganese removal pilot plant consists of three (3), 10” diameter, greensand filters, each loaded with a dual bed consisting of anthracite (15” bed depth) and greensand plus (GS+) media (24” bed depth). The filter vessels are installed and operate concurrently, in parallel, accepting a side stream of the pre-filtered, chlorinated water (chlorine contact basin effluent) produced by the HWWC water treatment facility. The three filters are supplied water from a common manifold pipe, with each filter provided with isolation and throttling valves. The valves are positioned to operate the filters at different nominal flowrates of 2 gpm, 3 gpm and 4 gpm, to allow an assessment of the impact of different hydraulic loading rates upon performance.

Table 4-7 presents a summary of the operating cycles including, backwash events. Within the 250-hour operating duration of the pilot plant GSF #1 (2 gpm) had three (3) operating cycles while GSF #2 (3 gpm) and GSF #3 (4 gpm) each had five (5) operating cycles. The operating cycle for each filter was initially programmed at 11,400 gallons however, the cycle duration was adjusted based upon observations and to assess performance for different operating duration.

- The operating cycle for each vessel was initially programmed for 11,400 gallons, equivalent to a volumetric loading of 20,917 gallons/ft^2. (Filter bed cross-section area is 0.545 ft^2). During the pilot plant the filter operating cycle volume was adjusted, based upon observations and analysis of the filter backwash water (TSS attenuation over time), to assess if shorter operating cycle duration/volume or longer backwash duration could enhance treated water quality or backwash efficiency.

- The backwash duration for each vessel was initially programmed for 12 minutes duration, at a flowrate of 6.5 gpm. This backwash flowrate is equivalent to an upflow loading rate of 12 gpm/ft^2.that is necessary to achieve a 40% bed fluidization for optimum solids flushing. Following the initial backwash cycle(s) for each filter unit, the backwash duration was extended, to as much as 22 minutes, based upon observation and testing of spent backwash water, to obtain additional data and information.

Table 4-8 presents a summary of the pilot plant operation from the operating logs. Figures 4-1 and 4-2 present a graphic illustration of the hydraulic loading rates for each filter unit. The individual filter vessels demonstrated the following:

• GSF#1 demonstrated hydraulic loading of 1.9 to 2.1 gpm, averaging 2.0 gpm; •

GSF#2 demonstrated hydraulic loading of 2.9 to 3.3 gpm, averaging 2.9 gpm;

• GSF#3 demonstrated hydraulic loading of 3.1 to 4.2 gpm, averaging 3.9 gpm.

Over the duration of the pilot plant program each filter unit was able to sustain operating flowrates and hydraulic loading in very close proximity to the target values. Operating cycle loading on the order of 10,000 to 11,000 gal./ft^2resulted in consistent performance, from the standpoint of sustaining pressure drop and hydraulic throughput across the filters, regardless of the hydraulic loading rates.

Table 4-7 Greensand Filter Operation and Backwash Summary									
Filter ID	**Filter Operating Cycle**			**Filter Bed Operation/Cycle**			**Filter Backwash**		
	Start Date	**End Date**	**Cycle Duration**	**Treated Volume**	**Volumetric Loading;**	**Avg. Hyd. Load**	**BW Initiation**	**Duration**	**Flowr**
			(hours)	(gallons)	(gallons/ft^2)	(gpm)		(minutes)	(gpr
GSF #1	9/14/2022	9/18/2022	95	11,400	20,917	2.0	7:02 AM	12 min.	6.5 g
	9/18/2022	9/22/2022	95	11,400	20,917	2.0	6:36 AM	20 min.	6.5 g

	9/22/2022	9/26/2022	Note 1	9,000	-----	-----	Note 1	-----	6.5 g
	9/26/2022	9/28/2022	48	5,750	10,550	2.0	9:30 AM	22 min.	6.5 g
GSF #2	9/14/2022	9/17/2022	63	11,400	20,917	3.0	11:50 PM	12 min.	6.5 g
	9/17/2022	9/19/2022	62	11,300	20,917	3.0	15:15 PM	12 min.	6.5 g
	9/19/2022	9/22/2022	63	11,340	20,826	3.0	6:06 AM	20 min.	6.5 g
	9/22/2022	9/27/2022	32	5,900	10,826	3.1	5:33 PM	22 min.	6.5 g
	9/28/2022	9/28/2022	17	3,100	5,688	3.0	10:02 AM	22 min.	6.5 g
GSF #3	9/14/2022	9/16/2022	46.5	11,400	20,917	4.1	9:55 AM	12 min.	6.5 g
	9/16/2022	9/20/2022	47	11,400	20,917	4.0	7:40 AM	16 min.	6.5 g
	9/20/2022	9/22/2022	47	11,350	20,826	4.0	7:09 AM	20 min.	6.5 g
	9/26/2022	9/27/2022	24	5,800	10,642	4.0	10:07 AM	22 min.	6.5 g
	9/27/2022	9/28/2022	24	5,800	10,642	4.0	10:33 AM	22 min.	6.5 g

Note 1: The pilot plant operation was suspended from 9/23/22 to 9/26/22 (10:00 AM) after short-term failure of the HWWC chlorine feed pump to allow for the pilot plant to return to full operational status and chlorine residual re-established to fully regenerate greensand media. The filters were backwashed on September 26th prior to return to service.

Table 4-8
GSF Operating Flowrate and Hydraulic Loading Rate – From Operator Log

Date/Time	GSF #1		GSF #2		GSF #3	
	Influent Flowrate	Hydraulic Loading	Influent Flowrate	Hydraulic Loading	Influent Flowrate	Hydraulic Loading
	(gpm)	(gpm/ft^2)	(gpm)	(gpm/ft^2)	(gpm)	(gpm/ft^2)
9/14/2022 11:30	2.1	3.9	3.1	5.7	4.0	7.3
9/14/2022 12:05	2.1	3.9	3.1	5.7	4.1	7.5
9/14/2022 12:34	2.1	3.9	3.1	5.7	4.1	7.5
9/14/2022 13:30	2.1	3.9	3.1	5.7	4.1	7.5

9/14/2022 16:00	2.1	3.9	3.1	5.7	4.1	7.5
9/14/2022 20:00	2.1	3.9	3.1	5.7	4.0	7.3
9/15/2022 07:15	2.0	3.7	3.0	5.5	3.9	7.2
9/15/2022 15:00	2.0	3.7	2.9	5.3	3.8	7.0
9/15/2022 20:00	2.0	3.7	2.9	5.3	4.1	7.5
9/16/2022 07:15	2.0	3.7	3.0	5.5	4.1	7.5
9/16/2022 09:00	2.0	3.7	2.9	5.3	3.8	7.0
9/19/2022 08:00	2.1	3.9	2.6	4.8	3.8	7.0
9/19/2022 14:00	2.0	3.7	2.9	5.3	3.9	7.2
9/19/2022 18:00	2.1	3.9	3.1	5.7	4.2	7.7
9/19/2022 19:00	2.1	3.9	-----	-----	-----	-----
9/20/2022 07:15	1.9	3.5	3.2	5.9	4.1	7.5
9/20/2022 14:00	2.1	3.9	3.2	5.9	3.2	5.9
9/20/2022 19:00	2.0	3.7	3.1	5.7	3.1	5.7
9/21/2022 08:30	2.2	4.0	2.9	5.3	3.9	7.2
9/21/2022 15:30	2.1	3.9	2.8	5.1	3.7	6.8
9/21/2022 17:00	2.1	3.9	3.0	5.5	3.8	7.0
9/22/2022 05:30	2.1	3.9	3.0	5.5	3.2	5.9
9/22/2022 09:00	2.2	4.0	2.2	-----	-----	-----
9/22/2022 14:00	1.9	3.5	3.0	5.5	3.8	7.0
9/22/2022 17:00	2.0	3.7	3.0	5.5	3.8	7.0
9/22/2022 20:00	1.9	3.5	2.9	5.3	3.7	6.8
9/23/2022 06:30	1.9	3.5	1.9	3.5		
9/26/2022 08:30	2.0	3.7	-----	-----	-----	-----
9/26/2022 10:00	2.0	3.7	2.9	5.3	4.1	7.5
9/26/2022 12:00	2.1	3.9	3.0	5.5	3.8	7.0
9/26/2022 19:20	1.9	3.5	2.9	5.3	4.0	7.3
9/27/2022 08:00	2.0	3.7	3.0	5.5	4.0	7.3
9/27/2022 10:30	2.2	4.0	3.3	6.1		
9/27/2022 13:30	2.1	3.9	2.8	5.1	4.1	7.5
9/27/2022 16:30	2.0	3.7	2.9	5.3	4.0	7.3
9/27/2022 17:15	1.9	3.5	2.9	5.3	4.0	7.3
9/28/2022 07:30	1.9	3.5	3.0	5.5	4.0	7.3
9/28/2022 10:00	-----	-----	-----	-----	4.0	7.3
Average	**2.0**	**3.8**	**2.9**	**5.4**	**3.9**	**7.1**

Figure 4-1 GSF Operation Flowrate, gpm

4.5
4
3.5
3
2.5
2
1.5
1
0.5
0

Note: 2 overlapping data points: GSF #1 & #2

GSF #1
GSF #2
GSF #3

Date Time

1.0
0.0

Figure 4-2 GSF Operation Hydraulic Loading Rate, gpm/ft²

9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0

Note: 2 overlapping data points: GSF #1 & #2

GSF #1
GSF #2
GSF #3

4.3 <u>Pilot Plant Performance Evaluation - Manganese Removal</u>

During the pilot plant operation influent and effluent water samples were obtained to assess the performance of the greensand filter units regarding removal of manganese, using a combination of real-time field testing (Hach DR900) and laboratory wet chemistry analysis.

4.3.1 <u>Laboratory Analytical Monitoring</u>:

A summary of the laboratory analyses is presented in Table 4-9 and Figure 4-3. Over the duration of the pilot plant influent, total manganese averaged 0.192 mg/L, with a range of 0.075 to 0.306 mg/L. Dissolved manganese demonstrated an average concentration 0.041 mg/L, with a range of non-detectible (<0.00204 mg/L) to 0.12 mg/L. On average, dissolved manganese represented 24.4% of the influent total manganese, with a highly variable range of 0% to 57.7% dissolved. A review of the monitoring data results in the following findings:

- The raw source water average total manganese concentration was 0.039 mg/L (0.02 – 0.092 mg/L). However, the total manganese concentration in GSF influent (i.e. finished water from the chlorine contact chamber) averaged 0.192 mg/L (range = 0.075 – 0.306 mg/L), significantly (≈5X) higher than the raw source water.

