BLACK & VEATCH

Black & Veatch Corporation
5400 LBJ Freeway, Suite 975, Dallas, TX 75240

AUG - 6 2018

WATER SUPPLY
APPROVED
OHIO ENVIRONMENTAL PROTECTION AGENCY
AS EVIDENCED BY COPY OF
LETTER OF APPROVAL
HERETO ATTACHED

April 24, 2018

Ohio Environmental Protection Agency Northwest District Office
Division of Drinking and Ground Water 347 N. Dunbridge Road
Bowling Green, OH 43402

Attention: Ryan Bertani, Division of Drinking and Ground Waters

Subject: City of Toledo, Collins Park Water Treatment Plant
Harmful Algal Bloom General Plan

On behalf of the City of Toledo (COT), please find enclosed for review an updated Harmful Algal Bloom (HAB) General Plan. The plan includes the approach that will be used to manage HAB events within the short-term and the long-term. This updated version addresses comments received from Ohio Environmental Protection Agency (OEPA) on the letter dated February 13, 2018, as summarized below:

Required Items:

1. Investigate worst case scenario for CT during a HAB event.
    a. The CT for the worst case scenario conditions was calculated using the AWWA CT calculator CyanoTOX Version 2.0, which is described in detail in revised Section 4.1.3.5. The results of those calculations are presented in revised Sections 4.1.3.5 and 5.1.
2. Include the approach to address how CT is being calculated through the East and West Reservoirs.
    a. This comment was addressed in revised Section 4.1.3.5. A more rigorous study will be undertaken to evaluate potential changes to the current reservoir operational strategy to optimize CT and Microcystin treatment. This study is anticipated to be completed by September 30, 2019.
3. The general plan will be approved with the caveat that a change in the City's treatment capabilities will require an amended general plan.
    a. Noted.

General Comments:

4. Monitoring treatment processes and optimizing treatment for future conditions.
    a. Standard operating procedures have been developed for the short term treatment processes and will be developed for the future processes including Ozone treatment. Those treatment processes will continue to be monitored and adjusted to maximize treatment for future conditions.
5. Include plans for COT involvement in source water protection programs.
    a. The COT will continue to drive the initiatives towards source water management to mitigate nutrient loading in Lake Erie through various protection and restoration programs, as described in Section 4.1.1. The source water monitoring efforts will continue, as described in Section 4.1.2. The COT will continue to support the Lake Erie and Maumee River initiatives and will reach out to the contact provided for additional information and assistance in the future.

Please feel free to contact me with any questions.

Very truly yours,

Black & Veatch

Nick Burns, P.E.
Director Water Treatment Technology

cc: Warren Henry
Jim Donnell
Andy McClure
Patekka Bannister
Jim Broz

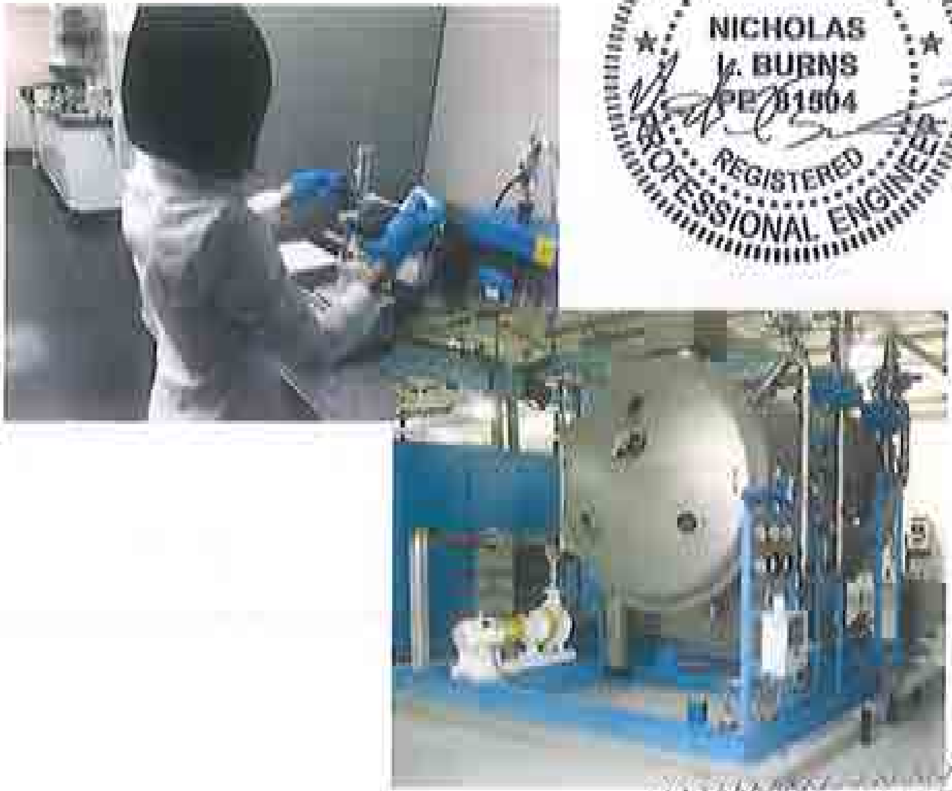
FINAL

HARMFUL ALGAL BLOOM GENERAL PLAN

Collins Park Water Treatment Plant

B&V PROJECT NO. 194953

STATE OF OHIO
NICHOLAS J. BURNS
PE 81504
REGISTERED
PROFESSIONAL ENGINEER



WATER SUPPLY
APPROVED
ENVIRONMENTAL PROTECTION AGENCY
AS EVIDENCED BY COPY OF
LETTER OF APPROVAL
HERETO ATTACHED

PREPARED FOR

Ohio EPA & City of Toledo

24 APRIL 2018

Ohio Environmental Protection Agency

BLACK & VEATCH
Building a world of difference.

Table of Contents

LIST OF TABLES

LIST OF FIGURES

1.0 Introduction and Purpose

The City of Toledo (COT) has been operating the Collins Park Water Treatment Plant (WTP) for over 75 years and provides potable water to a population of approximately 500,000 located in Toledo along with portions of Lucas, Wood, and Fulton Counties in Ohio and portions of southern Monroe County in Michigan.

The Collins Park WTP is a conventional treatment plant including processes for single-stage precipitative lime softening, recarbonation, filtration and chemical feed with a current capacity of 120 million gallons per day (mgd). Redundant capacity improvements are underway, which will provide a new rated plant capacity of 140 mgd and redundant capacity of 20 mgd. The existing chemical feed systems include potassium permanganate, alum, lime, soda ash, powdered activated carbon (PAC), carbon dioxide, polyphosphate, chlorine, chlorine dioxide, and fluoride. Following treatment, the water is stored in two 35 million gallon (MG) clearwells.

The water supply for the WTP is the western basin of Lake Erie, which is subject to seasonal harmful algae blooms (HABs) that can produce algal toxins, specifically microcystin (MC), which has been observed to reach total levels at the WTP intake as high as 50 micrograms per liter (µg/L) and extracellular (dissolved in the raw water) concentrations of 5 µg/L.

MC concentrations exceeded the 1.6 µg/L threshold defined in the Ohio Administrative Code (OAC) Rule 3745-90-05 on August 10, 2017 and August 16, 2017 at the Intake Crib of Collins Park WTP, instigating the need for a HAB General Plan. This General Plan documents the capabilities of the treatment in place to remove MC in the short term and how the existing treatment along with new treatment technologies will be capable of treating a 100 µg/L extracellular MC event in the long-term.

The General Plan presents many mediation options including source protection, management, and avoidance, as well as optimizing the existing treatment process within the Collins Park WTP and adding new technologies to prevent MC in the finished water supply for foreseeable future HAB events. As the OAC rule requires a multi-barrier approach to the treatment of MC, several treatment techniques will be adopted by the Collins Park WTP in order to efficiently and effectively remove MC from the drinking water. The COT is currently in the process of incorporating ozonation as another barrier to HAB toxins. To illustrate the robustness of the City's approach to HAB byproduct control, this plan includes the results of bench-scale testing and analytical work that was completed to optimize the design for the Collins Park WTP and demonstrate MC treatment performance.

2.0 Existing Situation

2.1 RAW WATER SOURCE

The Collins Park WTP draws its source water from the Western Basin of Lake Erie through an Intake Crib approximately three miles offshore, northeast of Reno Beach. The overall temperature at the intake crib ranges from 32°F (0°C) to 82°F (28°C) with an average of 59°F (15°C).

The range of raw water Total Organic Carbon (TOC) concentrations from 2009 to 2016 during HAB season is described in Table 2-1. The lowest observed reading was 1.1 mg/L on 10/10/2013 and the highest observed reading was 9.9 mg/L on 5/6/2011. During HAB season between 2011 and 2016, the average raw water alkalinity concentration was 94 mg/L as calcium carbonate ($CaCO_3$), with the lowest reading at 60 mg/L as $CaCO_3$ on 9/17/2015 and the highest reading at 145 mg/L as $CaCO_3$ on 6/21/2015.

Table 2-1 TOC Range at Intake Based on Historic TOC Data (2009-2016)

	TOC (mg/L)
1st Percentile	1.3
Average	3.6
99th Percentile	8.4

2.1.1 Historical HAB events in the Western Basin of Lake Erie

In August of 2014, a large HAB occurred near the intake crib for the Collins Park WTP, during which the MC concentration in the raw water increased up to 50 µg/L. This led to a "Do Not Drink" advisory for the COT and prompted efforts at the Collins Park WTP to research and invest in better MC removal technology including optimizing the current treatment processes. MC data measured from the raw water to the finished water during the summer of 2014 is shown in Figure 2-1. The following two years, during the typical HAB season, the highest recorded MC concentration in the raw water source was 3.5 µg/L. Figure 2-2 and Figure 2-3 show the MC data collected for 2015 and 2016, respectively. Note that the vertical scale is reduced to better illustrate the data.

2.1.2 2017 HAB Event

Figure 2-4 presents the MC concentrations observed in 2017 during HAB season. The MC concentrations at the intake crib were as high as 18 µg/L. Since the OAC Rule was passed after the 2016 HAB season, it is in 2017 that the MC levels at the Intake Crib activated the General Plan requirement. MC concentrations measured on August 10th and 16th were the ones to trigger the General Plan at 3.01 and 2.63 µg/L, respectively. The value of "80" in front of settled and filters in the label nomenclature refers to the older, west side of the WTP.

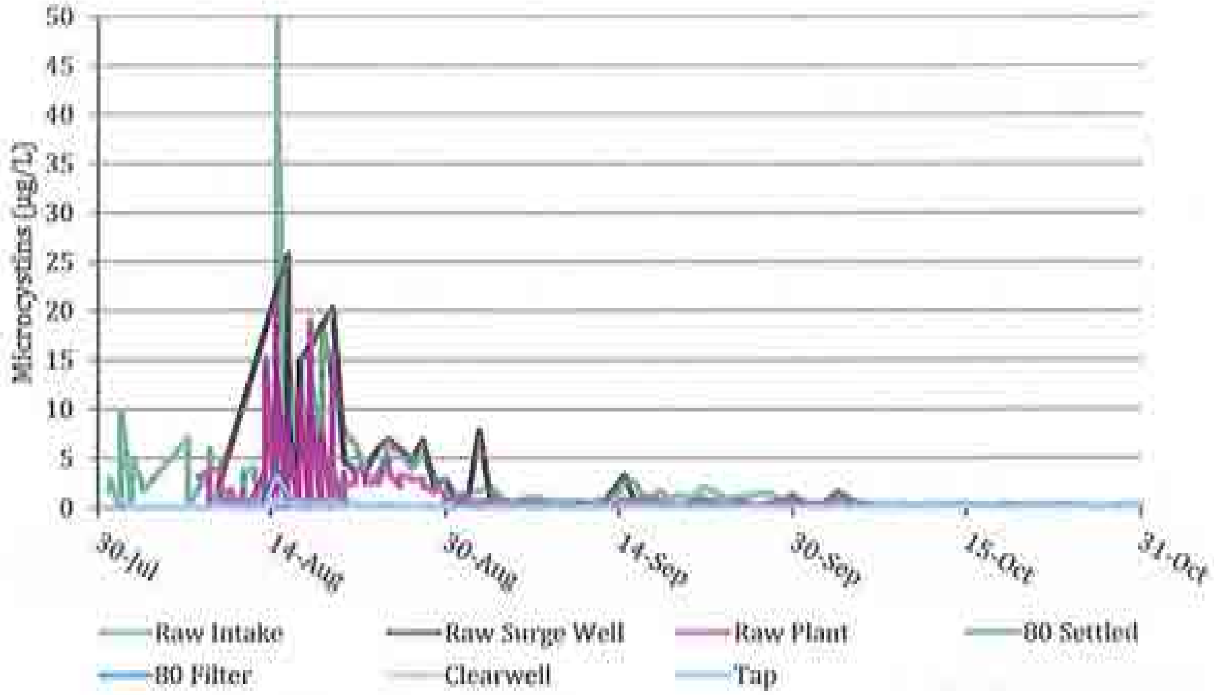


Figure 2-1 Seasonal Microcystin Data (2014)

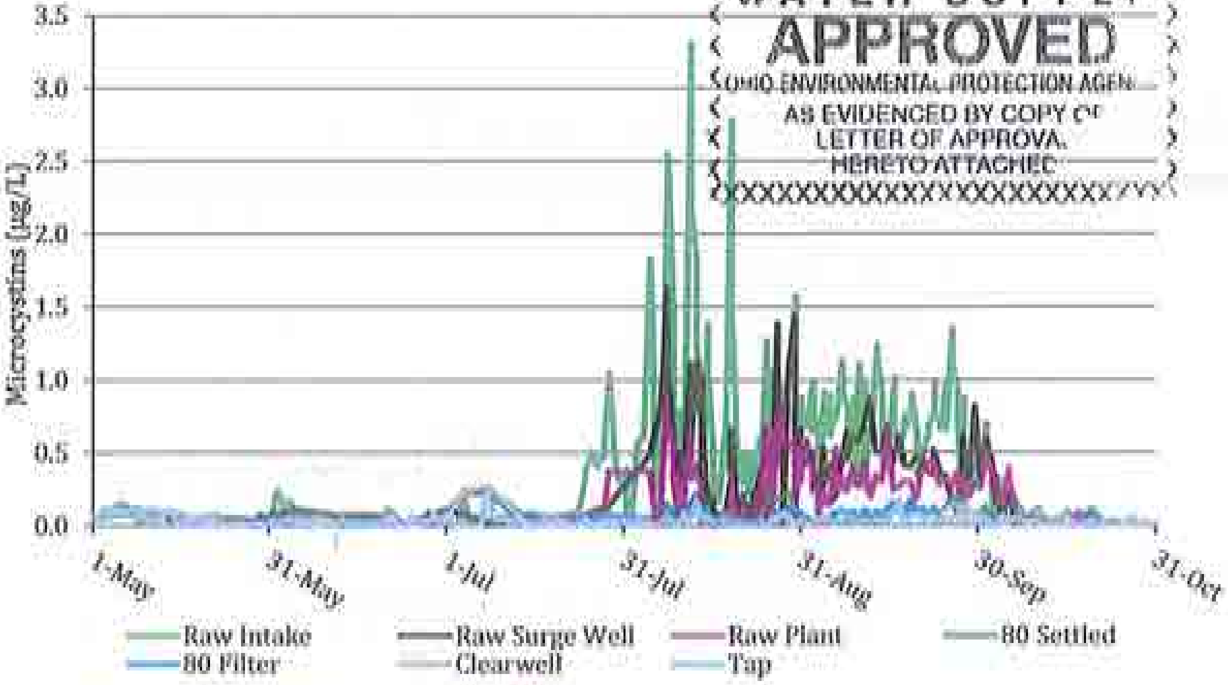


Figure 2-2 Seasonal Microcystin Data (2015)

