# FINAL REPORT

## Evaluation of Water Quality Data

Chester Water Department, Chester MA

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**1. Introduction and Objectives:**

The Chester Water Department operates a community water supply system (PWSID 1059000) that serves approximately 750 people through approximately 252 connections in this small town located in western Massachusetts.

The water system recently exceeded the allowable Maximum Contaminant Level (MCL) for the disinfection byproduct (DBP) class known as total trihalomethanes (TTHMs) for three quarters in a row – the third and fourth quarter of 2018 and the first quarter of 2019. The Massachusetts Department of Environmental Protection (MassDEP) issued a Notice of Noncompliance (Enforcement Number 00005564) to Chester on December 4, 2018 for the third quarter 2018 TTHM MCL exceedance, and a Notice of Noncompliance (Enforcement Number 00006424) to Chester on May 3, 2019 for the fourth quarter 2018 and first quarter 2019 TTHM MCL exceedances. Chester was also required to complete and submit an Operational Evaluation Report for exceeding the Operational Evaluation Level (OEL) limit for TTHM in the second and third quarters of 2018 (per MassDEP letter dated December 4, 2018). In addition, in a letter dated August 24, 2018, MassDEP required Chester to "prepare a written report to address the 2018 color, turbidity, source water quality, and disinfection byproduct concerns."

This report presents the findings, conclusions, and recommendations from an evaluation of available water quality data, and is intended to help satisfy the above MassDEP requirements. This evaluation includes the water quality parameters listed above, as well as observations and recommendations related to other operational topics.

## 2. Treatment System:

Chester's water treatment system is comprised mainly of the following, in the order presented:

1. Presently the source water is from Horn Pond, with the Austin Brook Reservoir serving as an alternate backup supply.
2. Slow sand filtration – three slow sand filters are available, and one includes a layer of granular activated carbon for removing natural organic matter (NOM), which is a precursor to DBP formation.
3. Disinfection with free chlorine – this is accomplished in the third segment of the clearwell (the whole clearwell is avoided to reduce chlorine contact time and thus reduce DBP formation).
4. pH adjustment using sodium hydroxide (NaOH), injected just after the clearwell and before the water leaves the treatment plant.
5. Disinfection with free chlorine – this second stage of primary disinfection is accomplished in the ~1,800-foot pipeline leading from the treatment plant down the hill to the old chlorinator building. Chorine is added at the treatment plant just after the NaOH addition, and the residual is measured at the old chlorinator building. Enough chlorine residual is targeted to maintain a residual in the distribution system (i.e., secondary disinfection). For chlorine disinfection, the pipeline has the advantage of a higher baffling factor than the clearwell (1.0 versus 0.13, respectively), but the disadvantage of a higher pH.
6. The old chlorinator building is considered to be the Point of Entry (POE) to the distribution system. Finished water turbidity and pH are also measured at the old chlorinator building.

## 3. Methodology:

Available water production and water quality data were reviewed for calendar year 2018. Most of the data were obtained from the Monthly Operating Reports (MORs) that are submitted to the MassDEP. The MORs were obtained from the Chester Water Department.

Flow and water quality data were plotted to identify trends, various data sets were compared to identify potential correlations, and results were compared to the corresponding regulatory requirements (e.g., MCLs) or other water quality targets. In addition, a distribution system chlorine residual mapping exercise was conducted on March 27, 2019.

**4. Drinking Water Production:**

The quantity of potable water produced each day in 2018 is presented in Figure 1. The reported peak hourly flows for each day are presented in Figure 2.

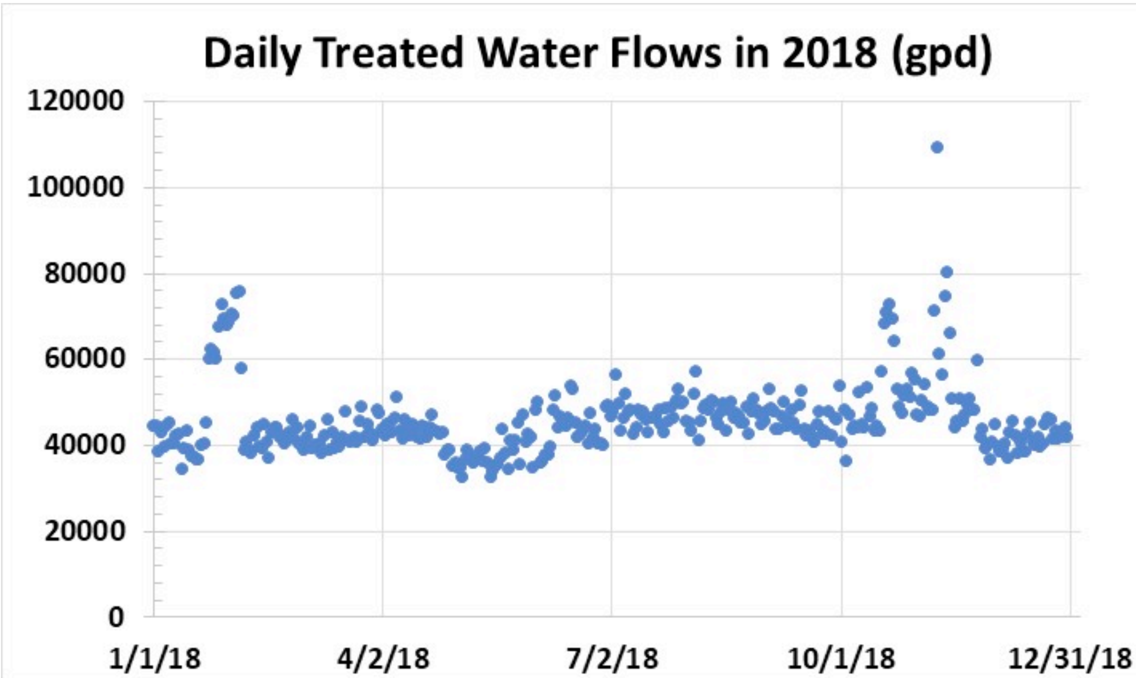


**Figure 1. Potable water produced per day (1/1/18 – 12/31/18)**

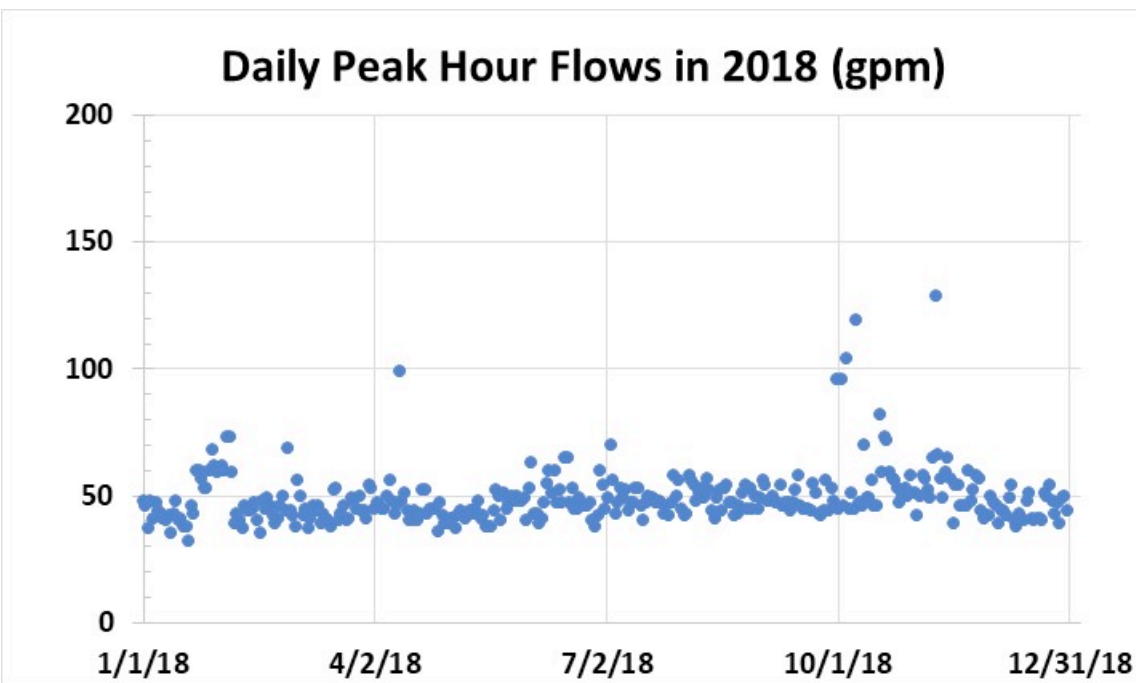


**Figure 2. Peak Hourly Flow for each day (1/1/18 – 12/31/18)**

The following observations are evident from the water production data:

- In 2018, daily flows averaged 45,691 gpd. The highest daily flow was 109,328 gpd, and the lowest daily flow was 32,672 gpd.
- Assuming a population size of 750 people, the average production corresponds to 61 gpd per person, which is very close to the national average of 58.6 gallons per capita per day for residential communities (DeOreo et al., 2016).
- In 2018, peak hourly flows averaged 49 gpm. The highest peak hourly flow was 129 gpm, and the lowest peak hourly flow was 32 gpm.
- The ratio of average peak hourly flow to annual average flow is 1.5 (49 gpm vs. 31.7 gpm).
- There were some periods of abnormally high flow, including late January – early February, and again in October and then November (Figure 1). These large increases in water production appear attributable to leaking pipes that were discovered and repaired. For example, the January/February issue was a pipe break on Emery Street that filled a basement.
- Chester uses the measured value of peak hourly flow for determining disinfection performance, instead of the alternate method of assuming a value for peak hourly flow based on the average annual flow and a peaking factor. A typical peaking factor used is 3.0, while Chester's measured peaking factor is only 1.5. It is recommended that Chester continue to use the measured peak hourly flow instead of using the alternate peaking factor method, as in this case that would typically result in less disinfection being required than via the peaking factor approach. This would be disadvantageous only in circumstances where there is an abnormal amount of flow, such as during a main break.
- No unresolved issues were identified regarding the water production data.

