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Hanover, Massachusetts
Project Number 2150458

October 29, 2015

Victor Diniak
Director of Public Works
40 Pond Street
Hanover, MA 02339

Re: Total Trihalomethane (TTHM) Reduction for the Hanover Water System

Mr. Diniak:

We are pleased to provide you with our letter report reviewing alternatives to reduce TTHMs in the Hanover Water System. In June 2015, the Town exceeded the TTHM maximum contaminant level (MCL) of 80 ppb with a locational running annual average (LRAA) of 84.3 ppb at the 70 Ponderosa Drive sample site. Because of this exceedance, the DEP required that Hanover conduct an evaluation of TTHM reduction in the water system.

Water System Description

The Hanover water system consists of about 110 miles of pipeline. Distribution storage facilities include three tanks with a total of 3.63 million gallons (mg) of storage. Information on the tanks is provided in Table 1 below. Currently, none of the tanks have mixing systems.

Table 1 – Distribution Storage

Tank	Height (ft)	Diameter (ft)	Volume (MG)	Year Built
Union Street 1	123	30	0.63	1932
Union Street 2	119	55	2.0	1971
Walnut Hill	89	44	1.0	1965

The Town of Hanover maintains three groundwater treatment plants (WTPs) that treat water from 9 well sources. All the well sources in the Town are treated at one of these three WTPs. The three plants include the Pond Street WTP built in 1973, the Beal WTP built in 1994 and the Broadway WTP built in 2001.

The Pond Street WTP is a conventional filtration plant that uses aluminum sulfate for coagulation to remove iron, manganese, color and turbidity. The Pond Street WTP received a major upgrade in 1992 and has had incremental upgrades since that time. The source of water for the Pond Street WTP includes three gravel-packed wells, Pond Street Wells 1, 2 and 3. Pond Street Well 1 was installed in 1943 and Pond Street Wells 2 and 3 were installed in 1975.

The Beal WTP is a manganese greensand pressure filtration facility that removes iron, manganese and radon, followed by air stripping. The source of water for the Beal WTP includes two bedrock wells, Beal Wells 1 and 2, both installed in 1994.

The Broadway WTP is a manganese greensand pressure filtration facility that removes iron, manganese and small amounts of color. An induced draft aerator is used prior to filtration. The source of water for the Broadway WTP includes four gravel-packed wells, Hanover Street Wells 1 and 2 installed in 1960, and Broadway Wells 1 and 2 installed in 1965. Currently Hanover Well 2 is offline due to poor water quality.

Water Quality

Hanover began monitoring for TTHMs under the Stage 2 Disinfection Byproduct (DBP) Rule in December 2013. Prior to that date, Hanover monitored TTHMs under the Stage 1 DBP Rule. There have been eight quarters of monitoring at four distribution sites under the Stage 2 DBP Rule, as shown in the Table 2 below.

Table 2 - Stage 2 DBP Rule TTHMs (ppb)

Location Name	Address	Dec 2013	Mar 2014	Jun 2014	Sep 2014	Dec 2014	Mar 2015	Jun 2015	Sep 2015
Fire Station #3	925 Circuit St	67.8	39.7	46.2	53.3	72.4	77.2	42.1	34.8
70 Ponderosa Dr	70 Ponderosa Dr	79.4	51.0	78.0	73.4	**86.3**	80.0	**97.5**	**82.7**
Computer Center	2055 Washington St	51.6	26.3	**84.2**	44.5	77.7	30.6	65.7	46.6
Hanover Fitness	33 Rockland St	74.2	74.3	40.3	**80.5**	57.0	**80.2**	76.6	8.0

Under the Stage 2 DBP Rule, compliance is now determined using quarterly locational running annual averages (LRAA), rather than a quarterly system-wide running annual average. LRAAs under the Stage 2 DBP Rule are shown in Table 3 below, starting with September 2014, which include five quarters of sampling data. The MCL is 80 ppb for the LRAA for TTHMs. The June and September 2014 LRAA for 70 Ponderosa Drive were exceedances of the MCL and are shaded and shown in bold. For reference, the individual site TTHMs in Table 2 that are over 80 ppb are also shaded and shown in bold.