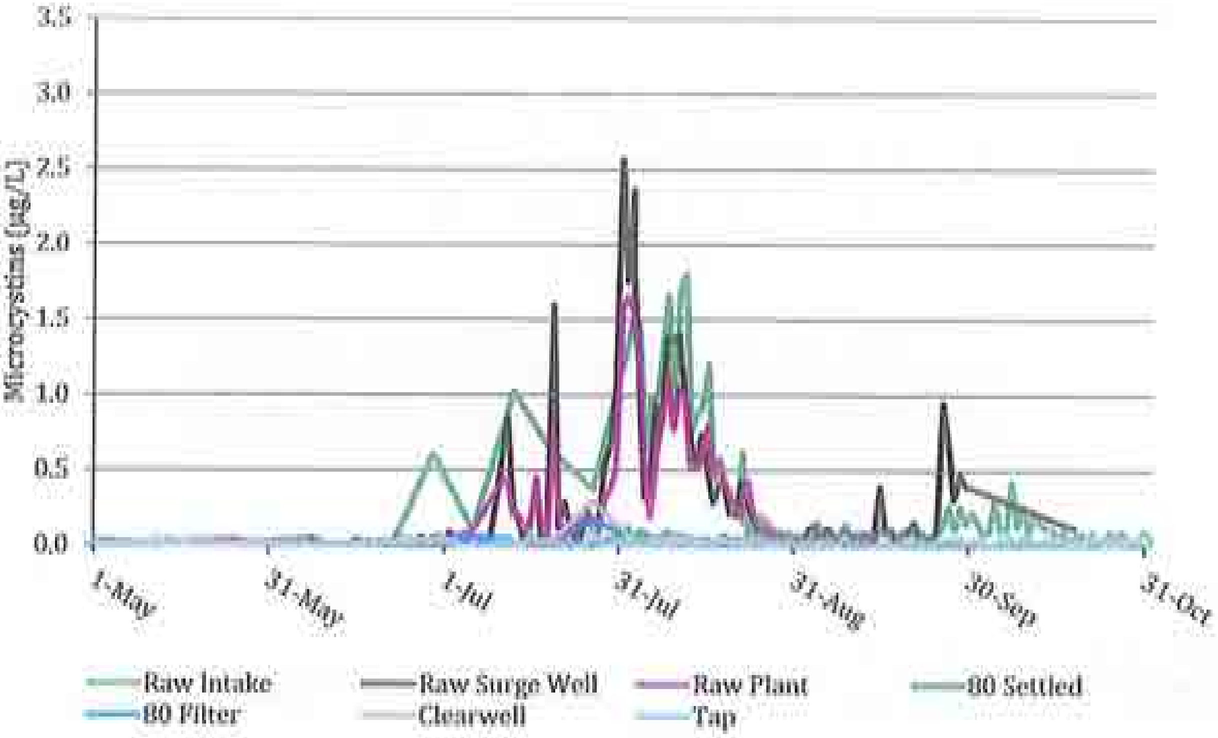


Figure 2-3 Seasonal Microcystin Data (2016)

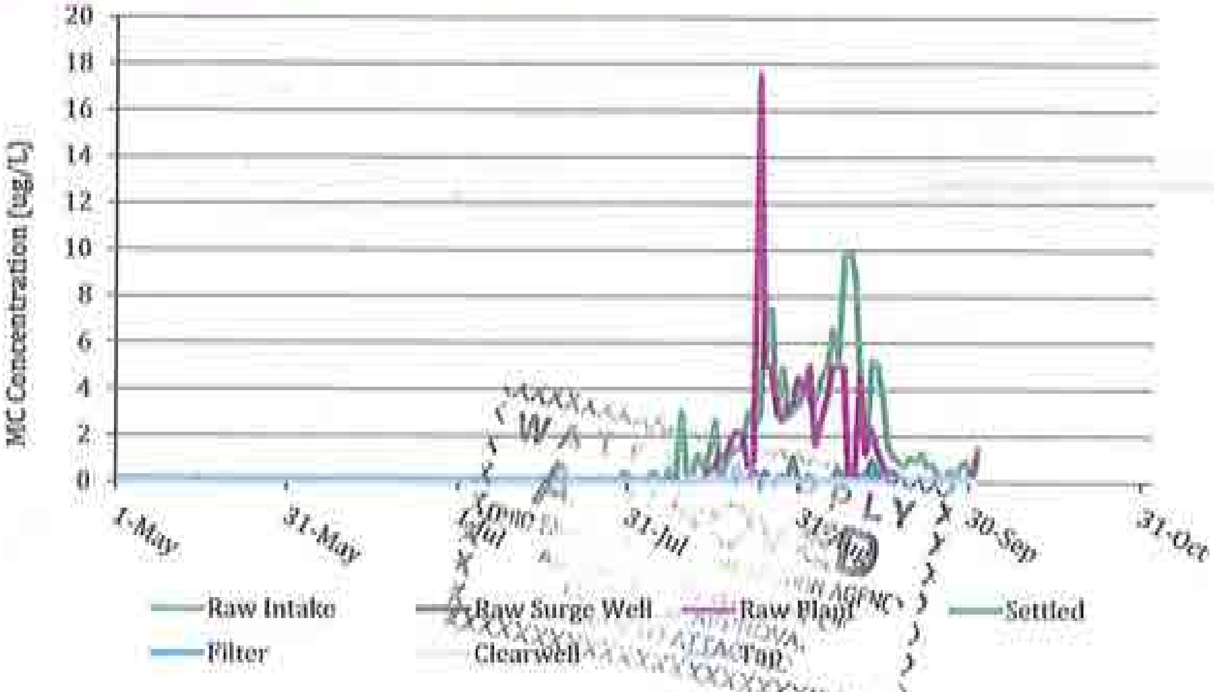


Figure 2-4 HAB Season Microcystin Data (May – Sept. 2017)

2.2 COLLINS PARK WTP SERVICE AREA

The Collins Park WTP currently serves approximately 500,000 customers through 125,000 residential, commercial and industrial accounts in the COT and the surrounding metropolitan area. The COT serves nine contract service areas, including Wood County/Northwestern Water and Sewer District, Sylvania, Maumee, Monroe County/South County Water, Perrysburg, Southwest Lucas County, Northwest Lucas County, Fulton County and Southeast Lenawee. Historical population counts for the COT and the surrounding service areas, as identified in the 2011 Master Plan and Needs Assessment Report, are summarized in Table 2-2.

Table 2-2 Historical Population Data for Collins Park WTP Service Area

SERVICE AREA	2000 CENSUS POPULATION	2005 SERVICE POPULATION
Toledo	313,619	304,326
Wood Co./NWW&SD	16,012	16,498
Sylvania	18,670	21,200
Maumee	15,237	15,000
Monroe Co./South County Water	39,940	34,112
Perrysburg	29,197	24,631
Southwest Lucas County	45,367	39,498
Northwest Lucas County	36,452	26,453
Fulton County	41,084	0
Southeast Lenawee	6,344	0
TOTALS	562,922	481,787

The Collins Park WTP normally experiences minimum, average, and maximum current daily demands of approximately 60, 80, and 120 MGD. The daily flowrate measurements at the plant from January 1, 2013 to December 31, 2016 are shown in Figure 2-5.

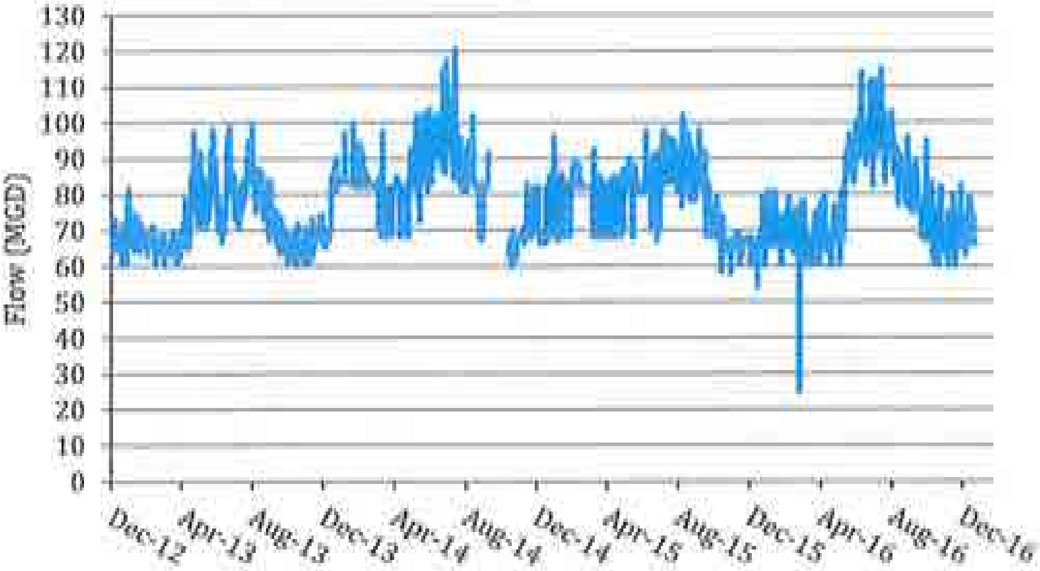


Figure 2-5 **Daily Flowrate Measurements at the Collins Park WTP**

2.3 CURRENT TREATMENT FACILITIES

The Collins Park WTP is a conventional plant with lime/soda-ash softening. An overview of the existing facility process is provided in Figure 2-6, and discussed in further detail below.

From the Intake Crib in Lake Erie, water is conveyed by gravity through a 108-inch diameter conduit to the Low Service Pumping Station (LSPS), which is equipped with fine screens and four (4) horizontal split-case centrifugal pumps. Potassium permanganate is dosed at the Intake Crib seasonally for zebra mussel control and year-round for taste and odor (T&O) control. PAC is also added year-round at the LSPS for T&O control, TOC removal and control of MC.

The Low Service Pumps convey the raw water through two pipelines to the Collins Park WTP, which discharge into a flume at the Chemical Building. There are two (2) rapid mix channels installed and depending on the operating flow water flows through one of the two channels before splitting off into six (6) lime-softening trains, and followed by thirty (30) high-rate, granular media filters (10 filters on the East side and 20 filters on the West side). Alum is used as the coagulant in the rapid mix process. Lime and soda ash are introduced separately within the flocculation processes for softening. There are PAC silos and feed equipment, which allows for an additional feed point in the sedimentation basins when needed. Downstream from filtration, chlorine and chlorine dioxide are applied to achieve primary disinfection and a residual concentration in the finished water. Fluoride is also added prior to being conveyed to the finished water clearwells. The finished water is stored in two (2) 35-million-gallon clearwells at the plant until it is pumped to the distribution system through six (6) high service pumps. The plant capacity is restricted by lime-softening trains, each of which have a 20-mgd capacity. Two additional basin trains are currently in construction, which will increase the total basin production capacity at the plant to 160 mgd (including 20 mgd of a redundant train). Construction of this WTP expansion project is anticipated to be substantially complete in April 2020.

Residuals from the sedimentation basins are discharged to thickening basins, where they are concentrated and then transferred and processed through plate and frame filter presses before the final residual cake is hauled offsite or to the lagoons as a backup, if required. Backwash from the dual media filters is sent to a separate lagoon. The lagoon storage is continuously decanted and then discharged to a local creek.

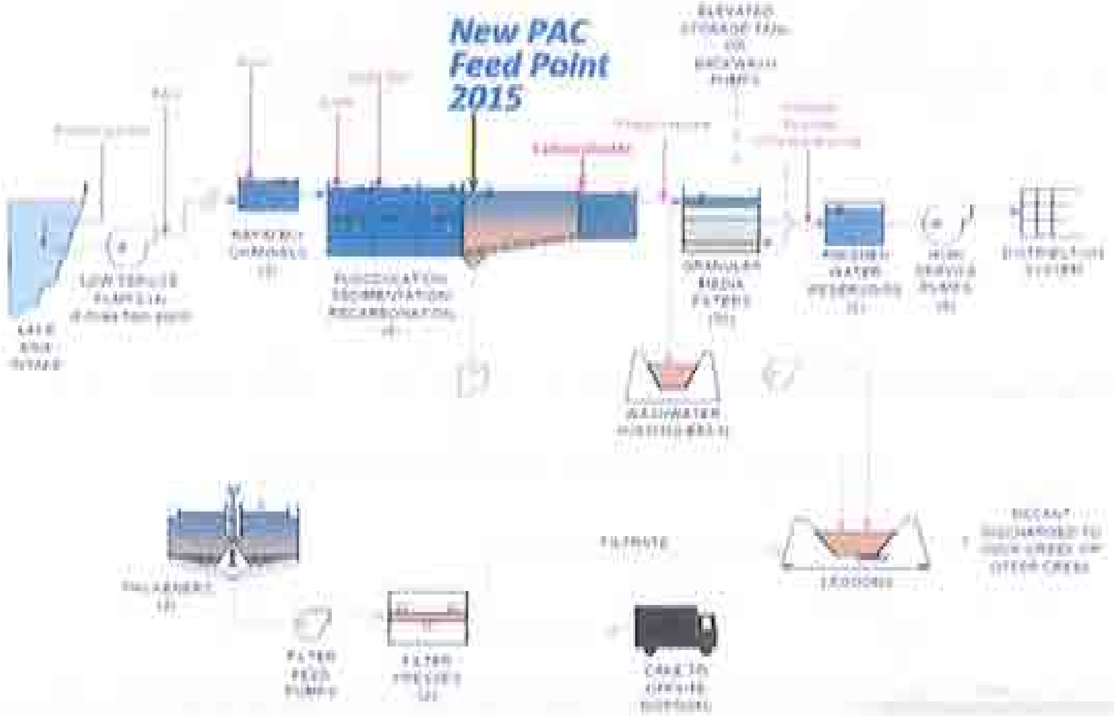


Figure 2-6 Existing Process Flow Diagram for the Collins Park WTP

3.0 Future Conditions

The 2035 population projections for the City of Toledo and the contract areas served by the Collins Park WTP, as identified in the 2011 Master Plan and Needs Assessment Report (Master Plan), are provided in Table 3-1. In the Master Plan, average per capita water demand and multipliers for maximum day and peak hour demands established using historical demand trends in the service area were used to project demands through 2035 have also been identified.