**5. Filtration:**

The Chester Water Department uses slow sand filtration as part of the treatment system. There are three filters, one of which (Filter #3) has a granular activated carbon (GAC) layer between two sand layers (a "carbon sandwich") for removing natural organic matter (NOM), which is a precursor to DBP formation. Anywhere from one to three filters may be operating at a given time, depending on flow requirements and impacts from filter head loss. During the March 27, 2019 site visit, Filter #2 was the only filter in operation. Turbidity has been monitored for the finished water, but not for the combined filter effluent. The turbidity meter is calibrated twice per year by the system Operator (typically around June 1 and during the December holidays).

For slow sand filtration, the regulatory requirements include the following two conditions (per 310 CMR 22.20A(4)(b):

1. At least 95% of the Combined Filter Effluent (CFE) turbidity readings in a given calendar month must be ≤ 1 NTU (Nephelometric turbidity unit). Given that only one significant digit is used for that limit, the data should also be rounded to one significant digit. This means that a value of 1.49 NTU would be rounded down to 1 NTU, and that would meet the limit. A value of 1.50 NTU would be rounded up to 2 NTU, and that would exceed the allowable limit.

2. At no time can the Combined Filter Effluent turbidity be above 5 NTU (thus allowing up to 5.49 NTU, but not 5.50 NTU).

The finished water turbidity for 2018 is plotted in Figure 3 (results were not available for the Combined Filter Effluent). The following observations were made regarding the filtration operations:

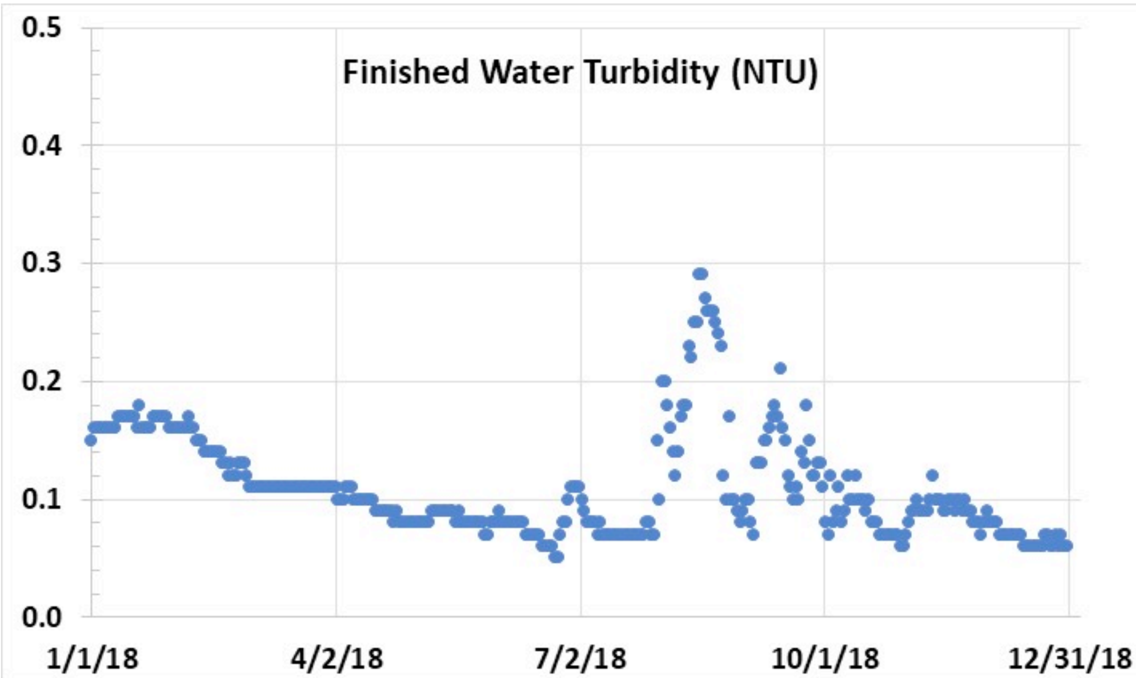


**Figure 3. Finished Water Turbidity**

- The required turbidity limits were met throughout 2018. The average daily value for 2018 was 0.11 NTU, and the highest daily value was 0.29 NTU. As such, there were no results near either the 95% limit of ≤ 1 NTU nor the absolute limit of ≤ 5 NTU.
- Chester has been collecting the samples for the turbidity analyses from the treatment plant finished water (Point of Entry, or POE). However, the proper location for sampling turbidity for regulatory compliance is the combined filter effluent water, before any further treatment or chemical addition (referred to as “filtered water” in 310 CMR 22.20A(4)(b)). Typically, filter effluent turbidities are lower than finished water turbidities. Raising the pH of the water can cause dissolved metals to precipitate and thus increase the turbidity. The filter effluent turbidity values should be used for regulatory compliance reporting, and for assessing the operation of the slow sand filters.

  Chester’s Operator reported that typically the filter effluent turbidities are around 0.03 to 0.04 NTU, as opposed to the average daily finished water turbidity of 0.11 NTU. When checked on March 27, 2019, the filtered water turbidity was 0.02 NTU and the finished water turbidity was 0.09 NTU.
- Chester should install sample taps for all three individual filter effluents (IFEs) and also the one combined filter effluent (CFE). There should be an online turbidity meter for the CFE sample, and that would be used for determining the maximum turbidity value for each day.

- There was an increase in finished water turbidity in August 2018, and then a second spike occurred for a little over a week in Sept 2018. However, the maximum turbidity was 0.29 NTU, which is well below the regulatory limit=. Therefore, while these turbidity increases are notable for operational purposes, there is no concern related to the regulatory requirements for turbidity. The system operator does not believe that source water quality was a cause of the increases in turbidity, and wondered if a filter was perhaps brought online prior to it being completely ripened.

  The turbidity data show the following (Figure 3):

  - Turbidity started to increase on July 31, 2018, reached a maximum on August 16-17, 2018, and then started decreasing until it reached normal levels around the end of August 2018.
  - Turbidity started increasing again on September 6, 2018, reaching a maximum on September 15, and was then back down to normal by about October 1.

  An excerpt of the Operator's logbook for that time period is provided as Figure 4. It is possible that the first turbidity spike is correlated, at least in part, to Filter #3 being taken offline. The second spike starts not long before Filter #1 was taken offline to drain for cleaning, and peaked on September 15, only two days before Filter #1 came back online on Sept. 17.

  In the future, any increase in turbidity should be investigated at the time it occurs. It is not readily evident from the Operator's Log which filters are online at a given time, though it appears that all three were online prior to the first turbidity spike that started on July 31, 2018. It may be helpful to track somewhat differently which filters are online. Figure 5 provides a sample template for a table to do that, which would make it somewhat easier in the future to try and correlate filter operations with turbidity spikes.

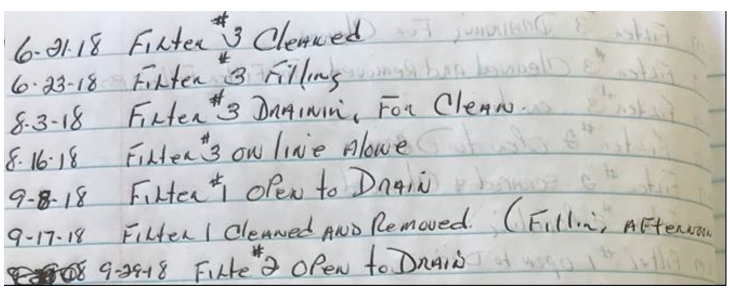
6-21-18 Filter #3 Cleaned
6-23-18 Filter #3 Filling
8-3-18 Filter #3 Draining For Clean.
8-16-18 Filter #3 on line Alone
9-8-18 Filter #1 Open to Drain
9-17-18 Filter 1 Cleaned AND Removed (Filling AFtern
9-29-18 Filte #2 Open to Drain

**Figure 4. Excerpt from Operator's Logbook**

| Day | Date | Filter #1 | Filter #2 | Filter #3 |
|---|---|---|---|---|
| ?? | ?? | ONLINE | ONLINE | ONLINE |
| ?? | ?? | taken OFFLINE at 9:15am; draining for cleaning | | |
| ?? | ?? | Put back ONLINE at 11:30am | | |
| ?? | ?? | | taken OFFLINE at 9:15am; draining for cleaning | |
| ?? | ?? | | Put back ONLINE at 9:30am | |

**Figure 5. Sample Filter Operations Log**

**6. Primary Disinfection:**

The Chester Water Department uses free chlorine for both primary and secondary (residual) disinfection. The regulatory requirements for primary disinfection for this water system are based on the ability to inactivate *Giardia* cysts, and requires a minimum of 1.0-log removal (1.0 log = 90% removal, and 2.0 logs = 99% removal). That removal is a function of the pH and temperature of the water, chlorine residual concentration, and chlorine contact time.

Chester's treatment plant uses two chlorine contact chambers for meeting the disinfection requirements. The target chlorine residuals are about 0.4 to 0.8 mg/L. There are tables available in the treatment plant that provide suggested chlorine residuals for a variety of operating conditions (e.g., different temperatures and pH). No attempt was made by RCAP to verify the accuracy of that information.

The finished water chlorine residuals for 2018 are plotted in Figure 6.