Table 3 - Stage 2 DBP Rule LRAAs for TTHMs (ppb)

Location Name	Address	Sep 2014	Dec 2014	Mar 2015	Jun 2015	Sep 2015
Fire Station #3	925 Circuit St	51.8	52.9	62.3	61.3	56.6
70 Ponderosa Dr	70 Ponderosa Dr	70.5	72.2	79.4	**84.3**	**86.6**
Computer Center	2055 Washington St	51.7	58.2	59.3	54.6	55.15
Hanover Fitness	33 Rockland St	67.3	63.0	64.5	73.6	55.45

Historically, individual site TTHMs for both the 70 Ponderosa Drive (Ponderosa), Hanover Fitness, and the Computer Center sampling sites have exceeded 80 ppb at times. The single excursion for the Computer Center seems to be an anomaly. Historically, the Hanover Fitness site has had TTHM results near 80 ppb. Recently, we assisted the Town in investigating the higher TTHMs at the Hanover Fitness site, because the water age in this area is low, and there are good chlorine residuals (also indicating low water age); therefore, we would expect that the TTHM results at this site should be lower than they have trended since December 2013. This site is also close to the Broadway WTP, which would also indicate younger water age. A sample taken from a site across the street (58 Rockland Street) from Hanover Fitness had a TTHM level of 7.1 ppb, so we would expect that the TTHM level across the street would be similar. After investigating, the Town discovered issues with the service lines into the building. The service line was flushed about 10 days prior to the September 2015 TTHM sample date and the resulting TTHM level for September 2015 was 8.0 ppb. The Town will work with Hanover Fitness to reconstruct the service line in 2016. Until the service line is reconstructed the Town will continue the practice of flushing the service line 10 days prior to the TTHM sampling date.

The Ponderosa site has always been elevated, however, recently this site exceeded the 80 ppb TTHM LRAA requirement of the Stage II DBP Rule. The more stringent Stage II DBP Rule requires LRAA compliance at each site, rather than under the Stage I DBP Rule, where compliance was determined by averaging all sites in the distribution system. The Ponderosa site is near the end of the distribution system in the northwest part of the system and has high water age and low chlorine residual which often occurs at elevated TTHM sites. We used the distribution system computerized hydraulic model to conduct a source trace of the water that reaches Ponderosa; under most circumstances all of this water is from the Pond Street WTP. Based on this, our focus for TTHM removal techniques will be on the Pond Street WTP.

As is well documented, TTHMs are developed by chlorinating organics in the raw water. One way to measure organics in the water is by measuring total organic carbon (TOC). Table 4 shows TOC statistics for Pond Street and Broadway. Figure 1 shows the detailed TOC data for Pond Street and Broadway. The Pond Street data was sampled between June 2014 and August 2015. The Broadway data was sampled between March and August 2015.