Table 3-1 Population and Demand Projections for the Collins Park WTP Service Area

SERVICE AREA	2035 SERVICE POPULATION	2035 AVG. DAY DEMANDS (MGD)	2035 MAX. DAY DEMANDS (MGD)	2035 PEAK HOUR DEMANDS (MGD)
Toledo	242,650	44.9	71.8	94.3
Wood Co./NWW&SD	19,812	4.1	6.5	8.5
Sylvania	21,200	2.1	3.4	4.5
Maumee	12,908	2.0	3.2	4.2
Monroe Co./South County Water	60,399	6.0	9.7	12.7
Perrysburg	37,744	4.0	6.3	8.3
Southwest Lucas County	61,730	10.2	16.3	21.4
Northwest Lucas County	35,943	3.8	6.0	7.9
Fulton County	15,789	5.0	8.0	10.4
Southeast Lenawee	13,252	1.2	1.9	2.5
TOTALS	**521,427**	**83**	**133**	**175**

As is common in most cities, the population is shifting from the city limits to the surrounding suburbs. Although the population in the City of Toledo is projected to decrease by 2035, the population in the surrounding contract areas will steadily increase. The ongoing redundancy improvements project that will increase the WTP's rated capacity to 140 mgd will allow the Collins Park WTP to meet these future demands and will allow for redundancy during average and maximum day conditions. The approach outlined in this HAB General Plan of both new and existing treatment processes will account for the treatment needs and the future demand projections using a 140 mgd firm design capacity.

WATER SUPPLY
APPROVED
ENVIRONMENTAL PROTECTION AGENCY
AS EVIDENCED BY COPY OF
LETTER OF APPROVAL
HERETO ATTACHED

4.0 Alternatives

4.1 SHORT-TERM TREATMENT OPTIONS

4.1.1 Source Management

The City of Toledo is one of many utilities that receive its source water from Lake Erie, which provides drinking water to over 11 million people in total. The Lake Erie watershed is the most populated of the Great Lakes Basins and is surrounded by industrial, agricultural and urban land areas. Due to extensive historical nutrient loading in the surrounding regions, Lake Erie has been subjected to eutrophication, which has resulted in severe algal blooms throughout the water source. The United States and Canada developed the Lake Erie Binational Nutrient Management Strategy in 2011, which outlines nutrient management actions to reduce phosphorus loading and associated algal blooms in the water source. The target total phosphorus concentration in the West Basin of Lake Erie was identified as 15 µg/L. The agreement indicates the shared responsibility from local governments, towns and organizations to work towards the goals outlined in the agreement.

As a result of the historical water quality issues in Lake Erie, the City of Toledo has implemented several initiatives to mitigate nutrient loading to the water source through both point and nonpoint sources, as described below.

1. Nutrient Removal at the Toledo Water Reclamation Facility (WRF): The Toledo WRF discharges to the Maumee River, which feeds into Lake Erie. The existing National Pollutant Discharge Elimination System (NPDES) permit phosphorous effluent limitation at the Toledo WRF is 1 mg/L. Iron is added to enhance removal of phosphorus at the WRF.
2. Toledo Waterways Initiative (TWI): The COT has combined sewers which can discharge directly into the Maumee River, Ottawa River and Swan Creek during heavy rain events. The COT is under a Consent Decree with the USEPA to eliminate eight of the 32 Combined Sewer Overflow (CSO) outfalls. The COT launched the TWI in 2002 to eliminate these overflows in order to reduce pollution in the local waterways. This is an 18-year, $527 million program that will reduce the average overflow volume by 80% through a series of deep tunnels and basins. The project is 84% complete to-date, and is expected to be completed in 2020.
3. Storm Water Management Program: The COT has implemented a Storm Water Management Program in accordance with the Ohio EPA regulations for Municipal Separate Storm Sewer Systems (MS4). This program regulates runoff through the use of best management practices such as detention basins, filter media barriers, interceptor swales, and construction site drainage controls in order to reduce the pollutant load in stormwater runoff. These practices are used to slow the runoff from non-point sources and trap phosphorus before it reaches local waterways.
4. Agricultural runoff: Phosphorus runoff from fertilizer application on agricultural land surrounding Lake Erie is a major contributor to the nutrient load. There are no governmental regulations on fertilizer applications to-date, but the Natural Resources Conservation Service of Ohio implemented an Environmental Quality Incentives Program, which provides technical and financial assistance for farmers to implement conservation practices to protect the local waterways. This program is voluntary, but it is encouraged and incentivized by the local government.

5. Public Education and Outreach: The Clear Choices Clean Water Program is actively promoted by the COT. This program encourages volunteers to help clean up the local waterways and provides educational campaigns to increase awareness for how to protect these waterways through using less fertilizer, managing yard/pet wastes, maintaining septic systems, etc.

4.1.2 Source Avoidance

The COT has initiated careful source water monitoring efforts per the requirements outlined in the OAC 3745-90-03. The COT Department of Public Utilities, Division of Water Treatment, placed two sondes, one on a buoy near the Intake Crib for the Collins Park WTP in Lake Erie which is equipped with a sonde at a depth of two (2) feet and another at a depth of 10 feet inside the intake crib. A third sonde was placed in the screen well at the LSPS. Each sonde contains six (6) probes, which take measurements for pH, temperature, specific conductivity (ORP), phycocyanin, chlorophyll, and turbidity every 10 minutes. The results of these measurements are available to the public online through the Great Lakes Observing System website. In addition to the measurements taken by the COT, the National Oceanic and Atmospheric Administration (NOAA) has several buoys placed throughout lake Erie, as shown in Figure 4-1. Each buoy contains sondes that are capable of the same water quality measurements taken at the buoy near the Intake Crib.

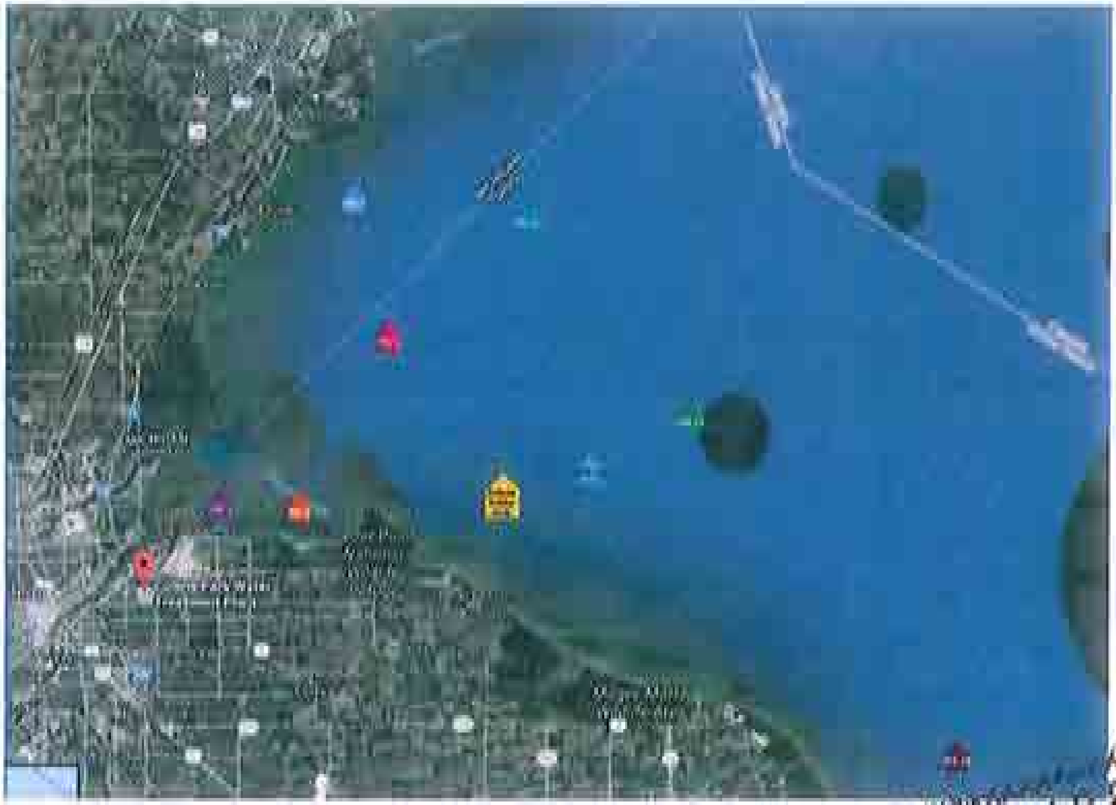


Figure 4-1 NOAA Station Locations on Lake Erie

In addition to the sonde data at the buoys, NOAA provides forecast of HABs for Lake Erie from July through October in bulletins available to the public. The forecast for August 10, 2017 (one of the two 2017 HAB events at the Collins Park WTP) is shown in Figure 4-2. All information is available to utilities in the region for use at the drinking water treatment plants in order to prepare for a HAB event.

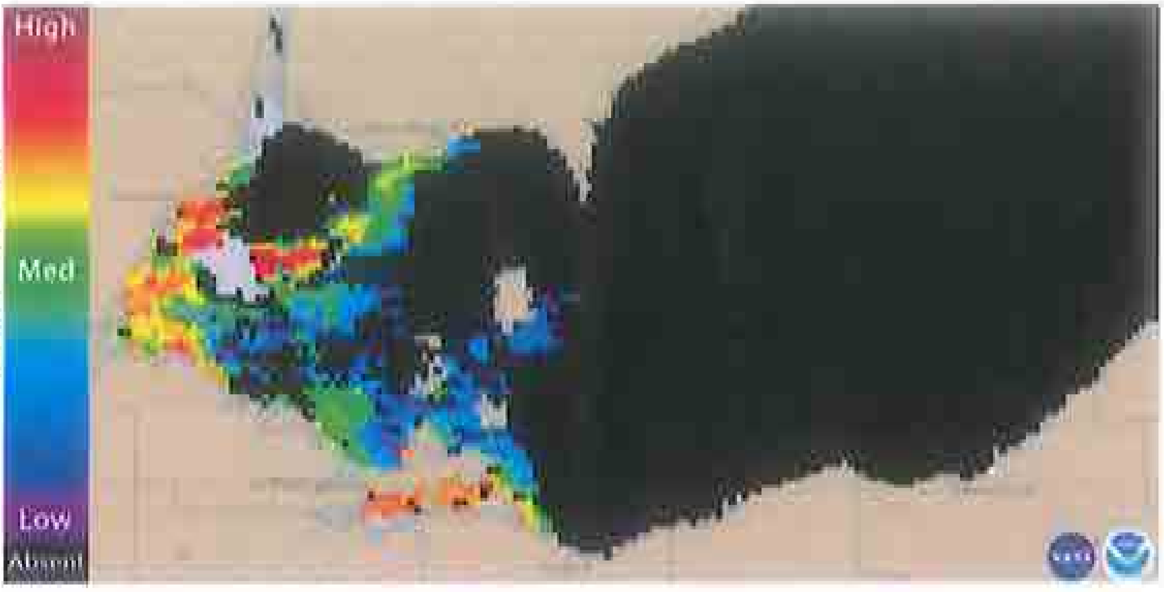


Figure 4-2 HAB Forecast from the NOAA Website for August 10, 2017

Additional sampling and analysis procedures are followed at the Collins Park WTP for MC. From November to April, raw water samples are collected and analyzed for MC once every two weeks. During typical HAB season from May to October, raw and finished water samples are collected and analyzed for MC once per week. When MC Levels in the raw water exceed 5 µg/L total, sampling and analysis of raw and tap samples increase to three times per week for both intracellular and extracellular toxins. If there is any detection in the finished water, sampling and testing will occur daily in the raw water, finished water, and in the treatment train for both intracellular and extracellular toxins.

The MC toxins are measured in the lab by the Enzyme-Linked Immunosorbent Assay (ELISA) test. Algae detection is measured under a microscope. Jar tests are performed as-needed during an HAB event to determine the amount of coagulant needed to remove the cells. Additional Cyanobacteria screening is completed by the Ohio EPA on raw and finished water samples once every two weeks.

Table 4-1 summarizes the indicators used to trigger process adjustments during a potential HAB event.

Table 4-1 Action Levels for Early Warnings of an HAB Event

Parameter/Bloom Severity	Minor Bloom	Moderate Bloom	Severe Bloom
pH	>8.5	>8.75	>9.0
Chlorophyll (µg/L)	2-5	5-50	>50
Phycocyanin (µg/L)	<2	2-6	>6
ORP (mV)	200-249	170-199	<170

An additional indicator for a potential HAB event is algae identification. As there is a dramatic shift in species in the algae identification, the probability of an HAB event is increased, which initiates more frequent monitoring efforts for pH, chlorophyll and phycocyanin levels. Additionally, after jar testing is complete, if there are cells floating on the surface of the jar, this is an indicator for a potential HAB event and the coagulant dose will be optimized.

The PAC feed rates at the LSPS are increased to at least 10 ppm for a minor bloom, 15 ppm for a moderate bloom and 20 ppm for a severe bloom. The redundant PAC feed at the third pass of the flocculation basins can also be implemented at a maximum rate of 1-2 ppm during a bloom event, if required. Although a low dose, the PAC accumulates in the filters. Additionally, between 2.0-2.5 mg/L of chlorine is fed after sedimentation when high concentrations of MC are measured. If MC is still present in the clearwell, more chlorine is dosed at the clearwell (approximately 0.5-0.75 mgL) without exceeding EPA limits based on the exiting residual.

4.1.3 Optimization of Current Treatment

The first step in addressing HAB control for any utility would be to optimize their existing treatment process. The COT has already enacted a program to address HAB contamination through the Collins Park WTP. Each treatment process that can be optimized to treat elevated concentrations of MC is discussed in this section.

As described earlier, the testing includes differentiation between intracellular and extracellular levels. Treatment optimization is described in general context and is revised based on the location of the toxin. E.g. if the toxin is intracellular, use of oxidants (permanganate, chlorine dioxide, free chlorine) may be delayed as a potential impact of chemical addition is lysing cells making the toxin more difficult to remove.

4.1.3.1 Potassium Permanganate Optimization

Potassium permanganate is dosed year-round at the intake crib of the WTP for T&O control and for seasonal zebra mussel control. While a direct correlation between the rate of permanganate dosing and MC removal efficiency has not been historically proven, it is clear that the presence of potassium permanganate does reduce MC. Currently, during an HAB event, the permanganate dose is set to the level that would normally treat zebra mussels and other organics. This requires that a permanganate residual between 0.3-0.5 mg/L be measured at the LSPS before PAC addition. In addition, PAC can be added at the LSPS (historically to control T&O causing compounds and remove TOC). Both of these chemicals can be used to control HAB byproducts; permanganate through oxidation and PAC through adsorption.

4.1.3.2 PAC Optimization

PAC at the LSPS was replaced to be capable of feeding a maximum dose of 40 mg/L, which is much higher than what could have been dosed during the 2014 HAB event. For example, on August 15, 2014, the MC measured at the Intake Crib was approximately 50 µg/L and 15 mg/L of PAC was dosed to bring the MC concentration down to 20.26 µg/L by the time it got to the plant. This was a 59% reduction in MC while using less than half the design capacity of the PAC feeding system. Therefore, optimizing the PAC dose by effectively increasing it as an HAB event begins can significantly reduce the MC concentration entering the plant before being further reduced through in-plant processes.