- Each of the individual greensand filter units demonstrated consistently effective manganese removal over the duration of the pilot testing. Over eleven (11) monitoring days, each filter unit demonstrated consistent compliance with the effluent performance criteria (Total Manganese ≤0.015 mg/L), with the following notations:

  - <u>Greensand Filter #1 (GSF #1)</u>: Effluent total and dissolved manganese was consistently non-detectable (<0.00204 mg/L) for all samples, excepting a single total manganese result (0.00357 mg/L) on September 18, 2022. The single sample with detectable manganese occurred in the latter stage of the initial filter operating cycle, <u>immediately prior</u> to initiating a backwash cycle;

  - <u>Greensand Filter #2 (GSF #2)</u>: Effluent total and dissolved manganese was consistently non-detectable (<0.00204 mg/L) for all samples, excepting a total manganese result (0.0054 mg/L) on September 14, 2022. This sample was obtained during the 1st day of operation, when this greensand filter was still undergoing restoration of its' catalytic oxidative capacity (see below);

  - <u>Greensand Filter #3 (GSF #3)</u>: Effluent total and dissolved manganese was consistently non-detectable (<0.00204 mg/L) for all samples, excepting:

    ➢ a single dissolved manganese result (0.00207 mg/L) on September 26, 2022, barely exceeding the detection limit (<0.00204 mg/L);

➢ a single total manganese sample (0.00273 mg/L) on September 27, 2022 when the filter was at the end of its operating cycle;

- In all cases the trace effluent manganese detected was more than an order of magnitude below the target water quality goal of 0.015 mg/L. (Table 4-9, Figure 4-3).

- Under all hydraulic loading conditions, the greensand filters demonstrated the ability to consistently oxidize and remove the dissolved manganese in the influent water

Table 4-9
Pilot Plant Manganese Concentrations – Laboratory Analysis

Date	GSF Influent Manganese			GSF Effluent Manganese		
				GSF #1	GSF #2	GSF #3
	(T) or (D)	mg/L	% Dissolved	mg/L	mg/L	mg/L
9/14/2022	(T)	0.208	57.7%	<0.00204	0.0054	<0.00204
	(D)	0.12		<0.00204	<0.00204	<0.00204
9/15/2022	(T)	0.203	48.0%	N/A	N/A	N/A
	(D)	0.0974		N/A	N/A	N/A
9/16/2022	(T)	0.194	26.7%	<0.00204	<0.00204	<0.00204
	(D)	0.0518		<0.00204	<0.00204	<0.00204
9/17/2022	(T)	0.19	N/A	<0.00204	<0.00204	<0.00204
9/18/2022	(T)	0.306	N/A	0.00357	<0.00204	<0.00204
9/19/2022	(T)	0.225	0.0%	<0.00204	<0.00204	<0.00204
	(D)	<0.00204		<0.00204	<0.00204	<0.00204
9/20/2022	(T)	0.233	<1%	<0.00204	<0.00204	<0.00204
	(D)	0.00211		<0.00204	<0.00204	<0.00204
9/21/2022	(T)	0.255	7.8%	<0.00204	<0.00204	<0.00204
	(D)	0.02		<0.00204	<0.00204	<0.00204
9/22/2022	(T)	0.213	15.6%	<0.00204	<0.00204	<0.00204
	(D)	0.0333		<0.00204	<0.00204	<0.00204
9/26/2022	(T)	0.101	28.3%	<0.00204	<0.00204	<0.00204
	(D)	0.0286		<0.00204	<0.00204	0.00207
9/27/2022	(T)	0.099	48.2%	<0.00204	<0.00204	0.00273
	(D)	0.0477		<0.00204	<0.00204	<0.00204

9/28/2022	(T)	0.075	10.8% <u><0.00204</u> <0.00204	<0.00204	<0.00204
	(D)	0.00813		<0.00204	<0.00204
Avg Total Mn		0.192	24.4% <u><0.00218</u>	<0.00235	<0.00210
% Total Mn Removed			<u>>98.9%</u>	>98.9%	>98.9%
Avg. Dissolved Mn		0.041	<u><0.00204</u>	<0.00204	<0.00204
% Dissolved Mn Removed			100%	100%	100%

The greensand filter unit manganese load was calculated as grains per square foot (gr./ft^2), summarized in Table 4-10 below. The manganese bed unit load was in the range of 25 to 301 grains/ft^2 which is lower that the assumed theoretical unit load capacity of 1,000 grains/ft^2. However, each filter demonstrated sustained effluent quality (total manganese <0.00204 mg/L) indicating longer operating cycles may be possible.

Figure 4-3: GSF Influent and Effluent Manganese Laboratory Analysis

0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0

SMCL = 0.05 mg/L

Target = 0.015 mg/L

Date

GSF Influent - Lab GSF #1 Effluent - Lab

GSF #2 Effluent- Lab GSF #3 Effluent - Lab

Table 4-10
GSF Bed Unit Load Calculations for Manganese

Filter ID	Filter Operating Cycle		Treated Volume	Influent T. Mn	Total Mn Load to Filter		
	Start	End	(gallons)	(mg/L)	(mg/cycle)	(gr./cycle)	(gr./ft^2)
GSF #1	9/14/2022	9/18/2022	11,400	0.22	9,501	147	269
	9/18/2022	9/22/2022	11,400	0.25	10,632	164	301
	9/22/2022	9/26/2022	9000	-----	-----	-----	-----
	9/26/2022	9/28/2022	5,750	0.09	1,995	31	57
GSF #2	9/14/2022	9/17/2022	11,400	0.20	8,576	133	243
	9/17/2022	9/19/2022	11,300	0.24	10,279	159	291
	9/19/2022	9/22/2022	11,340	0.24	10,316	159	292
	9/27/2022	9/28/2022	5,900	0.09	1,943	30	55
	9/28/2022	9/28/2022	3,100	0.08	880	14	25
GSF #3	9/14/2022	9/16/2022	11,400	0.20	8,702	134	247
	9/16/2022	9/20/2022	11,400	0.23	9,907	153	281
	9/20/2022	9/22/2022	11,350	0.23	10,038	155	285
	9/22/2022	9/27/2022	5,800	-----	-----	-----	-----
	9/27/2022	9/28/2022	5,800	0.09	1,910	30	54

- The pilot plant demonstrated effective performance to remove both particulate and dissolved manganese at all hydraulic loading rates tested.

4.3.2 Field Analytical Monitoring:

Field monitoring of influent and effluent total manganese (and other parameters) was performed to provide a real-time assessment of the pilot plant operation. A summary compilation of the total manganese field monitoring data is presented in Table 4-11 and Figure 4-4.

- The influent total manganese concentration averaged 0.289 mg/L with a range of 0.029 mg/L to >0.8 mg/L

Table 4-11
GSF Field Monitoring – Total Manganese[1]

Date	Time	GSF Influent Mn (mg/L)	GSF #1		GSF #2		GSF #3	
			Mn – GSF Effluent (mg/L)	**Removal Efficiency (%)**	**Mn – GSF Effluent (mg/L)**	**Removal Efficiency (%)**	**Mn – GSF Effluent (mg/L)**	**Removal Efficiency (%)**
9/14/2022	12:30 PM	0.220	0.00	100%	0.00	100%	0.00	100%
9/15/2022	7:15 AM	0.290	0.00	100%	0.004	99%	0.00	100%
9/15/2022	3:00 PM	0.210	0.00	100%	0.00	100%	0.002	99%
9/15/2022	8:00 PM	0.220	0.00	100%	-----	-----	-----	-----
9/16/2022	9:00 AM	0.029	0.00	100%	0.03	0%	0.018	38%
9/19/2022	8:00 AM	0.319	0.00	100%	0.00	100%	0.00	100%
9/19/2022	2:00 PM	0.285	0.00	100%	0.012	96%	0.011	96%
9/19/2022	6:00 PM	0.301	0.00	100%	0.00	100%	0.00	100%
9/19/2022	7:00 PM	0.64[2]	0.00	100%	-----	-----	-----	-----
9/20/2022	7:15 AM	0.294	0.00	100%	0.00	100%	0.014	95%
9/20/2022	2:00 PM	0.307	0.014	95%	0.012	96%	0.001	100%
9/20/2022	7:00 PM	0.271	0.016	94%	0.005	98%	0.002	99%
9/21/2022	8:30 AM	0.301	0.00	100%	0.012	96%	0.00	100%
9/21/2022	3:30 PM	0.299	0.011	96%	0.014	95%	0.005	98%
9/21/2022	5:00 PM	0.280	0.005	98%	0.01	96%	0.00	100%
9/22/2022	5:30 AM	0.770	0.024	97%	0.033	96%	0.074	90%
9/22/2022	9:00 AM	0.228	0.00	100%	0.00	100%	0.00	100%
9/22/2022	2:00 PM	0.300	0.002	99%	0.00	100%	0.001	100%
9/22/2022	5:00 PM	>0.8	0.007	99%	0.004	100%	0.015	98%
9/22/2022	8:00 PM	0.170	0.03	82%	0.004	98%	0.004	98%
9/23/2022	6:30 AM	0.260	0.007	97%	0.013	95%	0.008	97%
9/26/2022	8:30 AM	0.171	0.00	100%	-----	-----	-----	-----
9/26/2022	10:00 AM	0.171	0.01	94%	0.006	96%	0.006	96%
9/26/2022	12:00 PM	0.200	0.01	95%	0.007	97%	0.008	96%
9/26/2022	7:20 PM	0.298	0.018	94%	0.006	98%	0.014	95%
9/27/2022	1:30 PM	0.118	0.003	97%	0.011	91%	0.006	95%
9/27/2022	4:30 PM	0.209	0.003	99%	0.008	96%	0.005	98%
9/27/2022	5:15 PM	0.117	0.004	97%	0.011	91%	0.005	96%
Average		**0.289**	**0.005**	**98.3%**	**0.008**	**97.2%**	**0.008**	**97.2%**

Note 1: In many cases the GSF effluent field monitoring demonstrated positive manganese concentrations that were "false positive" compared to the laboratory analyses. This discrepancy is discussed in Section 4.3.3, below. Note 2: This spike of 0.64 mg/L in Mn coincides with HWWC plant switching to the larger water transfer pump. The increased Mn levels was observed for 1 hour after the increase in the pumping flowrate.

- The three (3) greensand filter units demonstrated consistently effective manganese removal:

  - ➢ GSF #1 demonstrated an average 98.3% removal with an average effluent total manganese concentration of 0.005 mg/l and a range of non-detectable to 0.0124 mg/L.

  - ➢ GSF #2 demonstrated an average 97.2% removal with an average effluent total manganese concentration of 0.008 mg/l and a range of non-detectable to 0.033 mg/L.

  - ➢ GSF #3 demonstrated an average 97.2% removal with an average effluent total manganese concentration of 0.008 mg/l and a range of non-detectable to 0.074 mg/L.