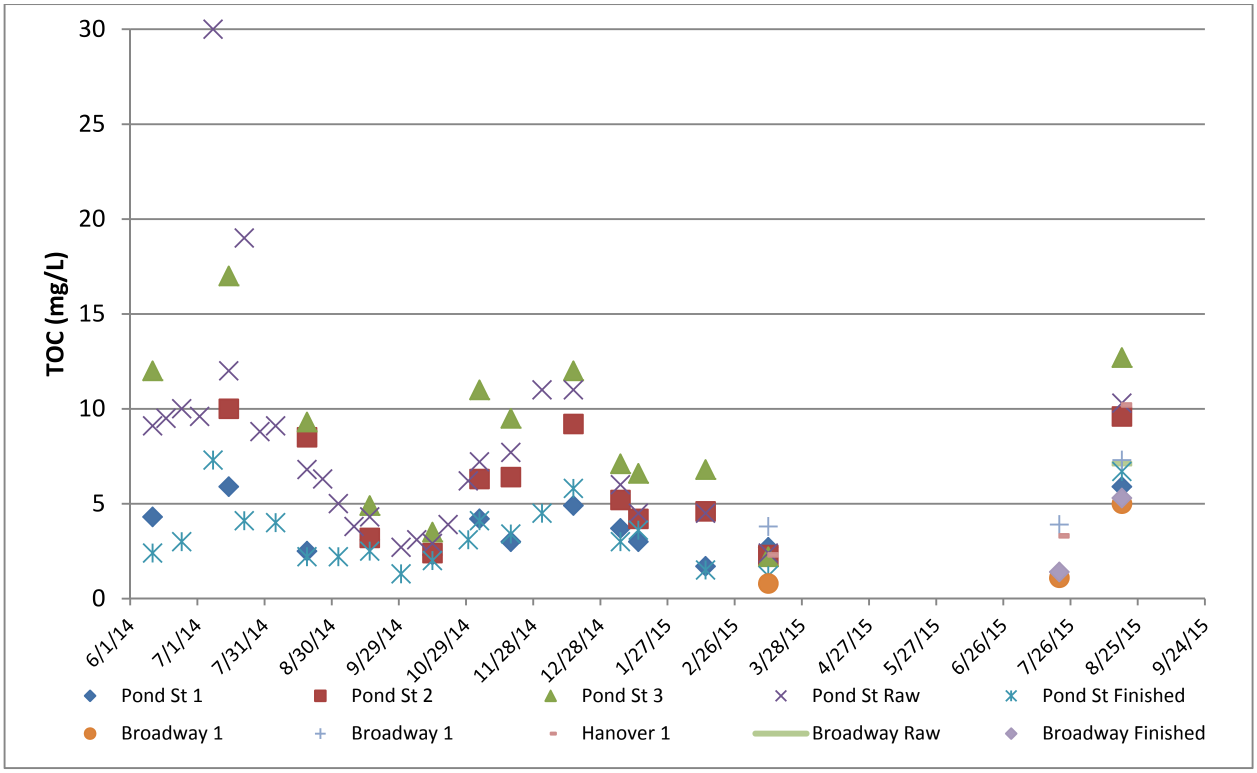
From the TOC data for Pond Street, we can conclude that Pond Street Well 3 consistently has the higher level of TOC of the three Pond street wells. Also, as may be expected the TOC at Pond Street is typically higher around July.

Table 4 - TOC (mg/L)

DATE	Pond St 1	Pond St 2	Pond St 3	Pond St Raw	Pond St Finished	Broadway 1	Broadway 1	Hanover 1	Broadway Raw	Broadway Finished
No. of Samples	13	12	13	28	20	3	3	3	1	2
Average	3.6	6.0	8.8	8.1	3.4	2.3	5.0	5.3	7.1	3.4
Maximum	5.9	10.0	17.0	30.0	7.3	5.0	7.3	10.2	7.1	5.3
Minimum	1.7	2.3	2.2	2.4	1.2	0.8	3.8	2.3	7.1	1.4

In order to determine the level of TTHMs that are generated at the Pond Street WTP, on March 17, 2015 Hanover sampled TTHM levels at the clearwell effluent and from the 100-foot sample line. The results were 4.6 ppb and 12.0 ppb, respectively. The Pond Street WTP TOC data from March 2015, shows that TOC levels were relatively low which would likely cause the TTHM levels to be low. We recommend that Hanover sample their three WTPs for TTHM levels for a one-year period at least quarterly at the same time the distribution TTHM samples are taken.

Figure 1 – TOC Data



TTHM Reduction Alternatives

In this section, we provide information on TTHM reduction alternatives, as listed below.

- Source/WTP flow optimization
- MIEX resin pretreatment
- Ozone
- Alternative coagulants at the Pond Street WTP
- Post-filtration granular activated carbon (GAC)
- Chloramination
- Distribution system tank mixing
- Distribution system tank TTHM air stripping

In Table 5, we have provided screening criteria to evaluate the previously mentioned alternatives. The main purpose of this table is to provide relative information on the eight alternatives to Hanover. After meeting with the Town, we agreed that the four most viable alternatives were ozone at the Pond Street WTP, an alternative coagulant at the Pond Street WTP, post-filtration GAC at the Pond Street WTP, and full-system chloramination. Following this section, we will provide cost estimates for these four alternatives.