Figure 4-2 presents the effectiveness of PAC during the HAB season of 2014-2017. The data presented shows median values ranging from 37-61% MC removal. The spread for removal is wide, in part caused by varying PAC doses and resulted MC removal response and periods of low influent MC which results in limited removal as the treated concentration can be below the detection limit. In addition, there is some discrepancy in the timing of sampling between the intake crib and points in the treatment process. This difference in sampling times can skew MC results since the samples may not represent the same aliquot of water as it passes through the plant. These three aspects results in the large range in performance observed. It is clear however, that if high concentrations of MC are present, and high dosages of PAC are applied, high levels of MC removal can be achieved.

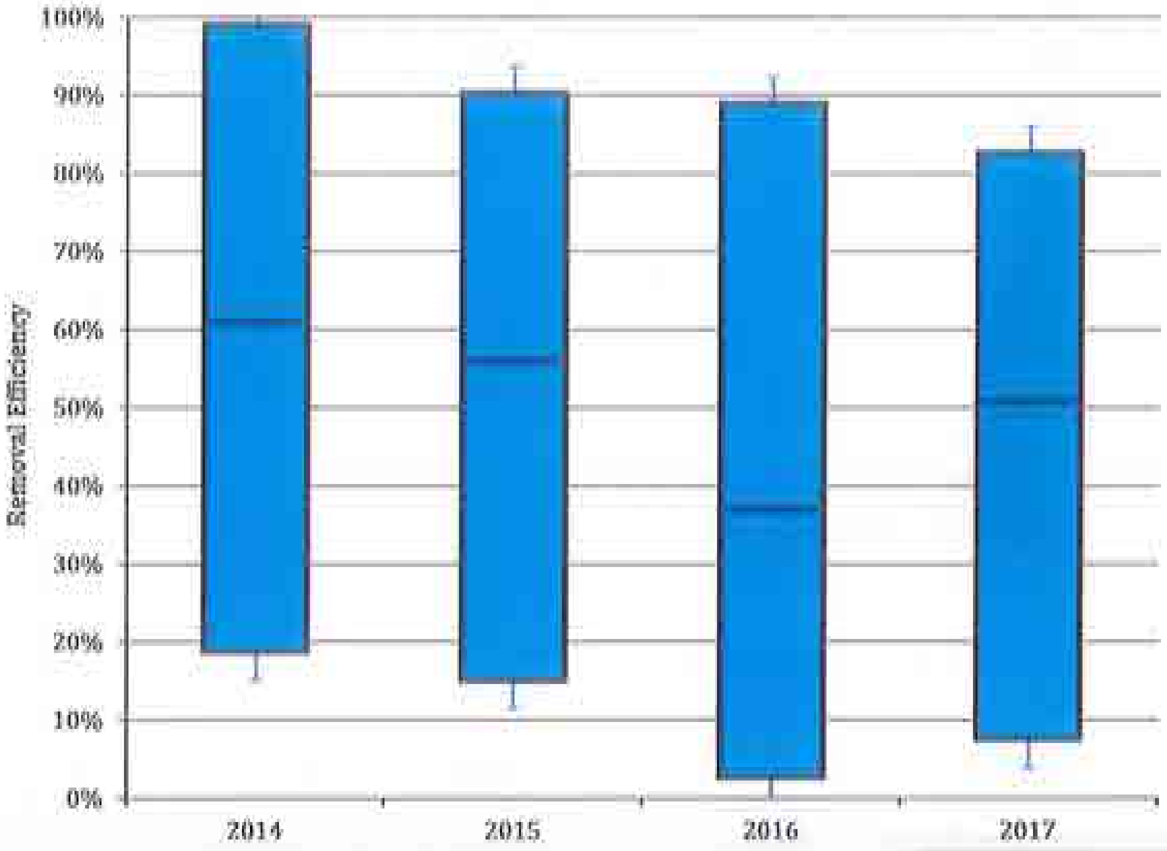


Figure 4-2 **Historic MC Removal Efficiency of PAC**

Figure 4-3 presents results from an earlier jar test done for raw water at Lake Erie. The figure shows varying influent extracellular MC concentrations (42.2 µg/L, 36.5 µg/L, and 21.5 µg/L, etc.) at 0 mg/L PAC dose, and the effluent MC concentration after treatment with the indicated PAC dose. The results of this test show the direct impact that a range of PAC doses have on MC concentrations. With the addition of 5 mg/L of PAC alone, and a 5-hour contact time which is representative of the time it takes for the water to travel from the LSPS to the plant, PAC was able to reduce 42.2 µg/L of MC to 5.5 µg/L. A low dose of 5 mg/L reduced MC concentration by 87%. With the capability of adding 8 times that dose, PAC is a significant treatment barrier for MC.

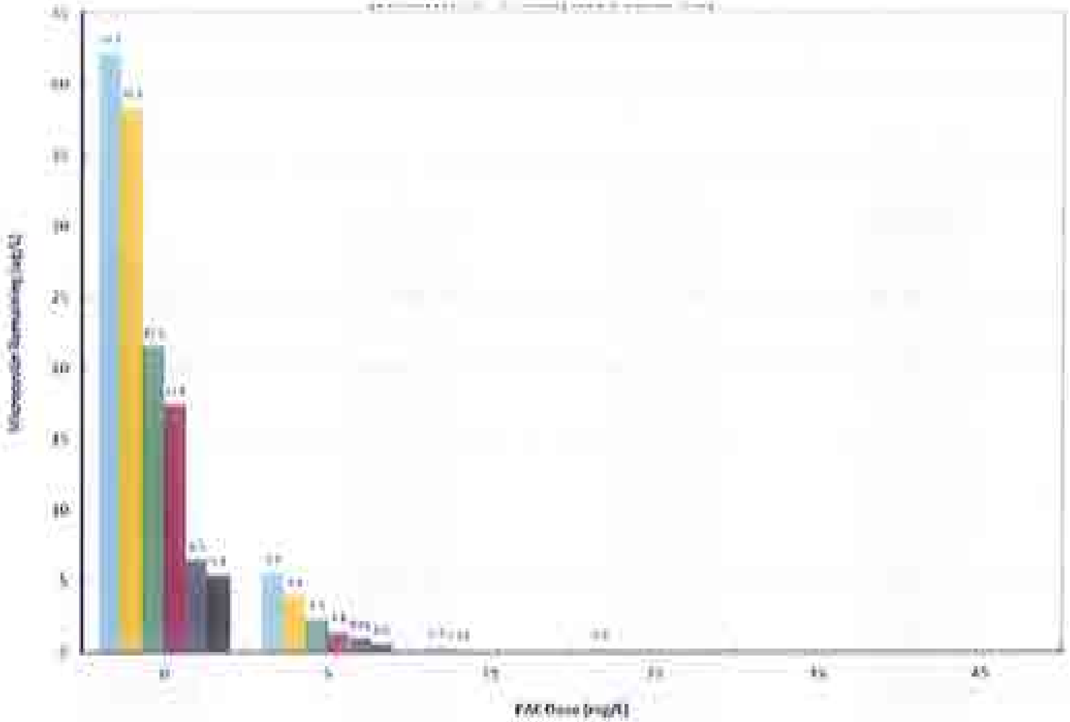


Figure 4-3 PAC Performance Jar Test[1]

The practice has been that based on several monitored water quality parameters, the LSPS PAC dose is increased. For example, as pH increases, a possible sign of an oncoming HAB event, PAC is proportionally increased even before an ELISA test can confirm the concentration of MC in order to be proactive in the treatment of MC.

The primary location for PAC feed at the plant is at the LSPS. When the PAC feed rate is ramped up at the pump station, there is time for the PAC to settle out of the water during sedimentation prior to the filters. Sweep coagulation is currently used to provide high levels of PAC removal during sedimentation.

The settled water PAC feeding system was added to the WTP in 2015 to provide an additional barrier to MC. During an HAB event, the plant has ability to feed up to an additional 6 mg/L of PAC to the third pass of the flocculation basins. When the settled water [illegible] not have as much time to settle out of the water prior to entering th[illegible]

---

[1] The different bars represent different initial MC concentrations. The concentrations are displayed over the first set of bars when 0 mg/L of PAC is added.

applied water turbidity and reducing the filter run times. The practical dose limit that maintains low filter effluent turbidity is 2 mg/L during HAB season.

4.1.3.3 Optimization of Softening

After preliminary treatment with permanganate and PAC, the water at the WTP is mixed with alum for coagulation, lime to remove hardness, soda ash to remove non-carbonate hardness, and carbon dioxide to decrease the pH. After soda ash, the water is sent through a sedimentation basin which removes much of the intracellular MC. Removal efficiency of the softening process at the WTP is presented in Figure 4-4. The softening process is extremely effective at removing MC (likely entirely intracellular MC), with a historical average removal efficiency of 90%.

Softening practices do not change significantly during a HAB event because the hardness and alkalinity goals of the treatment plant have to be maintained to ensure a stable water quality in the distribution system.

Although the process can be expected to achieve greater than 90% removal of intracellular MC, it is expected to achieve 0% of extracellular MC.

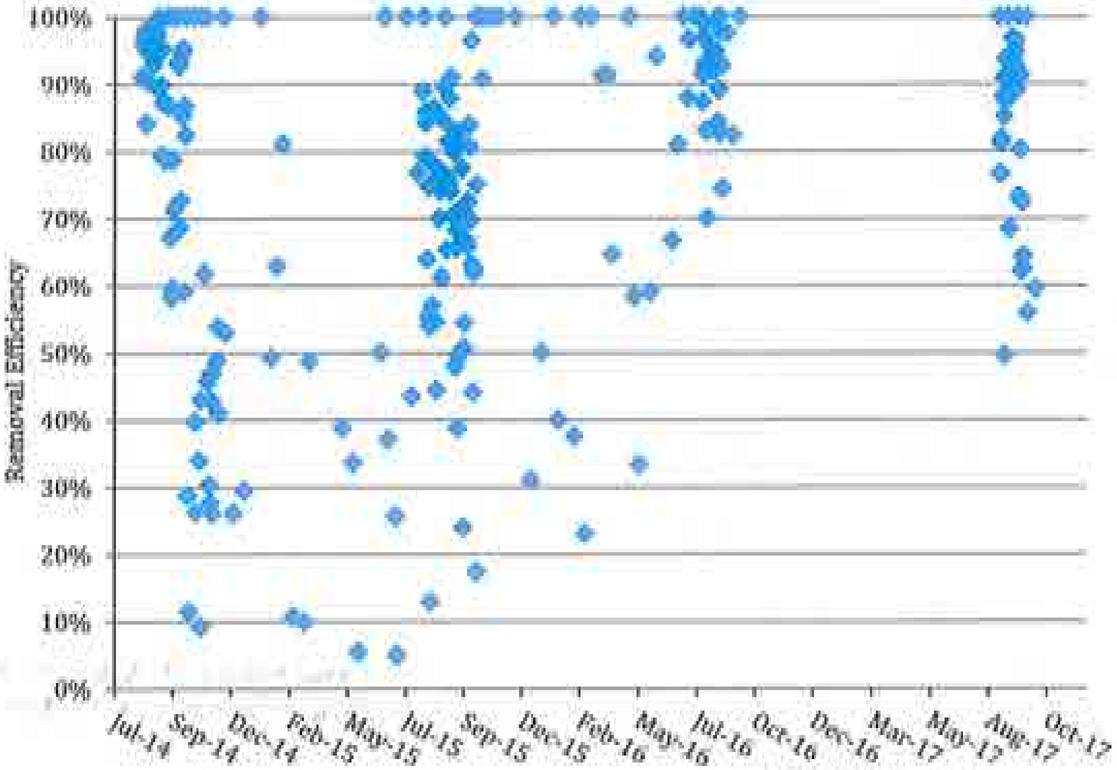


Figure 4-4 Historic MC Removal Efficiency through Softening Process

4.1.3.4 Filter Operation Optimization

Operational changes at the filters are known to remove MC. Currently at the beginnings of a HAB event, changes are made to the frequency of filter backwashes. If algae build-up is seen on the top of filters, backwashing occurs more frequently: every 40-90 hours as opposed to 80-120 hours.

Chlorine is also applied prior to the filters if there is algae build-up. Somewhere between 0.5 mg/L and 1.0 mg/L of chlorine is added for a 24 hour period at least if algae is seen in the filters.

4.1.3.5 Disinfection Optimization

Chlorine, the current primary disinfectant, is a very powerful oxidant and can significantly reduce whatever remains of the MC concentration once it has gone through all the other treatment optimizations. During the HAB event of 2014, disinfection through chlorine alone achieved a 75% reduction in MC, from 3.87 µg/L to 0.97 µg/L. Figure 4-5 presents the MC removal efficiencies achieved by chlorine disinfection alone.

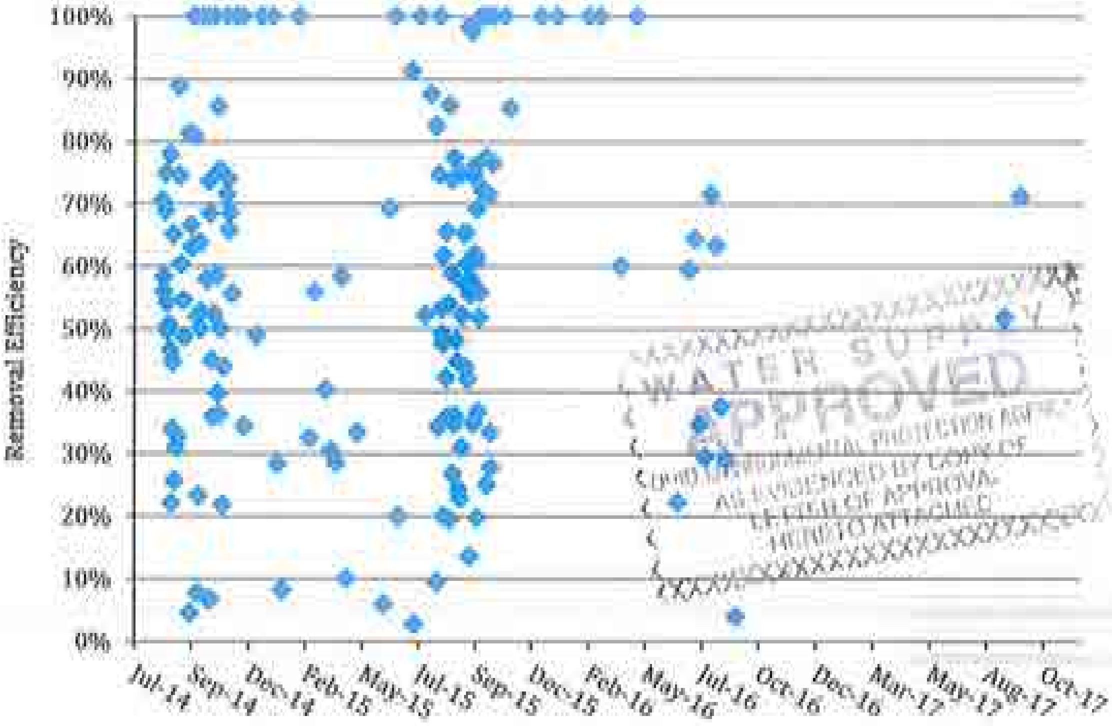


Figure 4-5 Historic MC Removal Efficiency of Chlorine Disinfection

Chlorine is increased based on the MC concentration so that a chlorine residual of at least 1.3-1.7 mg/L remains at the tap. While the chlorine residual does not exceed the 4 mg/L EPA limit, between 2.0-2.5 mg/L of chlorine is fed after sedimentation when high concentrations of MC are measured. If MC is still present at a significant concentration in the clearwell, more chlorine is dosed at the clearwell without exceeding EPA limits based on the existing residual.

