TATA & HOWARD

September 14, 2021

Mr. Robert Gallo, P.E., Vice President
New England Service Company
37 Northwest Drive
Plainville, CT 06062

Subject: Discoloration Assessment
FINAL Water Quality Evaluation
T&H No. 6959

Dear Mr. Gallo:

In accordance with our agreement, Tata & Howard is pleased to present you with this letterreport for the Water Quality Evaluation portion of the Colonial Water Company, Dover, Massachusetts (MA) Discoloration Assessment Project for the New England Service Company who currently own the Colonial Water Company water system. This evaluationfocuses on the existing water quality of the Colonial Water Company, Dover water system,specifically related to the levels of manganese in the wells and distribution system. Three options for manganese removal/ sequestration were reviewed and evaluated; sequestration with a blended orthophosphate, GreensandPlus™ filtration, and biological removal. Additionally, the operation of the water system was evaluated, and findings are containedwithin this report.

1.1 Background

The New England Service Company owns and operates the Colonial Water Company public water system in Dover, MA. Over the past few years, a number of customers havecomplained about the quality of their drinking water, mainly regarding discoloration issues. From June 17, 2021 through August 21, 2021, a total of 104 customer complaints have been recorded for the Colonial Water Company. The Massachusetts Department of Environmental Protection (MassDEP) consulted with the Colonial Water Company on June 21, 2021 to discuss customer complaints specific to water discoloration. In addition, the discussions included increased demand/water use, water conservation efforts, distribution pipe material, distribution flushing practices, leak detection, source operation,distribution pressure status, and water quality sampling such as bacteriological sampling results. On June 29, 2021, MassDEP met with Colonial Water Company representatives regarding corrective actions being taken to address the complaints of discoloration and required Colonial Water Company to provide a corrective action plan (CAP) by July 7,2021, including additional information and laboratory results. The Colonial Water Company submitted a proposed CAP and all required information to MassDEP on July 7,2021.

Upon review of the CAP, historical records, and customer complaints, MassDEP determined that the Colonial Water Company's CAP was technically deficient, and that the Colonial Water Company must complete a comprehensive assessment of the public watersystem's operations, maintenance, and management practices to determine the cause(s) of discoloration within the sources and distribution system and recommend corrective actionsfor resolution of the manganese problem.

2.1 Water Distribution System

The existing Colonial Water Company's distribution system in Dover, MA serves a population of 1,890 through 637 service connections and consists of approximately 11.5 miles of water main. The water main diameters range in size from 4-inch to 8-inch, with the highest percentage of water main diameter being 8-inch. The water mains arecomprised of cement lined cast iron and ductile iron.

Water is supplied from seven active groundwater sources contained within four well sites;the Francis Street, Draper Road, Knollwood Drive, and Chickering Drive wells. The Francis Street Wells consist of Well A, Well B, and Well C. The Draper Road Wells consist of Well No. 1 and Well No. 2. The seven active groundwater sources have varyinglevels of treatment at each of four active treatment plants, including:

- Francis Street Plant – This site is the largest source and treats Francis Street Well A, Well B, and Well C with potassium hydroxide for corrosion control and sodiumhypochlorite for disinfection with MassDEP-approved 4-log inactivation of viruses.
- Draper Road Plant – This site is the smallest source and treats Draper Road Wells No. 1 and 2 with potassium hydroxide for corrosion control and sodium hypochlorite for disinfection.
- Knollwood Drive Plant – This site treats Knollwood Drive Wells with potassium hydroxide for corrosion control.
- Chickering Drive Plant – This site treats Chickering Drive Wells with potassium hydroxide for corrosion control. The Chickering Drive Wells provide water to a small portion of the distribution system. It is completely isolated from the main water distribution system and is therefore a separate service area.

Both the Francis Street and Draper Road pump stations operate at a set range of pressuresthrough the use of hydropneumatics tanks. Colonial Water Company maintains one booster pump station known as the Cedar Hill Booster Station which supplies Tower Drive, High Rock Road and a portion of Cedar Hill Road. Each of the above noted treatment plants maintain hydropneumatic storage tanks only; there is no atmospheric storage within the distribution system. The map included in Appendix A presents the Colonial Water Company distribution system in Dover, MA.

The Draper Road Wells and Francis Street Wells are located within the Boston Harbor Basin. The authorized maximum daily withdrawal for Draper Road Wells No. 1 and 2 is 0.039 million gallons per day (mgd) each. The combined authorized maximum daily withdrawal for Draper Road Wells No. 1 and 2 is 0.078 mgd, or approximately 55 gallons per minute (gpm). The combined authorized maximum daily withdrawal for Francis Street Wells A, B, and C is 0.47 mgd, or approximately 325 gpm.

The Knollwood Drive Wells and Chickering Drive Wells are located within the Charles River Basin. The authorized maximum daily withdrawal for the Knollwood Drive Wells is 0.432 mgd, or 300 gpm. The authorized maximum daily withdrawal for the Chickering Drive Wells is 0.36 mgd, or 250 gpm.

3.1 Water Quality

Federal and state regulations and standards are set to protect the drinking water quality provided by public water systems. Standards and regulations continue to be amended as necessary to protect public health and provide consistent and safe water quality as research on emerging contaminants becomes available. Applicable regulations and sampling results for contaminants of concern present in the water from the Dover water supply sources are reviewed in this section. The focus of the water quality evaluation that follows is on elevated manganese levels present in the Francis Street Wells and Draper Road Wells. Manganese is nondetectable in the Knollwood Drive and Chickering Drive Wells. It should be noted that iron concentrations were non-detect at all sources. Therefore, iron is not further analyzed.