- All three (3) greensand filter units experienced comparatively elevated effluent total manganese concentration on the morning of September 22, 2022 when samples were taken at 5:30 AM. This sampling event occurred immediately prior to each filter completing its operating cycle at 6:36 AM (GAF#2), 6:36 AM (GSF#1) and 7:09 AM (GAF#3). Following post-backwash return to service, all three filter units demonstrated effective operation and non-detectable effluent total manganese.

Figure 4-4: GSF Influent and Effluent Manganese Laboratory & Field Testing

0.9

0.8

0.7

0.6 0.5

0.4 0.3

0.2 0.1 0

Date

GSF Influent - Lab GSF #1 Effluent - Lab GSF #2 Effluent- Lab GSF #3 Effluent - Lab GSF #1 Effluent-Field Monitoring GSF #2 Effluent - Field Monitoring GSF #3 Effluent - Field Monitoring GSF Influent- Field Monitoring

0.05

SMCL = 0.05
0.04

Figure 4-5:
GSF Effluent Mn vs. Hydraulic Loading Rate - Field Testing Data

mg/L
0.03

0.08

0.02

0.01

GSF #1

0

0.07

3.0 4.0 5.0 6.0 7.0 8.0
Hydraulic Loading Rate, gpm/ft2

GSF #2

0.06

GSF #3

Mn Removal Efficiency vs. Hydraulic Loading Rate - Field Testing Data 1.2

1

Figure 4-6:

0.8

0.6

0.4

0.2

0

3.0 4.0 5.0 6.0 7.0 8.0 Hydraulic Loading Rate, gpm/ft2

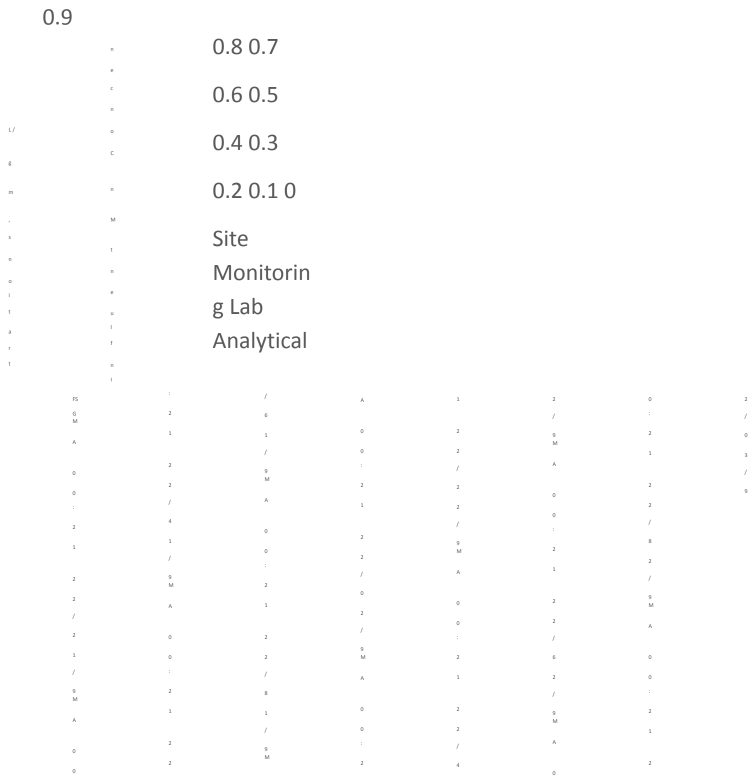
GSF #1 GSF #2 GSF #3

4.3.3 Comparison of Field and Laboratory Total Manganese Analysis:

Field monitoring demonstrated consistently higher Mn concentration values compared to the laboratory analytical results for both greensand filter influent and effluent monitoring. However, as presented in Figures 4-7 to 4-10, the magnitude of variability was much greater in the greensand filter effluent monitoring where manganese concentrations were extremely low or non-detectable.

- At the higher **influent** manganese concentration (typically 0.1 to 0.3 mg/L) the detection accuracy of the Hach DR 900 instrument used for field testing more closely approximates the accuracy of the laboratory wet chemistry methodology (Figure 4-7).

Figure 4-7: Comparation of GSF Influent Total Mn Field Testing Results vs. Lab Analytical Results



- The **<u>laboratory</u>** analysis of greensand filter **effluent** samples demonstrated detectable manganese in only 4 of 60 samples (0.00207 to 0.0054 mg/L), with all other samples non detectable (<0.00204 mg/L). At this vastly lower concentration regime the <u>field monitoring</u> indicated 27 of 78 samples to be non-detectable, with the balance ranging from 0.001 to 0.074 mg/L. The filter hydraulic loading, impacting turbidity, may be a factor, based upon the following:

  ➢ GSF#1 (≈2 gpm = 3.7 gpm/ft^2) demonstrated 13 of 28 samples as non-detectable, with 15 samples detecting a range of 0.002 to 0.03 mg/L.

  ➢ GSF#2 (≈3 gpm = 5.5 gpm/ft^2) demonstrated 7 of 25 samples as non-detectable, with 18 samples detecting a range of 0.004 to 0.033 mg/L.

  ➢ GSF#3 (≈4 gpm = 7.3 gpm/ft^2) demonstrated 7 of 25 samples as non-detectable, with 18 samples detecting a range of 0.001 to 0.074 mg/L.

Figure 4-8: GSF #1 Manganese Effluent Field Testing vs Lab Analytical Results

Field Testing Lab Analytical

0.035 0.03 0.025 0.02 0.015

Target = 0.015 mg/L

0.01 0.005 0

Date Time

Field Testing

Lab Analytical

0.035 0.03 0.025 0.02 0.015

0.01 0.005 0

Figure 4-9: GSF #2 Manganese Effluent Field Testing vs Lab Analytical Results

Target = 0.015 mg/L

Date Time

Figure 4-10: GSF #3 Manganese Effluent Field Testing vs Lab Analytical Results

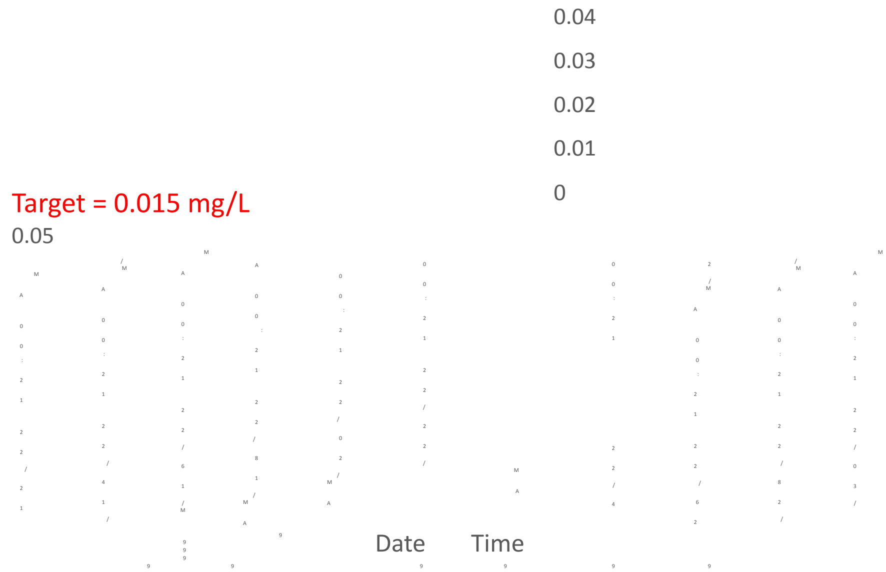
0.08

Field Testing

0.07

Lab Analytical

0.06



4.4 Pilot Plant Performance Evaluation – Turbidity, TSS and Iron

4.4.1 Turbidity:

The raw source water turbidity was monitored weekly, demonstrating turbidity values of 1.51 to 1.72 NTU. The downstream GSF influent was monitored each day demonstrating values of 0.83 to 2.77 NTU.

Table 4-12: Turbidity Monitoring – Laboratory Analysis (NTU)

Date	Raw Source Water Turbidity	GSF Influent Turbidity	GSF Effluent Turbidity		
			GSF #1	GSF #2	GSF #3
9/14/2022	-----	-----	<0.100	<0.100	<0.100
9/15/2022	1.72	1.22	-----	-----	-----
9/16/2022	-----	1.50	<0.100	<0.100	<0.100
9/19/2022	-----	2.09	0.160	0.130	0.270
9/20/2022	-----	2.77	0.240	0.130	0.100
9/21/2022	1.70	1.72/, 2.15	<0.100	<0.100	<0.100
9/22/2022	-----	1.52	<0.100	<0.100	0.170
9/26/2022	-----	1.18	<0.100	<0.100	<0.100
9/27/2022	-----	0.830	0.100	0.100	0.100
9/28/2022	1.51	0.83	0.160	0.210	0.140

The HWWC facility includes on-line monitoring of the slow sand filter effluent turbidity, presenting a dedicated monitoring output for each of the two (2) sand filters. Table 4-13 presents a summary of the on-line turbidity monitoring results.

**Table 4-13:
On-Line and Laboratory Turbidity Monitoring Results (NTU)**

Date	Source Water (Lab)	On-Line Turbidity Monitoring[1]		GSF Influent (Lab)	GSF Effluent Turbidity (Lab)		
		SSF #1	SSF #2		GSF #1	GSF #2	GSF #3
9/14/2022	-----	0.125	0.028	-----	<0.100	<0.100	<0.100
9/15/2022	1.72	0.156	0.028	1.22	-----	-----	-----
9/16/2022	-----	0.219	0.028	1.50	<0.100	<0.100	<0.100
9/19/2022	-----	0.198	0.029	2.09	0.160	0.130	0.270
9/20/2022	-----	0.222	0.030	2.77	0.240	0.130	0.100
9/21/2022	1.70	0.275	0.035	1.72/, 2.15	<0.100	<0.100	<0.100
9/22/2022	-----	0.261	0.041	1.52	<0.100	<0.100	0.170
9/26/2022	-----	0.229	0.026	1.18	<0.100	<0.100	<0.100
9/27/2022	-----	0.238	0.027	0.830	0.100	0.100	0.100
9/28/2022	1.51	0.238	0.024	0.83	0.160	0.210	0.140

Note 1: Average turbidity (NTU) over operating day.

Reviewing the on-line turbidity monitoring data results in the following findings:

- Based upon the results for SSF #1, the slow sand filtration system demonstrates a consistently effective filtration performance, reducing the turbidity by an order of magnitude. This would be consistent with the reduction of iron across the slow sand filter system.

- Comparing the results for SSF#1 to the GSF Influent Turbidity determined by laboratory wet chemistry analysis indicates an order of magnitude discrepancy. This discrepancy is attributed to the different analytical methodology used for field vs laboratory instrumentation.

