Northeast Water Solutions, Inc.

Evaluation of the Formation and Control of Disinfection Byproducts at the Housatonic Water Works Company

Prepared for

Housatonic Water Works Company, Inc.
80 Maple Avenue, STE1
Great Barrington, MA 01230
PWS ID#1113003

by
Water Compliance Solutions, LLC
and
Northeast Water Solutions, Inc.

February 1, 2023

COMMONWEALTH OF MASSACHUSETTS
ROBERT F. FERRARI
CIVIL
No. 31932
REGISTERED PROFESSIONAL ENGINEER

2/01/23

REPORT INDEX

List of Tables

List of Figures

EXECUTIVE SUMMARY

The Housatonic Water Works Company (HWWC) of Great Barrington, Massachusetts provides an average of 111,000 gallons per day (77 gpm) of potable drinking water to approximately 1,400 people via 824 service connections (PWSID #1113003). HWWC treats surface water from Long Pond via slow sand filtration and chlorine disinfection (sodium hypochlorite).

After years of having levels of chlorinated disinfection byproducts (DBPs) well below the regulated limits, in 2021 and 2022 the maximum contaminant level (MCL) was exceeded for haloacetic acids (HAA5). Compliance with the MCLs is based on the calculated Locational Running Annual Average (LRAA) of monitoring results from four consecutive quarters. HAAs and trihalomethanes (THMs) are formed when the chlorine used for microbial disinfection reacts with natural organic matter (NOM) in the source water.

This report provides an evaluation of the occurrence of HAAs and THMs and of different potential responses for HWWC to take to reduce HAAs and ensure consistent compliance with the MCL in the future.

Two primary alternative actions were examined and are summarized in Table ES-1. The two-stage chlorination procedure is recommended as a very effective, simple, and inexpensive option.

Table ES-1. Summary of Considered Alternatives for Reducing Chlorinated DBPs

Alternative	Advantages	Disadvantages	Cost	Effort
Two-Stage Chlorination	Lowers overall CT in WTP by ~ 2/3; steady-state process	Provides less primary disinfection than current practice	Low (a chlorine analyzer and perhaps an in-line mixer)	Minor modification
Granular Activated Carbon (GAC20)	Removes much of formed DBPs and some of NOM (~50% to 85%); non-steady-state process	Not as effective for NOM as for smaller organics; GAC media needs replacement/ regeneration	Very high for a small customer base. Will also need a chlorine analyzer and perhaps an in-line mixer.	Capital project

It is usually appropriate to employ operational adjustments such as this prior to embarking on more expensive capital projects, especially for small systems such as HWWC. And this water treatment plant's slow sand filters already removes during non-winter months approximately one-half of the natural organic matter (NOM) that serves as precursors to DBPs, and about one-third during the coldest months, so reducing the other reactant in DBP formation (the chlorine) is a more promising approach.

It is recommended that HWWC implement the two-stage chlorination option for control of DBPs in early 2023 after receiving MassDEP approval. HWWC already needs to finance a new GreensandPlus filtration system for manganese removal that will be a financial burden on the small customer base, and the two-stage chlorination option will be low cost. GAC20 would be another financial burden, but could be considered in the future if the reduced chlorine doses do not maintain compliance with the DBP MCLs. Otherwise the GAC option is considered unnecessary at this time.

1. INTRODUCTION

The Housatonic Water Works Company (HWWC; PWSID #1113003) treats surface water from Long Pond via slow sand filtration and chlorine disinfection with sodium hypochlorite. Water is pumped from the outlet end of the chlorine contact basin to a nearby 1.1-MG water standpipe storage tank for storage and further primary disinfection. Water flows by gravity from the storage tank into the distribution system at an average daily rate of ~111,000 gallons per day (77 gpm).

1.1 Problem Statement

The Stage 2 Disinfectants/Disinfection Byproducts Rule (D/DBPR) regulates the occurrence of chlorinated disinfection byproducts (DBPs) in public drinking water supplies. After years of having levels of the DBPs well below the maximum contaminant levels (MCLs), in 2021 and 2022 the LRAA exceeded the MCL for haloacetic acids (HAA5). In response, the Massachusetts Department of Environmental Protection (MassDEP) and HWWC agreed on an Administrative Consent Order (ACO) October 4, 2022 that requires certain actions be conducted by HWWC to reduce HAAs.

This report is provided to MassDEP to fulfill the following requirement of the Administrative Consent Order:

> *"Within 120 days of the effective date of this Consent Order, Respondent (HWWC) shall submit to MassDEP a report by a Massachusetts Registered Professional Engineer with expertise in drinking water compliance which:*
>
> i. *Documents the causes of the HAA5 MCL violation and the engineer's recommendations for preventing future HAA5 MCL violations in the water distribution system.*
> ii. *Includes an alternatives analysis including a feasibility evaluation, effectiveness determination, cost estimates, and implementation schedule.*
> iii. *Incorporates an evaluation of proposed treatment alternatives with respect to EPA's identified best available technologies (BAT) for achieving compliance with the maximum contaminant levels for disinfection byproducts (DBP) and provides an explanation as to why the selected alternative is Respondent's best option for achieving and maintaining DBP compliance.*
> iv. *Evaluates proposed treatment alternatives with respect to MassDEP's technology approval for achieving compliance with the maximum contaminant levels for disinfection byproducts, and details Respondent's intended method of obtaining approval for any technology not currently on MassDEP approved technologies list."*

1.2 Control of Disinfection Byproducts

HAAs and THMs are formed when the chlorine used for microbial disinfection reacts with natural organic matter (NOM) present in the source water. Strategies for controlling the formation of chlorinated disinfection byproducts may include one or more of the factors involved in the chemical reaction represented as follows:

$$\mathrm{Cl_2} + \mathrm{NOM} \xrightarrow[\text{pH (THM)}]{\text{°C, time}} \mathrm{THMs} + \mathrm{HAAs}$$

HAAs and THMs may be controlled by:
- reducing chlorine levels
- reducing NOM levels
- reducing reaction time between chlorine and NOM
- reducing temperature (not practical for most applications)
- reducing pH (for THMs, minimal opposite effect for HAAs)
- removing the reaction products (THMs and HAAs)

Key considerations for any of the options considered include the extent and rate of DBP formation or removal, as well as cost. Whatever option is selected for reducing DBPs, it must simultaneously comply with other Safe Drinking Water Act regulations, including those for filtration, primary disinfection, secondary disinfection (distribution system chlorine residuals), and lead and copper.

The following three methods are considered by the U.S. Environmental Agency (USEPA) and MassDEP (310 CM 22.07.E(4)(b)) as best available technologies (BATs) for control of DBPs:

- Enhanced coagulation or enhanced softening plus granular activated carbon with an empty bed contact time (EBCT) of 10 minutes (GAC10)
- Nanofiltration with a molecular weight cutoff ≤ 1,000 Daltons
- Granular activated carbon with an EBCT of 20 minutes (GAC20)

These BATs focus exclusively on reducing NOM as the strategy for reducing DBPs, and are limited to treatment that typically requires new capital projects in contrast to making simpler operational adjustments. HWWC's slow sand filters already remove about half of the NOM (Section 2), and total organic carbon (TOC) levels did not appear to have an impact on the atypically high DBP results from August 2021 that caused the MCL exceedances (Section 3), so a different strategy may be more effective for reducing DBPs than further removal of TOC.

USEPA notes that "*the Safe Drinking Water Act directs EPA to specify BAT for use in achieving compliance with the MCL. Systems unable to meet the MCL after application of BAT can get a variance (see section V.L. for a discussion of variances). Systems are not required to use BAT in order to comply with the MCL. They can use other technologies as long as they meet all drinking water standards and are approved by the State.*" (Federal Register August 18, 2003, page 49588)

USEPA (2020) further notes that *"EPA specified best available technologies (BATs) for each MCL and MRDL. These technologies and methods are believed to be effective in controlling chemicals in drinking water while remaining economically feasible. Public water systems (PWSs) must use the specified BAT if they wish to qualify for variances; otherwise, systems are not required to install a BAT and may use any approved technology to achieve compliance."*

As a temporary response action to the elevated haloacetic acids observed during the latter part of 2021, HWWC reduced the amount of chlorine disinfectant applied. Those adjustments have been relatively minor, and are restricted by the need to maintain necessary levels of chlorine at the point of entry (POE) to the distribution system and within the distribution system.

The strategy of using a **two-stage chlorination procedure** to lower chlorine doses and substantially reduce the reaction between chlorine and natural organic matter for reduction of DBPs is discussed in Section 4. An evaluation of the **granular activated carbon (GAC20)** option is provided in Section 5.

All other potential options for DBP control have been eliminated from further consideration at this time as not being feasible alternatives, and rationale for those assessments are provided below.

- **Enhanced coagulation** applies to treatment systems that have coagulation and clarification systems, which HWWC neither has nor does its water require. Even if new coagulation and clarification processes were installed, HWWC's Long Pond source water is very low in turbidity, and coagulation may not be effective if there aren't enough solids present. This option would be unnecessarily expensive.
- **Nanofiltration** would effectively remove NOM, but has many drawbacks for HWWC and is not a feasible option. Foremost, approximately 15 to 30 percent of the water drawn for treatment is wasted as the reject fraction of the feed water that enters the process and must be disposed of (USEPA, 2023a). With no sewer access, disposal currently is limited to the onsite lagoon. In the case of HWWC this is equivalent to 16,500 to 33,000 gallons per day and likely too much for disposal into the lagoon, especially during winter months. Nanofiltration could also replace the slow sand filters, but the filters have been very reliable and effective for years so that seems unnecessary.

- **Adjustment of pH** is not an applicable solution for HWWC. The regulatory concern is for HAAs and not THMs, and the pH would need to be lowered to reduce THMs. The natural water average pH of 7.6 is already at an effective if not optimum level for controlling lead and copper corrosion, and should not be lowered for that reason.
- **Reducing reaction time** between chlorine and NOM does not appear to be an appropriate solution for HWWC. Most of the DBPs are formed within the first 2 to 3 days (discussed in Section 3), and at present the disinfection process involves about 15 hours of water age in the contact basin and 9 days in the storage tank. Even if the storage tank is no longer used for primary disinfection, the chlorine contact basin and distribution system combined provide over 2 ½ days of chlorine contact time.