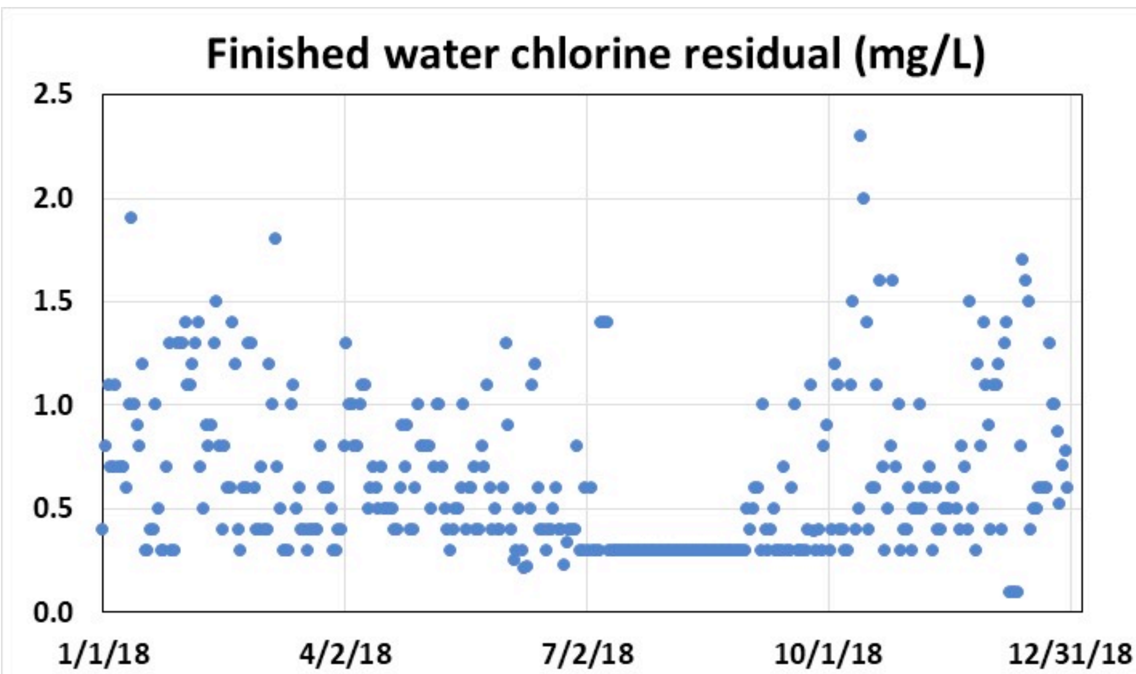


**Figure 6. Finished Water Chlorine Residual**

The following observations were made regarding the chemical disinfection operations:

- The required disinfection performance was met at all times in 2018.
- Chlorine residuals vary more than is desired for maintaining a consistent water quality. A range of +/- 0.2 mg/L or +/- 0.3 from the target concentration would be a reasonable goal. It is recommended that Chester investigate how to maintain a more consistent finished water chlorine residual.
- Finished water chlorine residual was constant at 0.3 mg/L from July 11 to August 31, 2018. The system Operator was not able to provide an explanation for this anomaly.

- RCAP's calculation of the achieved disinfection performance calculations confirmed that Chester is calculating disinfection performance accurately (within reasonable variances for rounding differences). However, the part of the calculation involving the volume of the chlorine contactor was not checked. RCAP was not able to obtain the specifications used in the SCADA calculations to determine the volume of the chlorine contactors (part of determining chlorine contact time), and thus could not confirm this accuracy. It is recommended that this information be obtained and reviewed for accuracy.
- A baffling factor of 0.13 is used for the chlorine contact chamber. The system Operator notes that this was determined via a tracer study conducted with assistance from the Massachusetts Rural Water Association and also Mike McGrath of MassDEP. No documentation of this tracer study was available. The tracer study report should be located and filed, and also perhaps be subject to a review. RCAP Solutions is available to conduct that review if so desired by the Chester Water Department.

**7. Secondary Disinfection (Distribution System Chlorine Residual):**

Secondary (residual) disinfection involves maintaining a detectable chlorine residual in the distribution system. This is monitored via the chlorine residual analyses conducted when sampling monthly for coliform bacteria as part of the Revised Total Coliform Rule (RTCR) monitoring program.

While the regulatory requirement is for a "detectable" chlorine residual, ideally chlorine residuals concentrations should be ≥ 0.2 mg/L throughout a distribution system. For the Chester distribution system, chlorine residual is currently monitored at 381 Huntington Road, which is near the end of a dead-end pipe in the southeastern part of the distribution system.

The 2018 distribution system chlorine residuals at 381 Huntington Road are plotted in Figure 7.

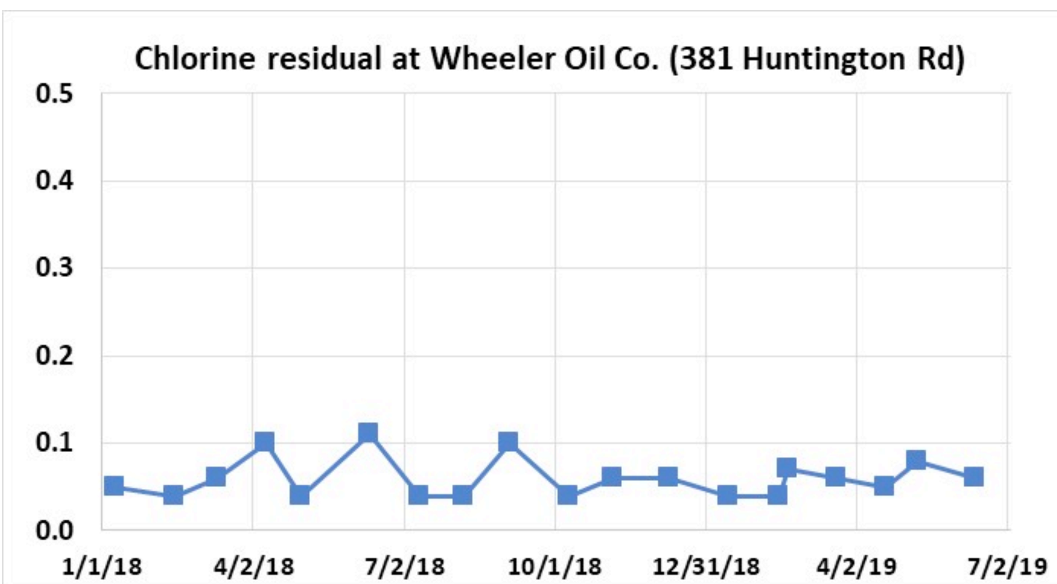


**Figure 7. Distribution System Chlorine Residual**

Based on those data, the following observations were made:

- The chlorine residuals monitored monthly at the Wheeler Oil location have been low but detectable, averaging 0.06 mg/L from January 2018 through April 2019, with a minimum of 0.04 mg/L and a maximum of 0.11 mg/L (Figure 7).
- The required minimum required chlorine residual of a "detectable" concentration was met during all RTCR sampling events in 2018.
- It would be helpful to maintain a higher chlorine residual at the ends of the distribution system such as the Wheeler Oil location.
- Biological growth in distribution systems can consume chlorine. One means for periodically restoring chlorine residuals is to conduct a high-velocity flushing program once or twice a year to help clean the pipes. That is recommended for Chester to help maintain the chlorine residuals.

To further investigate distribution system chlorine residuals, RCAP Solutions staff conducted a chlorine mapping exercise of the distribution system on March 27, 2019. Locations were selected both near the beginning of the distribution system, in the middle, and particularly near the edges. Results are presented in Figure 8 and Table 1.

