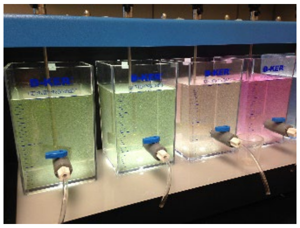
United States
Environmental Protection
Agency

Comprehensive Performance Evaluation Protocol to Address Harmful Algal Blooms and Associated Cyanotoxins



Prepared By:

U.S. EPA Office of Water
Office of Ground Water and Drinking Water
Standards and Risk Management Division
Technical Support Center
26 West Martin Luther King Drive
Cincinnati, Ohio 45268

Office of Water (MS-140) EPA 815-B-22-005 June 2022

TABLE OF CONTENTS

Appendices

DISCLAIMER

As used in this document, the term “optimization” refers to *voluntary* efforts on the part of primacy agencies (typically states) and public water systems (PWSs) to optimize PWS operations, without significant capital improvements, often leading to performance above and beyond the U.S. Environmental Protection Agency’s (EPA’s) regulatory requirements. As such, the contents of this guidance document do not have the force and effect of law and the agency does not bind the public in any way. The use of the term “should” in this document refers to recommended actions for those who choose to apply the described, optional optimization approach. For those PWSs that may not be in a position to optimize their operations in the near-term, but are simply seeking – as a first step – to *improve* their operations, many of the same concepts apply. In the latter cases, the state or PWS may wish to establish alternate, interim goals that differ from traditional AWOP program goals.

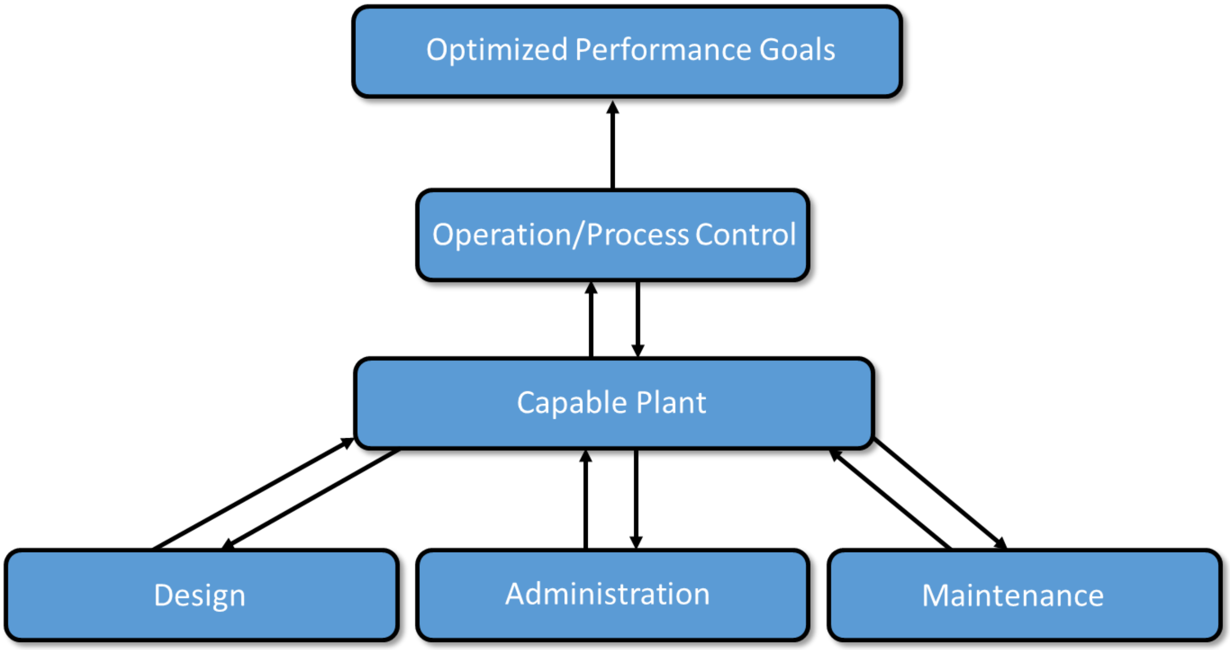
1. AREA-WIDE OPTIMIZATION PROGRAM (AWOP) AND HARMFUL ALGAL BLOOM/CYANOTOXIN (“HAB”) TREATMENT OPTIMIZATION BACKGROUND

In the late 1980s the U.S. Environmental Protection Agency (EPA) began its development of a voluntary national program to optimize surface water treatment plant performance for protection against drinking water microbial contaminants, such as *Giardia* and *Cryptosporidium*. This program is now known as the Area-Wide Optimization Program (AWOP) and is coordinated by EPA’s Technical Support Center (TSC) in Cincinnati, Ohio. The AWOP approach includes the Comprehensive Performance Evaluation (CPE), or evaluation phase, and can include a Comprehensive Technical Assistance (CTA), or performance improvement phase. The philosophy of the program is to optimize existing public water system (PWS) facilities to achieve desired performance goals without major capital improvements. The CPE was originally designed to assess plant performance, administration, and operations and maintenance practices to identify factors that may adversely impact the plant’s ability to achieve microbial performance goals (United States Environmental Protection Agency, 2004). For more information, refer to the EPA’s handbook on *“Optimizing Water Treatment Plant Performance Using the Composite Correction Program.”* The CPE approach has since been applied to distribution system optimization and this protocol describes yet another application for it.

More frequent occurrence and detection of cyanobacteria, along with the cyanotoxins they produce, in drinking water sources has become an increasingly important concern for some PWSs. In June 2015, EPA released Health Advisories for two cyanotoxins: microcystins and cylindrospermopsin (U.S. EPA 2015a, 2015b), as well as Health Effects Support Documents (HESDs) for three cyanotoxins: microcystins, cylindrospermopsin, and anatoxin-a (U.S. EPA 2015c, 2015d, 2015e). The Health Advisories include information on health effects, analytical methods and water treatment. The HESDs provide a comprehensive review of published literature on physical and chemical properties, environmental fate, known occurrence information, and health effects. Additionally, EPA released a *set of documents and tools intended to assist drinking water utilities in preparing for and responding to HABs in their source water*. Specifically pertinent to the content of this document is the “*Water Treatment Optimization for Cyanotoxins*” document, which is among the tools linked above.

To help address HAB and related cyanotoxin concerns and based on its experience developing and implementing optimization tools, EPA partnered with the Ohio Environmental Protection Agency to develop a CPE approach, hereinafter referred to as a “HAB-based CPE” for simplicity, to evaluate drinking water treatment plants. The focus of the approach was on plant capability to treat for cyanotoxins and to identify factors that may limit treatment plant performance during a source water HAB. This HAB CPE protocol was developed over the course of four pilot CPE field events conducted between August 2016 and March 2018 at Ohio water treatment plants whose source water is impacted by HABs. The purpose of this document is to describe the process of conducting a HAB CPE, as developed during EPA's pilot project with Ohio EPA for State drinking water staff or drinking water treatment plant operators.

As shown in Figure 1, the “capable plant optimization model” applies to HAB treatment optimization, where the objective is to achieve optimized performance. This is initiated through process control and utilizing data to help optimize plant operations. Sustaining optimization requires a capable PWS that has a strong foundation of administration-, design-, and maintenance support.



* **Figure 1: Capable plant optimization model**

The HAB CPE utilizes the framework of the microbial CPE due to its applicability to particulate-removal, including cyanobacterial cells (and associated "intracellular" cyanotoxins). On-site studies during the HAB CPE also address the removal of dissolved ("extracellular") cyanotoxins, with focus on adsorption and oxidation capabilities.

Additional resources that may be useful for PWSs seeking to improve their operations can be found at EPA's website, "*Building the Capacity of Drinking Water Systems.*"

2. HARMFUL ALGAL BLOOM CPE PROTOCOL

The components of the HAB CPE are shown in Figure 2 and are explained further in the following section.

The main activities of the HAB CPE are typically conducted over a five-day period. Typically, the CPE is conducted by an evaluation team with a minimum of three members, one of whom should be designated as the CPE coordinator.

This document also includes four appendices that provide supporting documentation for the CPE:

- Appendix A: Pre-HAB CPE Activities and Preparation
- Appendix B: On-Site Materials
- Appendix C: Exit Meeting and Final Report

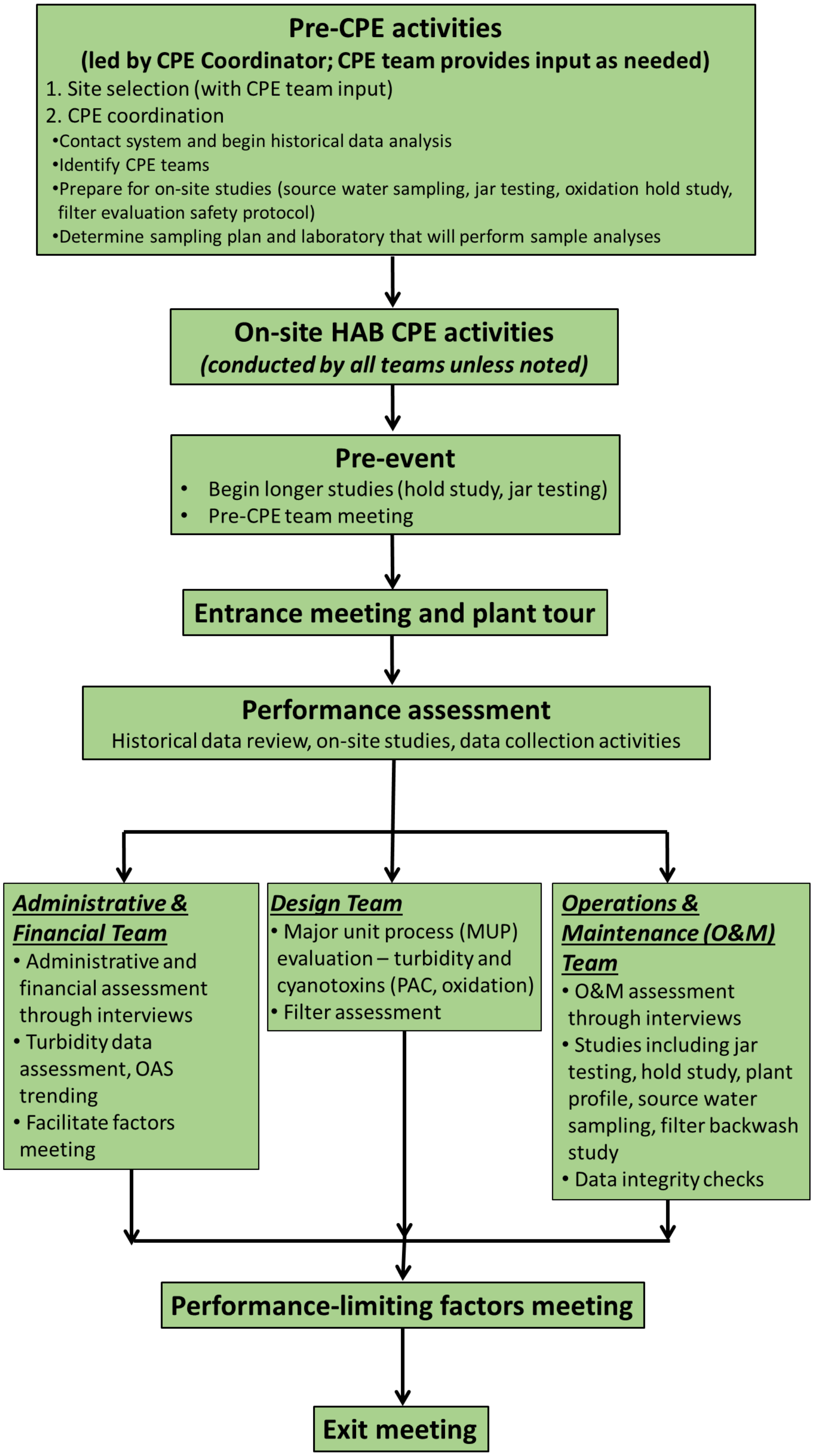


Figure 2: HAB CPE Protocol Framework

2.1 Off-Site Pre-CPE Activities

Activities that occur prior to the CPE include the following:

- Site prioritization and selection,
- Contacting the PWS about the event,
- Identifying, organizing CPE team
- Compiling and assessing historical water quality and PWS data, and
- Preparing for studies that may require a longer duration or more in-depth analysis than can be completed on-site during the week of the CPE.

The first of these activities should be initiated approximately two to three months in advance of the CPE if possible. A detailed description of the pre-CPE activities is provided below.

2.1.1 Site Prioritization and Selection

States can use their HAB monitoring results, knowledge of source waters impacted by HABs, and knowledge of disadvantaged communities to help guide PWS prioritization and selection. Examples of other selection criteria are provided in Appendix A. The site selection process should include a discussion with the candidate PWS to explain the objective and activities of the CPE and confirm their availability.

2.1.2 CPE Coordination

Once a PWS has been selected, the CPE coordinator and the PWS should address the activities described in the following sections before the CPE.

2.1.2.1 Team Identification

A key component of preparing for a CPE is identifying the CPE evaluation team coordinator and members of the three sub-teams that address administration/financial, design, and operation/maintenance. Each sub-team will have a leader. Generally, the CPE coordinator also acts as one of the sub-team leaders. The sub-team leader is responsible for understanding the CPE protocol, organizing and leading the team's activities, and obtaining the necessary materials and supplies. Each sub-team should also establish a tentative schedule of activities for the week.

2.1.2.2 Site Visit and CPE Overview Letter

The CPE coordinator should consider a site visit to the PWS to provide more details about the CPE and discuss the PWS's role during the CPE. Discussion topics may include accessing historical data, set-up for jar testing or hold study, information needed to support the major unit process evaluation, and safety considerations associated with the filter entry and inspection.

The CPE coordinator should send a formal letter to the PWS prior to the CPE. See Appendix A for an example. In this letter, the PWS should be asked to provide particular data prior to the CPE and to identify key personnel to assist during the CPE, participate in interviews, and support data collection activities. The critical components of this CPE overview letter are described below:

- ***Agenda:*** The tentative agenda should provide the PWS with a general idea of what to expect and when.
- ***Identification of Key PWS Personnel:*** Both operators and managers, including those responsible for making financial decisions at the treatment plant, will typically be asked to participate in interviews and to support the historical data collection activities.
- ***Data, PWS information and other resources:*** Information that is helpful for the CPE team to have prior to arriving on-site includes the following:
    - Raw, individual settled, and/or top-of-filter, individual filter effluent (IFE), and combined filter effluent (CFE) turbidity data
    - Any historical cyanobacteria or cyanotoxin-related monitoring data (e.g., chlorophyll-*a*, phycocyanin, microcystins, etc.)
    - Chlorine dose and residual, pH, and temperature data, or equivalent information used to calculate CT
    - Administrative data, such as budget information, capital improvement plans, and organizational charts
    - Design data, such as as-built plant drawings
    - Recent sanitary survey report, which may include water quality monitoring methods and locations, and chemical dosing information
    - HAB treatment contingency or optimization plans

2.1.2.3 CPE Equipment List

A recommended equipment list is provided in Appendix A. Each of the four pilot HAB CPEs included source water sampling, jar testing, and other studies that may require particular equipment. The supplies and approach for sampling may vary by site, so this list should be updated accordingly.

2.1.2.4 Initiate Historical Data Analysis

Any data received from the PWS prior to the CPE should be compiled electronically, such as in spreadsheets, for ease of use. For turbidity data, we recommend using EPA's *Optimization*

Assessment Spreadsheet. This spreadsheet helps organize and assess plant settled and filtered water turbidity performance and can be found on EPA's website *here*.

The CPE coordinator should also compile other relevant information that the PWS provides such as a plant schematic, organizational chart, PWS financial data, cyanotoxin sampling data, chemical dosing data, or recent sanitary surveys. The coordinator typically reviews this information with the CPE evaluation team during the pre-CPE meeting, described below.

2.1.2.5 Initiate Pre-CPE Studies

Studies anticipated to run longer than the duration of the CPE, or those that will provide data to support the exit meeting, such as a PAC jar test study or oxidant kinetic study, should be initiated off-site in advance to provide results in time for the exit meeting. Depending on the contact times and dosing concentrations that the team would like to evaluate, these types of studies may need to be conducted for longer durations, or through several iterations. AWWA has published a PAC jar testing protocol that is helpful for this purpose. An EPA cyanotoxin oxidation hold study protocol is included in Appendix B.

2.2 CPE Activities

Based on the pilot HAB CPE project, as well as experience with microbial CPEs, three to four days will typically be needed to conduct a HAB CPE. The following discussion addresses the activities that will generally take place over that period.

2.2.1 Pre-Event (Day 1)

The first day will often involve team travel to the CPE location and a pre-CPE team meeting. Equipment can be dropped off at the plant, and on-site studies can be set up and initiated as needed. A study organizational template to assist in planning on-site studies is included in Appendix B. On this first day we recommend that the CPE team briefly meet to review team assignments, plant information, and water quality performance data; confirm that each team understands their respective tasks; and discuss any outstanding logistics.

2.2.2 Entrance Meeting (Day 2)

On Day 2, an Entrance Meeting is conducted with PWS staff to introduce the CPE team, explain the importance of HAB water treatment optimization and the purpose of the CPE (see example bulleted ideas for including in a *"Why Optimize?"* presentation included in Appendix C), and develop a schedule for the team's activities in cooperation with the PWS staff. Additional examples of entrance meeting materials are provided in Appendix B.

2.2.3 Water Treatment Plant Tour (Day 2)

After the Entrance Meeting, the operators will typically lead the CPE team on a tour of the water treatment plant. The objective of this tour is to familiarize the team with the plant facilities, including physical layout, chemical dosing, and water-quality monitoring locations. Plant managers and staff who are familiar with the plant's design, operation and maintenance should lead the discussions. A list of suggested information to obtain during the plant tour is included in the CPE data collection forms in Appendix B. After the plant tour is complete, the CPE team, particularly the O&M team, should identify areas of interest for sampling and on-site studies.

2.2.4 Performance Assessment (Days 2-4)

During the performance assessment, three sub-teams will assess water quality performance (current and historical), plant design, administration, and operations and maintenance practices. Refer to Figure 2 for sub-team roles. The information gathered prior to the CPE and during the performance assessment will support the identification of performance-limiting factors (PLFs) – factors that could compromise the PWS's ability to optimize. Performance assessment activities generally begin after the plant tour and are generally completed no later than the morning of Day 4. A description of the performance assessment activities is provided in the following sections.

2.2.4.1 On-Site Studies

On-site studies are conducted during the CPE to support the identification of PLFs. The data integrity checks, filter assessment, source water sampling, plant profile, and jar testing are the primary studies, but other studies may be conducted if time permits. The on-site studies generally begin on the afternoon of Day 2 and are completed no later than the morning of Day 4. However, we recommend that any studies that require cyanotoxin analysis be initiated early (before the start of the CPE if need be) so that sample results can be included with the other exit meeting materials being prepared for Day 4. Arrangements may need to be made with the supporting lab to ensure that they can accommodate a quick turn-around time. On-site studies are discussed in more detail below.

2.2.4.1.1 Jar Testing Study

Jar testing is a valuable tool for assessing and optimizing water treatment plant chemical dosing, especially during a HAB event. When source water quality changes, it is important to determine if corresponding treatment changes need to be made to remove cyanotoxins, keeping in mind the importance of other treatment objectives, such as turbidity and TOC removal. Operators are encouraged to conduct jar testing in advance of, or during, the initial stages of HAB occurrences. Utilizing concentrated raw water samples or spiking commercially-available stock cyanotoxins can help a plant prepare for the changes in chemical dosing that may be necessary to address the HAB.

Jar testing is designed to simulate the water treatment plant's processes and evaluate the impact of treatment changes by adjusting mixing speeds or times.

Jar tests during a HAB-focused CPE typically evaluate PAC or pre-oxidant addition, or traditional coagulation, flocculation, sedimentation processes where cyanobacteria cells are a component of the raw water particulate loading. Note that jar test samples that contain PAC should be filtered using 0.6 µm glass fiber filters (e.g., Whatman, grade GF/F) to remove the PAC prior to cyanotoxin analysis. See *AWWA's PAC Jar Testing Protocol*.