  An evaluation was completed by Water Compliance Solutions, LLC in November 2022 on the impact of decreasing chlorine contact time by lowering storage tank levels on the formation of DBPs. It was shown that the current levels of water in the storage tank are necessary for maintaining adequate water pressure at the higher elevations of the distribution system, and reducing those levels would provide little if any benefit for reducing DBP levels. That report's conclusions were concurred with by MassDEP in a letter dated December 20, 2022.
- **Aeration** can be effective for removal of formed THMs, but HAAs are not volatile and so that option won't address HAA removal. If needed for THM control sometime in the future, installing a spray aeration system at the top of the storage tank would be a relatively economical and successful approach.
- **Chloramines** are used by some water systems as a secondary disinfectant since no formation of HAAs or THMs occurs after the ammonia is added and combines with the chlorine. This could potentially be done after the chlorine contact tank if enough primary disinfection is regularly achieved in that segment. Approximately 40% of the ultimate DBP formation occurs by the end of the contact basin (discussed in Section 3), and adding ammonia there would stop further DBP formation. That is not a feasible option for HWWC after the storage tank since most of the DBPs have formed by that time.

  HWWC prefers to continue using free chlorine in the distribution system since it is a much stronger disinfectant than chloramines.

2. HWWC DRINKING WATER TREATMENT SYSTEM

HWWC's drinking water treatment system is simple yet highly effective. A schematic of the treatment processes is provided in Figure 1. Highlights include:

- Serves ~1,400 people via 824 service connections
- Averages ~111,000 gallons per day (77 gpm)

- Small, mostly undeveloped watershed
- Long Pond is a very high-quality source water (except for periodic spikes of manganese)
- Treatment includes slow sand filtration and chlorine disinfection with sodium hypochlorite
- Uses as few chemicals as possible to keep the water natural (chlorine is the only chemical added)
- Chlorine contact tank and 1.1-MG standpipe tank provide primary disinfection contact time and volume storage (~9-day water age)
- Single pressure zone fed by 1.1-MG storage tank
- Approximately 20 miles of pipe (2 to 14-inch diameter)
- Periodic colored and dirty water episodes are caused by manganese
- No MCL exceedances for TTHM
- HAA5 first exceeded MCL in August 2021

A GreensandPlus™ filtration system has been proposed by HWWC as a means of removing manganese that has been the cause of occasional periods of colored water. This system would be installed after the pumps that transfer water from the chlorine contact basin up to the 1.1-MG storage tank.

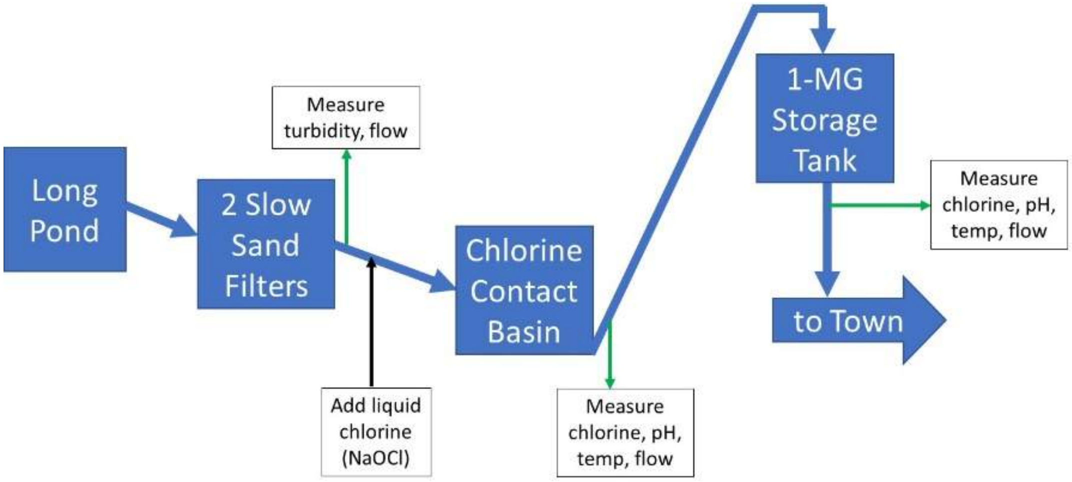


Figure 2-1. HWWC water treatment plant schematic

A pilot study test was conducted by NWSI for ~250 hours under a variety of flow conditions in September 2022, and at a time when the influent manganese from Long Pond was at relatively high levels. The GreensandPlus filters removed the high levels of manganese to mostly non-detect levels throughout the pilot study, always met the goal of ≤ 0.015 mg/L, and had no observed adverse impact on other water quality parameters. The filters consumed approximately 0.53 mg/L of chlorine upon reaching steady state operation during the pilot study.

Slow Sand Filtration:

Two slow sand filters remove particles and microorganisms. Slow sand filtration has long proven as a simple, reliable, and low-cost treatment method for small communities. Removal of particles and other substances is largely performed by microbial populations that are established on the sand media over time, and lesser so via physical straining by the sand itself (e.g., Huisman and Wood, 1974). As the upper zone of slow sand filters gets clogged from particles, water flow through the filters will decrease.

The traditional method of cleaning slow sand filters and restoring water flow rates is to manually scrape and remove approximately one-half inch of the top layer schmutzdecke. HWWC instead uses a custom hydraulic rake system to clean the filters. Resulting advantages include that the filters do not require a ripening period to reduce turbidity prior to return to service, and the sand has not needed to be replaced for a long time, allowing for a well-established microbial community.

HWWC employs continuous online turbidity monitoring for each filter. Turbidity removal is consistent and very effective, typically lowering turbidities down to ≤ 0.05 NTU, while the regulatory limits for slow sand filters are 1 NTU (for 95% of turbidity readings) and 5 NTU (maximum at any time). Figure 2-2 provides the combined filter effluent turbidity as required for reporting to MassDEP.

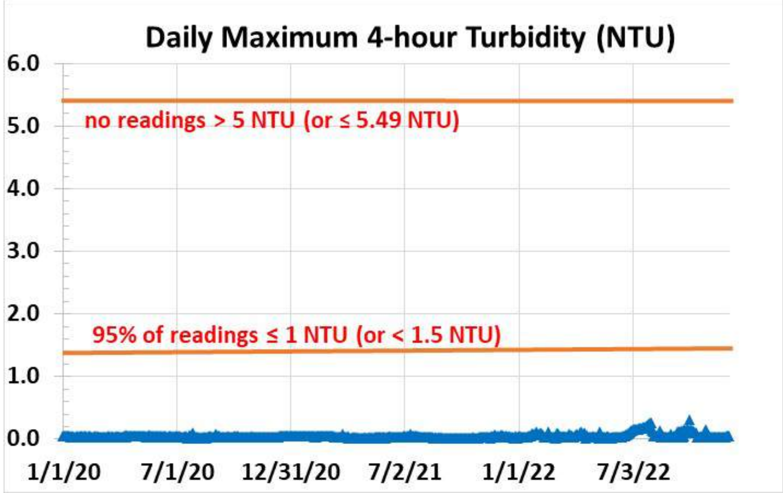


Figure 2-2. Regulated 4-hour combined filter effluent turbidity for HWWC

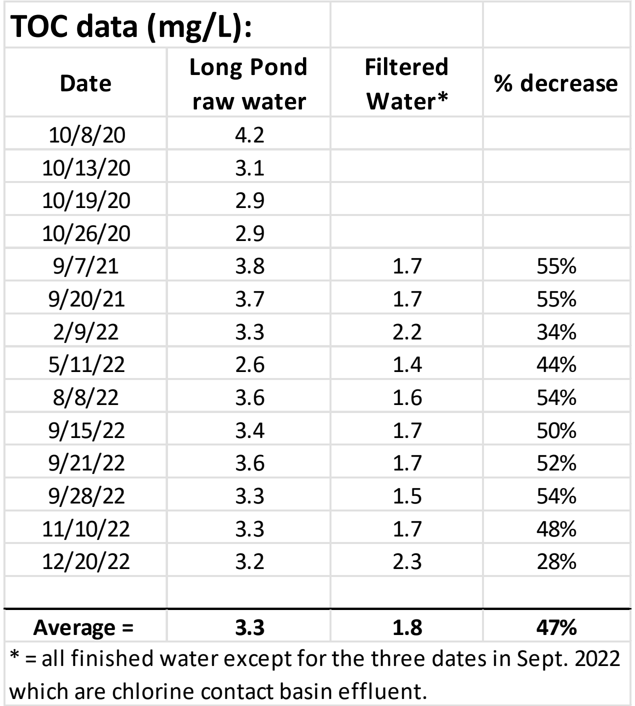
In addition to providing microbial and particle removal, HWWC's existing biological slow sand filters also remove a significant amount of natural organic matter. This serves as an effective and resilient means for controlling NOM levels to reduce formation of DBPs.

NOM is often measured using total organic carbon (TOC) analysis as a surrogate. Source water and treated water TOC levels are provided in Table 2-1. Source water TOC has averaged 3.4 mg/L, and treated water 47% less at 1.8 mg/L. During non-winter times the treated water has averaged only 1.6 mg/L of TOC (> 50% removal), which is already below typical goals of having TOC < 2.0 mg/L for DBP control. During cold winter months TOC removal has been ~33%.

This TOC removal is impressive for slow sand filters, which typically are expected to remove approximately 15 to 20% of TOC. Perhaps this success is partly due to the well-established age of the microbial population and HWWC's custom hydraulic rake filter cleaning system. Periodically cleaning the sand surface with water instead of physically removing the top layer has allowed the sand to not be replaced for many years, likely keeping more of the existing microbial population in place.

Dissolved organic carbon (DOC) and UV254 absorbance are also sometimes used as surrogate indicators of NOM. The TOC for both influent and effluent is mostly all DOC, which was expected since Long Pond's water is quite clear (non-turbid) and obviously the effluent has already passed through the slow sand filters.

Table 2-1. Total Organic Carbon levels in HWWC's source and treated water



TOC data (mg/L):

Date	Long Pond raw water	Filtered Water*	% decrease
10/8/20	4.2		
10/13/20	3.1		
10/19/20	2.9		
10/26/20	2.9		
9/7/21	3.8	1.7	55%
9/20/21	3.7	1.7	55%
2/9/22	3.3	2.2	34%
5/11/22	2.6	1.4	44%
8/8/22	3.6	1.6	54%
9/15/22	3.4	1.7	50%
9/21/22	3.6	1.7	52%
9/28/22	3.3	1.5	54%
11/10/22	3.3	1.7	48%
12/20/22	3.2	2.3	28%
Average =	**3.3**	**1.8**	**47%**

* = all finished water except for the three dates in Sept. 2022 which are chlorine contact basin effluent.

Naturally occurring organic compounds such as humic acids are aromatic and are known to be a precursor of DBP formation. UV254 is an indication of the amount of organic matter containing aromatic rings or unsaturated bonds in their molecular structures.

