



Disinfection By-Products Compliance Study

July 27, 2017

City of Pembroke Pines, FL



Disinfection By-Products Compliance Study

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Executive Summary

The City of Pembroke Pines water treatment plant (WTP) uses Biscayne Aquifer as its source water and has a rated capacity of 18.0 million gallons per day (MGD). The treatment process at the WTP is comprised of lime softening, filtration, ion exchange and disinfection with chloramine (chlorine and ammonia). Chloramines also help in maintaining a persistent residual in the distribution system. The City has contracted the operations of the WTP to CH2.

The City is required to measure disinfection by-products (DBPs) quarterly in their finished water at six sampling locations in the distribution system. Compliance with DBPs is determined by a locational running annual average (LRAA), as regulated by the USEPA Stage 2 Disinfection/Disinfection By-product Rule (Stage 2 D/DBPR) and Florida Department of Health (FDOH). Historically, the six locations have not experienced any exceedances in DBPs up until the last quarter of 2016. During the fourth calendar quarter of 2016, the City noticed an increasing trend in DBPs within their distribution system. Specifically, the City observed an increase in Total Trihalomethanes (TTHMs) and Haloacetic acids (HAA5) at three locations in its distribution system above the maximum contaminant level (MCL) of 80 and 60 ppb respectively. The LRAA for TTHM at the 901 NW 208th Ave Rose Price Park location was 88.42 ppb, exceeding the MCL of 80 ppb. As a result, FDOH-BC determined that the entire system is in violation of the TTHM MCL.

In May 2017, the City contracted with Jacobs to conduct a DBP study for compliance with Stage 2 D/DBPR and make recommendations for achieving regulatory compliance. Presented herein are a summary of findings, short- and long-term treatment and operational strategies to gain compliance with DBPs in the most cost-effective manner and in as short of duration as possible.

Summary of Findings

- Except for the past three quarters, the City has been in compliance with Stage 2 D/DBPR for TTHMs and HAAs. The reason for the recent non-compliance is the LRAA for TTHM exceeding the MCL of 80 ppb at the 901 NW 208th Ave Rose Price Park location. During the fourth calendar quarter of 2016 (November 29, 2016) TTHM and HAA concentrations exceeded the MCL at three locations i.e. 800 NW 217th Terrace, 901 NW 208th Ave Rose Price Park and 20426 SW 54th Place. These exceedances were observed right after the distribution system went through a maintenance procedure i.e. "free chlorine burn". This maintenance practice could have attributed to the high TTHMs and HAA5 observed at these locations.
- Despite the increase in quarterly DBP values at these locations, only the Rose Price Park location had an LRAA value for TTHMs that exceeded the regulatory MCL of 80 ppb. Most recent monitoring data (second quarter of 2017) shows that at the same location, LRAA for TTHM decreased and was slightly above the MCL of 80 ppb. The LRAA for HAA5 were below the regulatory limit at all the six locations.
- On June 12, 2017, as part of a special sampling event, Jacobs and CH2 staff collected water samples at the six (6) sampling locations which are representative of the City's entire distribution system for analysis of DBPs. The results of the sampling event showed that the DBPs were below the MCL at all of the six (6) sampling locations. DBP values reported by both laboratories were largely in agreement with some differences. Total/dissolved organic carbon (TOC/DOC) in the raw water and finished water were similar and were 10.4 mg/L and 5.5 mg/L respectively with a removal of 47%. Specific ultraviolet absorbance (SUVA) of the raw water was high (4.4 L/mg-m) indicating that the water has high humic content and is amenable for additional DOC removal by enhanced or optimized coagulation.
- The maintenance practice of flushing the system with free chlorine (free chlorine burn) appears to have contributed to the high TTHMs and HAA5 observed at these three locations. In addition, other factors that could have contributed to the increase in DBPs include increases in source water color (since summer of 2015) and finished water color above the water quality goal of 15 color units. This could have contributed to an increase in chlorine demand. Finished water color has increased due to the ion

exchange system being off-line since September 2015, which correlates well with the observed increase in DBP quarterly values. Another factor that could have contributed to the increase in DBPs is their location i.e. these monitoring sites are located in the extremities of the distribution system which have a higher water age. High water age contributes to an increase in DBPs.

- In addition to the DBP precursors (color, TOC) in the source water, other water quality parameters such as iron, ammonia increases the complexity of water treatment, distribution system operation and influence chlorine demand and DBP formation.
- An analysis of operational data showed that the following water quality parameters need to be optimized in the finished water:
 - a. Turbidity: Turbidity of the finished water was well above the water quality goal (industry standard) of 0.1 Nephelometric turbidity units (NTU) and greater than 0.3 NTU most of the time. The average turbidity was 0.3 NTU, 90th percentile was 0.7 NTU with a maximum of 1.1 NTU in the finished water. This indicates that the optimization of Accelerators® and filters is necessary.
 - b. pH: Average finished water pH was 8.9 with a 90th percentile pH of 9.5, exceeding the secondary maximum contaminant level (SMCL) water quality standard of 6.5-8.5. Although the FDOH allows the City to operate with a high finished water pH, it is important to note that TTHM formation is very rapid in a high pH environment. In addition, fluctuating pH levels can reduce monochloramine formation.
 - c. Iron: Iron in the raw water varied considerably with an average concentration of 1.2 mg/L; however iron concentrations peaked to 1.9 mg/L several times since May 2016. During the same time, finished water iron concentrations were ~0.1 mg/L and did not exceed the SMCL of 0.3 mg/L.
 - d. Ammonia: Free ammonia in the source water varies (0.38 mg/L-1.96 mg/L) which should be addressed prior to distribution. Current practice is to add high doses of chlorine (pre-filtration) to bind the ammonia. Free ammonia levels leaving the plant vary between 0.1-0.2 mg/L contributing to varying monochloramine residuals and creating a potential for nitrification. Free ammonia concentration in the distribution system ranged from 0-0.2 mg/L. Research indicates that free ammonia less than 0.05 mg/L (reported as NH₃-N) minimizes the potential for nitrification, corrosion, taste and odor complaints and water quality deterioration.
 - e. Chlorine residual: Data exhibited significant variation in total chlorine, free chlorine residuals and chlorine demand during different times of the year. Chlorine demand increased from November 2016-January 2017 indicating that the chlorine demanding constituents (e.g. ammonia, color, DOC) varied in the finished water as well. The average total chlorine residual in the distribution system was 2.75 mg/L. Typical chloramine concentrations of 0.2-2 mg/L are found in drinking water supplies where monochloramine has been used as a disinfectant to provide a residual in the distribution system. Chloramine residuals varied from 2.04-3.9 mg/L in the distribution system.

- Based on historical TTHM data, chloroform concentration is the predominant form of TTHMs in the City's distribution system, approximately eighty five percent (> 85%) or more of the total THMs and can be removed easily due to its high volatility. Hence, mechanical mixing in storage tanks or aeration towers will likely remove a significant portion of the TTHMs.

Recommendations

The recommended approaches for DBP control can be classified as short-term and long-term recommendations; short-term recommendations result in minor adjustments to the operational practices or addition of unit processes that do not involve major capital expenditure (Phase I) where-as long-term recommendations might involve significant capital expenditure (Phase II). These approaches will help the City improve plant operations and meet regulatory compliance for DBPs (specifically TTHMs) while producing safe, reliable, and high quality water.

Phase I: Short-Term Recommendations

- Optimize Source Water Quality-To the extent possible use wells with high quality water; minimize withdrawal from wells (e.g. #3 and #5) with poor water quality (high color, TOC, ammonia, iron).
- The City is currently rehabilitating the ion exchange units and is planning to bring them back into service in summer of 2017. Once the ion-exchange units are placed into service, the finished water color and DOC should decrease resulting in lower TTHMs. This will assist bringing the system back into compliance with Stage 2 D/DBPR. The ion exchange process should be in service at all times and operated at the full design capacity.
- The current practice of adding polyphosphate prior to filtration to tie up the calcium is creating an environment conducive to rapid ammonia oxidizing bacteria growth in the filters and the ion exchange system. The polyphosphate carried over to the filters and ion exchange units breaks down and serves as a nutrient promoting bacterial growth. Polyphosphate addition prior to pre-filtration should be replaced with carbon dioxide which will convert the calcium in the settled water to calcium carbonate. Addition of carbon dioxide will also help in optimizing pH, thus minimizing TTHM formation. The City should consider a phosphate-based corrosion control treatment chemical (e.g. orthophosphate) for adding to the finished water and stabilize water quality.
- To gain an in-depth understanding of the fate of the various water quality parameters at several locations in the treatment plant, a comprehensive water quality characterization program should be implemented. Results from this program will help in optimizing existing treatment processes (e.g. Accelator®, Filters and Ion Exchange processes) and maximize removal of color, TOC, turbidity, iron and ammonia.
- It is recommended that the City adopt the following water quality goals for the finished water:
 - Filtered water turbidity of less than 0.1 NTU
 - pH of 7.7-8.0
 - Color of filtered water less than 5 color units
 - TOC of filtered water less than 2.0 mg/L
 - TTHMs < 64 ppb; HAAs < 48 ppb
 - No free ammonia

Although the FDOH allows the City to operate with a high finished water pH, it is important to note that TTHM formation is very rapid in a high pH environment. In addition, fluctuating pH levels can reduce monochloramine formation. As such, pH should be more in line with the water quality goal/industry standard of 7.7-8.0. Optimizing chlorine dosages and the finished water pH will be critical to control DBP formation in the distribution system. Such optimization in pH and treatment changes should also consider and evaluate the potential effects

of the corrosivity of the treated water and the need for corrosion control. TOC is generally recommended as a better parameter as it correlates better to TTHM formation potential than color. Also, lower TOC levels in finished water has additional benefits, such as a lower chlorine demand, less DBP formation, more stable chlorine/chloramines residual, and reduced risk of nitrification in the distribution system. Currently the WTP is removing only 47% of the TOC and additional removal of TOC should assist in reducing the DBPs. Although ammonia is unregulated, its presence in the water has several implications (e.g. nitrification).

- Automation- It is recommended to install the following on-line analyzers:
 - On-line Ammonia Analyzer-Measuring ammonia in raw and finished water on a regular basis is recommended, especially as the water contains co-contaminants (e.g. color, TOC, iron). Online instrumentation is available for measuring free ammonia and combined ammonia (monochloramine). Continuous monitoring of free ammonia concentrations ensures that proper dosages of chlorine are applied at the pre- and post-filtration steps to maintain the proper chlorine:ammonia ratio.
 - On-line TOC Analyzer-Measurement of TOC and DOC in the raw and finished water is recommended on a continuous basis to adjust chemical doses (e.g. coagulant, lime, polymer) and accurately determine if TOC removal goals are being met. Also, TOC can be used as a surrogate parameter as an indicator of the DBP formation potential.
 - On-line THM Analyzer- Real-time measurements of TTHMs in the finished water will provide an indication of the overall performance of the WTP, optimize unit processes and achieve regulatory compliance.
- Conduct bench-scale studies with coagulant (alum, ferric, PACL, ACH etc.) and polymer combinations to reduce the turbidity, iron, TOC and maximize filter performance. SUVA of the source water was high (4.4 L/mg-m) indicating that the water has high humic content and is amenable for additional DOC removal by enhanced or optimized coagulation. It is recommended that the studies be conducted paying attention to proper mixing, at raw water pH and allowing a time lag of at least 5 minutes prior to the addition of lime and anionic polymer to observe the benefits of these chemicals.
- Conduct a distribution system water quality study to optimize finished water quality parameters. Such a study would provide recommendations in terms of optimal water quality parameters (e.g. pH, chlorine residual, hardness, alkalinity, TOC, ammonia) and a suitable corrosion inhibitor. The study may include coupon tests and pilot systems to assess any finished water quality changes.
- Develop a hydraulic model of the distribution system
 - A hydraulic model will assist in predicting water age, water quality (e.g. chlorine residual, nitrification potential) for existing and various operating conditions (e.g. valve closures) and
 - allow to run “what-if modeling scenarios” to optimize water age and improve water quality
- Implement best management practices in the distribution system, which include
 - Minimizing water age and hydraulic retention time
 - Increasing the frequency of distribution system flushing
 - Eliminating dead-ends
 - Performing unidirectional flushing in the distribution system as recommended by AWWA (every quarter)
 - Evaluating storage tank mixing protocols

- Installing mixers in storage tanks that can be added to strip off the chloroform which is a major species of the TTHMs (> 85%); mixing will also help in reducing water age, minimize loss of chlorine residual and potential nitrification.

Phase II: Long-Term Recommendations

The City should implement the above strategies in Phase I to minimize the DBPs in the distribution system. In the event DBPs continue to be an issue, the City should evaluate the following strategies:

- Adding an aeration-detention basin at the head of the plant which will reduce the iron
- Retrofit granular activated carbon (GAC) in existing filters i.e. replace anthracite media with GAC
- Operate filters with GAC in biological mode (biological filtration) to reduce DOC and convert ammonia to nitrate (intentional nitrification in filters)
- Consider decentralized treatment in the distribution system such as air stripping

Regardless of the treatment option chosen, treatability studies will be necessary for predicting system performance, developing design criteria and validating the process. It is strongly recommended that the City pilot the chosen technology. A small-scale pilot could help determine the effectiveness of the technology with respect to DBP reduction and address other water quality concerns such as iron and ammonia.

Other Recommendations

Other recommendations include

- Developing a Renewal and Replacement Program
 - will assist in evaluating existing equipment condition and capacity
 - predicting useful life expectancy
 - developing a prioritized rehabilitation or replacement schedule
- Developing a Long-term Masterplan
 - will help in identifying other sources for meeting future demand, improving production and better source water quality
 - identifying plant upgrades and expansion projects

1. Introduction

1.1 Background

The City of Pembroke Pines (City) is an existing public water supply provider, located in southeastern Broward County, Florida. The City owns a water treatment plant (WTP) which is located at 7960 Johnson Street, Pembroke Pines. The WTP provides potable water to residential and commercial users in its service area through its distribution system. The City has contracted the operations of the WTP to CH2M which also operates two wellfields, withdrawing raw water from the shallow Biscayne Aquifer. The treatment process at the WTP is comprised of lime softening, filtration, ion exchange and disinfection with chloramine (chlorine and ammonia). The WTP has a rated capacity of 18.0 million gallons per day (MGD) and an average capacity of 12.0 MGD.

Recently, the City was confronted with an increase in disinfection by-products (DBPs) within their distribution system. Specifically, the City observed an increase in Total Trihalomethanes (TTHMs) and Haloacetic acids (HAA5) at some locations in its distribution system above the primary maximum contaminant level (PMCL) of 80 and 60 ppb respectively, as regulated by the USEPA Stage 2 Disinfection/Disinfection By-product Rule (Stage 2 D/DBPR) and Florida Department of Health (FDOH).

As a result, the City contracted with Jacobs to conduct a technical audit for compliance with Stage 2 D/DBPR and make recommendations for achieving regulatory compliance.

1.2 Objectives

The objective of this Proposal is to assist the City reduce DBPs in its distribution system below the primary maximum contaminant level (PMCL), as required by the USEPA Stage 2 Disinfection/Disinfection By-product Rule (Stage 2 D/DBPR) and Florida Department of Health.

The objectives include:

- Review the issue of DBPs by evaluating operations and performance of the existing WTP
- Conduct water quality testing at the sampling locations for DBPs
- Identify and recommend cost-effective alternative(s) to minimize DBP formation

1.3 Scope and Limitations

This Report has been prepared by Jacobs for the City of Pembroke Pines and may only be used and relied on by the City for the purpose agreed between Jacobs and the City.

2. Water Chemistry

This section presents a brief description of water quality parameters that were evaluated as part of this study, and will be discussed throughout this report.

Natural organic matter (NOM): Natural Organic Matter (NOM), a precursor to Disinfection By-Products (DBPs), is a heterogeneous mixture of naturally occurring organic components consisting of humic substances (humic and fulvic acids), as well as various non-humic biochemicals such as proteins and carbohydrates. Adding further complexity is the fact that NOM varies significantly depending on its source. NOM is difficult to quantify due to its complexity. For practical purposes, organic matter is quantified by measuring organic carbon concentrations as total organic carbon (TOC), particulate organic carbon (POC), and dissolved organic carbon (DOC). It is also common to quantify NOM by measuring the amount of UV light it absorbs i.e. ultraviolet light absorbance at 254 nm (UV₂₅₄).

NOM can be broken down into two subcategories:

- a) High molecular weight, hydrophobic, aromatic NOM which is not only the most reactive (in terms of forming DBPs) but is also the most amenable to removal via coagulation. This type of NOM is also referred as the humic portion of NOM.
- b) Low molecular weight, hydrophilic NOM which is much less amenable to removal by coagulation but is also less reactive with chlorine to form DBPs. This type of NOM is also referred as the non-humic portion of NOM.

Assuming optimized treatment, the residual NOM remaining after enhanced coagulation is primarily made up of low-MW and non-humic material. The latter NOM fractions represent the portion of the NOM that is resistant to removal by coagulation.

Total Organic Carbon (TOC): TOC is a measure of the total organic content of water which includes POC and DOC. This test provides a generic measurement of organic carbon content and it is not necessarily a consistent measure of DBP precursor concentrations. This is because the TOC analysis includes both the high and low molecular weight NOM. Also TOC does not provide an indication of the aromaticity, aliphatic nature, functional group chemistry, or chemical bonding associated with natural organic molecules all of which may affect DBP formation. The reactivity of chemical bonds and functional groups is likely to be a significant factor in explaining why different waters with the same TOC concentration will form different DBP concentrations under identical disinfection conditions. In addition to reducing the potential to form DBPs, enhancing existing treatment to reduce TOC levels also can result in added benefits that include reduced potential for bacterial regrowth in the distribution system, improved taste and odor, reduction in disinfectant demand, and reduced levels of unknown or unregulated DBPs.

Dissolved Organic Carbon (DOC): DOC is operationally defined as the organic carbon in water that has passed through a 0.45 micron filter. For many freshwaters, it has been reported that DOC represents 83% to 98% of the TOC (Owen et al, 1993). Most of the DOC in natural waters consists of non-biodegradable (or refractory) organic matter. A smaller portion of the DOC consists of biodegradable (or assimilable) organic matter (biodegradable dissolved organic carbon-BDOC), most of which can be removed by biological activity within filters.

Absorbance of ultraviolet light at 254 nanometers (UV₂₅₄): UV absorbing constituents absorb UV light in proportion to their concentration. UV₂₅₄ absorbance can be used as a surrogate for the concentration of organic molecules with aromatic groupings or extended conjugation and helps to predict the tendency of NOM to produce DBPs. The relationship between UV₂₅₄ and TOC is unique for each raw water source. However, for a given raw water source, increases in either TOC or UV absorbance indicate increasing NOM concentrations. It is measured using water samples filtered through a 0.45 micron filter.

Specific ultraviolet absorbance (SUVA): SUVA provides (in theory) an indication of the humic content of NOM, which is believed to be the more reactive portion when it comes to DBP formation. It is calculated as follows: $SUVA = (UV_{254} \times 100) / DOC$. Table 2-1 summarizes the typical water treatment characteristics relative to the SUVA value. As shown in Table 2-1, $SUVA < 2.0$ low humic content-not amenable to enhanced coagulation; $SUVA 2-4$ moderate humic content amenable to enhanced coagulation; $SUVA > 4.0$ high humic content very amenable to enhanced coagulation. SUVA values of 4 to 5 L/mg-m are typical of waters containing primarily humic material. SUVA can be predictive of the removal capability of water treatment practices. Several studies reported that waters with a high SUVA value exhibited large reductions in SUVA and TOC as a result of enhanced coagulation, indicating an overall substantial removal of NOM. Waters with low SUVA values, however, exhibited relatively low reductions in SUVA and TOC, indicating an overall insignificant removal of NOM.

Table 2-1 Summary of SUVA Values

SUVA Value (L/mg-m)	NOM Composition	Coagulation Properties	Anticipated DOC Removal
Greater than 4.0	Mostly aquatic humics, high hydrophobicity, high molecular weight	NOM has large impact on coagulation, good DOC removal possible	Greater than 50 percent for aluminum based coagulants
2.0 to 4.0	Mixture of aquatic humics and other NOM. NOM is a mix of hydrophobic and hydrophilic, varying molecular weights	NOM has some impact on coagulation, some DOC removal possible	25 to 50 percent for aluminum-based coagulants
Less than 2.0	Mostly non-humics. Mostly hydrophilic, lower molecular weights	NOM has low impact on coagulation, low DOC removal	Less than 25 percent for aluminum-based coagulants

* Source: Edzwald, James, K. *Drinking Water Institute* (2006).

Total Trihalomethanes (TTHMs): TTHMs are a group of four chemicals (chloroform, bromodichloromethane, dibromochloromethane, and bromoform) that are formed along with other DBPs when chlorine reacts with naturally occurring organic and inorganic matter in water.

Haloacetic Acids (HAAs): HAAs are a group of chemicals that are formed along with other DBPs when chlorine reacts with naturally occurring organic matter in water. The regulated haloacetic acids is for the sum of five HAAs known as HAA5, which include: monochloroacetic acid, dichloroacetic acid, trichloroacetic acid, monobromoacetic acid, and dibromoacetic acid.

3. Regulatory Framework

Finalized regulations promulgated by the United States Environmental Protection Agency (USEPA) include primary and secondary drinking water standards. Primary standards address contaminants that may affect health and secondary standards address contaminants that may affect the aesthetic and economic qualities of the water. Primary standards are enforceable and are enforced by state agencies having primacy, in this case the Florida Department of Environmental Protection (FDEP) and Florida Department of Health in Broward County (FDOH-BC).

This section provides a summary of the current USEPA and FDOH-BC drinking water regulations applicable to the operation at the City's WTP.

3.1 Primary Drinking Water Standards

3.1.1 Stage 1 Disinfectants and Disinfection By-products Rule

Stage 1 of the Disinfectants and Disinfection By-products Rule (Stage 1 D/DBPR) was the first of a staged set of rules that were created to reduce the allowable levels of disinfection byproducts (DBPs) in drinking water. The existing Maximum Contaminant Levels (MCLs) included in the Stage 1 D/DBPR (published in 1998) are contained in Table 3-1. The MCL for Stage 1 is based on a system-wide four-quarter running annual average (RAA).

Table 3-1 Stage 1 D/DBPR Maximum Contaminant Levels (MCLs)

Disinfection By-product	Unit	MCL
Total Trihalomethanes (TTHMs)	ppb or µg/L	80
Haloacetic Acids (HAAs)	ppb or µg/L	60
Bromate	ppb or µg/L	10

The limits on disinfectants in the Stage 1 D/DBP Rule were finalized as Maximum Residual Disinfectant Levels (MRDLs) instead of MCLs. The final limits on disinfectants (MRDLs) are contained in Table 3-2. The City's WTP currently uses chloramines as the disinfectant in the distribution system.

Table 3-2 Maximum Residual Disinfectant Levels (MRDLs)

Disinfectant	Unit	MRDL
Chlorine (as Cl ₂)	ppm or mg/L	4.0
Chloramines (as Cl ₂)	ppm or mg/L	4.0

Under the final Stage 1 D/DBP rule, surface water systems or groundwater under the influence of surface water systems operating with conventional treatment were required to install (unless systems meet exception criteria) and operate enhanced coagulation or enhanced softening for removal of TOC that will further reduce DBP formation. *It is important to note that this requirement does not apply to WTPs that use groundwater as the source water i.e. City's WTP.*

Also, in the Stage 1 D/DBPR, USEPA added a requirement that all conventional filtration plants treating surface water reduce the concentration of TOC in their water by pre-determined amounts regardless of the TTHM and HAA levels they form. These requirements are shown in Table 3-3.

Table 3-3 Minimum TOC Removal Requirements under the Enhanced Coagulation and Softening Criteria of the Stage 1 D/DBPR

Source Water TOC (mg/L)	Required TOC Percent Removal		
	Source Water Alkalinity, mg/L as CaCO ₃		
	0-60	>60-120	>120
>2.0 to 4.0	35%	25%	15%
>4.0 to 8.0	45%	35%	25%
> 8.0	50%	40%	30%

This Table essentially states that if a conventional filtration plant is treating a water source containing a TOC concentration higher than 2.0 mg/L but less than or equal to 4.0 mg/L, and an alkalinity greater than 120 mg/L as CaCO₃, then the TOC removal required by enhanced coagulation at this plant is a minimum of 15%.