2.2.4.1.2 Data Integrity Study

A series of studies may be conducted to assess the accuracy, precision and representativeness (the "integrity") of the data by the plant. These studies focus on all aspects of measurement, including the sampling configuration and instrument operation and settings, since each can impact data quality. The team conducting the study checks the following:

- Online turbidimeter flow rates using a graduated cylinder or measuring cup, and stopwatch. When the flow is above the maximum recommended rate, the potential for turbulence and non-representative turbidity spikes increases.

- Sample detention time, which is the sample travel time between the filter effluent tap and the turbidimeter, based on the length and diameter of sample tubing. We recommend one minute or less so that water quality changes through filters are rapidly observed.

- Online IFE and CFE turbidimeter settings are also checked, including signal averaging, output span, bubble reject, and data logging settings. The turbidimeter output span should be at least 0 to 5.1 NTU to identify the magnitude of turbidity spikes and avoid "capping" data.

- The online turbidimeter readings are also compared with grab samples analyzed on a portable turbidimeter. Grab samples for this comparison study are ideally obtained from a sample tap off the turbidimeter feed line, however samples can also be obtained from the drain lines of the continuous turbidimeters. Readings from the continuous turbidimeter are generally considered to be the most accurate, due to the instrument design and continuous sample stream (i.e., no sample handling), presuming that the instruments are well maintained and routinely calibrated. By collecting a representative sample and using good testing techniques, high-quality readings may also be obtained from the portable and benchtop turbidimeters. Those readings are expected to be within 0.05 NTU of the continuous readings from IFE and CFE turbidimeters. Deviations greater than 0.05 NTU should be investigated and may suggest a continuous meter in need of calibration or maintenance.

- Chemical feeder calibration. Determining accurate chemical feed rates is an important part of plant process control and ensuring data integrity. Depending on the chemicals dosed at the plant, the team may wish to check coagulant, PAC, softening chemicals, or oxidant feeds versus reported dosages.

For more information on assuring the integrity of turbidity data, refer to EPA's "*Generating High-Quality Turbidity Data in Drinking Water Treatment Plants to Support System Optimization and Monitoring*" document.

2.2.4.1.3 Plant Profile Study

Process control sampling through the water treatment plant provides information on how each unit process is performing and contributing to meeting water quality goals. Developing a plant profile is a useful way of trending these process control sampling results. During a HAB, it is important for water utilities to understand how each water treatment unit process is performing at removing cyanobacteria cells and cyanotoxins, while maintaining other treatment objectives, such as turbidity and TOC removal and disinfection. Plant profile trending can provide operators with warning of a cyanotoxins propagating through the treatment plant and assist in identifying incremental process control changes that can be made to avoid passage of cyanotoxins to the finished water.

Plant profiles can be developed from sampling results obtained from grab samples or data sonde readings, or a combination of the two. Typically, data sondes can be fitted with sensors to provide chlorophyll-*a*, phycocyanin, temperature, pH and turbidity measurements. The pigments chlorophyll-*a* and phycocyanin can be used as indicators of total algal biomass (chlorophyll-*a*) and cyanobacteria biomass (phycocyanin, or "blue-green algae"). Grab samples can be analyzed for cyanotoxins. Conducting this study during a CPE, even if there is not a HAB at the time, is a valuable way to demonstrate the study approach to operators.

2.2.4.1.4 Cyanotoxin Oxidation Kinetic Hold Study

A cyanotoxin oxidation hold study approach was developed to simulate water quality dynamics relative to cyanotoxin oxidation in the clearwell of a water treatment plant. During this study, water is collected from a location between the filters and clearwell (e.g., combined filter effluent tap), dosed with known concentrations of a concentrated cyanotoxin solution and chlorine (if not previously added in the treatment process) and held in a container to simulate clearwell conditions. Water quality samples are periodically collected and used to estimate the oxidation rate of cyanotoxins in the water. Appendix B includes a protocol for conducting the hold study. See *EPA Method 127*, Appendix A for a protocol for making and standardizing a chlorine stock solution.

2.2.4.1.5 Source Water Sampling/Profiling Study

Many factors contribute to the concentration and vertical distribution of cyanobacteria in the source water column, including depth, temperature, turbulence (e.g., wind-induced mixing or currents), and cyanobacteria composition. For example, some bloom-forming cyanobacteria genera, such as *Microcystis*, have gas vesicles to regulate their buoyancy and can form scums on the surface of the water. However, other genera, such as filamentous *Planktothrix*, are typically distributed throughout the water column. Given the suite of influential variables, assessing the water quality and susceptibility to cyanobacteria blooms and cyanotoxins is an important step to inform avoidance strategies.

The source water cyanobacteria and cyanotoxin assessment includes a review of historical raw water data and on-site sampling at the intake structure or wet well. Parameters that can inform this study include chlorophyll-*a*, phycocyanin, cyanobacteria cell identification and counts, cyanotoxin concentrations, cyanotoxin-producing gene counts (i.e., through PCR), or other indicator parameters that could be correlated to the proliferation of cyanobacteria and cyanotoxin production.

Water column vertical profiling can also be conducted using a data sonde equipped with cyanobacteria-related sensors, such as chlorophyll-*a* and phycocyanin, as well as temperature, DO, and pH. Vertical profiling conducted at or near the raw water intake structure can inform decision-making related to water quality at the intake depth.

2.2.4.1.6 Filter Assessment Study

This study involves an evaluation of the filter media by probing and excavating a small amount of media for assessment (see below), as well as an evaluation of a filter backwash, including bed expansion measurement, developing a backwash waste turbidity profile, filter backwash recovery profile, and filter-to-waste data review. This assessment is typically conducted on the plant's worst-performing filter as judged by effluent turbidity, filter run times, headloss, etc.

Media assessment and safety considerations

Filter entry involves some safety precautions that require training, setting up and securing ladders, monitoring air quality, and lock-out/tag-out (LOTO) of the filter valves after the filter is drained and while personnel are on the filter media surface (engulfment hazard). Many filters require entry by ladder and have limited means of egress, which can classify them as confined spaces. This may warrant specialized training for personnel performing the inspection, including confined space and fall protection training.

The filter media assessment begins by draining the filter. LOTO devices are then attached to the appropriate valves or instrumentation to eliminate the engulfment hazard. Air monitoring is conducted throughout the space (for example, with an air meter with the sensor hanging down into the filter space) to determine if an atmospheric hazard is present. After LOTO precautions are made and it has been confirmed that no atmospheric hazard is present, the "Permit-Required Confined Space" may be temporarily reclassified through a certification as a "Non-Permit-Required Confined Space". At this point, the filter is deemed safe to enter and personnel can descend onto the filter media. Due to the risk of a fall, a harness with a retractable fall arrester, or some other type of fall protection equipment, should be used for filter entry. Throughout the evaluation, continuous atmospheric monitoring is conducted. The filter media assessment involves one or two personnel descending onto the filter media surface and probing the media to determine the overall depth of media in the filter. This is accomplished by probing the filter at approximately equally-spaced distances in a grid-like pattern across the surface of the filter. Media depth measurements are plotted and used to determine if areas of the filter bed are uneven and where media loss may have occurred. Test pits are also excavated, either by hand or using a shovel or trowel, to examine the extracted media for mud balls and to determine if media is still stratified as-designed. Once the filter media inspection is completed and personnel are off the filter, atmospheric monitoring is discontinued. LOTO devices are then removed from the plant equipment and the remaining portion of the filter assessment can be conducted (i.e., the filter backwash assessment).

Backwash assessment

After the filter media assessment, the CPE team typically requests that the plant operators conduct a filter backwash on the same filter in which the media was assessed. During the backwash, bed expansion is measured and grab samples of the backwash wastewater are analyzed for turbidity to create a backwash waste turbidity profile. This can provide information about the efficacy of the backwash. When the filter is placed back online (either filtering to waste or regular filtration), a backwash recovery turbidity profile is developed by observing the turbidity readings on the SCADA screen. The IFE turbidimeter sample tap should be located upstream of the filter-to-waste valve to support a proper assessment.

Filter bed expansion is measured during a typical backwash. The percent bed expansion can be calculated from the measurement of media expansion. This measure helps operators understand the effectiveness of the backwash in cleaning the media and the ability for media to re-stratify following a backwash. A minimum of 20 percent filter bed expansion is desirable; however, filters that use air scour can achieve satisfactory backwashing at lower bed expansion levels (e.g., 15 percent). Bed expansion is typically measured during a backwash using a Secchi disk attached to a pole, although other types of bed expansion measurement tools have been developed. The team marks the pole when the disk is sitting on top of the media prior to the filter backwash, and again at the high backwash flow rate when the Secchi disk is observed to disappear below the fluidized media. The measurement between these two markings represents the depth of media expansion.

Concurrent with the bed expansion measurement, the team also obtains grab samples of the backwash wastewater and analyzes them for turbidity. The purpose of this sampling is to determine the amount of time necessary for effective media cleaning. The equipment used to perform this part of the study includes a collection device for grab samples and a portable turbidimeter. The CPE team collects turbidity grab samples at varied times from the discharge of the backwash waste trough, using a long pole with a sample cup attached at the end. Grab samples are analyzed on a portable turbidimeter and then plotted in a spreadsheet. To support filter backwash optimization, a waste backwash water turbidity target can be established to determine when to end the backwash (e.g., 5 to 20 NTU). This target, along with other backwash-related parameters such as post-backwash recovery turbidity, can be used to optimize filter backwash.

Following the inspection and backwashing of the filter, the filter ripening period is then monitored, typically by observing the SCADA HMI screen. The IFE turbidimeter sample tap should be located upstream of the filter-to-waste valve to support proper monitoring. The filter ripening period is the time from when filter is placed back in operation, inclusive of the filter-to-waste period, until the time the turbidity meets the optimization goal. For plants with filter-to-waste capability, the optimization goal is to return the filter to service at ≤ 0.10 NTU. Achieving 0.10 NTU turbidity before placing a filter back in service after a backwash cycle can reduce the number of particles, including pathogens and cyanobacteria cells, that pass to the clearwell.

The study team can also retrieve historical backwash data to obtain a better understanding of typical operational practices and water quality performance during backwashing and returning filters to service. This type of data analysis can be used to identify areas where studies can be conducted to improve plant performance and potentially save operator time and reduce water usage associated with backwashing.

2.2.4.2 Information Collection

Information is compiled to assess historical water treatment performance, assess treatment plant operations based on operational data, and evaluate administration, operations and maintenance practices through discussions with PWS personnel. This information may also support the on-site studies.

2.2.4.2.1 Water Quality Performance Assessment

The PWS's historical water quality data should be assessed relative to the microbial (turbidity) optimization goals listed in Table 1 and the EPA Health Advisory values for microcystins and cylindrospermopsin (U.S. EPA, 2015a, 2015b). Ideally, these data will have been compiled using the *Optimization Assessment Spreadsheet (OAS)* prior to the CPE (see Section 2.1.2.4). If these data were not already collected, or if data were missing, this should be completed at this time.

∗ **Table 1: AWOP's Microbial Optimization Goals for Rapid Rate Filtration Plants**

Raw Water

Minimum Data Monitoring Goal

- Record maximum daily raw water turbidity.

Individual Sedimentation Basin

Performance Goals

- Settled water turbidity ≤ 2.0 NTU in 95% of readings when the annual average raw water turbidity is > 10 NTU. Optimization is based on the daily maximum values recorded from all readings.
- Settled water turbidity is ≤ 1.0 NTU in 95% of readings when the annual average raw water turbidity is ≤ 10 NTU. Optimization is based on the daily maximum values recorded from all readings.

Monitoring Goals

- Record individual sedimentation basin effluent turbidity readings at intervals of 4-hours or less if taking grab samples, or 15 minutes or less for continuous monitoring.

Individual and Combined Filters

Performance Goals

- Combined filter effluent turbidity ≤ 0.10 NTU in 95% of readings. Optimization is based on the daily maximum values recorded from all readings.
- Individual filter effluent turbidity ≤ 0.10 NTU in 95% of readings (excluding 15-minute period following filter backwash). Optimization is based on the daily maximum values recorded from all readings.
- Post-backwash individual filter effluent turbidity for filters without filter-to-waste capability: Maximum

individual filter effluent turbidity following backwash ≤ 0.30 NTU and achieve ≤ 0.10 NTU within 15 minutes.

- Post-backwash individual filter effluent turbidity for filters with filter-to-waste capability: Minimize individual filter effluent turbidity during filter-to-waste period and record maximum value. Return the filter to service at ≤ 0.10 NTU.

Monitoring Goals

- Record individual and combined filter effluent turbidity readings at intervals of 1-minute or less for continuous monitoring.

Disinfection

Performance Goals

- Meet CT requirements to achieve inactivation of *Giardia* and viruses plus a system-specific factor of safety.

Monitoring Goals

- Record disinfectant residual, temperature, and pH at maximum daily flow for CT calculations.

2.2.4.2.2 Administration, Operations, and Maintenance Assessment

The purpose of the administration, operations and maintenance assessment is to collect information to help identify PLFs related to the management, physical integrity, operation and maintenance of the water treatment plant. A data collection form is used to summarize discussions with plant staff and administrators. A copy of the *Administration, Operations and Maintenance Assessment* form is provided in Appendix B. The Administration and O&M Teams should conduct interviews with plant staff and key administrators, potentially including board members and the utility director, as appropriate.

Assessment activities and interview topics include:

- ***Administration/Financial (Administrative/Financial Sub-Team)***: Review organizational structure, staff roles and responsibilities, communication, management policies including water quality goals, financial support, long-term planning, and financial information. Collect information on administrative policies and procedures through interviews with PWS administrators and review pertinent financial records.
- ***Operations (O&M Sub-Team)***: Review water quality goals, policies, and practices, and decision-making related to areas such as unit process control, chemical dosing, and instrument calibration and maintenance. Review data management, problem solving skills, and laboratory capability. A critical element of this assessment is to understand the plant staff's approach to avoiding complacency and ensuring plant reliability and water quality.
- ***Maintenance (O&M Sub-Team)***: Review preventative and corrective maintenance practices, as well as resources available for maintenance activities such as equipment repair and parts, maintenance expertise, availability of tools, and maintenance tracking.

2.2.5 Identification of Performance Limiting Factors (Day 4)

Once each sub-team completes their performance assessment activities, they should conduct a "pre-factors" meeting. The purpose of this meeting is for each sub-team to individually review the list of potential PLFs (see Appendix B) and identify any that may be relevant based on the team's assessment. Once all sub-teams are ready, the collective CPE team meets to identify, rank, and prioritize the PLFs for the PWS. The Administrative Sub-Team typically leads this meeting, utilizing the information collected during their assessment, interviews, and notes to guide the team through the factor identification process.

The summary of the prioritized PLFs provides a guide for the PWS's future optimization efforts. It is helpful to organize the factors based on relative priority so that the PWS can appropriately target their initial efforts to address them. This is particularly true when many PLFs have been identified and there is potential for the PWS to otherwise be overwhelmed.

2.2.6 Exit Meeting (Day 5)

The exit meeting, conducted at the end of the CPE, is an opportunity to present the team's findings to the PWS personnel and to establish priorities for pursuing the optimization performance goals. The evaluation team may have additional points to discuss after the weeklong evaluation, but the exit meeting is the team's opportunity to provide an initial summary of the PWS's performance. A presentation of results generally includes the following:

- Recap of microbial/turbidity and HAB treatment optimization
- Performance goals
- Performance assessment findings
  - Historical performance data assessment findings
  - On-site studies summary
- Summary of PLFs
- Suggestions for further study as an initial approach for pursuing optimization

Example exit meeting files are included in Appendix C. The exit meeting should focus on presenting the data that supports the PLFs that were identified during the CPE. If CPE activities do not result in significant findings, the team typically does not present about those studies during the exit meeting.

Typically, all information that will be included in the final report is summarized at the exit meeting. However, if results from any on-site sampling are not available until after the CPE, the PWS staff should be informed that this supplemental information will be made available in the final report.

2.3 Post-CPE Activities

The two main activities after the CPE include preparation of the final report and support for any follow-up optimization activities that the PWS wishes to pursue.

2.3.1 Final Report

The purpose of the final report is to document the findings of the CPE for the PWS and to help establish priorities for pursuing optimized plant performance. The final report should generally reflect the exit meeting summary.

The members of the evaluation team are responsible for developing the sections of the report that correspond with their focus areas during the CPE. The evaluation team should strive to complete the report as quickly as possible following the CPE.

2.3.2 PWS Follow-up

Follow-up with the PWS after the CPE is very system specific but is typically initiated by delivery of the final report to PWS staff members, and further review of the report with the PWS as needed. Some PWSs may want to initiate further sampling or studies, while others may not currently have the resources. Interested PWSs should be encouraged, and supported if possible, by the state to begin the steps of implementing HAB treatment optimization. Ideally the PWS personnel will address the PLFs, but often this will require support from the state personnel. Comprehensive technical assistance or performance-based training are two approaches utilized by state personnel that have proven to be successful in achieving and sustaining optimized performance at water treatment plants.

3. IMPLEMENTING HAB TREATMENT OPTIMIZATION

This section summarizes information on how a PWS could begin pursuing water treatment *optimization*, or even simply *improving* their ability to avoid/manage HAB impacts, whether it be in conjunction with a CPE or on their own initiative (i.e., independent of a CPE). Similar information is also provided in the exit meeting handout, *"Possible Further Studies for Plant Staff to Conduct to Support Plant Optimization" Template* that is included in Appendix C. Often, there are both technical and non-technical challenges that PWSs face in implementing treatment optimization.

3.1 Effective Leadership and Management

Support and leadership from plant management is an important first step in achieving water treatment optimization and protecting public health. This might include:

- Establishing optimization goals that have the buy-in of utility staff and management.
- Creating accountability by defining expectations through clear roles and responsibilities, documentation of meeting outcomes, and assignment of tasks.
- Making decisions based on data to gain support from utility staff and management for making treatment process changes. Applying problem-solving skills, such as conducting studies and trending and interpreting data.
- Developing operational policies and procedures to enhance communication among utility staff and management on critical activities. This could include establishing sampling schedules for cyanotoxins and developing monitoring protocols.
- Establishing routine communication through regular meetings, data distribution, or memorandums to continuously assess PWS performance and provide a feedback loop.

3.2 Adopt Water Quality Goals

Adopting and communicating water quality goals throughout the utility is a critical step for optimizing treatment and helps to ensure that all staff is committed to maintaining water quality throughout the PWS.

The process of pursuing optimization to increase public health protection will likely require changes in operations and daily activities, which is why it is critical that all parties are committed. During the CPE, optimization goals are referenced during the historical data performance assessment and summarized during the exit meeting.

3.3 Establish a Consistent Sampling Approach

It is important to evaluate treatment efficacy throughout a PWS through regular monitoring and data trending. Establishing, documenting, and communicating a regular sampling approach for collecting water quality samples in the treatment plant ensures that everyone samples consistently. Monitoring at multiple locations in the process train can help water treatment plant operators evaluate the effectiveness of each unit process. The selection of process control sample locations will depend on the plant configuration and chemical feed locations.

3.4 Monitoring for HAB Treatment Optimization

The foundation of a water treatment optimization program is monitoring data. The historical data review and OAS analysis conducted as part of the CPE could be the start of a longer-term process to trend and analyze SCADA and grab sampling data. A sufficient quantity and frequency of representative monitoring from each unit process in the treatment plant is recommended to establish a water quality database from which process control decisions can be made.

There are three basic steps to establishing a monitoring plan:

1. ***Identify grab sample and continuous monitoring locations.*** These locations might include source water, raw water, recycled water feed, after chemical addition in the rapid mix (i.e., after chemicals are completely mixed), settled water, individual and combined filter effluent, and finished water.
2. ***Collect and analyze samples and record data.*** Individual and combined filter effluent turbidity data can be compiled from SCADA and trended in a spreadsheet (such as the Optimization Assessment Spreadsheet). This turbidity dataset should be updated regularly. Grab samples or sonde data that indicate cyanobacteria or cyanotoxins such as chlorophyll-*a* and phycocyanin are helpful for establishing baseline raw water quality and for assessing cyanotoxin treatment performance if regular cyanotoxin sampling is prohibitive. Grab samples for cyanotoxin analysis can be collected based on the results of indicator parameters, as appropriate. This HAB data should be compiled into a spreadsheet. This database can also incorporate data obtained from the sampling conducted during the CPE. These sampling results, along with established compliance monitoring locations, can be the basis of a long-term water quality monitoring plan.
3. ***Trend and analyze data.*** Trend the data that has been compiled on a regular basis, observing any relevant trends that may indicate the need for changes in process control. The approach to making treatment adjustments for cyanotoxins depends on the monitoring results and type of cyanotoxins present. These tools help operators use data to make better process control decisions and can provide an early warning system for water quality problems throughout the treatment plant.