Table 5 – Screening Matrix for TTHM Alternatives

Technique /Technology	Reduction of TTHMs	Ease of Implementation	Time to Completion	Relative Capital Cost	Relative Operational Cost	Comments
Source/WTP flow optimization	◆	◆◆	◆◆◆	◆◆◆	◆◆◆	Not easily practiced during high demand periods when TOC is higher
MIEX resin pretreatment	◆◆					High cost, sole source provider. Evaluate for use at Pond St WTP only.
Ozone	◆◆					High Cost. Evaluate for use at Pond St WTP only.
Alternative coagulants	◆	◆◆	◆◆◆	◆◆◆	◆◆◆	Evaluate for use at Pond St WTP only.
Blended post-filtration GAC	◆◆	◆		◆		Evaluate for use at Pond St WTP only.
Chloramination	◆◆	◆◆	◆◆	◆◆	◆◆	Cost effective technology for reducing TTHMs. Need to monitor system for nitrification.
Distribution system tank mixing		◆◆◆	◆◆◆	◆◆◆	◆◆◆	Limited reduction in TTHMs, but will help to provide better overall water quality
Distribution system tank TTHM air stripping	◆◆	◆◆	◆◆	◆◆	◆	May not be required for all tanks.

◆ Denotes a positive criteria
◆◆◆ Denotes most advantageous
No entry denotes a negative rating

Source/WTP flow optimization

During the lower-demand winter months and otherwise when possible, the Town has reduced the flow from the high-TOC wells, particularly Pond Street Well 3. In addition, Hanover Well 2 which has elevated organic levels, is rarely used. The Town will continue to follow this practice when possible. One further option could be to complete further groundwater evaluations to search for low-TOC sources. However, this will take a significant effort and cost and may not lead to any significant gain, if these sources cannot be found.

MIEX resin pretreatment

MIEX is a relatively new pretreatment technology that, in some cases, can significantly reduce TOC. The MIEX system utilizes a resin which absorbs the TOC, requiring a clarifier to filter out the resin and a brine to recharge the resin. It is typically used with surface water supplies. However, it has been used with some groundwater treatment, both before and after filtration. If it is used after filtration it is likely that a polishing filter would be required to remove any residual resin. It is a proprietary system and generates a brine waste that would need to be disposed of. There are high capital and operating costs associated with this technology. Hanover could consider the more economical alternative of constructing this system at a lower capacity than the current WTP.

A side-stream flow of water could be treated with MIEX and then blended back in. During certain times of the year, the Town could consider taking the MIEX system offline.

The system may not remove some types of NOM which means piloting is necessary for design and also necessary to determine if it would be incorporated before or after filtration. The MIEX system and disposal of the brine are both costly.

Ozone

Ozone is a complex pretreatment system that is costly to construct and to operate. Ozone (O_3) is both a strong oxidant and an effective disinfectant. Ozone very effectively removes tastes, odors, and color in water. It also oxidizes organic substances, which can reduce the formation of DBPs depending on its placement in the treatment plant process. Other benefits of ozone include improved coagulation, which lowers the costs of coagulant chemicals and sludge disposal, reduction of chlorine demand, and removal of iron, manganese, and sulfide.

Because ozone is an unstable molecule, it is generated at the point of application for use in water treatment. Ozone can be generated on site by means of a generator that converts oxygen gas into ozone through a uniformly charged air space with electrical energy. As a result, chemical storage and delivery are not needed if air is used as the source of oxygen. Liquid oxygen can also be used as the oxygen source for this application. Ozone generation requires considerable energy input and can significantly raise electrical costs.

Ozone is bluish, toxic gas with a pungent odor that is hazardous to health at relatively low concentrations in air: the threshold odor level is 0.05 ppm and the 8-hour OSHA standard is 0.1 ppm. Therefore, destruction of the off-gas ozone is necessary for safety reasons. Once the ozone has been produced, it is diffused through the raw water without being consumed, and is captured and converted back to oxygen gas before being released to the atmosphere. Three methods that may be used to eliminate off-gas are thermal destruction, thermal/catalytic destruction and catalytic destruction. The use of ozone may produce bromate, a disinfection byproduct (DBP) that also has adverse health effects. Although this is not likely to be a concern with Hanover’s water sources, monitoring for bromate would be required.

Ozone is chemically unstable and leaves no residual. Therefore, it is necessary to use chlorine or chloramines to maintain a disinfectant residual in the distribution system.

Ozone can oxidize organics and form simple organic compounds that commonly appear as biodegradable dissolved organic compounds (BDOC) or assimilated organic carbon (AOC). These compounds can contribute to the growth of biofilms in the distribution system. Typically, this is not a problem if some form of filtration follows the ozone process. Ozone may be added as a first step to the treatment process prior to rapid mix, or after sedimentation. Many times it is used upstream of GAC filters. Pilot testing would indicate the optimal location.