Manganese

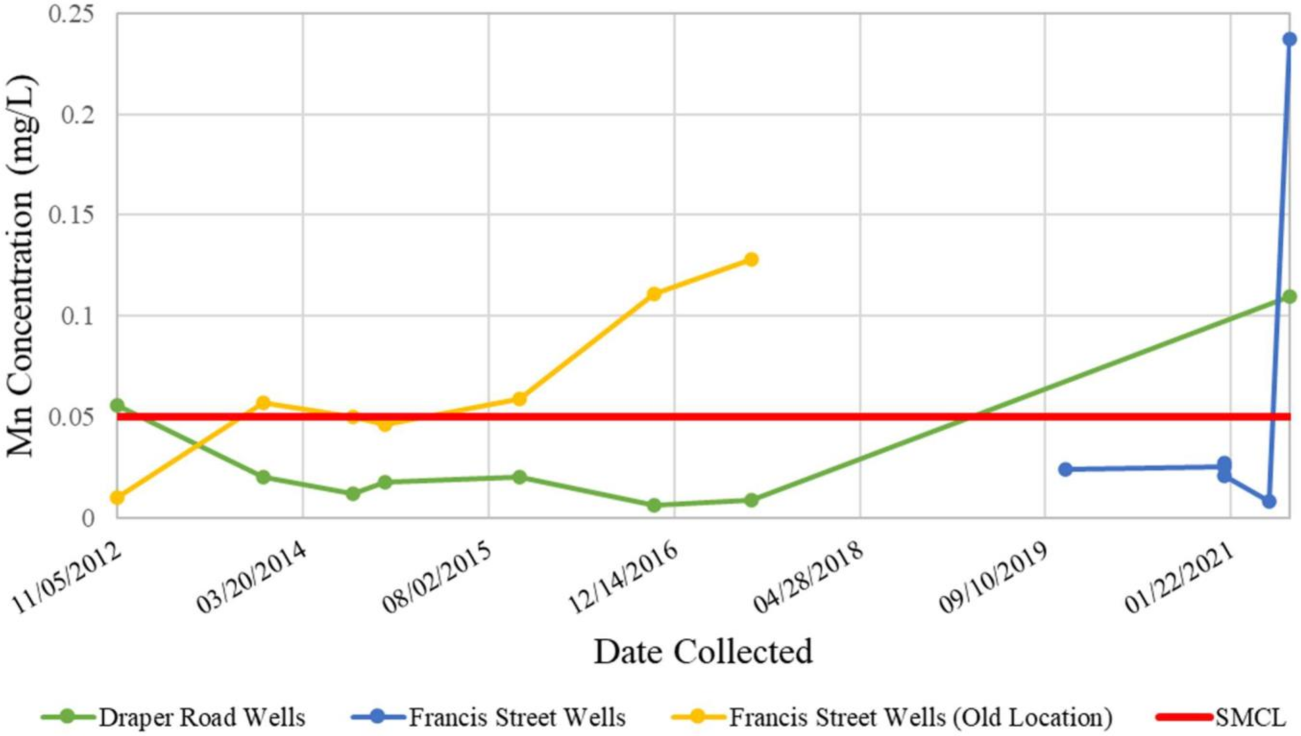
The United States Environmental Protection Agency (USEPA) set, and the MassDEP has adopted, secondary maximum contaminant levels (SMCLs) for manganese concentrations in drinking water of 0.05 milligrams per liter (mg/L). SMCLs are not federal or state enforceable regulations, however manganese levels in drinking water at or above the SMCL can result in taste, odor, and color complaints from water customers. Manganese deposits can build up in tanks, water heaters, and piping in the distribution system and in customer dwellings causing staining of plumbing fixtures and eventually forcing customers to replace plumbing equipment.

The USEPA and the Massachusetts Office of Research and Standards have also implemented Health Advisory (HA) levels and Office of Research and Standards Guideline Limits (ORSGLs) for manganese. The Massachusetts ORSGL for lifetime exposure by adults, and for acute exposure (ten days) by infants less than one year of age, is 0.3 mg/L. Lifetime exposure by adults or acute exposure by infants to concentrations of manganese at or above the MA ORSGL of 0.3 mg/L may have adverse neurological impacts. The acute exposure for infants has been established due to the possibility of higher absorption and lower excretion in young infants.

MassDEP has been enforcing treatment for manganese removal or blending of sources, if possible, to reduce manganese concentrations below the MA ORSGL of 0.3 mg/L. MassDEP requires manganese levels at the point of entry for any source or group of sources to be consistently and reliably below 0.3 mg/L, which is interpreted as the annual average being less than 0.21 mg/L and no samples exceeding 0.3 mg/L.

Laboratory results for manganese were reviewed from November 2012 through June 2021for the Francis Street Wells and Draper Road Wells. The laboratory sampling results are shown below in Figure No. 3-1. Manganese concentrations at the Francis Street Wells "oldlocation" increased from 2012 through 2017, with sample results above the SMCL in December 2013, October 2015, October 2016, and July 2017. At the Francis Street Wells"current" sampling location, manganese concentrations were below the SMCL November2019 through May 2021, until results increased to approximately 0.24 mg/L in June 2021.At the Draper Road Wells, manganese concentrations were slightly above the SMCL at 0.056 mg/L in November 2012. After the November 2012 sample, manganese concentrations decreased to below the SMCL through July 2017. The next lab sample wascollected in June 2021, and results indicated manganese concentrations above the SMCL at 0.11 mg/L.