REFERENCES

Hegg, B. A., DeMers, L. D., Bender, J. H., Bissonette, E. M., & Lieberman, R. J. (2004). Optimizing Water Treatment Plant Performance Using the Composite Correction Program. Cincinnati: United States Environmental Protection Agency.

U.S. EPA. 2015a. Drinking Water Health Advisory for the Cyanobacterial Toxin Cylindrospermopsin. EPA 820R15101. Available online at https://www.epa.gov/sites/production/files/2017-06/documents/cylindrospermopsin-report-2015.pdf

U.S. EPA. 2015b. Drinking Water Health Advisory for the Cyanobacterial Microcystin Toxins. EPA 820R15100. Available online at https://www.epa.gov/sites/production/files/2017-06/documents/microcystins-report-2015.pdf

U.S. EPA. 2015c. Health Effects Support Document for the Cyanobacterial Toxin Anatoxin-a. EPA 820R15104. Available online at https://www.epa.gov/sites/production/files/2017-06/documents/anatoxin-a-report-2015.pdf

U.S. EPA. 2015d. Health Effects Support Document for the Cyanobacterial Toxin Cylindrospermopsin. EPA 820R15103. Available online at https://www.epa.gov/sites/production/files/2017-06/documents/cylindrospermopsin-support-report-2015.pdf

U.S. EPA. 2015e. Health Effects Support Document for the Cyanobacterial Toxin Microcystins. EPA 82015102. Available online at https://www.epa.gov/sites/production/files/2017-06/documents/microcystins-support-report-2015.pdf

Appendix A:

Pre-HAB CPE Activities and Preparation

Contents

Example Drinking Water Treatment Plant Selection Considerations

1. **Plant Selection Considerations**
    - WTP staffing – The plant should have sufficient staffing to host a HAB-related CPE development team of ~15 people. At a minimum, a plant superintendent and two operators are typically needed to support a CPE team of this size.
    - WTP construction – The team should avoid selecting plants that would be undergoing major construction projects during the targeted dates for a CPE.
    - WTP performance – The CPE tool is most appropriate for surface water treatment plants that are currently not achieving the optimization turbidity goals. Plants with individual-filter or combined-filter turbidity performance of > 0.15 NTU would be good CPE candidates.
    - Turbidity data availability – Ideally, the host plant will have readily accessible electronic turbidity records for raw, settled, individual filter, and combined filter turbidity available for the past year. Access to turbidity data on plant SCADA is sometimes challenging, depending on the age and capability of the system. The CPE team can identify the data of interest to the WTP staff in advance to see if the team can readily access it, and if not, to see if the plant can provide access (likely by modifying the SCADA programming) before the team arrives on site.
    - Ability to feed PAC - the team will learn more about optimizing this process at a water system that is already feeding PAC, or has the ability to feed PAC and has done so in the past.
2. **Other Considerations**
    - Willingness to host – Some utilities that would otherwise be good CPE candidates may be hesitant to host an evaluation of their plant for different reasons. The team should consider whether the concerns of the utility can be addressed prior to scheduling the CPE.
    - Other performance issues – The primary focus of a traditional, microbial-focused CPE (which serves as the foundation for a HAB CPE) is turbidity removal and disinfection practices in the plant. If the utility performance issues are not related to these parameters (e.g., utility whose primary issue is elevated DBPs), they may not be the best candidate.

    - Accommodations – The proximity of lodging for the CPE team should be considered during plant selection. The team will be on-site at the plant for 3-1/2 days and ideally lodging will be close to the plant to minimize travel time.

Example State-to-PWS HAB CPE Overview Letter and Information Request

Date

Jane A. Doe
City of XXXX
123 Main Street
City, State 12345

RE: Microbial / Harmful Algal Bloom (HAB) Comprehensive Performance Evaluation (CPE) at the City of XXXX Water Treatment Plant on <<Date>>

Dear Ms. Doe:

John Smith of the State Environmental Protection Agency recently contacted you regarding an upcoming evaluation of your water treatment plant (WTP) and visited to collect some preliminary information. To further prepare you, this letter provides some additional information about the evaluation and describes the activities that will be conducted.

This CPE process was developed through EPA's national drinking water optimization program, which is coordinated out of the Technical Support Center (TSC) in Cincinnati, Ohio with contractor support from Process Applications, Inc. (PAI) of Fort Collins, Colorado. EPA's program develops compliance assistance tools and approaches that can be used by State drinking water programs and water systems to improve drinking water quality – either to compliance levels, or beyond - to enhance public health protection.

The philosophy of the program is to optimize *existing* facilities and staff to achieve the desired water quality performance goals. The program was originally developed to optimize surface water treatment plant performance for protection against microbial contaminants such as *Giardia* and *Cryptosporidium*. Recently, that approach was adapted for plants challenged by harmful algal blooms (HABs) and cyanotoxins. During the CPE, all aspects of your water system's administration, design, operation/treatment, and maintenance will be evaluated to assess their impact on achieving optimized performance.

Attachment 1 provides the tentative schedule of activities during the CPE and some additional details are provided below. If this schedule needs to change as the week progresses, we will work with all involved to avoid interfering with the water plant staff's responsibilities.

The CPE will begin with a brief entrance meeting on <<Date>> at 8:00 a.m. with plant staff and administrators. During this meeting, a brief overview of the optimization approach will be provided and the planned activities and schedule over the next three days will be discussed. Any questions or concerns regarding the evaluation can also be raised at this time. We recommend that the plant administrators and those responsible for plant budgeting and planning be present because this evaluation will include an assessment of these aspects of the water system.

At various times during the week, the CPE team will need the assistance from one or more water system staff. For example,

- On Day 1, following the entrance meeting, the team will need someone that is knowledgeable about water treatment plant design, operation, maintenance, and water quality to lead the water treatment plant tour.
- Starting on the afternoon of Day 1 through the morning of Day 3, the team will review questions with plant staff about performance, operations and maintenance practices. The team may also conduct particular studies to investigate, or simulate, the performance capabilities of the various unit treatment processes, including filtration. Requests to inspect filter media and monitor filter backwashes will be coordinated with plant staff to minimize the impact on plant operation.
- Members of the evaluation team may meet with system administrators on Day 1 or Day 2 to review the administrative policies, procedures, and financial records. Additionally, plant staff and administrator interviews will be conducted the morning of either Day 2 or Day 3. This can be scheduled around their availability.

The evaluation will close with an exit meeting and discussion of the CPE results on Day 4 at 8:00 a.m. In addition to the plant staff and administrators that participated in the CPE, any City of XXXX managers (decision makers) are invited to attend. An assessment of the performance capabilities of the treatment processes will be presented and any factors appearing to limit the performance of the plant will be discussed. The evaluation team will also answer questions regarding the results of the evaluation. The results presented during the exit meeting will form the basis of the final report, which will be likely completed within two to three months after the event.

Attachment 2 contains a list of information that the team will need during our site visit. Having this information available when the team arrives will allow us to make the best use of time during the week.

We look forward to conducting this evaluation at your facility and thank you for your collaboration. I will soon follow-up with a phone call to discuss this upcoming event, and to review the availability of information requested in Attachment 2. In the meantime, if want to contact me, please do so at (123)-456-7890 or <<email@email.com>>.

Sincerely,

Name
Organization

Example HAB CPE Itinerary

PWS Name, City, State

Date

Day 1, <<DATE>>

8:00 A.M.: Entrance Meeting at the WTP building or other designated conference room facility (all facility personnel involved with supporting the CPE are encouraged to attend)

- Introductions
- Background and purpose of the field event
- Review activities planned for the week
- Discuss involvement of plant staff and management (sampling, data collection, and interviews)
- Answer any questions and discuss any concerns

8:45 A.M. - Noon: Plant discussion and tour for CPE team by the plant manager/staff:

- Explanation of overall treatment process – including design and basic information on the water treatment plant.
- Tour of the water treatment plant – note the type and locations of water quality monitors (e.g., raw water monitoring, turbidimeters, streaming current monitor, etc.) and chemical addition points (e.g., preoxidant, coagulant, disinfection, etc.).
- Historical water quality and plant performance - discuss any potential concerns.

Afternoon: CPE team activities, with assistance from WTP staff as needed and (limited) management support; anticipate **two to three staff** needed to assist with:

- Additional data collection/review activities:
    - Historical data: turbidity, cyanotoxins or HAB related monitoring data (e.g., chlorophyll-a, phycocyanin)
    - Grab samples from the treatment process train, as necessary
    - Recent sanitary survey report
    - HAB treatment optimization plan
- Historical data review to support identification of potential studies (e.g., treatment train sampling study, jar testing) with operator input. Begin studies if time allows.
- Review of plant design and assessment of plant processes to judge turbidity removal; consider impact on HABs/HAB removal

- Begin review of administrative policies and financial records for the plant.

Wrap-up at the Water Plant by 3:30 p.m. (or end of shift)

Day 2, <<DATE>> (anticipate 8 a.m. to 3:30 p.m.)

Teams will continue with activities started on Day 1. Some from the CPE team will sample and conduct studies for some/all of the day, likely with assistance of plant operators. Other team members will focus on data gathering and interviews with water plant management and staff. These interviews will be scheduled with individuals as appropriate.

Day 3, <<DATE>>

Morning:

Collect additional samples and conduct studies, as needed (plant staff may be needed to assist)
Conduct additional interviews with plant representatives, if needed

Afternoon:

Compile the data and prepare for the Day 4 exit meeting (**no assistance needed from water system**)

Day 4, <<DATE>>

8:00 A.M.: Exit Meeting at the WTP building or other designated conference room facility (all facility personnel involved with supporting the CPE are encouraged to attend)

- Preliminary presentation of findings from the CPE
- Discuss the team's observations and answer questions
- Discuss next steps and final report schedule

9:30 A.M.: CPE Team will depart

Example Water System Data Request
PWS Name, City, State
Date

- Historical water quality data: *Any data (mentioned below) that are available in electronic format. If only paper records exist, the most important (and available) data can be identified. The team would like to review one year of historical data if available.*
    - Raw, Settled, Top of Filter, Individual Filter Effluent, and Combined Filter Effluent (and/or Finished) water turbidity values.
    - Any historical cyanotoxin/HAB-related monitoring data (e.g., chlorophyll-a, phycocyanin)
    - Chlorine dose and residual, pH, and temperature data (or equivalent information used to calculate CT)

- Administrative data
    - Budget information, including revenues and expenses, rate structure and debt service
    - Capital Improvement Plan(s)
    - Organizational Chart/Staff positions/certifications

- Design data: as-built drawings of the plant

- Recent sanitary survey report, which may include:
    - Type and locations of water quality monitors (e.g., turbidimeters, streaming current monitor, raw water monitoring, etc.)
    - Chemical dosing information (locations and chemicals used)

- HAB treatment plan (if developed)

Example Equipment and Document List (for use by CPE Team)

Equipment:

- Colorimeters or SL1000 (2 or 3?)
    - Associated reagents for:
        - Free ammonia
        - Total ammonia
        - Free chlorine
        - Total chlorine
        - Color – Hach Method 8025 (TSC doesn't have this…check with Nick…order some for next CPE)
        - Nitrate (8039)
        - Nitrite (8507)
        - Alkalinity

- ADDA-ELISA sampling kit?
    - Amber glassware
    - Coolers with ice?
    - Ensure that lab is informed of anticipated sampling load and to bring sampling/preservation stuff

- pH meter (there is also a pH meter on the sonde)

- YSI EXO sonde w/ probes: phycocyanin, chlorophyll, turbidity, DO (?), conductivity (?), pH, temperature
    - Associated calibration standards (rhodamine solution for pigments), etc.

- AquaFluor fluorometer for chlorophyll-*a*

- Thermometers?

- Turbidimeter? Hach 2100Q portable turbidimeter

- Spectrophotometer to run UV254? Need sampling cells and filtration apparatus, miliQ water

- Jar testing equipment

    - Phipps & Bird apparatus
    - Cylindrical glass jars + square jars
    - Syringes and filters for PAC jar testing
    - Sample cups
    - Filtration method to remove PAC (assume glass is needed)
    - Determine PAC, coagulant/polymer types, WTP chemical dosing at sampling point in order to accurately replicate in jar test

        - Microsyringes, slide covers, plastic dosing syringes and cups for dosing

- MC-LR toxins to spike in jars? Use concentrated raw water sample?
- Carboy to bring raw water back
- Sample pump in case needed to collect raw water
- Climbing gear: harness, strap and retractable cord, helmets, other, for filter inspection if needed.

- Sample dipper (2 – one long, one short). Make sure long enough to reach backwash troughs!

- Bed expansion test measurement tool again?

- Filter probe with measurement increments?

- Kimmerer sampler (depths) or well pump?

- Folding table

- Tape measures (recommended 200 ft)

- Flashlight

- Tool bag

- Plastic sample cups

- DI water – verify that they have this at the plant, otherwise bring our own

- Kim wipes

- 2 coolers

- Bag of post-it notes, pencils, pens, markers, tape

- Safety equipment (nitrile gloves, safety glasses, work gloves,

- Projector for entrance and exit meeting presentations

- Clip boards

- M57 and Walker texts, other supporting papers (PAC, oxidation, etc.)

- Portable table

Electronic Files:

- HAB CPE forms
- “Why Optimize” presentation slides
- Blank data log sheets
- Plant historical data
- AWWA’s CyanoTOX, PAC Calculator spreadsheets and protocols
- OAS
- Latest Optimization document
- Supporting papers (PAC, oxidation, etc.)

Appendix B:

On-Site Materials

Contents

Data Collection Forms and HAB CPE Agenda

A. KICK-OFF MEETING AGENDA

1. Purpose of the CPE

   - Background on CCP process development and application
   - Basis for conducting the CPE at the utility
   - Assess ability of plant to meet optimized performance goals

     Optimized performance criteria description

     Multiple barrier concept for microbial protection
   - Identify factors limiting plant performance
   - Describe follow-up activities

2. Schedule CPE events

Schedule CPE events	Utility Staff Involved	Date/Time
• Plant tour	________________________________	_____________
• On-site data collection		
Performance	________________________________	_____________
Design	________________________________	_____________
Operations	________________________________	_____________
Maintenance	________________________________	_____________
Administration	________________________________	_____________
• Studies	________________________________	_____________
• Interviews	________________________________	_____________
	________________________________	_____________

______________________________ ____________

______________________________ ____________

______________________________ ____________

______________________________ ____________

______________________________ ____________

- Exit meeting ______________________________ ____________

3. Information Resources

- Performance monitoring records ____
- Plant operating records ____
- As-built construction drawings ____
- Plant flow schematic ____
- As-built construction drawings ____
- O & M manuals ____
- Equipment manuals ____
- Previous and current year budgets ____
- Organizational structure ____
- Water rate structure ____

B. ATTENDANCE LIST

Utility Name ____ Date ____________________

Name	Title/Position	Telephone No.

A. NAME AND LOCATION

1. Name of Facility ____
2. Utility Name ____

3. Current Date ____

4. Contact Information:

	Administration	**Plant**	
Contact Name			
Title			
Mailing Address			
Phone			
Fax			

B. ORGANIZATION

1. Governing Body (name and scheduled meetings)

____

____

2. Utility structure (attach organizational chart if available)

B. ORGANIZATION (CONT.)

3. Plant Organizational Structure (include operations, maintenance, laboratory personnel; attach chart if available)

C. WATER QUALITY

1. Utility Vison / Mission Statement

____

____

____

____

2. Water Quality Goals (turbidity, disinfections, DBPs, cyanotoxins)

____

____

____

____

3. Water Quality Reporting (type of reports, data reviewed by administrators)

____

____

____

____

C. WATER QUALITY (CONT.)

4. Management Style and Impact on Plant Operations and Performance (i.e., decision making process, chain-of-command, level of involvement)

____

____

____

____

____

5. Complacency and Reliability (approaches / activities used to prepare for unexpected events)

Topic	Description/Information
1. Complacency • How does utility respond to unexpected or infrequent water quality events (e.g., harmful algal bloom, seasonal changes)? • Does utility have an emergency response plan? How does staff train for unusual conditions or events?	
2. Reliability • Does staff capability to make process control decisions	

Topic	Description/Information
exist at more than one level? - Have process or equipment limitations / deficiencies been identified and corrections plans been developed?	

D. COMMUNICATIONS

Type	Description
☐ Staff Meetings	
☐ Administrator/Board Visits to Plant	
☐ Reports (plant staff to manager; manager to governing board)	

☐ Public Relations/ Education	

E. PLANNING

1. Short-Term Needs

____

____

____

2. Long-Term Needs

____

____

____

F. PERSONNEL

Title/Name	No.	Certification	Pay Scale	% Time at Plant

Comments (e.g., vacant positions, adequacy of current staffing):

G. PLANT COVERAGE

1. Shift Description (e.g., length, number per shift, weekend/holiday coverage)

____

____

____

____

2. Unstaffed Operation Safeguards (e.g., alarm/shutdown capability, dialer)

____

____

____

H. FINANCIAL INFORMATION

1. Budget (basis for budget: total utility ☐ plant only ☐)

	Last Year Actual	Current Year Budget
Enter Year		
1. Beginning Cash on Hand		
2. Cash Receipts		
a. Water Sales Revenue		
b. Other Revenue (connection fees, interest)		
c. Total Water Revenue (2a +2b)		
d. Number of Customer Accounts		
e. Average Charge per Account (2a ÷ 2d)		
3. Total Cash Available (1 + 2c)		
4. Operating Expenses		
a. Total O&M Expenses *		
b. Replacement Expenses		
c. Total O,M&R Expenses (4a + 4b)		
d. Total Loan Payments (interest + principal)		
e. Capital Purchases		
f. Total Cash Paid Out (4c + 4d + 4e)		
g. Ending Cash Position (3 - 4f)		
5. Operating Ratio (2a ÷ 4c) ±		

6. Coverage Ratio (2c - 4c) ÷ (4d) †		
7. Year End Reserves (debt, capital improvements)		
8. End of Year Operating Cash (4g - 7)		
Source: USEPA Region 8 Financial Analysis Document (1997)		

* Includes employee compensation, chemicals, utilities, supplies, training, transportation, insurance, etc.

± Measure of whether operating revenues are sufficient to cover O,M&R expenses. An operating ratio of 1.0 is considered minimum for a self-supporting utility.

† Measure of the sufficiency of net operating profit to cover debt service requirements of the utility. Bonding requirements may require a minimum ratio (e.g., 1.25).

2. Supporting Financial Information

Category	**Information**
☐ Rate Structure • User fees • Connection fees • Planned rate changes	
☐ Debt Service • Long-term debt • Reserve account	
☐ Capital Improvements • Planning • Reserve account	
☐ Budget Process • Staff involvement	

☐ Spending Authorization • Administrator • Plant staff	

A. PLANT SCHEMATIC AND CAPACITY INFORMATION

1. Attach or draw plant flow schematic; include the following details:

- Source water type/location
- Major unit processes
- Flow measurement locations
- Chemical injection locations
- Piping flexibility
- On-line monitoring type/location

2. Flow Conditions:

Parameter	Flow	
Design Capacity		
Average Annual Flow		
Peak Instantaneous Flow		

B. MAJOR UNIT PROCESS INFORMATION

1. Intake:

Topic	Description	Information
1. Description	Locations	
	List intake depths	
	Description of source mixing or aeration facilities	
2. HAB control / impacts	Ability to add preoxidant or other chemicals	
	Ability to adjust intake depth	
	Ability to change source water or use other intakes	
	Does design promote algae growth (Uncovered/long detention time)	
3. Other design Information or limitations observed.		