3.1.2 Stage 2 Disinfectants and Disinfection By-products Rule

The Stage 2 Disinfectants and Disinfection By-products Rule (Stage 2 D/DBPR) and the Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR) are a set of interrelated regulations that address risks from microbial pathogens and disinfectants/disinfection byproducts. Both the Stage 2 D/DBPR and the LT2ESWTR were promulgated simultaneously in January 2006 to address concerns about risk tradeoffs between pathogens and DBPs. The goal of the Stage 2 DBPR is to target the highest risk systems for changes beyond those required by Stage 1 DBPR.

DBPs as currently regulated under Stage 2 of the D/DBP rule, retain the same MCLs for DBPs from Stage 1, but also require that reporting of DBPs be site specific, based on locational running annual averages (LRAAs) instead of reporting running annual average values (RAAs). Sampling sites for the Stage 2 DBP Rule are selected through the Initial Distribution System Evaluation (IDSE) process as required by Stage 2 of the D/DBPR.

3.1.3 Ground Water Rule (GWR)

The Ground Water Rule (GWR) was enacted on November 8, 2006. The Rule was published in the Federal Register to provide increased protection against microbial pathogens in public water systems that use groundwater sources. Since disease-causing pathogens are found in fecal contamination, the EPA is concerned about the groundwater systems that are susceptible to fecal contamination. The GWR applies to public water systems that use ground water and also applies to systems that use both groundwater and surface water sources in their system.

Public groundwater systems (GWSs) that do not conduct compliance monitoring and are notified of a total coliform-positive routine sample collected in compliance with the TCR (40 CFR 141.21) must conduct triggered source water monitoring and must take corrective action if a significant deficiency is identified. In order not to be subject to triggered source water monitoring, a GWS can notify the state that it provides at least 4-log treatment of viruses using virus inactivation, removal, or a state-approved combination of 4-log virus inactivation and removal before or at the first customer.

3.2 Secondary Drinking Water Standards

Secondary standards are not enforced by the USEPA but are strongly recommended and may be enforced at the discretion of individual state primacy agencies. The Secondary Drinking Water Standards are summarized in Table 3-4.

Table 3-4 Secondary Drinking Water Standards

Parameter	Standard	Parameter	Standard
Aluminum	0.05 to 0.2 mg/L	Iron	0.3 mg/L
Chloride	250 mg/L	Manganese	0.05 mg/L
Color (True)	15 color units	Odor	3 threshold odor number
Copper	1.0 mg/L	pH	6.5 to 8.5
Corrosivity	Non-corrosive	Silver	0.10 mg/L
Fluoride	2.0 mg/L	Sulfate	250 mg/L
Foaming Agents	0.5 mg/L	Total Dissolved Solids	500 mg/L
Zinc	5 mg/L	Hardness	none

3.3 Future Drinking Water Regulations

An increasing number of drinking water utilities in the United States have been using or considering chloramination over chlorination. In comparison with chlorination, chloramination has been shown to minimize the formation of THMs and HAAs, thereby offering a cost-effective means to comply with the Stage 2 D/DBPR. However, chloramines have been implicated in the formation of nitrosamines such as N-nitrosodimethylamine (NDMA).

Currently there are no US EPA regulations for nitrosamines. Five nitrosamines were listed on the third and fourth contaminant candidate lists (CCL3 and CCL4) indicating that US EPA is considering these contaminants for potential regulatory determination. Nitrosamines (including NDMA) are also under evaluation in the third Six-Year review of the Microbial and Disinfection By-product Rules (US EPA, 2016).

Two California agencies have developed notification level and public health goal for nitrosamines (Table 3-5).

Table 3-5 Notification Level or Public Health Goal for Nitrosamines

Contaminant	Unit	Notification Level or Public Health Goal	Agency
N-nitrosodiethylamine (NDEA)	ppt or µg/L	Notification Level = 10	California Department of Public Health
N-nitrosodimethylamine (NDMA)	ppt or ng/L	Notification Level = 10	California Department of Public Health
N-nitrosodi-N-propylamine (NDPA)	ppt or ng/L	Notification Level = 10	California Department of Public Health
N-nitrosodimethylamine (NDMA)	ppt or ng/L	Public Health Goal = 3	California Office of Environmental Health Hazard

In the future, drinking water utilities using chloramines (e.g. City of Pembroke Pines) *could* face the challenge of achieving compliance with Stage 2 D/DBPR and other microbial regulations while minimizing nitrosamine formation in their systems.

3.4 Regulatory Implications for the City

This study will assess compliance with the current Stage 2 D/DBPR, existing DBP data will be summarized and discussed. In order for the City to consistently meet the Stage 2 D/DBPR requirements, it may be necessary for the City to make operational changes at the WTP, add new unit processes for treatment and or/disinfection, make distribution system operational changes, or a combination of these items.

4. Existing WTP

The City of Pembroke Pines currently owns and manages a conventional lime softening ground water treatment plant (WTP) with a rated capacity of 18.0 million gallons per day (MGD). The City's withdraws raw water from two wellfields which have a total of eight (8) wells, approximately 112 feet deep. The raw water is withdrawn from the Biscayne aquifer. The wells are also owned by City of Pembroke Pines. The wellfields are both located on Johnson Street and are approximately one mile apart. Central Wellfield has wells 1 through 5 that are located at the water treatment plant and Eastern Wellfield has wells 6, 9, 10, and 11, which are located on the corner of N.W. 72 Avenue and Johnson Street. The WTP and wellfields are currently operated by CH2M, a private operating company. The WTP is located at the intersection of Johnson Street and University Drive in the City of Pembroke Pines. Water withdrawn from these wells are combined and treated at the WTP.

The WTP is comprised of a combination of structures built over 30 years ago and has undergone subsequent expansions and improvements over the years. The WTP provides potable water to residential and commercial users in its service area through its distribution system. Table 4-1 shows salient features of the WTP and associated water quality issues.

Table 4-1 Salient Features of Existing WTP

System	Location	Capacity	Description	Key Issues of Concern
City of Pembroke Pines WTP	Johnson Street and University Drive	12.0 MGD (average) 18.0 MGD (rated) 24.0 MGD (peak)*	Source: Shallow Biscayne Aquifer Treatment: Conventional Population: 164,626 Number of Service Connections: 43,143	DBP precursors (color, TOC), ammonia, iron, disinfection by-products (DBPs)

* 6 MGD treatment capacity was added for redundancy.

Treatment of the source water (groundwater) includes lime softening, filtration, ion exchange and disinfection with chloramine (chlorine and ammonia). Figure 4-1 shows the various processes in the WTP.

Table 4-2 shows various unit processes at the WTP and design and operational criteria. The source water is usually treated by three Accelator® clarifiers/softeners (Infilco Degremont) with the 4th Accelator® as stand-by for routine maintenance. Accelator® clarifier is a high-rate treatment process incorporated in a single basin that employs the principle of internal slurry recirculation to accelerate chemical reactions and promote dense particle growth leading to better settleable floc. Lime and polymer are fed to the influent in the Accelator® and a pH of 9.7-10.0 is maintained for removing hardness. The clarified water is filtered by four (4) dual media filters (Greenleaf by Infilco Degremont). The media is comprised of anthracite and sand. The filter influent is injected with polyphosphate to sequester remaining calcium. Chlorine is also added which combines with natural ammonia to form chloramine. After filtration, under normal operation a portion of the flow (10%-50%) is treated by ion exchange units for color and TOC removal. Ion exchange units are currently not in operation due to bio-fouling problems experienced in the past (see below). Filtered and ion exchange treated water are recombined in the clearwell where additional chlorine and ammonia are added to generate monochloramines for disinfection and maintaining a residual in the distribution system. From the clearwell, the finished water is pumped by transfer pumps to two storage tanks and then into the distribution system by high service pumps.

At present, the ion exchange units are being rehabilitated and are anticipated to be on-line by end of June 2017. The ion exchange system was taken off-line on 9/1/2015 due to elevated bacteria activity occurring in the units. The ion exchange units require backwashing followed by a brine rinse. The backwash water and brine rinse from ion exchange are pumped to Hollywood's wastewater plant.

Table 4-2 Existing Design and Operational Criteria for Unit Processes at WTP

Unit Process	Description and Units	Value
Raw water wells (East and Central Wellfields)	Number of Wells	8
	Eastern Wellfield	6,9,10,11
	Central Wellfield	2,3,4,5
	Capacity of pumps (GPM)	525-2800
Accelator® Clarifier/Softener	Number of Units	4
	Number of duty units	3
	Number of Stand-by Units	1
	Rated Capacity (MGD)	6
	Total Rated Capacity (MGD)	24
Greenleaf Filters	Number of Filters	4
	Number of cells per Filter	4
	Dual Media (sand, anthracite)	
Ion Exchange*	Number of Units	8.0
	Maximum Flow Rate (MGD)	12.0
	Average Flow Rate (MGD)	6.0
Transfer Pumps	Number of Pumps	7
	Rated Capacity of Each Pump (MGD)	
Clearwell	Storage Capacity (MG)	
	Number of Tanks	1
	Total Storage Capacity (MG)	5.0
Ground Storage Tanks	Number of Tanks	3
	Storage Capacities of Tanks (MG)	2.0, 2.0, 1.0
	Number of Motors	9
High Service Pump Station	Power (HP)	40-125
	Total Pumping Capacity (GPM)	18,120
	Number of Transfer Pumps	1
Backwash Basin and Transfer Pumps	Number of backwash basins	1
	Number of Transfer Pumps	1
Sludge Pond	Number of sludge ponds	2
Lime Slakers	Number of Units	3

Notes: 1. Values obtained from CH2M. Report titled "City of Pembroke Pines WTP, Technical and Compliance Audit" dated December, 2015

* Ion exchange units currently off-line, anticipated to be in service during summer of 2017

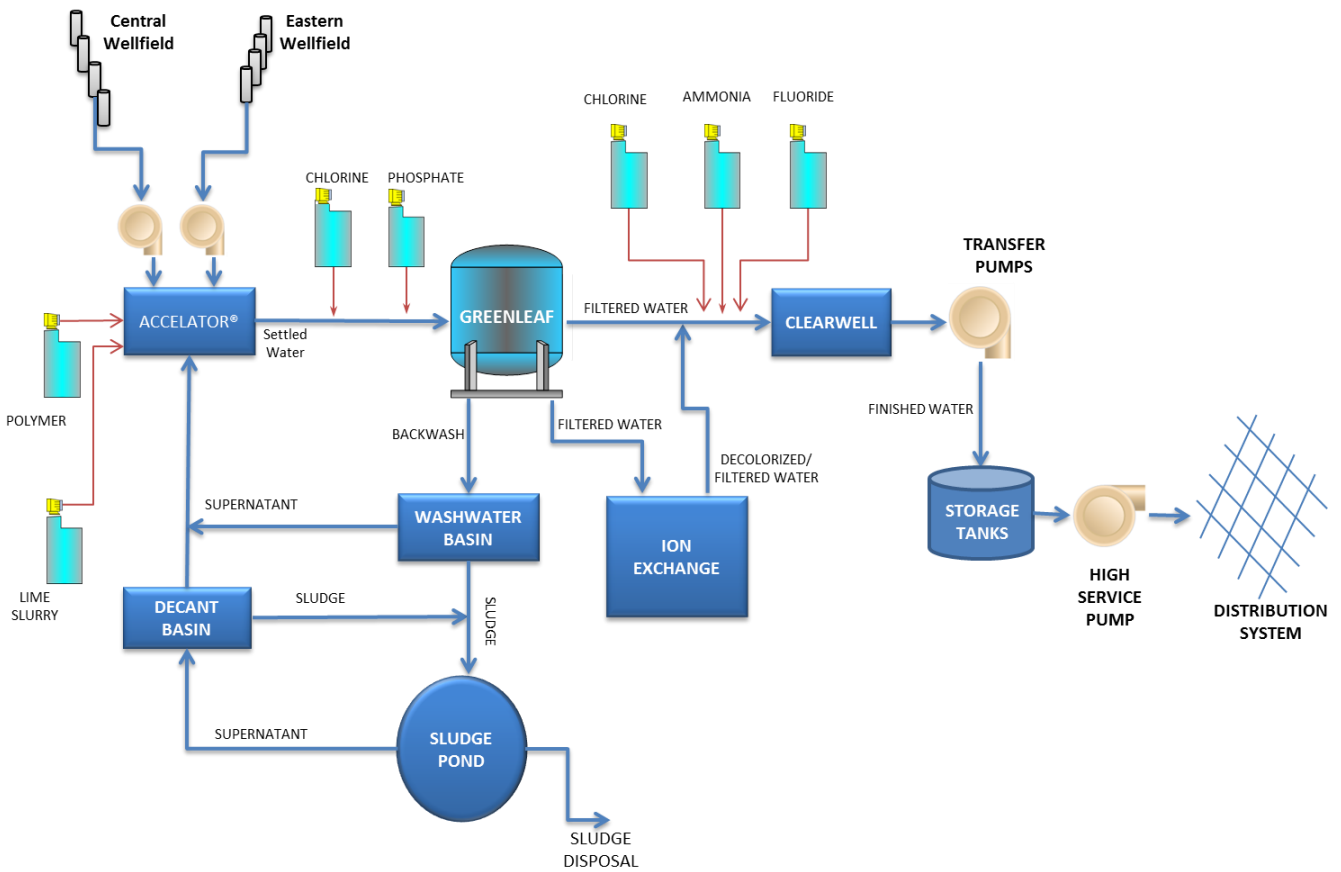


Figure 4-1 City of Pembroke Pines Water Treatment Plant Process Diagram¹

NOTES: 1. At present, the Ion Exchange process is off-line, anticipated to be back on-line in summer of 2017

4.1 Existing Operations

4.1.1 Chemical Usage

Chemicals used by the WTP and their point of addition in the WTP are summarized in Table 4-3.

Table 4-3 Water Treatment Chemicals¹

Chemical	Point of Addition	Purpose
Lime	Mixing Chamber of Accelator® Clarifier/Softener	To raise pH and reduce hardness To reduce DBP precursors (color)
Anionic Polymer	Mixing Chamber of Accelator® Clarifier/Softener	Promote floc formation and help floc settle
Chlorine	Pre-filtration	To form chloramines with natural ammonia
Polyphosphate	Pre-filtration	To sequester iron, calcium and corrosion inhibitor
Fluoride	Post-filtration	To reduce tooth decay
Chlorine and anhydrous ammonia (Chloramines)	Post-Filtration	Secondary disinfection and maintain a residual in the distribution system

Note: 1. "City of Pembroke Pines WTP, Technical and Compliance Audit" by CH2M dated December 2015 and site visit on 5/3/17

Table 4-4 summarizes the chemical use at the WTP. The chemicals used at the WTP are included in the first column and the minimum, median, average, 90th percentile and maximum chemical usages are included in the subsequent columns. The 90th percentile is included in the Table to eliminate potential outliers that may exist in the 'maximum' column. As seen in this Table, excessive chlorine doses are being applied prior to filtration to bind the naturally occurring ammonia.

Table 4-4 Typical Chemical Use at the WTP

Daily Chemical Usage ¹						
Parameters	Units	Average	Maximum ³	Minimum	Median	90 th Percentile
Lime	mg/L	112.18	229.00	5.00	110.00	150.00
Anionic Polymer	mg/L	0.16	1.11	0.01	0.10	0.33
Pre-filtration Chlorine	mg/L	5.06	8.00	1.40	5.00	6.90
Polyphosphate	mg/L	1.16	1.72	0.00	1.50	1.50
Fluoride	mg/L	0.42	32.00	0.00	0.31	0.64
Post-filtration Chlorine	mg/L	3.70	8.00	0.10	4.50	4.78
Ammonia	mg/L	0.72	7.80	0.00	0.70	1.00

- Notes:
1. Data from March 2013 - March 2017
 2. Data not recorded for July and December of 2013
 3. Data for 2014 not used.
 3. Extreme values suggest that there was an error in collecting the data.

4.1.2 Plant Operations

Jacobs staff conducted a site visit to the WTP on May 3rd 2017, to observe plant operations and meet with the operations staff to discuss plant operating procedures. On that day, wells 2, 3, 4 and 6, 9, 10, 11 were being operational; Accelerator®s B, C, D were operational and Accelerator® A was off-line. All of the ion exchange units were off-line. Table 4-5 shows the water quality data for the raw, settled water and finished water obtained from the daily test sheet (DTS). Operators measure some water quality parameters hourly (e.g. pH) and some parameters every four hours (e.g. alkalinity, hardness) using state approved methods for analysis.

Table 4-5 Raw, Settled and Finished Water Quality*

Water Quality Parameter	Units	Raw Water	Accelerator® B	Accelerator® C	Accelerator® D	Finished Water
pH	standard units	6.6	9.85	9.91	9.8	9.48
Iron	mg/L	0.98	NM	NM	NM	0.14
Chloride	mg/L	30	NM	NM	NM	NM
Color	color units	50	NM	NM	NM	13
Total Alkalinity	mg/L CaCO ₃	198	40	50	47	46
Calcium Hardness	mg/L CaCO ₃	200	61	65	62	60
Magnesium Hardness	mg/L CaCO ₃	5	7	15	13	10
Total Hardness	mg/L CaCO ₃	205	68	80	75	70
Turbidity	NTU	0.32	0.92	0.83	0.73	0.33
Total Chlorine Residual	mg/L	NA	NA	NA	NA	3.8
Chloramine residual	mg/L	NA	NA	NA	NA	3.4
Free Ammonia	mg/L	NA	NA	NA	NA	0.05

* Values from Daily Test Sheet (DTS) provided by CH2 and dated 5/3/17

NM=Not measured, NA=Not Applicable

As seen in the Table, the finished water met the secondary drinking water standards for iron, color except for pH which has a secondary maximum contaminant level of 6.5-8.5. FDOH allows the City to operate with a high finished water pH. A detailed discussion of water quality is presented in the Section 5.

4.2 Disinfection Practices

Chlorine (sodium hypochlorite) and anhydrous ammonia are added at the clearwell to maintain a monochloramine residual leaving the plant (target is 4.0 mg/L). The WTP staff rely on a total chlorine analyzer to maintain a chlorine:ammonia ratio, target is to maintain a 4:1 ratio. Throughout the entire water distribution system, a detectable combined chlorine residual must also be present to prevent harmful microbial re-growth that could affect public health (EPA/FDEP requirements). Goal is to provide adequate disinfection protection in the distribution system and meet FDEP standards by maintaining a minimum combined chlorine residual (monochloramine residual) of 0.6 mg/L or higher throughout the distribution system (FAC 62-555). To maintain these levels, the total chlorine residual level in the water leaving the WTP (post-filtration) must be higher to account for chlorine demands and avoid nitrification in the distribution system. To have a combined residual of

0.6 mg/L or higher at the extremes of the distribution system, the finished water total chlorine residual leaving the plant averages 3.7 mg/L with a 90th percentile of 4.8 mg/L (Table 4-4). Typical chloramine concentrations of 0.2-2 mg/L are found in drinking water supplies where monochloramine has been used as a disinfectant to provide a residual in the distribution system. As shown in Table 3-2 in Section 3, the MRDL is 4.0 mg/L as chlorine (3 mg/L monochloramine equivalent), while using chlorine or chloramine as a disinfectant.

The City of Pembroke Pines WTP does not conduct compliance monitoring (4 log removal/inactivation of viruses) but uses source water monitoring instead to comply with the GWR microbial requirements. The production wells are monitored on a monthly basis for total coliforms. If the City is notified of a total coliform-positive in the distribution system for a routine sample collected in compliance with the total coliform rule (TCR; 40 CFR 141.21), then the City must conduct triggered source water monitoring and implement corrective measures, per the GWR requirements.

5. Water Quantity and Quality

In this Section, an analysis of the raw water quantity and quality, finished water quality and disinfection by-products is presented. This analysis is based on an extensive review of the monthly operating reports (MORs), daily testing sheets (DTS), other reported documents shown in the Reference Section and from personal communications with plant operators and managers.

5.1 Water Quantity

The WTP has an average water production capacity of 12.0 MGD, rated capacity of 18.0 MGD and a peak capacity of 24.0 MGD (Table 4-1). A statistical analysis of the last 5 years of data showed that the average flow of treated water from the plant is 13.0 MGD (Table 5-1) with a 90th percentile of 14.0 MGD. The 90th percentile is included in the Table to eliminate potential outliers that may exist in the 'maximum' column. The maximum flow treated by the plant was 16.4 MGD. Peaking factors (maximum day/average day) were calculated based on the data in Table 5-1. Typical peaking factors range from 1.5-2.0 and the peaking factor for the WTP is below typical values. Figure 5-1 shows the finished water production in graphical form.

Table 5-1 Water Quantity (March 2013-March 2017)

Average	Maximum	Minimum	Median	90 th Percentile	Peaking Factor
13.0	16.4	10.0	13.0	14.0	1.30

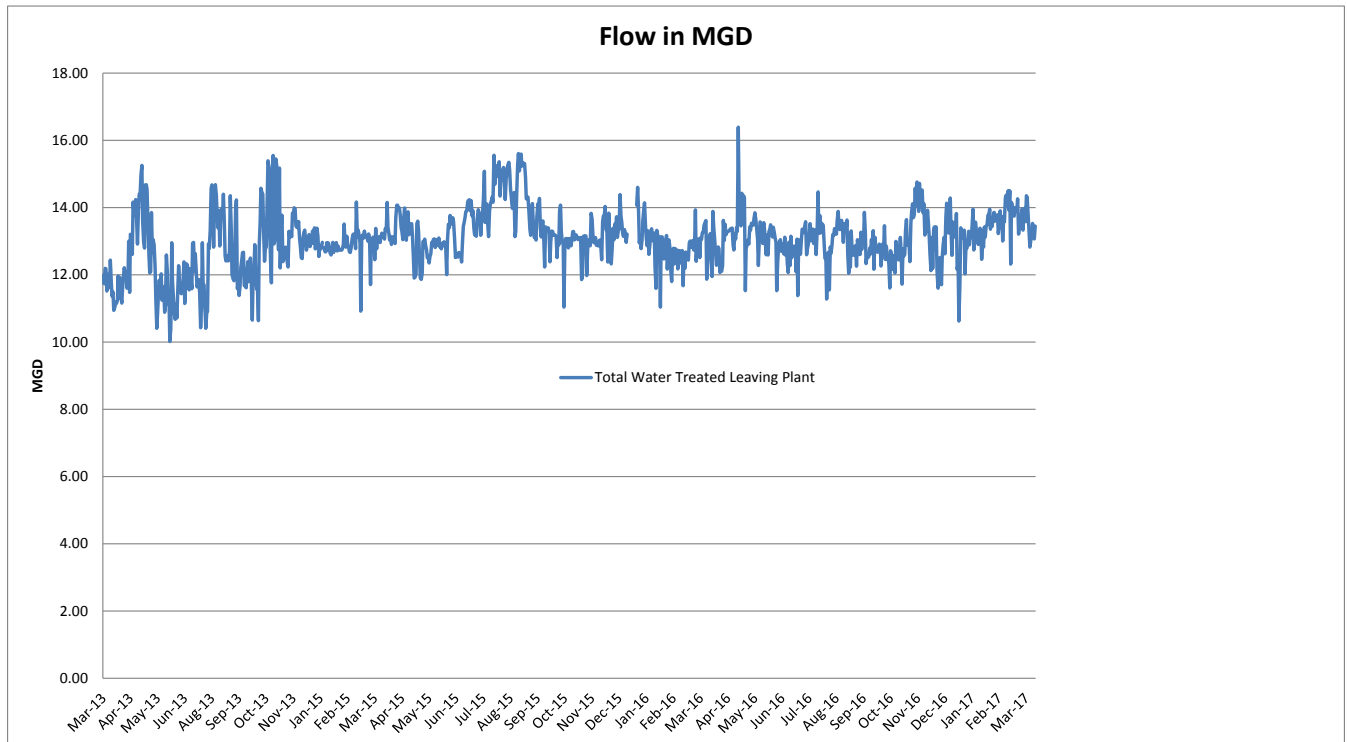


Figure 5-1 Production (Flow in MGD from March 2013-March 2017)

5.2 Raw Water Quality

As noted earlier, the source water for the WTP is shallow Biscayne Aquifer withdrawn from different wells (#1 through #9) with varying water quality (Table 1 of Appendix A). Groundwater (e.g. Biscayne Aquifer) under the hydrologic influence of Florida everglades generally contain high color, TOC and hardness. Well #5 is a high production well and contributes to 34% of the flow when used. Wells #3 and #5 are typically used as backup wells due to their poor water quality of high iron, color, TOC and free ammonia (City of Pembroke Pines WTP, Technical and Compliance Audit, CH2M, 2015). Wells #5 has very poor water quality; high iron (1.4 mg/L), color (165 units), TOC (9.7 mg/L) and free ammonia (1.96 mg/L).