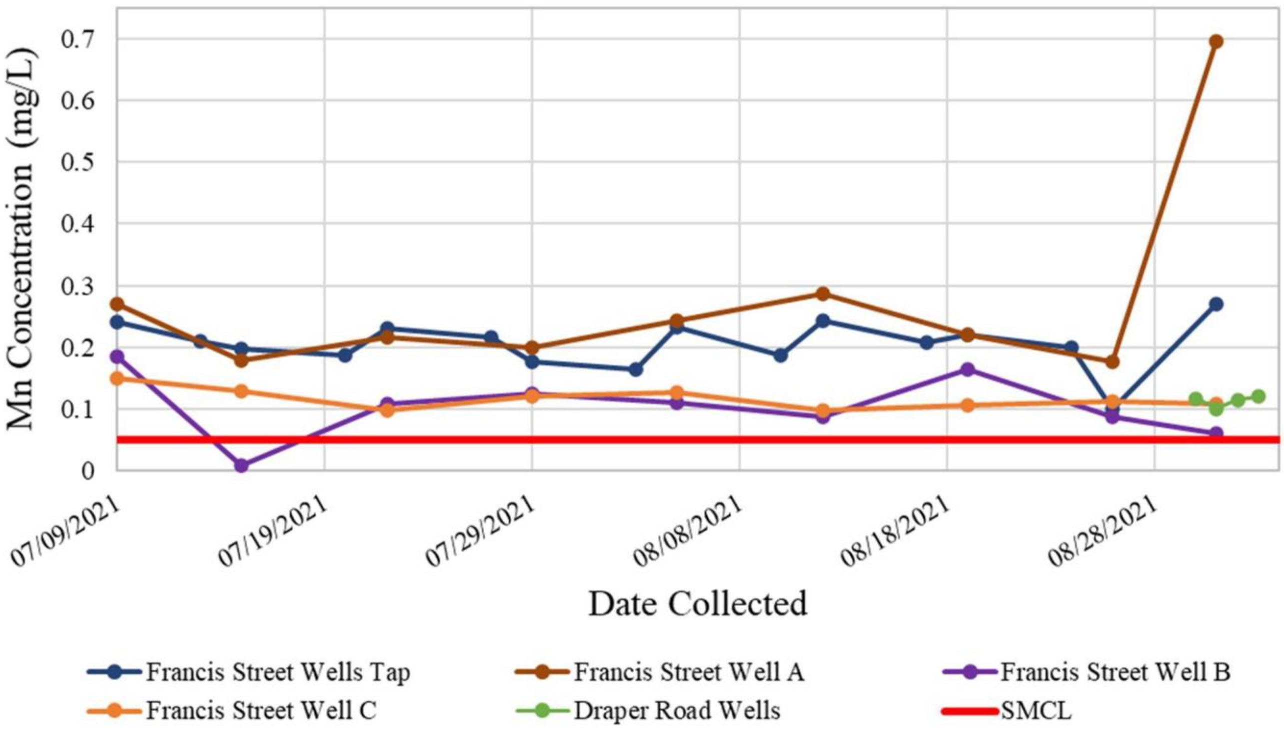
Figure No. 3-1
Manganese Laboratory Testing Results
Francis Street Wells and Draper Road Wells



Secondary contaminant sampling results for manganese were also provided as in-house sampling analytical results from July 9, 2021 through August 31, 2021 for the Francis Street Wells A, B, C, and the Francis Street treatment plant tap which represents a blend of the three wells post pH adjustment and disinfection. The in-house sampling results are shown below in Figure No. 3-2. Results for the Francis Street Wells A, B, and C are raw water samples collected prior to pH adjustment and disinfection. All sample results indicate a manganese concentration ranging from approximately 0.01 mg/L to 0.29 mg/L for the sampling period. The August 31, 2021 sample result from Francis Street Well A indicates a manganese concentration of approximately 0.7 mg/L. This result is a significant outlier.

Colonial Water Company collected in-house samples for manganese testing at the Draper Road Wells on August 30 through September 2, 2021, and manganese concentration results ranged from approximately 0.1 mg/L to 0.12 mg/L. The Draper Road Wells manganese concentration results are also shown in Figure No. 3-2. Results for the Draper Road Wells are raw water samples collected prior to disinfection.

Figure No. 3-2
Manganese In-House Testing Results
Francis Street and Draper Road Wells



pH and Chlorine

Daily pH levels at each source from 2018 through April 2021 were provided by the Colonial Water Company. Daily chlorine levels from 2018 through April 2021 were also provided for the Francis Street Wells and Draper Road Wells. The Knollwood Drive Wells and Chickering Drive Wells do not disinfect. Table No. 3-1 shows the minimum and maximum pH and chlorine levels at each source monthly from January 2020 through April 2021 with the exception of December 2020 which was not provided. The reported pH levels and chlorine residuals represent finished water. Based on MassDEP's response to the Colonial Water Company's proposed CAP, dated July 23, 2021, pH throughout the distribution system was within normal range between 7.2 – 7.9 and chlorine residuals leaving the Draper Road and Francis Street Stations were within regulatory requirements.