The raw source water demonstrated a UV254 value of ~0.08 cm^{-1}, while filtered water was 0.03 cm^{-1}, for a decrease of 63% (somewhat more than the percent of TOC and DOC removed). UV254 values in the Long Pond source water appear to be within a "typical" range. As a comparison, the Massachusetts Water Resource Authority (MWRA) reported in August 2022 average UV254 results consistently over the preceding year of ~0.03 cm^{-1}

for Quabbin Reservoir, while UV254 decreased for the Wachusett Reservoir from ~0.10 cm^{-1} down to 0.05 cm^{-1} over that year (MWRA, 2022).

The specific UV absorbance (SUVA) concept normalizes UV254 by the DOC content, where SUVA = UV254/DOC in L/mg-m). In September 2022 SUVA for the raw water was ~2.4 L/mg-m and ~2.0 L/mg-m for the filtered water, for a decrease of ~17%. 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%.

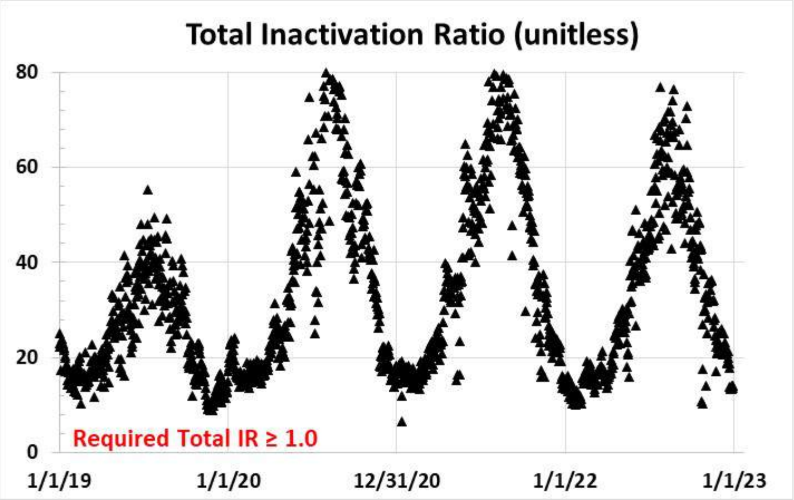
Based on those criteria, HWWC's water is considered to be "low SUVA". Since HWWC does not use coagulation, the relevance of the SUVA correlation is limited. However, organic compounds that are more hydrophilic tend to be less adsorbable for GAC than compounds considered as more hydrophobic. The low SUVA value may suggest the NOM would be less adsorbable on GAC than would be waters with a higher SUVA value.

Chlorine disinfection:

Sodium hypochlorite (NaOCl) is used by HWWC for microbial disinfection. Disinfection performance monitoring is conducted for two stages of disinfection. The single chlorine feed is introduced after the slow sand filters, in the transfer pipe leading to the 136,000-gallon chlorine contact basin. Chlorine residuals are continuously monitored along with pH and temperature to determine disinfection credit for both the contact basin effluent (Segment #1) and the storage tank effluent (Segment #2). Having a second disinfection segment provides monitoring redundancy and also further ensures compliance with the primary disinfection requirements.

The contact basin achieves approximately 25% of HWWC's primary disinfection credit (Segment #1), and the 1.1-MG storage tank contributes the other ~75% (Segment #2). The contact basin alone can typically provide enough primary disinfection to meet the requirements (with the chlorine doses that have been used). However, Inactivation Ratios (IR) calculated in cold water for Segment #1 are close to the minimum requirement of 1.0, so it is preferred to use the storage tank for further primary disinfection performance credit.

Total IR is plotted in Figure 2-3 for the past four years. The Inactivation Ratio is calculated as the achieved "*CT*" divided by the required "*CT*", where *CT* is the disinfection segment effluent chlorine residual (*C*, mg/L) multiplied by the chlorine contact time (*T*, min). The contact time is the product of the water age (segment volume divided by flow rate) and a baffling factor that accounts for non-ideal flow behavior (0.1 for mixed vessels and 1.0 for plug flow behavior such as in pipes). The baffling factors used for HWWC are 0.2 for Segment #1 (chlorine contact basin) and 0.1 for Segment #2 (1.1-MG storage tank).



IR = $CT_{achieved} / CT_{required}$ *Range of 6 to 80; ≥ 1.0 is required*

Figure 2-3. Primary Chlorine Disinfection of *Giardia* for HWWC

Maintaining a chlorine residual of at least 0.2 mg/L in the far reaches of a distribution system is the standard minimum goal in the U.S. drinking water supply industry. Operationally, if 0.2 mg/L is a minimum goal in the distribution system, then one would need to target a range higher than that to provide a factor of safety in the outcome. HWWC endeavors to have minimum readings of 0.2 to 0.5 mg/L of chlorine in the distribution system.

Since primary disinfection credit is easily achieved in the two segments, the chlorine dose needed is typically based on maintaining those chlorine residuals at monitoring sites within the distribution system. The chlorine level in the finished water at the POE typically ranges from 1.0 to 2.0 mg/L (Figure 2-4). Contact basin residuals are necessarily higher, and are also more varied (Figure 2-5). The chlorine concentrations are steadier after the water flows through the 1.1-MG storage tank. Final effluent chlorine concentrations must be at least 0.2 mg/L, a requirement HWWC has always met.

With this single-dose chlorination procedure enough chlorine must be added before the contact basin to maintain sufficient level all the way through the 1.1-MG storage tank and still provide enough residual in the distribution system. A modification of this procedure into a two-stage chlorination process is discussed as an option for DBP reduction in Section 4.

In 2022, the contact basin effluent averaged 1.57 mg/L chlorine residual, and the storage tank effluent (finished water) averaged 1.28 mg/L, for a decrease of about 0.3 mg/L. That's only an 18% decrease in chlorine during a contact time of over 9 days in the storage tank, suggesting the filtered Long Pond water has a very low chlorine demand.

Typically a surface water would be expected to experience a greater loss of chlorine over that time, with a chlorine half-life on the order of several days.

The distribution system, however, appears to have a greater chlorine demand than the storage tank, with residuals decreasing further down to an average in the range of 0.49 mg/L (for biweekly distribution system samples) to 0.65 mg/L (for monthly Revised Total Coliform Rule data; plotted in Figure 2-6). That corresponds to a chlorine demand of 0.6 to 0.8 mg/L in the distribution system, with the total distribution system representing approximately 2 days of contact time. The greater chlorine demand in the distribution system is likely due to interactions between chlorine and the pipe materials, deposits collected on the pipe surfaces, and sediment. So some of the chlorine demand is due to factors other than the chemical quality of the water passing through the water treatment plant.

For HWWC there is a long lag time between changes in chlorine dose at the water treatment plant and when those changes are observed near the ends of the distribution system (including about 9 days of time in the 1.1-million gallon storage tank). Chlorine targets should not be set too low because of the long time that occurs between a change in chlorine dose and the resulting response many days later in the distribution system. Raising low distribution system chlorine residuals currently requires over a week of time for an increased chlorine dose to reach that far.

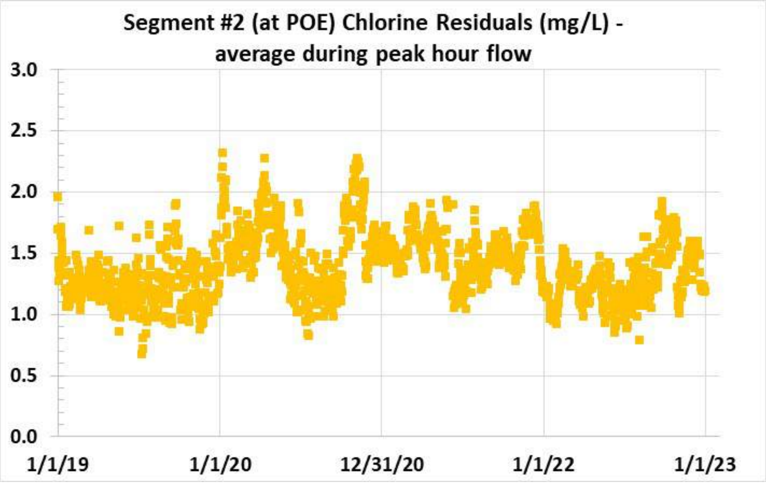


Figure 2-4. Finished Water Chlorine Residuals

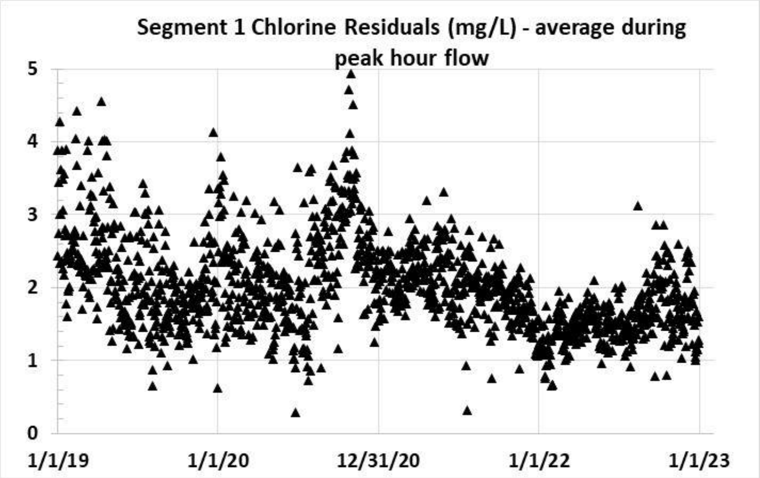


Figure 2-5. Contact Basin Chlorine Residuals

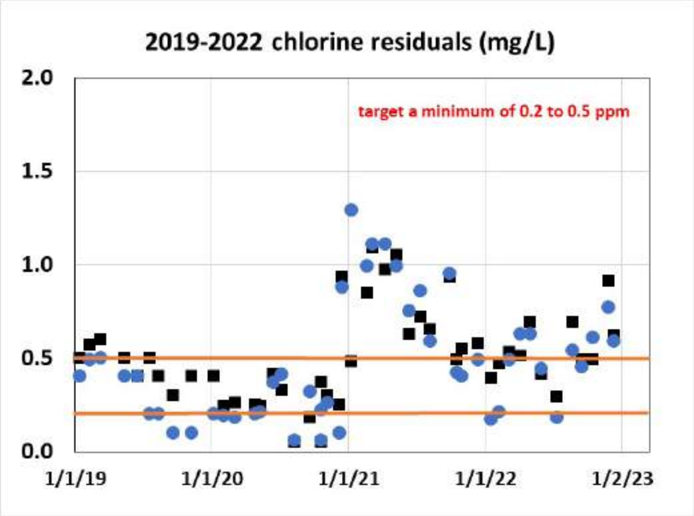


Figure 2-6. Distribution System Chlorine Residuals Sampled for the Revised Total Coliform Rule

3. FORMATION AND OCCURRENCE OF DBPs IN HWWC'S WATER

MassDEP has set MCLs of 60 µg/L (ppb) for HAA5 and 80 µg/L TTHM. Compliance with the MCLs is based on the calculated Locational Running Annual Average (LRAA) of monitoring results from four consecutive quarters.