The CyanoTOX calculator version 2, approved by the EPA, was used to predict the effects of chlorine on 100 µg/L of MC. Inputs to the calculator included a pH of 9.8 and temperature of 29 °C. The CT that was used for this evaluation was the historical minimum of the daily minimum CTs measured during previous HAB seasons: 146.3 mg-min/L. This CT is calculated based on one reservoir in operation while in reality the reservoirs work in series. However there is no flow meter between the East and West reservoir so CT credit is not calculated for the West reservoir. Hence, this CT of 146.3 mg-min/L is divided by 2 to represent the current CT operations resulting in a CT of 73.2 mg-min/L. At the request of OEPA, an additional safety factor of 2 is applied to this value when using the CyanoTOX calculator which results in a CT of 36.6 mg-min/L. At this CT and the above stated temperature and pH, the CyanoTOX calculated that chlorine could reduce 100 µg/L of MC to 74.9 µg/L, a reduction of 25.1%.

This low of a CT is not representative of the level of disinfection that has been typically observed at the WTP and would only be indicative of a situation the WTP failed to meet primary disinfection requirements. Section 5.1 discusses the predicted treatment of MC at various levels of MC concentrations by chlorine.

The CT calculations for the reservoirs is under discussion with OEPA and OEPA has suggested that flow meter(s) be added and calculate CT separately for each reservoir. This approach, while improving the CT calculations, is unlikely to provide increased CT credit through the existing infrastructure as CT would still be limited by the East Reservoir as the flow through that reservoir would still be higher given the current operational configuration.

A more rigorous study will be undertaken by the City to evaluate potential changes to the current reservoir operational strategy to optimize CT and Microcystin treatment. The study will evaluate the feasibility of installing flow metering devices to monitor flow in the filtered water conduits, evaluate parallel reservoir operation as an alternative to the current operational strategy, and determine the improvements necessary to implement any proposed changes. The City anticipates completing the study by September 30, 2019 (allowing for RFP, consultant selection, and contracting, if necessary).

Currently at the WTP, the water height at the clearwell is increased to optimize CT during an HAB event, so the removal efficiency of chlorine alone can be maximized. In addition, chlorine is the final treatment barrier for MC which means that, when the prior treatments are optimized as well, chlorine acts as a polishing barrier.

4.2 LONG-TERM TREATMENT OPTION

As part of the Basin 7 & 8 project, there were several alternatives initially considered to provide an additional treatment barrier for HAB events. The "Basis of Design Report of the Redundant Capacity Improvements Project" includes the complete evaluation but those alternatives have been summarized in this section.

4.2.1 Optimization of Permanganate, PAC, and Chlorination Processes

The first alternative included enhancements to the existing permanganate, PAC and chlorination processes at the plant, which could be completed in a relatively short time frame to prepare the plant to treat MC for HAB events in the near-term. These system improvements would provide the capability to apply up to 6.5 mg/L of potassium permanganate and 40 mg/L of PAC to the source water with the facilities at the LSPS, and up to 6 mg/L of PAC to the treated water in the third pass of flocculation at the plant. PAC jar testing on the raw water demonstrated that the MeadWestvaco PAC product currently used by the City was successful in removing large quantities of extracellular microcystin in the water. This alternative was selected as a short-term solution for the plant and then evaluated for effectiveness in the long-term as well.

4.2.2 Post Filtration GAC Contactors

The second alternative included the use of post filtration GAC contactors for treatment of MC. Bench scale studies confirmed that a lignite-based GAC was capable of reducing MC in the water down to acceptable levels and that the MC removal efficacy could be increased further once the filters become biologically-active. This alternative would include a new GAC contactor facility, a pump station to convey water from the filters to the contactors and to provide flow for backwashing the GAC, and equipment to replace the GAC, which would be required every two years. The life cycle cost for this alternative was much higher than the ozone alternative and was therefore excluded from the analysis.

4.2.3 Raw Water Ozone

Ozone is known to be a powerful oxidant. It is often used at water treatment plants for primary disinfection, T&O treatment, and treatment of algal toxins. Ozone has been considered and studied for its use at the WTP since the HAB event in 2014. Several ozone contactor locations were considered for this treatment technology, including the raw water pipeline. The main negative aspect of raw water ozonation is that it typically results in relatively high ozone demands due to higher TOC levels ahead of settling. This results in higher capital and operating cost. In addition, the presence of PAC and permanganate would be problematic as ozone is reduced by PAC and ozone reacts with manganese dioxide (reduced permanganate) to reform permanganate. Solids deposition in the ozone contactors was yet an additional complication potentially resulting in frequent cleaning of the contactors to maintain raw water quality. As a result of the higher life-cycle cost and increased maintenance of raw water ozone, intermediate ozone was selected as the preferred location to apply ozone.

4.2.4 Intermediate Ozone

An alternative ozone contactor location that was considered was downstream of the sedimentation basins, upstream of the filters. Implementing ozonation at this location will allow for a majority of the TOC to be removed prior to treatment, resulting in a lower ozone demand and lower operating cost when compared to the raw water dosing location. Two new contactor facilities, each containing two 40-mgd contactor basins with a 10-minute contact time, will be required for this alternative. The contactor facilities will be placed for both the West and East plants to minimize conveyance distance from the sedimentation basins to the facilities and then back to the filters. Intermediate pumping will be required to overcome the hydraulic constraints on the existing plant between the sedimentation basins and the filters during maximum and near-maximum day conditions.

The intermediate ozone alternative was determined to be the most viable option for implementation at the Collins Park WTP. This option provides the necessary ozone contact for oxidation of MC, has the additional benefit of T&O control, and fits within the current space availability at the WTP. In Section 5.2, a full process analysis of ozone and its treatment efficiency of MC as well as other design considerations are discussed.

5.0 Selected Alternative

The selected long-term alternative to treat MC in the water supply was to install intermediate ozone facilities at the WTP. Since design and construction of these new facilities will take some time, the existing PAC and permanganate feed systems at the LSPS, PAC feed system dosing to the third pass of the flocculation basins, and optimization of the disinfection system will continue to be used in the near-term.

5.1 EFFICIENCY OF OPTIMIZATION OF CURRENT TREATMENT PROCCESS

The optimization of the current treatment processes within the WTP is an effective and cost-efficient measure that can be taken to treat MC. As presented in Section 4.1.3, many of the process treatments have historically been able to treat MC individually to very low levels. But a few further improvements can ensure a more consistent and reliable multi-barrier approach to the treatment of MC. This includes:

1. Setting permanganate dosing at the intake to a level that is typically used to treat mussels and other organics. This permanganate dose is the first line of defense against high soluble MC concentrations without going as far as lysing the intracellular algal toxins. This higher dose could be adjusted to manage algal toxins (as needed or as required).
2. Increasing PAC dose at the LSPS is the next process to treat MC. PAC has been shown to be very effective in the treatment of MC as shown in Section 4.1.3.2. As shown by the bench-scale testing using COT water, even at low doses of PAC, high levels of MC removal can be achieved. Since MC cannot be calculated as fast as some of the indicator parameters (pH, temperature, chlorophyll, etc.), PAC is proportionally increased based on indicating parameter levels.
3. More frequent filter backwashing during a HAB event to limit algae build-up on the filters. Chlorine can be applied to the top of the filters at a low dose to provide MC oxidation.
4. Increase chlorine dose and reservoir elevation to maximize CT value. Increasing the clearwell depth will improve contact time and ensure a higher CT.

Figure 5-1 is a graphical representation of the historically achieved multi-barrier approach of the WTP. The maximum, average, and minimum removal efficiencies of each major treatment system during the HAB seasons from 2014 through 2016 were used to predict the removal capacity at the WTP in the case of 100 µg/L of extracellular MC. The chlorine treatment efficiencies are based on the maximum, average, and minimum CT achieved during HAB seasons, which was entered into the CyanoTOX calculator version 2 developed by Hazen-Adams. At the request of OEPA, to evaluate the worst case scenario, a safety factor of 2 was applied to the CTs prior to entering them into the calculator. These efficiencies are representative of treatment capabilities before the implementation of the above stated optimizations (i.e. PAC dose increase, chlorine dose increase, CT increase, etc.). With the further optimization of treatment processes, these efficiencies are likely to increase. Sedimentation is highly effective for removal of intracellular MC, but is not included because sedimentation will not remove extracellular MC.

The basis for the treatment conditions is as follows:

- PAC removal of 82 percent is based on use of the top of the box plot for the year of 2017 (Figure 4-2), which was the lowest removal of microcystin of the four years of data compared. Average and minimum removal is based on the removal efficiencies observed during previous four HAB seasons.
- Chlorine removal efficiencies are based on historical daily minimum chlorine CTs observed during previous HAB seasons. The worst case scenario, historical minimum removal, has an additional safety factor of 2 applied prior to using the CyanoTOX calculator version 2. A pH of 9.8 and temperature of 29, which are worst case conditions, were used in the CyanoTOX calculator.
- Settled Water PAC was not included in the evaluation as the effective dose is only 2 mg/L. Although would be applied and remove microcystin, the level of removal is relatively small in comparison to raw water PAC or chlorine.

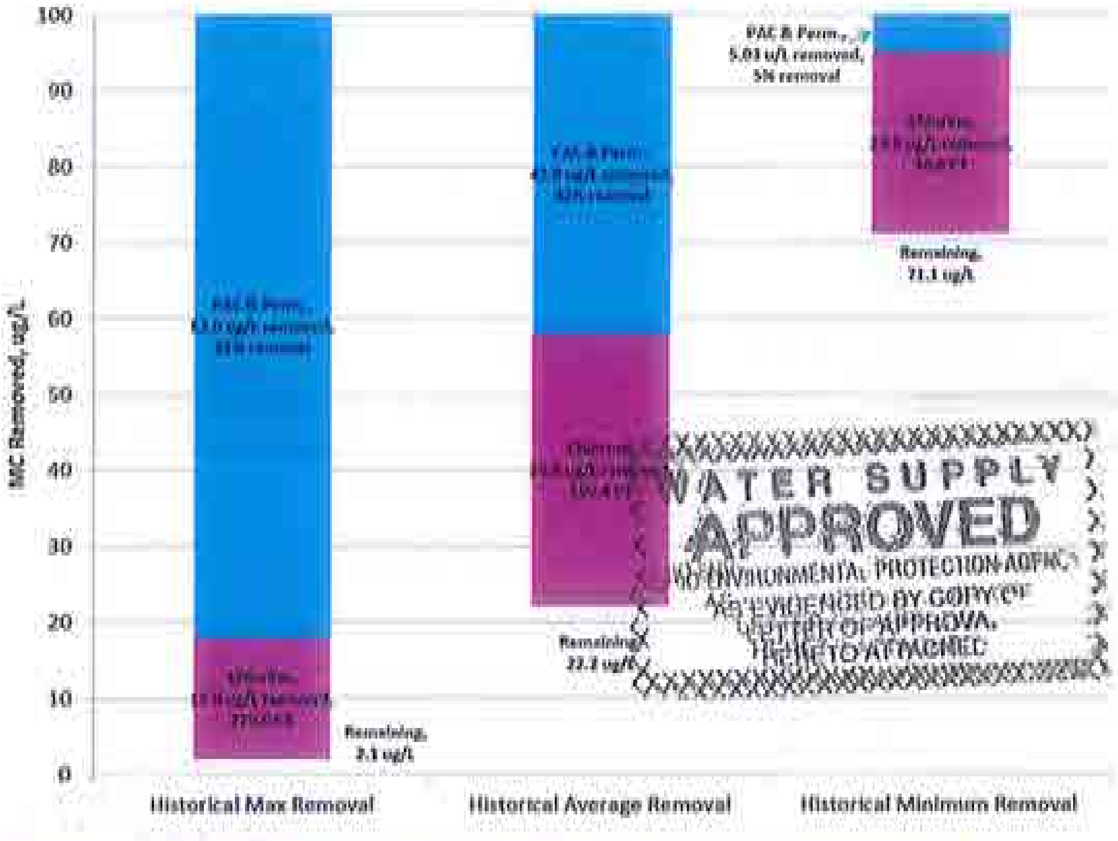


Figure 5-1 Historical Treatment Efficiency for Initial Extracellular MC of 100 µg/L

The worst case scenario represented in Figure 5-1is based on the historical minimum removals observed. While this scenario captures the effects of being ill-prepared for an HAB event or a case when the operators are not aware of the HAB event, it is not representative of standard operation at the WTP. The standard operations protocol (SOP) for an algal bloom event would require the highest level of treatment be applied from each treatment process. While the Health Advisory for

MC is not met based on historically observed treatment efficiencies at the worst case scenarios, the historical minimum removal scenario is likely never to occur at the WTP because SOP are in place to prevent it. Further, with proposed operational enhancements (increased low-lift pump station PAC dose, increase backwash frequency, and operation of the clearwells nearly full) to the treatment processes, the treatment efficiencies of the various processes are likely to substantially increase and further protect the Toledo population from MC contamination.

While this multi-barrier approach will significantly reduce MC levels during HAB events, a long-term treatment option will be adopted to achieve lower MC levels and provide increased treatment confidence.

5.2 EFFICIENCY OF OZONE

Ozone has been proven through studies, tests, and multiple analyses to be a highly effective treatment option for MC. The ozone treatment facilities at the Collins Park WTP are currently in the design phase. Section 6.0 will describe the schedule for when ozone can begin to be used as a treatment barrier for MC. Ozone will be added to the WTP after recarbonation and before filtration. The following sections will describe the tests that were conducted in order to determine the optimal ozone dose to treat MC levels at the WTP as well as the ozone system design.

5.2.1 Determining Ozone Design Dose

5.2.1.1 Bench-Scale Testing

Multiple rounds of bench-scale testing were conducted at different water qualities to determine the ozone dose required to overcome the initial oxidant demand exerted by different constituents while also treating MC. The main water quality constituent that competes for ozone is TOC. The bench-scale tests used waters with a range of TOC concentrations to select the design ozone dose of ozone needed to treat MC.