B. MAJOR UNIT PROCESS INFORMATION (CONT.)

2. Rapid Mix:

Topic	Description	Information
1. Description	Type (reel, hydraulic, turbine)	
	Describe Flow Splitting	
	Control (variable/constant speed)	
2. Unit Process Evaluation	Mixing Energy (G)	
3. Other design information or limitations observed		

Calculation of mixing energy as expressed by the mean velocity gradient (G) for mechanical mixing:

$$G = \left(\frac{P}{\mu v} \right)^{1/2}$$

G = Velocity gradient, sec $^{-1}$

μ = viscosity, lb-sec/ft^2

v = volume, ft^3

Viscosity of Water Versus Temperature

P = energy dissipated, ft-lb/sec

= hp x 550 ft-lb/sec/hp

Calculation of G for hydraulic mixing:

$$G = \left(\frac{\rho \, h_L}{\mu \, t} \right)^{1/2}$$

ρ = water density, 62.4 lb/ft^3

h_L = head loss, ft

t = detention time, sec

Temp. (°F)	Temp. (°C)	Viscosity x 10^{-5} (lb-sec/ft^2)
32	0	3.746
40	4	3.229
50	10	2.735
60	16	2.359
70	21	2.050
80	27	1.799
90	32	1.595
100	38	1.424

B. MAJOR UNIT PROCESS INFORMATION (CONT.)

3. Adsorption (PAC for cyanotoxin reduction, TOC removal):

Topic	**Description**	**Information**
1. Description	Type (wood, coal, other)	
	Feed location	
	Feed capacity (lb/day)	
	Available contact volume (gal)	
2. Target contaminant removal	Influent concentration	
	Target effluent concentration	
3. Unit Process Evaluation	Required PAC dose (mg/L)	
	Assigned process capacity *	
4. Other design information or limitations observed (mixing to keep carbon suspended)		

* Assigned process capacity (use historical data and site specific studies to determine expected reduction in contaminants by PAC)

B. MAJOR UNIT PROCESS INFORMATION (CONT.)

4. Flocculation:

Topic	Description	Information
1. Description	Type (reel, turbine, hydraulic)	
	Number trains/stages per train	
	Control (constant/variable speed)	
2. Dimensions	Length per stage:	
	Width per stage:	
	Depth per stage:	
	Total volume:	
3. Major Unit Process Evaluation	Detention Time (min)	
4. Other Design Information or limitations observed (G values*)		

* See mixing energy calculation in Rapid mix section.

B. MAJOR UNIT PROCESS INFORMATION (CONT.)

5. Sedimentation:

Topic	Description	Information
1. Description	Type (Conventional/tube settlers)	
	Number of trains	
	Weir location	
	Sludge collection	
2. Dimensions	Length or Diameter	
	Width:	
	Depth:	
	Total Surface Area:	
3. Unit Process Evaluation	Surface Loading Rate	
	Assigned process capacity	
4. Other design information or limitations observed (sludge removal capability, ability to handle carbon removal)		

B. MAJOR UNIT PROCESS INFORMATION (CONT.)

6. Filtration:

Topic	Description	Information
1. Description	Type (Mono/dual/mixed)	
	Description (sand, anthracite, GAC)	
	Number of filters	
	Filter control (Constant/declining rate)	
	Surface wash or air scour?	
2. Dimensions	Length or diameter:	
	Width:	
	Total surface area	
3. Media design conditions (depth/effective size/uniformity coefficient)		
4. Backwash	Backwash initiation (Time, headloss, turbidity)	
	Sequence (surface wash/air scour/ramping up/down/filter to waste)	
	Backwash storage / disposal	

B. MAJOR UNIT PROCESS INFORMATION (CONT.)

6. Filtration (cont.):

Topic	Description	Information
5. Unit Process Evaluation	Surface Loading rate (gpm/sf)	
	Assigned process capacity	
6. Other design information or limitations observed (ability to add a filter aid polymer, ability to remove carbon fines)		

B. MAJOR UNIT PROCESS INFORMATION (CONT.)

7. Disinfection / oxidation:

Topic	Description	Information
1. Description	Contact Type (Clearwell/storage tank)	
	T_{10}/T factor (See Table 4-4 or use tracer study results)	
2. Dimensions	Length or Diameter:	
	Width:	
	Minimum Operating Depth:	
	Total Volume	
	Volume Adjusted for T_{10}/T	
3. Unit Process Evaluation (disinfection)	Disinfectant (free chlorine/chloramines)	
	Max. disinfectant residual (mg/L)	
	Maximum pH	
	Minimum temperature (°C)	
	Required Giardia inactivation	
	Required virus inactivation	
	Assigned process capacity	
3. Unit Process Evaluation (cyanotoxin oxidation)	Toxin reduction (µg/L)	
	Required CT	
	Assigned process capacity	

5. Other design information or limitations	

C. MISCELLANEOUS EQUIPMENT INFORMATION

1. Miscellaneous Equipment/Unit Processes:

Topic	Description	Information
1. Presedimentation	Detention Time	
	Flexibility to by-pass	
	Chemical feed capacity (Preoxidant, etc.)	
	Design limitations	
2. Backwash decant treatment	Description	
	Recycle practices	
	Design limitations	
3. Sludge Handling	On-site storage volume	
	Long-term disposal	
	Design limitations	

C. MISCELLANEOUS EQUIPMENT INFORMATION (CONT.)

2. Chemical Feed Equipment:

Chemical Feed System • Chemical name/characteristics (e.g., product density, strength) • Purpose (e.g., coagulant, filter aid, cyanotoxin removal, disinfection) • Number/type feed pumps or dry feeders	**Capacity (ML/min or mg/min)** • Design • Operating range	**Comments** • Dose control (e.g., flow paced) • Manufacturer's information • Calibration method • Design issues
1.		
2.		
3.		
4.		

C. MISCELLANEOUS EQUIPMENT INFORMATION (CONT.)

3. Instrumentation:

On-Line Instrumentation • Type (e.g., turbidimeter, flow meter, particle counter, pH monitor, chlorine monitor, fluorescence sensor) • Manufacturer	**Location** • Process stream	**Comments** • Process purpose • Calibration • Alarm/shutdown capability • Design issues
1.		
2.		
3.		
4.		
5.		

6.		
7.		

C. MISCELLANEOUS EQUIPMENT INFORMATION (CONT.)

4. Pumping:

Flow Stream Pumped • Location • Number of pumps • Rated capacity	**Pump Type** • Turbine • Centrifugal	**Comments** • Flow control method • Design issues • Source of rated capacity (name plate, specifications, flow meter)
1.		
2.		
3.		
4.		
5.		

6.		
7.		

A. PROCESS CONTROL STATEGY AND COMMUNICATION

Describe the process control strategy used by the staff and associated communication mechanisms.

Topic	Description/Information
1. Process Control Strategy	
• Does the staff set specific performance targets/goals? Are they posted?	
• Who sets process control strategies and decisions?	

- Are appropriate staff members involved in process control and optimization activities?	
2. Communication Methods - Does the staff have routine plant/shift meetings? - How is communication conducted among operations, maintenance, and lab? - Does the staff develop and follow operational procedures?	

B. PROCESS CONTROL PROCEDURES

Describe specific process control procedures for the following available processes.

Process	Description/Information
1. Source Water / Intake Structure	
• Source water description / quality	
• Monitoring (turbidity, pH, TOC, algae identification, chlorophyll, phycocyanin, cyanotoxins – intra & extracellular)	
• Flexibility to draw water from different locations & depths	
• Operational problems (e.g., capacity limitations, prone to seasonal algal blooms)	
2. Pumping/Flow Control	
• Flow measurement and control	
• Proportioning to multiple units	

Process	Description/Information
• Operational problems	
3. Presedimentation • Chemicals used / purpose • Dose control • Monitoring (turbidity, pH, TOC, algae identification, chlorophyll, phycocyanin, cyanotoxins – intra & extracellular)	
• Sludge removal • Operational problems	
4. Preoxidation • Chemicals used / purpose / location	

Process	Description/Information
• Dose control	
• Monitoring (oxidant residual, chlorophyll, phycocyanin, cyanotoxins – intra & extracellular)	
• Operational problems	
5. Powdered Activated Carbon	
• Chemicals used / purpose / location	
• Dose control	
• Monitoring (TOC, chlorophyll, phycocyanin, cyanotoxins – intra & extracellular)	
• Operational problems (inadequate mixing, insufficient feed rate)	

Process	Description/Information
6. Rapid Mix / Coagulation • Chemicals used / feed location	
• Dose control (adjustment for flow changes; adjustment for water quality - jar testing, streaming current, pilot filter) • Monitoring (streaming current) • Operational problems	
7. Flocculation • Mixing energy adjustment • Use of flocculant aid • Monitoring	

Process	Description/Information
• Operational problems	
8. Sedimentation • Performance goals/ monitoring (turbidity, chlorophyll, phycocyanin, cyanotoxins – intra & extracellular) • Sludge removal (control, adjustment) • Operational problems (e.g., turbidity/ carbon carryover, inadequate sludge removal, release of cyanotoxins)	
9. Filtration • Performance goals / monitoring (turbidity, particles, chlorophyll, phycocyanin, cyanotoxins – intra & extracellular)	

Process	**Description/Information**
• Rate control (constant, declining) • Use of filter aid polymer • Basis for backwash initiation (turbidity, particles, headloss, time) • Backwash procedures (wash sequence, duration and rates, basis for returning filter to service) • Filter/media inspections (frequency and type) • Operational problems (e.g., turbidity / carbon breakthrough, post backwash turbidity spikes, short filter runs, insufficient backwash supply or waste storage)	

Process	**Description/Information**
10. Disinfection • Performance goals/ monitoring (residual, CT, cyanotoxins) • CT factors (pH, minimum depth of contactor, T_{10}/T, maximum residual)	
• Operational problems	
11. Stabilization • Chemical used / purpose • Feed location • Performance goals/ monitoring (pH, corrosion index, corrosion inhibitor) • Operational problems	

Process	**Description/Information**
12. Decant Recycle • Duration, % of plant flow • Type of treatment (settling, chemical addition) • Operational problems (e.g., recycle of cyanotoxins)	
13. Sludge Treatment (on-site, off-site disposal / reuse)	

C. DATA MANAGEMENT

Describe data collection and management approaches and tools used by plant staff.

Topic	Description/Information
1. Data collection • Type of forms used (water quality testing, shift rounds, plant log) • Computer (SCADA, database)	
2. Data application • Use of daily, monthly reports (request examples) • Use of trend charts (request examples)	

D. PROBLEM SOLVING AND OPTIMIZATION ACTIVITIES

Describe specific approaches and tools used to solve problems or optimize plant processes.

Topic	Description/Information
1. Problem solving/optimization	

• Use of studies (request example documentation)	
• Pilot plant	
• List recent and ongoing problem solving/optimization activities	
• Available resources (technical assistance providers, training, manuals of practice)	

E. COMPLACENCY AND RELIABILITY

Describe specific approaches used to address complacency and reliability issues in the plant.

Topic	**Description/Information**
1. Complacency	
• How does utility respond to unexpected or infrequent water quality events (e.g., harmful algal blooms, seasonal changes)?	
• Does utility have an emergency	

Topic	Description/Information
response plan? How does staff train for unusual conditions or events?	
2. Reliability • Does staff capability to make process control decisions exist at more than one level? • Have process or equipment limitations / deficiencies been identified and corrections plans been developed?	

F. LABORATORY CAPABILITY

1. Describe available analytical testing capability.

Analytical Capability	Capability ✓	Description/Comments
• Color		
• Jar test		
• Particle counting		
• pH		
• Solids (dissolved)		
• Taste and odor		
• Temperature		
• Turbidity		
• Aluminum		
• Calcium		
• Fluoride		
• Hardness		
• Iron		
• Magnesium		
• Manganese		
• Sodium		
• Alkalinity		

• Ammonia Nitrogen		
• Nitrite/Nitrate		
• Phosphate		
• Sulfate		
• Chlorine residual		
• Bacteriological		
• Chlorophyll		
• Phycocyanin		
• Algae/cyanobacteria cell identification		
• Microcystins (ELISA, LC/MS/MS, other screening assays)		
• Disinfection byproducts		

2. Describe laboratory space/equipment and procedures.

Process	Description/Information
Lab Space and Equipment • Does adequate lab space exist? • Do adequate equipment and facilities exist?	
Lab Procedures • Is testing conducted following standard procedures? • Where is lab data recorded? • Describe quality control procedures.	
Equipment Calibration • Describe procedure for calibrating turbidimeters	

• Describe procedures for calibrating other equipment (continuous chlorine and pH monitors)	

A. MAINTENANCE PROGRAM

Describe the plant maintenance program.

Topic	Description/Information
1. Preventive Maintenance • Describe equipment inventory method (cards, computer). • Describe maintenance scheduling method (daily, weekly, monthly, annual).	
2. Corrective Maintenance • Describe the work order system (issuing orders/documentation). • Describe priority setting (relationship to process control and plant performance needs). • List major equipment out of service within last 6 months.	

3. Predictive Maintenance • Describe methods used to predict maintenance needs (vibration, infrared analysis).	
4. Housekeeping • Does poor housekeeping detract from plant performance/image?	

B. MAINTENANCE RESOURCES

Describe the available maintenance resources at the plant.

Topic	Description/Information
1. Equipment Repair and Parts • Are critical spare parts stored at the plant? • Can vendors provide quick response to spare parts needs? • What is the policy on parts procurement by staff?	
2. Maintenance expertise • Describe staff expertise (mechanical, electrical, instrumentation). • Does the staff use any contract maintenance services? How responsive are they to needs? • Do staff develop and use maintenance procedures?	

3. Work Space and Tools • Does the plant have adequate work space and tools to perform maintenance tasks?	
4. Performance Monitoring • How is maintenance performance measured (time to complete task, work order backlog)?	

A. HISTORICAL WATER PRODUCTION DATA

1. Use the following table to determine the peak instantaneous operating flow for the plant.

Month/Year	Maximum Daily Flow	Operating Time per Day	Flow during Operation [1]	Instantaneous Peak Flow [2]

(1) If a plant operates less than 24 hr/day, flow during operation can be determined from the equation below:

$$Q_A = \frac{Q_T}{T} \text{ x } \frac{24\text{ hr}}{\text{day}}$$

Q_A = Average flow during operation

Q_T = Total flow in 24-hour period

T = Time of plant operation, hours

(2) Peak instantaneous flow through a plant is often different than the average flow due to changing water demands that the plant must meet. The peak instantaneous flow during a day can sometimes be obtained from plant logs (e.g., raw pump operation, rate change time and flow).

B. WATER USAGE

1. Determine the water usage per capita based on water production records and population served. Water usage statistics for the United States are shown in the table below.

$$Q_C = \frac{Q_T}{P}$$

Q_C = Usage per capita per day

Q_T = Total flow in 24-hour period

P = Population served

Population ___________________________

Q_C Avg. ___________________________

Q_C Peak ___________________________

State	Use (gpcpd)	State	Use (gpcpd)
Alabama	191	Nebraska	174
Alaska	134	Nevada	306
Arizona	191	New Hampshire	85
Arkansas	154	New Jersey	131
California	175	New Mexico	184
Colorado	188	New York	166
Connecticut	120	North Carolina	107
Delaware	124	North Dakota	114
Florida	146	Ohio	127
Georgia	160	Oklahoma	173
Hawaii	180	Oregon	164
Idaho	163	Pennsylvania	128
Illinois	154	Rhode Island	115
Indiana	115	South Carolina	148
Iowa	131	South Dakota	121
Kansas	144	Tennessee	148
Kentucky	128	Texas	176
Louisiana	147	Utah	255
Maine	81	Vermont	80
Maryland	165	Virginia	119
Massachusetts	119	Washington	217
Michigan	136	West Virginia	96
Minnesota	105	Wisconsin	118
Mississippi	127	Wyoming	188
Missouri	131	Puerto Rico	115
Montana	164	Virgin Islands	63

Source: Solley, W. B., Preliminary Estimates of Water Use in the United States, 1995, U.S. Geological Survey (1997)

2. Determine unaccounted for water based on monthly or annual water production and meter records. Unaccounted for water typically varies from 10 to 12 percent for new systems and 15 to 30 percent for older systems (Metcalf and Eddy, Inc. 1991).

$$Q_{\%} = \frac{(Q_T - Q_M)}{Q_T} \text{x}\,100$$

$Q_{\%}$ = % unaccounted

Q_T = Total plant water production for month or year

Q_M = Total metered water for month or year

Q_T ___________________________

Q_M ___________________________

$Q_{\%}$ ___________________________

3. Determine backwash water percent based on volume of water filtered and volume of water used for backwash. Typically, the amount of water used for backwash ranges for 2 to 6 percent for conventional plants. Higher percentages can occur for direct filtration plants.

$$BW_{\%} = \frac{(V_F - V_{BW})}{V_F} \text{x}\,100$$

$BW_{\%}$ = % backwash water

V_F = Volume of water filtered

V_{BW} = Volume of water used for backwash

V_F ___________________________

V_{BW} ___________________________

$BW_{\%}$ ___________________________

C. IN-PLANT STUDIES

Describe results of in-plant studies conducted during the CPE.

Topic	Description/Information/Findings
1. Filter media evaluation	
• Check media depth and type	
• Check media condition (presence of chemicals/debris, mudballs, worn media)	
• Check support gravel level (variation of less than 2 inches acceptable)	
2. Backwash evaluation	
• Check backwash rate (measure rise rate in the filter versus time and convert to backwash rate; > 15 gpm/ft^2 acceptable)	

• Check bed expansion > 20 percent acceptable)	

C. IN-PLANT STUDIES (CONT.)

Describe results of in-plant studies conducted during the CPE.

Topic	Description/Information/Findings
2. Backwash evaluation (cont.) • Observe backwash procedure (flow distribution, ramping of flow rate, turbidity of water at end of backwash)	
3. Coagulant dosage evaluation • Verify reported dose with actual; measure liquid or dry feed rate (lb/min, mL/min) and convert to dose (mg/L)	
4. Turbidity meter evaluation	

- Check meter calibration or compare with calibrated meter	

C. IN-PLANT STUDIES (CONT.)

Data Integrity Study 1: Sample Line Detention Calculation

Use the table below to calculate the detention time in the sample line from each sample tap to the turbidimeter. Is the detention time excessive or are there other findings?

Sample Tap Description	Line Volume, gal	Line Flow Rate, gal/min	Line Detention Time, min

C. IN-PLANT STUDIES (CONT.)

Data Integrity Study 2: Turbidimeter Settings

Review the turbidimeter settings and record findings in the table below.

Turbidimeter Location								
Turbidimeter Model								
Controller Model and Data Logging Setting (1)								
Signal Averaging (2)								
Bubble Reject (3)								
Error Hold Mode (4)								
Output Span (5)								
Other								

(1) Check to see if current data and time are correct. Check frequency of data logging. Default is 15 minutes for Hach models.

(2) Default for Hach models is 30 seconds. This is acceptable in most cases.

(3) Default is Yes for Hach models. This is acceptable in most cases.

(4) Specific to Hach 1720E and FilterTrak 660 models. Default is to Hold Outputs (HO) and send last known value to SCADA when turbidimeter loses communication with controller. Better option is Transfer Ouputs (TO) to send an operator-selected value to SCADA (e.g., 0, 10) to make operator aware of problem.

(5) To avoid *"capping"* of data to SCADA, the output span should be at least 0 to 5.1 NTU (applicable to analog signals).
Accessing output span for Hach SC200 controller: Menu/SC200 setup/Output setup (select 1 or 2; select Source to see which turbidimeter is highlighted and then Back button)/Activation (low value; high value).

Data Integrity Study 2 (cont.)

Findings:

C. IN-PLANT STUDIES (CONT.)

Data Integrity Study 3: Turbidity Data Signal Verification

Simultaneous readings of the signal output monitor at a turbidimeter, as well as remote locations such as the HMI monitor or a PLC readout.

Turbidimeter	Instrument Values	Remote Location No.1 and Values	Remote Location No.2 and Values

Findings:

C. IN-PLANT STUDIES (CONT.)

Data Integrity Study 4: Identification and Verification of Log Removal Value (LRV) Calculation Input Parameters

Identify the location of the Log Removal Value (LRV) calculation input variables shown in the table below. Provide as much specific information as possible (e.g., instrument tag number, physical location).

LRV Input	Plant Location Input Measured or Obtained	Data Assess (e.g., SCADA screen, historian report)	Comments on Data Integrity (e.g., frequency of meter calibration)
Pressure Decay Test Start and End Pressures ($P_{Test\ Start}$, $P_{Test\ End}$, psig) Enter test values below:			
Pressure Decay Test Hold Time (minutes) Enter test value below:			
Back Pressure (BP, psig) (1) Enter test value below:			
Atmospheric Pressure (P_{atm}, psi) (2) Enter test value below:			

LRV Input	Plant Location Input Measured or Obtained	Data Assess (e.g., SCADA screen, historian report)	Comments on Data Integrity (e.g., frequency of meter calibration)
Water Flow Rate (Q_{flow}, gpm) (3) Enter test value below:			
Water Temperature (F) Enter test value below:			
Transmembrane Pressure (TMP, psig) (3) Enter test value below:			
Vendor Provided Parameters: System volume (L)	Volume concentration factor (VCF)	Resistance coefficient (K)	Net expansion factor (Y)

(1) Water head above the DIT sensor (feet converted to psi).