3.1 Extent of DBP formation

HWWC has conducted HAA5 and TTHM monitoring quarterly in the distribution system at the MassDEP-required monitoring site (10 Depot St.) since the start of the Stage 2 D/DBPR sampling in November 2013. Initially, for several years the levels of both HAA5 and TTHM were fairly steady and well below the MCLs. However, during the past four years results have varied more over time and on average have been increasing (Figures 3-1 and 3-2).

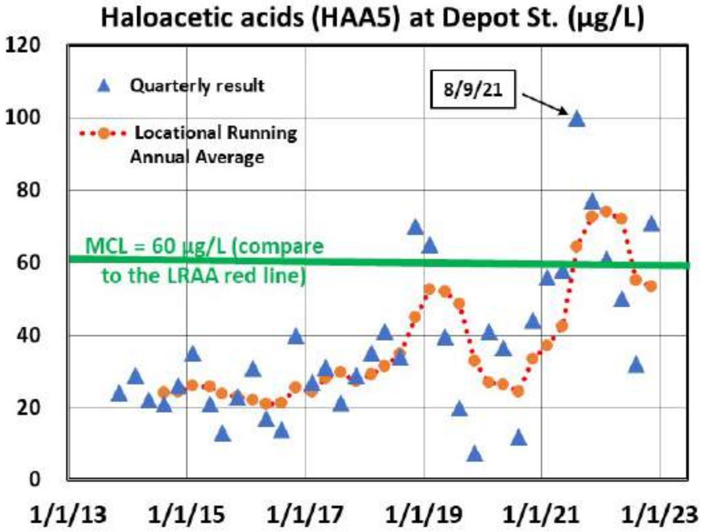


Figure 3-1.

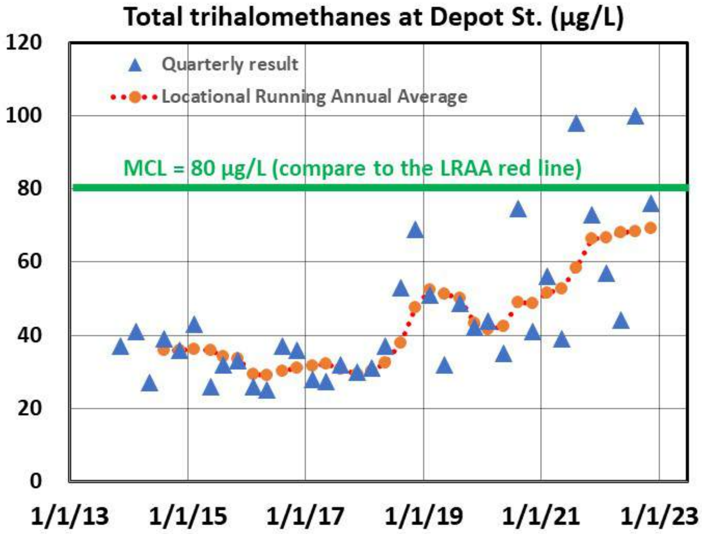


Figure 3-2.

After 37 quarters of monitoring over the 9 ¼ years from 2013 through 2022, only six (6) quarters have had a result above 60 µg/L for HAA5 (Figure 3-1), and only two quarters had individual results above 80 µg/L for TTHM (Figure 3-2).

To date HWWC’s water has always met the MCL for TTHM (LRAA ≤ 80 µg/L). However, an abnormally high result for HAA5 (100 µg/L) was detected at this site in August 2021 following record rainfall that was experienced the previous month (Figure 3-1). That resulted in an LRAA of 65 ug/L, above the MCL of 60 µg/L. HAA5 then decreased substantially over the next four quarters down to 32 µg/L, before rising again some in November 2022 to 71 µg/L.

The MCL for HAA5 was exceeded for each of the four quarters that included the August 2021 result (100 µg/L) in the calculation for LRAA, from third quarter 2021 through second quarter 2022. Since then, the LRAA for HAA5 at 10 Depot St. has been below the MCL (for the third and fourth quarters of 2022), and is currently at 54 µg/L from November 2022 (Figure 3-1).

Three primary changes may be observed in the occurrence of HAAs and THMs over the past ~10 years (Figures 3-1 and 3-2). First was a marked increase in the magnitude and variability of the results in Fall 2018, possibly related to a change in piping to the storage tank around that time. Second was a large and sudden increase in HAAs and THMs in August 2021, apparently related to historic rainfall that occurred in July 2021. Third, after both of those sudden increases there was a sharp continued decrease in the HAA5 levels over the next 4 quarters (Figure 3-1)

After the MCL for HAA5 was exceeded at the Depot St. location in 2021, MassDEP required HWWC to monitor HAA5 and TTHM at a second distribution system site starting in February 2022 (314 N. Plain Road). Results of that monitoring are presented in Figures 3-3 and 3-4, respectively. Determination of MCL compliance began for the new N. Plain Road sampling site after four quarters of sample results provided the first LRAA calculation. The LRAA for HAA5 in November 2022 was 66 µg/L, above the MCL of 60 µg/L (Figure 3-3). The LRAA for TTHM was 65 µg/L, below the MCL of 80 µg/L (Figure 3-4).

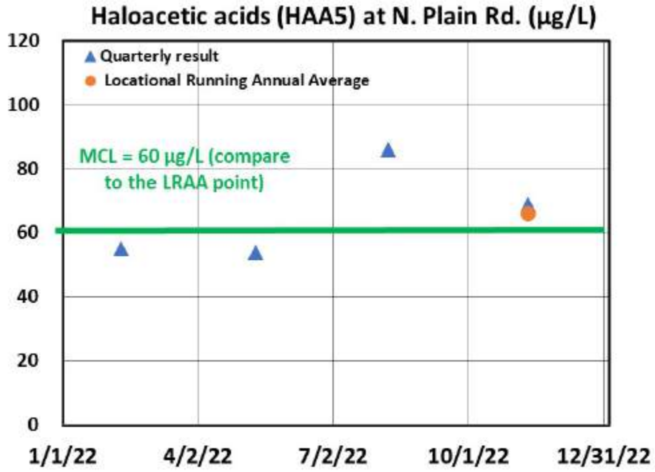


Figure 3-3.

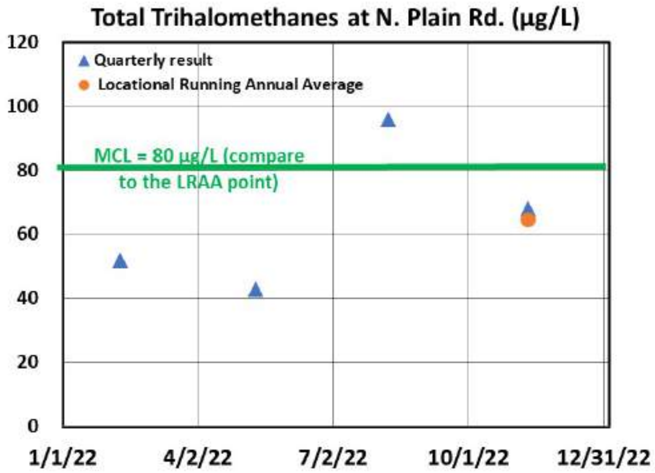


Figure 3-4.

3.1.1 Sudden increase in DBPs during 2018:

After 19 rounds of quarterly sampling through May 2018 (4 ¾ years) the highest HAA5 level detected was 41 µg/L, and the highest TTHM result had been 43 µg/L. Then HAA5 more than doubled from 34 µg/L in August 2018 up to 70 µg/L in November 2018 (Figure 3-1). TTHM reached its highest detection of 53 µg/L in August 2018, and then increased to 69 µg/L in November (Figure 3-2).

Prior to 2018 HWWC pumped water from the chlorine contact basin to the bottom of the storage tank, where water would flow in or out of the tank depending on the balance between the pumping rate and the rate of consumer demand. In that manner, much of the water in the upper part of the storage tank likely had low chlorine residuals. Starting in 2018 HWWC has pumped the water to the top of the tank so that all of the water flows down through the tank, and that became the second segment for primary disinfection. MassDEP approved the system piping change on October 18, 2018.

While it is understandable that the increased chlorine contact time in the storage tank would increase DBP formation, the DBP results may have been expected to be steadier than was observed given the change in water flow with the contact basin effluent now flowing into the top of the storage tank and the inadvertent mixing in that volume of water that occurs via differing flow currents and hydrodynamic dispersion. Regardless, the timing of this change in plant piping suggests it may have had an impact on the magnitude of the DBPs formed.

3.1.2 Sudden increase in DBPs in August 2021:

It seems clear that the large sudden increase observed in HAAs in August 2021 was a result of the historically heavy rainfall that fell in July 2021. That month was by far the wettest July in recorded history in the area, and there was also heavy rain in late October (DBP samples were collected on 8/9/21, 11/10/21, and 2/9/22). So that may have affected the amount and/or type of organic matter in the Long Pond source water. Several other surface water supplies in western Massachusetts also experienced elevated DBPs in August and fall of 2021, and those water systems also attributed that to the unique weather circumstances.

The August 2021 HAA5 result was exceptionally rare, as shown in Figure 3-5 which includes all of the August HAA5 monitoring results for HWWC at the Depot St. location during the Stage 2 D/DBPR. The August 2021 result was more than twice as high as any of the eight other August results over the years.

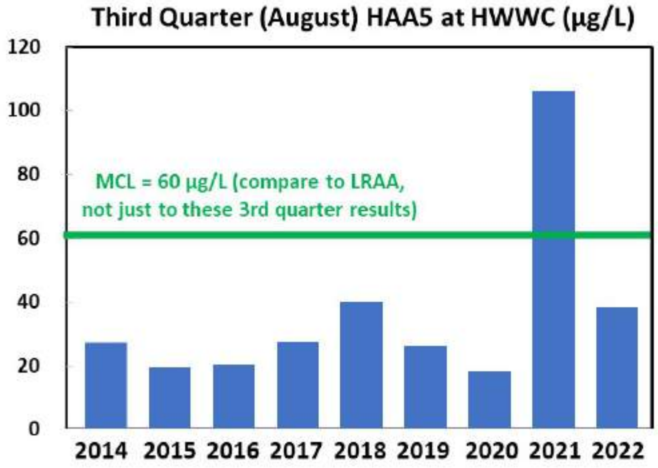


Figure 3-5.