The bench-scale testing performed in 2014-2015 tested water with varying water qualities. Temperature, pH, and TOC were varied to determine what ozone dose would be required to treat 50 µg/L of MC. Though the MC concentrations tested did not reach levels as high as expected, the test results did provide value in understanding how ozone reacts under varying TOC conditions.

In the water used for bench-scale testing, TOC ranged from the 30th to the 90th percentile in historically observed settled TOC. As Table 5-1 presents, at a MC concentration of 35 µg/L and a TOC of 2.5 mg/L (greater than the 90th percentile of settled water TOC seen historically at the WTP), a transferred ozone dose of 1.2 mg/L was able to reduce MC concentrations to non-detectable levels (ND) of < 0.1 µg/L. This testing was useful in determining the ozone demand, decay, and the correct ozone dose to treat MC.

In 2017, further bench-scale testing was completed to test ozone treatment of higher concentrations of MC. The results of this testing are shown in Table 5-2. In Jars 3 and 4, where the MC concentrations were upwards of 80 µg/L, an applied ozone dose of even 1 mg/L reduced the MC concentrations to ND levels. Though the TOC levels were not quite as high (the highest was the 80th percentile of historical settled water TOC), even a 1 mg/L ozone dose was able to surpass the TOC demand and treat high MC levels.

During one series of tests, Jar 2 (J2) from the 2017 testing was to represent the capability of ozone to treat actual algal toxins, as opposed to the lab-grade MC that is spiked into WTP waters. However, the method of concentrating the naturally-occurring MC also concentrated the TOC to very high, atypical concentration (more than three times the historical maximum). Therefore, the results of JZ testing are considered to be representative of the treatment capabilities of ozone (ozone effectively oxidizes MC at conditions less than ozone demand), but not representative of TOC levels expected in the settled water at the Collins Park WTP. The tested design doses would not be expected to be capable of effective treatment when the TOC is several times higher than the historical values.

Table 5-1 2014-2015 Bench-Scale Testing Results

Location	12/18/2014			08/17/2015			09/14/2015			09/14/2015		
pH	9.7			9.7			9.9			9.9		
Total Organic Carbon, mg/l	1.4 (30th Percentile TOC)			2.5 (~90th Percentile TOC)			1.9 (~65th Percentile TOC)			1.9 (~65th Percentile TOC)		
Bromide, µg/l	23			17			20			20		
Ozone Dosage, mg/l	1	2	3	1.2	2	3	1	2	3	1	2	3
Influent MC, µg/l	20			35			6.3			10		
Effluent MC, µg/l	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.14	0.15	0.14
Oxidation Efficiency, percent	>99.5%	>99.5%	>99.5%	>99.7%	>99.7%	>99.7%	>98.4%	>98.4%	>98.4%	98.6%	98.5%	98.6%
Initial Residual, mg/l	0.3	0.9	1.3	0.48	0.81	1.18	0.29	0.95	1.91	0.31	1.07	1.47
Bromate, µg/l	ND	2.8	6.4	0.5	2.2	5.1	0.5	2.4	6.1	-	-	-

Table 5-2 2017 Bench-Scale Testing Results

		Eurofins Test Results			Toledo ELISA Results[2]		B&V Results		
		MC-LR	Bromate	Bromide	Results (1st run)	Results (2nd run)	Initial Ozone Residual	TOC	O3/TOC Ratio
	Sample Name	µg/L	µg/L	µg/L	µg/L	µg/L	mg/L	mg/L	
J1- Control, Plant settled water plus lab grade MC	J1 Softened			25				1.21	
	J1 MC Spiked	38							
	J1-Oz 1 mg/L	0.13	2.4				0.53		0.06
	J1-Oz 2 mg/L	ND	6.8				1.15		
	J1-Oz 3 mg/L	ND	13				1.7		
J2- OEPA Initial Concentration of MC diluted with 2 parts Raw w/PAC and Lab grade MC spike[1]	OEPA concentrated MC (~120 ug/L)	45			145.35	145.1			
	Raw w/PAC + Natural MC + Lab Grade MS (J2 Raw)	43			37.4	21.6		28.7	
	J2 Softened	40			50.65	41.7		13.5	
	J2 Softened + Filtered				46.65	48.85		12.3	
	J2- Oz 2 mg/L	13	ND		18.9	17	0		
	J2-Oz 3 mg/L	13	ND		24.9	19.45	0		
	J2-Oz 6 mg/L	0.16	ND		1.026	0.891	0		
J3- Raw water w/o PAC spiked with lab grade MC	J3 Raw							5.36	
	J3 Softened + MC Spiked	86						2.1	
	J3-Oz 1 mg/L	ND	ND		<0.30	<0.30	0.42		0.157
	J3-Oz 2 mg/L	ND	1.7		<0.30	<0.30	1.07		
	J3-Oz 3 mg/L	ND	5.3		<0.30	<0.30	1.69		
J4- Raw water w/PAC spiked with lab grade MC	J3 Raw							4.12	
	J4 Softened + MC Spiked	89						1.27	
	J4-Oz 1 mg/L	ND	1.4				0.69		0.016
	J4-Oz 2 mg/L	ND	5.5				1.36		
	J4-Oz 3 mg/L	ND	10				2.04		

[1] Testing for J2 is not representative of full scale results since TOC value, 12.3 mg/L, was several times greater than historical maximum settled water TOC concentration 3.8 mg/L. The high TOC is the result of concentrating the MC also resulted in concentrating the TOC. The results are not considered for the COT ozone system design because they are a condition that is not representative.

[2] Toledo ELISA results include all variants for MC.

5.2.1.2 Ozone Demand

Initial ozone residual is plotted against applied ozone dosage for all of the testing periods in Figure 5-2 and the calculated ozone demands are shown in Table 5-3. Ozone demand is a useful parameter in selection of the design ozone dose as the ozone to TOC ratio can be applied to waters with differing levels of TOC. The range of ozone demand was between 0.1 to 0.56 mg/L for the range of tests performed which translates into an ozone to TOC ratio of <0.1 to 0.28 mg ozone per mg TOC.

The demand figures are valuable when predicting initial dissolved ozone residual for any given ozone dosage. When additional ozone is applied, only a fraction of it is actually observed as an increase in dissolved ozone residual. The slope of the lines in Figure 5-2 illustrate this concept: for every additional 1 mg/L ozone applied, the increase in dissolved ozone residuals is 0.5 to 0.7 mg/L. This is useful in establishing the design ozone dosage, since process control will rely on obtaining an initial dissolved-ozone residual. Obtaining an initial dissolved ozone residual of 0.3 mg/L was demonstrated to achieve complete microcystin removal during bench-scale tests, as shown in Table 5-1 and Table 5-2. Therefore, after ozone demand is met, an additional 0.4 to 0.6 mg/L of ozone is assumed to be applied to achieve the above mentioned initial residual of 0.3 mg/L and provide greater than 99 percent oxidation of microcystin. The demand ratio of the 2015 testing was more consistent than the other periods, so a slope of 0.6 mg ozone residual per mg of ozone applied above demand was used to determine the design dosage.

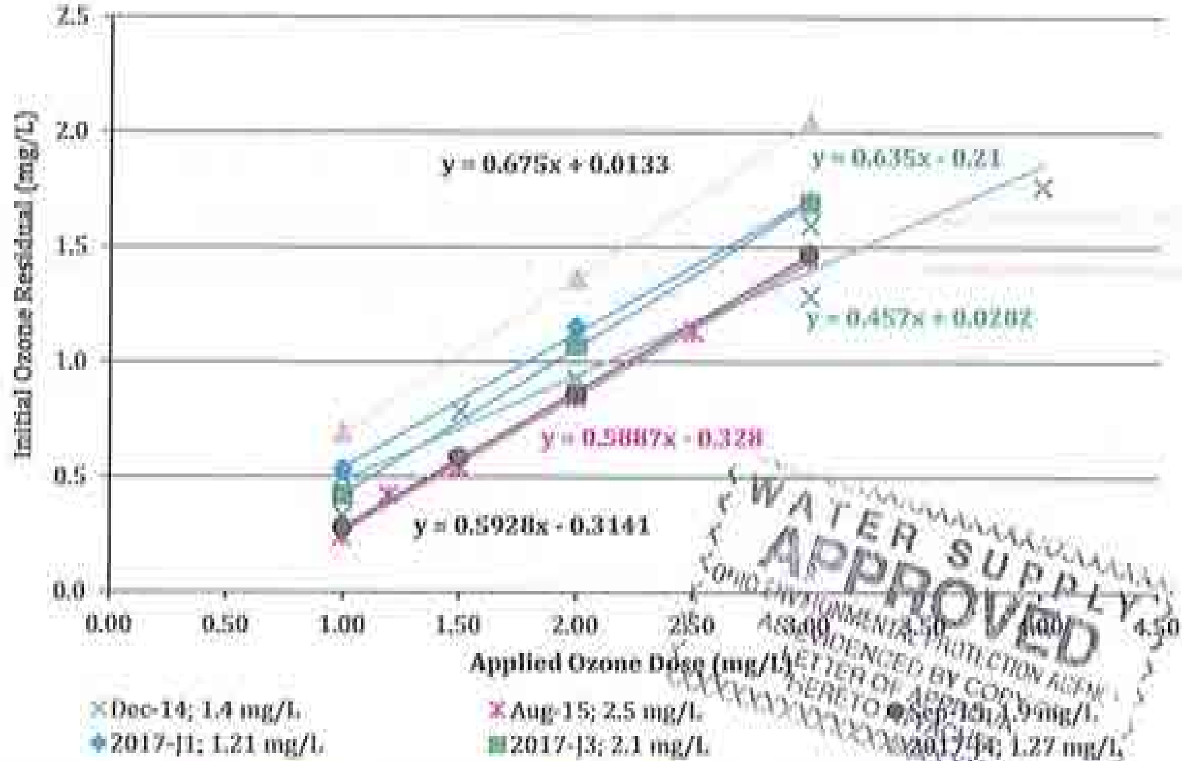


Figure 5-2 Initial Ozone Residual Based On Ozone Dose; (date of testing; settled water TOC)

Table 5-3 **Ozone Demand Calculated During Bench-Scale Testing**

SAMPLE	OZONE : TOC RATIO
Dec 2014	0.04
Aug 2015	0.22
Sep 2015	0.28
2017- J1	0.06
2017- J3	0.16
2017- J4	0.02

5.2.1.3 DBP Formation Mitigation

Bromate is a disinfection byproduct (DBP) formed through oxidation of naturally occurring bromide with ozone. Factors that impact bromate formation include the following:

- pH: In general, higher pH results in more bromate formation.
- Ozone exposure (CT): In general, higher ozone residuals (and resulting CT values) result in more bromate formation.
- TOC: In general, higher TOC results in less bromate formation, as ozone reacts with the organic compounds first (resulting in a lower ozone residual and CT value).

The bromide concentration during all the testing periods ranged between 17 to 42 µg/L. Bromate values are illustrated in Table 5-1 and Table 5-2.

Ozone dosages less than 2 mg/L produce bromate levels less than the MCL of 10 µg/L. Operationally, the 2 mg/L condition that resulted in the highest bromate formation (2017-J1) also had one of the lowest ozone demands and resulted in an initial dissolved ozone residual of 1.15 mg/L. This is a clear indication of overdosing, as conditions that had 0.3 mg/L of initial dissolved ozone residual were demonstrated to meet complete oxidation of microcystin. The easiest and most effective strategy to manage bromate formation is dosage control and operating at conditions nearer to an initial dissolved residual of 0.3 mg/L, which clearly result in bromate levels well below the MCL. Bromate mitigation strategies were not tested as dosage control was found to be effective to control bromate formation.

A 5-day simulated distribution system (SDS) test was performed on ozonated settled water at the WTP to predict effects of ozone on chlorinated DBP formation. Settled water was dosed with 2 mg/L of ozone and varying doses of chlorine and held in the dark at room temperature (20° C) for 5 days to simulate distribution system conditions. Samples were analyzed for total-trihalomethane (TTHM) and five haloacetic acids (HAA5s) at the end of the hold time. The ozonated samples were compared to non-ozonated settled water samples that were also dosed with varying amounts of chlorine.

Table 5-4 presents the results of the 5-day SDS testing. The federal maximum contaminant level (MCL) for TTHMs and HAA5s are 80 µg/L and 60 µg/L, respectively.

Table 5-4 5 Day SDS Testing Results

5-DAY SDS TESTING						
WATER SOURCE	SETTLED WATER			OZONATED SETTLED WATER		
Chlorine Dose (mg/L)	1.5	2.0	2.5	1.5	2.0	2.5
5 Day Chlorine Residual (mg/L)	0.54	1.11	1.47	0.32	0.8	1.29
TTHMs (μg/L)	72.0	76.0	82.0	93.0	99.0	97.0
HAA5s (μg/L)	9.6	9.6	12	14	15	14

In the single SDS test completed on COT water, treatment by ozonation appears to result in an increase in TTHMs and HAA5s. The increase in TTHMs is problematic as it resulted in a value over the annual locational running annual average limit of 80 μg/L. The increase was nominally 20 μg/L or 25 percent. The increase in HAA5 is much less problematic as values remained well below the MCL. Additional investigation is required to validate the results and if necessary investigate means to decrease TTHM formation that may include additional TOC removal, optimization of biofiltration, installation of GAC filter caps, or removal of TTHMs through aeration. It is worth noting the CPWTP will operate their filters as biofilters upon implementation of ozonation. Biofilters would remove more TOC and lower TTHM and HAA5 levels. That process component is not illustrated within this dataset. The COT is currently developing a strategy to test the potential for DBP mitigation through biofiltration downstream of ozone treatment to ensure that DBPs will not become an issue in the water supply once the ozone system is activated.

Additional bench-scale testing is being performed to: 1) Verify that an increase does occur, 2) the frequency of that outcome over the course of the year, and 3) quantify the impact biofiltration following ozonation has on TTHM formation. If the outcome of those tests support that an increase in TTHMs will occur, treatment strategies will be implemented to ensure compliance with TTHM limits.

5.2.1.4 Design Ozone Dosage

The settled water ozone dose for the Collins Park WTP was calculated using the following equation:

$$Ozone\ Dosage = TOC \times 0.34 + \frac{C_I}{0.60}$$

Where:

$Ozone\ Dosage$ = Transferred Ozone Dosage, mg/L

TOC = Settled water TOC, mg/L

0.34 = Ozone to TOC ratio, mg ozone per mg TOC

C_I = Target initial dissolved ozone residual, mg/L

0.6 = Ratio of ozone residual to the ozone applied, unitless

The design ozone dosage is recommended based on the following[2]:

- The 99th percentile settled water TOC concentration from the entire 2001-2017 dataset during HAB season is 3.1 mg/L. To incorporate a safety factor, a settled water TOC of 3.5 mg/L was used for the design ozone dosage calculations. This is representative of the TOC concentration if the PAC feed system were offline, even though this system includes redundancy.
- The maximum observed ozone to TOC ratio during bench scale testing (0.28) plus a 20 percent safety factor resulting in a ratio of 0.34.
- A 0.3 mg/L dissolved ozone residual, which requires an additional 0.5 mg/L transferred ozone. The ratio of 0.3 mg/L to 0.6 (unitless) represents the amount of ozone that will need to be added to achieve the desired residual (see Section 5.2.1.2 for further explanation).