(2) Sea level pressure adjusted to site elevation.

(3) Value or average value if variable prior to the DIT.

C. IN-PLANT STUDIES (CONT.)

Data Integrity Study 4 (cont.)

Findings:

C. IN-PLANT STUDIES (CONT.)

Data Integrity Study 5: Portable and Bench Turbidimeter Monitoring and Comparison to Online Turbidimeters

Develop and implement a sampling plan to compare individual filter(s) effluent turbidity using a portable or bench top turbidimeter and compare the results with the continuous reading turbidimeter(s). Follow quality control procedures to assure comparable results between grab samples and continuous meters (i.e., use indexed sample cells and use clean, scratch-free sample cells, oil cells, and de-gas samples). Take three measurements for each turbidimeter and average the results. Lab and portable turbidimeter readings for filtered water should be within 0.05 NTU of online turbidimeter readings.

Sample Location	Continuous Turbidimeter Readings, NTU	Lab Turbidimeter Readings, NTU	Portable Turbidimeter Readings, NTU

C. IN-PLANT STUDIES (CONT.)

Data Integrity Study 5 (Cont.)

Findings:

C. IN-PLANT STUDIES (CONT.)

Describe results of in-plant profiles conducted during the CPE (e.g., manganese, cyanotoxins).

Process Location	Parameter	Parameter	Parameter	Parameter

A. INTERVIEW GUIDELINES

The following interview guidelines are provided to assist CPE providers with the interview process.

1. **Conduct interviews with one staff person at a time in a private location.**

    - It is important to create a comfortable environment for the interview process to take place. Confidentiality of the interview should be explained

2. **Keep the interview team size small.**

    - The number of people included on each interview team should be kept to a minimum (e.g., 1 to 3) to avoid overwhelming the person being interviewed. If more than one person is included on the team, one person should be assigned as the lead interviewer.

3. **Allow 30 to 45 minutes for each interview.**

    - Interview times will vary depending on the personality of the individual being interviewed and the number and type of issues involved. It is the responsibility of the interviewer to maintain the focus on performance-related issues. Interviews can easily be detracted by individuals who find an "open ear" for presenting grievances.

4. **Explain the purpose of the interview and use of the information.**

    - It is important for the people being interviewed to understand that any information obtained from this process is only used to support identification of factors limiting performance (i.e., areas impacting performance). The interview information is not used to place blame on specific individuals or departments.

5. **Conduct interviews after sufficient information has been gathered from CPE activities.**

    - Utilize results and observations gained from the plant tour, performance assessment, major unit process evaluation, and data collection activities to identify areas of emphasis during the interviews.

6. **Progress through the interview in a logical order.**

    - For example, if an administrator is being interviewed, focus questions on administrative support, then on design issues, followed by operation and maintenance capabilities.

7. **Ask relevant questions with respect to staff area of involvement.**

    - For example, when interviewing maintenance personnel, ask questions related to relevant topics such as maintenance responsibilities, communication with supervisors, and administrative support for equipment.

8. **Ask open-ended questions.**

- For example, a question such as "Are you aware of any design deficiencies with the current plant? " would provide better information than a question like "Do you think that the flocculation basin provides sufficient detention time for flocculation?".

9. **Ask the questions; don't give the answers.**

   - The purpose of the interview is to gain the perspective of the person being interviewed. Ask the question, and wait for the response (i.e., don't answer your own question based on information you may have received from previous activities). Rephrasing the question may sometimes be necessary to provide clarity.

10. **Repeat a response to a question for clarification or confirmation.**

    - For example, the interviewer can confirm a response by stating, "If I understand you correctly, you believe that the reason for poor plant performance during April was due to excessive algae growth in the source water."

11. **Avoid accusatory statements.**

    - Accusatory statements will likely lead to defensiveness by the person being interviewed. Rather, if an area of concern is suspected, ask questions that can confirm or clarify the situation.

12. **Use the interview to clarify or confirm field information.**

    - For example, if performance problems occurred during one month of the past year, ask questions to clarify the perceived reasons for these problems.

13. **Note specific responses that supports factor identification.**

    - During or following the interview, the interviewer may want to note or underline specific responses that support the identification of possible factors limiting performance. This summary can then be used during team debriefing and factor identification meetings.

B. PERSONNEL INTERVIEW FORM

Name ______________________________ Title ______________________________

Time at plant ______________________________ Years of experience ______________

Education/training/certification ____

____

Interview notes (concerns, recommendations in administration, design, operation, and maintenance):

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

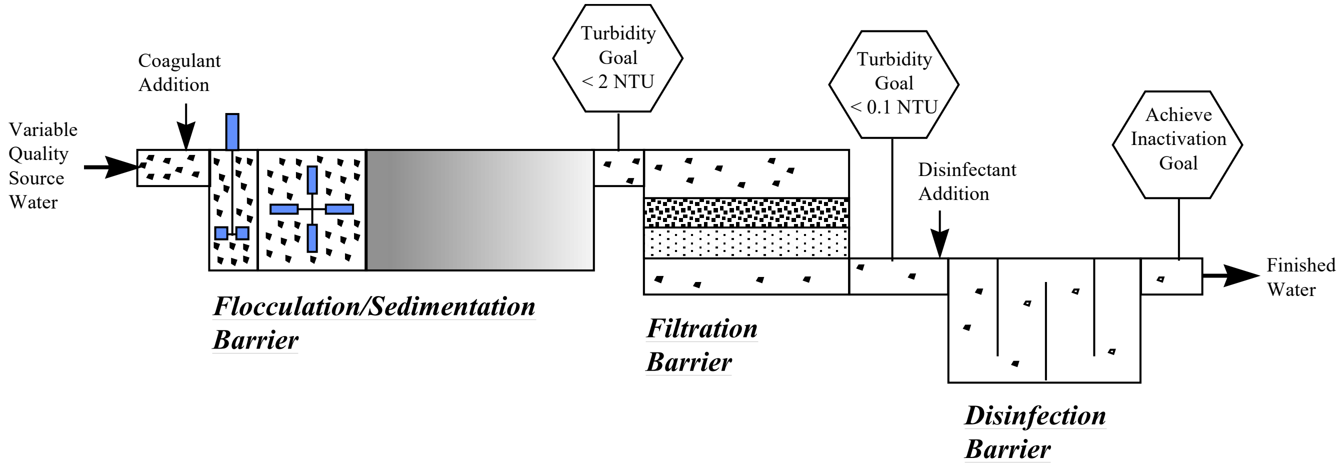
....

A. ATTENDANCE LIST

Utility Name ____ Date _____________

Name	**Title/Position**	**Telephone No.**

B. MUTIPLE BARRIER CONCEPT FOR MICROBIAL CONTAMINANT PROTECTION



- Given a variable quality source water, the treatment objective is to produce a consistent, high quality finished water.
- Protozoan parasites, such as *Giardia* and *Cryptosporidium*, are found in most source waters; however, it is difficult to quantify their presence and assess their viability.
- Microbial pathogens in the source water, such as protozoan parasites, bacteria, and viruses, can be physically removed as particles in treatment processes and inactivated through disinfection.
- Multiple barriers are provided in a treatment plant to remove or inactivate microbial pathogens.
- Key treatment barriers include flocculation/sedimentation, filtration, and disinfection.
- Since measurement of protozoan parasites is difficult, surrogate parameters, such as turbidity, particle counting, and pathogen inactivation, are used to assess the performance of each barrier.

C. OPTIMIZATION PERFORMANCE CRITERIA

A summary of performance criteria for surface water treatment plants to provide protection against microbial contaminants is presented below:

I. Minimum Data Monitoring Requirements

- Daily raw water turbidity
- Settled water turbidity at 4-hour time increments from each sedimentation basin
- On-line (continuous) turbidity from each filter
- One filter backwash profile each month from each filter

II. Individual Sedimentation Basin Performance Criteria

- Settled water turbidity less than 1 NTU 95 percent of the time when annual average raw water turbidity is less than or equal to 10 NTU
- Settled water turbidity less than 2 NTU 95 percent of the time when annual average raw water turbidity is greater than 10 NTU

III. Individual Filter Performance Criteria

- Filtered water turbidity less than 0.10 NTU 95 percent of the time (excluding 15-minute period following backwashes) based on the <u>maximum</u> values recorded during 4-hour time increments
- Maximum filtered water measurement of 0.3 NTU
- Initiate filter backwash immediately after turbidity breakthrough has been observed and before effluent turbidity exceeds 0.10 NTU.
- Maximum filtered water turbidity following backwash of less than 0.3 NTU
- Maximum backwash recovery period of 15 minutes (i.e., return to less than 0.10 NTU)
- Maximum filtered water measurement of less than 10 particles (in the 3 to 18 μm range) per milliliter (if particle counters are available)

IV. Disinfection Performance Criteria

- CT values to achieve required log inactivation of *Giardia* and virus

Study Format, Elements, and Template

Study Topic: Identify the name of the study and briefly describe why the study is being conducted (i.e., one to two sentences).

Hypothesis:

Describe what is to be proved by completing the study (show cause/effect relationship).

Focus study on a specific activity.

Approach and Resources:

Describe how the study will be conducted (i.e., processes and equipment involved).

Describe resources required (i.e., staff, sampling, and testing).

Involve plant staff in development (operations, maintenance, and laboratory).

Determine whether any background data is needed before initiating the study.

Duration of Study:

Define the time estimated to complete the study (important to clarify for staff).

Expected Results:

Describe expected results from the study.

Describe how the data will be presented to support the hypothesis.

Define measures of success for the study.

Summary & Conclusions:

To be completed at the end of the study.

Document results of the study (brief written summary with charts).

Present findings to utility staff and management (use as training tool for all utility staff).

Implementation:

To be completed at the end of the study.

Document changes to current plant procedures based on study results.

Study Topic:

Hypothesis:

Approach & Resources:

Duration of Study:

Expected Results:

Summary and Conclusions:

Implementation:

Cyanotoxin Oxidation Hold Study Protocol

Overview:

The objective of the *Cyanotoxin Oxidation Hold Study* is to simulate water quality dynamics relative to cyanotoxin oxidation within the clearwell of a water treatment plant. During this study, water is collected from a location between the filters and clearwell prior to chlorination (e.g., combined filter effluent tap), dosed with known concentrations of a concentrated cyanotoxin solution and chlorine (if not previously added in the treatment process) and held in a container to simulate clearwell conditions. Water quality samples are periodically collected and are used to estimate the oxidation rate of cyanotoxins in the water.

Hypothesis:

The hypothesis of this study will be system-specific, depending on the desired objective of the study (see the Overview section, above).

Resources:

- Required Personnel:
  - One to two (1-2) investigators
- Required Equipment:
  - Large Erlenmeyer flask (e.g., 6 liter) prepared chlorine demand-free, and wrapped in aluminum foil to minimize UV light penetration

    Note: All glassware should be pretreated to be chlorine demand-free using the following, or similar, procedure:

    - Completely fill each glass container with a 10 – 20 mg/L chlorine solution, by adding 0.3 mL of household bleach[1] (typically 5.25% w/v), or stock chlorine solution of comparable strength, per liter of water[2]. Assuming a household bleach of 5% chlorine (SDS states 5-10%) and a target chlorine concentration of 15 mg/L, it would take 0.32 mL of bleach per liter of water.
    - Allow the chlorine solution to soak in the containers for at least 24 hours.
    - Thoroughly rinse each bottle three times with water[2].
  - One (1) portable colorimeter with necessary instructions and reagents for total chlorine, free chlorine (DPD and indophenol method reagents), monochloramine, and free ammonia residual analysis
  - Magnetic stir plate and large stir bar

---

[1] Confirm that product contains only sodium hypochlorite and does not include other chemicals or fragrances.

[2] Water used to prepare glassware chlorine demand-free should be of the highest quality available. If laboratory clean water (RO/IX/GAC, distilled, or deionized) is not available, treatment plant effluent water may be used.

- Sample bottles, preservatives, and quenching agents for cyanotoxin analysis
- Sample bottles, filtration apparatus for TOC and DOC. UV spectrophotometer and quartz cuvette for UV_{254} analysis
- 50-100 mL glass Griffen beakers for sample collection, prepared chlorine demand-free as noted above
- 250 mL amber glass Packer bottles with caps, prepared chlorine demand-free as noted above for demand study.
- Glass pipets prepared chlorine demand-free with rubber bulb
- Pipettes and disposable pipette tips (pipette volumes dictated by necessary dosing)
- One (1) pH meter with calibration standards
- One (1) digital thermometer
- Deionized (DI) water
- One (1) water bath to incubate samples at the clearwell temperature if unable to conduct hold study in a temperature-controlled environment. Options include:
  - Laboratory water bath or incubator that can maintain a specific temperature (preferred)
  - Container designed (or modified) for continuous flow-through of study water (i.e., plant effluent, sink's cold tap)
  - Cooler filled with water and changed periodically

Procedure

1. Make a chlorine stock solution and standardize its concentration, according to the protocol found in Appendix A of EPA Method 127 (p. 24-27).

2. To determine the appropriate chlorine dose for the hold study, an oxidant demand study may need to be conducted. This is especially beneficial when using a concentrated cyanotoxin spike from an ambient water body as the challenge for the hold study, as there could be additional chlorine demanding constituents, such as ammonia, organics, iron or manganese, that exert oxidant demand concurrent with cyanotoxins. The objective of this study is to determine the appropriate chlorine dose to achieve breakpoint chlorination such that free chlorine residual is available for cyanotoxin oxidation.
   a) The demand study is conducted using 250 mL amber glass bottles with caps, all prepared to be chlorine demand-free (see above procedure). The desired free chlorine residual can be used as a benchmark, and a range of doses selected based on that target residual.

b) The challenge water is prepared using a plant water sample (post-filter, pre-chlorination) and the concentrated cyanotoxin solution to achieve the desired cyanotoxin concentration. Bottles are then filled with this challenge water.

c) Each bottle is then dosed with chlorine, at varying doses within the range selected previously. To dose the chlorine, the appropriate amount of challenge water is pipetted out and replaced by chlorine stock (see *Free Chlorine Stock UV-VIS (SOP-V4).docx* for a protocol on making and standardizing the chlorine stock solution; see *Toxin Oxidation Hold Study.xlsx* spreadsheet for calculating doses based on the chlorine stock solution concentration).

d) The bottles are then held for a sufficient amount of time such that breakpoint chlorination can be observed. Intermediate samples can be taken to better understand the dose and time where breakpoint occurs and better inform sampling later in the study. Typically, breakpoint chlorination will occur relatively quickly (≈15 min.), but under certain conditions additional time may be needed[3] for the breakpoint reactions to take place.

e) For each sample, total and free chlorine are measured using the colorimetric DPD method, and paired with free chlorine analysis by the indophenol method due to the potential for interferences. The indophenol method is less prone to positive interference from chloramines and manganese than the DPD free chlorine method.

f) At the end of the study, the dose that resulted in the desired free chlorine residual is the dose that should be used for the hold study.

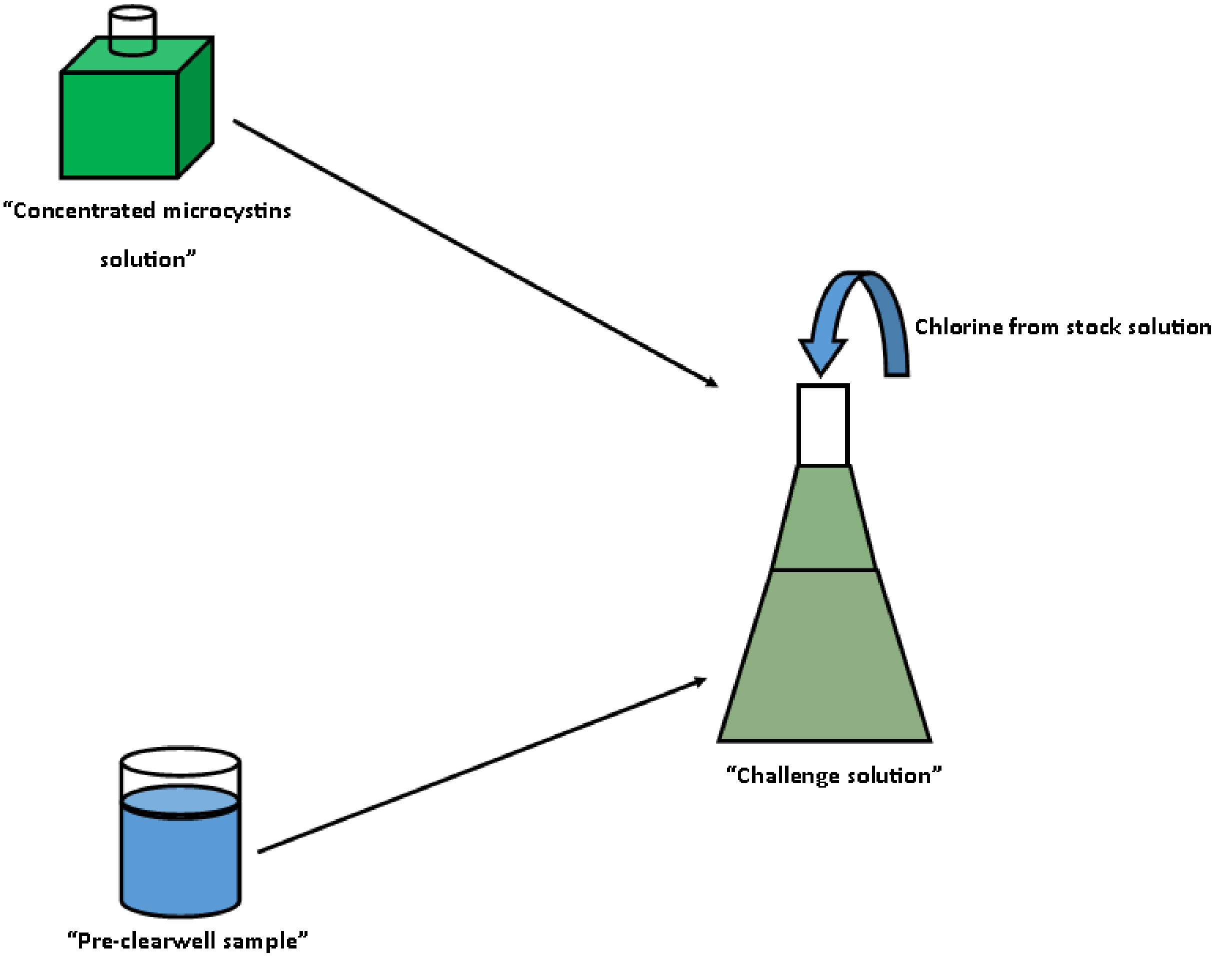
3. Calculate the appropriate dosing volume for the volume of challenge water. Determine the necessary volume of challenge water needed based on the number and volume of samples to be taken during the hold study.

4. Set up a sampling plan. It is important to take frequent samples in the initial moments of the hold study once chlorine is dosed, as the initial chlorine and cyanotoxin decay can often occur quickly. For example, immediately after dosing, a 30-second sample should be taken, and thereafter at approximately 5-minute intervals for the first 30 minutes, or as frequently as sample analysis will allow. Samples can be collected less frequently after the first hour of the study, such as 15-minute or 30-minute sampling intervals. Typically, free and total chlorine and cyanotoxins samples are analyzed. TOC/DOC/UV254 can also be measured as deemed appropriate. Other chlorine demanding constituents such as free ammonia, iron, manganese, and TOC should also be measured prior to the start of the hold study. If free ammonia is present in the challenge solution, it is recommended that a chlorine demand study should first be conducted, so the appropriate chlorine dose may be determined. Monochloramine, free ammonia, and free chlorine by indophenol method should also be analyzed to ensure that breakpoint chlorination has occurred. The initial chlorine dose may need to be increased to achieve breakpoint chlorination and the desired free chlorine residual for microcystins oxidation analysis.

---

[3] The U.S. EPA Office of Research & Development has created a web-based application (https://usepaord.shinyapps.io/Breakpoint-Curve/) that may be used to estimate the time needed for breakpoint reactions to take place under specific conditions (e.g., pH, temperature).