Following that atypically high value, the HAA5 concentrations decreased for four consecutive quarters from 100 µg/L down to 32 µg/L. Further, the difference compared to the historical average for each season was decreasing, cutting in about half from August 2021 to November and then again in half from November to February 2022. That suggests the water was returning to its more normal state in terms of the potential for formation of DBPs, though it was still somewhat elevated. Then in November 2022 HAA5 rose to 71 µg/L, the third highest HAA5 result to date. The sharp continued decrease in HAA5 observed for four quarters after the atypically high result in 2021 was similar to the HAA5 data pattern observed after the atypically high November 2018 result (Figure 3-1).

Notably, the surge in DBPs in August 2021 does not appear related to an increase in TOC in the source water after the record rainfall in July 2021. This suggests that removing more TOC will not necessarily solve the issue of those elevated HAAs. While TOC samples were not collected in August 2021, finished water samples from September 2021 showed TOC levels of only 1.7 mg/L, basically the same as it typically is in non-winter months (Table 2-1). For the Long Pond source water, the TOC was ~3.75 mg/L in September 2021, just slightly above the long-term average of 3.3 mg/L (Table 2-1).

While the HAA results decreased substantially over the following year, TOC levels remained fairly steady for both source water and filtered water. That level of TOC (1.7

mg/L) typically would not cause problems with formation of excessive DBPs, and the large increase in HAAs is not correlated to a change in TOC levels. Apparently something else changed in the Long Pond source water to cause the suddenly elevated HAAs other than the quantity of TOC.

3.2 Speciation of DBPs formed

Examples of the formation of the five individual HAAs and the four TTHM species are provided in Table 3-1. These three rounds of sampling results were obtained during HWWC's September 2022 pilot plant study conducted by NWSI for manganese removal with GreensandPlus filtration (GSF). As expected, the chlorinated species dominates over the brominated compounds, particularly chloroform (a THM) and the chloroacetic acids (especially trichloroacetic acid and dichloroacetic acid).

The pilot study results in Table 3-1 also show the GreensandPlus filters had perhaps some but minimal impact on DBP formation. For two of the three sampling events for THMs (and for one of two samples for HAAs) the GreensandPlus filters did not affect the TTHM or HAA concentrations, and the other sampling event (9/21/22) demonstrated about a 10 percent decrease in THMs and HAAs (Table 3-1). Based on those results, no benefit for DBP control may currently be relied on via the GreensandPlus filters.

Table 3-1
Chlorinated Disinfection Byproducts (DBPs)

Parameter	**9/15/22**		**9/21/22**		**9/28/22**	
	GSF Influent	**GSF Effluent***	**GSF Influent**	**GSF Effluent***	**GSF Influent**	**GSF Effluent***
TTHM (all µg/L)	**48.5**	**49.0**	**63.5**	**54.8**	**39.8**	**41.9**
Bromodichloromethane	5.9	5.71	8.34	6.27	4.44	5.04
Bromoform	<0.500	<0.500	<0.500	<0.500	<0.500	<0.500
Chloroform	42.6	43.3	54.6	48.5	34.9	36.9
Dibromochloromethane	<0.500	<0.500	0.57	<0.500	<0.500	<0.500
HAA5 (all µg/L)	**60.6**	**60.6**	**70.4**	**65.0**	**-----**	**56.9**
Chloroacetic acid	1.41	1.41	1.42	<1.00	-----	1.43
Bromoacetic acid	<1.00	<1.00	<1.00	<1.00	-----	<1.00
Dichloroacetic acid	21.1	21.1	20.8	20.1	-----	21.0
Trichloroacetic acid	38.1	38.1	48.2	44.9	-----	34.5
Dibromoacetic acid	<1.00	<1.00	<1.00	<1.00	-----	<1.00

*Composite samples: 1/3 from each GSF
"-----" = not analyzed

3.3 Rate of DBP formation

A simulated distribution system (SDS) study was conducted in September 2022 to help determine the rate of formation for both THMs and HAAs. This was done as part of the pilot study evaluating manganese removal by GreensandPlus™ filters. Effluent from the

GSF filters was allowed to react with the chlorine present in the water for a variety of contact times (water ages) ranging up to 15 days. The samples were collected on September 28, 2022, immediately prior to the completion of the pilot study. The samples subsequently underwent THM and HAA analysis after water ages of 0, 1, 2, 3, 5, 10, and 15 days. The initial chlorine residual at time 0 was 2.43 mg/L. The GreensandPlus system was shown to have no or minimal effect on DBP formation, and so the greensand effluent water may be assumed to be similar to the greensand influent water (contact basin effluent) for evaluation of the rate of DBP formation.

The rate results are presented in Table 3-2, and plotted in Figure 3-6. The GreensandPlus effluent water sampled for this testing had already experienced approximately 15 hours of chlorine contact time in the contact basin, and so 15 hours was added to the sample times in Figure 3-6 (e.g., time 0.0 hours was changed to 15 hours).

Table 3-2
THMs and HAAs vs. Water Age

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	**MCL 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

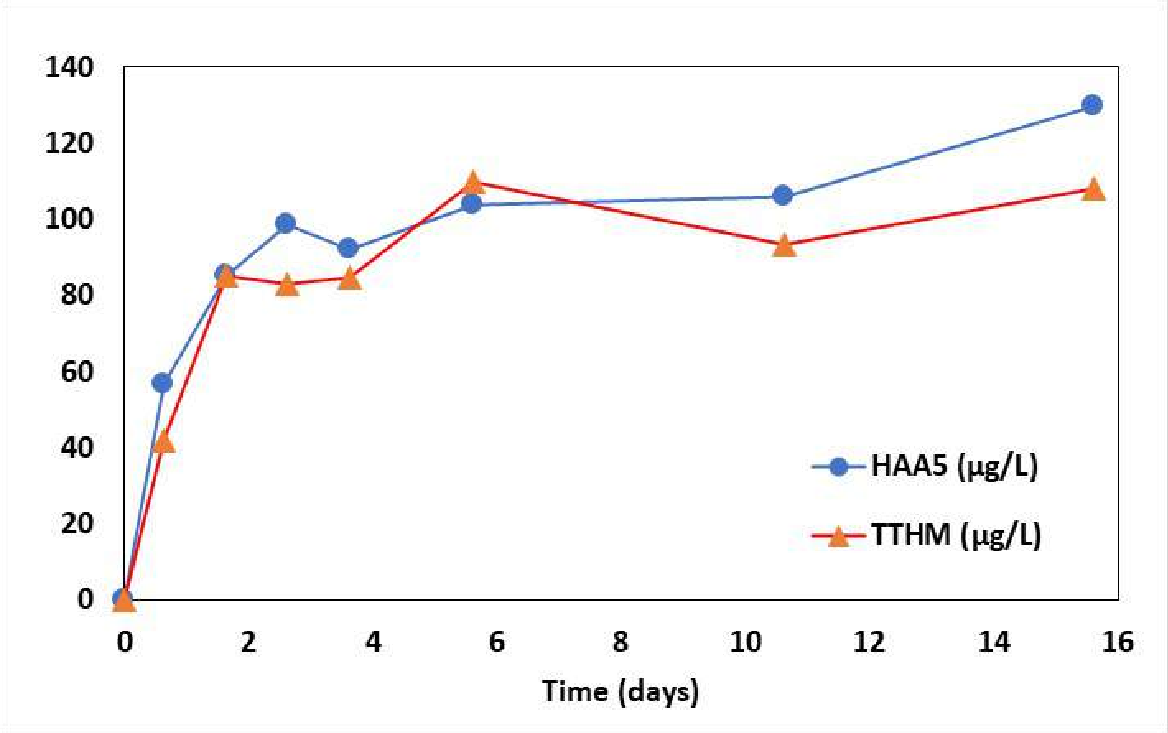


Figure 3-6. DBP formation over time (starting 9/28/22)

Key takeaway points from the rate data include:

- Approximately 40% of the HAA5 and TTHM that will ultimately form have done so by the end of the chlorine contact basin (~15 hours contact time)
- Over 80% of HAA5 and ~100% of the TTHM formed by the time the water age corresponded to the exit of the 1.1-MG storage tank
- Approximately 75% of the THMs and HAAs existing after 15 days are formed within about the first 2.5 days.
- Approximately 90% of the THMs and HAAs existing after 10 days are formed within about the first 2.5 days.
- Given the storage tank contains about 9 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 rate study samples other than the 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 will exceed that occurring in real pipe systems where there are other competing chlorine demands.

This data trend over time is expected given the approximately first-order kinetics of DBP formation. An example from the literature is provided in Figure 3-7 of the typical non-linear formation of trihalomethanes over time (these are not HWWC data). The data trend flattens as time progresses, and thus incremental increases of THMs over time continue to get smaller.

It is not surprising to find at least half of the THMs for a water system to have formed within the first day or two of contact time. So while saving 25% (or some other amount) of contact time over the first day or two may be very helpful, it is not necessarily of much benefit when contact times are substantially longer such as in HWWC's case. Basically, after the first few days the water age does not contribute much to DBP formation.

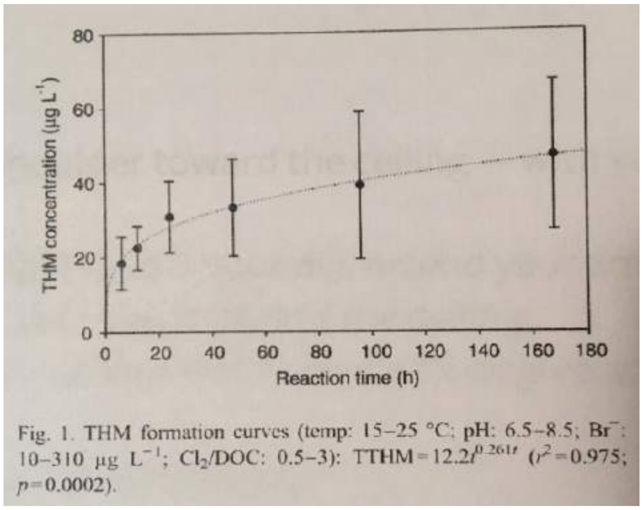


Fig. 1. THM formation curves (temp: 15–25 °C; pH: 6.5–8.5; Br^-: 10–310 μg L^{-1}; Cl_2/DOC: 0.5–3): $TTHM = 12.2t^{0.261}$ ($r^2 = 0.975$; $p = 0.0002$).

Figure 3-7: Typical pattern of THM formation over time (literature data)

Source: H.C. Hong, et al., *Science of the Total Environment*, 385 (2007), 45-54.