The water withdrawn from various wells is combined at the WTP and the influent is treated. Table 5-2 includes a summary of raw water quality measured daily from March 2013 to March 2017. The main water quality parameters are included in the rows and the minimum, median, average, 90th percentile and maximum levels are included in the columns. The 90th percentile is included in the Table to eliminate potential outliers that may exist in the 'maximum' column.

Table 5-2 Raw Water Quality (March 2013-March 2017)

Raw Water Quality						
Water Quality Parameter	Units	Average	Maximum	Minimum	Median	90 th Percentile
pH	standard units	7.47	8.70	6.60	7.50	7.80
Iron	mg/L	1.20	32.0	0.10	1.04	1.20
Chloride	mg/L	30.4	70.0	15.00	30.00	32.00
Color	color units	47.9	86.0	6.0	50.0	60.0
Total Alkalinity	mg/L CaCO ₃	218.0	340.0	30.00	218.00	242.00
Calcium Hardness	mg/L CaCO ₃	209.0	320.0	0.86	208.0	239.4
Magnesium Hardness	mg/L CaCO ₃	27.1	226.0	4.0	20.0	48.0
Total Hardness	mg/L CaCO ₃	235.8	350.0	12.0	230.0	264.0

Notes: 1) Total ammonia in the source water range from 0.38-1.96 mg/L (Distribution Technical Compliance Audit for Pembroke Pines, FL, CH2M, 2015).

The raw water can be characterized as neutral to slightly alkaline pH, high alkalinity, hard water (hardness of 150-300 mg/L as CaCO₃ is classified as hard water), with high color and iron. Hardness is primarily composed of calcium hardness. Ammonia and TOC are not measured on a regular basis. Raw water color and TOC are direct precursors for the formation of disinfection by-products.

5.3 Treated Water Quality Goals

The water quality goals for full-scale treatment include compliance with all primary and secondary water quality standards (see Section 2), as applicable to WTPs. Table 5-3 summarizes the finished water quality standards and goals (industry standards) relevant to this project. It is important to note that water quality standards for turbidity and TOC are not applicable to City's WTP as source water is groundwater, however it is recommended to meet water quality goals (industry standards) for these parameters to produce high quality water.

Table 5-3 Finished Water Quality Goals

Water Quality Parameter	Significance	Water Quality Goal (Industry Standard)	Water Quality Standard	Standard Reference
Total Organic Carbon (TOC)*	<ul style="list-style-type: none"> DBP precursors Chlorine demand Stable water quality 	(TOC < 2.0 mg/L or SUVA < 2.0); Higher removals strongly recommended ⁴	30% removal	Stage 1 D/DBP Rule
Turbidity*	<ul style="list-style-type: none"> Filtration effectiveness Indicator parameter for pathogens 	< 0.1 NTU	<ul style="list-style-type: none"> <1 NTU at all times <0.3 NTU 95% of all daily samples per month 	NPDWR ¹ Treatment Technique IESWTR

Water Quality Parameter	Significance	Water Quality Goal (Industry Standard)	Water Quality Standard	Standard Reference
Color	<ul style="list-style-type: none"> Aesthetic value indicator of organics in the water which are DBP precursors 	< 5 color units	< 15 color units	NSDWR ²
pH	<ul style="list-style-type: none"> Quantity of chemicals DBP formation Concrete erosion, calcification, corrosion potential 	7.7-8.0 ⁵	Between 6.5 – 8.5	NSDWR ²
Conductivity	<ul style="list-style-type: none"> Lead and Copper uptake potential 	<500 mg/L as Total Dissolved Solids	<500 mg/L as Total Dissolved Solids	NSDWR ²
Iron	<ul style="list-style-type: none"> Filter Clogging Color in finished water 	< 0.15 mg/L	<0.3 mg/L	NSDWR ²
Manganese	<ul style="list-style-type: none"> Filter Clogging Color in finished water 	< 0.05 mg/L	< 0.05 mg/L	NSDWR ²
TTHMs	<ul style="list-style-type: none"> Disinfection By-products <ul style="list-style-type: none"> Cancer risk 	<64 ppb or µg/L ⁶	<80 ppb or µg/L	Stage 1 D/DBP Rule
HAAs	<ul style="list-style-type: none"> Disinfection By-products <ul style="list-style-type: none"> Cancer risk 	<48 ppb or µg/L ⁶	<60 ppb or µg/L	Stage 1 D/DBP Rule
Hardness	<ul style="list-style-type: none"> Distribution System Scale buildup 	120-150 mg/L as CaCO ₃ ³	N/A	N/A
Nitrite (measured as Nitrogen)	<ul style="list-style-type: none"> Nitrification Blue-baby syndrome 	1.0 mg/L	1.0 mg/L	NPDWR ¹
Nitrate (measured as Nitrogen)	<ul style="list-style-type: none"> Nitrification Blue-baby syndrome 	10.0 mg/L	10.0 mg/L	NPDWR ¹

Notes: * Water quality standard not applicable to City of Pembroke Pines WTP as source water is groundwater (Biscayne Aquifer). However water quality goals (industry standards are recommended).

1. National Primary Drinking Water Regulations

2. National Secondary Drinking Water Regulations

3. If Softening is used, it is assumed that finished water target is 120 mg/L as CaCO₃

4. Lower TOC levels in filtered water have additional benefits, such as a lower chlorine demand, less THM/HAA formation, more stable chlorine/chloramines residual, and reduced risk of nitrification in the distribution system.

5. Finished water pH is partly dependent upon source and treatment process

6. Goal is set at 20% below the Standard as an operational target for to provide assurance of one hundred percent regulatory compliance.

5.4 Finished Water Quality Analysis

The finished water quality for the WTP was reviewed using the MOR and daily test sheets which had manual entries. Table 5-4 shows a statistical analysis of last 4 years of water quality data.

Table 5-4 Finished Water Quality (March 2013-March 2017)

Finished Water Quality						
Water Quality Parameter	Units	Average	Maximum	Minimum	Median	90 th Percentile
pH	standard units	8.90	10.50	7.50	8.90	9.50
Total Alkalinity	mg/L CaCO ₃	40.30	150.00	2.00	36.00	58.00
Total Hardness	mg/L CaCO ₃	70.07	270.00	34.00	66.00	90.00
Color	color units	8.63	66.00	0.00	8.00	16.00
Fluoride as F	mg/L	0.42	1.48	0.00	0.31	0.64
Turbidity	NTU	0.29	1.10	0.01	0.24	0.67
Iron	mg/L	0.08	0.63	0.01	0.06	0.18
Total Residual Chlorine	mg/L	3.87	4.70	0.20	4.00	4.20

The raw water alkalinity and the finished water alkalinity are shown in Figure 5-2. The raw water source for the WTP has high alkalinity, usually ranging between 30 and 340 mg/L as CaCO₃ with an average value of 218 mg/L as CaCO₃ (Table 5-2). The finished water alkalinity ranges from 2-150 mg/L with an average value of 40 mg/L as CaCO₃ (Table 5-4 and Figure 5-2 indicating that a substantial portion of the alkalinity is removed (average removal is 81%). As lime is primarily used for softening, substantial amount of the hardness is removed (average removal is 70%), as shown in Figure 5-3. The average finished water hardness concentration (70 mg/L) is well below the water quality goal of 120-150 mg/L as CaCO₃.

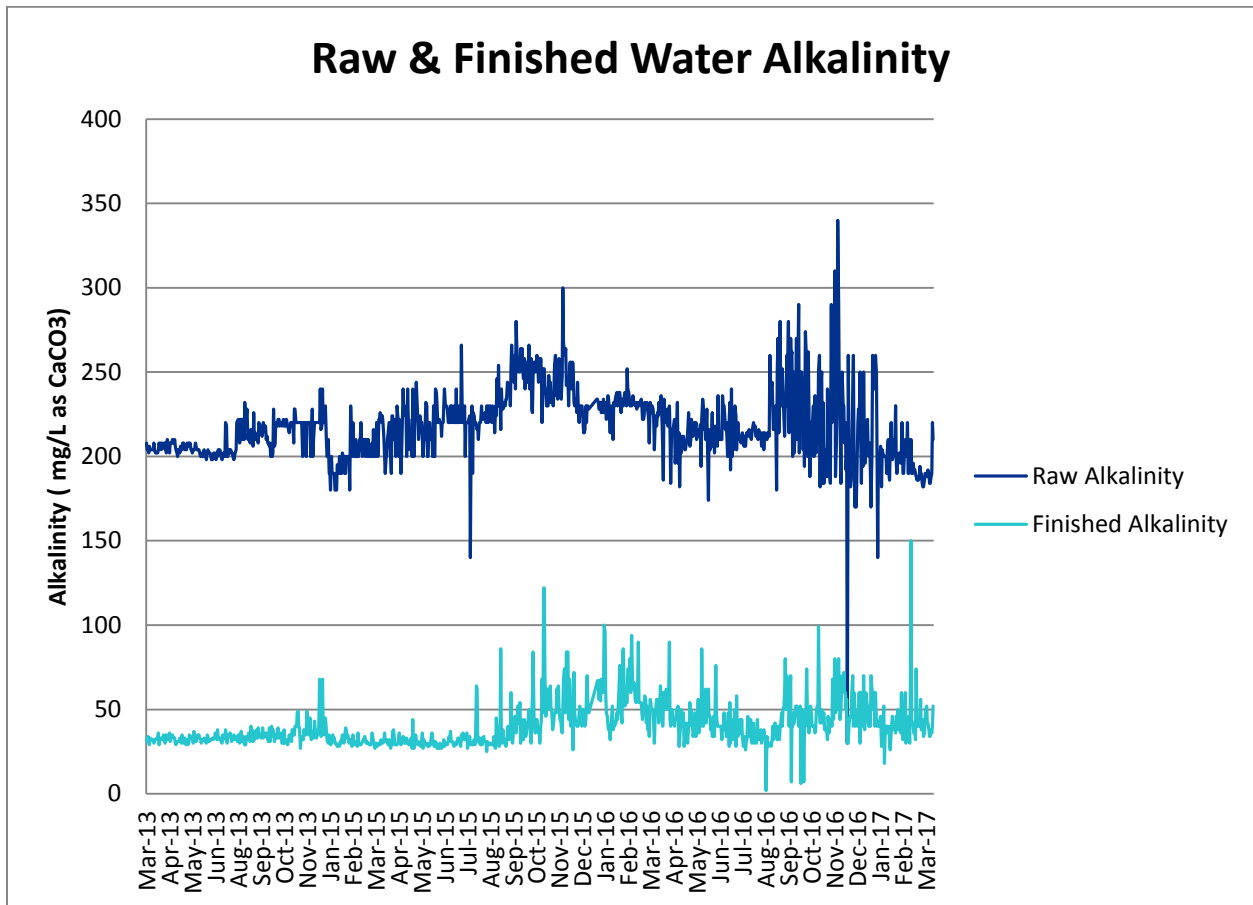


Figure 5-2 Raw Water and Finished Water Alkalinity

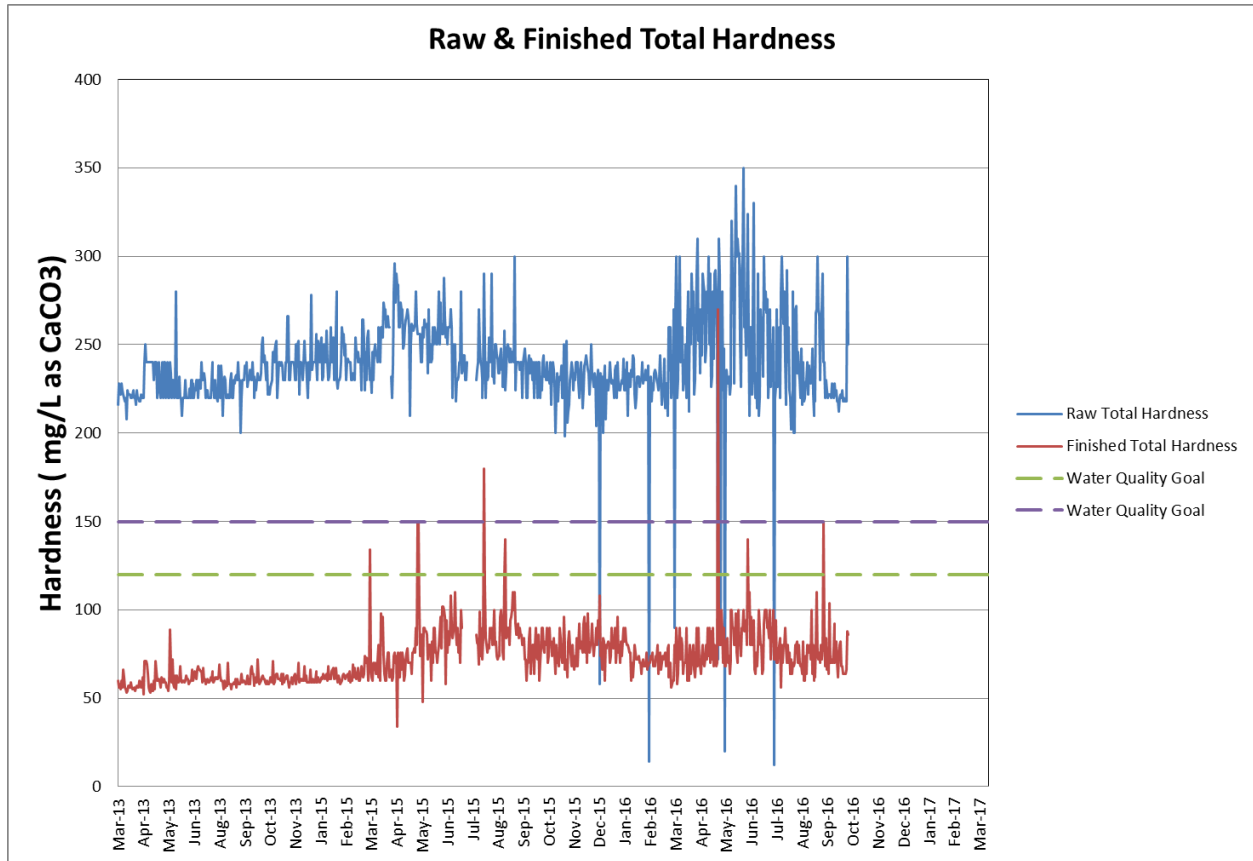


Figure 5-3 Raw Water and Finished Water Hardness

Figure 5-4 shows the finished water turbidity. The turbidity of the finished water was well above the water quality goal (industry standard) of 0.1 NTU and greater than 0.3 NTU most of the time. The average turbidity was 0.3 NTU, 90th percentile was 0.7 NTU with a maximum of 1.1 NTU in the finished water (Table 5-4). This indicates that the filter media is not effectively removing turbidity. During the site visit on 5/3/2017, it was noticed the effluent turbidity from the Accelerators® ranged between 0.73-2.32 NTU with an average turbidity of 1.4 NTU. Treated water turbidity guaranteed by Accelerators® is normally between 1-3 NTU. Although this might be considered as normal Accelerators® performance, settled water turbidities of 1.0 NTU or less (industry standard) are recommended for satisfactory filter performance.

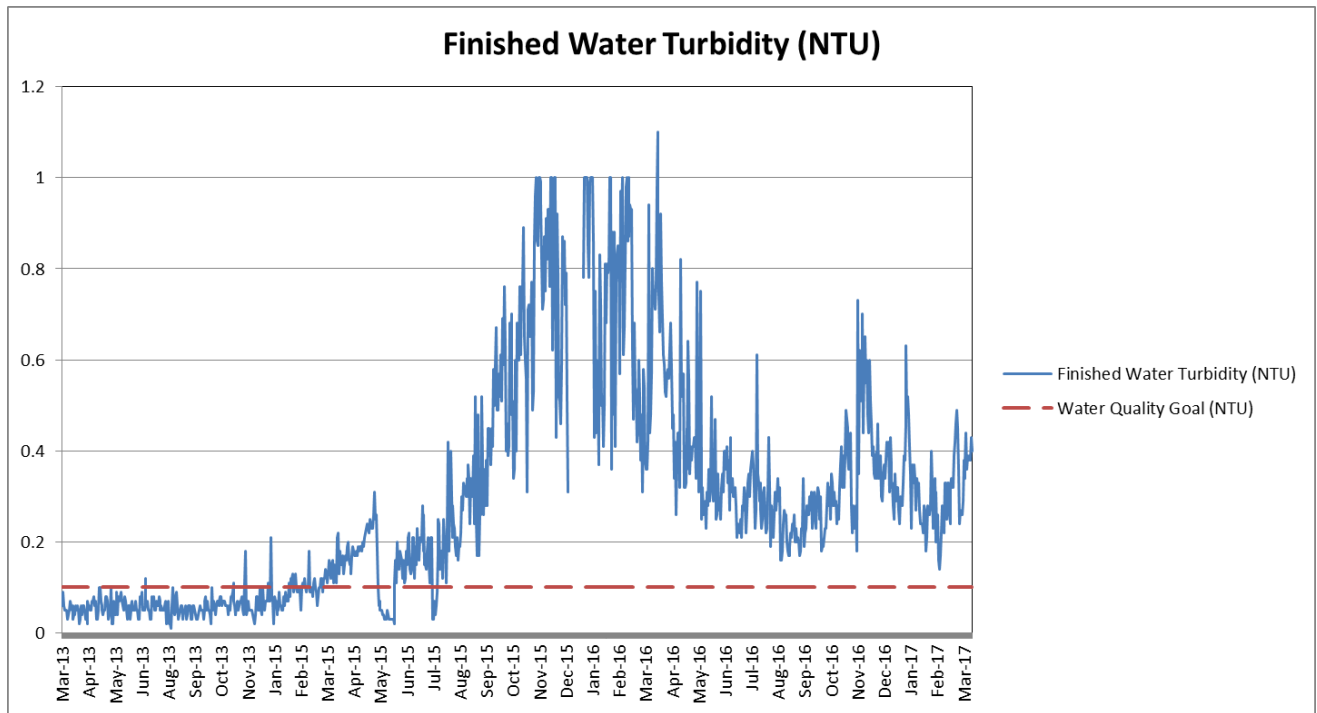


Figure 5-4 Finished Water Turbidity

Figure 5-5 shows the raw water and finished water pH. Average raw water pH is 7.5 (Table 5-2). Settled water pH has an average pH of 10.0 (Monthly Operating Reports). Average finished water pH was 8.9 with a 90th percentile pH of 9.5, exceeding the SMCL water quality standard of 6.5-8.5 (Tables 5.3, 5.4 and Figure 5-5). Although the FDOH allows the City to operate with a high finished water pH, it is important to note that TTHM formation is very rapid in a high pH environment. In addition, fluctuating pH levels can reduce monochloramine formation. As pH, should be more in line with the water quality goal/industry standard of 7.7-8.0 (Table 5.3).

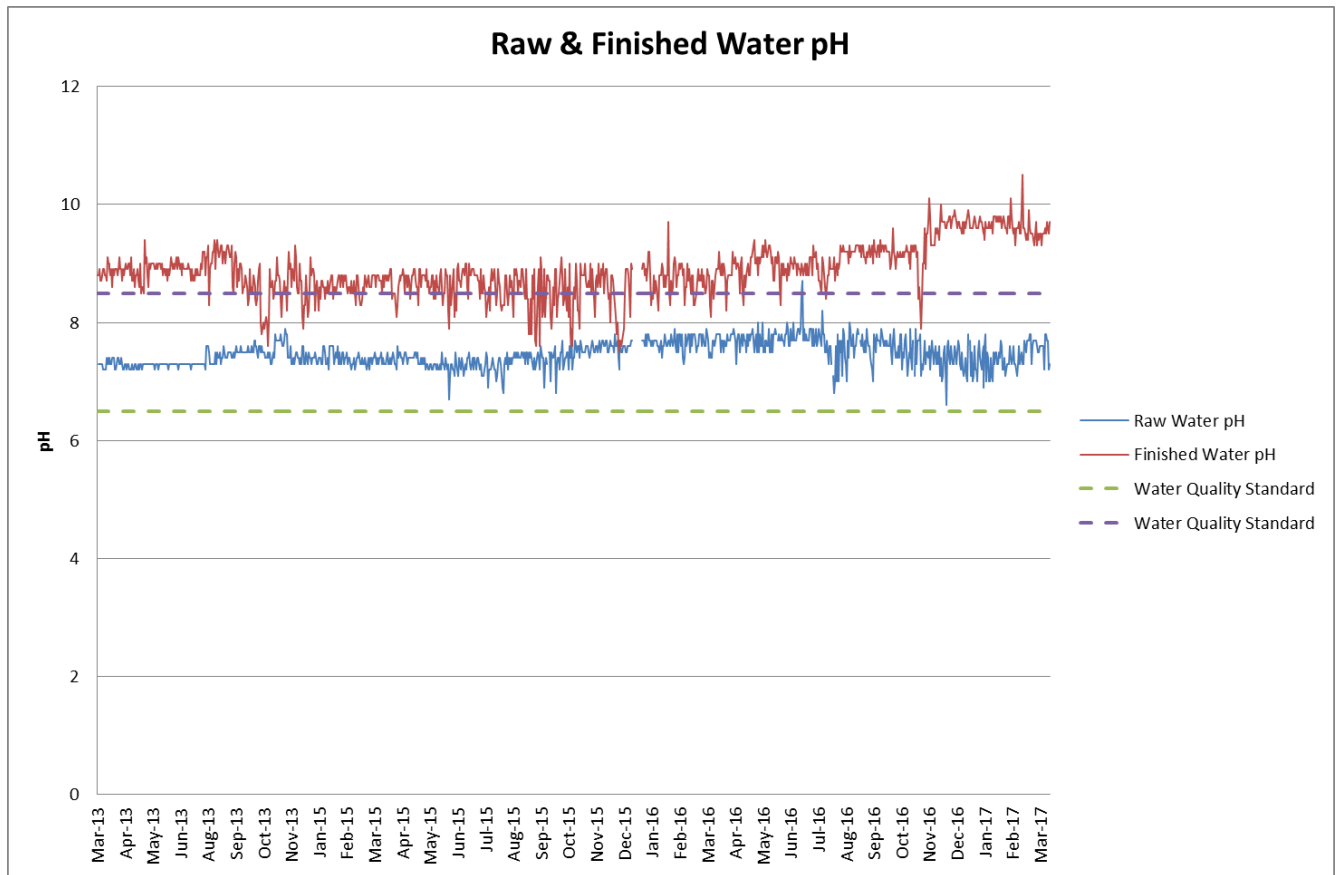


Figure 5-5 Raw and Finished Water pH

Figure 5-6 shows the raw and finished water iron. Iron in the raw water varies considerably with an average concentration of 1.2 mg/L (Table 5-2), however iron concentrations peaked to 1.9 mg/L several times since May 2016. During the same time, finished water iron concentrations were ~0.1 mg/L.