Alternative Coagulant at the Pond Street WTP

Polyaluminum chloride (PACl) is an alternative coagulant which may increase TOC removal and provide better-settled turbidity. Other potential advantages of PACl include reducing settled turbidity which may reduce backwash frequency of the filters, reduction of the coagulant dose and lower production of treatment residuals that are more easily handled. PACl, however, is typically more expensive than alum.

Hanover conducted jar testing of several alternative coagulants (2011) and full scale pilot testing using the PACl PCH-180 (2012) at the Pond Street WTP. The focus of this work was to reduce the aluminum content of the water treatment residuals due to changes with the US EPA NPDES General Permit for discharges from potable WTPs.

During the jar testing phase of the evaluation, iron-based coagulants were eliminated as good options because the current coagulant, aluminum sulfate (alum) performed better. Alum was then compared to two PACl blends. Of the two PACl blends tested, PCH-180 performed the best and also provided greater UV-254 removal (a surrogate for organic content) than alum. Based on the results of the jar tests the Town conducted a full-scale pilot test using PCH-180. The full-scale testing showed that PCH-180 improved organic removal, but operational costs would be 3% greater than alum.

Post-filtration GAC

GAC is very effective in removing organics prior to the addition of chlorine. However, it is very costly on both a capital and operational basis. This technology would be most appropriate for the Pond Street WTP and would follow after filtration. The existing filters do not have the capacity to be retrofitted with an adequate depth of GAC and sand. Hanover may want to consider the more economical alternative of constructing this system at a lower capacity than the current WTP. A side-stream flow of water could be treated with GAC and then blended back in. During certain times of the year, the Town could consider taking the GAC offline.

Chloramination

The disinfection method of chloramination uses ammonia and chlorine to generate chloramines, which maintain a disinfectant residual in the distribution system. The optimum ratio of chlorine to ammonia-nitrogen used for generating chloramines for drinking water is between 3:1 and 5:1. Higher ratios begin to generate di- and tri-chloramines which can cause taste and odor problems. Lower ratios allow free ammonia into the distribution system and can cause nitrification. There has been some research that shows that biofilms are more sensitive to inactivation by chloramination than chlorination. Several communities in Massachusetts have started chloraminating over the past 5 to 10 years to lower TTHMs. Also, water supplied by the MWRA is chloraminated.

The major advantage of chloramine disinfection is the reduction of TTHM levels as water ages through the distribution system. Generally, chloramine application tends to "freeze" the level of TTHMs for the source it is applied to, so that the TTHMs do not increase significantly for that specific source. Other benefits include reduced taste and odor, potential inactivation of biofilms in the distribution system, and greater resistance to decay than chlorine.

Disadvantages of chloramines are potential nitrification in the distribution system which could lead to a violation of the Total Coliform Rule, and more complicated operation and higher costs than chlorine. NDMA, which is a disinfectant byproduct, may also be a byproduct of chloramination, however it is not currently regulated by the EPA. There are some systems where HAA5 levels have increased when chloramination replaced chlorination.

Sources of ammonia would be required at all WTPs for chloramination. There are four sources of ammonia including anhydrous ammonia, ammonium hydroxide, granular ammonium sulfate, and liquid ammonium sulfate. Anhydrous ammonia is in gaseous form and must be stored in a pressurized container. We would recommend the use of liquid ammonium sulfate as it is the safest and easiest form of ammonia to handle.

Distribution System Tank Mixing

Distribution system tank mixing systems are relatively inexpensive for most locations and are helpful in maintaining overall better water quality in a tank. However, they will not remove TTHMs from the water.

Distribution System In-Tank TTHM Removal

As previously mentioned, TTHMs increase as the water ages in the distribution system and also in water storage tanks. THM's are volatile compounds that can be removed from water by aeration. There are several manufacturers that have aeration systems that can be installed in water storage tanks to reduce TTHMs. Aeration technologies currently in use in the drinking water industry include:

- Fixed spray aeration
- Floating spray aeration
- Diffused bubble systems

The best removal efficiencies have been by spray aeration and surface aerators (45 to 50 percent removals). Although, this technology is not a new technique for removing chloroform (the major portion of TTHMs), it does not have a lot of history of use in drinking water systems. There are two aeration technologies that are most prevalent, the GridBee floating spray nozzle technology by Medora Corporation and a fixed spray nozzle system by PAX. A minimum head space above the water level in the reservoir is needed to allow the THMs to volatilize and then by use of ventilation fans, exhausted into the atmosphere.