In summary:

- HWWC's HAA5 levels have exceeded the MCL in 2021 and 2022
- TTHM has not exceeded the MCL in the past, but reduction of levels would be helpful
- The rate of HAA and THM formation is relatively fast, with most occurring within the treatment plant and within two to three days of water age. Given that, lowering the water age by either lowering the storage tank levels or through bleeding water from ends of the distribution system are not expected to be an effective solution for controlling DBPs.

4. ALTERNATIVE OPPORTUNITY #1: TWO-STAGE CHLORINE DISINFECTION

This strategy for DBP control reduces the chlorine dose applied for primary disinfection and adds a second chlorine feed to boost the residual for secondary disinfection just prior to the point of entry (POE) to the distribution system. Using a lower chlorine dose reduces the thermodynamic driving force for the formation of DBPs, thus decreasing both the extent and rate of DBP formation.

This approach can be accomplished with a relatively minor modification to the treatment system. A new second chlorine feed would be installed between the storage tank and the POE. As is currently done, an online analyzer would measure chlorine, pH, and temperature for disinfection credit for the storage tank effluent before the chlorine addition (Segment #2). A chlorine analyzer would be installed after the chlorine feed to monitor the residual entering the distribution system at a newly established POE, along with a data connection to the SCADA system.

The second chlorine feed should also provide for a more controlled and consistent chlorine residual in the distribution system, as that dosing would be applied just before the water enters the distribution system instead of ~9 days earlier as part of the single dose now being fed before the contact basin.

Depending on the distance between the booster chlorine feed and the POE, an in-line mixer may be necessary shortly downflow after the chlorine feed to ensure consistent sampling at the POE chlorine monitor. It is also possible a new POE location will need to be established a short distance downflow from the current location, but before the first customer. These modifications are projected to cost approximately $25,000 to $40,000 depending upon the location of the chlorine feed line, monitoring station, communications line, etc.

This is an alternative that wasn't taken advantage of in the past because there were no issues meeting the HAA MCL requirements, and HWWC prefers to disinfect thoroughly. Now having experienced an MCL exceedance for a disinfection byproduct, the amount of disinfection can be reduced some to balance simultaneous compliance with the D/DBPR requirements, while still exceeding the required primary disinfection at all times.

This approach would significantly reduce the exposure of natural organic matter to chlorine during the contact times of the HWWC contact basin and storage tank, resulting in a reduction in the formation of HAAs and THMs. MassDEP has advocated for and/or required a similar two-stage chlorination practice at other water systems as a means of lowering DBPs.

Given the long contact times in the chlorine contact basin and storage tank, the primary disinfection requirements can be met year-round with a relatively low chlorine residual. Typically, the *CT* achieved by HWWC is 10 to 90 times higher than the *CT* required (Figure 2-2), with the lower levels experienced during the winter and higher levels during the summer due to the impacts of higher temperature on disinfection effectiveness. As such, *CT* can be decreased substantially and still exceed the primary disinfection requirements.

A two-stage chlorination approach should consider the water's chlorine demand (*demand = dose – residual*) and ensure enough of the demand has been met prior to the second chlorine dose, otherwise that chlorine dose may be consumed too quickly in the distribution system. Since most of the HAAs form while chlorine residuals are relatively high in the water treatment plant, lowering chlorine levels has good potential to be successful at reducing DBP formation. Given that DBPs are a non-acute health issue and that the compliance goal is to meet the four-quarter LRAA, it is appropriate to consider average DBP values over time instead of individual worst-case sample results for planning purposes.

The proposed future chlorine doses are based on the demand experienced in 2022 and the targets for chlorine residual after the GreensandPlus filters and in the distribution system. Demand should be less with lower doses in the future, but this provides a conservative starting point for operations. Note this concept is presented on a relative annual average basis, and is not intended to prescribe doses or targets for any particular season or circumstance.

The proposed average chlorine residuals are compared to the current status in Table 4-1. In 2022 the average calculated chlorine dose was ~3.4 mg/L. The average chlorine demand through the contact basin was ~1.8 mg/ L, and was about ~0.3 mg/L in the storage tank, for a total chlorine demand in the treatment plant of ~2.1 mg/L.

The proposed two-stage chlorination procedure would reduce the 2022 average chlorine residual levels by ~0.37 mg/L over ~19 hours in the contact basin, and by ~0.87 mg/L over ~8 days in the storage tank. The chlorine change in the storage tank reduces the initial (influent) reaction driving force (chlorine concentration) from 1.57 mg/L down to 0.7 mg/L, and the final (effluent) driving force from ~1.28 down to 0.3 mg/L. So basically on average the chlorine throughout the storage tank would be about 0.9 to 1.0 mg/L lower than in 2022.

Table 4-1. Average 2002 Chlorine Levels and Proposed Initial Future Targets

Location	2022 Average Chlorine (mg/L)	2022 Chlorine demand (mg/L)	Future Chlorine Target (mg/L)	Change in chlorine residual (2022 to proposed) (mg/L)
Dose before contact basin	3.38	NA	3	-0.38
After contact basin	1.57	1.81	1.2	-0.37
After GreensandPlus filters	NA	0.53 (pilot)	0.7	NA
After storage tank	1.28	0.29	0.3	-0.87
At POE	1.28	NA	boost +1.0 mg/L up to 1.3 mg/L	NA
In distribution system	0.57	0.71	0.6 mg/L (goal a minimum 0.2 to 0.5 mg/L)	0.03

Note: the chlorine demands used are those experienced on average during 2022 and based on the chlorine dosage applied. Lower chlorine doses would be expected to result in lower chlorine demands due to a smaller thermodynamic driving force for the redox reactions.

Experiments conducted for a Virginia water utility by EE&T, Inc. (now Cornwell Engineering Group) showed approximately linear reduction in HAA5 in response to reductions of chlorine dose. Those data are shown in Table 4-2 for a treated surface water (EE&T, 2015), and provide a general example of the potential for HAA reduction from lowering chlorine levels for waters with similar TOC levels:

Table 4-2. Effect of Chlorine Dose on HAA formation after 5 days

Cl_2 dose (mg/L)	Cl_2 (mg/L)	HAA5 (μg/L)	% drop in Cl2 from 4.2 mg/L	% drop in HAA5 from 65.6 μg/L	% drop in Cl2 from 3.0 mg/L	% drop in HAA5 from 52.3 μg/L
2.0	trace	32.5	52%	50%	33%	61%
2.3	0.1	26.0	45%	60%	23%	50%
3.0	0.4	52.3	29%	20%		
4.2	1.3	65.6				

As a rough estimate based on those data, a particular percent decrease in chlorine dose may be expected to result in a similar percent decrease in HAA5. The percent decreases in chlorine dose proposed in Table 4-1 would correspond to decreases in HAA5 of ~11% in the contact basin and ~55% in the storage tank.

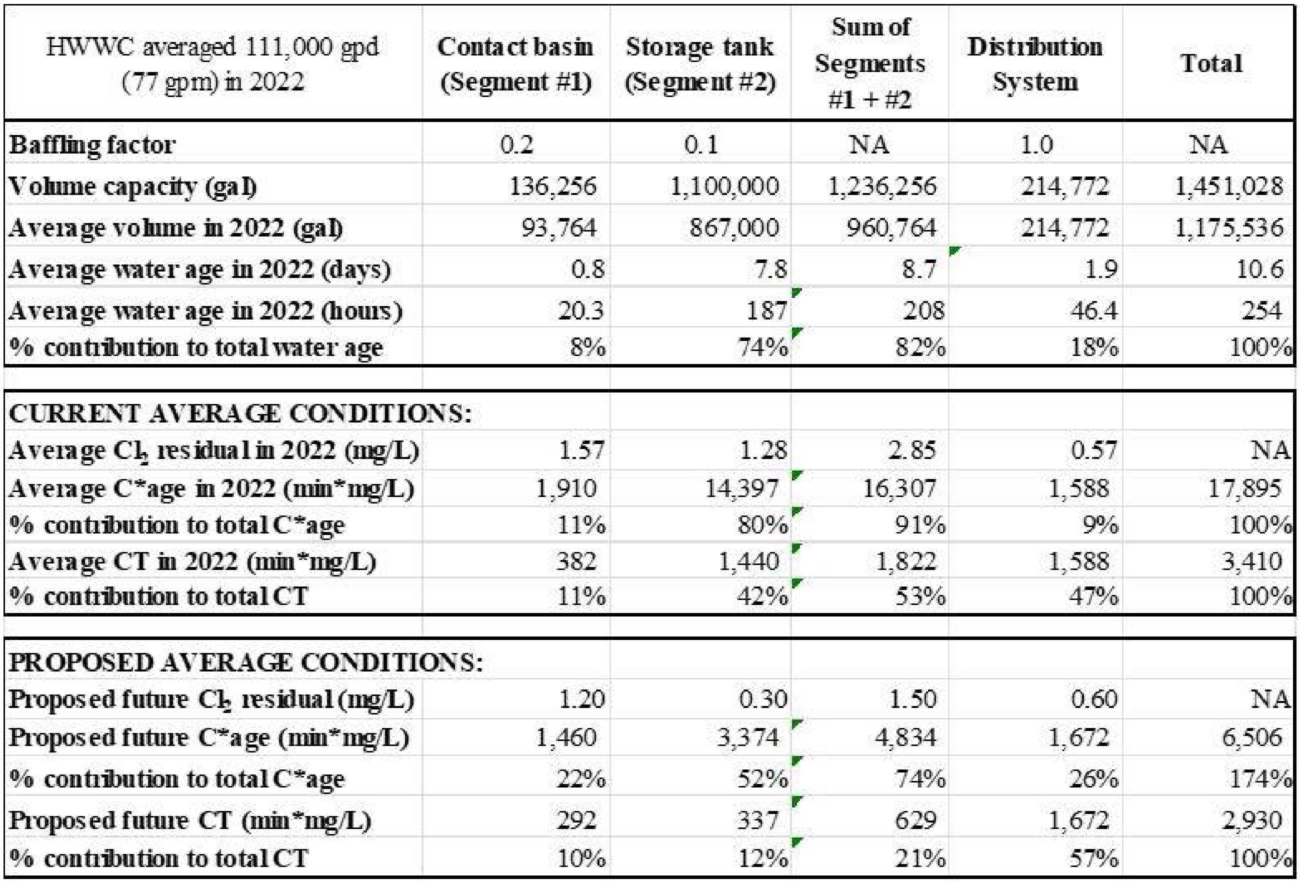
Then assuming 40% of the total HAA5 form in the clearwell and 40% form in the storage tank (discussed in Section 3), then that would correspond to total reductions of 4.5% and 22%, respectively, for approximately a 27% reduction in total HAA5 formed. For THMs, which were 100% formed by the time the water would leave the tank (Figure 3-6), this would suggest a 38% reduction in total THMs would be achieved.