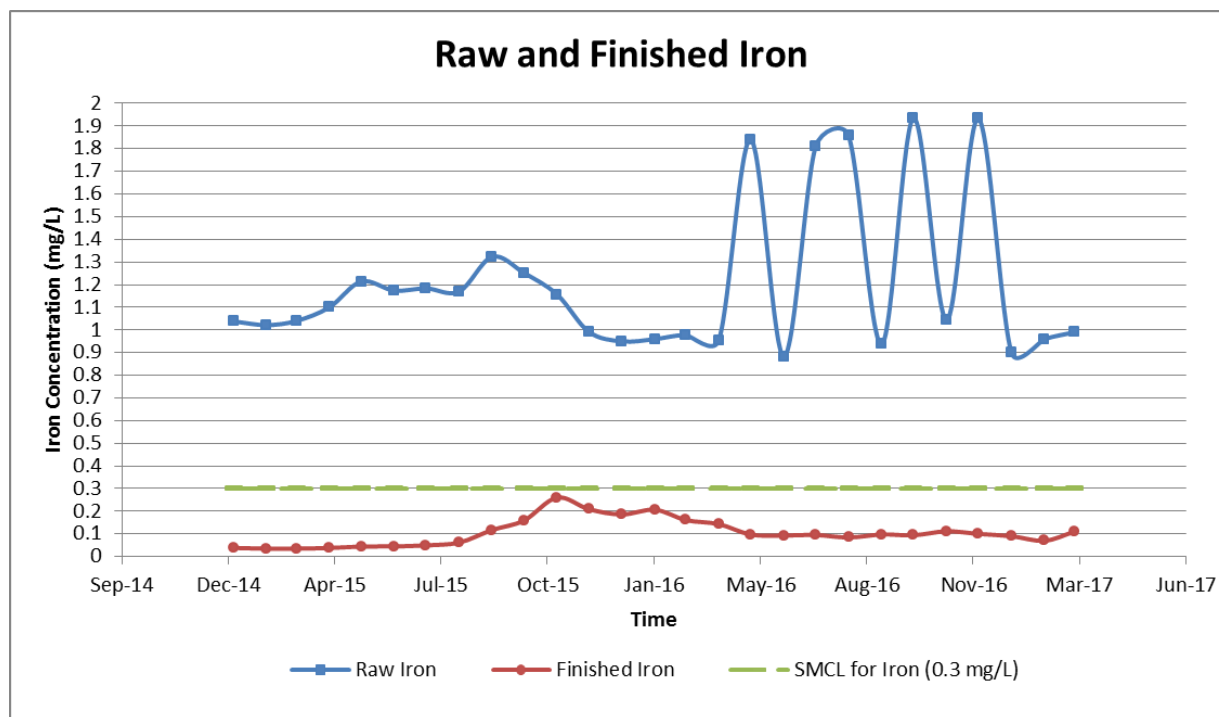


Figure 5-6 Raw and Finished Water Iron

Raw water color ranges from 6-86 units with an average of 48 units (Table 5-2). As shown in Figure 5-7, the raw water color increased during the summer of 2015 and was attributed to two wells with high color and iron being placed on-line and providing 43% of the raw water entering the WTP and malfunctioning lime slakers leading to sludge blanket carryover to the filters (City of Pembroke Pines WTP, Technical and Compliance Audit, CH2M, 2015).

Finished water color from the WTP had an average concentration of 8.6 units, which represents an average color removal of 82% (Table 5-4 and Figure 5-7). When the lime softening system is working properly, 73% reduction in color is possible (City of Pembroke Pines WTP, Technical and Compliance Audit, CH2M, 2015) and additional color is removed by the ion exchange process.

The 1st set of 4 ion exchange vessels was placed in service in 1999 to remove DBP precursors such as color and TOC. The 2nd set was placed in service in 2009. At the WTP, less than half of the plant water produced is treated by the ion exchange process and is recombined with the remainder of the lime softened water. Removal efficiencies of the ion exchange process alone are as follows (Cost Effective Color Removal for South Florida Drinking Water, Kennedy, K. 2005):

Color removal -95%
 TOC removal-67%
 TTHM formation potential reduction- 67%

In the past, the color removal efficiencies have exceeded 90%, TTHMs have been reduced by 39% and finished water color has been less than < 1 color units (Cost Effective Color Removal for South Florida Drinking Water, Kennedy, K., WQTC, 2004).

Due to biological fouling leading to nitrite formation, the ion exchange system was taken off-line September 1st 2015 for refurbishment, as indicated by the vertical line in Figure 5-7. Prior to the ion exchange units being taken off-line the color removal was > 85%. Up until then, the finished water met the water quality goal of 5 color units. After the ion exchange units were taken off-line, the finished water color started increasing but met

the water quality standard of 15 color units. However, the water quality goal of 5 color units was exceeded. The color removal dropped to as low as 68%. Also, the iron concentrations in the finished water increased.

During the site visit conducted by Jacobs staff on 5/3/2017, it was noticed that the raw water color was 50 units and the removal ranged from 60%-78%. Filtration by itself is not effective in removing dissolved constituents such as color and ion exchange is necessary to reduce color to acceptable levels. Low removal of DBP precursors such as color can increase the formation of DBPs.

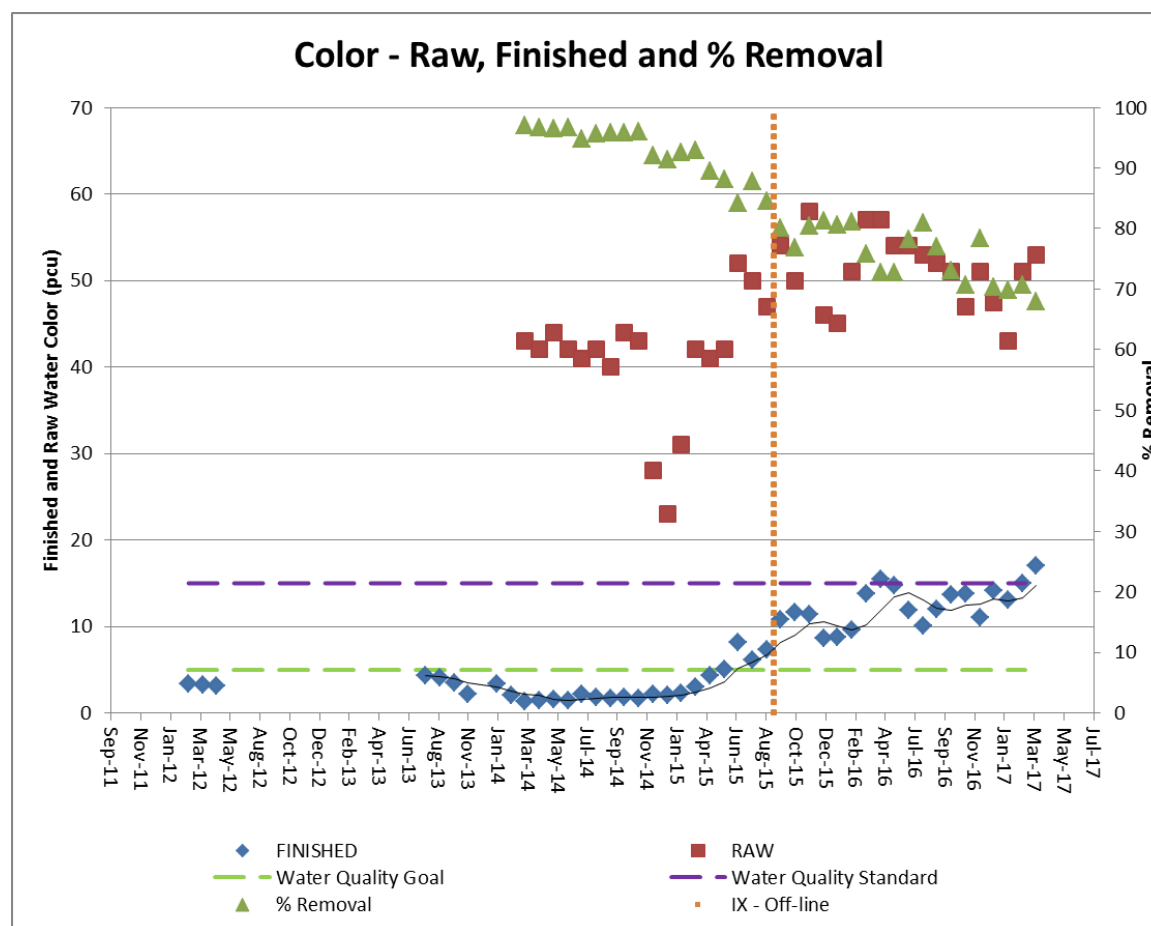


Figure 5-7 Raw, Finished Water Color and Removal (%)

Table 5-5 shows the applied and total residual chlorine obtained from the MORs. The chlorine demand varied with an average chlorine demand of 1.3 mg/L. Free ammonia levels leaving the plant vary between 0.1-0.2 mg/L (Distribution technical compliance audit for Pembroke Pines, Florida, CH2M, 2015). Figure 5-8 shows the variation in total chlorine dosages and chlorine demand during different times of the year with the highest values observed in April of 2013 and summer months of 2016. The chlorine dose started varying since November 2015 and more so in summer of 2016 and that trend appears to be continuing to the present date. Due to a lack of an on-line ammonia analyzer and reliance on the total chlorine analyzer leads to varying monochloramine residuals.

Chlorine demand in general, increased during the summer months and decreased during the winter months. However the chlorine demand also increased from November 2016-January 2017 indicating that the chlorine

demanding constituents (e.g. ammonia, iron, color, DOC) varied in the finished water as well. This trend of varying color in source water (due to using wells with poor water quality) and finished water (due to ion exchange off-line) observed in Figure 5-6 could explain the varying chlorine demand.

Table 5-5 Total Chlorine and Chlorine Demand (March 2013-March 2017)

Chlorine Data in the Finished Water						
Water Quality Parameter	Units	Average	Maximum	Minimum	Median	90 th Percentile
Total Residual Chlorine	mg/L	3.87	4.7	0.2	4.0	4.2
Applied Chlorine	mg/L	5.12	8.0	1.4	5.0	6.9
Chlorine Demand (calculated)	mg/L	1.25	3.3	1.2	1.0	2.7

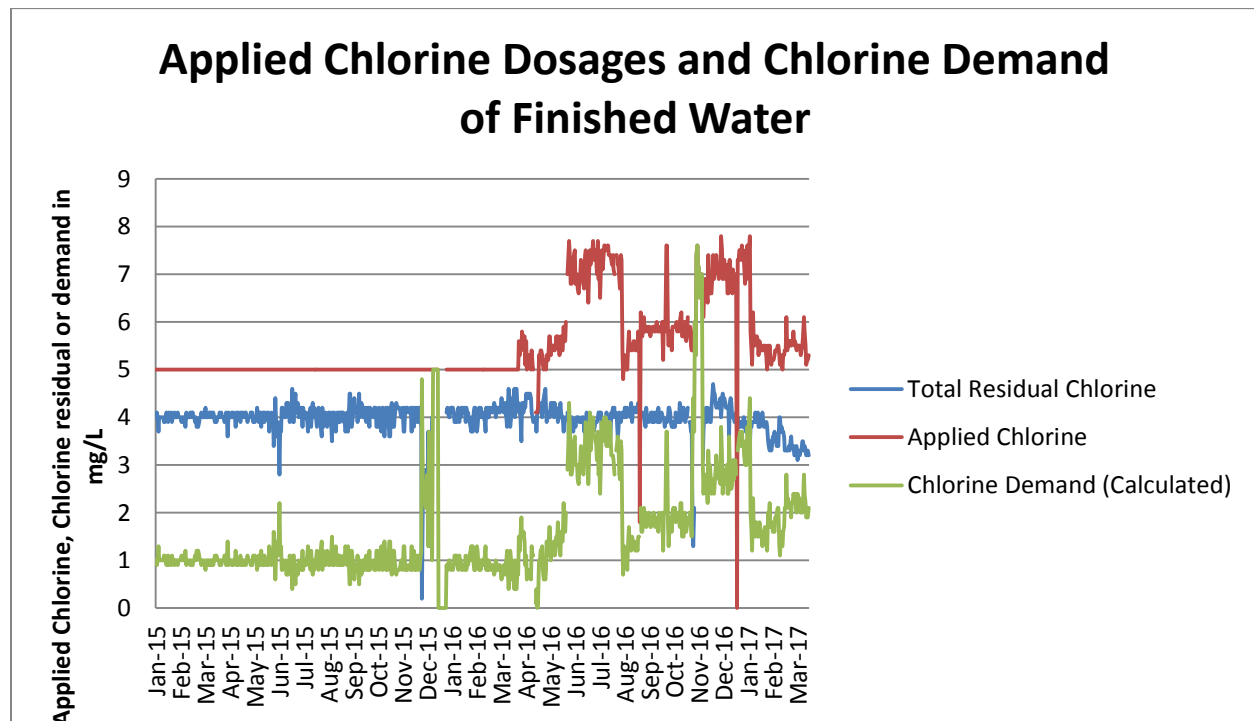


Figure 5-8 Applied Chlorine Dosages and Chlorine Demand of Finished Water

The operators try to maintain a residual at the point of entry (POE) around 4 mg/L. The increase in dosages is due to an increase in chlorine demand caused by organics, ammonia and iron in the finished water. Re-chlorination with sodium hypochlorite is practiced at the ground storage tanks to maintain an adequate disinfectant residual. Figure 5-9 shows the total chlorine residual at the POE and at different locations in the distribution system. Lowest chlorine residuals were observed at the 20426 SW 54th Place, which is the farthest location from the WTP in the distribution system.

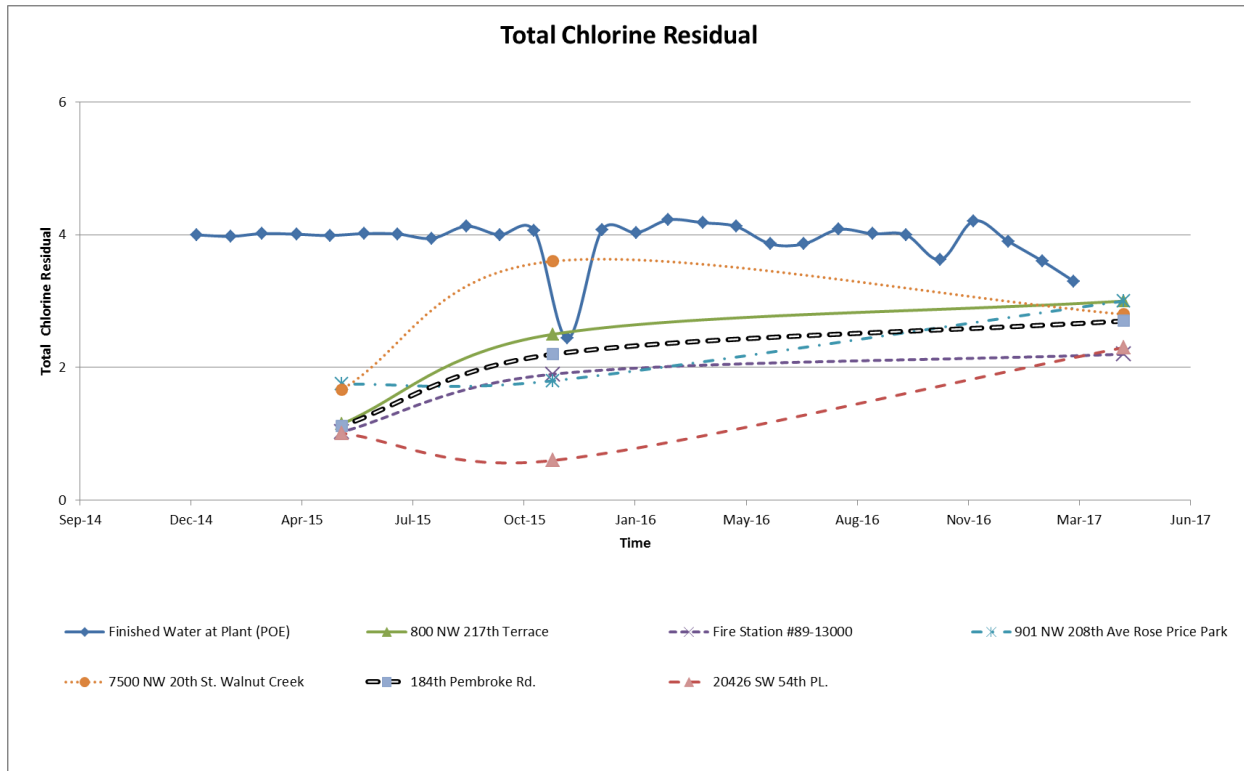


Figure 5-9 Total residual chlorine at the WTP and in the Distribution System

5.5 Disinfection By-Products

One current regulation that has a significant impact on the required treatment at the WTP is the Stage 2 Disinfectant/Disinfection Byproduct Rule (Stage 2 D/DBPR), described in Section 2 earlier. Stage 2 D/DBPR requirements became effective for the City of Pembroke Pines in April 2012 and retain the same MCLs for DBPs from Stage 1, but also require that reporting of DBPs be site specific, based on locational running annual averages (LRAAs) instead of reporting running annual average values (RAAs). Per Stage 2 D/DBPR requirements, the LRAA of TTHMs and HAAs at each of these locations has to be below 80 ppb ($\mu\text{g/L}$) and 60 ppb ($\mu\text{g/L}$) respectively.

The City of Pembroke Pines is required to measure TTHM and HAA quarterly in their finished water at six monitoring locations in the distribution system. These six (6) sampling locations which are representative of the City's entire distribution system are as follows (Table 5-6):

Table 5-6 Standard Monitoring Sites*

Standard Monitoring Site or Monitoring Point (MP)	Stage 2 Compliance Monitoring Location ID	Site Type	Description
MP1	800 NW 217 th Terrace	High TTHM	Represents high water age, at the Southwestern edge of the system
MP2	Fire Station #89-13000 Pine Blvd	Average TTHM and HAA5	Represents average residence time, near the centroid of the City
MP3	901 NW 208 th Ave Rose Price Park	High TTHM and high HAA5	Represents high water age, at the edge of the system
MP4	7500 NW 20 th St. Walnut Creek	High HAA5	Represents low water age, near the WTP
MP5	SW 184 th Ave and Pembroke Rd.	High TTHM	Represents high water age, near the southern perimeter of the system
MP8	20426 SW 54 th Place	High TTHM	Represents highest water age, located at the northwestern edge of the system

* Stage 2 D/DBPR Monitoring Plan, IDSE Plan for the City of Pembroke Pines WTP (2007)

Figure 5-10 shows the monitoring locations in relation to the WTP along with the water storage tanks (Holly and Academic).

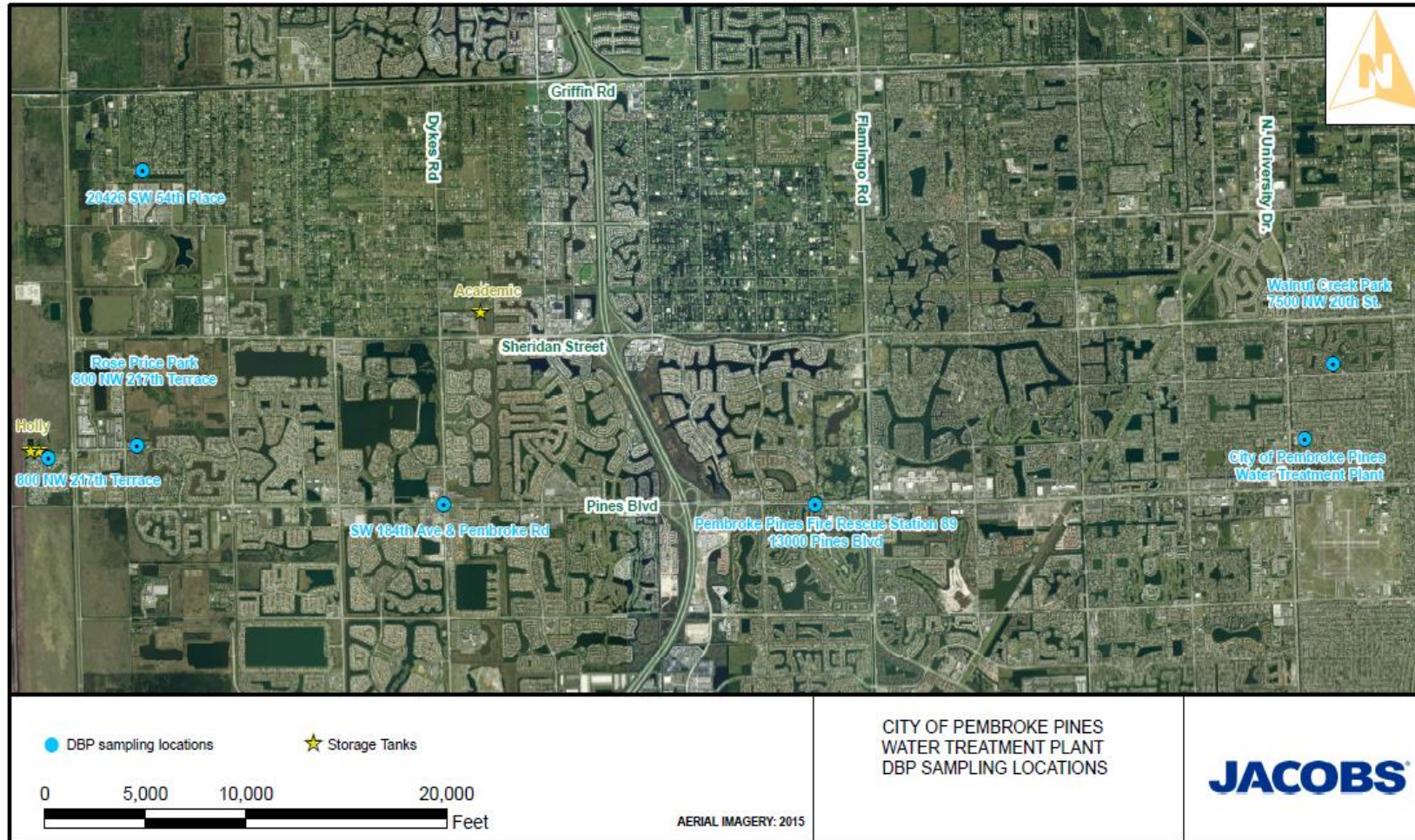


Figure 5-10 Stage 2 DBP Monitoring Points

5.5.1 Review of Historical Data

Figures 5-11 and 5-12 show the TTHM and HAA LRAA values in the distribution system at the six Stage 2 D/DBPR monitoring locations. The graphs also show the prescribed MCLs and the water quality goals for TTHMs and HAAs i.e. 64 ppb and 48 ppb respectively (Table 5-3).

During the fourth calendar quarter of 2016, the MCL for TTHMs and HAA5 was exceeded at three locations i.e. 800 NW 217th Terrace, 901 NW 208th Ave Rose Price Park and 20426 SW 54th Place which are at the extremities of the distribution system (Table 2, Appendix A shows quarterly values). Other locations (e.g. Fire Station # 89-13000; average residence time location) did not depict the same trend. Figures 5-13 through 5-15 show the TTHM and HAA LRAA averages at these three locations.

The LRAA for TTHM at the Rose Price Park location was 88.42 ppb (Figure 5-11). As a result, FDOH-BC determined that the entire system is in violation of the TTHM MCL (FAC, Rule 62-550.500 (7)). The LRAA for HAA5 at all locations were below the MCL (Figure 5-12). Prior to the sampling event i.e. during the fourth calendar of 2016 (sampling date of 11/29/2016), the distribution system went through a maintenance procedure “free chlorine burn” (11/4-11/18, 2016). This maintenance practice could have attributed to the high TTHMs and HAA5 quarterly values observed at *three locations* noted above. In addition, other factors that could have contributed to the increase in DBPs include increases in source water color, finished water color above the water quality goal (Figure 5-7), contributing to an increase in chlorine demand. Finished water color increased due to the ion exchange system being off-line since September 2015 which correlates well with the observed increase in DBP quarterly values.

During the first calendar quarter of 2017, the LRAA exceeded at the Rose Price Park location (92.7 ppb in Figure 5-11). The LRAA for HAA5 at all locations were below the MCL (Figure 5-10). The LRAA for both TTHMs and HAAs incorporating the latest DBP results which include the first and second quarters of 2017 show that LRAA at the Rose Price Park location is decreasing (83.4 ppb in Figure 5-11), and is slightly above the MCL of 80 ppb. The LRAA for HAA5 at all locations are below the MCL (Figure 5-12).

Comparing the LRAA to the water quality goals for TTHMs (64 ppb), it can be observed in Figure 5-11 and 5-12 that these goals were exceeded at the same three locations as above, during the 4th quarter of 2016 and the first quarter of 2017. These locations showed a decrease in LRAA for TTHMs during the second quarter of 2017 (Figure 5-11). At the same locations, the LRAA exceeded the HAA5 goals (48 ppb) starting from second quarter of 2016 but were below the LRAA MCL of 60 ppb (Figure 5-12).