5. Make the challenge solution (see the figure below) by combining a sample from the water treatment plant process just prior to chlorine addition before water enters the clearwell with the concentrated cyanotoxins solution. The latter can be a laboratory grade cyanotoxin standard, or be concentrated from an ambient water body with a phytoplankton net. If opting for the latter, the sample will need to undergo freeze/thaw and filtration through a 0.45 µm glass fiber filter to ensure that the cyanotoxins are extracellular. If cyanotoxins break through to the clearwell at a water treatment plant, they will likely be in extracellular form, as the coagulation/flocculation/sedimentation and filtration processes would likely remove the intracellular cyanotoxins by removing the cyanobacteria cells.



6. Dose the chlorine to the challenge solution and mix at a slow rate to mimic clearwell conditions. Collect samples according to the sampling plan and analytical methods. Sampling and analysis vessels should be rinsed with DI water after each sample is analyzed to prevent cross-contamination of subsequent samples.

7. Plot the sample results with time on the x-axis and chlorine residual and cyanotoxin concentrations on the y-axis. This is helpful to visualize the decay curves and make informed process control decisions.

Considerations:

- Headspace vs. headspace-free?
- Temperature control during the study (water bath, controlled temperature room, etc.)
- Limit UV penetration (such as wrapping hold study vessel in aluminum foil, or using amber glass)
- How to introduce the cyanotoxins? Laboratory-grade cyanotoxin solution from a vendor vs. concentrating a cyanotoxin solution from ambient water using a phytoplankton net.

HAB CPE Performance-Limiting Factors (PLFs)

CPE Factor Summary Sheet Terms

Plant Type	Brief but specific description of plant type (e.g., conventional with flash mix, flocculation, sedimentation, filtration and chlorine disinfection; or direct filtration with flash mix, flocculation and chlorine disinfection).
Source Water	Brief description of source water (e.g., surface water including name of water body).
Performance Summary	Brief description of plant performance based on performance assessment component of the CPE (i.e., ability of plant to meet optimized performance goals).
Ranking Table	A listing of identified performance limiting factors that directly impact plant performance and reliability.
Rank	Relative ranking of factor based on prioritization of all "A" and "B" rated factors identified during the CPE.
Rating	Rating of factor based on impact on plant performance and reliability: A — Major effect on a long-term repetitive basis B — Moderate effect on a routine basis or major effect on a periodic basis C — Minor effect
Performance Limiting Factor (Category)	Factor identified from Checklist of Performance Limiting Factors, including factor category (e.g., administration, design, operation, and maintenance).
Notes	Brief listing of reasons each factor was identified (e.g., lack of process control testing, no defined performance goals).

CPE Performance Limiting Factors Summary

Plant Name/Location:

CPE Performed By:

CPE Date:

Plant Type:

Source Water:

Performance Summary:

Ranking Table

Rank	Rating	Performance Limiting Factor (Category)

Rating Description

A — Major effect on long-term repetitive basis.
B — Moderate effect on a routine basis or major effect on a periodic basis.
C — Minor effect.

Performance Limiting Factors Notes

Factor	Notes
	•
	•
	•
	•

Checklist of Performance Limiting Factors

A. ADMINISTRATION

1. Plant Administrators
    1. ☐ Policies ________________________________
    2. ☐ Familiarity With Plant Needs ________________________________
    3. ☐ Supervision ________________________________
    4. ☐ Planning ________________________________
    5. ☐ Complacency ________________________________
    6. ☐ Reliability ________________________________
    7. ☐ Source Water Protection ________________________________
2. Plant Staff
    1. ☐ Number ________________________________
    2. ☐ Plant Coverage ________________________________
    3. ☐ Personnel Turnover ________________________________
    4. ☐ Compensation ________________________________
    5. ☐ Work Environment ________________________________
    6. ☐ Certification ________________________________
3. Financial
    1. ☐ Operating Ratio ________________________________
    2. ☐ Coverage Ratio ________________________________
    3. ☐ Reserves ________________________________

2. DESIGN

1. Source Water Quality
    1. ☐ Microbial Contamination ________________________________
2. Unit Process Adequacy
    1. ☐ Intake Structure ________________________________
    2. ☐ Presedimentation Basin ________________________________
    3. ☐ Raw Water Pumping ________________________________
    4. ☐ Flow Measurement ________________________________
    5. ☐ Chemical Storage and Feed ________________________________
       Facilities ________________________________
    6. ☐ Flash Mix ________________________________
    7. ☐ Flocculation ________________________________
    8. ☐ Sedimentation ________________________________

9. ☐ Filtration ____________________________________

10. ☐ Disinfection ____________________________________

11. ☐ Sludge/Backwash Water ____________________________________
Treatment and Disposal ____________________________________

3. Plant Operability
   1. ☐ Process Flexibility ____________________________________
   2. ☐ Process Controllability ____________________________________
   3. ☐ Process Instrumentation/ ____________________________________
      Automation ____________________________________
   4. ☐ Standby Units for Key ____________________________________
      Equipment ____________________________________
   5. ☐ Flow Proportioning ____________________________________
   6. ☐ Alarm Systems ____________________________________
   7. ☐ Alternate Power Source ____________________________________
   8. ☐ Laboratory Space and Equipment ____________________________________
   9. ☐ Sample Taps ____________________________________

3. OPERATION

1. Testing
   1. ☐ Process Control Testing ____________________________________
   2. ☐ Representative Sampling ____________________________________
2. Process Control
   1. ☐ Time on the Job ____________________________________
   2. ☐ Water Treatment Understanding ____________________________________
   3. ☐ Application of Concepts and ____________________________________
      Testing to Process Control ____________________________________
3. Operational Resources
   1. ☐ Training Program ____________________________________
   2. ☐ Technical Guidance ____________________________________
   3. ☐ Operational Guidelines/Procedures ____________________________________

4. MAINTENANCE

1. Maintenance Program
   1. ☐ Preventive ____________________________________

2. ☐ Corrective ____________________________________

3. ☐ Housekeeping ____________________________________

2. Maintenance Resources
    1. ☐ Materials and Equipment ____________________________________
    2. ☐ Skills or Contract Services ____________________________________

Definitions for Assessing Performance Limiting Factors

NOTE: The following list of defined factors is provided to assist the evaluator with identifying performance limitations associated with protection against microbial contaminants in water treatment systems. Performance limiting factors are described below using the following format.

A. CATEGORY
- 1. Subcategory
    - a. Factor Name
        - ◆ Factor description
            - ➢ *Example of factor applied to specific plant or utility*

A. Administration

1. Plant Administrators
    1. Policies
        - ◆ Do existing policies or the lack of policies discourage staff members from making required operation, maintenance, and management decisions to support plant performance and reliability?
            - ➢ *Utility administration has not communicated a clear policy to optimize plant performance for public health protection.*
            - ➢ *Multiple management levels within a utility contribute to unclear communication and lack of responsibility for plant operation and performance.*
            - ➢ *Cost savings is emphasized by management at the expense of plant performance or at the expense of HAB preparedness.*

    - *Utility managers do not support reasonable training and certification requests by plant staff.*

    - *Administration continues to allow connections to the distribution system without consideration for the capacity of the plant.*

2. Familiarity With Plant Needs
   - Do administrators lack first-hand knowledge of plant needs?
     - *The utility administrators do not make plant visits or otherwise communicate with plant staff.*

     - *Utility administrators do not request input from plant staff during budget development.*

     - *Administrators are not familiar with HAB preparedness needs at the plant (e.g., on site PAC, chemical supplier reliability, critical equipment O&M status).*

3. Supervision
   - Do management styles, organizational capabilities, budgeting skills, or communication practices at any management level adversely impact the plant to the extent that performance is affected?
     - *A controlling supervision style does not allow the plant staff to contribute to operational decisions.*

     - *A plant supervisor's inability to set priorities for staff results in insufficient time allocated for process control.*

4. Planning
   - Does the lack of long range planning for facility replacement or alternative source water quantity or quality adversely impact performance?
     - *A utility has approved the connection of new customers to the water system without considering the water demand impacts on plant capacity.*

     - *An inadequate capital replacement program results in utilization of outdated equipment that cannot support optimization goals.*

   - *The utility does not have sufficient capability to handle additional sedimentation and backwash sludge/decant treatment or disposal.*

     - *A HAB event results in additional sludge production and backwash waste overloading existing facilities.*

     - *A HAB event results in the need to stop waste decant recycle in the plant and an alternative disposal option is not available (e.g., discharge to sanitary sewer, discharge to receiving stream with NPDES permit).*

5. Complacency
   - Does the presence of consistent, high quality source water result in complacency within the water utility?
     - *Due to the existence of consistent, high quality source water, plant staff are not prepared to address unusual water quality conditions.*

        - *A utility does not have an emergency response plan in place to respond to unusual water quality conditions or events.*

        - *Utility does not have a contingency plan to prepare for a HAB event including an alternate raw or finished water source and considerations for simultaneous treatment objectives (e.g., DBPs, corrosion control).*

        - *Utility has perception that a HAB event is not likely at their utility, and this position has deterred them from being prepared (e.g., monitoring, providing treatment).*

6. Reliability
    - Do inadequate facilities or equipment, or the depth of staff capability, present a potential weak link within the water utility to achieve and sustain optimized performance?
        - *Outdated filter control valves result in turbidity spikes in the filtered water entering the plant clearwell.*

        - *Plant staff capability to respond to unusual water quality conditions exists with only the laboratory supervisor.*

7. Source water management and planning
    - Does the utility have the ability to access multiple water sources; does the plant have the ability to draw water from multiple intake locations or water levels?
        - *The utility is limited to one intake location during a HAB event.*

8. Source Water Protection
    - Does the water utility lack an active source water protection program?
        - *The absence of a source water protection program has resulted in the failure to identify and eliminate the discharge of failed septic tanks into the utility's source water lake.*

        - *Utility management has not evaluated the impact of potential contamination sources on water quality within their existing watershed including HABs.*

2. Plant Staff
    1. Number
        - Does a limited number of people employed have a detrimental effect on plant operations or maintenance?
            - *Plant staff are responsible for operation and maintenance of the plant as well as distribution system and meter reading, limiting the time available for process control testing and process adjustments.*

    2. Plant Coverage
        - Does the lack of plant coverage result in inadequate time to complete necessary operational activities? (Note: This factor could have significant impact if no alarm/shutdown capability exists - see design factors).
            - *Staff are not present at the plant during evenings, weekends, or holidays to make appropriate plant and process control adjustments.*

        - *Staff are not available to respond to changing source water quality characteristics.*

  3. Personnel Turnover
     - Does high personnel turnover cause operation and maintenance problems that affect process performance or reliability?
        - *The lack of support for plant needs results in high operator turnover and, subsequently, inconsistent operating procedures and low staff morale.*

  4. Compensation
     - Does a low pay scale or benefit package discourage more highly qualified persons from applying for operator positions or cause operators to leave after they are trained?
        - *The current pay scale does not attract personnel with sufficient qualifications to support plant process control and testing needs.*

  5. Work Environment
     - Does a poor work environment create a condition for "sloppy work habits" and lower operator morale?
        - *A small, noisy work space is not conducive for the recording and development of plant data.*

  6. Certification
     - Does the lack of certified personnel result in poor O & M decisions?
        - *The lack of certification hinders the staff's ability to make proper process control adjustments.*

3. Financial
  1. Operating Ratio
     - Does the utility have inadequate revenues to cover operation, maintenance, and replacement of necessary equipment (i.e., operating ratio less than 1.0)?
        - *The current utility rate structure does not provide adequate funding and limits expenditures necessary to pursue optimized performance (e.g., equipment replacement, chemical purchases, spare parts).*

  2. Coverage Ratio
     - Does the utility have inadequate net operating profit to cover debt service requirements (i.e., coverage ratio less than 1.25)?
        - *The magnitude of a utility's debt service has severely impacted expenditures on necessary plant equipment and supplies.*

  3. Reserves
     - Does the utility have inadequate reserves to cover unexpected expenses or future facility replacement?
        - *A utility has a 40-year-old water treatment plant requiring significant modifications; however, no reserve account has been established to fund these needed capital expenditures.*

2. Design

1. Source Water Quality
    1. Microbial Contamination
        - ♦ Does the presence of microbial contamination sources in close proximity to the water treatment plant intake impact the plant's ability to provide an adequate treatment barrier?
            - ➢ *A water treatment plant intake is located downstream of a major wastewater treatment plant discharge and is subject to a high percentage of this flow during drought periods.*

2. Unit Process Adequacy
    1. Source Treatment
        - ♦ Does the lack of source water treatment facilities result in degraded water quality?
            - ➢ *Inadequate mixing or aeration of the source water results in stagnant water that supports HABs.*
    2. Intake Structure
        - ♦ Does the design of the intake structure result in excessive clogging of screens, excessive detention time, build-up of silt, or passage of material that affects plant equipment?
            - ➢ *The location of an intake structure on the outside bank of the river causes excessive collection of debris, resulting in plugging of the plant flow meter and static mixer.*
            - ➢ *High detention time in uncovered intake structure results in excessive algae growth.*
            - ➢ *The design of a reservoir intake structure does not include flexibility to draw water at varying levels to minimize algae concentration.*
    3. Presedimentation Basin
        - ♦ Does the design of an existing presedimentation basin or the lack of a presedimentation basin contribute to degraded plant performance?
            - ➢ *The lack of flexibility with a presedimentation basin (i.e., number of basins, size, bypass) causes excessive algae growth, impacting plant performance.*
            - ➢ *A conventional plant treating water directly from a "flashy" stream experiences performance problems during high turbidity events.*
    4. Raw Water Pumping
        - ♦ Does the use of constant speed pumps cause undesirable hydraulic loading on downstream unit processes?
            - ➢ *The on-off cycle associated with raw water pump operation at a plant results in turbidity spikes in the sedimentation basin and filters.*
    5. Flow Measurement
        - ♦ Does the lack of flow measurement devices or their accuracy limit plant control or impact process control adjustments?
            - ➢ *The flow measurement device in a plant is not accurate, resulting in inconsistent flow measurement records and the inability to pace chemical feed rates according to flow.*

6. Chemical Storage and Feed Facilities
   - Do inadequate chemical storage and feed facilities limit process needs in a plant?
     - *Inadequate chemical storage facilities exist at a plant, resulting in excessive chemical handling and deliveries.*

     - *Capability does not exist to measure and adjust the coagulant and flocculant feed rates.*

     - *Plant has inability to feed high PAC dose (i.e., > 20 mg/L) to treat for a HAB event (i.e., storage and feed equipment).*

     - *Plant has inability to feed PAC because of design limitations (e.g., direct, pressure filters).*

7. Flash Mix
   - Does inadequate mixing result in excessive chemical dose, insufficient coagulation, or inability to suspend PAC to the extent that it impacts plant performance?
     - *A static mixer does not provide effective chemical mixing throughout the entire operating flow range of the plant.*

     - *Absence of a flash mixer results in less than optimal chemical addition and insufficient coagulation.*

     - *High PAC feed in rapid mix results in PAC settling to bottom of basin or mechanical failure.*

8. Flocculation
   - Does a lack of flocculation time, inadequate equipment, or lack of multiple flocculation stages result in poor floc formation and degrade plant performance? Does inadequate mixing in flocculation basin fail to suspect PAC?
     - *A direct filtration plant, treating cold water and utilizing a flocculation basin with short detention time and hydraulic mixing, does not create adequate floc for filtration.*

     - *High PAC feed to flocculation results in PAC settling to bottom of basin or mechanical failure.*

9. Sedimentation
   - Does the sedimentation basin configuration or equipment cause inadequate solids removal that negatively impacts filter performance?
     - *The inlet and outlet configurations of the sedimentation basins cause short-circuiting, resulting in poor settling and floc carryover to the filters.*

     - *The outlet configuration causes floc break-up, resulting in poor filter performance*

     - *The surface area of the available sedimentation basins is inadequate, resulting in solids loss and inability to meet optimized performance criteria for the process.*

     - *Inability to frequency clean sedimentation basins during a HAB event.*

        - *Lack of sedimentation process limits ability to treat water during a HAB event.*

    10. Filtration
        - Do filter or filter media characteristics limit the filtration process performance?
            - *The filter loading rate in a plant is excessive, resulting in poor filter performance.*

            - *Either the filter underdrain or support gravel have been damaged to the extent that filter performance is impacted.*

        - Do filter rate-of-flow control valves provide a consistent, controlled filtration rate?
            - *The rate-of-flow control valves produce erratic, inconsistent flow rates that result in turbidity and/or particle spikes.*
        - Do inadequate surface wash or backwash facilities limit the ability to clean the filter beds?
            - *The backwash pumps for a filtration system do not have sufficient capacity to adequately clean the filters during backwash.*

            - *The surface wash units are inadequate to properly clean the filter media.*

            - *Backwash rate is not sufficient to provide proper bed expansion to properly clean the filters.*

    11. Disinfection
        - Do the disinfection facilities have limitations, such as inadequate detention time, improper mixing, feed rates, proportional feeds, or baffling, that contribute to poor disinfection?
            - *An unbaffled clearwell does not provide the necessary detention time to meet the Giardia inactivation requirements of the SWTR.*

            - *Plant has inability to treat HAB toxins through oxidation during the disinfection process (e.g., use of chloramines).*

    12. Sludge/Backwash Water Treatment and Disposal
        - Do inadequate sludge or backwash water treatment facilities negatively influence plant performance?
            - *The plant is recycling backwash decant water without adequate treatment or during an HAB event.*

            - *The plant is recycling backwash water intermittently with high volume pumps.*

            - *The effluent discharged from a sludge/backwash water storage lagoon does not meet applicable receiving stream permits.*

            - *Inadequate sludge disposal exists at a plant, resulting in reduced cleaning of settling basins and recycle of solids back to the plant.*

3. Plant Operability
    1. Process Flexibility
        - Does the lack of flexibility to feed chemicals at desired process locations or the lack of flexibility to operate equipment or processes in an optimized mode limit the plant's ability to achieve desired performance goals?

  - *A plant does not have the flexibility to feed either a flocculant aid to enhance floc development and strength or a filter aid to improve filter performance.*
  - *A plant includes two sedimentation basins that can only be operated in series.*
  - *Plant has inability to feed PAC at location not impacted by oxidant(s).*
  - *Plant does not have the ability to bypass treated water during plant upsets.*

2. Process Controllability
   - Do existing process controls or lack of specific controls limit the adjustment and control of a process over the desired operating range?
     - *Filter backwash control does not allow for the ramping up and down of the flow rate during a backwash event.*
     - *During a filter backwash, the lack of flow control through the plant causes hydraulic surging through the operating filters.*
     - *The level control system located in a filter influent channel causes the filter effluent control valves to overcompensate during flow rate changes in a plant.*
     - *Flows between parallel treatment units are not equal and cannot be controlled.*
     - *The plant influent pumps cannot be easily controlled or adjusted, necessitating automatic start-up/shutdown of raw water pumps.*
     - *Plant flow rate measurement is not adequate to allow accurate control of chemical feed rates.*
     - *Chemical feed rates are not easily changed or are not automatically changed to account for changes in plant flow rate.*

3. Process Instrumentation/Automation
   - Does the lack of process instrumentation or automation cause excessive operator time for process control and monitoring?
     - *A plant does not have continuous recording turbidimeters on each filter, resulting in extensive operator time for sampling.*
     - *The indication of plant flow rate is only located in the pipe gallery, which causes difficulty in coordinating plant operation and control.*
     - *Automatic shutdown/start-up of the plant results in poor unit process performance.*

4. Standby Units for Key Equipment
   - Does the lack of standby units for key equipment cause degraded process performance during breakdown or during necessary preventive maintenance activities?
     - *Only one backwash pump is available to pump water to a backwash supply tank, and the combination of limited supply tank volume and an unreliable*

pump has caused staff to limit backwashing of filters during peak production periods.