Although the pH and chlorine levels are withing regulatory requirements, the levels being dosed are high and the levels fluctuate as well. There are two reasons for this. First, the Colonial Water Company aims for a pH range of 7.2 to 7.8. These pH levels are considered normal in a system without manganese issues. Second, the well pumps and chemical feed pumps are not flow paced; they are constant speed pumps. The high pH and chlorine levels are likely leading to a portion of the water quality issues in the distribution system. At higher pH levels (typically greater than 7.2 to 7.3), the oxygen in the source water will oxidize the manganese and it will drop out of solution. The same is true for the high chlorine levels.

An analysis of the pH range of the raw water sources will be necessary to determine which process will operate optimally, as each treatment process is pH dependent. If necessary, pH adjustment of the raw source water can be controlled chemically to maintain an optimal pH range.

Table No. 3-1
pH and Chlorine Levels at Sources

	Francis Street Wells[2]				Draper Road Wells				Knollwood Drive Wells[1]				Chickering Drive Wells[2]			
	pH		Cl_2		pH		Cl_2		pH		Cl_2		pH		Cl_2	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
January 2020	7.3	7.8	-	-	7.2	8.1	0.11	0.24	7.5	8.6	-	-	7.1	7.6	-	-
February 2020	7.2	7.6	-	-	-	-	-	-	7.5	8.5	-	-	7.3	7.6	-	-
March 2020	7.2	8.1	-	-	7.2	7.7	-	-	7.6	8.8	-	-	7.2	7.4	-	-
April 2020	7.4	8.0	-	-	7.2	8.0	-	-	7.3	8.4	-	-	7.2	7.4	-	-
May 2020	7.1	7.8	-	-	7.0	7.7	-	-	7.6	8.8	-	-	7.1	7.6	-	-
June 2020	7.0	8.4	-	-	7.0	8.9	0.11	1.7	7.1	8.4	-	-	6.9	8.9	-	-
July 2020	7.1	8.5	1.29	2.08	7.1	8.3	0.45	1.69	7.2	8.1	-	-	6.9	8.6	-	-
August 2020	7.0	7.9	1.6	2.1	7.4	7.8	0.80	1.54	7.0	8.8	-	-	6.9	7.5	-	-
September 2020	7.5	7.9	1.29	2.1	7.3	7.8	0.75	1.69	7.2	7.8	-	-	7.1	7.4	-	-
October 2020	7.3	7.7	1.3	1.86	7.3	8.4	0.69	1.57	6.8	8.45	-	-	6.8	7.5	-	-
November 2020	7.1	8.4	1.34	2.2	6.9	8.2	0.49	2.2	6.9	8.1	-	-	6.6	7.1	-	-
2020 Min. & Max.	7.0	8.5	1.29	2.20	6.9	8.9	0.11	2.20	6.8	8.80			6.6	8.9	-	-
January 2021	7.6	8.1	0.83	1.83	6.8	8.0	0.56	1.57	7.0	8.5	-	-	7.2	7.5	-	-
February 2021	7.6	8.2	0.92	1.64	7.7	8.1	0.70	1.40	7.2	8.6	-	-	7.2	7.7	-	-
March 2021	7.8	8.2	0.88	1.54	7.2	8.2	0.80	1.21	7.0	8.5	-	-	7.0	8.0	-	-
April 2021	7.6	8.1	0.92	1.56	7.5	8.3	0.78	1.37	7.2	8.1	-	-	7.2	8.1	-	-
2021 Min. & Max.	7.6	8.2	0.83	1.83	6.8	8.3	0.56	1.57	7.0	8.6	-	-	7.0	8.1	-	-

1. Knollwood Drive Wells and Chickering Drive Wells are not treated with chlorine.
2. Francis Street Wells are treated with chlorine for 4-log inactivation of viruses.

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Water Discoloration

Based on the manganese sample results indicated above, the significant amount of customer complaints over the past few years regarding water discoloration is likely due to the increased levels of manganese at the Draper Road and Francis Street wells. To note, based on the Colonial Water Company's 2020 demands, there was a significant increase in water demand from approximately 100,000 gpd to over 200,000 gpd from early May into June. This increase was likely due to seasonal irrigation, hydrant flushing, and the increase in household usage related to the COVID-19 outbreak. Recent significant increases in system demands have likely played a role in increased levels of manganese and consequently water discoloration complaints as discussed below.

The soluble manganese, which is found in groundwater, is usually in the unstable manganous (Mn^{2+}) form with an electron charge of plus two. The manganese will remain in this unstable state in groundwater because there is generally no oxygen present. However, the turbulence that occurs at the well screen and at the well pump causes atmospheric oxygen to be dissolved in the water. The manganese combines readily with this dissolved oxygen to form the insoluble precipitate, manganese dioxide.

This black colored manganese dioxide precipitate is then pumped with the well water into the distribution system. If the velocity of the water is great enough, the precipitated manganese will remain suspended in the water until it reaches the consumer's tap. Any remaining manganese that was not previously precipitated will now combine with atmospheric oxygen at the tap to form additional precipitates.