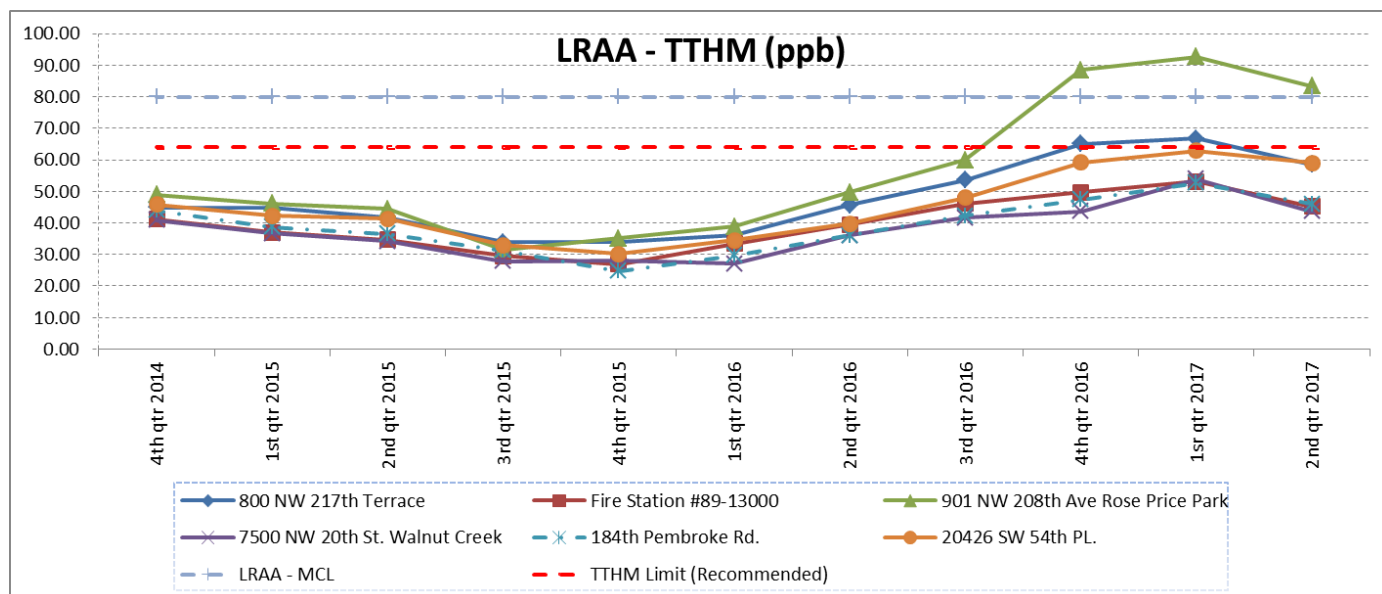


Figure 5-11 Locational Running Annual Average (LRAA) of TTHMs in the distribution system; ion exchange system taken off-line September 1, 2015

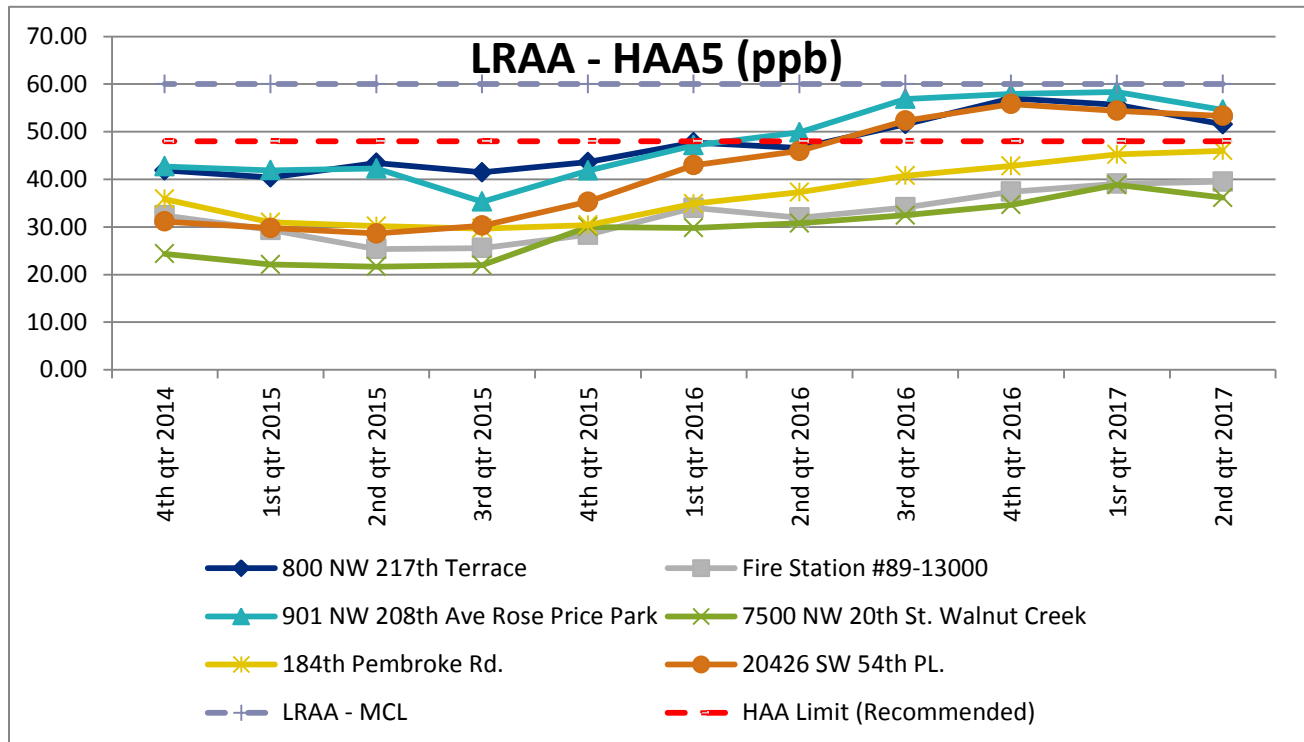
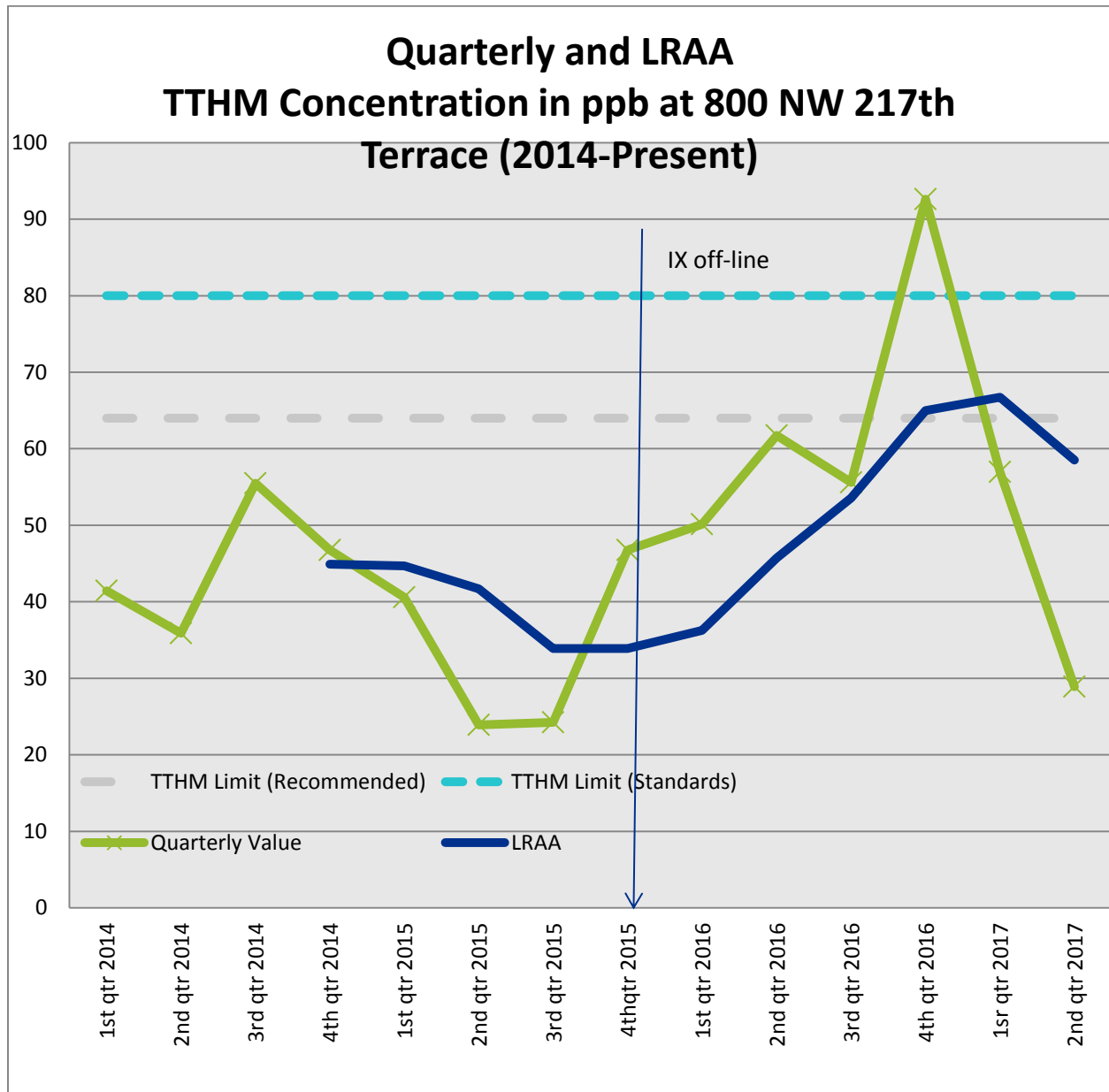


Figure 5-12 Locational Running Annual Average (LRAA) of HAAs in the distribution system; ion exchange system taken off-line September 1, 2015

800 NW 217th Terrace

Figure 5-13 shows the quarterly values and LRAA trends for TTHMs and HAA at this location. These graphs depict clearly an increase in the quarterly value of the TTHM and HAA during November 2016, the effect of the “chlorine burn”. In addition, other factors that could have contributed to the increase in DBPs include increases in source water color, finished water color above the water quality goal (Figure 5-7), contributing to an increase in chlorine demand. Finished water color increased due to the ion exchange system being off-line since September 2015.

Although the TTHM LRAA compliance value increased in the first quarter of 2017, it has decreased in the second quarter of 2017 and is well below the MCL of 80 ppb. The LRAA for the second quarter of 2017 is also below the water quality goal of 64 ppb. The LRAA for HAAs is also below the MCL of 60 ppb but above the water quality goal of 48 ppb.



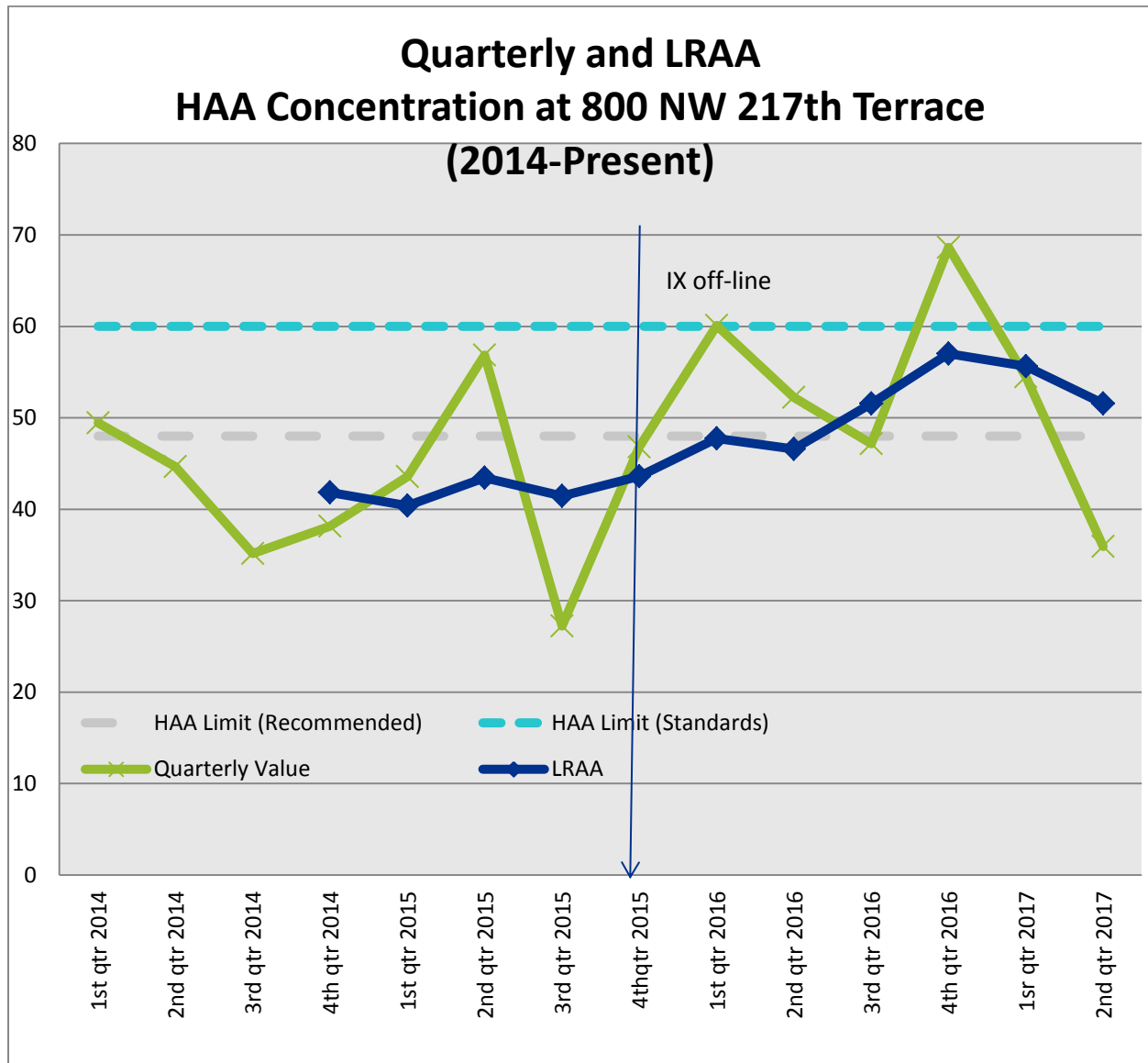
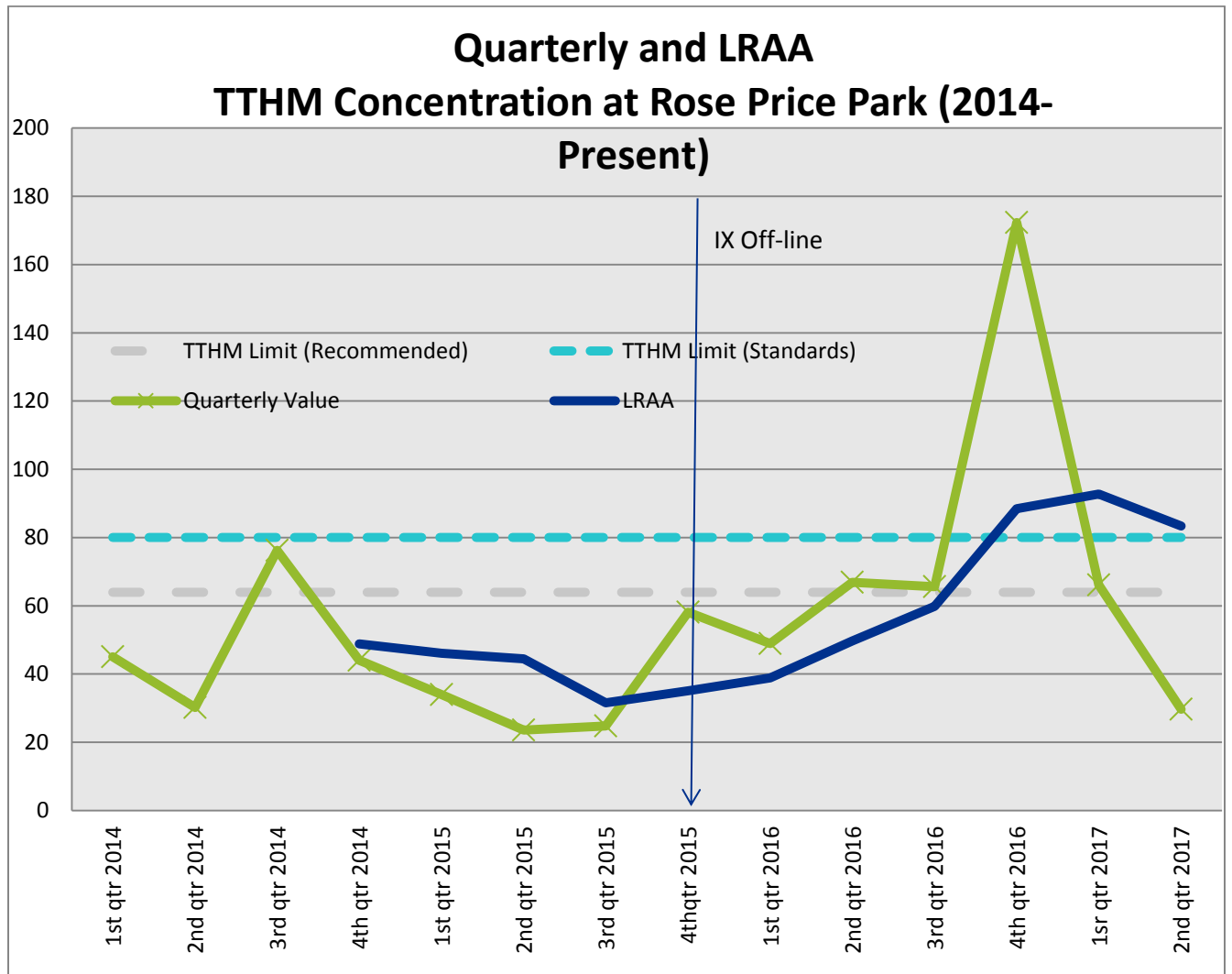


Figure 5-13 Locational Running Annual Average (LRAA) of TTHMS (top) and HAAs (bottom) at 800 NW 217th Terrace Location; ion exchange system taken off-line September 1, 2015

901 NW 208th Ave Rose Price Park

Figure 5-14 shows the quarterly values and LRRA trends for TTHMs and HAA at this location. These graphs depict clearly an increase in the quarterly value of the TTHM and HAA during November 2016, the effect of the “chlorine burn”. In addition, other factors that could have contributed to the increase in DBPs include increases in source water color, finished water color above the water quality goal (Figure 5-7), contributing to an increase in chlorine demand. Finished water color increased due to the ion exchange system being off-line since September 2015.

Although the TTHM LRAA compliance value increased in the first quarter of 2017, it has decreased in the second quarter of 2017 and is slightly above the MCL of 80 ppb. The LRAA for HAAs is also below the MCL of 60 ppb but above the water quality goal of 48 ppb.



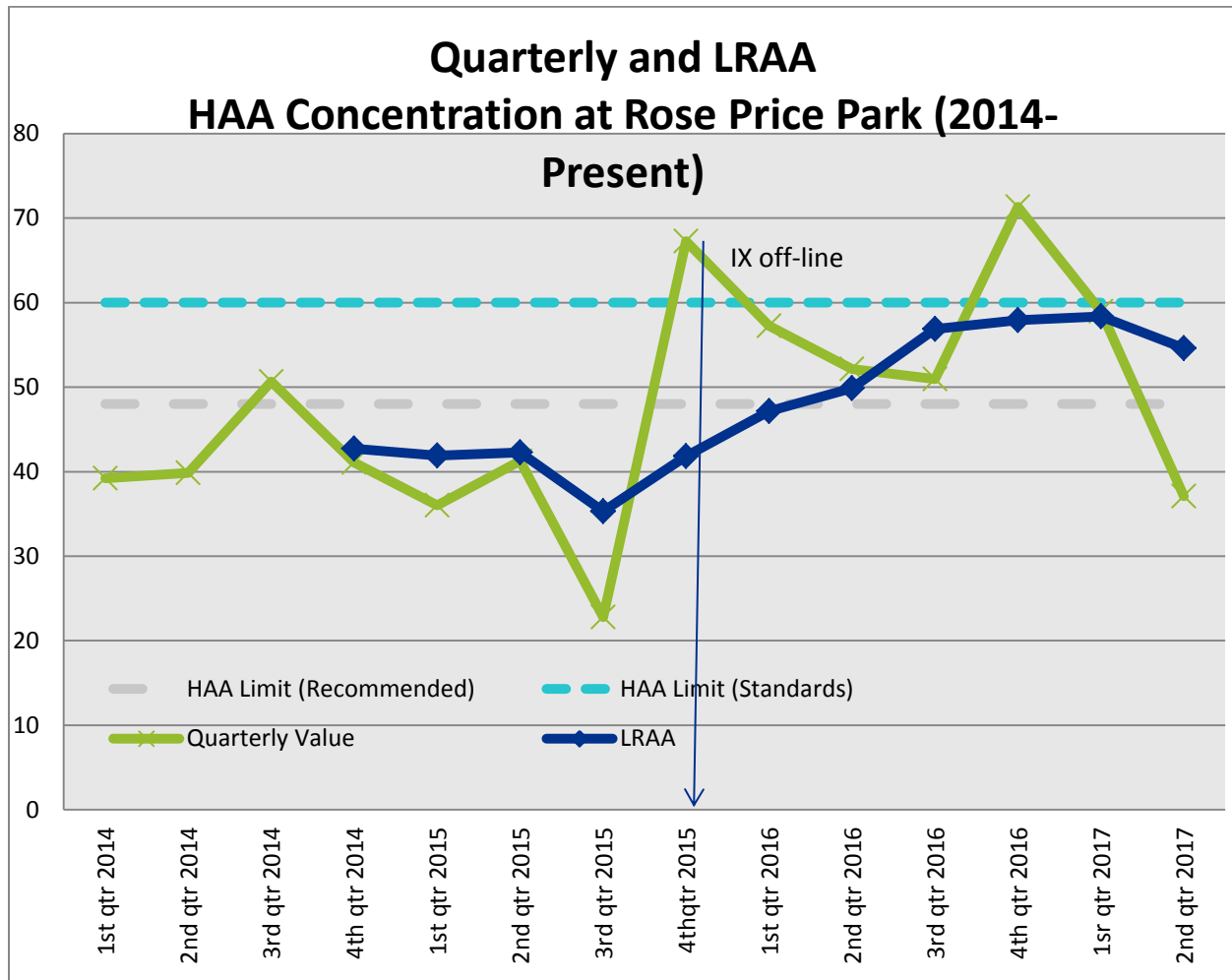
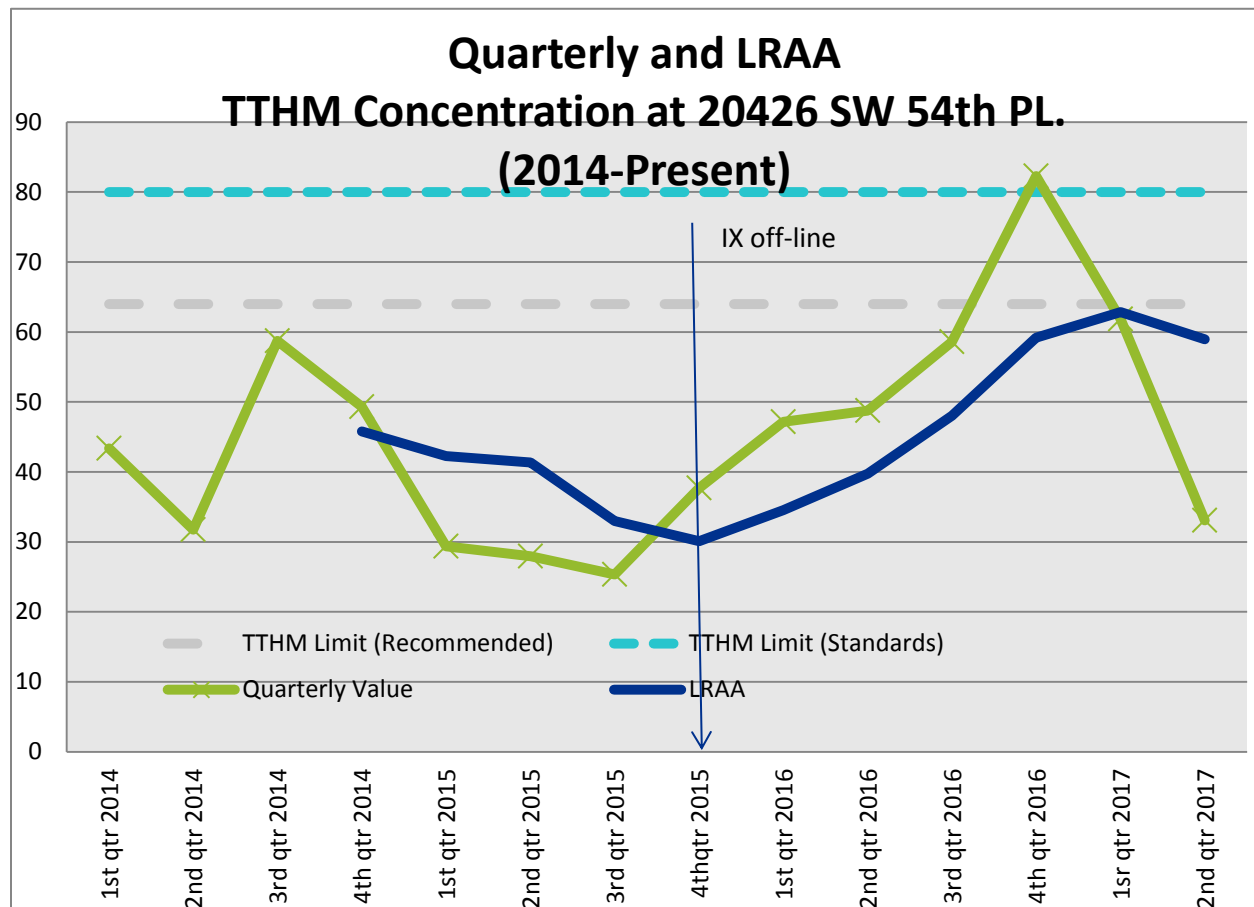


Figure 5-14 Locational Running Annual Average (LRAA) of TTHMs (top) and HAAs (bottom) at Rose Price Park Location; ion exchange system taken off-line September 1, 2015

20426 SW 54th PL

Figure 5-15 shows the quarterly values and LRAA trends for TTHMs and HAA at this location. These graphs depict clearly an increase in the quarterly value of the TTHM and HAA during November 2016, the effect of the “chlorine burn”. In addition, other factors that could have contributed to the increase in DBPs include increases in source water color, finished water color above the water quality goal (Figure 5-7), contributing to an increase in chlorine demand. Finished water color increased due to the ion exchange system being off-line since September 2015.