5. Flow Proportioning
    - ♦ Does inadequate flow splitting to parallel process units cause individual unit overloads that degrade process performance?
        - ➢ *Influent flow to a plant is hydraulically split to multiple treatment trains, and uneven flow distribution causes overloading of one flocculation/sedimentation train over the others.*

6. Alarm Systems
    - ♦ Does the absence or inadequacy of an alarm system for critical equipment or processes cause degraded process performance?
        - ➢ *A plant that is not staffed full-time does not have alarm and plant shut-down capability for critical finished water quality parameters (i.e., turbidity, chlorine residual).*

7. Alternate Power Source
    - ♦ Does the absence of an alternate power source cause reliability problems leading to degraded plant performance?
        - ➢ *A plant has frequent power outages, and resulting plant shutdowns and start-ups cause turbidity spikes in the filtered water.*

8. Laboratory Space and Equipment
    - ♦ Does the absence of an adequately equipped laboratory limit plant performance?
        - ➢ *A plant does not have an adequate process control laboratory for operators to perform key tests (i.e., turbidity, jar testing).*

9. Sample Taps
    - ♦ Does the lack of sample taps on process flow streams prevent needed information from being obtained to optimize performance?
        - ➢ *Filter-to-waste piping following plant filters does not include sample taps to measure the turbidity spike following backwash.*

        - ➢ *Sludge sample taps are not available on sedimentation basins to allow process control of the sludge draw-off from these units.*

3. Operation

1. Testing
    1. Process Control Testing
        - ♦ Does the absence or wrong type of process control testing cause improper operational control decisions to be made?
            - ➢ *Plant staff do not measure and record raw water pH, alkalinity, and turbidity on a routine basis; consequently, the impact of raw water quality on plant performance cannot be assessed.*

            - ➢ *Sedimentation basin effluent turbidity is not measured routinely in a plant.*

      - *Plant staff do not measure toxins or surrogates (indicators) for cyanotoxin removal (e.g., to be determined; ELISA, NOM, phycocyanin, chlorophyll-a, streaming current, particle count, turbidity).*

  2. <u>Representative Sampling</u>
     - ♦ Do monitoring results inaccurately represent plant performance or are samples collected improperly?
       - *Plant staff do not record the maximum turbidity spikes that occur during filter operation and following filter backwash events.*
       - *Turbidity sampling is not performed during periods when the reclaim backwash water pump is in operation.*
       - *Source water sampling does not accurately represent water quality (e.g., sampling reservoir to characterize water quality at various depths).*

2. Process Control
   1. <u>Time on the Job</u>
      - ♦ Does staff's short time on the job and associated unfamiliarity with process control and plant needs result in inadequate or improper control adjustments?
        - *Utility staff, unfamiliar with surface water treatment, were given responsibility to start a new plant; and lack of experience and training contributed to improper coagulation control and poor performance.*
   2. <u>Water Treatment Understanding</u>
      - ♦ Does the operator's lack of basic water treatment understanding contribute to improper operational decisions and poor plant performance or reliability?
        - *Plant staff do not have sufficient understanding of water treatment processes to make proper equipment or process adjustments.*
        - *Plant staff have limited exposure to water treatment terminology, limiting their ability to interpret information presented in training events or in published information.*
        - *Plant staff feed PAC at same location or close to oxidant feed in process.*
        - *Plant staff feed algaecide to a reservoir indiscriminately or feed pre-oxidants in the plant resulting in the possibility of cell lysis during HAB events.*
        - *Plant staff recycle backwash/sludge decant water to plant during HAB event.*
        - *Plant staff do not consider sedimentation sludge age and the potential for toxin release during a HAB event.*
   3. <u>Application of Concepts and Testing to Process Control</u>
      - ♦ Is the staff deficient in the application of their knowledge of water treatment and interpretation of process control testing such that improper process control adjustments are made?
        - *Plant staff do not perform jar testing to determine appropriate coagulant dosages for different water quality conditions.*
        - *Plant staff do not perform studies to determine most effective PAC type, dose, and mixing energy to treat for HABs.*

- ➢ *Dedicated studies are not conducted to evaluate treatment options to optimize plant performance and consider simultaneous treatment objectives.*
- ➢ *Plant filters are placed back in service following backwash without consideration for effluent turbidity levels.*
- ➢ *Filter to waste valves are available but are not used following filter backwash.*
- ➢ *Plant staff do not calculate chemical dosages on a routine basis.*
- ➢ *Plant staff do not change chemical feed systems to respond to changes in raw water quality.*
- ➢ *Filters are backwashed based on time in service or headloss rather than on optimized performance goal for turbidity or particle removal.*
- ➢ *Sedimentation basin performance is controlled by visual observation rather than process control testing.*

3. Operational Resources
    1. Training Program
        - ♦ Does inadequate training result in improper process control decisions by plant staff?
            - ➢ *A training program does not exist for new operators at a plant, resulting in inconsistent operator capabilities.*
    2. Technical Guidance
        - ♦ Does inappropriate information received from a technical resource (e.g., design engineer, equipment representative, regulator, peer) cause improper decisions or priorities to be implemented?
            - ➢ *A technical resource occasionally provides recommendations to the plant staff; however, recommendations are not based on plant-specific studies.*
    3. Operational Guidelines/Procedures
        - ♦ Does the lack of plant-specific operating guidelines and procedures result in inconsistent operational decisions that impact performance?
            - ➢ *The lack of operational procedures has caused inconsistent sampling between operator shifts and has led to improper data interpretation and process control adjustments.*

4. Maintenance

1. Maintenance Program
    1. Preventive
        - ♦ Does the absence or lack of an effective preventive maintenance program cause unnecessary equipment failures or excessive downtime that results in plant performance or reliability problems?
            - ➢ *Preventive maintenance is not performed on plant equipment as recommended by the manufacturer, resulting in premature equipment failures and degraded plant performance.*

    - *A work order system does not exist to identify and correct equipment that is functioning improperly.*

2. Corrective
    - ♦ Does the lack of corrective maintenance procedures affect the completion of emergency equipment maintenance?
        - *A priority system does not exist on completion of corrective maintenance activities, resulting in a critical sedimentation basin being out of service for an extended period.*

        - *Inadequate critical spare parts are available at the plant, resulting in equipment downtime (e.g., critical parts are not available for mixing and sludge collection equipment during PAC feed season).*

3. Housekeeping
    - ♦ Does a lack of good housekeeping procedures detract from the professional image of the water treatment plant?
        - *An unkempt, cluttered working environment in a plant does not support the overall good performance of the facility.*

2. Maintenance Resources
    1. Materials and Equipment
        - ♦ Does the lack of necessary materials and tools delay the response time to correct plant equipment problems?
            - *Inadequate tool resources at a plant results in increased delays in repairing equipment.*

    2. Skills or Contract Services
        - ♦ Do plant maintenance staff have inadequate skills to correct equipment problems or do the maintenance staff have limited access to contract maintenance services?
            - *Plant maintenance staff do not have instrumentation and control skills or access to contract services for these skills, resulting in the inability to correct malfunctioning filter rate control valves.*

Appendix C

Exit Meeting and Final Report

Contents

“Exit Meeting Agenda” Template

City of XXXX Water Treatment Plant
City, State
Date

Optimization Overview: Why Optimize

Performance Assessment – Historical Data

- **Historical turbidity data**

- **Historical backwash data**

On-Site Studies (as applicable)

- **Sedimentation Basin Backup**

- **Filter Assessment Study**

- **Filter backwash study**

- **Turbidity data integrity assessment**

- **PAC Jar Test**

- **Source Water Sampling**

Major Unit Process Evaluation/Summary

- **Microbial**
- **HABs**

Path to Optimization: Factors Limiting Performance

Potential follow-up studies

Wrap up

“Exit Meeting Presenters’ Agenda” Template

City of XXXX Water Treatment Plant
City, State
Date

Assign a moderator for the meeting, who will introduce each speaker, point out take-home messages and draw connections between each topic. Use of a computer/projector is optional, but may enhance the data-based discussions (e.g., historical performance data, study data, etc.).

Optimization Overview: Why Optimize

Set the stage by discussing the optimization goals and the multiple barrier approach. High level reiteration of key points about optimization and “why optimize” and remind attendees of the handout from the entrance meeting which provides more information.

Performance Assessment – Historical Data

- **Historical turbidity data**

Present the optimization assessment software summary of the raw, settled and finished water turbidity data. Emphasize raw/settled/finished water trends (i.e., spikes in the raw water passing through to settled and finished water, performance relative to the optimization goals).

- **FTW time analysis**

Discuss historical filter-to-waste data compared to the optimization goals. The data indicated the filter-to-waste periods are exceeding the recommended period of 30 minutes.

On-site studies

Discuss any planned on-site studies, relating each to the goals and historical performance data findings.

- **Study #1**

- **Study #2**

- **Study #3**

- ***Etc….***

Major Unit Process Evaluation/Summary

Three MUPs were developed – one for microbial/turbidity performance, one for HAB adsorption and one for HAB oxidation. The MUP assessment intends to determine whether the system has the "concrete and steel" in place to meet the optimization goals. Tie the discussion back to the goals by assessing if the major unit processes and HAB control process are capable of meeting the optimization goals.

Explain the assumptions used in the evaluation.

Factors Limiting Performance

Potential follow-up studies

Wrap up

- *Present a summary of the evaluation and describe follow-up activities that potentially exist. This will likely be the responsibility of the host state to make this presentation.*

“Possible Further Studies for Plant Staff to Conduct to Support Plant Optimization” Template

City of XXXX WTP HAB CPE

Study #1 – Title

- Description
    -
- Benefits
    -

Challenges	Solutions
	• •

Study #2 – Title

- Description
    -
- Benefits
    -

Challenges	Solutions

Study #3 – Title

- Description
    -
- Benefits
    -

Challenges	Solutions

Example "Why Optimize?" Exit Meeting Handout

WHY OPTIMIZE?

- Drinking water research indicates that achieving optimized performance goals provides increased public health protection.
- Field work demonstrates that optimization goals are achievable at most plants without major capital expenditures

- Optimization is a promising approach for controlling the impacts of HABs (i.e., reducing cyanobacteria and related cyanotoxins)

OPTIMIZED PERFORMANCE GOALS

Minimum Data Monitoring

- Daily raw water turbidity
- Settled water turbidity at 4-hour time increments from each sedimentation basin
- On-line (continuous) turbidity from each filter
- One filter backwash profile each month from each filter

Individual Sedimentation Basin Performance Criteria

- Settled water turbidity less than 1 NTU 95 percent of the time based on daily maximum values when annual average raw water turbidity is less than or equal to 10 NTU
- Settled water turbidity less than 2 NTU 95 percent of the time based on daily maximum values when annual average raw water turbidity is greater than 10 NTU

Individual Filter Performance Criteria

- Filtered water turbidity less than 0.10 NTU 95 percent of the time (excluding 15-minute period following backwashes) based on the maximum daily values
- Maximum filtered water measurement of 0.3 NTU
- Initiate filter backwash immediately after turbidity breakthrough has been observed and before effluent turbidity exceeds 0.10 NTU.
- Post backwash individual filter effluent turbidity for filters with filter-to-waste capability: Minimize individual filter effluent turbidity during filter-to-waste period and record maximum value. Return the filter to service at ≤ 0.10 NTU.

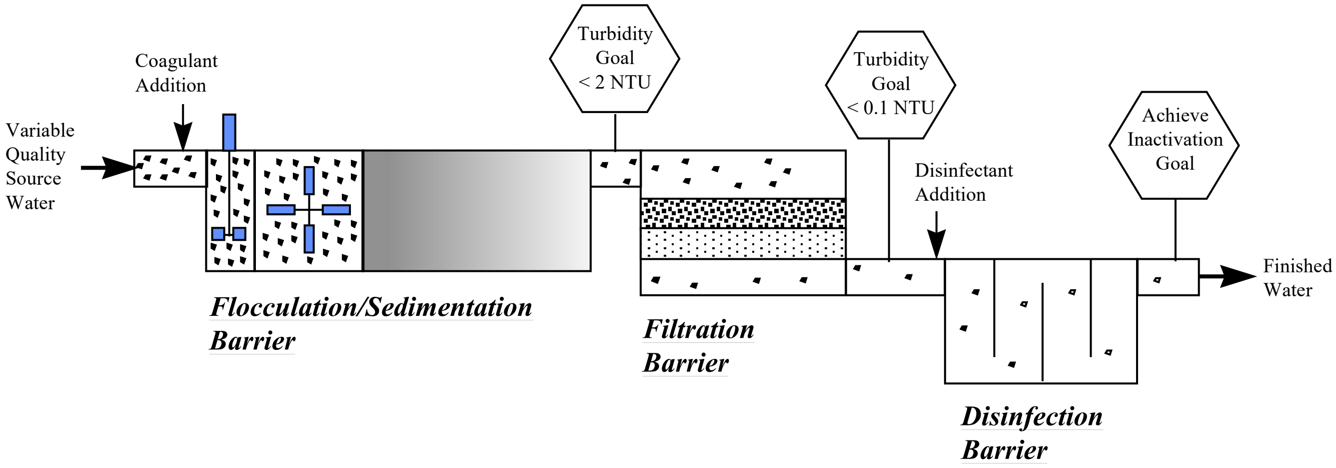
- Post backwash individual filter effluent turbidity for filters <u>without</u> filter-to-waste capability: Maximum individual filter effluent turbidity following backwash ≤ 0.30 NTU and achieve ≤ 0.10 NTU within 15 minutes.

Disinfection Performance Criteria

- CT values to achieve required log inactivation of *Giardia* and virus

OPTIMIZATION UTILIZES THE MULTIPLE BARRIER STRATEGY TO ENHANCE FINISHED WATER QUALITY:

- Key treatment barriers include flocculation/sedimentation, filtration, and disinfection. Each barrier is important when striving for optimized performance
- Performance of each barrier can often be assessed using surrogates, such as turbidity; disinfection effectiveness can be measured directly. Toxin sampling/measurement is needed on some basis to assess impact.
- Treatment objective is to produce a consistent, high quality finished water.



Example HAB CPE Reports

Results of the
Harmful Algal Bloom
Comprehensive Performance Evaluation
for the
ABC Treatment Plant
Anytown, State

August 1 - 5, 2016

Prepared By:

Process Applications, Inc.
2627 Redwing Road, Suite 340
Fort Collins, Colorado 80526

USEPA Technical Support Center
26 West Martin Luther King Drive
Cincinnati, Ohio 45268

State Environmental Protection Agency

Table of Contents

List of Figures

List of Tables

SITE VISIT INFORMATION

Site and Mailing Address:

Removed

Date of Site Visit:

August 1 - 5, 2016

ABC Water Treatment Plant Personnel Participating:

Commissioner
Sanitary Engineer
Administrator
Superintendent
Assistant Superintendent
HR Department
Operator
Operator
Operator
Operator

CPE Team:

USEPA Technical Support Center, 26 West Martin Luther King Drive, Cincinnati, Ohio 45268
Alison Dugan – 513-569-7122; Dugan.Alison@epa.gov
Rick Lieberman – 513-569-7604; Lieberman.Richard@epa.gov
Tom Waters – 513-569-7611; Waters.Tom@epa.gov

USEPA Office of Research and Development, 26 West Martin Luther King Drive, Cincinnati, Ohio 45268
Craig Patterson – 513-487-2805; Patterson.Craig@epa.gov

Process Applications, Inc., 2627 Redwing Road, Suite 340, Fort Collins, Colorado 80526
Bill Davis – 469-338-1823; waterbilldavis@gmail.com
Larry DeMers –970-223-5787; ldemersco@aol.com

State Environmental Protection Agency
HAB Engineer
HAB Coordinator
Design Engineer
Field Engineers/Staff/Inspectors

INTRODUCTION

The Composite Correction Program (CCP)[4] is an approach developed by the U. S. Environmental Protection Agency (USEPA) and Process Applications, Inc. (PAI) to improve surface water treatment plant performance and to achieve compliance with the Surface Water Treatment Rule (SWTR). Its development was initiated by PAI and the state of Montana[5], which identified the need for a program to address performance problems at its surface water treatment plants. The approach consists of two components, the Comprehensive Performance Evaluation (CPE) and the Comprehensive Technical Assistance (CTA).

A CPE is a thorough evaluation of an existing treatment plant, resulting in a comprehensive assessment of the unit process capabilities and the impact of the operation, maintenance, and administrative practices on performance of the plant. The results of the evaluation establish the plant capability to meet the optimization goals and list a set of prioritized factors limiting performance. A CTA is used to improve performance of an existing plant by systematically addressing the factors limiting performance identified during the CPE.

The implementation of the Interim Enhanced Surface Water Treatment Rule (IESWTR), promulgated in December 1998, required plants that serve greater than 10,000 customers to achieve less than 0.3 NTU (nephelometric turbidity units) turbidity in 95 percent of the monthly combined filter effluent samples and to monitor individual filter performance. The requirement went into effect for all surface water treatment plants in 2005. Research results and field experience have shown that just meeting the requirements of the IESWTR does not guarantee adequate protection against some pathogenic microorganisms, as evidenced by some waterborne disease outbreaks.

Producing a finished water with a turbidity of less than or equal to 0.10 NTU provides much greater protection against pathogens like *Cryptosporidium*[3]. This microorganism that passed

---

[4] Hegg, B.A., L.D. DeMers, J.H. Bender, E.M. Bissonette, and R.J. Lieberman, Handbook - Optimizing Water Treatment Plant Performance Using the Composite Correction Program, EPA 625/6-91/027, USEPA, Washington, D.C. (August 1998).

[5] Renner, R.C., B.A. Hegg, and D.F. Fraser, Demonstration of the Comprehensive Performance Evaluation Technique to Assess Montana Surface Water Treatment Plants, Association of State Drinking Water Administration Conference, Tucson, AZ (February 1989).

[3] Patania et al., Optimization of Filtration for Cyst Removal. American Water Works Association Research Foundation. Denver, CO. 1995.

through the public water supply was responsible for a large outbreak of *Cryptosporidiosis* in Milwaukee, Wisconsin in April 1993, where 400,000 people became ill, and nearly 100 deaths occurred. *Cryptosporidium* cysts are extremely resistant to chlorine disinfection, necessitating optimization of physical removal of particles.

Since the development of the CCP for optimization of surface water treatment plants for protection from microbial pathogens, PAI and the USEPA’s Technical Support Center (TSC) have adapted the CCP protocol to the additional public health parameters such as DBP control and distribution system optimization. Given the recent concerns with harmful algal blooms (HABs) and their impact on surface water treatment plants in this state and nationwide, the State EPA, in partnership with TSC, has initiated a project to expand the CCP to include optimization for the removal of blue-green algae (cyanobacteria) cells and the reduction of associated toxins. This CPE for the ABC Water Treatment Plant (WTP) represents the first of four developmental CPEs that will be conducted in the state focused on these performance goals.

The following report presents all of the findings from this CPE and will hopefully provide ABC Water with valuable information that can be used to enhance and maintain water quality. The CPE team would like to thank the plant staff and utility management for hosting this event and for taking the time to assist the team in completing the evaluation. During the evaluation, utility staff members were very accommodating in providing plant information and sharing their experience and knowledge regarding treatment approaches to address HAB events. This type of attitude represents a strong foundation for development of an optimization approach to address HAB events that public water systems may face in the future. This report documents the findings of the CPE conducted at the ABC WTP on August 1-5, 2016.

DESCRIPTION OF WATER TREATMENT PLANT

Overview

The ABC WTP is the main source of potable water for the unincorporated eastern portion of ABC as well as a nearby city and village. Additionally, ABC Water has interconnections with a nearby village and another Water and Sewer Authority to provide purchased potable water on an emergency basis. Potable water is delivered to approximately 17,000 direct consumers and a total of 28,000 consumers, including purchased water in the neighboring communities. ABC Water operates and maintains the system.

Source Intake and Pump Station

A schematic of the water treatment plant, provided by the utility, is shown in Figure 1. The source water is supplied to the plant from an intake on a nearby lake, with an alternate supply available on a nearby river. The Lake intake structure is located approximately 1,500 feet off-shore at a depth of about eight feet, and the intake pumping station building is located along the southern bank of the lake. Approximately 2,000 feet of raw water line connects the Lake intake to the raw water pump station. An additional raw water line from an intake on the River is located northeast of the raw water pump station and 55 feet into the river. This intake ties into the raw water line from the Lake intake with a length of approximately 200 feet of raw water pipe, and it is operating by way of a gate valve. The River is typically only used in cold weather when frazil ice is a problem in the lake. The water quality from the two sources tends to trend together. Three raw water pumps within the pump station transport the raw water to the water treatment plant. The plant has the ability to feed sodium permanganate at the intake pump station with a chemical feed point located on the pump discharge line. Sodium permanganate was being fed during the CPE.