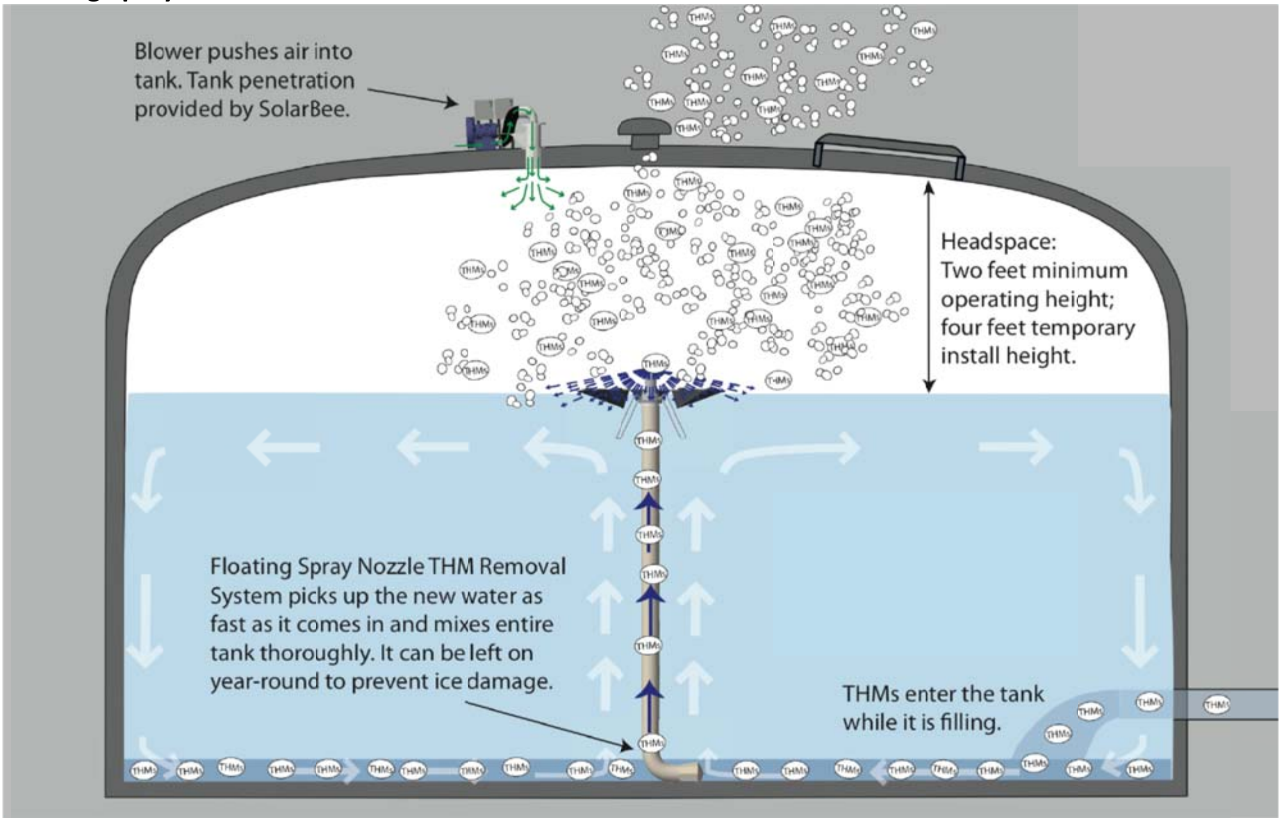
Should the Town proceed with this alternative, we recommend conducting a monthly sampling program of TTHM levels from water flowing out of their storage tanks. This data will allow the Town to make a more educated decision regarding effectiveness of in-tank TTHM removal systems at each tank.

The GridBee system has been installed at two sites in New England, in Connecticut for Foxwoods and the Connecticut Water Company in Stafford Springs. One system was installed at each site (on a rent to own basis) and both water suppliers bought the systems based on positive performance, but they are also purchasing systems for other tanks. The basis of design for each application by the manufacturer is for a minimum of 40% reduction in TTHMs from water in to water out. A minimum two-foot head space above the water level in the tank is needed to allow the TTHMs to volatilize and then by use of ventilation fan(s), exhausted into the atmosphere.