The resultant transferred ozone dosage was calculated as follows:

$$3.5\ mg/L \times 0.34 + \frac{0.3\ mg/L}{0.6} = Ozone\ Dosage\ = 1.69\ mg/L$$

The applied ozone dosage is 1.8 mg/L assuming a transfer efficiency of 95 percent. At this dose, a firm production capacity of 2,400 ppd would be required at a plant operating capacity of 160 mgd. At this production capacity and a flow of 140 mgd, the applied dose would be 2.05 mg/L and the transferred dose would be 1.95 mg/L.

Previous discussion included a request to determine the maximum settled water TOC that would likely still provide high level (> 99%) microcystin removal with ozone. The mathematical means to illustrate that are included in Table 5-5. The TOC values that would be expected to still achieve greater than 99% MC oxidation were calculated using the original dosage selection calculation as well as a ratio of two of the bench-scale tests that had the highest level TOC.

Eliminating the demand safety factor and applying the above equation to solve for TOC using the true transferred ozone dosage at 140 mgd, 1.95 mg/L, a TOC of 5.1 mg/L should still provide very high level (>99%) MC removal.

The two best bench-scale data sets from which to extrapolate the TOC data to illustrate high level MC removal are also included in Table 5-5. The result of those calculations illustrates a settled water TOC level of 4.1 mg/L. Even at TOC levels above, 4.1 mg/L, MC will continue to be removed; however, the data is not available to mathematically demonstrate what level of treatment will be achieved. Some level of treatment would continue to be achieved at higher settled water TOC.

---

[2] Technical Memorandum No. 1 (TM1), from February 1, 2017, provides thorough detail regarding the calculations used to determine the required ozone dose for the CPWTP. Refer to TM1 for further detail.

Table 5-5 Calculated TOC level while Achieving Greater Than 99% MC Reduction

BENCH-SCALE TEST SAMPLE	DESIGN APPROACH*	RATIO OF TOC AUG. 2015	RATIO OF TOC 2017-J3
Transferred Ozone Dose	1.95 mg/L	1.2 mg/L	1.0 mg/L
Settled Water TOC	Calculated	2.5 mg/L	2.1 mg/L
Percent MC Removal	>99 percent	> 99.7 percent	> 99.6 percent
Design Transferred ozone dose (at 140 mgd)	1.95 mg/L	1.95 mg/L	1.95 mg/L
Calculated TOC Capable of 99% MC removal at the Design Ozone Dose:	5.1 mg/L	4.1 mg/L	4.1 mg/L
Calculation:	$\frac{1.95\ mg/L - (0.3\ mg/L\ /\ 0.6)}{0.28 \frac{mg\ O3}{mg\ TOC}}$	$\frac{1.95\ mg/L}{1.2\ mg/L} \times 2.5 \frac{mg}{L} TOC$	$\frac{1.95\ mg/L}{1.0\ mg/L} \times 2.1 \frac{mg}{L} TOC$

*Safety factors were removed to illustrate difference between the design value (3.5 mg/L) and the value supported directly by bench-scale testing results.

With the addition of ozone, the MC removal efficiency of the whole WTP will increase. The multi-barrier approach represented in Figure 5-1 has been updated with the removal efficiencies expected to result from the addition of ozone. Figure 5-3 presents the expected treatment efficiencies within the plant after the addition of ozone using the average removal efficiency observed during the 2014 HAB event and the predicted maximum removal. Ozone is assumed to achieve 99 percent reduction although higher levels (99.7%) have been observed during bench-scale testing. With the addition of ozone, a HAB event that produces 100 µg/L of MC can be treated to below detection limits at the average and maximum treatment efficiencies. Considering that the treatment processes will be enhanced (increased low-lift pump-station PAC dose, increased backwash frequency, and increased water elevation in the reservoirs), as described in the short-term treatment section, adding ozone as a treatment process will reduce MC concentrations to below detection in all scenarios. At the minimum treatment condition, the microcystin level would be just above 0.3 ug/L, but that is only after a failure to meet SOP requirements for both PAC and chlorine and the application of a 2-fold safety factor to chlorine treatment. The minimum conditions is highly unlikely requiring that COT would fail to meet primary disinfection and COT has in place SOPs to ensure that situation cannot occur.

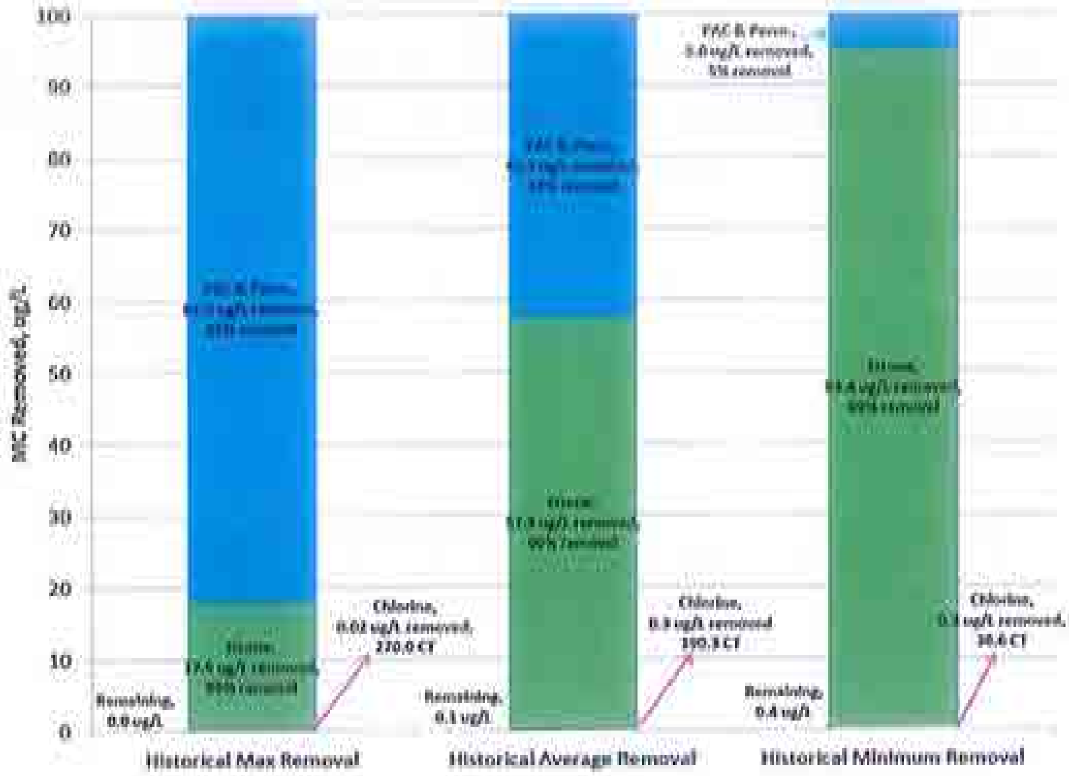


Figure 5-3 Treatment Efficiency for Initial Extracellular MC of 100 µg/L with Ozone

5.2.2 Ozone Infrastructure Design

The ozone system will include a Liquid Oxygen (LOX) Storage Facility, an Ozone Generation Building, two Ozone Contactor Facilities (West and East), and a Chemical Feed System. The effluent water from existing Basins 1-4 will flow to the West Contactor Facility, and the effluent from existing Basins 5-6 and future Basins 7-8 will flow to the East Contactor Facility to be treated with ozone prior to filtration. The Process Flow Diagrams for each Contactor Facility have been included in Appendix A. Each of the new facilities has been described in further detail below. The description includes the specified design values. Following is the dosage capacity when the safety factors are exposed and standby equipment utilized. This illustrates that the system is capable of delivering much more ozone than specified.

- Liquid Oxygen (LOX) Storage Facility: Ozone will be produced on-site using high purity oxygen stored in two (2) new 11,000 gallon pressurized and insulated storage tanks as LOX. Space for a third tank will be included. LOX will be converted to gaseous oxygen (GOX) through the use of one of three ambient vaporizers, each with a rated capacity of 160 scfm. Each vaporizer will be sized to deliver at least 110 percent of the system demand during the peak operating condition at 2,400 ppd of ozone and a 12 percent weight (12% wt.) concentration. Downstream from the vaporizers, the GOX will be conveyed through an orifice plate flow meter, followed by one of two oxygen particulate filters. The GOX will then flow through the pressure reducing station, which will reduce the pressure from a range of 75-130 psig to 15-20 psig.

- Ozone Generation Building: The ozone generation building will contain three (3) ozone generators, each of which will have a dedicated Power Supply Unit (PSU). Each generator will include a purge connection that will allow the gas to be conveyed to the Ozone Purge Destruct Unit to remove ozone gas from the generating vessels during a startup/shutdown oxygen cycle. The generators will be configured to discharge into a header that conveys gas to the East and West Contactor Facilities. The Ozone Generation Building will be designed such that the building can be expanded to add a future fourth generator if needed due to unforeseen water quality changes. A closed loop-type cooling water system, comprised of pumps, heat exchangers, an air separation vessel and an expansion tank, will be installed to supply cooling water to the generators and the PSUs. A supplemental compressed air system will be included as part of the ozone generation system to add nitrogen (from air) to the gas stream to increase system efficiency.

- Ozone Contactor Facilities: Gas flow will be controlled to each basin using thermal mass flow meters and a modulating v-port ball valves. Each contactor basin will have a dedicated gas valve train, with a redundant flow meter and modulation v-port ball valve, for a total of three trains within each facility. Process water will flow into two separate Ozone Contactors at the West and East Ozone Contactor Facilities through settled water flumes, located downstream from the sedimentation basins at the plant. Ozone gas will be fed to each ozone contact basin utilizing a sidestream injection system via a pipeline flash reactor (PFR). The sidestream systems will pump a small portion of the process stream through venturi injectors, which will draw ozone gas under vacuum into the high velocity sidestream flow. The ozonated sidestream will be conveyed into the main process stream through sidestream nozzles, supplied individually by dedicated ozone injector assemblies and sidestream pumps, to the PFR and mixed with the bulk flow upstream from the ozone contactor basins. The ozone dissolution system for each contactor basin will provide at least 95 percent ozone transfer efficiency at the maximum production rate. The bulk flow will pass through a baffle wall and into the ozone contactors with a minimum hydraulic residence time of 10-minutes before exiting through another baffle wall and entering the Low Lift Pumping Station wetwell. Each Contactor Facility has one shared wetwell, which is the common effluent for both contactor basins. The water will typically flow through the ozonated water flumes into the filter gallery by gravity via two (2) slide gates. During periods of higher demands, the water will be pumped through two of three Low Lift Pumps to meet the higher required hydraulic grade line condition. Three (3) ozone destruct units will be provided for each Ozone Contactor Facility in order to reduce the ozone concentration in the off-gas to levels suitable for discharge to the atmosphere.

- Chemical Feed: Calcium thiosulfate, if needed, will be used to quench the ozone residual at the outlet of each contactor basin. Each Ozone Contactor Facility will have two drums to store the chemical and three pumps. Calcium thiosulfate will also be used to dechlorinate the filter backwash water to improve biofiltration performance. A chemical tote and day tank will be provided to store the chemical, and two metering pumps will be installed.

The ozone system was designed to allow for redundancy so the system will be capable of treating the water at any time, as illustrated in Table 5-6. In addition to the allowed redundancy in the new ozone system, the design includes room for expansion in case additional capacity is required in the future. Specifically, these planning efforts accounted for the facilities listed out below.

- Space will be left available for the addition of a 3rd LOX tank in the LOX Storage Facility in anticipation for additional ozone capacity.

- A knockout wall in the Ozone Generation Building for a fourth generator.
- Space for larger sidestream pumps, injection piping and destruct equipment will be left at each of the Ozone Contactor Facilities in order to match future dispersion requirements of the fourth generator .
- The electrical room at these facilities are designed such that there is room for additional gear to match the future loads.

Table 5-6 Ozone Infrastructure Component Summary

LOCATION	EQUIPMENT	NUMBER
LOX Storage Facility	LOX Storage Tanks	2 Future: Space for future third unit
	LOX Vaporizers	3 (1 duty, 1 defrost, 1 standby)
Ozone Generation Building	Ozone Generators	3 (2 duty, 1 standby) Emergency Space: Electrical connection available and fourth generator can be housed in maintenance pathway Future: Building includes knockout wall to accommodate future fourth generator.
	Closed-Loop Heat Exchangers	2 (1 duty, 1 standby)
	Closed-Loop Water Pumps	3 (2 duty, 1 standby)
Ozone Dissolution System	Gas Train Manifolds	6 (3 per Contactor Facility: 2 duty, 1 standby)
	Sidestream Pumps	10 (5 per contactor complex: 4 duty, 1 common standby)
	Sidestream Injector Trains	10 (5 per contactor complex: 4 duty, 1 common standby)
	Pipeline Flash Reactor	4 (1 per contactor)
	Ozone Destruct System	6 (3 per contactor complex; 2 duty, 1 common standby)
	Low Lift Pumps	6 (3 per contactor complex; 2 duty, 1 common standby)

LOCATION	EQUIPMENT	NUMBER
Chemical Feed	Quench Chemical Metering Pumps (Ozone Contactor Basin)	6 (3 per Contactor Facility: 2 duty, 1 standby)
	Quench Chemical Metering Pumps (Filter Backwash Supply)	2 (1 duty, 1 standby)

5.2.3 Ozone System Capacity Capabilities

The ozone system is actually capable of more ozone production than specified. This section describes the actual capacity at the following conditions:

- Design Point. The design operating condition is at 12 percent weight (% wt) ozone concentration, utilizes firm capacity (largest unit out of service) and preserves all safety factors within the design.
- Peak Flow Condition. The condition is operation at 10% wt which allows higher production from the ozone generators but continues to utilize only firm capacity (largest unit out of service). This operating point is the maximum gas flow through the system as limited by the firm ozone destruct capacity.
- All Destruct Units in Operation. This is the same as the peak flow condition utilizing only firm capacity equipment with the exception that all ozone destruct units are in operation. Ozone off-gas destruct units are simple equipment comprising a heater, destruct catalyst, and blower. They have high availability and if needed, all units could be operated.
- Operation of All Equipment. This condition is operation of all installed equipment.

The gas flow capacity at each of these operating conditions, ozone concentration and resultant transferred ozone dosage at 140 mgd is listed in Table 5-7.

Table 5-7 Ozone System Design Capacity Description

DESCRIPTION	GAS CAPACITY, SCFM	PRODUCTION CAPABLE, PPD	TRANSFERRED OZONE DOSE, MG/L
Design Point (Firm Capacity at 12% wt)	167	2,400	1.95
Peak Flow Condition (Firm Capacity at 10% wt)	246	2,930	2.4
All Destruct Units in Operation (Firm capacity for all equipment with exception of ozone destruct units)	279	3,320	2.7
Operation of All Equipment (Installed Capacity at 11% wt)	301	3,940	3.2

When considering the design point, the limiting component is the most costly, the ozone generators and they have been sized to produce 1,200 ppd each at 12% wt ozone. This is a transferred ozone dose of 1.95 mg/L at the plant rated flow of 140 MGD.