The result of these chemical reactions is often a series of complaints from consumers who report discolored water and/or black solids that are appearing in their water and stains which are appearing on their laundry. The precipitates may also attach to the interior walls of pipes or settle to the bottom of pipes in the distribution system. The accumulation of precipitates can be particularly high in areas of low flow, such as dead end water mains and large diameter water mains. The accumulated precipitates may then be resuspended or loosened from the walls of the pipes during periods of high demand or unusually high velocities, such as when a fire hydrant is opened. This resuspension will also likely result in consumer complaints in the immediate area of the high velocity and eventually in other areas of the distribution system as the material is transported through the water mains.

4.1 Treatment Options

As previously mentioned, MassDEP Drinking Water Policy (DWP) 90-04 includes requirements for water treatment piloting. The policy states that the first step required for all water treatment projects is the completion of an engineering study, as outlined in the MassDEP's Guidelines and Policies for Public Water Systems. The pilot studies required as part of the Design Engineer's Report shall include a Pilot Test Proposal, followed by pilot testing. After pilot testing, a Pilot Test Report must be submitted to the MassDEP. The Pilot Test Proposal to be submitted to the MassDEP will contain anticipated time frames for piloting, raw and finished water parameters to be analyzed, and specific analysis methods and testing intervals, as well as and proposed methods of water treatment to be piloted.

The Final Pilot Test Report will summarize the piloting events, results, water quality analyses, recommended method of treatment and cost effectiveness. Both the Pilot Test Proposal and the Pilot Test Report require MassDEP concurrence and written approval. All of the treatment options evaluated in this report will require a pilot study prior to full- scale implementation to develop a treatment method to produce water that consistently meets current and future state and federal drinking water standards, specifically to reduce manganese levels to below the SMCL of 0.05 mg/L. The pilot testing results assist in determining the specific operational and performance characteristics of a treatment process throughout the anticipated range of raw water quality, hydraulic loading, pretreatment requirements, and operational conditions. It will also assist in the preparation of budgeting more accurate estimates for capital costs, operational costs, and chemical costs for the proposed treatment facility upgrades. Therefore, piloting costs are included for each of the treatment processes.

The MassDEP has required the Colonial Water Company to evaluate options for corrective actions to address the discoloration issues within the water distribution system. This evaluation reviews three options for manganese removal/sequestration. These processes include sequestration with a blended ortho-polyphosphate, GreensandPlus™ filtration, and biological removal. A summary of the treatment processes, advantages/disadvantages, and estimated costs are presented below for each of the three manganese treatment options.

Manganese Removal - GreensandPlus™ Filtration

The GreensandPlus™ pressure filtration process removes manganese via contact oxidation. The media will be housed within pressure vessels. An oxidizing agent, such as sodium hypochlorite or potassium permanganate, is added to the raw water which is then fed through the GreensandPlus™ filters. The insoluble, oxidized manganese is removed by the media and the soluble manganese will be adsorbed onto the surface of the GreensandPlus™ media. An additional benefit of GreensandPlus™ media for removal of manganese is that it will likely reduce the amount of sedimentation and possibly reduce the chlorine demand at the facility.

Due to the small effective size of the GreensandPlus™ media, a measurable headloss is experienced across the filter as manganese adsorbs to the media. As a result, routine backwashing of the media is required. After the adsorption capacity of the media is exhausted, regeneration of the media with an oxidant, typically potassium permanganate or chlorine, is required. GreensandPlus™ pressure filtration has been used successfully in many applications around New England and in Massachusetts for iron and manganese removal to levels below the SMCLs and possibly to below detectable limits. MassDEP permitting for system modifications will be required to implement the system.

Advantages of GreensandPlus™ filtration for use in manganese removal include the following:

- GreensandPlus™ filtration will remove manganese to finished water levels below SMCLs rather than sequestering the manganese in solution, which prevents the formation of objectionable color and turbidity caused by manganese but does not remove it from the water.

- GreensandPlus™ filtration will also remove some turbidity and some organics from the raw water.
- GreensandPlus™ filtration will likely reduce the amount of sediments and chlorine demand at the facility which could reduce the current chemical costs.
- The GreensandPlus™ filtration process has a long and successful history as a treatment process for public water supplies. The tasks involved in its daily operation and maintenance are also familiar to most water treatment personnel.
- The GreensandPlus™ system's media may possibly last for ten to twenty years if carefully operated.
- The GreensandPlus™ system is simple in operation to stop/start as long as the water is not allowed to go "stale" (system down longer than 7 days).

Disadvantages of GreensandPlus™ filtration for use in manganese removal include the following:

- Capital costs cost are significantly more expensive than the use of sequestration.
- A GreensandPlus™ system will require construction of a new building at both the Francis Street Station and the Draper Road Station.
- The GreensandPlus™ process will generate residuals. Residuals and the options for treatment should be considered when selecting a removal process. There is no sewer system in Dover, MA in which to discharge backwash in that manner. Therefore, this system would require on-site treatment/holding tanks to process the backwash and residuals. There are options available to minimize the quantity of backwash produced. However, backwash management and residuals handling processes would add to the overall footprint of the treatment plant.
- The addition of a GreensandPlus™ system requires a pilot study.
- The area surrounding the Francis Street Station contains wetlands which should be considered in the overall cost of implementing a filtration system.

Manganese Removal - Biological Filtration

Biological filtration processes include biological, chemical, and physical mechanisms for removal of dissolved contaminants. During biological filtration, raw water is pumped through a pressure vessel containing a granular media. Conditions are established in the pressure vessel that foster the growth of bacteria. The naturally occurring manganese in the raw water will be consumed by the bacteria which will oxidize the manganese, which is then retained within the filter in the form of dense precipitates.