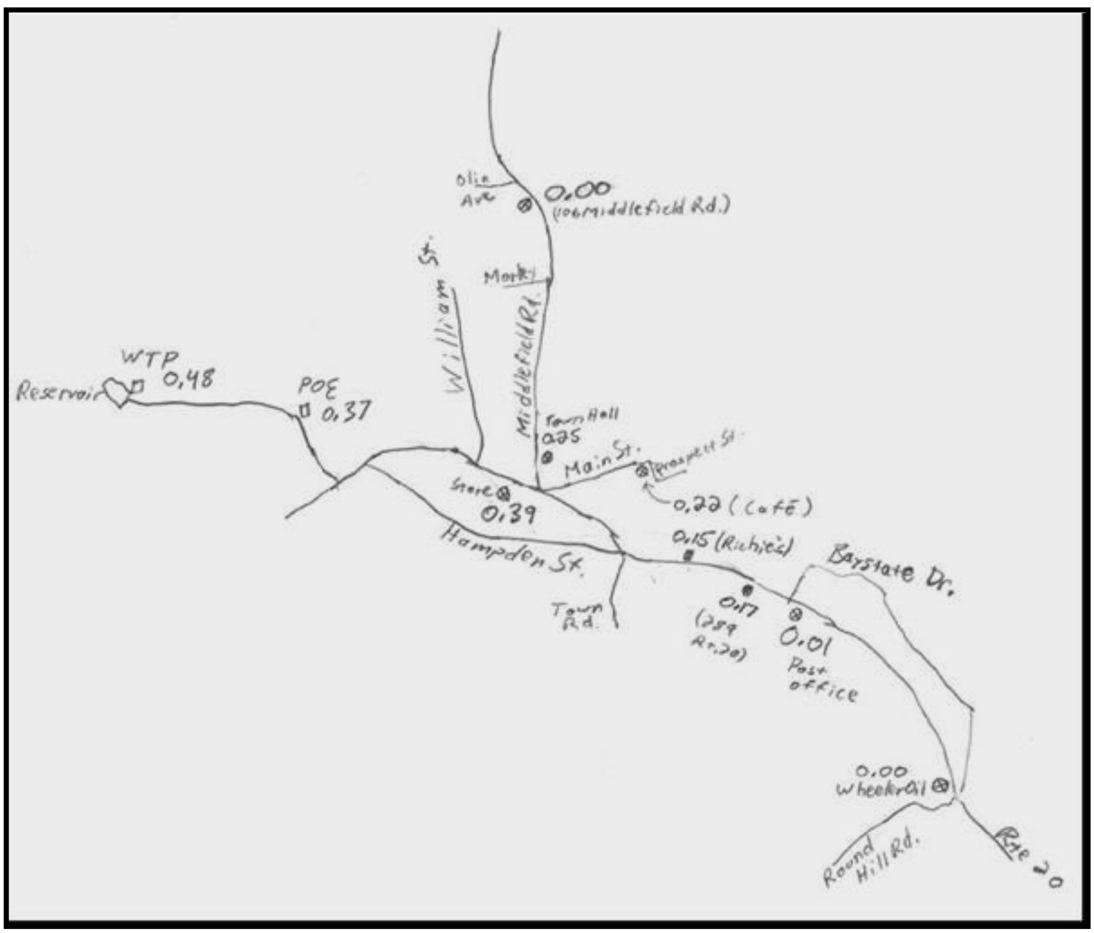


**Figure 8. Distribution System Chlorine Mapping Results (3/27/19)**

**Table 1. Distribution System Chlorine Mapping Results (3/27/19)**

| ~ time | free chlorine (mg/L) | ~ flush rate (gpm) | ~ flush time (min) | ~ flushed volume (gal) | Location |
|---|---|---|---|---|---|
| 12:15 | 0.48 | NM | NM | NM | POE - lower bulding at WTP (former lower chlorinator building) |
| 12:35 | 0.37 | NM | NM | NM | WTP clearwell effluent |
| 14:02 | 0.39 | 2 | 3 | 6 | 191 Rte. 20 (Chester Village Market) |
| 14:20 | 0.00 | 7.5 | 12 | 90 | 381 Rte. 20 (Wheeler Oil) |
| 14:40 | 0.01 | 4.3 | 16 | 69 | 309 Rte. 20 (Post Office) |
| 15:20 | 0.15 | NM | 4 | 8 | 260 Rte. 20 (Richie's General Service) |
| 15:50 | 0.25 | NM | 4 | 8 | 29 Main St. (Classic Pizza/Bluenote Café) |
| 16:45 | 0.25 | NM | 2 | 4 | 15 Middlefield Road (Town Hall) |
| 17:00 | 0.00 | 5 | 6 | 30 | 106 Middlefield Road (residence) |
| 17:40 | 0.17 | 1.4 | 5 | 7 | 289 Rte. 20 (David Shepherd residence) |
| | | *NM = not measured* | | | |

The following observations were made from the chlorine mapping study results:

- Chlorine residual levels in and near the center of town were satisfactory, ranging from a high of 0.39 mg/L at the Chester Village Market location to a low of 0.15 mg/L at Richie's General Service at 260 Rte. 20.
- No chlorine residual was detected near the ends of the distribution system on both Rte. 20 (0.01 mg/L at the Post Office, and 0.00 mg/L at Wheeler Oil Co.) and Middlefield Road (0.00 mg/L at 106 Middlefield Rd.).
- There was a sudden change in the chlorine residual level in a very short distance on Rte. 20. Specifically, a residence at 289 Rte. 20 had 0.17 mg/L chlorine, while the Post Office a few buildings further out on Rte. 20 had only 0.01 mg/L. The reason for that is the Post Office is on a dead-end part of the piping. After passing 289 Rte. 20, the piping splits with a dead end going to the Post Office, and the main piping leaving Rte. 20 and following Bay State Drive back to Rte. 20 near the Wheeler Oil Co. monitoring location at 381 Rte. 20 and then a short ways to the end of the distribution system.

RCAP Solutions also used the distribution system map to develop an inventory of the piping in the system. Determining the total volume in the distribution system compared to the chlorine contact time in the treatment plant can help determine if bleeding water out of the distribution system (e.g., via blow-off valves or a bleeder assembly) can significantly help reduce overall water age and thus shorten chlorine contact time. At present, the chlorine contact tank (clearwell) volume averages ~98,000 gallons, and second primary disinfection segment of the 8-inch pipe (between the treatment plant and the old chlorinator building) is ~4,363 gallons. The combined total volume for chlorine contact time during primary treatment is ~102,000 gallons. The volume of water in the distribution system piping was calculated to be approximately 57,000 gallons. Combining those two volumes results in a total volume of ~159,000 gallons, of which 64% is primary disinfection and 34% is in the distribution system. With an average demand of 45,000 gpd, that corresponds to water ages of 2.3 days for the treatment system and 1.3 days for the distribution system.

This means that even if the whole distribution system was flushed out, the water age would still be ~64% of what it had been. So large changes in overall water age are not expected to result from bleeding water at the edges of the system. Nonetheless, bleeding water out at the edges of the distribution system may be a possible means of improving chlorine residual at those locations. That option may be considered if the recommended unidirectional flushing program is not implemented or does not provide the necessary results.

If bleeding it to be conducted, it is useful to calculate the volume of water that is desired to be wasted. One possible goal would be to waste (and thus move) a volume of water equivalent to the volume of water in the piping between the end of a dead-end pipe and the location of the nearest acceptable chlorine concentration. Using that approach and the chlorine residual data from the March 27, 2019 chlorine mapping study, the following volumes would need to be wasted from each of the two dead ends:

- Rte. 20: ~13,500 gallons from 289 Rte. 20 (0.17 mg/L chlorine) around Baystate Drive and to the very southeast end of the system on Rte. 20 past Wheeler Oil Co. at 381 Rte. 20
- Middlefield Road: ~8,700 gallons between the Town Hall at 15 Middlefield Road (0.15 mg/L chlorine) out to the end of the pipe at the north end of Middlefield Road

In the field, flushing could continue until all color is gone and an acceptable chlorine residual is obtained (and assuming adequate pressure remains throughout the distribution system).

**8. pH:**

The final component of the treatment system is pH adjustment with sodium hydroxide. Unless otherwise specified, drinking water should have a pH of 6.5 to 8.5 (per the USEPA secondary MCL). Optimal Corrosion Control Treatment (OCCT) often involves a narrower target range for pH, and is typically above 7.0 or higher.

The finished water pH values for 2018 are shown in Figure 9. The following observations were made regarding pH:

- The pH data are relatively scattered, covering a range from below 7.0 to above 8.5, with an arithmetic average of 7.7. It is best for distribution system water quality to maintain a more constant pH. The system Operator is aware of this issue, and has tried to maintain as constant a pH as practical. Chester could investigate how to maintain a more constant pH.

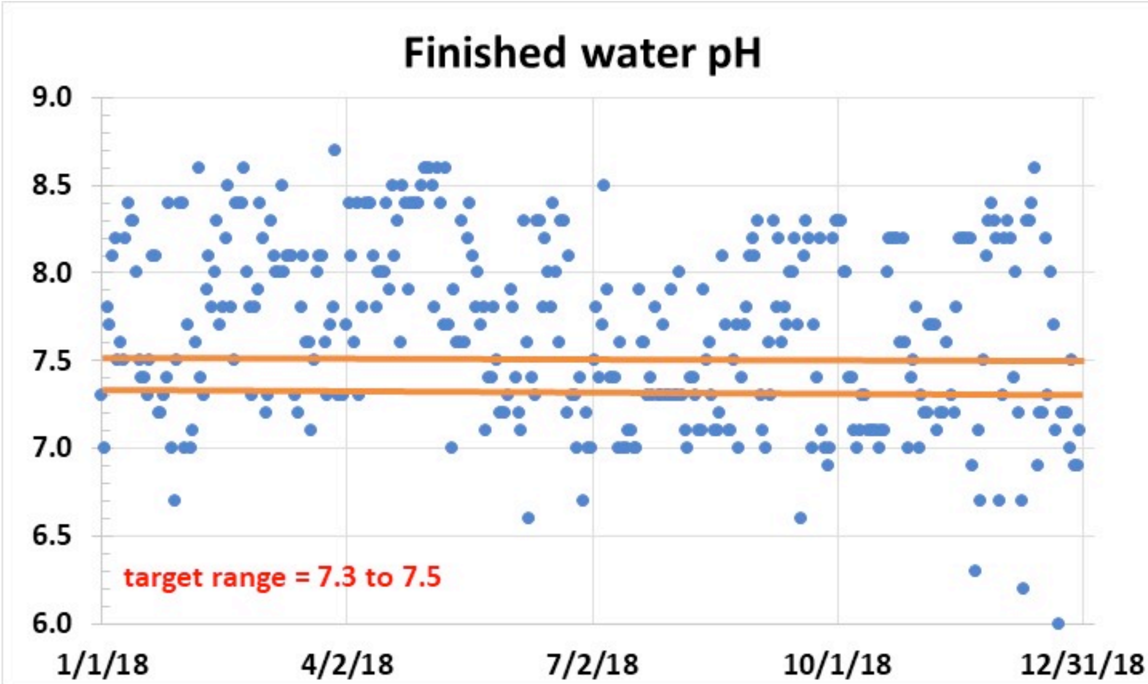


**Figure 9. Finished Water pH in 2018**

- RCAP Solutions did not find a specific MassDEP requirement for the finished water pH. However, the system Operator explained that Dan LaPrade of MassDEP told him to use a finished water pH range of 7.3 to 7.5. That is too narrow a range of pH for practical implementation, especially for a low-alkalinity water, and should be widened. As is shown in Figure 9, that narrow pH target was not met very frequently.
- Given that the regulatory compliance issue is with THMs and not lead and copper, raising the pH is not recommended as that can result in higher THMs (higher pH also results in a weaker chlorine disinfectant).
- RCAP Solutions recommends a target finished water pH of 7.5 +/- 0.3 (i.e., pH of 7.2 to 7.8). This would widen the allowable range from a difference of 0.2 up to a difference of 0.6 pH units.