Over the duration of the pilot plant, the GSF effluent turbidity was consistently excellent with 14 of 27 analyses demonstrating non-detectable (<0.100 NTU) and all GSF filter effluent turbidity values being significantly below the USEPA/MassDEP MCL (1.0 NTU). The following should be noted regarding the GSF effluent turbidity results:

- September 19, 2022: GSF #3 demonstrated the highest effluent turbidity (0.270 NTU) identified during the pilot plant program. This is believed due to the sample being taken shortly prior to the end of this filter operating cycle, which occurred early on the following day (September 20, 2022);

- September 28, 2022: All three (3) GSF filters demonstrated slightly elevated turbidity (0.140 to 0.210 NTU), However, GSF #1 (0.160 NTU) and GSF #3 (0.140 NTU) were at the end of their respective, shortened, operating cycles, immediately prior to backwash being initiated.

Figures 4-11 to 4-14 present a comparison of effluent turbidity and manganese concentration determining there is no identifiable correlation

Figure 4-11: GSF #1 Effluent Mn vs. Turbidity Laboratory Analysis

1
0.9 0.8 0.7 0.6
0.5 0.4 0.3 0.2
0.1 0

0.3
0.25 0.2
0.15 0.1
0.05 0

Date

Mn Total
Turbidity

Figure 4-12: GSF #2 Effluent Mn vs. Turbidity Laboratory Analysis

1
0.9 0.8 0.7 0.6
0.5 0.4
0.3
0.2
0.1
0

0.25 0.2
0.15 0.1
0.05 0

Date

Mn Total Turbidity

Figure 4-13: GSF #3 Effluent Mn vs. Turbidity Laboratory Analysis

0.0025 0.002
0.0015
0.001
0.0005
0

0.3
0.25 0.2
0.15 0.1
0.05 0

Date

Mn Total Turbidity

Figure 4-14: Composite GSF #1, #2, & #3 Effluent Mn vs. Turbidity

0.3 0.05 0
0.0025 0.002 0.0015
0.25 0.2
0.001 0.0005 0
0.15 0.1

Laboratory Analysis

Date

GSF#1 Mn GSF#2 Mn GSF #3 Mn GSF #1 Turbidity GSF #2 Turbidity GSF #3 Turbidity

4.4.2 Total Suspended Solids:

Total Suspended Solids (TSS) were monitored throughout the pilot plant program. Summarized in Table 4-14, in all cases the GSF Influent TSS was non-detectable, due to the slow sand filtration pre treatment, and in all cases the GSF effluent demonstrated non-detectible TSS.

Table 4-14
TSS Monitoring – Lab Analytical (mg/L)

Date	TSS - GSF Influent	Greensand Filter Effluent TSS		
		GSF #1	GSF #2	GSF #3
9/14/2022	<2.50	<2.50	<2.50	<2.50
9/15/2022	<2.50	-----	-----	-----
9/16/2022	<2.78	<2.78	<3.13	<2.78
9/19/2022	<2.78	<16.7	<2.78	<2.78
9/20/2022	<3.13	<2.78	<3.13	<2.78
9/21/2022	<2.78	<2.78	<2.78	<2.78
9/22/2022	<3.13	<3.13	<3.58	<3.13
9/26/2022	<2.78	<3.13	<3.13	<3.13

9/27/2022	<3.13	<3.13	<2.78	<3.13
9/28/2022	<3.13	<2.78	<3.13	<3.13

4.4.3 Iron:

Summarized in Table 4-15, the total iron concentration was monitored in the greensand filtration system influent and effluent over the duration of the pilot plant, demonstrating non-detectable (<0.0500 mg/L) in all samples.

Table 4-15
Total Iron Concentration in GSF Influent and Effluent
Laboratory Analysis (mg/L)

Date	GSF Influent	Greensand Filter Effluent		
		GSF #1	GSF #2	GSF #3
9/14/2022	<0.0500	<0.0500	<0.0500	<0.0500
9/15/2022	<0.0500	-----	-----	-----
9/16/2022	<0.0500	<0.0500	<0.0500	<0.0500
9/17/2022	<0.0500	<0.0500	<0.0500	<0.0500
9/18/2022	<0.0500	<0.0500	<0.0500	<0.0500
9/19/2022	<0.0500	<0.0500	<0.0500	<0.0500
9/20/2022	<0.0500	<0.0500	<0.0500	<0.0500
9/21/2022	<0.0500	<0.0500	<0.0500	<0.0500
9/22/2022	<0.0500	<0.0500	<0.0500	<0.0500
9/26/2022	<0.0500	<0.0500	<0.0500	<0.0500
9/27/2022	<0.0500	<0.0500	<0.0500	<0.0500
9/28/2022	<0.0500	<0.0500	<0.0500	<0.0500

4.5 Chlorine Pre-Oxidant Dosage

The free chlorine residual in the greensand filter influent is continuously monitored by the on-line instrumentation (Segment 1 – chlorine contact chamber effluent), augmented by periodic field monitoring by the pilot plant operator. The differential between the GSF influent and effluent chlorine residual was calculated as the total filter chlorine demand (Tables 4-16 to 4-18, Figures 4-15 to 4-18). In addition to soluble manganese, chlorine demand can include oxidizable organics and other materials in the feedwater and the demand to maintain the catalytic oxidation of the greensand media. A review of the monitoring data and the resultant chlorine consumption, summarized in Table 4-19 results in the following findings:

- Upon initiation of the pilot plant operation the three (3) filter units demonstrated elevated chlorine demand, due to the need to fully regenerate the filter media and attain maximum oxidative capacity. The oxidative capacity status of each filter is demonstrated by the effluent free chlorine residual, which increases as the filter media regenerates.

- When the greensand media was fully regenerated, the filters all demonstrated a similar chlorine unit demand (Figure 4-18 & Table 4-19) with GSF #1 and GSF#2 at 2.04 mg/gallon and GSF #3 at 1.97 mg/gallon.

GSF #1 Chlorine Demand

Table 4-16

Date/Time	**Treated Volume GSF #1**	**Chlorine Residual GSF #1 Chlorine**		
		Influent	**Effluent**	**Demand**
	(gallons)	(mg/L)	(mg/L)	(mg/L)
9/14/22 11:30 PM	-----	1.6	-----	-----
9/14/22 12:05 PM	86	1.55	0.17	1.38
9/14/22 12:34 PM	61	1.51	0.21	1.3
9:14/22 1:30 PM	138	1.61	0.26	1.35
9/14/22 4:00 PM	250	1.65	0.3	1.35
9/14/22 8:00 PM	538	1.81	0.45	1.36
9/15/22 7:15 AM	1586	1.68	0.53	1.15
9/15/22 3:00 PM	927	1.75	0.45	1.3
9/15/22 8:00 PM	569	1.64	0.93	0.71
9/16/22 7:15 AM	1409	1.75	0.78	0.97
9/16/22 9:00 AM	193	1.7	0.86	0.84
9/19/22 8:00 AM	-----	2.03	1.67	0.36
9/19/22 2:00 PM	739	1.9	1.56	0.34
9/19/22 6:00 PM	509	1.8	1.43	0.37
9/19/22 7:00 PM	-----	-----	-----	0
9/20/22 7:15 AM	1576	2.32	1.53	0.79
9/20/22 2:00 PM	571	2.23	1.6	0.63
9/20/22 7:00 PM	791	2.43	1.48	0.95

9/21/22 8:30 AM	1268	2.41	1.59	0.82
9/21/22 3:30 PM	931	2.49	1.68	0.81
9/21/22 5:00 PM	247	2.45	1.66	0.79
9/22/22 5:30 AM	1284	1.49	1.15	0.34
9/22/22 9:00 AM	-----	1.6	1.39	0.21
9/22/22 2:00 PM	682	1.76	1.29	0.47
9/22/22 5:00 PM	425	1.93	1.58	0.35
9/22/22 8:00 PM	344	1.92	1.62	0.3
9/23/22 6:30 AM	1213	0.2	0.1	0.1
9/26/22 8:30 AM	-----	2.52	-----	2.52
9/26/22 10:00 AM	3022	2.5	2.05	0.45
9/26/22 12:00 PM	229	2.53	1.86	0.67
9/26/22 7:20 PM	950	2.43	2.18	0.25
9/27/22 8:00 AM	1560	2.53	2.14	0.39
9/27/22 10:30 AM	281	2.41	1.88	0.53
9/27/22 1:30 PM	367	2.40	1.5	0.9
9/27/22 4:30 PM	346	2.43	1.8	0.63
9/27/22 5:15 PM	78	2.50	1.75	0.75
9/28/22 7:30 AM	1710	3	2.43	
9/28/22 10:00 AM	-----	-----	-----	-----

GSF #2 Chlorine Demand

Table 4-17

Date/Time	**Treated Volume GSF #2**	**Chlorine Residual GSF #2 Chlorine**		
		Influent	**Effluent**	**Demand**
	(gallons)	(mg/L)	(mg/L)	(mg/L)
9/14/22 11:30 PM	-----	1.6	-----	-----
9/14/22 12:05 PM	173	1.55	0.11	1.44
9/14/22 12:34 PM	89	1.54	0.16	1.38

9:14/22 1:30 PM	144	1.61	0.2	1.41
9/14/22 4:00 PM	432	-----	-----	-----
9/14/22 8:00 PM	784	-----	-----	-----
9/15/22 7:15 AM	2390	-----	-----	-----
9/15/22 3:00 PM	1217	1.75	0.69	1.06
9/15/22 8:00 PM	854	1.64	0.9	0.74
9/16/22 7:15 AM	2023	1.75	0.69	1.06
9/16/22 9:00 AM	275	1.7	0.81	0.89
9/19/22 8:00 AM	1611	2.03	1.34	0.69
9/19/22 2:00 PM	1006	1.9	1.56	0.34
9/19/22 6:00 PM	-----	1.8	1.58	0.22
9/19/22 7:00 PM	-----	-----	-----	-----
9/20/22 7:15 AM	2546	2.32	1.09	1.23
9/20/22 2:00 PM	1277	2.23	1.32	0.91
9/20/22 7:00 PM	961	2.43	1.84	0.59
9/21/22 8:30 AM	1797	2.41	1.55	0.86
9/21/22 3:30 PM	1260	2.49	1.71	0.78
9/21/22 5:00 PM	363	2.45	1.64	0.81
9/22/22 5:30 AM	1891	1.49	1.14	0.35
9/22/22 9:00 AM	-----	1.6	1.43	0.17
9/22/22 2:00 PM	901	1.76	1.41	0.35
9/22/22 5:00 PM	642	1.93	1.61	0.32
9/22/22 8:00 PM	422	1.92	1.9	0.02
9/23/22 6:30 AM	650	0.2	0.1	0.1
9/26/22 8:30 AM	6300	2.52	-----	2.52
9/26/22 10:00 AM	-----	2.5	2	0.5
9/26/22 12:00 PM	296	2.53	2.1	0.43
9/26/22 7:20 PM	1437	2.43	2.13	0.3
9/27/22 8:00 AM	2345	2.53	1.93	0.6
9/27/22 10:30 AM	436	2.41	1.89	0.52
9/27/22 1:30 PM	549	2.40	1.86	0.54
9/27/22 4:30 PM	503	2.43	1.55	0.88
9/27/22 5:15 PM	135	2.50	1.6	0.9
9/28/22 7:30 AM	-----	3	2.68	-----