Biological filtration has many potential advantages over traditional catalytic media filtration. Biological filtration can often provide greater removal capacity per unit media volume than absorptive media. Greater media capacity would allow a more efficient filtration process with an increase in iron and manganese levels. MassDEP permitting for system modifications will be required to implement the system.

Advantages of biological filtration for use in manganese treatment include the following:

- Biological filtration will remove manganese to finished water levels below SMCLs rather than sequestering the manganese in solution, which prevents the formation of

objectionable color and turbidity caused by manganese constituents but does not remove it from the water.
- The biological filtration media may possibly last for five to twenty years.

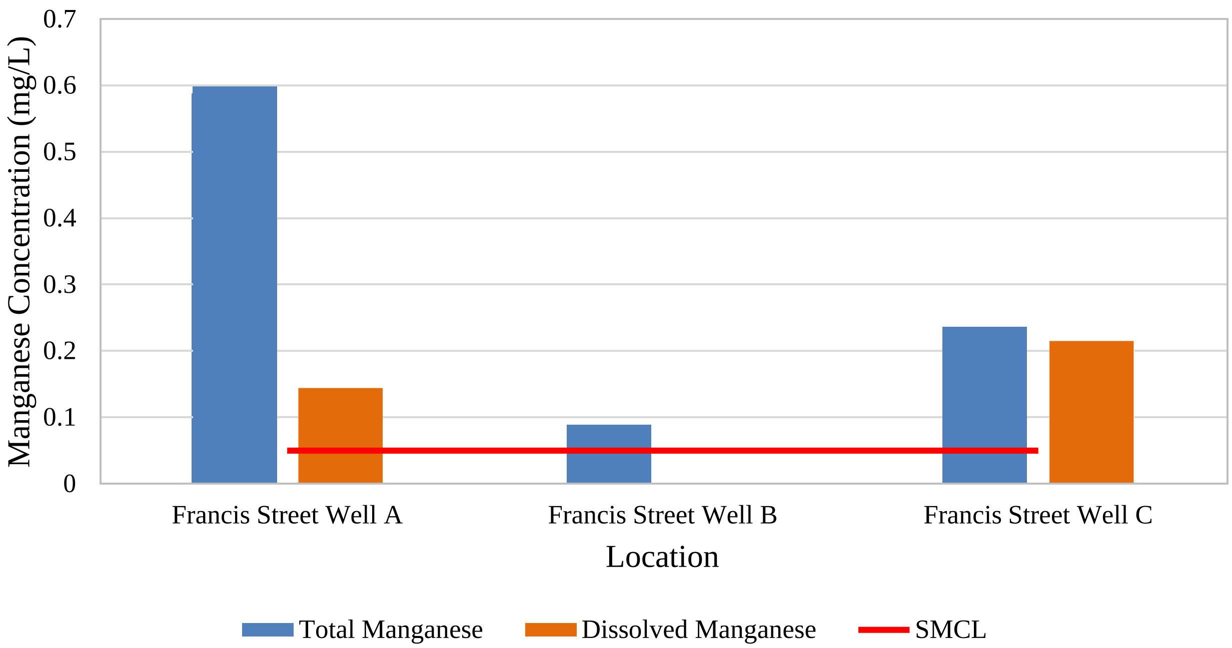
Disadvantages of biological filtration for use in manganese treatment include the following:
- Capital costs, annual operation, and maintenance costs are significantly more expensive than the use of sequestration.
- The biological filtration system will generate residuals. Residuals and the options for treatment should be considered when selecting a removal process. There is no sewer system in Dover, MA in which to discharge backwash in that manner. Therefore, this system would require on-site treatment/holding tanks to process the backwash and residuals. There are options available to minimize the quantity of backwash produced. However, backwash management and residuals handling processes would add to the overall footprint of the treatment plant.
- A biological filtration system will require construction of a new building at both the Francis Street Station and the Draper Road Station.
- The addition of a biological filtration system requires a pilot study.
- Biological filters are much more sensitive to duty cycle. For example, if a filter is only run a few hours per day, it is very unlikely that biological filtration will be successful. If the filters operate greater than 12 hours per day, biological filters will start having success.
- The area surrounding the Francis Street Station contains wetlands which should be considered in the overall cost of implementing a filtration system.

The granular media used for biological filtration may be sand, or sand with an anthracite cap depending on raw water levels of iron and manganese. Since there are no issues with iron at the Colonial Water Company sources, it is recommended to use silica sand for the granular media.

Manganese Removal - Sequestration

Sequestration is a form of treatment in which a chemical, known as a sequestering agent, forms a bond around the manganese ions, allowing them to remain in solution. Sequestering agents complex manganese, or Mn (II), to prevent oxidation/precipitation, and subsequent water quality problems, associated with manganese. Sequestration does not remove the manganese from the water as GreensandPlus™ filtration or biological treatment do. Rather, it remains in solution. Based on the most recent raw water quality data for the Francis Street Wells, shown in Figure 4-1, the majority of the manganese is in the oxidized form. Sequestering is only an option when most of the manganese is in the dissolved form. In addition, the manganese levels in the Francis Street Wells are too high for sequestration. Above levels of 0.21 mg/L, the MassDEP would likely not approve of it at the Francis Street Wells. They will want to see the manganese "removed" from the system and consistently, and reliably, removed to below 0.3 mg/L. Therefore, this option is ruled out for the Francis Street Wells.