**9. Disinfection Byproducts:**

Two classes of disinfection byproducts (DBPs) are regulated by the Disinfectant/Disinfection Byproduct Rule (D/DBPR): total trihalomethanes (TTHM, the total of the four THMs) and the total of five haloacetic acids ($HAA_5$). Compliance is determined by monitoring for THMs and HAAs at select distribution system locations once per quarter, and then calculating the Locational Running Annual Average (LRAA) for each sample site. The TTHM and $HAA_5$ LRAA concentrations at each sample site must not be above the MCLs of 80 µg/L and 60 µg/L, respectively. The current DBP monitoring locations are at 191 Huntington Road (Chester Village Market), which is located not far from the water treatment plant, and 381 Huntington Road (Wheeler Oil Co.), which is located on a dead-end line near the southeast end of the distribution system.

The Locational Running Annual Average results for TTHMs are presented in Figure 10, and for $HAA_5$ in Figure 11. The individual TTHM results are plotted in Figure 12 for the sample site at Wheeler Oil Co., and for the Chester Village Market in Figure 13. Individual $HAA_5$ results are shown in Figures 14 and 15, respectively, for Wheeler Oil and Chester Village Market. These data cover the full period that the Stage 2 D/DBPR has been in effect, since the beginning of 2013, and up through the 2nd quarter of 2019.

The following observations were made regarding TTHM and $HAA_5$ at the two monitoring locations:

- TTHMs have been highest at the Wheeler Oil Co. location, and $HAA_5$ have been highest at the Chester Village Market.
- In terms of regulatory compliance, the MCL for TTHMs was exceeded at the Wheeler Oil Company location (381 Huntington Road) for three quarters in a row (the third and fourth quarters of 2018 and the first quarter of 2019). The most recent quarter's results are in compliance with the DBP limits, as the maximum LRAA for TTHM is 79 µg/L.
- While there have been no exceedances of the MCL for $HAA_5$, the LRAA has at times come close to the MCL (Figure 11 and Figure 15). The highest LRAA for $HAA_5$ was 58 µg/L at the Chester Village Market location (191 Huntington Road) on 2/20/18, close to the MCL of 60 µg/L. As such, $HAA_5$ are also of concern in addition to TTHMs.
- There appears to be a steady increase in TTHM at the Wheeler Oil Co. location (381 Huntington Road) starting in 4$^{th}$ quarter of 2016. That has resulted in a steady increase in the LRAA for TTHMs at that site, increasing from 40 µg/L in 3$^{rd}$ quarter 2017 up to 92 µg/L in the 4$^{th}$ quarter of 2018. $HAA_5$ also increased during a similar time period. The cause of these increases has not been identified. It is noted that the flushing program ended sometime around two years ago. It is also possible that this change was attributable at least in part to switching source water from Austin Brook Reservoir to Horn Pond, but the timing of that switch could not be determined and thus no correlation could be made.
- The trend of increasing TTHM concentration over time during the past two years contrasts with the typical TTHM seasonal pattern where the highest results are found in August due to the warmer temperatures, and the lowest results in February due to colder temperatures. However, for the Chester Village Market location, the highest TTHM value since 2013 was 100 µg/L in February 2018 ($HAA_5$ also was at its highest for that location in February 2018), and the second-highest value of 87 µg/L was in November 2018. In contrast, the August 2018 sample was only 38 µg/L. No explanation was found for this anomaly.
- The LRAA data for TTHMs shown in Figure 10 suggest that there have been periods where the TTHMs levels were not much different between the two sampling locations, including 2013 through early 2015, and 2017 through early 2018. Given both sample sites receive water from the same source, the only factor that would be expected to impact differences in their TTHM levels would be water travel time (i.e., chlorine contact time). There appears to be a period from late 2015 through 2016 when the water age difference may have been greater, as there is a larger difference between the two sample sites for the TTHM LRAAs.