Although the TTHM LRAA compliance value increased in the first quarter of 2017, it has decreased in the second quarter of 2017 and is well below the MCL of 80 ppb. The LRAA for all the quarters are below the water quality goal of 64 ppb. The LRAA for HAAs is also below the MCL of 60 ppb but above the water quality goal of 48 ppb.



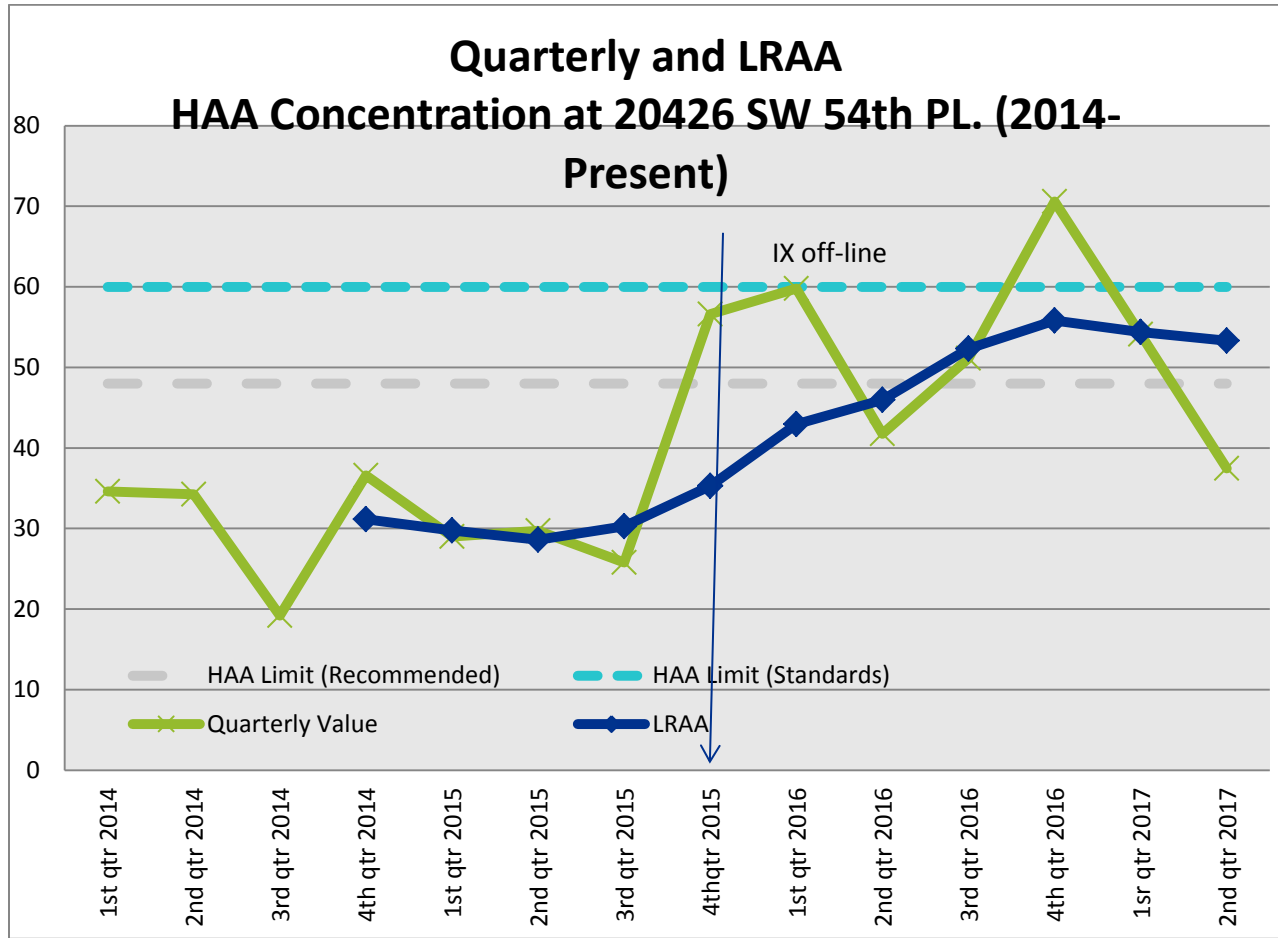


Figure 5-15 Locational Running Annual Average (LRAA) of TTHMs (top) and HAAs (bottom) at 20426 SW 54th PL. Location; ion exchange system taken off-line September 1, 2015

5.5.2 Special Sampling Event

On June 12, 2017, as part of a special sampling event, Jacobs and CH2 staff collected water samples at the six (6) sampling locations which are representative of the City's entire distribution system for analysis of DBPs. The details of the sampling and analysis plan developed by Jacobs are provided in Appendix B. The purpose of this sampling and analysis was to compare the results obtained from two independent laboratories used by Jacobs and CH2.

Jacobs also collected samples of raw and finished water for measuring water quality parameters such as ammonia, TOC, DOC, and UV absorbance. The samples were analyzed by an independent state certified laboratory (Eurofins) utilizing the established EPA methods for DBPs i.e. TTHMs and HAA5. TTHMs were analyzed using EPA Method 524.2 and HAA5 were analyzed using EPA Method 552.2.

In addition to the samples collected by Jacobs, CH2 also collected samples at the same time (split samples), from the same six representative sampling locations and sent them to their independent laboratory for analysis (Pace Analytical). TTHMs and HAA5 were analyzed using same analytical method as Eurofins i.e. EPA Method 524.2 and EPA Method 552.2.

Results of the sampling are shown in Figure 5-16 and Table 5-7. As seen in the Table, pH ranged from 9.23-9.39 in the distribution system and the water temperature ranged from 28.1-30.1 degree C. TOC/DOC in the raw water and finished water were similar and were 10.4 mg/L and 5.5 mg/L respectively with a removal of 47%. SUVA of the raw water was high (4.4 L/mg-m) indicating that the water has high humic content and is amenable for DOC removal by enhanced or optimized coagulation (Table 2-1). Typically, a SUVA value in the 4 to 5 range indicates that the water is high aromaticity, has high molecular weight organics, is associated with a high negative charge and DOC reduction of 50% or greater by enhanced or optimized coagulation is possible.

The total residual chlorine in the finished water was 3.4 mg/L and goal by operations is to maintain it around 4.0 mg/L. The average total chlorine residual in the distribution system was 2.75 mg/L. Chloramine residuals varied from 2.04-3.9 mg/L in the distribution system. Typical chloramine concentrations of 0.2-2 mg/L are found in drinking water supplies where monochloramine has been used as a disinfectant to provide a residual in the distribution system. Free ammonia concentration in the distribution system ranged from 0-0.2 mg/L. The free ammonia was analyzed with an understanding that the presence of a free chlorine residual is false when there is an ammonia residual. Research indicates that free ammonia less than 0.05 mg/L (reported as $\text{NH}_3\text{-N}$) minimizes the potential for nitrification and water quality deterioration.

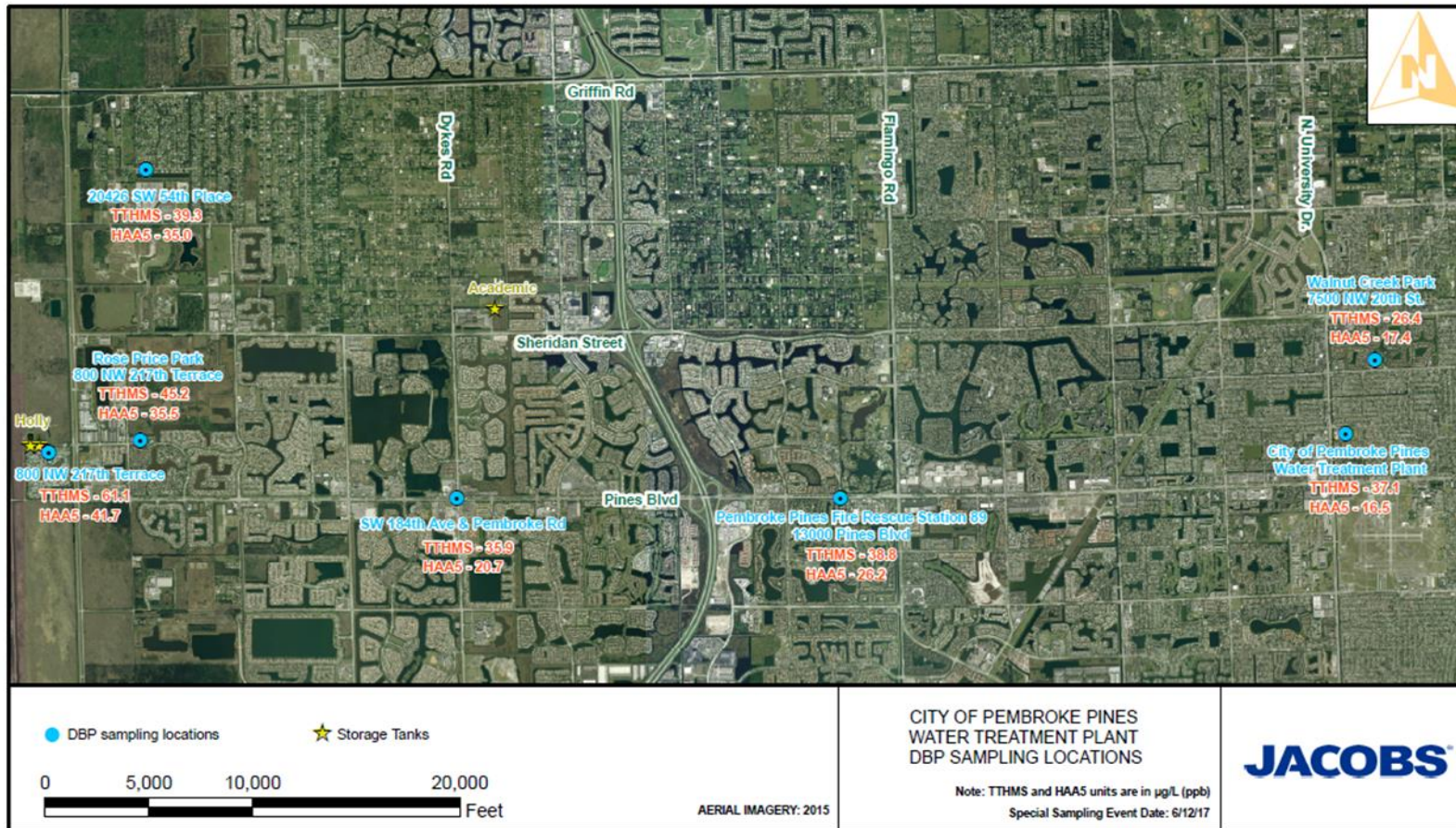


Figure 5-16 DBP Sampling Results at Stage 2 Compliance Monitoring Locations (Samples collected on 6-12-17)

Table 5-7. Water Quality Analyses at the WTP and Distribution System

WATER QUALITY ANALYSES AT THE WTP AND DISTRIBUTION SYSTEM								
Sampling Date 6/12/17	Location							
Water Quality Parameter	Raw Water in the WTP	Finished Water in the WTP	800 NW 217 th Terrace	Fire Station #89-13000 Pines Boulevard	901 NW 208 th Ave Rose Price Park	7500 NW 20 th St. Walnut Creek	SW 184 th Avenue & Pembroke Rd	20426 SW 54 th Place
pH	7.48	9.61	9.39	9.3	9.28	9.3	9.23	9.35
Temperature (°C)	25.3	26.5	28.9	29.2	30.1	28.1	29.6	29.5
Turbidity (NTU)	0.19	0.26	NA	NA	NA	NA	NA	NA
Color (pcu)	65	17	NA	NA	NA	NA	NA	NA
TOC (mg/L)	10.4	5.5	NA	NA	NA	NA	NA	NA
DOC (mg/L)	10.4	5.5	NA	NA	NA	NA	NA	NA
UV ₂₅₄ (cm ⁻¹)	0.456	0.183	NA	NA	NA	NA	NA	NA
SUVA (L/mg-m)	4.38	3.32	NA	NA	NA	NA	NA	NA
Alkalinity (mg/L as CaCO ₃)	243	43	NA	NA	NA	NA	NA	NA
Hardness (mg/L as CaCO ₃)	241	67	NA	NA	NA	NA	NA	NA
Total Iron (mg/L)	1.25	0.09	NA	NA	NA	NA	NA	NA
Ammonia-N (mg/l)	1	0.6	NA	NA	NA	NA	NA	NA
Total Chlorine Residual (mg/L)	NA	3.4	3	2.1	2.7	3.4	2.8	2.5
Free Chlorine Residual (mg/L)	NA	0.21	0.13	0.23	0.13	0.37	0.36	0.21
Chloramine Residual/Free Ammonia (mg/L)	NA	3.27/0.023	3.8/0.0	2.04/0.11	3.90/0.01	3.13/0.09	3.58/0.15	2.40/0.20
TTHMs (ppb)	NA	37.1	61.1	38.8	45.2	26.4	35.9	39.3
HAA5 (ppb)	NA	16.5	41.7	26.2	35.5	17.4	20.7	35
On Site- Measurements by CH2								
Eurofins-Jacobs contracted Lab								
NA-Not Applicable								

Figures 5-17 and 5-18 are a comparison of the TTHMs and HAA-5 values obtained from the two laboratories i.e. Eurofins and Pace Analytical. Both TTHMs and HAA were below the MCL at all locations. The highest TTHM was observed at the 800 NW 217th Terrace (61.1 ppb by Eurofins and 67.1 by Pace). The result by Pace is slightly higher than the water quality goal of 64 ppb (dashed line). The highest HAA5 was also observed at the same location and was lower than the water quality goal of 48 ppb as measured by both laboratories. This location represents high water age and is at the Southwestern edge of the system. It is also next to the storage tanks (Holly) and may be indicative of poor mixing in the storage tanks.

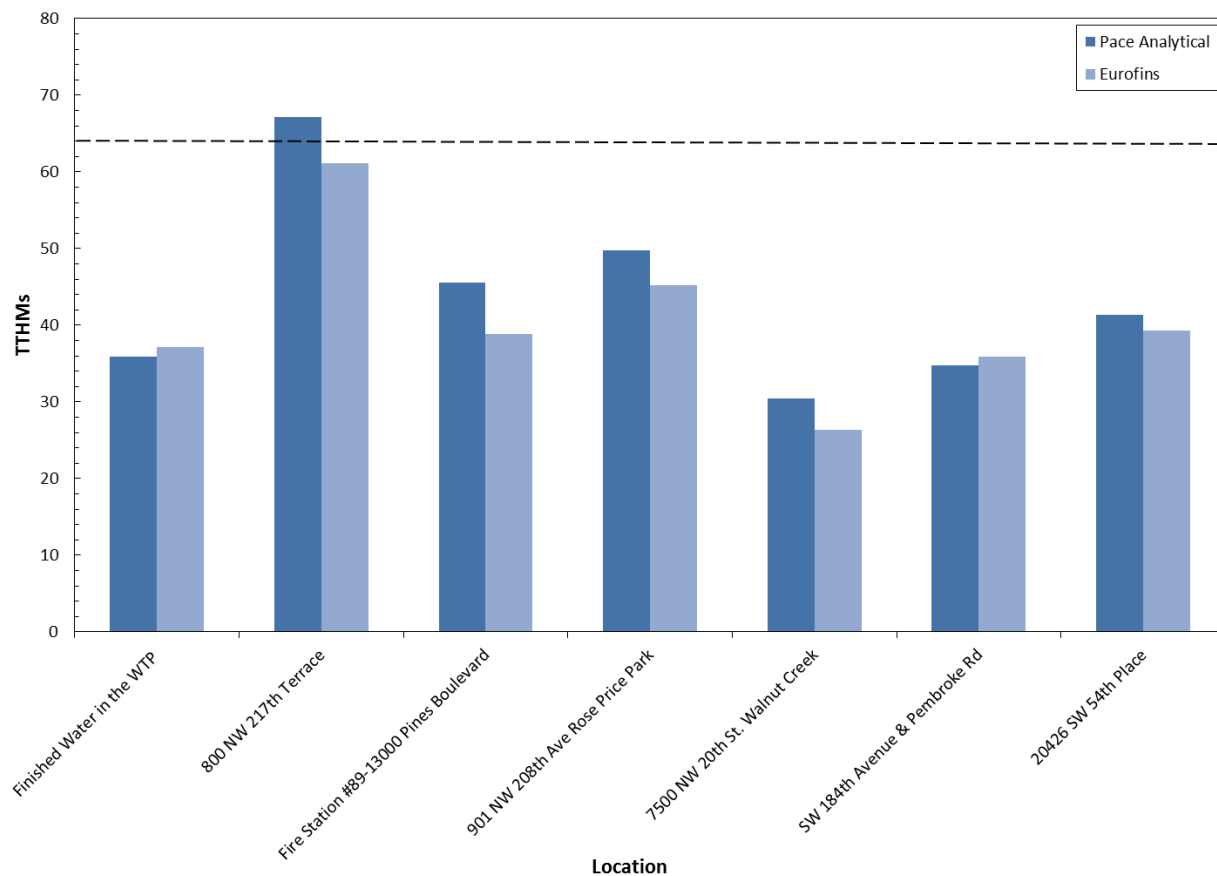


Figure 5-17. TTHMs as measured by Eurofins and Pace Analytical in the distribution system and finished water.

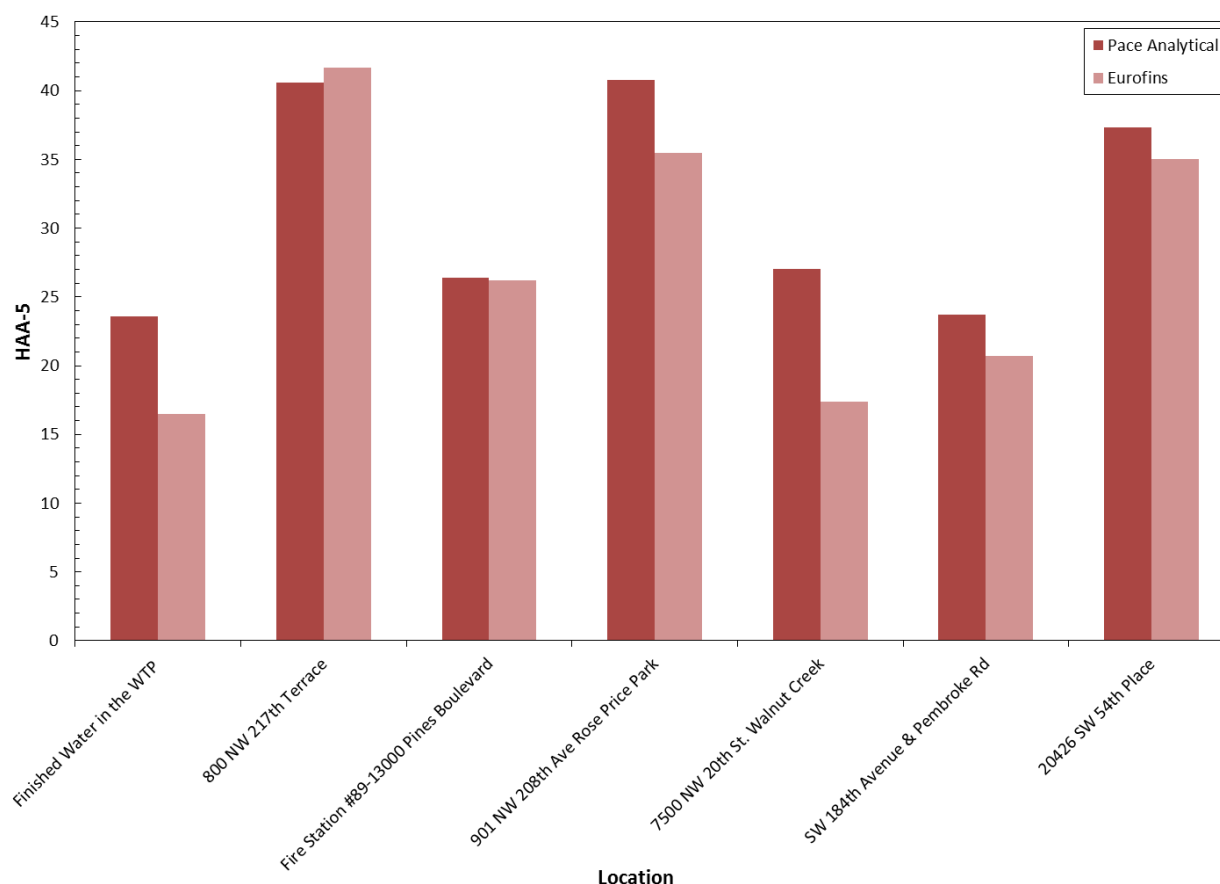


Figure 5-18. HAA-5 as measured by Eurofins and Pace Analytical in the distribution systems and the finished water

Figure 5-19 shows the percentage difference in the measurements of DBPs as measured by the two laboratories. The percentage difference in TTHM measurements varied between 3-16% whereas for HAA-5 it varied from 1-43%. The DBP values reported by Eurofins are generally lower than the values reported by Pace Analytical. The difference in values could be due to differences in sample handling, preservation and shipping (QA/QC) adopted by CH2 and Jacobs. The large total HAA5 differences might be due to:

- Differences in dichloroacetic acid between the two laboratories
- Pace Analytical had higher surrogate recoveries associated with the two samples that demonstrated larger differences.
- Pace Analytical showed high 21% percentage difference for one pair of matrix spike/matrix spike duplicate (MS/MSD) of which MS had a recovery of 144%.
- Eurofins Analytical Inc. used an internal standard for quantitation. It is not clear if Pace Analytical also used an internal standard technique. Eurofins's internal standards were well within the recovery acceptance criteria.