In addition to comparing chlorine residuals (Table 4-1), contact time has also been incorporated into the evaluation by comparing the average amount of *CT* achieved for the current practice with that calculated for the proposed new chlorination procedure, both with and without the use of baffling factors in the calculation of *CT* (Table 4-3).

For the product of *C* and water age (*C*age*, no baffling factor), the total water treatment plant (Segments #1 and #2) current average is 16,307 min*mg/L, and that would be reduced to 4,834 min*mg/L with the proposed two-stage chlorination procedure, **for a decrease in *C*age* of 70%.** When including consideration of the baffling factors for the two disinfection segments (used for compliance calculations), ***CT* would decrease 65%** from 1,822 to 629 min*mg/L.

The GreensandPlus filters will be beneficial for reducing DBPs as they demonstrated a chlorine demand of ~0.53 mg/L, which effectively quenches some of the chlorine that would have just been used for primary disinfection credit and before that chlorine can react to form more DBPs.

Table 4-3. Proposed CT vs. 2022 Average CT



HWWC averaged 111,000 gpd (77 gpm) in 2022	Contact basin (Segment #1)	Storage tank (Segment #2)	Sum of Segments #1 + #2	Distribution System	Total
Baffling factor	0.2	0.1	NA	1.0	NA
Volume capacity (gal)	136,256	1,100,000	1,236,256	214,772	1,451,028
Average volume in 2022 (gal)	93,764	867,000	960,764	214,772	1,175,536
Average water age in 2022 (days)	0.8	7.8	8.7	1.9	10.6
Average water age in 2022 (hours)	20.3	187	208	46.4	254
% contribution to total water age	8%	74%	82%	18%	100%
CURRENT AVERAGE CONDITIONS:					
Average Cl_2 residual in 2022 (mg/L)	1.57	1.28	2.85	0.57	NA
Average C*age in 2022 (min*mg/L)	1,910	14,397	16,307	1,588	17,895
% contribution to total C*age	11%	80%	91%	9%	100%
Average CT in 2022 (min*mg/L)	382	1,440	1,822	1,588	3,410
% contribution to total CT	11%	42%	53%	47%	100%
PROPOSED AVERAGE CONDITIONS:					
Proposed future Cl_2 residual (mg/L)	1.20	0.30	1.50	0.60	NA
Proposed future C*age (min*mg/L)	1,460	3,374	4,834	1,672	6,506
% contribution to total C*age	22%	52%	74%	26%	174%
Proposed future CT (min*mg/L)	292	337	629	1,672	2,930
% contribution to total CT	10%	12%	21%	57%	100%

Note: Only Segment #1 and Segment #2 are included in calculations for the achieved disinfection performance.

5. ALTERNATIVE OPPORTUNITY #2: GRANULAR ACTIVATED CARBON (GAC20)

USEPA's Stage 2 D/DBPR Implementation Guidance provides the following definition for GAC20 (USEPA 2007):

> *"GAC20 means granular activated carbon filter beds with an empty bed contact time of 20 minutes based on average daily flow and a carbon reactivation frequency of every 240 days."*

As background on granular activated carbon, the following is quoted from USEPA (2023a) guidance:

> *"Granular activated carbon (GAC) is a porous adsorption media with extremely high internal surface area. GACs are manufactured from a variety of raw materials with porous structures including:*
>
> - *bituminous coal*
> - *lignite coal*
> - *peat*
> - *wood*
> - *coconut shells*
>
> *Physical and/or chemical manufacturing processes are applied to these raw materials to create and/or enlarge pores. This results in a porous structure with a large surface area per unit mass.*
>
> *GAC is useful for the removal of taste- and odor-producing compounds, natural organic matter, volatile organic compounds (VOCs), synthetic organic compounds and disinfection byproduct precursors. Organic compounds with high molecular weights are readily adsorbable.*
>
> *Treatment capacities for different contaminants vary depending on the properties of the different GACs, which in turn vary widely depending on the raw materials and manufacturing processes used.*
>
> *The media has to be removed and replaced or regenerated when GAC capacity is exhausted. In some cases, disposal of the media may require a special hazardous waste handling permit. Other adsorbable contaminants in the water can reduce GAC capacity for a target contaminant."*

While the chlorine reduction option is a steady-state process with consistent output for consistent input, GAC contactors are a non steady-state process. After an initial period of time, the target chemical(s) will begin to breakthrough the media, and concentrations in the effluent will increase over time until the GAC is exhausted and the effluent concentration equals the influent concentration. Unless contactors are operated in series the GAC will be replaced before full exhaustion is reached, perhaps even before or shortly after breakthrough is observed, depending on the nature of the target chemical(s).

Removal percent for a specific contaminant and GAC type is often expressed as a function of bed volumes processed. GAC contactors cannot be described as removing a certain percentage of a contaminant, as the removal will start at ~85-100% and once breakthrough starts (if left operating) the effluent concentration will increase until exhaustion is reached and removal is 0% where the effluent and influent concentration are the same.

Generally, after an initial lag period and breakthrough starts the TOC concentration increases linearly over time. As one example, data from the Cincinnati Water Works using GAC contactors with an EBCT of 21 days showed 85-90 percent TOC removal for about 80 days, then TOC increased linearly until removal was down to 50% after about 210 hours, and was down to ~43% after 240 hours (Jacangelo et al. 1995).

Other examples of typical breakthrough curves from GAC contactors are shown in Figure 5-1 for TOC and Figure 5-2 for UV254. These data are from tests using four different types of GAC and a Virginia surface water. There is an initial period of roughly 5,000 to 10,000 bed volumes with low concentrations in the effluent, and then TOC and UV254 increase linearly over time and at similar rates for the different types of GAC tested. These are “shallow” breakthrough curves, as opposed to some chemicals which exhibit much sharper breakthrough curves with GAC.

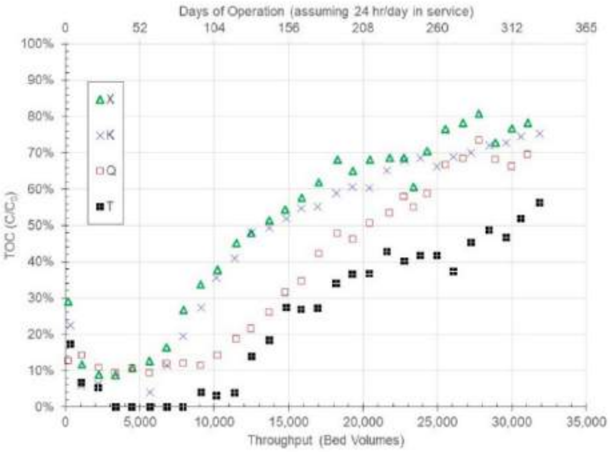


Figure 5-1. TOC Breakthrough for 4 GACs in a Virginia Surface Water

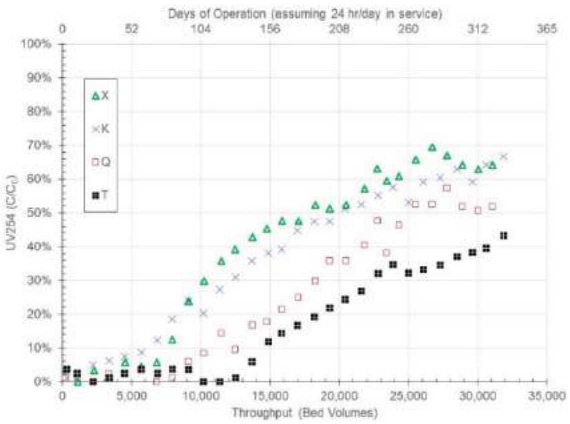


Figure 5-2. UV254 Breakthrough for 4 GACs in a Virginia Surface Water

The primary difference between the four GACs was how long it took for breakthrough to start occurring. The GAC labeled “T” in the dark squares in Figures 5-1 and 5-2 was the preferred GAC as it took the longest to show breakthrough as defined by any percent removal. Operating lead-lag in series will help optimize the removal of TOC and maximize utilization of the GAC’s capacity for adsorbing TOC. In this case, approximately 30 to 60 percent removal of TOC was shown by the four different types of GAC after 240 days, and approximately 40 to 70 percent removal of UV254.

Based on those examples, it is a reasonable estimate for HWWC to achieve approximately 85% removal of TOC at the start of a GAC cycle, and that would decrease down to 50% removal before replacement of the media is needed after 240 days per the GAC20 criteria.

When new GAC is installed there may be a temporary increase in pH observed. The effluent pH will then decrease over time as more water is treated, and will eventually return to the influent value (NYSDOH 2021). An increase in pH would lower the chlorine disinfection credit achieved, though not enough to risk disinfection compliance, and if the GAC is located after the storage tank there would be no impact on primary disinfection at all. An increase in pH would also potentially render the water more resistant to corrosion of lead or copper, though that does not appear necessary given the low lead and copper results typically monitored at HWWC’s distribution system.

For HWWC, given the natural purity of the Long Pond source water, there are no other ancillary benefits of GAC to be gained beyond removing DBPs or the precursor TOC. For example, there are no volatile organic compounds (VOCs) or PFAS chemicals to remove.

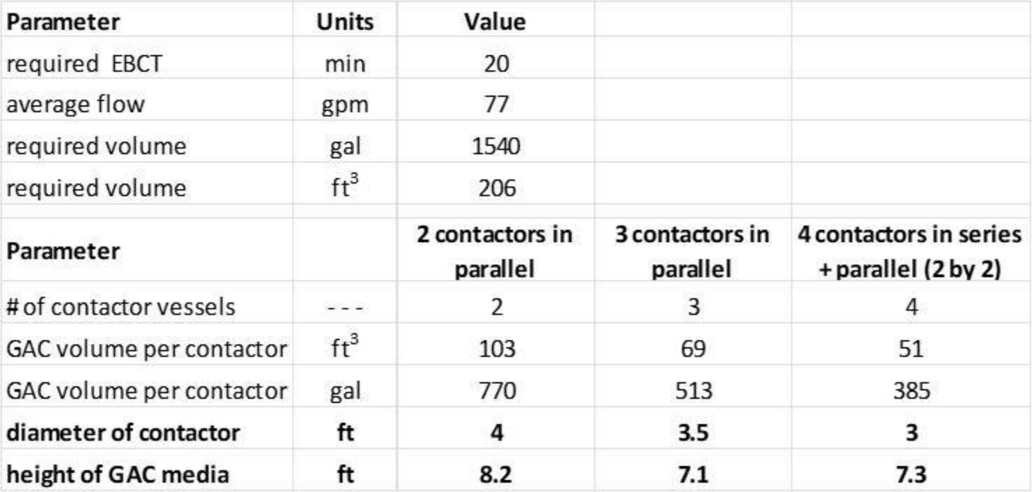
5.1 GAC Contactor Sizing

HWWC’s average production flow rate is 111,000 gpd (77 gpm). For an empty bed contact time (EBCT) of 20 minutes, the required total GAC volume is calculated as:

$$\text{EBCT} * \text{average flow rate} = 20 \text{ min} * 77 \text{ gal/min} = 1{,}540 \text{ gallons}$$

The 1,540 gallons (206 ft^3) is the required volume of the contactor section containing the GAC media, and additional volume is required for a top layer of media (e.g., anthracite) and space for media expansion during backwashing. Three potential options of the necessary sizing of the GAC contactors are shown in Table 5-1. In each case a contactor diameter was selected and then the corresponding contactor height was calculated for the required total volume of 1,540 gallons (206 ft^3).