9/28/22 10:00 AM	-----	-----	-----	-----

Table 4-18
GSF #3 Chlorine Demand

Date/Time	Treated Volume GSF #3	Chlorine Residual GSF #3 Chlorine Influent	Effluent	Demand
	(gallons)	(mg/L)	(mg/L)	(mg/L)
9/14/22 11:30 PM	-----	-----	-----	-----
9/14/22 12:05 PM	185	-----	-----	-----
9/14/22 12:34 PM	113	-----	-----	-----
9:14/22 1:30 PM	271	1.61	0.46	1.15
9/14/22 4:00 PM	495	1.65	0.6	1.05
9/14/22 8:00 PM	1054	1.81	0.79	1.02
9/15/22 7:15 AM	2768	-----	-----	-----
9/15/22 3:00 PM	1744	1.75	1.19	0.56
9/15/22 8:00 PM	1293	1.64	1.05	0.59
9/16/22 7:15 AM	2789	1.75	0.87	0.88
9/16/22 9:00 AM	354	1.7	0.93	0.77
9/19/22 8:00 AM	-----	2.03	1.65	0.38
9/19/22 2:00 PM	1441	1.9	1.67	0.23
9/19/22 6:00 PM	108	1.8	1.78	0.02
9/19/22 7:00 PM	-----	-----	-----	-----
9/20/22 7:15 AM	3882	2.32	1.49	0.83
9/20/22 2:00 PM	1702	2.23	1.76	0.47
9/20/22 7:00 PM	1185	2.43	1.69	0.74
9/21/22 8:30 AM	-----	2.41	1.64	0.77
9/21/22 3:30 PM	1637	2.49	1.69	0.8
9/21/22 5:00 PM	934	2.45	1.74	0.71
9/22/22 5:30 AM	2050	1.49	1.17	0.32

9/22/22 9:00 AM	-----	1.6	1.43	0.17
9/22/22 2:00 PM	-----	1.76	1.6	0.16
9/22/22 5:00 PM	827	1.93	1.53	0.4
9/22/22 8:00 PM	523	1.92	1.76	0.16
9/23/22 6:30 AM	Note 1	0.2***	0.1***	-----
9/26/22 8:30 AM	-----	2.52	-----	2.52
9/26/22 10:00 AM	630	2.5	2.14	0.36
9/26/22 12:00 PM	420	2.53	2.19	0.34
9/26/22 7:20 PM	1816	2.43	2.3	0.13
9/27/22 8:00 AM	3234	2.53	1.82	0.71
9/27/22 10:30 AM	-----	2.41	-----	2.41
9/27/22 1:30 PM	-----	2.40	1.76	0.64
9/27/22 4:30 PM	-----	2.43	1.79	0.64
9/27/22 5:15 PM	878	2.50	1.88	0.62
9/28/22 7:30 AM	3609	3	2.5	0.5
9/28/22 10:00 AM	-----	2.9	2.35	0.55

Note 1: 9/23/2022 6:00 A.M. HWWC Chlorine Metering Pump out of service.

Figure 4-15: GSF #1 Influent/Effluent Chlorine Residual 3.5

Chlorine Residual Influent

3

Chlorine Residual Effluent

2.5

2

1.5

1

0.5

0

Date, Time

Figure 4-16: GSF #2 Influent/Effluent Chlorine Residual

3.5
Chlorine Residual Influent
3
Chlorine Residual Effluent
2.5
2
1.5
1
0.5
0

Date, Time

Figure 4-17: GSF #3 Influent/Effluent Chlorine Residual

3.5
Chlorine Residual Influent
3
Chlorine Residual Effluent
2.5
2
1.5

1 0

0.5

Date, Time

Figure 4-18: GSF Net Chlorine Demand GSF

#3 GSF #1 GSF #2

1.6 1.4 1.2 1

0.8 0.6 0.4 0.2 0

Date, Time

Table 4-19
Greensand Filter Chlorine Consumption

	Free Chlorine Residual			Treated Volume	Chlorine Mass Consumed	Chlorine Unit Demand
	GSF Influent	GSF Effluent	Δ Cl_2			
	(mg/L)	(mg/L)	(mg/L)	(gallons)	(mg)	(mg/gal.)
GSF #1						

All Data	2.00	1.26	0.72	24,880	67,803	2.72
Fully Regenerated	2.13	1.59	0.54	19,123	39,085	2.04
GSF #2						
All Data	2.02	1.33	0.68	35,709	91,908	2.57
Fully Regenerated	2.13	1.58	0.54	27,328	55,856	2.04
GSF #3						
All Data	2.15	1.57	0.56	35,942	76,183	2.12
Fully Regenerated	2.20	1.68	0.52	31,056	61,124	1.97

Tables 4-20 to 4-22 present an evaluation of the chlorine demand vs manganese removal, following attainment of "full" regeneration of the greensand filter media beds. This is an approximation because it only considers oxidation of manganese, with no consideration of other potentially oxidizable material in the water. Also, it utilizes the field monitoring data, which demonstrates greater variability in comparison to the laboratory wet chemistry analyses for manganese, particularly in the greensand filter effluent. A review of the data indicates the following:

- All three (3) filters demonstrated variability in the chlorine-to-manganese mass ratio. However, each filter demonstrated extended periods of operation with a consistent ratio in the range of 2.0 to 3.5 mg of chlorine per mg of manganese removed.
- Manganese removal was very consistent over the duration of the pilot plant program for all three (3) filter units.
- Once the greensand media was fully regenerated the typical chlorine demand across the filter was on the order of 0.5 mg/L, with some variability that is attributed to variable manganese and organic load in the water.

Table 4-20
Greensand Filter #1

Summary of Chlorine Oxidation Efficiency– Fully Regenerated Greensand Media (field monit									
Date	Time	Influent Flowrate, gpm	Flow Meter Reading	Treated Volume (gallons)	Influent Mn (mg/L)	Effluent Mn (mg/L)	Δ Mn Removed (mg/L)	Mn Removed (mg)	Influent Cl Residual (mg/L)
9/19/2022	8:00 AM	2.1	8172	-----	0.319	0	0.319	-----	2.03
	2:00 PM	2	7433	739	0.285	0	0.285	757	1.9
	6:00/6:25 PM	2.1	6924	509	0.301	-----	0.301	580	1.8
	7:00 PM	2.1	-----	-----	0.64[1]	-----	0.64[1]	-----	-----
9/20/2022	7:15 AM	1.9	5348	1576	0.294	0	0.294	1,754	2.32
	2:00 PM	2.1	4777	571	0.307	0.014	0.293	633	2.23
	7:00 PM	2	3986	791	0.271	0.016	0.255	763	2.43
9/21/2022	8:30 AM	2.2	2718	1268	0.301	0	0.301	1,445	2.41
	3:30 PM	2.1	1787	931	0.299	0.011	0.288	1,015	2.49
	5:00 PM	2.1	1540	247	0.28	0.005	0.275	257	2.45
9/22/2022	5:30 AM	2.1	256	1284	0.77	0.024	0.746	3,626	1.49
	9:00 AM	2.2	8964	-----	0.228	0	0.228	-----	1.6
	2:00 PM	1.9	8282	682	0.3	0.002	0.298	769	1.76
	5:00 PM	2	7857	425	> 0.8	0.007	0.793	1,276	1.93
	8:00 PM	1.9	7513	344	0.17	0.03	0.14	182	1.92
9/23/2022	6:30 AM	1.9	6300	1213	0.26	0.007	0.253	1,162	0.2
9/26/2022	8:30 AM	2	9000	-----	0.171	-----	0.171	-----	2.52
	10:00 AM	2	5978	3022	0.171	0.01	0.170	1,945	2.5
	12:00 PM	2.1	5749	229	0.2	0.01	0.190	165	2.53
	7:20 PM	1.9	4799	950	0.298	0.018	0.280	1,007	2.43
9/27/2022	8:00/8:30 AM	2	3239	1560	-----	-----	-----	-----	2.53
	10:30 AM	2.2	2958	281	-----	-----	-----	-----	2.41
	1:30 PM	2.1	2591	367	0.118	0.003	0.115	158	2.40
	4:30 PM	2	2245	346	0.209	0.003	0.206	270	2.43
	5:15 PM	1.9	2167	78	0.117	0.004	0.113	33	2.50
9/28/2022	7:30 AM	1.9	457	1710	-----	-----	-----	-----	3

Note 1: Increase in pre-treated water pumping rate.

Table 4-21
Greensand Filter #2
Summary of Chlorine Oxidation Efficiency – Fully Regenerated Greensand Media (field monit

Date	Time	Influent Flowrate, gpm	Flow Meter Reading	Treated Volume (gallons)	Influent Mn (mg/L)	Effluent Mn (mg/L)	Δ Mn Removed (mg/L)	Mn Removed (mg)	Influent Cl Residual (mg/L)
9/19/2022	8:00 AM	2.6	1407	1611	0.319	0	0.319	1945	2.03
	2:00 PM	2.9	401	1006	0.285	0.012	0.273	1040	1.9
	6:00/6:25 PM	3.1	10981	-----	0.301	0	0.301	-----	1.8
	7:00 PM	-----	-----	-----	-----	-----	-----	-----	-----
9/20/2022	7:15 AM	3.2	8435	2546	0.294	0	0.294	2833	2.32
	2:00 PM	3.2	7158	1277	0.307	0.012	0.295	1426	2.23
	7:00 PM	3.1	6197	961	0.271	0.005	0.266	968	2.43
9/21/2022	8:30 AM	2.9	4400	1797	0.301	0.012	0.289	1966	2.41
	3:30 PM	2.8	3140	1260	0.299	0.014	0.285	1378	2.49
	5:00 PM	3	2777	363	0.28	0.01	0.270	371	2.45
9/22/2022	5:30 AM	3	886	1891	0.77	0.033	0.737	5275	1.49
	9:00 AM	2.2	8915	971	0.228	0	0.228	837	1.6
	2:00 PM	3	8014	901	0.300	0	0.300	1023	1.76
	5:00 PM	3	7372	642	>0.8	0.004	0.796	1934	1.93
	8:00 PM	2.9	6950	422	0.17	0.004	0.166	265	1.92
9/23/2022	6:30 AM	1.9	6300	650	0.26	0.013	0.247	608	0.20
9/26/2022	8:30 AM	-----	-----	6300	0.171	-----	-----	-----	2.52
	10:00 AM	2.9	5916	384	0.171	0.006	0.165	240	2.5
	12:00 PM	3	5620	296	0.2	0.007	0.193	216	2.53
	7:20 PM	2.9	4183	1437	0.298	0.006	0.292	1588	2.43
9/27/2022	8:00/8:30 AM	3	1838	2345	-----	-----	-----	-----	2.53
	10:30 AM	3.3	1402	436	-----	-----	-----	-----	2.41
	1:30 PM	2.8	853	549	0.118	0.011	0.107	222	2.40
	4:30 PM	2.9	350	503	0.209	0.008	0.201	383	2.43