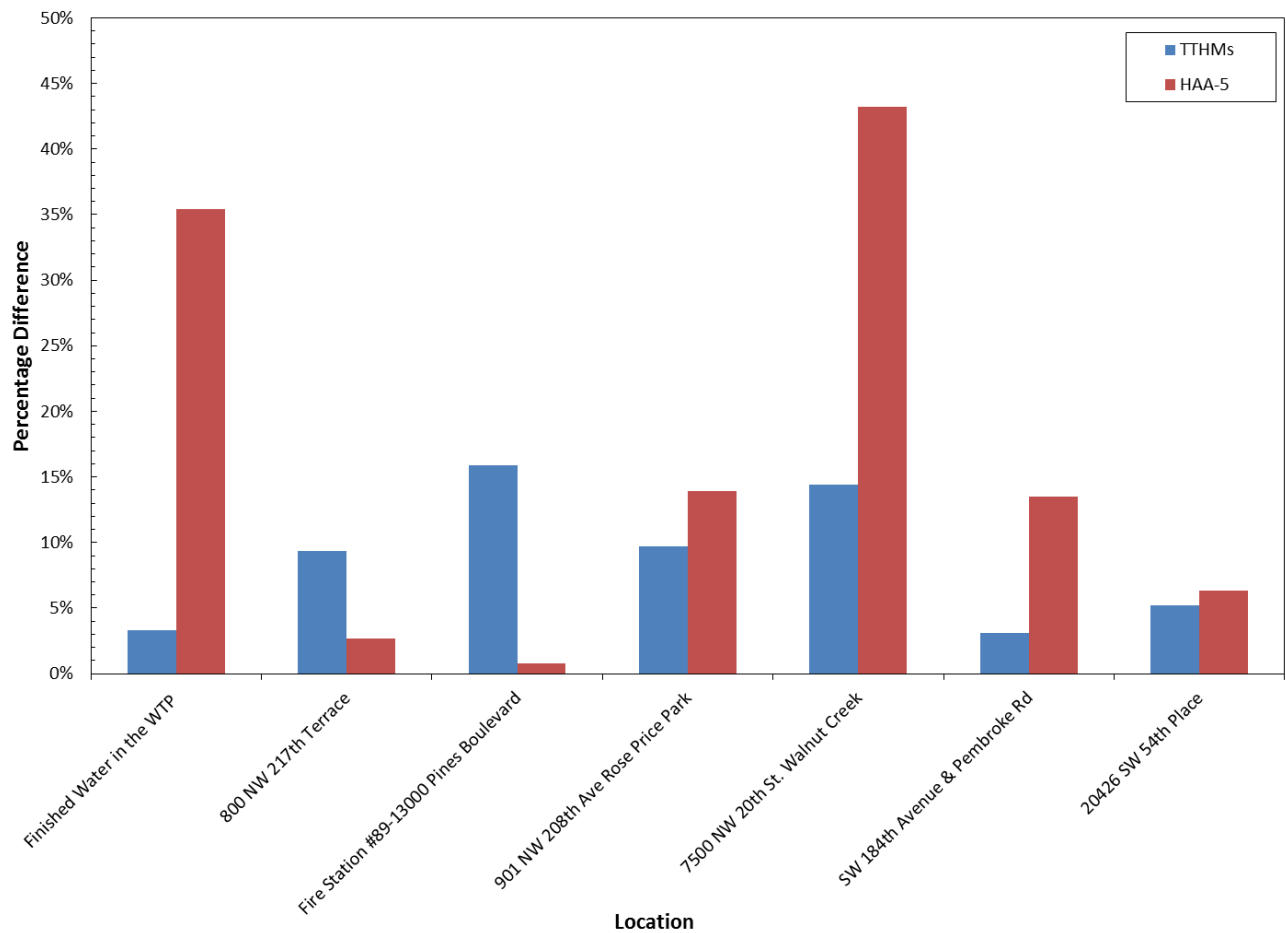


Figure 5-19. Percentage Difference in the measurements of DBPs as measured by Eurofins and Pace Analytical

5.6 Summary

In summary, the quarterly values for TTHMs and HAA5 exceeded the MCL at three locations i.e. 800 NW 217th Terrace, 901 NW 208th Ave Rose Price Park and 20426 SW 54th Place during the fourth calendar quarter of 2016, right after the distribution system went through a maintenance procedure i.e. “free chlorine burn”.

The Rose Price Park location had the highest TTHM and HAA concentrations during the 4th quarter of 2016. Despite the increase in quarterly values at these locations, only the Rose Price Park location had an LRAA value for TTHMs that exceeded the regulatory MCL of 80 ppb. The LRAA for HAA5 were below the regulatory limit at all the six locations. Most recent monitoring data shows that at the Rose Price Park location, TTHM LRAA compliance value decreased and was slightly above the MCL of 80 ppb. The LRAA for HAAs is also below the MCL of 60 ppb but above the water quality goal of 48 ppb. The current TTHM values show that at all the remaining five (5) locations the LRAA for TTHMs is not only below the MCL of 80 ppb but is also below the water quality goal of 64 ppb. The current HAA5 values show that at all the six (6) locations the LRAA is below the MCL of 60 ppb. Only at the three (3) locations noted above, the LRAA for HAA5 is above the water quality goal of 48 ppb.

Historically, these locations have not experienced any TTHM or HAA exceedances up until November 2016 and the DBPs LRAA were within regulatory limits and in compliance with Stage 2 D/DBPR requirements for TTHMs and HAAs. This maintenance practice of flushing the system with chlorine (free chlorine burn) appears to have attributed to the high TTHMs and HAA5 observed at these three locations. In addition, other factors that could have contributed to the increase in DBPs include increases in source water color, finished water color above the water quality goal, contributing to an increase in chlorine demand. Finished water color has increased due to the ion exchange system being off-line (since September 2015) which correlates well with the observed increase in DBP quarterly values. Another factor that could have contributed to the increase in DBPs is their location i.e. these monitoring sites are located in the extremities of the distribution system (dead-end). High water age contributes to an increase in DBPs.

On June 12, 2017, as part of a special sampling event, Jacobs and CH2 staff collected water samples at the six (6) sampling locations which are representative of the City's entire distribution system for analysis of DBPs. The results of the sampling event showed that the DBPs were below the MCL at all of the six (6) sampling locations. TOC/DOC in the raw water and finished water were similar and were 10.4 mg/L and 5.5 mg/L respectively with a removal of 47%. SUVA of the raw water was high (4.4 L/mg-m) indicating that the water has high humic content and is amenable for DOC removal by enhanced or optimized coagulation.

6. Control Measures to Minimize DBPs

This Section presents several control measures to minimize DBPs in the City's distribution system. Offered herein are a screening of several treatment and potential operational changes with an associated discussion on the merit of each alternative to achieve the City's goal to gain TTHM compliance in the most cost effective manner in as short of a duration as possible. In addition, we have offered some longer term considerations and recommendations as well.

6.1 Overview of Control Measures

Disinfection by-product (DBP) formation is influenced by several factors such as pH, organics (color, TOC) and inorganics (e.g. bromide, ammonia), chlorine residual and contact time, which are thus considered as the key parameters in controlling DBP formation. Temperature is another key parameter that impacts DBP formation, however it is impractical to control it. The highest water temperatures occur in the summer months i.e. mid-July to mid-September and the DBPs are generally higher than other parts of the year. The water quality analysis in Section 5 showed that the primary factors that contributed to excessive TTHM formation in the distribution system:

- pH
- precursors (Color, TOC)
- Chlorine residual

The bromide content of the source water is not known at this time. The level of bromide in the raw water impacts the rate and amount of THM formation in the finished water (e.g. brominated DBPs such as bromoform). The presence of ammonia in the source water increases the complexity of water treatment and distribution system operation as well as it exerts a huge chlorine demand. To remove 1 mg/L of ammonia, about 8-11 mg/L of chlorine is needed.

Three basic control measures are available to minimize DBPs:

- 1) Use an alternative source, treat the source, or minimize using the raw water source with problematic water quality.
- 2) Control DBP formation in the treatment plant.
- 3) Control DBPs in the distribution system.

Each of these control measures is described briefly here.

6.1.1 Alternative Source or Minimize Use of Source with Problematic Water Quality

The shallow Biscayne Aquifer is the sole source of drinking water for the City of Pembroke Pines as well as most of Broward County. It is our understanding that the City will continue to utilize the Biscayne Aquifer and is expected to continue using it in the foreseeable future, through buildout.

There are limited options for the City to use other sources (e.g. groundwater) or consider blending with a source that has better water quality. The Floridian Aquifer, which lies some 1,500 feet below the surface, is another potential source of water, and could be investigated in the future for full potential.

Increases in source water color have been observed since summer of 2015 (Figure 5-6). This increase could be due to using wells with poor water quality. In the near term, the City should maximize the withdrawal from wells that have high quality of water and minimize the use of wells that have poor water quality. As Wells #3 and #5

have poor water quality (high iron, color, TOC and free ammonia), withdrawal from these wells should be minimized to the extent possible.

Practical control measures available for the City include control measures in the treatment plant and the distribution system.

6.1.2 Control DBP formation in the plant

Several alternatives are available in the treatment plant to reduce the DBP precursors and these include:

- Optimizing Treatment Plant Operations
- Installing New Treatment Technologies

Optimizing Treatment Plant Operations

A review of previous reports and water quality indicates that potential options for reducing the DBPs include:

- Enhanced Coagulation
- Enhanced Softening
- Optimizing Finished Water Quality

Enhanced Coagulation: Enhanced coagulation is defined by US EPA as the addition of excess coagulant to improve removal of TOC. Enhanced coagulation with a coagulant (e.g. alum, ferric chloride, ferric sulfate, etc.) and polymer are very effective in reducing TTHM concentrations as they remove the DBP precursors (i.e. TOC, DOC, and color).

Bench-scale studies have been conducted in the past with various coagulants (Aluminum Chlorohydrate (ACH), Polyaluminum chloride (PACL), ferric chloride with anionic polymer-clarifloc A-3333P) to evaluate color removal performance (City of Pembroke Pines WTP, Jar Test Results and Cost Analysis for Color removal in the Clarifiers, CH2M, December, 2015). The bench-testing results showed that coagulant addition with the current operating conditions improved color removal by 70% and 84% reduction in turbidity. However, the study concluded that addition of a coagulant may or may not be as cost-efficient as operating the ion exchange units.

Following this bench-scale study, a six (6) month pilot study was conducted to evaluate true color and turbidity reduction and the associated chemical costs (Pembroke Pines, Aluminum Chlorohydrate Pilot Summary Report, CH2, 2016). ACH was added to a single clarifier to evaluate the effect of the coagulant. Although the addition of ACH reduced iron and discolored water complaints, apparent color was not reduced, and true color was only reduced by 2 color units. As a result, ACH was determined to be an inefficient coagulant and a decision was made to use only lime and polymer and not use any coagulant in the Accelerators.

The special sampling event revealed that the SUVA of the raw water was high (4.4 L/mg-m) indicating that the water has high humic content and is amenable for DOC removal by enhanced or optimized coagulation. In the above studies, coagulant was added along with lime and polymer all at the same time, which leads to potential interactions and changes in water chemistry (e.g. pH) negating the beneficial effects of each chemical. Also, in the pilot studies ACH produced a small pin floc in the clarifier and it was attributed to poor rapid mixing. It is recommended that bench and pilot studies be conducted with coagulant and a cationic polymer addition with proper mixing, at raw water pH and allowing a time lag of at least 5 minutes prior to the addition of lime and anionic polymer to observe the benefits of these chemicals.

Enhanced Softening: Precursor (color, TOC) removal can be increased by increasing the lime dosage and pH (10.0-11.0). Also, conversion of ammonia into the gas form occurs around pH 9.0. Although lime softening does not remove precursors as effectively as high dosages of coagulants, its effectiveness is similar to that observed using relatively low dosages of coagulants. There are important practical considerations in significantly increasing the lime dosage at the WTP. If the carbonate alkalinity is exhausted, addition of soda ash or caustic soda may be necessary for proper treatment, resulting in increased chemical costs and a higher sodium level in the finished water. Production of residuals might also increase and increased chemical dosages may be required to properly stabilize the water. Primary concern would be the rapid formation of TTHMs in a high pH environment.

Optimizing Finished Water Quality: As shown in Table 5-4 and Figure 5-6 (Section 5) total chlorine residual varies significantly, since summer of 2016. Amongst other factors, DBP formation is influenced by pH, chlorine dose, chlorine residual and contact time. In general, THM formation increases as pH increases and HAA formation increases as pH decreases. Compliance with the MCL for THMs is especially difficult for WTPs, such as Pembroke Pines WTP, that practice precipitative softening, as THM formation is very rapid in a high pH environment (pH=9-10). As such, optimizing chlorine dosages and the finished water pH will be critical to control DBP formation in the distribution system. Such optimization in pH and treatment changes should also consider and evaluate the potential effects on the corrosivity of the treated water and the need for corrosion control.

The City is in the process of rehabilitating its ion exchange units and converting from gas chlorine to liquid sodium hypochlorite. The City will be also adding a carbon dioxide system to adjust pH. If carbon dioxide were to be added prior to the filters, it will dissolve any precipitated calcium eliminating the need for polyphosphate addition prior to the filters. Polyphosphate, when broken down acts as a key nutrient for bacteria growing on the filters in the ion exchange process. The elimination of addition of polyphosphate prior to filtration will minimize bacterial activity in the filters and ion exchange process. The point of application of phosphate-based corrosion control treatment chemical (e.g. orthophosphate) should be moved downstream, where it can be added to the finished water as a corrosion inhibitor and stabilize the water quality.

Installing New Treatment Technologies

The first step to take in reducing DBP formation is optimizing current treatment plant operations. It is anticipated that City will put the ion exchange process in service by July, 2017. This should help in reducing the DBPs by reducing the precursors (color, TOC) in the raw water. A color reduction of 23% and a 39% reduction in TTHMs with less than half the water being treated by the ion exchange system has been observed in the past (Cost effective Color removal for South Florida Drinking Water, Kennedy, K, WQTC, 2004).

In the future, the City may wish to consider a new treatment technology that will significantly reduce TOC in the source water to minimize DBP formation. An ion exchange approach that has recently attracted attention for its DOC removal capabilities, relatively low cost, and small footprint is the proprietary Magnetic Ion Exchange (MIEX) process, under patent by Orica Watercare of Australia. MIEX has been shown to be particularly effective at DOC removal. The MIEX process is a continuous ion exchange process using a patented magnetized ion exchange resin designed for DOC removal from drinking water supplies. In this process, negatively charged DOC is exchanged with chloride ions on the MIEX resin surface, with resin particles suspended in a continuously stirred tank reactor. MIEX systems use smaller resin beads than conventional ion exchange resin beads, and include a magnetic component dispersed within the resin particles. The magnetic component allows the resin to rapidly settle into large, fast settling particles, increasing resin recovery rates and reducing recovery times. The majority (90 – 95%) of settled resin is recycled back to the contactor as a concentrated suspension, with the remainder continuously diverted to a resin regeneration system. The resin which is removed for regeneration, and resin lost due to carryover from the separator, is replaced by fresh resin. Regeneration is achieved by contacting spent resin with concentrated brine solution. Adsorbed molecules on the spent resin are replaced by chloride ions, and the previously adsorbed molecules are released into the brine solution for disposal. MIEX processes have been shown to reduce DOC concentrations by as much as 70% in municipal drinking water applications.

Several potential treatment technologies with their merits, demerits and a qualitative comparison of the lifecycle costs are shown in the Table below.

Table 6-1. Merits, Demerits and Life-cycle Costs of Various Alternatives

Number	Alternative	Merits	Demerits	Lifecycle Costs
1	Reverse Osmosis Membranes (RO)	Excellent removal of dissolved ions including color, ammonia, DOC and hardness	Expensive Reject water disposal issues Membrane Fouling	\$\$\$\$\$
2	Nanofiltration (NF)	Good for softening, removal of color and DOC	Expensive Reject water disposal issues Membrane Fouling	\$\$\$\$
3	Magnetic Ion Exchange (MIEX)	Good removal of color and DOC, small footprint	Waste stream disposal issues; resin regeneration	\$\$\$
4	Granular Activated Carbon (GAC)	Good removal of color and DOC, synthetic and trace organics	Regeneration frequency can be significant	\$\$

In a general sense, MIEX and membranes have higher life-cycle costs than GAC (Roy, A. 2010). While high pressure membranes such as nanofiltration or reverse osmosis are the most effective method of removing DOC from water, membrane technology is a very expensive treatment option. Membranes, such as reverse osmosis or nanofiltration, would also require high-pressure pumps, adding significant electrical power costs and requiring additional electrical infrastructure to support the additional horsepower. In addition, membranes would produce a high salinity waste stream that would have to be disposed of. Finally, membrane operations require specialized skills and training that would add to plant operational costs. MIEX resin was also not considered further because the resin must be regenerated with salt brine. This produces a high salinity waste stream that would have to be disposed of. Also, as the WTP has an ion exchange process for color and DOC removal, MIEX process is not recommended at this time.

Granular Activated Carbon (GAC) is a highly macroporous and regenerable filter media specially designed for purification of drinking water and is a proven treatment technology that is effective for the removal of DOC and TTHMs. It also provides a treatment barrier for taste and odor compounds, TTHMs, volatile organic compounds, synthetic and trace organics. The disadvantage of GAC is that continuous replacement of the GAC is necessary (e.g. 3-5 years) because organics (DOC) present in the source water rapidly consumes the adsorptive capacity of the GAC.

GAC filters when operated in a biological mode are very effective for the removal of ammonia, DOC and emerging contaminants. Biological growth occurs on the GAC filters with bacteria consuming the biodegradable organic carbon further reducing the DOC of the water. Ammonia is removed through biological treatment by the microbial oxidation of ammonia to nitrite by ammonia oxidizing bacteria (AOB) followed by oxidation of nitrite to nitrate by nitrite oxidizing bacteria (NOB). The goal is convert ammonia to nitrate that has an MCL of 10 mg/L as N. Biological treatment can be a cost-effective solution for high concentrations of ammonia, up to 1.96 mg/L of ammonia has been observed in the source water (City of Pembroke Pines WTP, Technical and Compliance

Audit, CH2M, 2015). Also, replacement frequency of GAC is considerably reduced when operated in biological mode. If ammonia is removed effectively in the treatment process, the City has the ability to convert potentially to 4-log virus treatment to comply with GWR which provides for a more reliable disinfection strategy and more straightforward monitoring and controls. However, biological treatment may present regulatory or/and public acceptance challenges for implementation.

Alternative disinfectants such as chlorine dioxide, ozone and ultraviolet (UV) light are not recommended at this time as they have several disadvantages; they require secondary disinfection, produce their own DBPs (e.g. chlorite with chlorine dioxide, bromate with ozone) and are complex to operate.

6.1.3 Control DBPs in the Distribution System

As noted earlier, DBP formation is influenced by several factors, such as TOC in the treated water, ammonia, temperature, pH, and chlorine residual and contact time, which need to be optimized. Hence, optimizing DBPs can be a challenging for utilities, considering that there are several variables impacting DBP formation. The combination of optimized treatment and finished water quality might provide for substantial reduction of TTHMs in the distribution system. However, other strategies might need to be incorporated in the management of the distribution system to mitigate the DBPs. Also, there is the need for utilities to simultaneously comply with multiple distribution system regulations. There are several best management practices (BMPs) recommended by the American Water Works Association (AWWA) in their publication *BMPs for Maintaining Water Quality in the Distribution System*, AWWA, (2001). BMPs include:

- Minimizing water age
- Flushing
- Decentralized Treatment

Minimizing Water Age and Flushing

Water age refers to the time it takes for water to travel from source to consumers. Water age is a hydraulic parameter that depends on flow velocities and pipe lengths in the distribution system. Water age is also a general indicator of water quality. Excessive water age can reduce the residual disinfectant concentration as chlorine or reacts with organic material in the water and on the pipe walls. Lower water age indicates better water quality. The average water age in the City's distribution system appears to be one (1) day (CH2-personal communication). TTHM concentrations increase with water age. HAA5 concentrations increase with age to a certain level, after which biological activity lowers concentrations. As seen in Figure 5-9 and 5-10, DBP quarterly values increased at the three locations i.e. 800 NW 217th Terrace, 901 NW 208th Ave Rose Price Park and 20426 SW 54th Place. These locations are at the extremities of the distribution system (high water age).

Reducing the water age in the City's distribution system would reduce the concentration of DBPs observed at the various monitoring locations. Water age can be reduced by improved mixing and reducing the detention time in finished water storage tanks, eliminating dead ends with pipe looping, optimizing the water velocity in large pipe sections, and proper valve management. Unidirectional flushing as recommended by the AWWA and increasing the frequency of flushing helps in lowering the water age and can reduce DBPs.

Long runs of pipe combined with low usage rates combine to extend water age in the distribution system. Since pipe lengths and usage rates are inherent characteristics of the system, these cannot typically be changed without excessive costs. However, water usage can be artificially accelerated by flushing the water lines on a routine basis at fire hydrants or blow-down valves. Areas of the distribution system that show elevated water age should be considered for routine flushing. Flushing is a maintenance activity and does not require the addition of capital equipment. Any flushing program must consider the flushing velocities imposed on the lines being flushed to ensure adequate velocity to remove not only old water but also accumulated sediment and rust, both of which can also contribute to the continued formation of DBPs.

The need for distribution system improvements should be evaluated through a computer hydraulic model analysis of the distribution system, which would show where long detention times could lead to DBP formation. The results of this modelling could discover areas of “dead-end” pipe (which should be abandoned or flushed), indicate where valves may have been left closed impeding system circulation, or identify areas where oversized water mains may be contributing to extended reaction times, or indicate where storage tank stratification may be occurring. Knowing the areas of extended reaction times could guide a flushing program, indicate areas where valve and/or pipe improvements need to be made, show where replacing or lining old and corroded lines or replacing oversized mains may be required, or indicate where tank mixing may be appropriate. A hydraulic model may also show where low chlorine residual may be expected to occur and aid in the design of chlorine booster systems. In the event DBPs continue to be an issue, the City should evaluate decentralized treatment such as air stripping.

Decentralized Treatment

Treatment options available in the distribution system are air stripping by aeration and installing mechanical mixers in finished water storage tanks. Aeration is an appropriate solution for localized TTHM reduction.

Mechanical mixing can be employed in the storage tanks to reduce DBPs. There are three (3) storage tanks located in the distribution system i.e. Academic storage tank (2.3 MG capacity) located in the north side of the distribution system and Holly tanks (2 tanks each 2.1 MG capacity) on the west side of the distribution system. Several alternatives are available; bubble aerators, surface aerators and spray aerators. About 50%-60% reduction in 24 hours is possible with surface aerators when chloroform is the predominant form of TTHMs (>50%). Based on historical TTHM data, chloroform concentration is the predominant form of TTHMs in the City's distribution system, approximately eighty five percent (> 85%) or more of the total THMs. Hence, mechanical mixing will likely remove a significant portion of the TTHMs.

As an alternative to treating the entire flow at a centralized facility, many utilities are considering treating only a partial flow in the distribution system with air stripping to be in compliance with the Stage 2 D/DBPR requirements. Over the years, the cost of the centralized treatment (e.g. optimized coagulation, ion exchange, GAC, membranes) gets expensive and is not effective at reducing TTHM levels at distant locations within the water distribution system. Localized or decentralized treatment at the point of non-compliance is a cost-effective option as only the flow that is necessary is treated, to be in compliance with regulations.

Air strippers remove volatile organic chemicals (VOCs) from liquid (water) by providing contact between the liquid and gas (air). The gas (air) may then be released to the atmosphere or treated to remove the volatile organic compounds (VOCs) and subsequently released to the atmosphere. In general, the removal efficiency of air stripping for THMs is as follows:

Chloroform>Bromodichloromethane>Dibromochloromethane>Bromoform

As chloroform is the predominant form of the TTHMs in the City's distribution system (> 85%), packed aeration towers will likely remove a significant portion of the TTHMs (Mysore, C. 2013).

6.2 Summary

In summary, the City may need to implement some or several strategies to minimize DBPs in the finished water. These include:

- Optimizing Source Water Quality
 - Minimize withdrawal from wells (#3 and #5) with poor water quality
- Optimizing Treatment Plant Operations
 - Use Ion exchange process at all times and at the full design capacity
 - Optimize Finished Water Quality (pH, chlorine dose/residual)
- Implement BMPs in the distribution system
 - Minimizing water age and flushing
 - Add mixers in storage tanks

The City should implement the above strategies to minimize the DBPs in the distribution system. In the event DBPs continue to be an issue, the City should evaluate the following strategies:

- a) Adding an aeration-detention basin at the head of the plant which will reduce the iron
- b) Retrofit GAC in existing filters i.e. replace anthracite media with GAC
- c) Operate filters with GAC in biological mode to reduce DOC and convert ammonia to nitrate (intentional nitrification)
- d) Consider decentralized treatment in the distribution system such as air stripping.

Regardless of the treatment option chosen, treatability studies will be necessary for predicting system performance, developing design criteria and validating the process. It is strongly recommended that the City pilot the chosen technology. A small-scale pilot could help determine the effectiveness of the technology with respect to DBP reduction and address other water quality concerns such as iron and ammonia.

7. SUMMARY AND RECOMMENDATIONS

The City of Pembroke Pines WTP uses Biscayne Aquifer as its source water and has a rated capacity of 18.0 MGD. The treatment process at the WTP is comprised of lime softening, filtration, ion exchange and disinfection with chloramine (chlorine and ammonia). Chloramines also help in maintaining a persistent residual in the distribution system.