Table 5-1. Possible GAC Contactor Dimensions for the Required EBCT of 20 minutes



Parameter	**Units**	**Value**		
required EBCT	min	20		
average flow	gpm	77		
required volume	gal	1540		
required volume	ft^3	206		
Parameter		**2 contactors in parallel**	**3 contactors in parallel**	**4 contactors in series + parallel (2 by 2)**
# of contactor vessels	- - -	2	3	4
GAC volume per contactor	ft^3	103	69	51
GAC volume per contactor	gal	770	513	385
diameter of contactor	**ft**	**4**	**3.5**	**3**
height of GAC media	**ft**	**8.2**	**7.1**	**7.3**

As noted above, TOC is likely to elicit a shallow breakthrough curve without a sharp change in concentration over time. In that circumstance, it is useful to use GAC contactors in a lead-lag series mode so that more of the GAC's capacity can be used before it is considered exhausted and is then replaced. However, GAC20 specifies reactivation of the GAC media after 240 days that timing does not consider how little TOC is in the effluent or how little GAC adsorptive capacity has been used for a specific water supply. Given that, the lead-lag benefit may not be fully taken advantage of. It would need to be determined if longer GAC run times would be allowed by MassDEP and under what conditions. Per USEPA's description of the BATs, that could be done but without the corresponding variance that could potentially be available by meeting the BAT requirement of a 240-day reactivation frequency.

Optimal operation of GAC contactors involves monitoring the breakthrough of TOC traveling through the column, Contactors can be operated until a specified target is reached, and GAC replaced or regenerated only after sufficient TOC breakthrough has occurred. What level those particular TOC goals are set at depends on the particular situation. For HWWC, TOC averages 1.6 mg/L in the filtered water during non-winter conditions when DBPs are of more concern.

5.2 GAC Contactor Location

Three different locations are theoretically possible for pressure GAC contactors in HWWC's treatment plant, as discussed below. The location must consider that chlorine reacts with GAC and will be totally removed from water that passes through GAC.

The GAC should be located somewhere after the slow sand filters to take full advantage of the filters removing the more readily biodegradable components of the TOC. In other words, the remaining portion of TOC would be the less biodegradable but more adsorbable components of the TOC.

1. <u>After the slow sand filters and before the current chlorine addition</u>:

   This would require pumping through pressure GAC contactors, and the chlorine feed would need to be located after the GAC. NOM would be reduced to varying levels over time as discussed above.

   NWSI recommends this location be used if installation of GAC is deemed appropriate at some time in the future. Precursor NOM material would be reduced, and chlorine would not be expended in the GAC filters (chlorine would be added after the GAC).
2. <u>After the proposed new GreensandPlus filtration system</u>.

   The GAC would be in pressure contactors, receiving the effluent from the proposed new greensand filters. The GAC should remove most of the HAAs and THMs that would have already formed in the contact basin. That would constitute approximately 40% of the DBPs that form over time (Figure 3-6). The GAC would also remove some of the NOM remaining after the slow sand filters, though not likely as efficiently as it removes THMs and HAAs.

   The GAC would also remove the ≥ 0.5 to 1.0 mg/L of chlorine residual that would be in the greensand filter effluent. Primary disinfection credit would only be available for Segment #1 unless a chlorine feed was established for Segment #2 after the GAC and before the 1.1-MG storage tank. If that was not done HWWC would need to establish a chlorine feed after the storage tank for secondary disinfection with residual chlorine in the distribution system, and perhaps an in-line mixer. That same chlorination strategy is part of the two-stage chlorination procedure considered in Section 4.
3. <u>After the 1.1 MG storage tank</u>:

The GAC would be in pressure contactors, receiving the effluent from the 1,1-MG storage tank. The GAC should remove most of the HAAs and THMs that would have already formed in both the contact basin and storage tank. That would constitute approximately 80% of the HAAs and 100% of the THMs that form over time (Figure 3-6). The GAC would also remove some of the NOM remaining after the slow sand filters, though not likely as efficiently as it removes THMs and HAAs.

As with option #2 above, a chlorine feed would need to be established after the GAC to provide residual chlorine in the distribution system for secondary disinfection, and perhaps an in-line mixer would be needed. That same chlorination strategy is part of the two-stage chlorination procedure considered in Section 4.

Flow rates would change based on distribution system demands, potentially leading to larger sizing of a GAC system. Water pressure after the storage tank is about 15 psi (based on tank elevation of 35 feet). The head loss expected though the GAC contactors would need to be considered in terms of impact on distribution system pressures.

5.3 GAC Contactor Costs

USEPA has generated cost models for a variety of drinking water treatment technologies, including GAC, which are available for public access as *Excel* workbooks from a USEPA website (USEPA 2023b). The work breakdown structure (WBS) model estimates costs for both gravity and pressure GAC contactors, and is described in detail elsewhere (USEPA 2017). The necessary input was provided to the model as applicable to HWWC. Given the EBCT was specified as 20 minutes and GAC reactivation at 240 days, the model produced the same cost estimates for different organic adsorbates including NOM.

The USEPA cost model results are provided in Table 5-2 in both the model's 2013 dollars and in terms of 2023 dollars. The inflation rate from 2013 to 2023 has been reported as 29 percent, so that was added to the 2013 estimates to provide estimates for 2023.

Table 5-2. Estimated GAC Contactor Costs per USEPA 2013 Cost Model

	2013 estimate	2023 estimate	2023 per customer
Direct capital costs	$ 1,232,765	$ 1,590,267	$ 1,930
Total capital costs	$ 1,832,394	$ 2,363,788	$ 2,869
Annual O&M costs	$ 50,774	$ 65,498	$ 79
Annualized cost (12.3 yrs @ 7%)	$ 277,833	$ 358,405	$ 435

The total cost estimate for installation of the GAC system is ~$2,364,000 with an additional ~65,500 per year for operating expenses. For HWWC's customer base of 824 accounts, the capital cost would be $2,869 per customer and $79 per year in operating costs. That would be extremely expensive for this particular issue given a major decrease in HAA5 is not necessary for achieving compliance. The highest HAA5 LRAA to date at HWWC was 74 ug/L in 1st quarter 2022, after three consecutive quarters had their highest HAA5 results ever starting in August 2021 following the historic rainfall in July 2021. The USEPA cost model estimate also seems rather high for this size of a system, and real costs may be somewhat lower. Space would be needed in HWWC's new treatment building being planned for the greensand filtration system for removal of manganese.

Another cost estimate may be made by considering that currently expected for installation of the GreensandPlus filters for manganese removal, which is currently estimated by NWSI as approximately $250,000 for the filter system itself not counting the necessary building. Both the greensand filters and GAC involve pressure vessels, so the capital costs should be roughly similar. The GAC requires replacement for regeneration while the GreensandPlus may require its own type of reactivation annually when the system is started up for the summer season.

5.3 Schedule for GAC

If it is determined that GAC contactors are desired by HWWC or required by MassDEP, it would be most practical for that to be installed at the same time the greensand filters are installed since planning for that effort and the associated financing is currently underway. If not then, it is recommended that space be reserved in the planned new building for a GAC system in case that is needed in the future, along with saving space available to house a potential pH adjustment system., If required to be installed in conjunction with the greensand system, that is expected to be later in 2023 or in 2024, depending on the timing of MassDEP approval.

6. SUMMARY AND RECOMMENDATIONS

Two potential alternative solutions were evaluated for controlling DBPs at Housatonic Water Works Company. The two-stage chlorination strategy is recommended over the granular activated carbon option. Both would provide good reduction in DBPs, but the chlorine strategy is simpler, quicker to implement, and much less expensive than GAC. And as a simple operational modification the two-stage chlorination strategy should be employed before the expensive capital project of installing GAC contactors.

7. REFERENCES

EE&T, Inc. (now Cornwell Engineering Group). 2015. DBP Evaluation at RWSA Drinking Water Facilities. Newport News, VA. December 2015.

Huisman, L. and W.E. Wood. 1974. Slow Sand Filtration. World Health Organization, Geneva, Switzerland.

Jacangelo, Joseph G., Jack DeMarco, Douglas M. Owen, and Stephen J. Randtke. 1995. Selected Processes for Removing NOM: An Overview. *Journal AWWA*, Vol. 87, No. 1, pp. 64-77, January 1995.

MWRA (Massachusetts Water Resource Authority. 2022. Water Quality Update – An Analysis of August 2022 Sampling Data. September 20, 2022. Available at https://www.mwra.com/monthly/wqupdate/pdf/cy2022/082022.pdf.

NYSDOH (New York State Department of Health, Bureau of Water Supply Protection). 2021. Interim Recommendations for Granular Activated Carbon (GAC) Installations - Design Review, Startup and Operations. Available at https://www.health.ny.gov/environmental/water/drinking/docs/interim_recommendations_for_granular_activated_carbon_installations_v_1.pdf. April 25, 2021.

USEPA (Office of Water). 2007. The Stage 2 Disinfectants and Disinfection Byproducts Rule (Stage 2 DBPR) Implementation Guidance. EPA 816-R-07-007. August 2007.

USEPA (Office of Water). 2017. Work Breakdown Structure-Based Cost Model for Granular Activated Carbon Drinking Water Treatment. No EPA# (EPA *-***-*****). December 2017.

USEPA (Office of Water). 2020. The Disinfectants and Disinfection Byproducts Rule (Stage 1 and Stage 2) – What Do They Mean To You? EPA 815-R-20-005. June 2020.

USEPA (Office of Water). 2023a. Overview of Drinking Water Treatment Technologies. Website accessed January 9, 2023. https://www.epa.gov/sdwa/overview-drinking-water-treatment-technologies#GAC

USEPA (Office of Water). 2023b. Drinking Water Treatment Technology Unit Cost Models. Website accessed January 9, 2023. https://www.epa.gov/sdwa/drinking-water-treatment-technology-unit-cost-models