Figure No. 4-1
Manganese Laboratory Testing – Total vs. Dissolved Manganese
Francis Street Wells – Raw Water



Additional sampling of the raw water is being collected by the Colonial Water Company for the Draper Road wells. This includes an analysis of total vs. dissolved manganese, as was recently done for the raw Francis Street Wells. Since the Draper Road wells are onlypermitted for a daily pumping volume of 0.08 MGD, it would likely be cost prohibitive toinvest in sequestering at that location. In addition, the laboratory reports for the Draper Road Wells may also indicate that the majority of the manganese is in the suspended form, which would rule out sequestering at the Draper Road Station.

5.1 Costs

The costs associated with the three systems evaluated are presented in the tables below forthe Francis Street Station. Treatment through the use of GreensandPlus™ and biological filtration is cost prohibitive at the Draper Road Station, especially since it is a small source. For GreensandPlus™ filtration, or biological filtration, at the Draper Road Station, the system would cost an estimated $1,000,000 for either system.

Manganese Removal - GreensandPlus™ Filtration

Table No. 5-1
Total Estimated Capital Costs - GreensandPlus™ Filtration

Description	Estimated Cost Francis Street Station
CMU Building, Mechanical, Doors and Windows, Roofing, Waterproofing, Finishes, Specialties	$300,000 (3, 8 Foot Diameter Filters)[1]
Structural Steel and Metals	$40,000
Foundation and Backwash Tank	$200,000
Site Work	$40,000
GreensandPlus™ Filtration Equipment and Appurtenances, Chemical Feed Equipment	$600,000
Electrical with Possible Service Upgrade	$250,000
Instrumentation, SCADA, Integration	$70,000
Subtotal	$1,500,000
Contractor Overhead & Profit (15%)	$225,000
General Conditions, Bonds, Insurance (15%)	$225,000
Pilot Plan, Study, and Report for GreensandPlus™ Filtration	$90,000[2]
Engineering (Design, Permitting, Bidding, Construction Services) and Contingency (25%)	$375,000
GreensandPlus™ TOTAL ESTIMATED PROJECT COST	**$2,465,000**[3,4,5]

[1] Each system consists of three filters. One of the filters is provided for redundancy.
[2] The pilot study cost represents piloting of both the GreensandPlus™ and biological filtration together as one pilot study. Therefore, the cost is only carried in this estimate.
[3] Chemical costs are not included. Chemical needs will be determined through the pilot study.
[4] Does not include operation and maintenance costs. These values will be determined through the pilot study.
[5] Backwash management and disposal costs are not included.

Manganese Removal - Biological Filtration

Table No. 5-2
Total Estimated Capital Costs - Biological Filtration

Description	Estimated Cost Francis Street Station
CMU Building, Mechanical, Doors and Windows, Roofing, Waterproofing, Finishes, Specialties	$300,000 (3, 8 Foot Diameter Filters)[1]
Structural Steel and Metals	$40,000
Foundation and Backwash Tank	$200,000
Site Work	$40,000
Biological Filtration Equipment and Appurtenances, Chemical Feed Equipment	$600,000
Electrical with Possible Service Upgrade	$250,000
Instrumentation, SCADA, Integration	$70,000
Subtotal	$1,500,000
Contractor Overhead & Profit (15%)	$225,000
General Conditions, Bonds, Insurance (15%)	$225,000
Pilot Plan, Study, and Report for Biological Filtration	$0[2]
Engineering (Design, Permitting, Bidding, Construction Services) and Contingency (25%)	$375,000
GreensandPlus™ TOTAL ESTIMATED PROJECT COST	**$2,375,000**[3,4,5,6]

[1] Each system consists of three filters. One of the filters is provided for redundancy.
[2] The pilot study cost represents piloting of both the GreensandPlus™ and biological filtration together as one pilot study. The total cost of piloting both systems was included in the GreensandPlus™ cost estimate above.
[3] Chemical costs are not included. Chemical needs will be determined through the pilot study.
[4] Does not include operation and maintenance costs. These values will be determined through the pilot study.
[5] Backwash management and disposal costs are not included.
[6] Does not include land acquisition costs.

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6.1 Conclusions and Recommendations

When comparing the three systems evaluated for treatment/removal of manganese, it is clear that sequestration is not an option for the Francis Street Wells. Sequestering would not be effective because the manganese levels are too high, and most of the manganese is in the oxidized form. Sequestration at the Draper Road Station is possible if most of the manganese is in the dissolved form. The Colonial Water Company has collected samples from the Draper Road Wells to determine this and are waiting for the laboratory results. However, since Draper Road has a very small capacity, sequestering will likely be cost prohibitive.

One disadvantage to sequestration is that it does not remove the manganese from the water. Rather, it keeps the manganese in suspension. There is the possibility that the manganese can be converted back to its insoluble form in the far reaches of the distribution system. This would result in more customer complaints. In addition, the chemistry of the water system will change with the addition of the ortho-polyphosphate. When the full-scale system is initially implemented, most of the manganese buildup that is on the pipe walls in the distribution system will break loose. Significant flushing of distribution system water mains will be necessary to minimize this problem. However, the water main flushing will likely lead to additional customer complaints. Even with pilot testing, it still may not be known how the distribution system will "react" to the new water chemistry. Therefore, this is possibly a significant risk in choosing sequestration as an investment in pilot testing could be lost if a full-scale system is implemented and is not effective. Finally, the raw water manganese must be in the dissolved form to consider this option.