The GridBee system has DEP New Technology Approval based on the DEP's review of references from Connecticut, New York, California, Ohio and other states.

The fixed spray aeration system that is manufactured by PAX requires installation of many spray nozzles within a tank. This system does not appear to have as in-depth a track record as the GridBee system. Also, the maintenance of what could be many fixed spray nozzles (20-50 depending on tank configuration) could be problematic as the system ages.

Floating Spray Aeration Schematic



Fixed Spray Aeration

Cost Estimates

Estimated costs are present day costs including design, bidding, construction administration, construction, and contingency. For budgeting purposes, we apply 50% of the construction cost for design, bidding, construction administration, and contingency. Weston & Sampson follows the American Association of Cost Engineer's guidelines for a cost estimating classification system. Typically there are three cost estimating stages of water engineering projects, including the conceptual/evaluation estimate, the pre-design estimate and the final design estimate. The estimates provided in this report are at the conceptual level. The table below summarizes the expected range of accuracy for each of the three typical phases of a project.

Table 6 - Cost Estimation Classifications

Project Maturity Level	Low Range of Expected Accuracy	High Range of Expected Accuracy
Conceptual	-15% to -30%	+20% to +50%
Pre-Design	-10% to -20%	+10% to +30%
Final Design	-3% to -10%	+3% to +15%

Table 7 below presents the estimated capital costs for the four selected alternatives, as well as including tank mixing in the three water storage tanks which Hanover will install to improve tank water quality. As expected the capital cost for ozone at the Pond Street WTP is the highest of the four alternatives. The capital cost for conversion from aluminum sulfate to PACl at the Pond Street WTP is the lowest, however, although this alternative will likely reduce TTHMs from the Pond Street WTP, it will likely not be significant enough for TTHM compliance.

Table 7 – Estimated Capital Costs

Technique /Technology	Estimated Cost	Notes
Ozone at Pond Street WTP	$4,500,000	Cost does not include conversion to GAC filtration
PACl at Pond Street WTP	$200,000	Cost includes replacement of aluminum sulfate tank, pumps and controls
Blended post-filtration GAC at Pond Street WTP	$2,400,000	Cost includes two pressure filtration vessels to take 50% of flow and a new pre-engineered building. Operational costs are high and estimated at $120,000 to $180,000 annually depending on the frequency of carbon replacement necessary.
Chloramination (Ammonium Sulfate at 3 WTPs)	$1,000,000	Cost includes ammonium sulfate systems at 3 WTPs and sodium hypochlorite modifications at the Broadway WTP.
Distribution system tank mixing	$200,000	Cost for mixing systems at all three water tanks

Recommendations and Schedule

Based on our evaluation of the alternatives and working sessions with the Town, we recommend Hanover proceed with conversion to PACl at the Pond Street WTP and chloramination at all plants. Hanover will submit the design to the DEP and will also prepare a chloramination start up plan and nitrification action plan. Hanover has also committed to installing tank mixing systems in their three water storage tanks to help promote better water quality in the tanks.

In our working sessions with the Town, the GAC alternative at the Pond Street WTP ranked high, but was not selected due to the higher capital and operational costs. The Town may reconsider this alternative in 10 to 20 years after other water system improvements have been constructed.

It will be important to coordinate this design and construction work with other work to be determined under the WTP Capital Improvements Program (CIP). As part of the WTP CIP, it is likely that Hanover will replace the chlorine gas systems at the Pond Street and Beal WTPs with sodium hypochlorite.

The schedule for the design and construction of the improvements is outlined below. The total project duration is 22 months. This work can be completed prior to the ACO requirement for completion of improvements of July 2, 2018.

	Duration
Design	6 months
DEP Review	2 months
Bidding & Award	4 months
Construction	10 months

The Town will continue to practice the short-term action items detailed in their letter to you dated July 31, 2015 until the recommended alternative is constructed and online.

Thank you for this opportunity to serve the Town of Hanover. Please contact me or William Nunnery if you have any questions regarding this report.

Sincerely,

WESTON & SAMPSON,

Barbara K. Cook, PE
Vice President

William J. Nunnery, PE
Senior Project Manager

cc: Neal Merritt, Hanover Deputy Superintendent Water Operations
Troy Clarkson, Hanover Town Manager

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