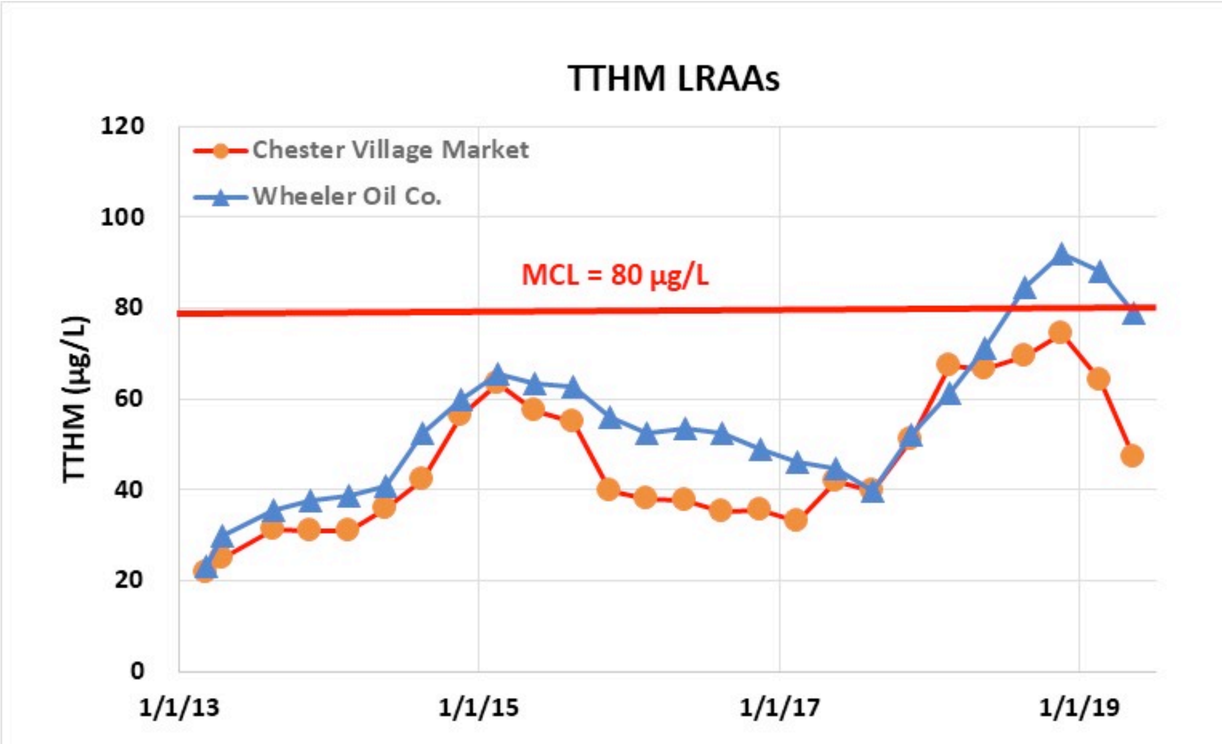


**Figure 10. TTHM Locational Running Annual Averages**

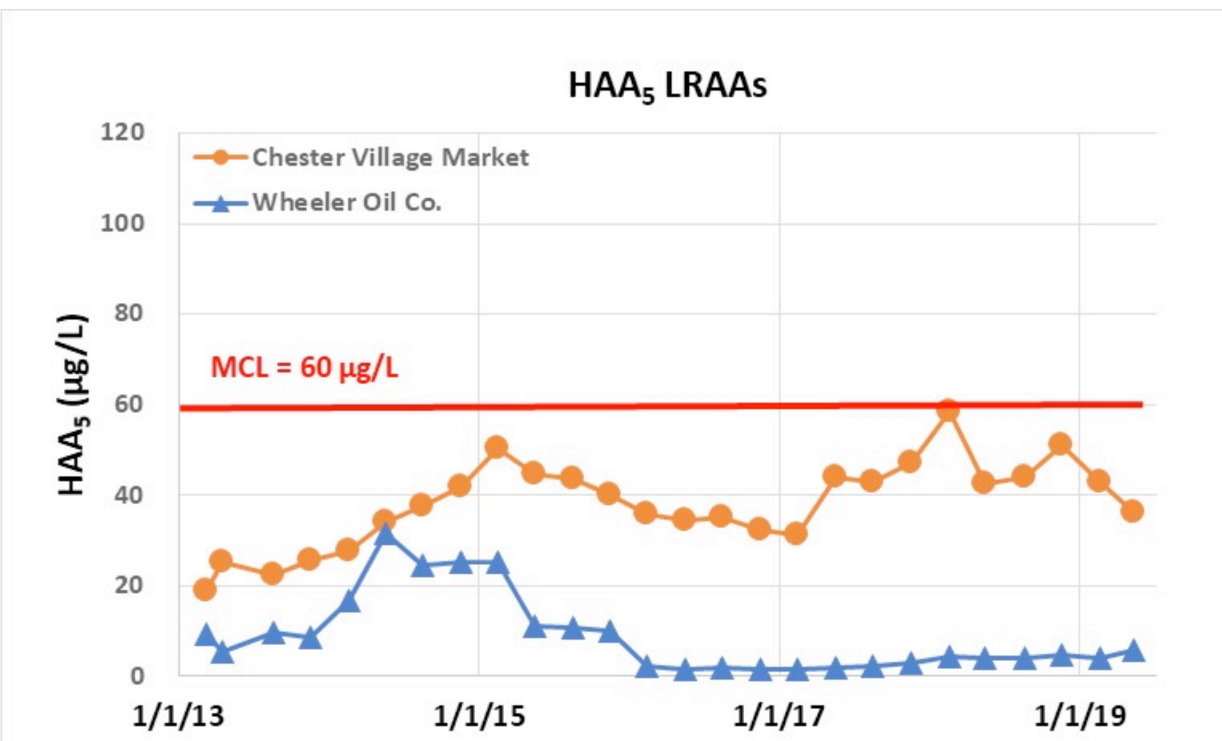


**Figure 11. $HAA_5$ Locational Running Annual Averages**

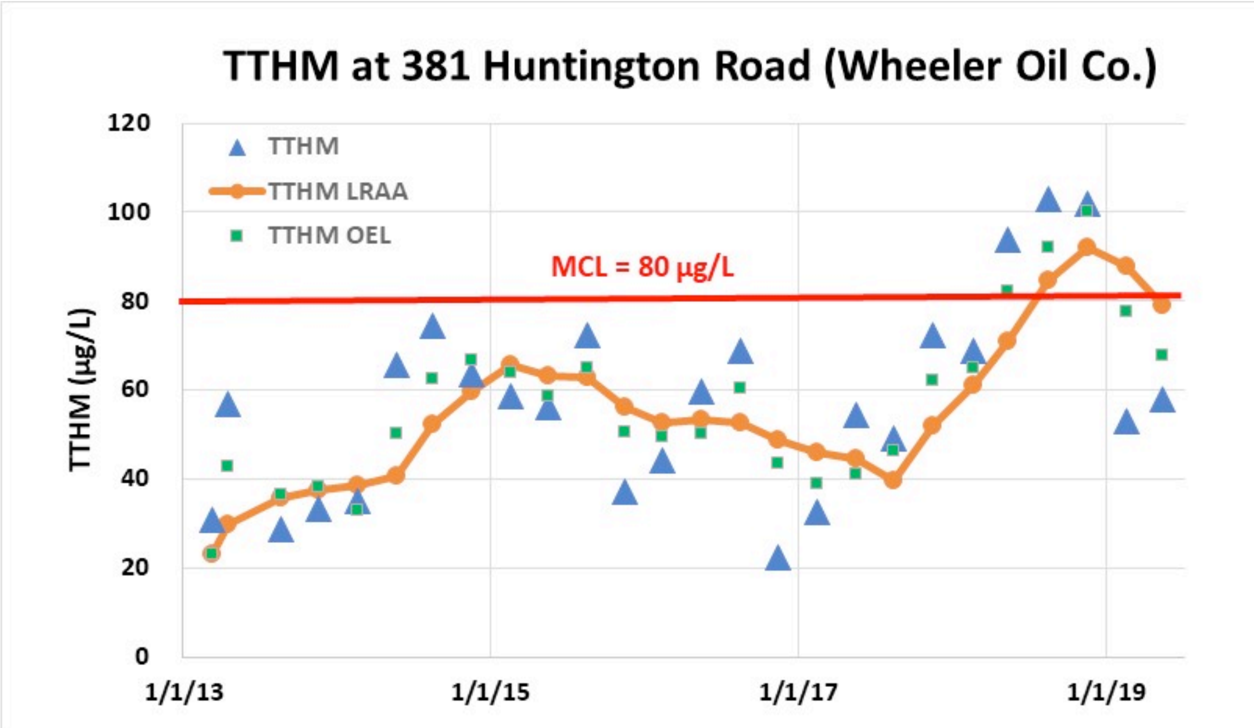


**Figure 12. TTHM at 381 Huntington Road (Wheeler Oil Co.)**

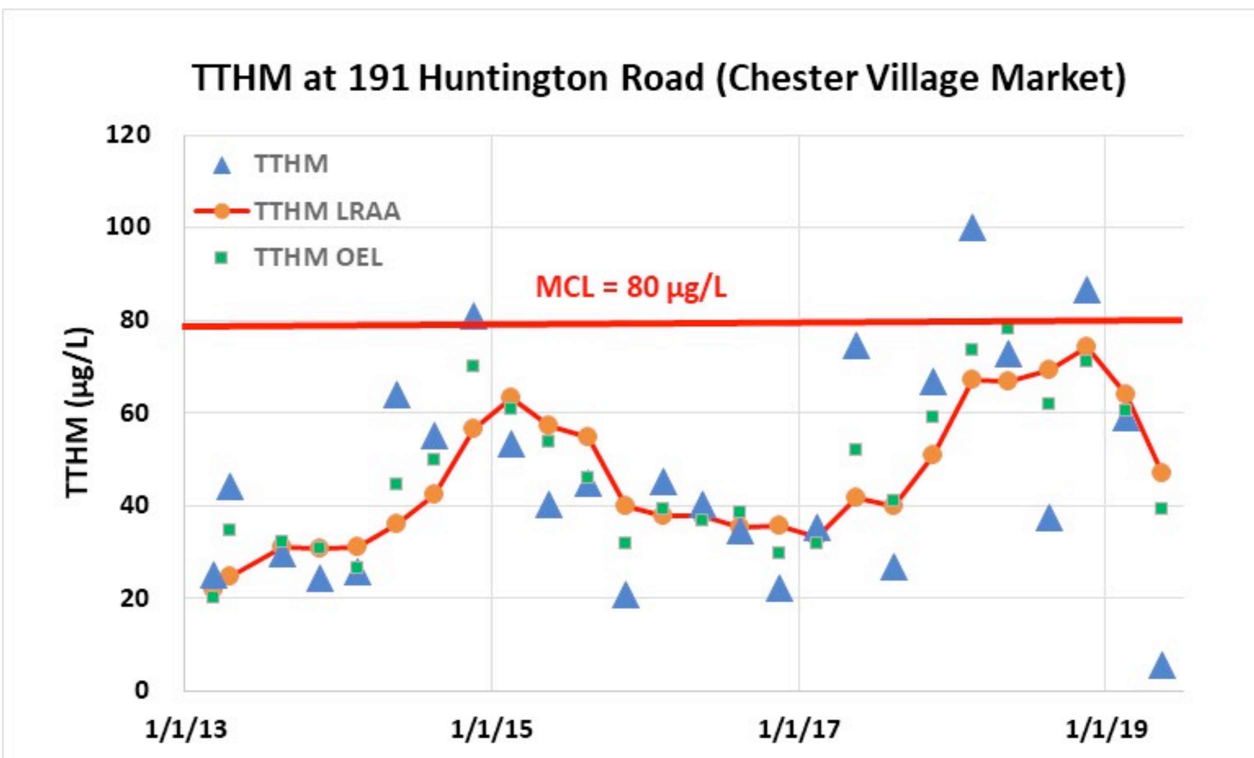


**Figure 13. TTHM at 191 Huntington Road (Chester Village Market)**

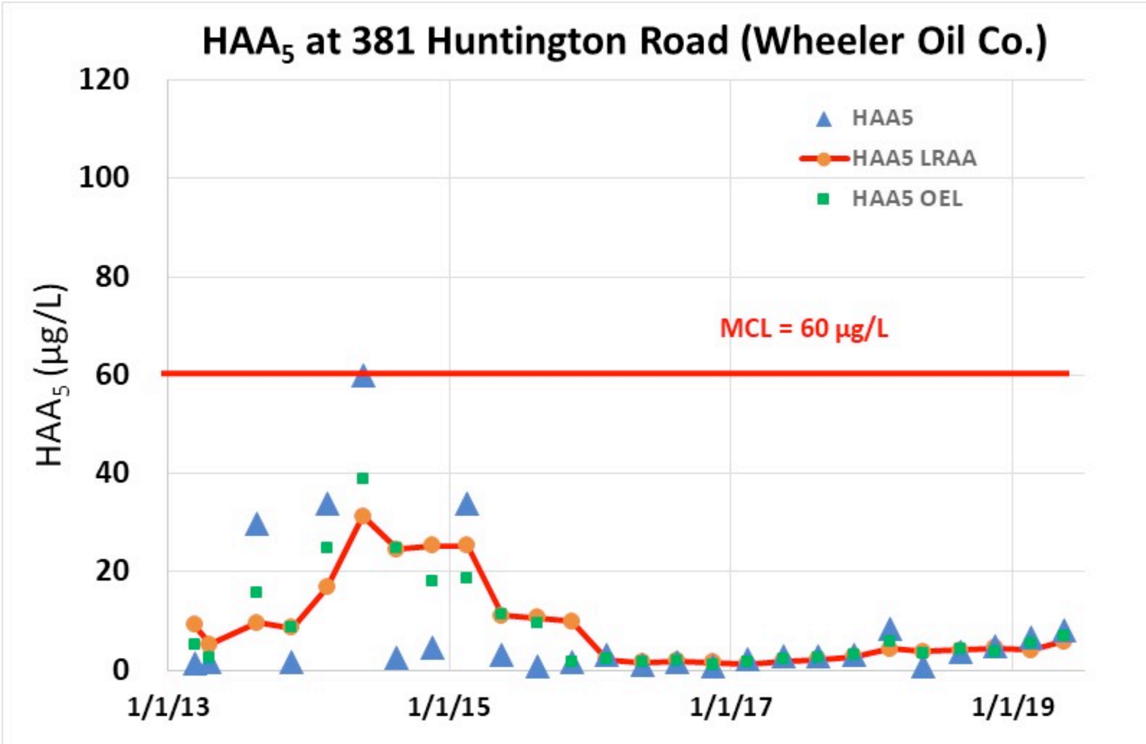


**Figure 14. HAA$_5$ at 381 Huntington Road (Wheeler Oil Co.)**

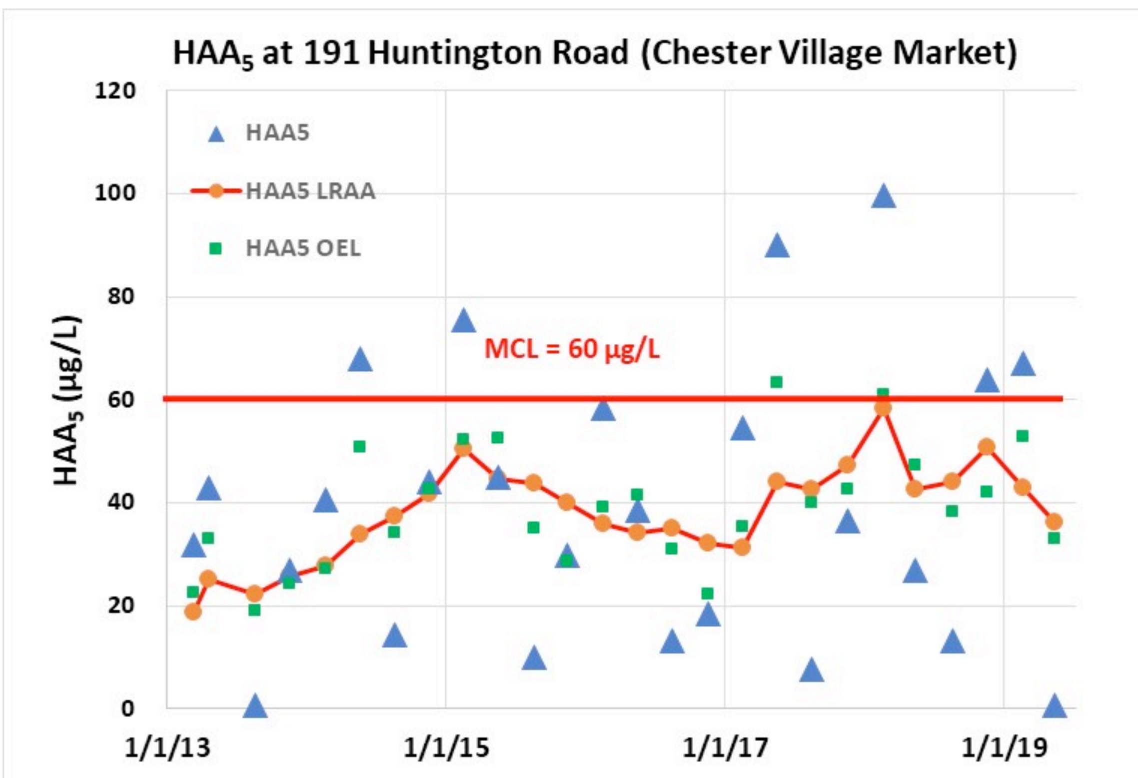


**Figure 15. HAA$_5$ at 191 Huntington Road (Chester Village Market)**

- In the case of HAAs, there is a clear difference in $HAA_5$ levels at the two monitoring sites, with levels at the Wheeler Oil Co. near zero. This difference in $HAA_5$ is likely a result of biodegradation of $HAA_5$ within the distribution system, and given the longer water age at Wheeler Oil Co. there is more time for the biodegradation to occur. While the biodegradation is common in the warmer months, it normally is less impactful during the colder months. In this case, however, for the past four years basically all of the $HAA_5$ that had been formed had degraded by the time the water reached the Wheeler Oil Company site (Figure 14).
- Another notable trend is that three of the five highest $HAA_5$ results over the past six years for the Chester Village Market were in February (Figure 15). Typically, $HAA_5$ would be higher in May and November than in February. This may suggest substantial biodegradation of $HAA_5$ leading to the Chester Village Market site (despite the presumed relatively short water age at that site), as the February results were often substantially higher than the data for the other quarters, especially the 3rd quarter sampling in August.

Given there have been no MCL exceedances for $HAA_5$, and that the highest TTHM exceedance was by only 15 percent over the MCL (as opposed to much higher values), a very large reduction in DBPs may not be necessary. Simple operational improvements may be sufficient to regain and maintain compliance with the DBP MCLs. Those improvements should be implemented and evaluated prior to considering any major capital addition to the treatment system.

Three approaches are recommended at this time for improved control of DBPs:

1. *Implement a regular flushing program:*
   As was discussed previously, semi-annual unidirectional high-velocity flushing of the distribution system is recommended to help maintain chlorine residuals near the ends of the system. Flushing has also been known to be able to reduce DBPs, and thus is also recommended for that purpose, especially for reduction of THMs. Flushing could remove some biofilm from the interior of the pipes, which could potentially reduce the biodegradation of HAAs, and thus result in higher levels of HAAs. That potential effect should be looked for when receiving the quarterly monitoring results for DBPs.
2. *Potentially switch source water to reduce influent natural organic matter (NOM):*
   Two source waters are available to feed the treatment plant. It is recommended that Chester regularly monitor both source waters for total organic carbon (TOC). TOC serves as a surrogate for NOM. UV-254 and dissolved organic carbon (DOC) are also available surrogates for NOM. Monthly monitoring of TOC is recommended for the first year, but at minimum Chester should sample both source waters for TOC once per quarter on the same days that sampling for DBPs is conducted. Turbidity should also be monitored, as the decision of which source to use may be predicated on the relative levels of both turbidity and TOC. The TOC data may be used to determine which source water to use, especially during the warmer months when TTHM formation is more of a problem. It is expected that the TOC in Austin Brook Reservoir will be lower than that in the shallower and slower-flowing Horn Pond. The raw water tap in the treatment plant may be used for sampling the current source water, while a sample of the other source water can be collected near where the water exits the pond/reservoir.

The source water was monitored for TOC four (4) times TOC in 2018, with values ranging from 4.3 to 5.0 mg/L. While those samples were labeled as being from Austin Brook Reservoir, they were reportedly from Horn Pond as that was the source water being used at the time. As such, caution should be exercised in using any recent data because of the issue with some Horn Pond samples being labelled as Austin Brook Reservoir.