	5:15 PM	2.9	215	135	0.117	0.011	0.106	54	2.50
9/28/2022	7:30 AM	3	3477	-----	-----	-----	-----	-----	3

Table 4-22
Greensand Filter #3
Summary of Chlorine Oxidation Efficiency– Fully Regenerated Greensand Media (field monit

Date	Time	Influent Flowrate, gpm	Flow Meter Reading	Treated Volume (gallons)	Influent Mn (mg/L)	Effluent Mn (mg/L)	Δ Mn Removed (mg/L)	Mn Removed (mg)	Influent Cl Residual (mg/L)
9/19/2022	8:00 AM	3.8	8473	-----	0.319	0	0.319	-----	2.03
	2:00 PM	3.9	7032	1441	0.285	0.011	0.274	1494	1.9
	6:00/6:25 PM	4.2	6924	108	0.301	0	0.301	123	1.8
	7:00 PM	-----	-----	-----	-----	-----	-----	-----	-----
9/20/2022	7:15 AM	4.1	3042	3882	0.294	0.014	0.280	4114	2.32
	2:00 PM	3.2	1340	1702	0.307	0.001	0.306	1971	2.23
	7:00 PM	3.1	155	1185	0.271	0.002	0.269	1207	2.43
9/21/2022	8:30 AM	3.9	6202	5353	0.301	0	0.301	6098	2.41
	3:30 PM	3.7	4565	1637	0.299	0.005	0.294	1822	2.49
	5:00 PM	3.8	3631	934	0.28	0	0.28	990	2.45
9/22/2022	5:30 AM	3.2	1581	2050	0.77	0.074	0.696	5400	1.49
	9:00 AM	-----	-----	-----	0.228	0	0.228	-----	1.6
	2:00 PM	3.8	7890	5041	0.3	0.001	0.299	5704	1.76
	5:00 PM	3.8	7063	827	>0.8	0.015	0.785	2457	1.93
	8:00 PM	3.7	6540	523	0.17	0.004	0.266	329	1.92
9/23/2022	6:30 AM	-----	-----	-----	0.26	0.008	0.252	-----	0.20
9/26/2022	8:30 AM	-----	-----	-----	0.171	-----	-----	-----	2.52
	10:00 AM	4.1	5910	630	0.171	0.006	0.165	393	2.5
	12:00 PM	3.8	5490	420	0.2	0.008	0.192	305	2.53
	7:20 PM	4	3674	1816	0.298	0.014	0.284	1952	2.43
9/27/2022	8:00/8:30 AM	4	440	3234	-----	-----	-----	-----	2.53
	10:30 AM	-----	-----	-----	-----	-----	-----	-----	2.41
	1:30 PM	4.1	5331	909	0.118	0.006	0.112	385	2.40

	4:30 PM	4	-----	-----	0.209	0.005	0.204	----- 2.43	
	5:15 PM	4	4453	878	0.117	0.005	0.122	372 2.50	
9/28/2022	7:30 AM	4	844	3609	-----	-----	-----	----- 3	

4.6 Greensand Filter Backwash

GSF were backwashed when the treated water volume reached the preset operation volume listed in Table 4-7. Backwash flowrate was set at 6.5 gpm, equivalent to a hydraulic loading rate of 12 gpm/ft^2. The operating cycle for each filter was initially programmed at 11,400 gallons, and then adjusted based upon observations over the duration of the pilot plant operation. The backwash schedule and durations for each GSF are presented in Table 4-7 as well. The backwash water was filtered water supplied at a pressure of ≈36 psi.

During each backwash cycle samples of the spent backwash water were obtained at 2-minute intervals and submitted to the laboratory for analysis of TSS, turbidity and manganese. Table 4-23 to 4-25 present summaries of the backwash monitoring data.

4.6.1 Spent Backwash Water – Total Suspended Solids (TSS):

Each backwash cycle demonstrated a significantly elevated TSS content in the initial 2 minutes of operation however the concentration rapidly declined within a few minutes (Figure 4-19). Specific findings included the following:

- The 1st backwash cycle for each filter unit demonstrated the highest TSS concentration during the initial 2-minute sample, compared to all other backwash events. This indicates there was residual solids fines in the media bed following the initial media installation despite subjecting the media to a double backwash, followed by a sodium hypochlorite soak and another backwash following installation of the overlying anthracite media layer. This finding is not unusual, and emphasizes the need for aggressive backwashing at the time of initial filter bed installation.

- In all cases the TSS concentration declined an order of magnitude after 4 minutes backwash duration, and then demonstrated an extended backwash "tail" with a very low TSS concentration. The majority of the TSS was flushed within 6 – 8 minutes on most backwash cycles.

- The backwash efficiency can be substantially enhanced with the addition of an air scour assist, that will reduce the backwash water requirements and improve flushing of TSS from the fluidized filter bed.

4.6.2 Spent Backwash Water - Turbidity:

Illustrated in Figure 4-20, the spent backwash water demonstrated a more elongated duration of elevated turbidity, **up to 8 minutes duration**, before declining.

- The majority of the backwash events demonstrated a profile with an initial elevated turbidity content for **2 – 4 minutes**, followed by a substantial decline in concentration.

- The final backwash event for GSF #1 and the final 2 for GSF #2 demonstrated a relatively consistent turbidity concentration over the duration of the backwash event.

- The backwash efficiency can be enhanced with an air scour assist backwash.

Figure 4-19: Spent Backwash Water TSS

1600

1400

1200

9/28/2022

GSF #2, 9/28/2022 GSF #3, 9/28/2022 GSF #2, 9/27/2022

GSF #2, 9/27/2022

1000

800

600

400

200

0

2 4 6 8 10 12 14 16 18 20 22 Cumulative Backwash Time, min

GSF #3 9/16/2022 GSF #2, 9/17/2022 GSF #1, 9/18/2022

GSF #3, 9/20/2022 GSF #1, 9/22/2022 GSF #2, 9/19/2022

GSF #2 9/22/2022 GSF #3, 9/22/2022 GSF #1,

Figure 4-20: Spent Backwash Water Turbidity

300

250

200

150

100

50

0

2 4 6 8 10 12 14 16 18 20 22 Cumulative Backwash Time, min

GSF #3 9/16/2022 GSF #2, 9/17/2022 GSF #1, 9/18/2022 GSF #3, 9/20/2022 GSF #1, 9/22/2022 GSF #2, 9/19/2022 GSF #2 9/22/2022

GSF #3, 9/22/2022 GSF #1, 9/28/2022 GSF #2, 9/28/2022 GSF #3, 9/28/2022 GSF #2, 9/27/2022 GSF #3, 9/27/2022

GSF #3, 9/22/2022
GSF #1, 9/28/2022
GSF #2, 9/28/2022
20

Figure 4-21: Spent Backwash Water Manganese Concentration 60

GSF #3 9/16/2022
GSF #2, 9/17/2022
50

GSF #3, 9/28/2022
GSF #2, 9/27/2022

GSF #1, 9/18/2022
GSF #3, 9/20/2022
GSF #1, 9/22/2022
40

10

0
2 4 6 8 10 12 14 16 18 20 22
Cumulative Backwash Time, min

GSF #2, 9/19/2022
GSF #2 9/22/2022
30

4.6.3 Spent Backwash Water – Total Manganese:

Illustrated in Figure 4-21, the spent backwash water demonstrated an elevated total manganese content in the initial 2 minutes of operation however the concentration rapidly declined within a few minutes (Figure 4-20). Specific findings included the following:

- The majority of the backwash events demonstrated a profile similar to that of the TSS with an initial elevated total manganese content for 2 – 4 minutes, followed by a substantial decline in concentration. The majority of the manganese was backwashed within 6 – 8 minutes on most backwash cycles.

- The 3rd backwash event for GSF #1 and the 4th and 5th for GSF #2 demonstrated a relatively consistent total manganese concentration over the duration of the backwash.

- Consistent with the previous findings, the backwash efficiency can be enhanced with an air scour assist to front-load the manganese flushing.

Table 4-23 Greensand Filter #1 – Summary of Spent Backwash Water Monitoring									
Backwash Evens	**Backwash Duration - Minutes**								
	2	**4**	**6**	**8**	**10**	**12**	**14**	**16**	**18**
Backwash Date: 9/18/2022									
Total Suspended Solids (TSS), mg/L	**130**	76.5	55.6	41.2	32.6	5.68	-----	-----	----
Turbidity, NTU	207	211	194	176	157	17.2	-----	-----	----
Total Manganese, mg/L	29.8	13.4	12.3	10.9	8.53	1.52	-----	-----	----
Backwash Date: 9/22/2022									
Total Suspended Solids (TSS), mg/L	82.0	35.2	37.2	28.0	49.5	32.4	28.4	23.2	24.
Turbidity, NTU	229	189	181	174	191	163	157	148	14.
Total Manganese, mg/L	22.0	10.1	8.24	8.79	13.9	9.28	8.43	7.62	7.9
Backwash Date: 9/28/2022									
Total Suspended Solids (TSS), mg/L	92.0	25.8	16.2	14.8	14.0	12.0	17.8	15.2	10.
Turbidity, NTU	225	118	94.0	91.4	85.8	76.4	87.9	83.6	71.
Total Manganese, mg/L	2.92	4.51	3.55	3.29	2.96	2.64	3.23	2.95	2.2