If the ozone gas concentration is lowered, and gas flow increased, additional ozone generating capacity can be achieved. Operating the ozone generators at 10% wt is estimated to result in a production capacity of 1,660 ppd each, a 25 percent increase in capacity. Under firm-capacity conditions, the limiting factor then becomes the ozone off-gas destruct units. Although oversized by 30 percent, the gas flow vastly increases at that operating condition and the resultant maximum transferred ozone dose increases to 2.4 mg/L. Ozone off-gas destruct units are simple equipment comprising a heater, destruct catalyst, and blower. They have high availability and if needed, all units could be operated increasing the allowable transferred dosage to 2.7 mg/L (limited by the firm number of ozone generators, i.e., 2 generators).

Operating all installed equipment at an 11% wt concentration allows a transferred ozone dosage of 3.2 mg/L, approximately 65 percent higher than the design dosage. The operating condition then becomes limited by the gas control valves and conveyance pipelines.

5.2.4 Other Infrastructure Changes

In addition to the new ozone system design, the existing PAC silos near the flocculation basins will be relocated to the LSPS for additional supply at the primary feed location. If the redundant PAC feed to the third pass of the flocculation basins were to remain, the PAC may interfere with the ability of the ozone system to effectively remove trace MC in the water due to competing reactions that the PAC would exert on the ozone demand. After the ozone system is completed and the PAC feed to the flocculation basins is eliminated, the plant may reduce the need to use sweep coagulation and the filters will experience less clogging. This will result in lower costs for chemical dosing and more efficient filter runs. Additionally, after the redundant PAC feed to the sedimentation basins is removed, solids handling costs will be reduced since the quantity of solids generated in the plant will be reduced.

6.0 Schedule for Implementation

The COT and the Collins Park WTP have various projects occurring and planned for the future that will provide the multi-barrier approach for harmful algal blooms (HABs). Ozone treatment will be one of the larger components of this approach. Currently, the Collins Park WTP Ozone Treatment Facilities project is under design with construction commencing during the fall of 2018. The goal of the Ozone Treatment Facilities project is to have the capability of treating HAB toxins with ozone by August of 2020, which is when microcystin generally peaks in the raw water based on historical data. The construction schedule of the Ozone Treatment Facilities project will be influenced by other projects occurring at the WTP.

The proposed construction sequencing plan for the Ozone Treatment Facilities Project has the interconnection of the West Plant (Basin trains 1 thru 4) recarbonation basins to the new settled and ozonated water flumes planned for the winter of 2019/2020. This interconnection will allow the West Ozone Contactor Facility to receive water for testing during spring and summer of 2020, which provides the WTP with 80-mgd of ozone treatment capacity. For the East Ozone Contactor Facility, the Basins 7 & 8 Improvements project is anticipated for completion in April 2020, so that testing and startup of the new ozone system and initiation of system operation at a 120-mgd capacity can be completed by August 2020. Once Basins 7 & 8 are operable, the existing Basins 5 & 6 trains are planned to be shut down for approximately 8 months for major upgrades. Upon completion of the Basins 5 & 6 Improvements project, the Ozone Treatment Facilities Project would be fully tested, capable of 140 mgd, and reach final completion in 2021.

Below is a summary of the planned major milestones. Note that these milestones can be influenced by changes in design, contractor's work and equipment delivery schedules, other projects on site, and other unknown influences.

- Final Design – Completed by early May 2018, including OEPA review and approval
- Construction Contract Bid and Award – May to September 2018
- Construction Notice to Proceed – September 2018
- Development of HAB Treatment Optimization Protocol and Ozone Manual O&M- April 2020
- Ozone System Substantial Completion (without Basins 5 and 6) – August 2020
- Final Completion –February 2021

In addition to the Ozone Treatment Facilities project, there are other projects planned that influence the HAB multi-barrier approach. One such project is the relocation of the existing PAC silos that currently reside at the Collins Park WTP. These silos will not be relocated until after the ozone system is fully operational.

7.0 Summary

The COT has successfully operated the Collins Park WTP and has provided high quality potable water to the citizens of greater Toledo for over 75 years. Due to HAB events in recent years, the COT has developed a range of strategies to allow for continued production of safe drinking water for their customers. These strategies include both short-term and long-term solutions to address HABs in the water supply.

The short-term solutions include:

1. Source water management through various Lake Erie protection and restoration programs to mitigate nutrient loading and the associated algal blooms in the water source. These programs include nutrient removal at the Toledo WRF, the Toledo Waterways Initiative, the storm water management program, agricultural runoff management incentive programs, and continued public education and outreach.
2. Source avoidance through careful source water quality monitoring and sampling efforts, in addition to HAB forecasts.
3. Optimization of the current treatment process at the WTP, including:
    a. Increased potassium permanganate dose for treatment of zebra mussels and other organics.
    b. Increase PAC dose at the low-lift pump station at a rate that is based on the HAB indicating water quality parameters at the raw water.
    c. Increase filter backwash frequency to ensure high efficiency filter runs during HAB events.
    d. Increase the primary chlorine dose to achieve disinfection and MC inactivation requirements, and utilize the clearwell chlorine dose as necessary to achieve the required residual and as an additional MC barrier. Also, increase the clearwell water level to optimize CT during an HAB event in order to maximize the removal efficiency through chlorine alone.

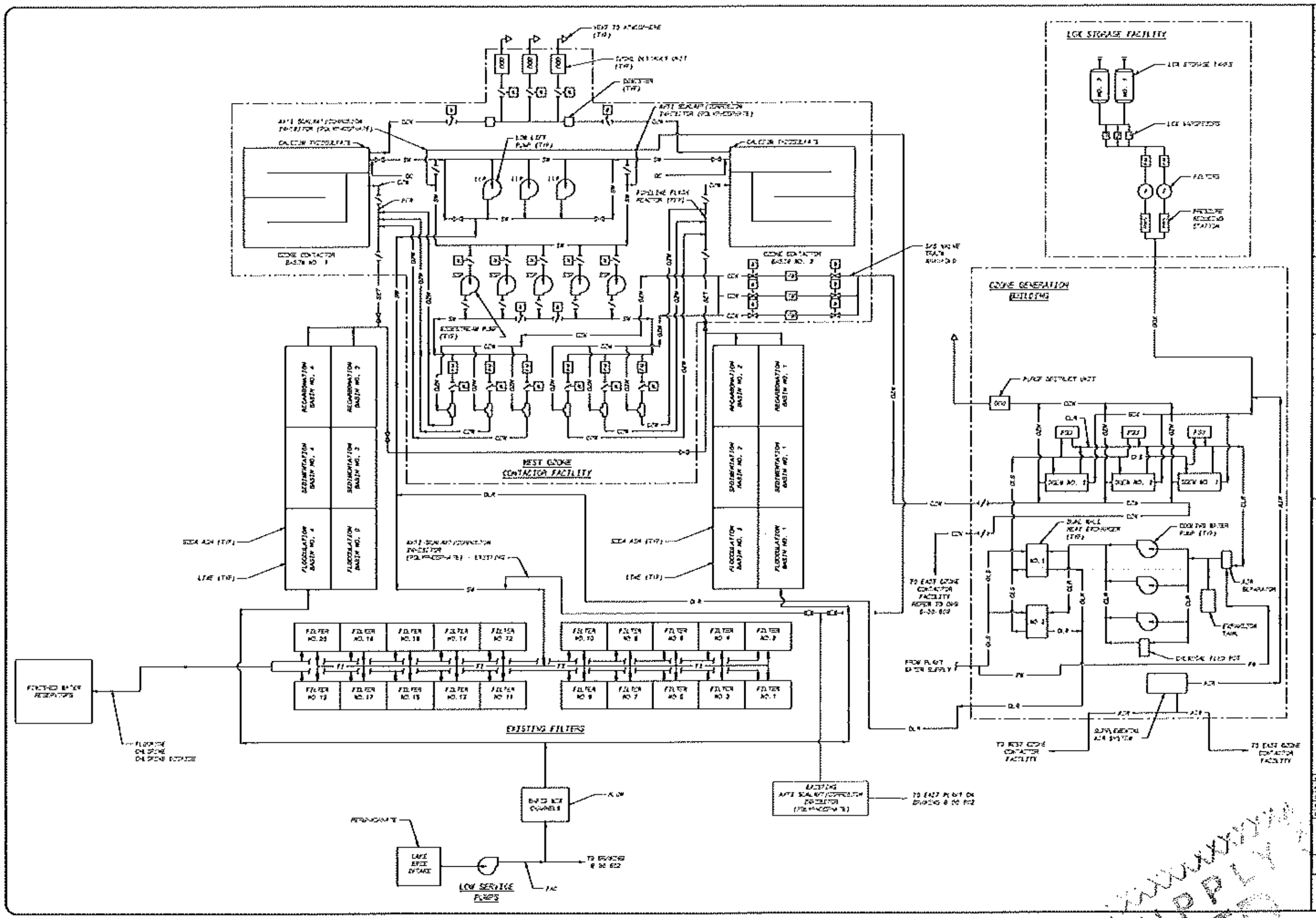
These optimized treatment processes are outlined in the WTP's HAB Standard Operating Procedure. These processes will continue to be monitored and adjusted to further improve MC reduction and inactivation in the short-term.

The long-term solution includes a new ozone treatment system, designed to inactivate MC in the water supply below detection limits during future HAB events. The effectiveness of treatment with ozone has been proven through various studies and conservative bench-scale testing. The design for this new ozone system is currently being finalized. Construction is anticipated to be complete in February of 2021.

Source water management, source avoidance, optimization of current treatment processes, and the addition of the future ozone treatment system will provide an efficient, effective, multi-barrier approach that will protect the citizens of Toledo from algal toxins resulting from HABs in the water supply.

Appendix A – Process Flow Diagrams

WATER SUPPLY
APPROVED
OHIO ENVIRONMENTAL PROTECTION AGENCY
AS EVIDENCED BY COPY OF
LETTER OF APPROVAL
HERETO ATTACHED



CITY OF TOLEDO, OHIO
COLLINS PARK WATER TREATMENT PLANT
OZONE TREATMENT FACILITIES

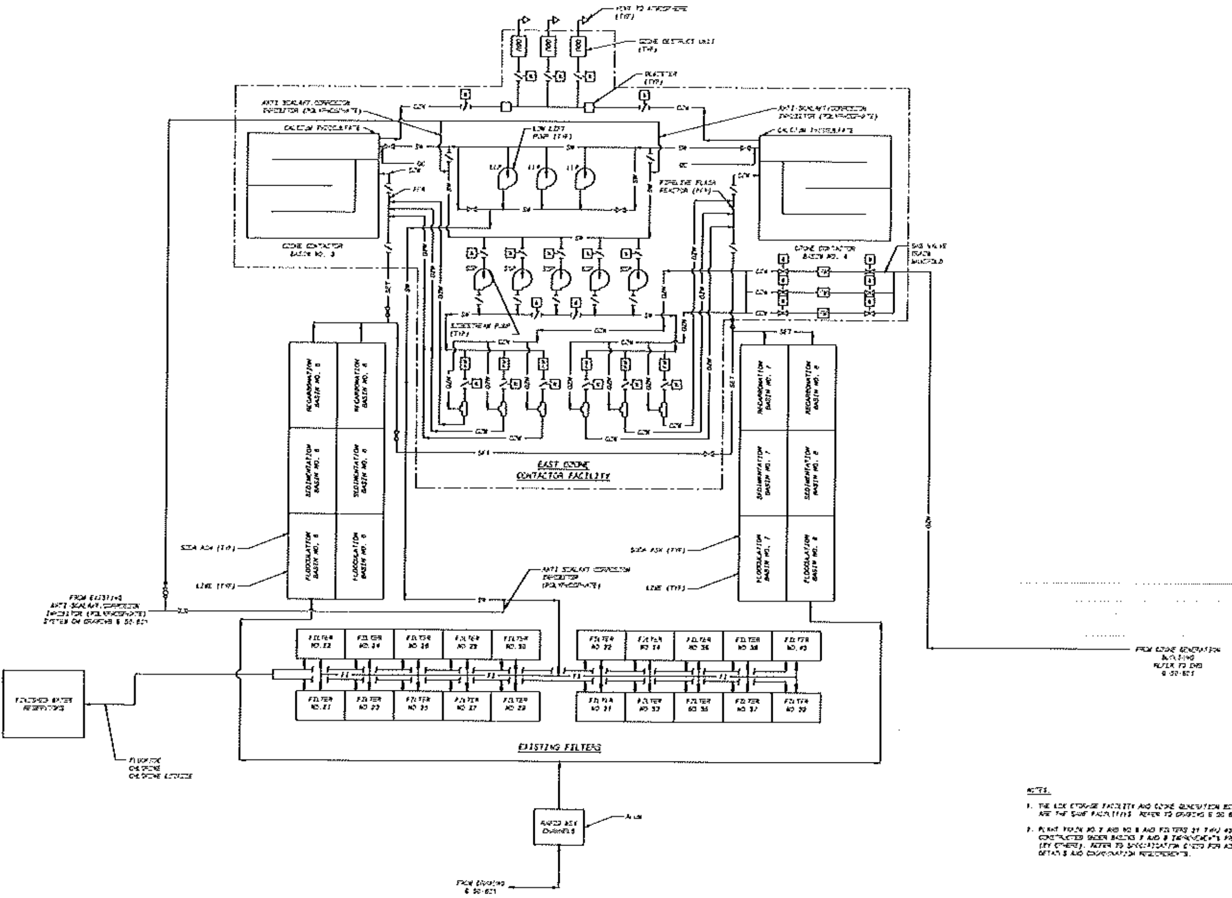
GENERAL
PROCESS FLOW DIAGRAM - WEST PLANT

BLACK & VEATCH
Black & Veatch Corporation

PROJECT NO.
194953

G-00-601
SHEET
OF

WATER SUPPLY
APPROVED
ENVIRONMENTAL PROTECTION AGENCY
EVIDENCED BY COPY OF
LETTER OF APPROVAL
HERETO ATTACHED



NOTES:

1. THE LOX STORAGE FACILITY AND OZONE GENERATION BUILDING ARE THE SAME FACILITIES. REFER TO DRAWING G-00-601.
2. PLANT TRAIN NO. 7 AND NO. 8 AND FILTERS 31 THRU 40 TO BE CONSTRUCTED UNDER BASINS 7 AND 8 IMPROVEMENTS PROJECT (BY OTHERS). REFER TO SPECIFICATION [illegible] FOR ADDITIONAL DETAILS AND COORDINATION REQUIREMENTS.

BLACK & VEATCH

Black & Veatch Corporation
Toledo, Ohio

CITY OF TOLEDO, OHIO
COLLINS PARK WATER TREATMENT PLANT
OZONE TREATMENT FACILITIES

GENERAL
PROCESS FLOW DIAGRAM - EAST PLANT

PROJECT NO.
131653

G-00-602
SHEET
OF