3. *Optimize use of the granular activated carbon (GAC) sandwich filter for removal of NOM through improved monitoring of TOC:*

   Filter #3 has the granular activated carbon (GAC) sandwich, with a layer of GAC between two layers of sand. The GAC was added to this filter for removal of natural organic matter (NOM), which is a precursor to DBP formation. The sorptive capacity of the GAC for NOM and other organic chemicals is limited. The extent the sorptive capacity has been exhausted can, in part, be monitored by periodically analyzing total organic carbon (TOC) in the influent and effluent from this filter. When the effluent TOC approaches the level of the influent TOC, the activated carbon is nearing exhaustion for adsorbing NOM. Consideration should be given to replacing the activated carbon prior to exhausting its capacity to remove NOM.

   A TOC monitoring program is recommended to help optimize use of the GAC sandwich in Filter #3. Monthly monitoring of TOC is recommended for the first year, but at minimum Chester should sample filter influent and filter effluent for TOC once per quarter on the same days that sampling for DBPs is conducted. Sample and analyze for TOC in the filter influent, the Filter #3 effluent, and either the Filter #1 or Filter #2 effluent as a control sample. Only filters currently online should be monitored for TOC. Since the filter influent sample is effectively the same as the source water sample for the current source being used, it would be prudent to do this sampling on the same days that the raw water TOC is sampled, as recommended above.

   TOC was monitored for both the raw water and finished water on 9/17/18 and 11/26/18, with TOC removal being 33% and 13%, respectively (averages of 4.7 mg/L influent and 3.6 mg/L effluent). It is hoped that a more strategic and targeted use of the carbon sandwich filter will result in improved TOC removal.

If those approaches do not satisfactorily reduce DBPs, then other approaches would need to be considered, including possibly bleeding water out of the ends of the system to reduce water age, installing additional treatment capability to reduce NOM, or reducing pH to decrease THM formation.

**10. Color:**

No historical color data were found during this investigation. MassDEP mentioned color issues in their August 24, 2018 letter to Chester, and also mentioned in an internal MassDEP e-mail dated August 16, 2018 that an earlier brown water complaint had been resolved upon discovery and repair of a leak. The water system Operator has received a few complaints about the water’s appearance, including a yellowish color, and a light brownish tea-like color. RCAP Solutions staff spoke with some town residents about their perception of the water quality during a site visit on March 27, 2019, and some of the residents noted that the water is sometimes colored either light yellow or light brown.

RCAP staff conducted a visual examination of the water color from each location that chlorine residual was measured during the chlorine mapping study conducted on March 27, 2019. This simple test involves looking for color in a water sample inside a white Styrofoam cup. Distilled water was used for comparison as needed.  A yellow tinge to the water was evident at some of the locations (but not at all locations), and it was a lighter yellow at some locations than at others.  An example of the yellow tint is shown in Figure 16, which compares a distribution system sample with distilled water.  No color was detected in the treatment plant's finished water.

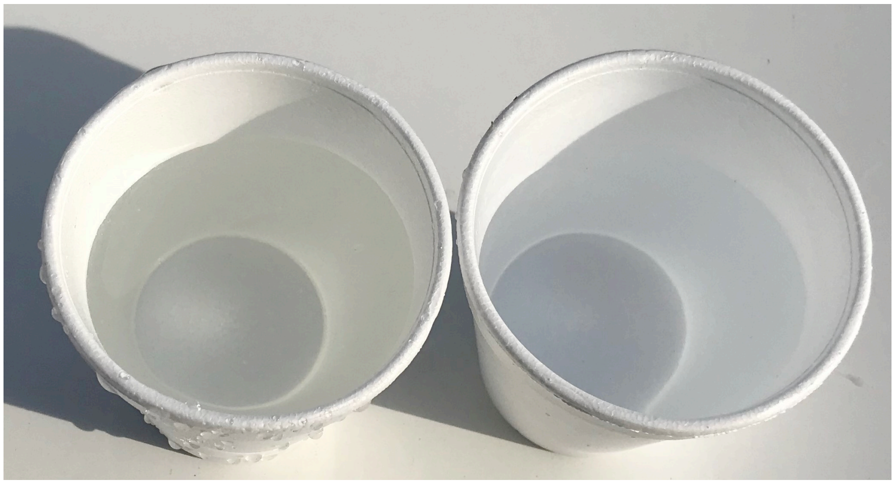

**Figure 16.  Yellow-tinged Water (3/27/19) –**
**Distribution system sample is on the left, distilled water on the right**

One common cause of coloration of distribution system water is the release of iron, manganese, and/or other metals from the interior surface of the pipe.  Some of the pipes are made of iron, while manganese can deposit over time and be a source of color if it dissolves into the water.  Manganese can cause water to be yellow, brown, or even black, depending on the concentration.  Iron typically results in a rust-colored water.  One means for reducing these color issues is to maintain a sound flushing program that helps clean deposits off of the inside of the pipes.