Table 4-24
Greensand Filter #2 – Summary of Spent Backwash Water Monitoring

Backwash Evens	**Backwash Duration - Minutes**

	2	4	6	8	10	12	14	16	18
Backwash Date: 9/17/2022									
Total Suspended Solids (TSS), mg/L	**1380**	93.0	49	35.5	30.4	24.8	-----	-----	----
Turbidity, NTU	89.8	248	216	193	165	155	-----	-----	----
Total Manganese, mg/L	29.5	12.4	12.1	10.2	7.89	7.66	-----	-----	----
Backwash Date: 9/19/2022									
Total Suspended Solids (TSS), mg/L	118	54.0	41.2	36.4	34.0	28.4	-----	-----	----
Turbidity, NTU	200	203	192	170	156	153	-----	-----	----
Total Manganese, mg/L	32.7	16.7	8.26	8.06	9.65	8.64	-----	-----	----
Backwash Date: 9/22/2022									
Total Suspended Solids (TSS), mg/L	109.0	55.0	40.0	30.8	25.2	18.0	20.8	19.0	18.
Turbidity, NTU	228	201	174	157	139	131	130	120	11
Total Manganese, mg/L	24.7	14.0	10.9	9.62	7.86	7.87	7.19	6.62	6.5
Backwash Date: 9/27/2022									
Total Suspended Solids (TSS), mg/L	98.0	36	21.2	17.6	12.8	12.2	12.0	11.8	19.
Turbidity, NTU	213	132	101	94.0	78.1	70.5	69.4	73.5	92.
Total Manganese, mg/L	1.31	1.65	1.88	1.79	2.02	1.88	1.58	1.75	1.4
Backwash Date: 9/28/2022									
Total Suspended Solids (TSS), mg/L	38.8	16.6	11.8	11.4	10.0	12.2	9.40	23.40	12.
Turbidity, NTU	139	82.6	66.5	64.6	62.0	67.9	56.7	96.7	65.
Total Manganese, mg/L	3.26	3.19	2.49	2.44	2.17	2.72	2.19	3.83	2.4

Table 4-25
Greensand Filter #3 – Summary of Spent Backwash Water Monitoring

Backwash Event	**Backwash Duration - Minutes**								
	2	4	6	8	10	12	14	16	18
Backwash Date: 9/16/2022									
Total Suspended Solids (TSS), mg/L	**430**	132	48.0	34.0	31.5	26.0	-----	-----	----

Turbidity, NTU	194	235	214	188	174	163	-----	-----	----
Total Manganese, mg/L	48.9	26.5	11.4	9.5	6.84	7.47	-----	-----	----
Backwash Date: 9/20/2022									
Total Suspended Solids (TSS), mg/L	121	44.5	46.8	54.0	26.8	25.6	21.2	21.6	----
Turbidity, NTU	236	184	162	178	132	126	116	114	----
Total Manganese, mg/L	29.6	14.5	11.7	15.7	9.05	8.29	7.07	7.59	----
Backwash Date: 9/22/2022									
Total Suspended Solids (TSS), mg/L	124	57.0	17.2	18.8	16.2	17.8	18.0	22.0	18.
Turbidity, NTU	243	177	102	106	95.0	93.1	98.8	108	96.
Total Manganese, mg/L	30.5	17.6	5.70	6.64	5.45	5.52	8.01	8.51	6.7
Backwash Date: 9/27/2022									
Total Suspended Solids (TSS), mg/L	56.0	26.0	12.5	14.0	14.4	13.6	12.2	12.0	9.6
Turbidity, NTU	159	90.7	71.4	72.1	73.2	67.5	61.6	63.2	55.
Total Manganese, mg/L	13.7	6.56	4.52	4.64	4.75	4.04	3.83	4.15	3.1
Backwash Date: 9/28/2022									
Total Suspended Solids (TSS), mg/L	35.0	15.2	10.8	10	10	10	10	10	10
Turbidity, NTU	139	75.8	67.0	57.0	52.4	48.1	54.3	47.5	46.
Total Manganese, mg/L	13.8	7.11	4.50	4.63	3.25	3.05	3.32	2.57	2.7

4.7 Disinfection By-Products (DBPs)

Three (3) rounds of DBP monitoring were conducted over the duration of the pilot plant program, including both the greensand filter influent and effluent water. The initial findings of this analytical investigation include the following:

- The greensand filter influent demonstrated Total Trihalomethane (TTHMs) with concentrations ranging from 39.8 ug/L to 63.5 ug/L, in all cases, below the USEPA LRAA limit of 80 ug/L.

- The monitoring events on September 15th and 28th indicated the greensand filtration process had no impact upon the TTHM content in the GSF treated water. However, the September 21st monitoring determined a reduction in TTHM across the greensand filter, from an initial 63.5 ug/L to 54.8 ug/L.

Table 4-26
Disinfection By-Products (DBP) Monitoring

Parameter	9/15/2022			9/21/2022			9/28/2022		
	Raw	GSF Influent	GSF Effluent*	Raw	GSF Influent	GSF Effluent*	Raw	GSF Influent	GSF Effluent*
pH, s.u.	-----	7.75	-----	7.93	7.53	-----	7.93	7.95	-----
UV254 (absorbance) /cm	-----	0.028	-----	0.087	0.032	-----	0.077	0.029	-----
TOC, mg/L	3.43	1.72	-----	3.56	1.70	-----	3.30	1.51	-----
DOC, mg/L	3.51	1.88	-----	3.51	1.59	-----	3.44	1.52	-----
TTHM, µg/L		**48.5**	**49**		**63.5**	**54.8**		**39.8**	**41.9**
Bromodichloromethane, µg/L	-----	5.9	5.71	-----	8.34	6.27	-----	4.44	5.04
Bromoform, µg/L	-----	<0.500	<0.500	-----	<0.50	<0.500	-----	<0.500	<0.500
Chloroform, µg/L	-----	42.6	43.3	-----	54.6	48.5	-----	34.9	36.9
Dibromochloromethane, µg/L	-----	<0.500	<0.500	-----	0.57	<0.500	-----	<0.500	<0.500
HAA5, µg/L		**60.6**	**60.6**		**70.4**	**65.0**			**56.9**
Chloroacetic acid, µg/L	-----	1.41	1.41	-----	1.42	<1.00	-----	-----	1.43
Bromoacetic acid, µg/L	-----	<1.00	<1.00	-----	<1.00	<1.00	-----	-----	<1.00
Dichloroacetic acid, µg/L	-----	21.1	21.1	-----	20.8	20.1	-----	-----	21.0
Trichloroacetic acid, µg/L	-----	38.1	38.1	-----	48.2	44.9	-----	-----	34.5
Dibromoacetic acid, µg/L	-----	<1.00	<1.00	-----	<1.00	<1.00	-----	-----	<1.00

***Composite samples: 1/3 from each GSF**

- The greensand filter influent demonstrated Haloacetic Acid (HAA5) with concentrations of 60.6 ug/L and 70.4 ug/L, exceeding the USEPA LRAA limit of 60 ug/L.

- The monitoring event on September 15th indicated the greensand filtration process had no impact upon the HAA5 content in the finished water. However, the September 21st monitoring determined a reduction in HAA5 across the greensand filter, from an influent concentration of 70.4 ug/L to 65.0 ug/L in the effluent sample.

The potential for disinfection byproduct formation downstream of the treatment process was tested using GSF effluent water samples obtained on September 28, 2022, immediately prior to the completion of the pilot plant program. After collection the sample subsequently underwent a formation study using water age intervals of: 0, 1, 2, 3, 5, 10, and 15 days. The results are presented in Table 4-27, and plotted in Figure 4-23. The GSF effluent water sampled for this testing had already experienced approximately 15 hours of chlorine contact time in the contact basin. Therefore, the "Day 0" sample in Table 4-27 and Figure 4-23 actually represented ≈15 hours of water age following chlorination.

- TTHM demonstrated a concentration of 41.9 µg/L on Day 0, increasing to 75.8 µg/L after 24-hours (Day 1), then 83.0 µg/L on Day 2 (exceeding USEPA LRAA, 80 ug/L), subsequently increasing to 110 ug/L on Day 5. TTHMs did not increase after Day 5.

- HAA5 demonstrated a concentration of 56.9 µg/L on Day 0, increasing to 85.3 µg/L on Day 1, exceeding the USEPA LRAA (60 µg/L), increasing to 98.6 ug/L on Day 2. The rate of increase was then very gradual through Day 15 (130 ug/L).

Table 4-27
DBPR vs. Water Age, Sample Collected on 9/28/2022

Water Age		**Day 0**	**Day 1**	**Day 2**	**Day 3**	**Day 5**	**Day 10**	**Day 15**
Date of DBP Analysis		9/28/22	9/29/22	9/30/22	10/1/22	10/3/22	10/8/22	10/13/22
Parameters	**LRAA or MCLG***	9:20 am	15:40	15.35	15.35	15:50	14:00	14:00
Total Trihalomethanes, µg/L	80	**41.9**	**75.8**	**83.0**	**84.8**	**110**	**93.6**	**108**
Bromodichloromethane, µg/L	zero*	4.44	7.77	8.29	8.19	9.85	10.6	10.3
Bromoform, µg/L	zero*	<0.500	<0.500	<0.500	<0.500	<0.500	<0.500	<0.500
Chloroform, µg/L	70*	37.4	68.0	74.2	76.1	99.5	82.4	97.1
Dibromochloromethane, µg/L	60*	<0.500	<0.500	0.510	0.550	0.520	0.570	0.600
Total Haloacetic Acids, µg/L	60	**56.9**	**85.3**	**98.6**	**92.2**	**104**	**106**	**130**
Chloroacetic acid, µg/L	70*	1.43	1.93	2.86	2.59	3.09	2.87	4.83
Bromoacetic acid, µg/L	no MCLG	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
Dichloroacetic acid, µg/L	zero*	21.0	32.9	33.9	35.9	40.2	43.2	56.8
Trichloroacetic acid, µg/L	20*	34.5	50.5	61.9	53.7	60.4	59.7	68.6
Dibromoacetic acid, µg/L	no MCLG	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00

Although a simplified assessment of water age impact, this test provides indication that water age is a significant factor impacting formation of DBPs. The primary takeaway of this rate study is that the majority (≈75%) of the THMs and HAAs existing after 15 days are formed within the initial 2.5 +/- days. Also, the results for TTHM and HAA5 after ≈2.5 days are approximately 89% and 93% of the levels observed after 10 days, respectively. Given the storage tank has approximately 10 days of water age and the distribution system contributes about another 2 days, reducing water age will not provide substantial reduction in the DBPs formed.

For all samples other than the GSF effluent sample at time zero, the magnitude of the DBPs formed should be considered only as theoretical maximum values, and should not be construed to predict actual full-scale field conditions. DBP formation in laboratory glassware can exceed that occurring in actual pipe infrastructure systems where there are other competing chlorine demands.

Figure 4-22: DBPs vs. Water Age

140
120
100
80
60
40
20
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 Days

Total trihalomethanes, µg/L Total haloacetic acids (HAA5), µg/L

4.8 Spent Backwash Water Handling and Disposal

The options for final residuals handling and disposal are limited given the locational site constraints. There is no municipal sewer within a reasonable distance to use for disposing of spent filter backwash water. Off-site disposal of bulk backwash water will be cost prohibitive. Currently, HWWC uses an existing, small lagoon system for land surface disposal of cleaning water from the slow sand filters.