The City is required to measure DBPs quarterly in their finished water at six sampling locations in the distribution system. Compliance with DBPs is determined by a LRAA, as regulated by the Stage 2 D/DBPR and FDOH. Historically, the six locations have not experienced any exceedances in DBPs up until the last quarter of 2016. During the fourth calendar quarter of 2016, the City was confronted with an increase in DBPs within their distribution system. Specifically, the City observed an increase in TTHMs and HAA5 at three locations in its distribution system above the PMCL of 80 and 60 ppb respectively. The LRAA for TTHM at the 901 NW 208th Ave Rose Price Park location was 88.42 ppb, exceeding the MCL of 80 ppb. As a result, FDOH-BC determined that the entire system is in violation of the TTHM MCL.

In May 2017, the City contracted with Jacobs to conduct a DBP study for compliance with Stage 2 D/DBPR and make recommendations for achieving regulatory compliance. Presented herein are a summary of findings, short- and long-term treatment and operational strategies to gain compliance with DBPs in the most cost-effective manner and in as short of duration as possible.

7.1 Summary of Findings

- Except for the past three quarters, the City has been in compliance with Stage 2 D/DBPR for TTHMs and HAAs. The reason for the recent non-compliance is the LRAA for TTHM exceeding the MCL of 80 ppb at the 901 NW 208th Ave Rose Price Park location. During the fourth calendar quarter of 2016 (November 29, 2016) TTHM and HAA concentrations exceeded the MCL at three locations i.e. 800 NW 217th Terrace, 901 NW 208th Ave Rose Price Park and 20426 SW 54th Place. These exceedances were observed right after the distribution system went through a maintenance procedure i.e. “free chlorine burn”. This maintenance practice could have attributed to the high TTHMs and HAA5 observed at these locations.
- Despite the increase in quarterly DBP values at these locations, only the Rose Price Park location had an LRAA value for TTHMs that exceeded the regulatory MCL of 80 ppb. Most recent monitoring data (second quarter of 2017) shows that at the same location, LRAA for TTHM decreased and was slightly above the MCL of 80 ppb. The LRAA for HAA5 were below the regulatory limit at all the six locations.
- The current TTHM quarterly values show that at all the remaining five (5) locations the LRAA for TTHMs is not only below the MCL of 80 ppb but is also below the water quality goal of 64 ppb. The current HAA5 value shows that at all the six (6) locations the LRAA is below the MCL of 60 ppb. Only at the three (3) locations noted above, the LRAA for HAA5 is above the water quality goal of 48 ppb.
- On June 12, 2017, as part of a special sampling event, Jacobs and CH2 staff collected water samples at the six (6) sampling locations which are representative of the City’s entire distribution system for analysis of DBPs. The results of the sampling event showed that the DBPs were below the MCL at all of the six (6) sampling locations. DBP values reported by both laboratories were largely in agreement with some differences. TOC/DOC in the raw water and finished water were similar and were 10.4 mg/L and 5.5 mg/L respectively with a removal of 47%. SUVA of the raw water was high (4.4 L/mg-m) indicating that the water has high humic content and is amenable for additional DOC removal by enhanced or optimized coagulation.

- The maintenance practice of flushing the system with free chlorine (free chlorine burn) appears to have contributed to the high TTHMs and HAA5 observed at these three locations. In addition, other factors that could have contributed to the increase in DBPs include increases in source water color (since summer of 2015) and finished water color above the water quality goal of 15 color units. This could have contributed to an increase in chlorine demand. Finished water color has increased due to the ion exchange system being off-line since September 2015, which correlates well with the observed increase in DBP quarterly values. Another factor that could have contributed to the increase in DBPs is their location i.e. these monitoring sites are located in the extremities of the distribution system which have a higher water age. High water age contributes to an increase in DBPs.
- In addition to the DBP precursors (color, TOC) in the source water, other water quality parameters such as iron, ammonia increases the complexity of water treatment, distribution system operation and influence chlorine demand and DBP formation.
- An analysis of operational data showed that the following water quality parameters need to be optimized in the finished water:
 - a. Turbidity: Turbidity of the finished water was well above the water quality goal (industry standard) of 0.1 NTU and greater than 0.3 NTU most of the time. The average turbidity was 0.3 NTU, 90th percentile was 0.7 NTU with a maximum of 1.1 NTU in the finished water. This indicates that the optimization of Accelerators® and filters is necessary.
 - b. pH: Average finished water pH was 8.9 with a 90th percentile pH of 9.5, exceeding the SMCL water quality standard of 6.5-8.5. Although the FDOH allows the City to operate with a high finished water pH, it is important to note that TTHM formation is very rapid in a high pH environment. In addition, fluctuating pH levels can reduce monochloramine formation.
 - c. Iron: Iron in the raw water varied considerably with an average concentration of 1.2 mg/L, however iron concentrations peaked to 1.9 mg/L several times since May 2016. During the same time, finished water iron concentrations were ~0.1 mg/L and did not exceed the SMCL of 0.3 mg/L.
 - d. Ammonia: Free ammonia in the source water varies (0.38 mg/L-1.96 mg/L) which should be addressed prior to distribution. Current practice is to add high doses of chlorine (pre-filtration) to bind the ammonia. Free ammonia levels leaving the plant vary between 0.1-0.2 mg/L contributing to varying monochloramine residuals and creating a potential for nitrification. Free ammonia concentration in the distribution system ranged from 0-0.2 mg/L. Research indicates that free ammonia less than 0.05 mg/L (reported as NH₃-N) minimizes the potential for nitrification, corrosion, taste and odor complaints and water quality deterioration.
 - e. Chlorine residual: Data exhibited significant variation in total chlorine, free chlorine residuals and chlorine demand during different times of the year. Chlorine demand increased from November 2016-January 2017 indicating that the chlorine demanding constituents (e.g. ammonia, color, DOC) varied in the finished water as well. The average total chlorine residual in the distribution system was 2.75 mg/L. Typical chloramine concentrations of 0.2-2 mg/L are found in drinking water supplies where monochloramine has been used as a disinfectant to provide a residual in the distribution system. Chloramine residuals varied from 2.04-3.9 mg/L in the distribution system.

- Based on historical TTHM data, chloroform concentration is the predominant form of TTHMs in the City's distribution system, approximately eighty five percent (> 85%) or more of the total THMs and can be removed easily due to its high volatility. Hence, mechanical mixing in storage tanks or aeration towers will likely remove a significant portion of the TTHMs.

7.2 Recommendations

The recommended approaches for DBP control can be classified as short-term and long-term recommendations; short-term recommendations result in minor adjustments to the operational practices or addition of unit processes that do not involve major capital expenditure (Phase I) where-as long-term recommendations might involve significant capital expenditure (Phase II). These approaches will help the City improve plant operations and meet regulatory compliance for DBPs (specifically TTHMs) while producing safe, reliable, and high quality water.

Phase I: Short-Term Recommendations

- Optimize Source Water Quality-To the extent possible use wells with high quality water; minimize withdrawal from wells (e.g. #3 and #5) with poor water quality (high color, TOC, ammonia, iron).
- The City is currently rehabilitating the ion exchange units and is planning to bring them back into service in summer of 2017. Once the ion-exchange units are placed into service, the finished water color and DOC should decrease resulting in lower TTHMs. This will assist bringing the system back into compliance with Stage 2 D/DBPR. The ion exchange process should be in service at all times and operated at the full design capacity.
- The current practice of adding polyphosphate prior to filtration to tie up the calcium is creating an environment conducive to rapid ammonia oxidizing bacteria growth in the filters and the ion exchange system. The polyphosphate carried over to the filters and ion exchange units breaks down and serves as a nutrient promoting bacterial growth. Polyphosphate addition prior to pre-filtration should be replaced with carbon dioxide which will convert the calcium in the settled water to calcium carbonate. Addition of carbon dioxide will also help in optimizing pH, thus minimizing TTHM formation. The City should consider a phosphate-based corrosion control treatment chemical (e.g. orthophosphate) for adding to the finished water and stabilize water quality.
- To gain an in-depth understanding of the fate of the various water quality parameters at several locations in the treatment plant, a comprehensive water quality characterization program should be implemented. Results from this program will help in optimizing existing treatment processes (e.g. Accelator®, Filters and Ion Exchange processes) and maximize removal of color, TOC, turbidity, iron and ammonia.
- It is recommended that the City adopt the following water quality goals for the finished water:
 - Filtered water turbidity of less than 0.1 NTU
 - pH of 7.7-8.0
 - Color of filtered water less than 5 color units
 - TOC of filtered water less than 2.0 mg/L
 - TTHMs < 64 ppb; HAAs < 48 ppb
 - No free ammonia

Although the FDOH allows the City to operate with a high finished water pH, it is important to note that TTHM formation is very rapid in a high pH environment. In addition, fluctuating pH levels can reduce monochloramine

formation. As such, pH should be more in line with the water quality goal/industry standard of 7.7-8.0. Optimizing chlorine dosages and the finished water pH will be critical to control DBP formation in the distribution system. Such optimization in pH and treatment changes should also consider and evaluate the potential effects on the corrosivity of the treated water and the need for corrosion control. TOC is generally recommended as a better parameter as it correlates better to TTHM formation potential than color. Also, lower TOC levels in finished water has additional benefits, such as a lower chlorine demand, less DBP formation, more stable chlorine/chloramines residual, and reduced risk of nitrification in the distribution system. Currently the WTP is removing only 47% of the TOC and additional removal of TOC should assist in reducing the DBPs. Although ammonia is unregulated, its presence in the water has several implications (e.g. nitrification).

- Automation- It is recommended to install the following on-line analyzers:
 - On-line Ammonia Analyzer-Measuring ammonia in source water on a regular basis is recommended, especially as the water contains co-contaminants (e.g. color, TOC, iron). Online instrumentation is available for measuring free ammonia and combined ammonia (monochloramine). Continuous monitoring of free ammonia concentrations ensures that proper dosages of chlorine are applied at the pre- and post-filtration steps to maintain the proper chlorine:ammonia ratio.
 - On-line TOC Analyzer-Measurement of TOC and DOC in the raw and finished water is recommended on a continuous basis to adjust chemical doses (e.g. coagulant, lime, polymer) and accurately determine if TOC removal goals are being met. Also, TOC can be used as a surrogate parameter as an indicator of the DBP formation potential.
 - On-line THM Analyzer- Real-time measurements of TTHMs in the finished water will provide an indication of the overall performance of the WTP, optimize unit processes and achieve regulatory compliance.
- Conduct bench-scale studies with coagulant (alum, ferric, PACL, ACH etc.) and polymer combinations to reduce the turbidity, iron, TOC and maximize filter performance. SUVA of the source water was high (4.4 L/mg-m) indicating that the water has high humic content and is amenable for additional DOC removal by enhanced or optimized coagulation. It is recommended that the studies be conducted paying attention to proper mixing, at raw water pH and allowing a time lag of at least 5 minutes prior to the addition of lime and anionic polymer to observe the benefits of these chemicals.
- Conduct a distribution system water quality study to optimize finished water quality parameters. Such a study would provide recommendations in terms of optimal water quality parameters (e.g. pH, chlorine residual, hardness, alkalinity, TOC, ammonia) and a suitable corrosion inhibitor. The study may include coupon tests and pilot systems to assess any finished water quality changes.
- Develop a hydraulic model of the distribution system
 - A hydraulic model will assist in predicting water age, water quality (e.g. chlorine residual, nitrification potential) for existing and various operating conditions (e.g. valve closures) and
 - allow to run “what-if modeling scenarios” to optimize water age and improve water quality
- Implement best management practices in the distribution system, which include
 - Minimizing water age and hydraulic retention time
 - Increasing the frequency of distribution system flushing
 - Eliminating dead-ends

- Performing unidirectional flushing in the distribution system as recommended by AWWA (every quarter)
- Evaluating storage tank mixing protocols
- Installing mixers in storage tanks that can be added to strip off the chloroform which is a major species of the TTHMs (> 85%); mixing will also help in reducing water age, minimize loss of chlorine residual and potential nitrification.

Phase II: Long-Term Recommendations

The City should implement the above strategies in Phase I to minimize the DBPs in the distribution system. In the event DBPs continue to be an issue, the City should evaluate the following strategies:

- Adding an aeration-detention basin at the head of the plant which will reduce the iron
- Retrofit GAC in existing filters i.e. replace anthracite media with GAC
- Operate filters with GAC in biological mode (biological filtration) to reduce DOC and convert ammonia to nitrate (intentional nitrification in filters)
- Consider decentralized treatment in the distribution system such as air stripping.

Regardless of the treatment option chosen, treatability studies will be necessary for predicting system performance, developing design criteria and validating the process. It is strongly recommended that the City pilot the chosen technology. A small-scale pilot could help determine the effectiveness of the technology with respect to DBP reduction and address other water quality concerns such as iron and ammonia.

7.3 Other Recommendations

Other recommendations include

- Developing a Renewal and Replacement Program
 - will assist in evaluating existing equipment condition and capacity
 - predicting useful life expectancy
 - developing a prioritized rehabilitation or replacement schedule
- Developing a Long-term Masterplan
 - will help in identifying other sources for meeting future demand, improving production and better source water quality
 - identifying plant upgrades and expansion projects

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Appendix A. Source Water Quality and DBP Data

Table 1. Source Water Quality ("City of Pembroke Pines WTP, Technical and Compliance Audit" CH2M, 2015)

Table 1. Source water quality

	Well #2	Well #3	Well #4	Well #5	Well #6	Well#10	Flow-Weighted WQ
pH	7.66	7.53	7.42	7.49	7.69	7.59	7.54
Temp °C	26	26.2	26.3	26	26.2	26.5	26.17
Alkalinity mg/L as CaCO ₃	220	224	210	254	190	200	224.47
Ca Hard mg/L as CaCO ₃	209	210	220	236	182	192	215.51
T-Hard mg/L as CaCO ₃	208	234	225	236	206	200	221.87
F-NH ₃ mg/L as N-NH ₃	0.62	0.74	0.56	1.96	0.38	0.42	1.03
Color	112	105	97	165	98	114	125.77
Iron mg/L	1.16	1.26	0.84	1.4	0.93	1.17	1.17
Turbidity NTU	0.55	0.48	0.45	1.49	1.18	0.83	0.95
TOC mg/L			7.9	9.7			
Flow - gpm	1214	828	1723	3102	800	1361	
Percent flow	13%	9%	19%	34%	9%	15%	

Table 2. Quarterly values of TTHMs and HAA5 (2014-Present)

TTHM COMPLIANCE SUMMARY														
Monitoring Location*	2nd qtr 2017	1sr qtr 2017	4th qtr 2016	3rd qtr 2016	2nd qtr 2016	1st qtr 2016	4th qtr 2015	3rd qtr 2015	2nd qtr 2015	1st qtr 2015	4th qtr 2014	3rd qtr 2014	2nd qtr 2014	1st qtr 2014
800 NW217 th Terrace	28.89	56.96	92.6	55.58	61.72	50.12	46.76	24.23	23.9	40.6	46.76	55.5	35.9	41.42
Fire Station #89-13000	16.54	66.49	48.11	49.74	48.31	52.71	33.95	23.08	23.61	26.71	44.97	43.52	32.56	43.67
901 NW208 th Ave Rose Price Park	29.64	66.08	172.29	65.58	66.86	48.95	58.11	24.76	23.6	33.93	43.98	76.28	30.19	45.03
7500 NW20 th St. Walnut Creek	16.16	64.21	49.19	44.92	57.11	23.08	41.2	22.96	21.15	26.74	40.52	48.37	31.02	43.38
184 th Pembroke Rd.	23.65	66.18	44.83	49.48	50.21	45.15	24	25.08	24.32	25.79	49.67	46.18	33.06	46.68
20426 SW 54 th PL.	33.08	61.83	82.27	58.58	48.76	47.15	37.71	25.35	27.94	29.37	49.32	58.72	31.74	43.37

HAA5 COMPLIANCE SUMMARY														
Monitoring Location*	2nd qtr 2017	1sr qtr 2017	4th qtr 2016	3rd qtr 2016	2nd qtr 2016	1st qtr 2016	4th qtr 2015	3rd qtr 2015	2nd qtr 2015	1st qtr 2015	4th qtr 2014	3rd qtr 2014	2nd qtr 2014	1st qtr 2014
800 NW217 th Terrace	35.93	54.49	68.63	47.15	52.23	60.09	46.81	27.22	56.85	43.57	38.16	35.15	44.66	49.43
Fire Station #89-13000	21.58	52.03	49.04	35.44	19.78	45.33	35.91	26.77	28.03	22.73	24.69	26.02	44.05	34.96
901 NW208 th Ave Rose Price Park	37.11	58.98	71.34	50.94	52.14	57.24	67.26	22.8	41.27	36	41.1	50.67	39.87	39.23
7500 NW20 th St. Walnut Creek	23.56	46.58	42.24	32.24	34.31	29.71	33.55	25.53	30.47	30.49	1.38	24.28	32.29	39.52
184 th Pembroke Rd.	41.57	55.89	47.39	39.08	38.46	46.23	39.24	25.25	28.71	28.39	36.31	27.2	32.02	47.83
20426 SW 54 th PL.	37.46	54.12	70.59	51.13	41.75	59.77	56.6	25.77	29.71	29.01	36.59	19.18	34.24	34.61

Appendix B

Sampling and Analysis Plan

Sampling and Analysis Plan

City of Pembroke Pines

Broward County, Florida

June 2017

1.0 Introduction

The City of Pembroke Pines retained professional services from Jacobs Engineering Group, Inc. The purpose is to assist the City reduce Total Trihalomethanes (TTHMs) in its distribution system below the primary maximum contaminant level (PMCL) of 80 ppb, as required by the US EPA stage 2 Disinfection/Disinfection By-product Rule (Stage 2 D/DBPR) and Florida Department of Health.

The City of Pembroke Pines Water Treatment Plant facility is located at 7960 Johnson Street. The existing water treatment plant has a capacity of 18 million gallons per day (MGD). The method of treatment is by lime softening, filtration, ion exchange, and disinfection. The water treatment plant is supplied by a total of nine (9) wells.

Jacobs Engineering Group, Inc. will assess the drinking water at six (6) sample locations within the City's distribution system and two (2) sample at the Water Treatment Plant (WTP).

The sample locations are listed below:

SAMPLE LOCATION	SAMPLE ID
800 NW 217th Terrace	PP01-061217
Fire Station #89, 13000 Pines Blvd.	PP02-061217
Rose Price Park, 901 NW 208th Ave	PP03-061217
7500 NW 20th St. Walnut Creek	PP04-061217
SW 184th Ave & Pembroke Rd	PP05-061217
20426 SW 54th Place	PP06-061217
WTP- Raw Water	PP07-061217
WTP- Finished Water	PP08-061217

A drinking water sampling location map is shown as Figure 1.

2.0 Sampling Procedures

2.1 Drinking Water Sampling

Drinking water samples will be collected on June 12, 2017 for laboratory analysis.

Drinking water sampling will be conducted in accordance with the sampling protocols outlined in DEP-SOP-001/01 FS 2300 (Drinking Water Sampling). General sample collection procedures are:

- Select a cold water faucet for sampling which is free of contaminating devices such as screens, aeration devices, hoses, purification devices or swiveled faucets. Check the faucet to be sure it is clean. If the faucet is in a state of disrepair, select another sampling location.
- Collect samples in an area free of excessive dust, rain, snow or other sources of contamination.
- Flush the lines for two to five minutes before collecting any samples.
- Reduce the flow rate to less than 500 mL/minute (1/8" stream) or approximately 0.1 gal/minute before collecting samples other than for VOCs. Minimize aeration when filling VOC sample containers. Reduce the flow rate to approximately < 100 mL/minute when collecting VOC samples.
- In many instances, the water supply to residences may be treated with chlorine, which causes interference with certain types of analyses (e.g., VOCs, Extractable Organics and some bacteriological samples).
- Use a chemical test kit to check a separate sample for residual chlorine. If residual chlorine is present, collect the sample in the appropriate sample container(s) using the required preservatives.
- Replace the screw cap securely on the bottle and tip the container several times to mix the preservative with the sample.
- Dry the exterior surface of the bottle using a clean paper towel.
- Affix a sample label and seal (if required), and complete the chain of custody form.
- Place the sample bottle in a plastic sample bag and cool (where required) to 4°C on wet ice in cooler and nestle in ice, making sure that any melted ice water does not raise above the sample containers.

Drinking water samples at each location will analyze by Eutrophics, Inc., a state-certified fixed-based laboratory for the following target compounds:

- Total Trihalomethanes (TTHMs)
- Haloacetic acids(HAA5s)
- Raw water samples collected from the WTP will be analyzed for :
 - Total Organic Carbon (TOC)
 - Dissolved Organic Carbon (DOC)
 - UV-254
 - Ammonia
- Finished water samples collected from the WTP will be analyzed for:
 - Total Organic Carbon (TOC)
 - Dissolved Organic Carbon (DOC)
 - UV-254
 - Ammonia
 - Total Trihalomethanes (TTHMs)
 - Haloacetic acids(HAA5s)

SAMPLING FOR TOTAL ORGANIC CARBON

Bottles to Use



Glass bottles are preferred but plastic may be used as well.

Preservatives to Use

Check with the lab to verify the type of preservation required which depends on laboratory method in use. Generally, preservation includes

**Hydrochloric (HCl) or Sulfuric (H₂SO₄)
or Phosphoric Acid (H₃PO₄) to pH <2
and
Cool to ≤ 4 °C (≤ 39.2 °F) but do not freeze**

Holding Time

28 days

Sampling Instructions

Check with the laboratory on the sample volume required for analysis. Wear gloves when handling acids and other preservatives and while collecting samples. If the bottle contains a preservative, do not rinse the bottle. If the preservatives are not included in the bottle, rinse the bottle and cap three times with sample water, fill the bottle, and then carefully add the preservatives following the instructions provided by the laboratory. The bottle should be filled to within one to two inches from the top. Place the sample into a cooler with ice for delivery or shipment to the laboratory.

SAMPLING FOR HALOACETIC ACIDS (HAA5s)

Monochloroacetic Acid, Dichloroacetic Acid, Trichloroacetic Acid,
Monobromoacetic Acid, Dibromoacetic Acid

Bottles to Use



Glass bottles must be used.

Preservatives to Use

Ammonium Chloride

and

Cool to $\leq 4^{\circ}\text{C}$ ($\leq 39.2^{\circ}\text{F}$) but do not freeze

Keep samples in the dark

Holding Times

Holding times are either 14 or 28 days depending upon the laboratory method in use.

Sampling Instructions

Check with the laboratory on the sample volume required for analysis. Wear gloves and eye protection when handling acids and other preservatives and while collecting samples. Do not rinse the bottle. If the preservatives are not included in the bottle, carefully add the preservatives following the instructions provided by the laboratory. Fill the bottle to within one to two inches from the top. Place the sample in a cooler with ice for delivery or shipment to the laboratory.

SAMPLING FOR TOTAL TRIHALOMETHANES (TTHMs)

Bromodichloromethane, Dibromochloromethane, Tribromomethane (Bromoform),
Trichloromethane (Chloroform)

Bottles to Use



Or

Clear or amber volatile organic analysis (VOA) glass bottles with Teflon septum-cap must be used.

Preservatives to Use

Check with the lab to verify the type of preservation required which depends on laboratory method in use. Generally, preservation includes the following...

**Sodium Thiosulfate or Ascorbic Acid if sample chlorinated
and Hydrochloric Acid (HCl) to pH < 2 and
Cool to $\leq 4^{\circ}\text{C}$ ($\leq 39.2^{\circ}\text{F}$) but do not freeze**

Holding Time

14 days

Sampling Instructions

Check with the laboratory on the sample volume required for analysis. Typically duplicate samples must be collected (triplicate preferred) at each sampling location. Wear gloves and eye protection when handling acids and other preservatives and while collecting samples. Do not rinse the bottle as it should contain the preservatives before it is filled. Check to make sure this is the case and if not add the preservative. Slowly fill the bottle by allowing the sample to gently flow down the inside of the bottle. Create a meniscus of water at the mouth so that the bottle is actually overfilled. Cap the bottle so that no air bubbles are present in the bottle and the excess water spills down the sides of the bottle. Check to make sure that the bottle does not contain bubbles by inverting the bottle several times. Place the sample into a cooler with ice for delivery or shipment to the laboratory.