Chester has historically conducted a distribution system flushing program twice per year, but reportedly did not do that the past two years.  Resuming the semi-annual flushing program is recommended to help reduce the color observed in the water.  The flushing program should be conducted unidirectionally, and with sufficient velocity to sufficiently clean the interior of the pipes.  As noted earlier, a properly conducted flushing program can also help maintain chlorine residuals and reduce disinfection byproducts.

**11.  Lead and Copper:**

The Chester Water Department provides pH adjustment as a corrosion control measure.  The finished water pH is plotted in Figure 9, and was discussed previously.  The Lead and Copper Rule (LCR) distribution system lead monitoring data are presented in Figure 17 and for copper in Figure 18.  Based on the available data, lead and copper corrosion does not appear to be an issue, as neither Action Level has been exceeded, and all individual sample results were below the Action Levels.  Though not optimal, the fluctuating pH and chlorine levels do not appear to have caused any LCR compliance issues.

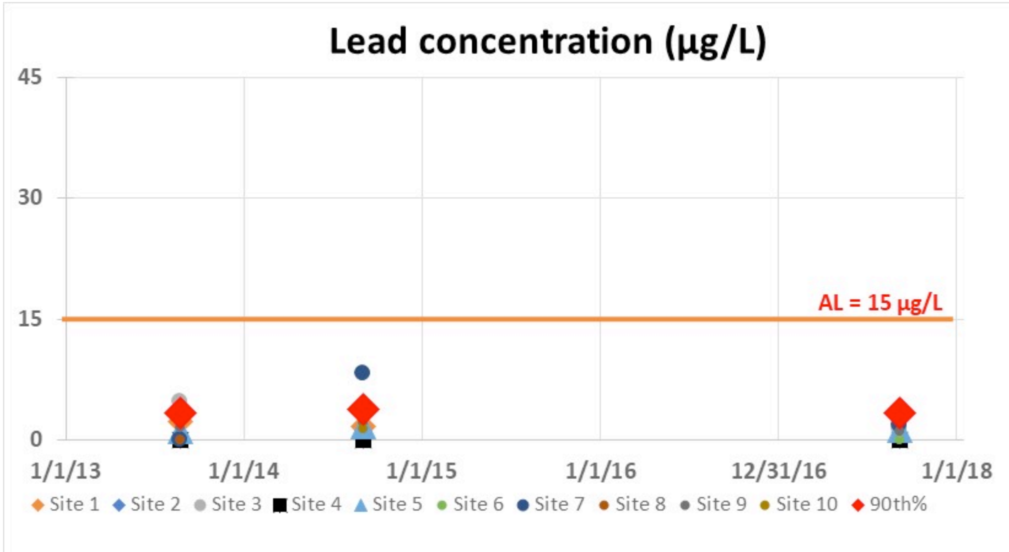


**Figure 17. LCR Lead Monitoring Results (2013-2017)**

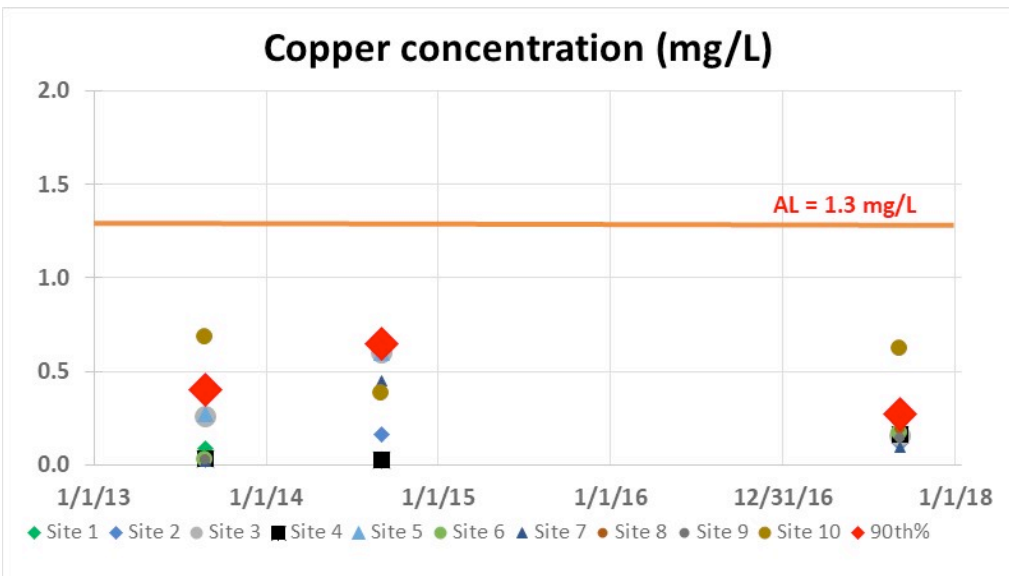


**Figure 18. LCR Copper Monitoring Results (2013-2017)**

## 12. Summary and Conclusions:

Much of the water quality is good, but improvement could be made in reducing THMs, HAAs, and color, and also for increasing chlorine residuals at the ends of the distribution system. Implementation of a semi-annual high-velocity unidirectional high-velocity flushing program is recommended, and could help achieve all four of those goals. Implementation of a monitoring program for TOC is also recommended to help select which source water to use to minimize influent NOM, and to optimize use of the activated carbon sandwich filter for removal of NOM.

Based on the available data, lead and copper corrosion does not appear to be an issue, as neither Action Level has been exceeded, and all individual sample results were below the Action Levels. Though not optimal, the fluctuating nature of the pH and chlorine levels do not appear to have caused any LCR compliance issues.

**13. Recommendations:**

The following list summarizes the primary recommendations developed during this evaluation to help the Chester Water Department improve operations and water quality:

DBP control:

1. Implement a semi-annual, unidirectional, high-velocity flushing program to help clean the distribution system pipes. This can help to reduce DBPs, maintain distribution system chlorine residuals, and reduce incidents of colored water. Those three issues should be monitored closely after flushing has been conducted. For maintaining chlorine residual, focus on the north end of Middlefield Road and the southeast end of Rte. 20.
2. Implement a TOC monitoring program for the two source waters (monitor turbidity also). Consider using the source water with the lower TOC during the warmer seasons to reduce the amount of influent NOM, as long as turbidity is not an issue. Detailed sampling recommendations are provided above in Section 9.
3. Implement a TOC monitoring program for the filter effluent to help determine the saturation status of the granular activated carbon in Filter #3. Use these data to optimize timing of the use of Filter #3 for removal of NOM. Detailed sampling recommendations are provided above in Section 9.

Additional primary recommendations include the following:

4. If the unidirectional flushing does not solve the DBP and chlorine residual issues, then water age could be controlled some at the edges of the distribution system by wasting water through blow-off assemblies (i.e., bleeding water out of the distribution system). This could be done at the north end of Middlefield Road and at the east end of Rte. 20.
5. Properly label the source water samples as Horn Pond or Austin Brook Reservoir (they have been mislabeled recently as Austin Brook Reservoir when it really was Horn Pond that was sampled).
6. Install sample taps for all three individual filter effluents (IFEs) and also for the one combined filter effluent (CFE). There should be an online turbidity meter for the CFE sample to use for regulatory compliance reporting.

7. Turbidity results reported to MassDEP have been for the finished water (i.e., treatment plant effluent at the POE), but instead should be for the combined filter effluent (CFE). Reporting combined filter effluent should lower the results reported from an average of ~0.11 NTU to approximately ~0.03 NTU.
8. Implement a new target finished water pH range of 7.5 +/- 0.3 (i.e., 7.2 to 7.8).
9. Investigate how to maintain a more consistent finished water pH.
10. Investigate how to maintain a more consistent finished water chlorine residual.

Other recommendations include the following:

11. RCAP was not able to obtain the specifications used in the SCADA calculations to determine the volume of the chlorine contactors (part of determining chlorine contact time), and thus could not confirm this accuracy. Also, the tracer study that resulted in determining a baffling factor of 0.13 also was not located. This information should be obtained and reviewed for accuracy. That would help confirm chlorine is not being under dosed or over dosed as a result of using an inaccurate chlorine contact time, and confirm that both disinfection segments are necessary.
12. The SCADA system could be improved to include trend charts of all water quality data.
13. The Town of Chester should become more involved in the water system operations, especially the treatment system, to reduce reliance on the contracted certified operator, and to gain a better understanding of the issues facing the water system, as well as the time and resource commitments that are needed to ensure efficient and sustainable operations and future compliance with all applicable regulations.
14. Improve data management, including tabulating and plotting all historical data. Someone at the Town should follow the data and compliance issues, not just the certified operator.
15. Develop and maintain a customer comment log.
16. Develop and implement a public relations campaign about water quality.
17. For monitoring sites, include the address in the site name (e.g., “381 Rte. 20” or “Wheeler Oil Co./381 Rte. 20”).
18. Update the name of the Walker Brook Store sample site to the current name of Chester Village Market (at 191 Rte. 20/Huntington Rd.).