The costs of the GreensandPlus™ and biological treatment for the Francis Street Station are essentially the same, at approximately $2,400,000, because they will each use the same tank sizes and general equipment. The only difference is due to the piloting cost, which was only carried in the GreensandPlus™ estimate. To pilot both systems, the total cost would be approximately $90,000. The GreensandPlus™ system is a widely proven application for removal of manganese to below the SMCL. The system may also reduce some sediments from the raw water, which could reduce chlorine demands and thereby result in lower disinfection chemical costs. The GreensandPlus™ system is more flexible in operation than biological filtration because it can be used intermittently if a source is offline for up to one week. A GreensandPlus™ system or a biological system will require construction of a new building at the Francis Street Station. Residuals will be produced from system backwashing from both systems. There is no sewer system in Dover, MA in which to discharge backwash in that manner. Therefore, this system would require on-site treatment/holding tanks to process the backwash and residuals. There are options available to minimize the quantity of backwash produced. However, backwash management and residuals handling processes would add to the overall footprint of the treatment plant.

Biological filtration can provide a greater degree of manganese removal capacity than GreensandPlus™ systems which could become important if manganese levels continue to trend upward at the sources. The biological systems are also a widely proven application for removal of manganese to below the SMCL. However, a biological filtration system is very sensitive to intermittent usage. The microorganisms cannot go more than ten to twelve hours without a food source. Therefore, the biological system should only be utilized in applications where the system will be used on a more frequent and consistent basis.

Our recommendations are as follows:

1. It is recommended that the Colonial Water Company perform a feasibility study which will focus on the possibility of further utilizing the Knollwood Drive source where there are no manganese issues. The maximum daily withdrawal volume permitted from the Knollwood Drive Station is 0.43 MGD. The study would include an evaluation of the capacity of the existing pump at the Knollwood Drive Station.

   The Knollwood Drive Station currently only feeds the downtown area of Dover. There is a pressure reducing valve (PRV) between the downtown distribution system and the main Dover distribution system. The Colonial Water Company could utilize their hydraulic model and historical data as an aid in evaluating the feasibility of utilizing the Knollwood Drive Station to feed both the downtown area it currently serves as well as to feed the main Dover system. As mentioned above, the capacity of the existing pump at the Knollwood Drive Station should be evaluated to determine if it can produce 300 gpm. Since sequestration is not a viable option at the Francis Street Station, reliance on the Knollwood Drive Station could be the most expeditious solution to the manganese problem.

   This study should include a cost/benefit analysis which takes the cost of treatment at the Francis Street Wells, and possibly sequestering at the Draper Road Wells, into account. The GreensandPlus™ system or biological filtration may be determined to be cost prohibitive for the Francis Street Wells. In addition, sequestering may not be an option at the Draper Road wells if most of the manganese is determined to be in the suspended form.

   In conjunction with this study, the Colonial Water Company may consider evaluating the option of connecting the Chickering Drive Station to the main Dover water system. However, as a result of the long distance from the Chickering Drive Station to the main Dover system, it may be determined to be cost prohibitive. Finally, this study could also evaluate the possibility of utilizing an existing inter-connection which exists between the Dover water distribution system and the Springdale distribution sys

2. It is recommended that the Colonial Water Company perform a cost/benefit analysis for the continued use, and possible treatment of, the Draper Road Station. Since this is a very small source, with high levels of manganese, it may be beneficial to use the other wells in the system. This source is only approved to withdraw 0.08 mgd. In addition, a 4-log system is required to be installed at the Draper Road Station. The results of the above-mentioned feasibility study and cost/benefit analysis may indicate that these funds could be better utilized in implementing the use of the Colonial Water Company's sources which are not currently experiencing elevated levels of manganese.

3. It is recommended that the Colonial Water Company perform a comprehensive review

of pH and chlorine levels, both at the wells and in the distribution system. Consideration should be given to converting from constant speed well pumps and chemical feed pumps to flow paced pumps for the wells, potassium hydroxide and sodium hypochlorite feed systems. Developing a consistent, and optimal, pH range and chlorine residual will help stabilize the water in the distribution system. This could lead to less customer complaints in the future.

4. It is recommended that the Colonial Water Company collect water samples from a few extremities of the distribution system and from each raw water source to further evaluate the water chemistry of the system. This would include, at a minimum, raw water pH, raw water alkalinity, and raw water hardness.

5. The Colonial Water Company will be analyzing their system's hydraulic model. This includes an evaluation of flushing practices and development of a unidirectional flushing program. This will likely significantly reduce the oxidized manganese from the system. This analysis will also include the possibility of adding an elevated tank to the system. Ice pigging may be an option to remove the manganese from the distribution system piping.

At this time, we wish to express our appreciation to the Colonial Water Company for their participation in this evaluation and for their help in collecting information and data. We appreciate the opportunity to assist the Colonial Water Company on this important project.Should you have any questions or require additional information please do not hesitate to contact our office.

Sincerely,

TATA & HOWARD, INC.

Jennifer M. Werner

Jennifer M. Werner
Project Manager

TATA & HOWARD

Water Distribution System
Colonial Water Company
Dover, Massachusetts

TATA & HOWARD

Approximate Scale: 1" = 1,300'

September 2021