The recommended alternative is to discharge the spent filter backwash water to a sedimentation tank for capture of particulate manganese, with the overflow discharging to the existing lagoon. Based upon the use of 36” Ø greensand filters, the full backwash volume is approximately 847 gallons per event. However, using an air scour assist will reduce the backwater water volume to approximately 320 gallons per event. Operating projections indicate an average of 5 filter backwash events per week, equivalent to 1,600 to 4,235 gallons per week. Therefore a 2,000-gallon settling tank would provide a minimum of 2 – 3 days settling time, up to 5 days settling time, sufficient to capture the majority of suspended solids in the backwash water.

It is anticipated the volume of backwash water produced by this small system would not cause any problems in terms of its disposal at the current onsite lagoon. Other than minor quantities of chlorinated compounds, the backwash water will contain no materials that were not already present in the Long Pond source water. Allowing what is effectively lake water with slightly elevated manganese to percolate into the ground is of no threat to the environment.

V. PILOT PLANT IMPACT UPON FINISHED WATER QUALITY

Implementation of greensand filtration represents a change in the water treatment process that can impact the finished water characterization, including a corrosion evaluation. Three (3) rounds of GSF influent and effluent monitoring were conducted to facilitate this assessment, augmented with field monitoring data, summarized in Table 5-1.

5.1 Impact of Greensand Filtration on Finished Water Inorganic Characterization

The HWWC water is generally characterized as slightly alkaline, with moderately low TDS, elevated alkalinity and total hardness, with low chloride, sulfate, sodium, magnesium and potassium. All other monitored inorganic/metal parameters are either non-detectable or present at trace concentrations. A summary assessment of the impact of the Greensand Plus filtration process includes the following:

- Total Dissolved Solids (TDS): Consistent with all granular media filters, Greensand Plus filtration will only remove particulate solids. This is validated by the minimal impact upon the total dissolved solids concentration, across the filter beds. The three (3) samples demonstrated an average GSF influent TDS of 141.7 mg/L, with a range of 139 to 153 mg/L, which is also consistent with historical monitoring. The GSF effluent demonstrated an average TDS of 136.3 mg/L, with a range of 128 to 152 mg/L. Examining each pairing of influent/effluent samples demonstrated a net ΔTDS of 10 mg/L, 1 mg/L and 5 mg/L.

  Additionally, each pairing of the significant dissolved inorganic constituents including alkalinity (as $CaCO_3$), chloride, calcium, magnesium, potassium and sodium all demonstrated nearly identical influent/effluent concentrations, indicating no impact from the filtration process. Sulfate was non-detectable in all samples.

- Specific Conductance and Conductivity/TDS Ratio: Each pairing of influent/effluent samples demonstrated nearly identical specific conductance values across the filter system. The respective Conductivity/TDS ratios also demonstrated similar values across the filter system for each pairing. This is further evidence of no impact of the greensand filtration process upon the dissolved inorganic characterization of the water.

- Water pH: Field monitoring demonstrated a very consistent GSF influent pH with a range of 7.3 to 7.4 S.U. and GSF effluent pH 7.15 to 7.3 S.U. The laboratory pH analyses demonstrated higher pH values with GSF influent pH of 7.53 to 7.95 S.U. and GSF effluent pH of 7.45 to 7.76 S.U. The pH values are consistent with historical monitoring. Each pairing of influent/effluent laboratory pH samples demonstrated a small, but consistent decrease across the greensand filtration system, on the order of <0.1 to 0.25 S.U. The field pH monitoring demonstrated a somewhat lower pH decrease across the filter system, on the order of 0.0 to 0.2 S.U.

• Alkalinity (as $CaCO_3$): The alkalinity concentration was consistent for all samples, demonstrating an average of 90.8 mg/L (as $CaCO_3$) with a range of 90 to 92.5 mg/L (as $CaCO_3$). Additionally, each pairing of GSF influent/effluent samples demonstrated

identical alkalinity concentrations, indicating no change across the filter system. The alkalinity concentrations are consistent with historical monitoring

• Chloride: The chloride concentration was consistent for all samples, with GSF influent demonstrating an average concentration of 14.4 mg/L with a range of 12.6 to 16.0 mg/L. GSF effluent demonstrated an average concentration of 14.8 mg/L, with a range of 12.6 to 16.3 mg/L. Additionally, each pairing of GSF influent/effluent samples demonstrated identical or closely similar chloride concentrations, indicating no change across the filter system.

• Sulfate: All influent and effluent samples demonstrated non-detectable sulfate (<5.00 mg/L), consistent with historical monitoring.

• Calcium, Magnesium and Total Hardness: The three (3) pairs of samples (total 6 samples) demonstrated virtually identical calcium content with an average of 23 mg/L and an range of 22.2 to 23.5 mg/L. There was no change in calcium concentration through the filter system. The GSF influent magnesium concentration demonstrated a slight variability, with a range of 9.14 to 9.67 mg/L however, each pairing of GSF influent/effluent samples demonstrated closely similar magnesium concentrations, indicating no change across the filter system. As a result, total hardness was also consistent across the filtration system with GSF influent demonstrating and average of 95.8 mg/L (as $CaCO_3$) and GSF effluent an average of 96.1 mg/L (as $CaCO_3$).

• Potassium: Potassium was present at a low concentration with GSF influent demonstrating an average concentration of 0.585 mg/L and GSF effluent an average concentration of 0.600 mg/L. Additionally, each pairing of GSF influent/effluent samples demonstrated minimal change across the filtration system.

• Sodium: Sodium demonstrated consistently low concentrations in all samples with GSF influent demonstrating an average concentration of 9.93 mg/L and GSF effluent an average concentration of 10.1 mg/L. Additionally, each pairing of GSF influent/effluent samples demonstrated minimal change across the filtration system.

In summary, excepting the removal of manganese, the Greensand Plus filtration process had **no impact upon the inorganic characterization of the treated water discharged to the water storage tank and distribution POE**. All significant inorganic constituents, summarized above, demonstrated closely similar concentrations when comparing filter influent and effluent sample results, within the expected range of natural variability and the expected performance and purpose of the greensand filtration treatment process.

5.2 Impact of Greensand Filtration on Other Parameters

Water color and color removal was assessed in the field via visual comparison of samples in white Styrofoam cups. While yellow color was evident in the GSF influent, no color was visually observed in any of the GSF effluent samples during the entire pilot study, demonstrating the effectiveness of the Greensand Plus filter media for removal of manganese at HWWC.

Laboratory

measurements demonstrated GSF influent with apparent color on the order of 30 to 60 c.u., similar to the color observed by customers and plotted in Figures 1-1 and 1-2. All GSF effluent samples measured at the lab were non-detect for color, further confirming the effectiveness of Greensand Plus for removing the water's manganese.

Table 5-1
Greensand Filter Influent/Effluent Water Characterization (mg/L, unless noted)

Sample Date	09/15/22		09/21/22		09/28/22	
Parameter/Location:	**GSF Influent**	**GSF Effluent**	**GSF Influent**	**GSF Effluent**	**GSF Influent**	**GSF Effluent**
Temp.– Field (°C)	21.3 – 21.7	21.3 – 21.7	20.7 – 20.9	20.7 – 20.9	17.8	17.8
pH – Laboratory (s.u.)	7.75	7.68 – 7.71	7.53	7.45 – 7.60	7.95	7.69 – 7.76
pH – Field (s.u.)	7.3 – 7.32	7.3	7.3 – 7.34	7.15 – 7.2	7.4	7.2
Dis. Oxygen - Field	4.87 – 5.80	5.12 – 5.78	N/A	N/A	N/A	N/A
Carbon Dioxide	10	-----	8.00	10.0	8.00	10.0
Turbidity (NTU)	1.22	<0.100	1.72	<0.100	0.83	0.160 – 0.210
Apparent Color (C.U.)	50	-----	60	<1	30	<1
True Color (C.U.)	0	-----	0	0	0	0
UV 254 (absorb/cm)	0.028	0.027 – 0.030	0.032	0.032 – 0.036	0.029	0.027 – 0.028
Total Organic Carbon	1.72	-----	1.70	0.790 – 1.70	1.51	1.50 – 1.52
Dis. Organic Carbon	1.88	-----	1.59	1.59 – 1.76	1.52	1.52 – 1.55
Total Suspended Solids	<2.50	-----	<2.78	<2.78	<3.13	<2.78 - <3.13
Total Dissolved Solids	139	129	153	152	133	128
Sp. Cond. (umhos/cm)	225	224	233	233	231	232
Cond./TDS Ratio	1.62	1.74	1.52	1.53	1.74	1.81
Free Cl_2 Res. – Field	1.64 – 1.75	0.45 – 1.19	2.41 – 2.49	1.55 – 1.74	3.0	2.35 – 2.68
Alkalinity (as $CaCO_3$)	90	90	92.5	92.5	90	90.0
Chloride	12.6	12.6	14.7	15.5	16.0	16.3
Sulfate	<0.500	<5.00	<5.0	<5.00	<5.0	<5.00
Nitrate – N	0.0852	0.0818	0.0988	0.0709	0.107	0.0724
Nitrite-N	<0.0100	<0.0100	<0.0100	<0.0100	<0.0100	<0.0100
Aluminum	<0.051	<0.0510	<0.01	<0.01	<0.01	<0.01
Arsenic	<0.0040	<0.0040	<0.0040	<0.0040	<0.0400	<0.0040
Beryllium	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010
Cadmium	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010

Calcium	23.4	23.4	23.2	23.5	22.3	22.2
Chromium	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010
Copper	0.0103	0.0091	0.0144	0.0122	0.0146	0.0153
Iron	<0.050	-----	<0.050	<0.050	<0.050	<0.500
Lead	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010
Magnesium	9.67	9.71	9.27	9.39	9.14	9..13
Manganese (T)	0.203	ND – 0.002	0.255	<0.00204	0.075	<0.00204
Manganese (D)	0.0974	-----	0.020	<0.00204	0.00813	<0.00204
Mercury	<0.00020	<0.00020	<0.00020	<0.00020	<0.00020	<0.00020
Potassium	0.559	0.579	0.601	0.627	0.595	0.595
Sodium	9.38	9.54	10.3	10.6	10.1	10.1
Zinc	0.0253	0.0154	0.0230	-----	0.0184	0.0266
T. Hardness (as $CaCO_3$)	98.1	98.3	96.0	97.2	93.2	92.9
Corrosion/Scale Index:						
Langelier Sat. Index -pK[1]	-1.05	-1.05	-1.05	-1.17	-1.07	-1.27
Langelier Sat. Index -A+B[2]	-0.90	-0.90	-0.89	-1.01	-0.89	-1.09
Larson-Skold Index	0.20	0.26	0.28	0.29	0.31	0.31
CSMR	<25	>2.5	<2.94	>3.1	<3.2	>3.26
Alkalinity-to-Cl Ratio	7.14	7.14	6.29	5.97	5.63	5.52

Note 1: Langelier Saturation Index calculation uses field pH and temperature.