A raw water sample line is located in the pump station, and it collects raw water from the wet well prior to permanganate addition. Monitoring instrumentation includes a turbidimeter and pH meter. Also located within the wet well is a data sonde, which captures and logs continuous data including: turbidity, phycocyanin, chlorophyll, pH, and dissolved oxygen. These data are used by the operators to monitor for HABs and to adjust treatment during these events.

Water Treatment Processes

The ABC WTP utilizes conventional surface water treatment processes, including: coagulation, flocculation, sedimentation, filtration, and disinfection. The reported plant capacity is 9.0 MGD. A pretreatment step precedes the conventional plant and includes four pretreatment basins, each equipped with two top-mounted axial flow impeller mixers, to allow for the addition of powdered activated carbon (PAC) and a secondary permanganate feed point, if necessary. At the time of the CPE, no additional chemical or PAC was being added to the pretreatment basins.

FIGURE 1. Schematic Removed.

The plant staff have experienced significant plugging problems with the PAC feed system to the pretreatment basins, and, as a result, have stopping using this feed location. These basins do not have sludge removal but are drained and cleaned out in the fall.

From the pretreatment basins, the water travels through a flume to the two rapid mix units. At the time of the CPE, aluminum chlorohydrate (ACH) was being added to the rapid mix units for coagulation along with PAC for taste and odor and cyanotoxin control. Additional chemicals, including caustic soda, permanganate, and polymer, can also be fed at this location.

Flocculation and clarification are accomplished with three solids contact clarifiers. Each unit has an inner flocculating zone, an outer settling zone, and an effluent collection system. The solids contact clarifiers are operated in parallel. Each clarifier is equipped with a turbidimeter to measure settled water turbidity, and an additional turbidimeter measures the combined settled water turbidity from a common outlet flume. An online pH meter also measures the pH of the combined settled water.

From the solids contact clarifiers, settled water travels to the filter building through a common flume, where flow is divided among two trains of four-cell cluster filters. Filtration in the plant is achieved through eight filter cells equipped with dual-media anthracite and sand. Each filter effluent is sampled. The samples are transferred to turbidimeters and particle counters located on the operating floor, using high suction lift sample pumps. Backwash supply is provided by the filters in service and supplemented by the high service pump discharge. Air scour is also provided as part of the filter backwash procedure. The filters have the ability to function in filter-to-waste mode following a backwash or during filter startup.

Filtered water flows to a common transfer wet well, where the combined filter effluent turbidity is sampled and directed to a continuous turbidimeter. Sodium hypochlorite is injected into the wet well before filtered water is pumped to the clearwells. Three vertical turbine transfer pumps pump water from the transfer wet well to two ground level clearwells. Located on the discharge line of the transfer pumps are injection points for the addition of caustic soda, fluoride, and a poly/orthophosphate blend corrosion inhibitor. Each clearwell holds a volume of 625,000 gallons of water, and both are constructed of concrete with fiberglass domes. The clearwells are baffled, operate in parallel, and are utilized for disinfection contact time. Treated water is pumped to the distribution system from a 30-inch suction line from the clearwells by way of three horizontal, centrifugal high service pumps. An additional feed point for chlorine also exists on the high-pressure discharge line manifold to boost levels after the clearwells, if needed. A sampling location after the high service pumps is used to measure pH and chlorine residual of the finished water as well as to take other compliance samples.

Waste filter backwash water is collected in a backwash holding tank and is pumped to sludge lagoons. Sludge from the solids contact clarifiers is also sent to the two sludge lagoons. A NPDES permit allows decant from the lagoons to be discharged to a receiving stream.

PERFORMANCE ASSESSMENT

Historical Performance Assessment

Optimized performance, for the purposes of this CPE report, represents performance beyond the Surface Water Treatment Rule (SWTR) requirements. To achieve optimized performance, a water treatment plant must demonstrate that it can take a raw water source of variable quality and produce consistent, high quality finished water. In addition, the performance of each treatment unit process must demonstrate its capability to act as a barrier against the passage of particles at all times.

Administration Assessment

An assessment of the administration of the ABC WTP and its possible effect on plant performance was performed by collecting information through interviews in the following general areas: utility structure, vision, mission, water quality goals, reporting, data review, management style, communications, planning, plant coverage, financial management, and spending authority. Two possible administrative issues were identified that could potentially affect performance. These issues, as well as others, are considered in subsequent sections of the report:

- Individual filter effluent turbidity data review and reporting, and
- Formal adoption of optimization turbidity goals for unit process performance.

Historical Water Quality Performance Assessment

Turbidity and Disinfection – Historical turbidity data were collected from three sources during this CPE. Monthly *““Sanitary Engineers Reports”,”* which are in spreadsheet format and generated by the ABC Regional WTP SCADA system, served as one source of historical data. These reports contain data that are collected from online instrumentation and from laboratory bench analyses entered and stored in the water treatment plant SCADA system. Data from these monthly reports were provided to the CPE team in electronic format, which allowed for direct copying and pasting of data into an Optimization Assessment Spreadsheet (OAS) that is used to assess performance against the optimization goals for turbidity.

Operators' daily log sheets, in hard copy format, were a second source of historical data that were provided to the CPE team onsite in the form of paper copies. These logs were especially useful in assessing the performance of the three up-flow clarifiers. Members of the CPE team determined the maximum daily turbidity values from each individual clarifier and entered these values into the OAS.

A third source of historical turbidity data used by the CPE team was a Hach SC200 Controller, which stores and transmits data from the Hach 1720E Turbidimeters, measuring individual filter effluent (IFE) turbidity values for filter No. 2 and No. 4. These data were downloaded from the controller and used to compare the IFE values from those two filters against the same IFE values obtained from the *““Sanitary Engineers Reports””* generated by the SCADA system. This was done to check on the integrity of the data that were generated by the turbidimeters and then transmitted electronically to the SCADA system, which stores and generates reports from the data. Filter No. 4 was selected for this analysis because the data can be accessed from the SC200 Controller. Turbidity data from the other filters were stored and transmitted via SC100 Controllers, and these data were not accessible by the CPE team.

Historical performance was generally assessed over a 12-month time period, starting on August 1, 2015 and ending on July 31, 2016. Table 1 describes in more detail the exact source of the data used in the CPE performance assessment.

TABLE 1. CPE Turbidity Performance Analysis; Data Acquisition Description

Performance Parameter	Data Used in the CPE Performance Analysis
Maximum Daily Raw Water Turbidity Entering the Plant	Maximum daily raw water turbidity data were obtained from monthly *"Sanitary Engineers Reports"* in the column labeled **Rpt_RawWaterTurbidity_Max**. The values were located on the spreadsheet tab named ***data*** in ***column EJ***, starting in ***row 9***. These data represent values obtained from an online turbidimeter located in the raw water pump station. The sample tap is located in a raw water line in the pump station, opposite of the $NaMnO_4$ injection point.
Individual Clarifier Effluent, or *"Settled Water"* Turbidity	Operators' logs of two-hour turbidity test results were utilized to determine the maximum turbidity value for each day, from each clarifier. *"Sanitary Engineers Reports"* included combined clarifier effluent data from online instrumentation and daily 12:00 P.M. grab samples of individual clarifier effluent which were entered into the SCADA system. These values were used for comparison, but the daily maximum individual clarifier effluent values obtained from operators' logs were used to assess performance against the optimization goals.
IFE Turbidity	The individual filter effluent (IFE) daily maximum turbidity records were taken from monthly *"Sanitary Engineers Reports"* in each column labeled **Rpt_Filter_X_Turbidity_Max,** with the *"X"* representing each of the eight filter numbers. The values were located on the spreadsheet tab named ***data*** in ***columns EO through EV***, starting in ***row 9***. The CPE team attempted to use the operators' logs to eliminate high turbidity values associated with turbidimeter maintenance, calibration, sample pump maintenance, filter, and backwashing. The team also attempted to eliminate values associated with filter-to-waste cycles. However, the operators' logs could not explain all of the irregularities, and the CPE team could not access additional information from the SCADA system. Therefore, all IFE data were used in the performance assessment analysis, even though the CPE team does not believe the data accurately represent true IFE quality.
CFE Turbidity	The combined filter effluent (CFE) daily maximum turbidity records were obtained from monthly *"Sanitary Engineers Reports"* in the column labeled ***Maximum Turbidity*** from the ***SWTR MOR*** tab, ***column S,*** beginning in ***row 18.*** These data are also available from the ***data*** tab in the column labeled ***Rpt_TransferWellTurbidity_Max.*** The values were located on the spreadsheet tab named ***data*** in ***column FU***, starting in ***row 9***. However, the difference is that the SCADA system uses an algorithm to eliminate what are considered errant CFE spikes from the SWTR MOR data. In addition, operators' logs are used to verify CFE spikes that may not be eliminated by the SCADA algorithm and could be eliminated manually if there is justification from the operators' logs. Therefore, the *SWTR MOR* data were used to populate the OAS rather than the data from the ***TransferWellTurbidity*** column.

Performance Parameter	Data Used in the CPE Performance Analysis
Disinfection	Monthly *"Sanitary Engineers Reports"* include spreadsheets generated by the plant SCADA report function. Reports were provided covering the period from January through December 2015.

Historical disinfection data were made available to the CPE team in the monthly *"Sanitary Engineers Reports"* generated through the plant SCADA report writer function in the form of an *Excel* spreadsheet. Each report contains a tab that uses plant data to calculate the daily minimum CT (disinfectant concentration times effective contact time) and to record the required CT entered by the operator. The operators determine the required CT via interpolation from published USEPA CT tables. The disinfection data were available from January 2015 through December 2015 for this analysis.

The turbidity data described in the table below were entered into an OAS, and these data were analyzed through the spreadsheet calculations and charts, comparing values to optimization goals. Figure 2 displays a turbidity profile which is a graphical description of water treatment plant performance over the past year, and Table 2 shows the OAS summary statistics for the plant.

The turbidity profile reveals general trends and also a sharp decline in raw water turbidity in December 2015. There is a possibility of seasonal influences over clarifier performance, as indicated by the black line in Figure 2, and IFE data reveal significant turbidity spikes which need to be investigated, as indicated by the dashed blue line. There is no visual evidence of significant pass-through of raw water spikes, and this observation is supported by the RSQ values in Table 2 below.

TABLE 2. OAS Summary Statistics

ANNUAL DATA	Avg	Min	Max	RSQ	95%	Opt. Goal	Reg.
	NTU	NTU	NTU		NTU	% Values	% Values
Max. Raw Turbidity	51.1	0.6	500.0	n/a	177.0	n/a	n/a
Max. Clarifier Effluent Turbidity	1.6	0.4	4.5	0.00	3.2	76	n/a
Max. Filtered Turbidity	0.25	0.05	5.00	0.00	0.52	15	n/a
Combined Filtered Turbidity	0.09	0.03	5.00	0.00	0.15	88	100

RSQ = Correlation Coefficient for two selected data sets (> ~ 0.25 suggests correlation)

95% = 95th Percentile value for data set

Opt. Goal = % of values in data set that are less than or equal to the selected optimization turbidity goal

Reg. = % of values in data set that are less than or equal to the regulated turbidity requirement

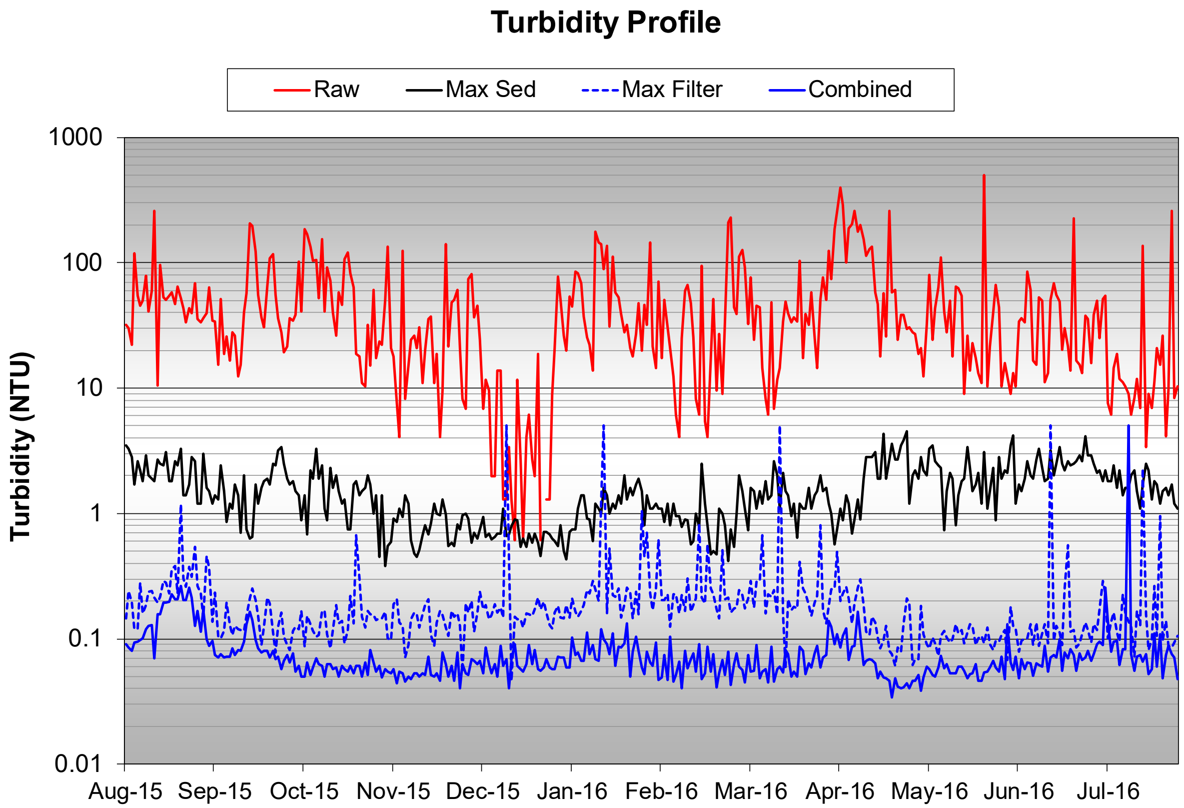


FIGURE 2. ABC WTP Turbidity Profile.

Individual clarifier performance appears to be better in the colder months of the year. Individual filter effluent performance is very erratic, with significant spikes throughout the time period. As described, the IFE data appears to be heavily influenced by issues impacting the accuracy of the data. The combined filter effluent data show much better performance than the IFE data, and they are generally below the optimization goal for filtration of 0.10 NTU, although still not meeting the goal 95 percent of the time, as shown in Table 2.

The statistics in Table 2 are based on the maximum daily values for raw water, individual clarifier effluent, IFE, and CFE turbidity during the August 1, 2015 to July 31, 2016 time period. These statistics are then compared to optimization goals. The optimization program utilizes the *"maximum"* daily turbidity readings to assess worst-case performance by each of the barriers. If the plant can perform within the optimization goals at the time of its worst daily performance, then the plant staff can be assured that the plant is maximizing its ability to protect public health against the passage of pathogens and cyanobacteria. Table 2 shows that the daily maximum raw water turbidity values average for the ABC WTP was 50.9 NTU. For raw water conditions such as this, where the average maximum daily raw water turbidity is greater than 10 NTU, the optimization goal for settled water turbidity is 2 NTU and the optimization goal for filtered water turbidity is 0.10 NTU.

The maximum daily clarifier effluent turbidity, as measured with grab samples from the effluent of each clarifier, met the optimization goal 76 percent of the time. The maximum clarifier effluent turbidity was 3.2 NTU or lower 95 percent of the days during the evaluation period. A closer look at the settled water turbidity is shown in Figure 3. The red line in the graph represents 2.0 NTU, the optimization goal for settled water turbidity. It is also more apparent in Figure 3 that the clarifier performance appeared to be the worst in the late spring and summer, as compared to the winter months. The OAS statistics from the *"Optimization Trend"* tab (see Table 3) revealed that clarifier No. 1 effluent turbidity performance was slightly worse than the other clarifiers from September 2015 to January 2016. Then, clarifier No. 3 had the highest effluent turbidities from February to June 2016. However, the overall performance was fairly even across the three clarifiers, with the 95th percentile values for the three clarifier effluents listed as 2.6, 2.7, and 2.8 NTU, respectively.

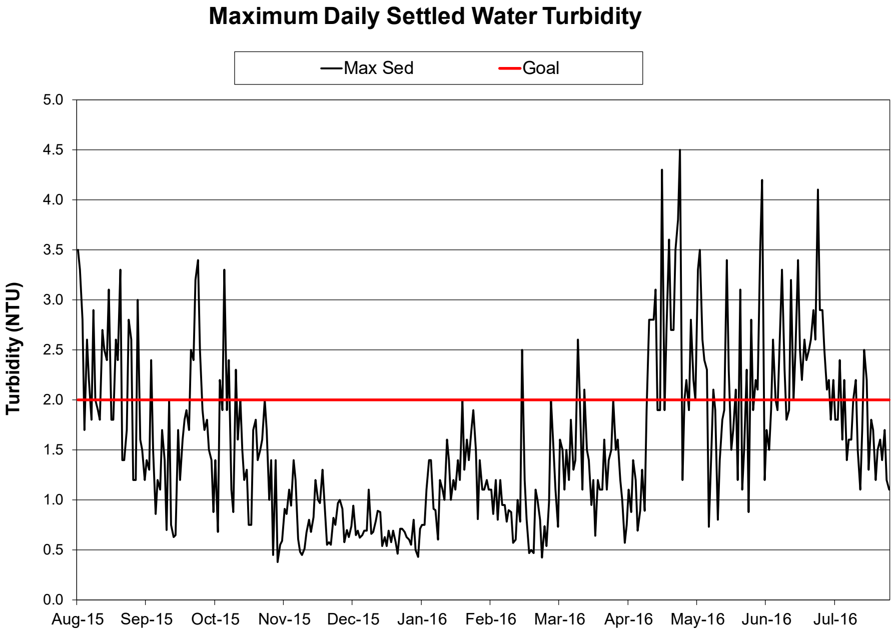


FIGURE 3. Maximum Daily Individual Clarifier Effluent Turbidity.

TABLE 3. OAS Optimization Trend – Settled Water

	Settled Water Turbidity							
	95th Percentile Values (NTU)					% Values Meeting Goal		
	Sed 1	Sed 2	Sed 3	Sed 4	All Sed	3 NTU	2 NTU	1 NTU
Aug-15	2.95	2.95	**3.10**		3.04	94.62	66.67	14.0
Sep-15	**2.89**	2.28	2.18		2.50	96.67	88.89	32.2
Oct-15	**2.37**	2.20	1.50		2.20	98.86	93.18	46.6
Nov-15	**1.26**	1.00	0.88		1.18	100.00	100.00	93.0
Dec-15	**0.92**	0.69	0.71		0.81	100.00	100.00	98.9
Jan-16	**1.80**	1.60	1.40		1.60	100.00	100.00	55.9
Feb-16	1.06	**1.16**	**1.16**		1.17	100.00	98.85	88.5
Mar-16	1.50	1.85	**1.90**		1.88	100.00	97.85	41.9
Apr-16	2.97	3.11	**4.08**		3.56	90.00	67.78	33.3
May-16	2.40	2.85	**3.35**		2.94	95.70	78.49	19.4
Jun-16	3.36	3.11	**3.37**		3.36	91.11	55.56	6.7
Jul-16	**2.50**	2.20	2.45		2.44	100.00	82.80	18.3
Yr. 95%	2.60	2.70	2.80					
Yr. Goal	86.5%	86.5%	84.3%					

It is noteworthy that plant staff routinely enter the individual clarifier effluent turbidity values from daily samples obtained at **12:00 noon**. These are the values used for process control decisions. The CPE team entered the noon values into the OAS to compare the performance of the clarifiers when using these data versus the maximum daily values. When only using the noon values, the clarifiers met the optimization goal for clarifier effluent 98 percent of the time, as shown in the statistics of Table 4. Operator interviews revealed that clarifier performance may degrade in the evening hours. Assessing values from samples obtained only at noon will not account for particles passing the clarification barrier during worst-case scenarios. Figure 4 was generated using the values collected at noon, and it reveals the same trend of seasonal performance degradation, although much less pronounced, in the late spring and summer months.

TABLE 4. OAS Clarifier Effluent Statistics, Daily Max vs. Noon Sample Values

Annual Data	Avg NTU	Min NTU	Max NTU	95% NTU	% Meeting Opt Goal
Max values	1.6	0.4	4.5	3.2	76
Noon values	0.9	0.2	3.4	1.8	98

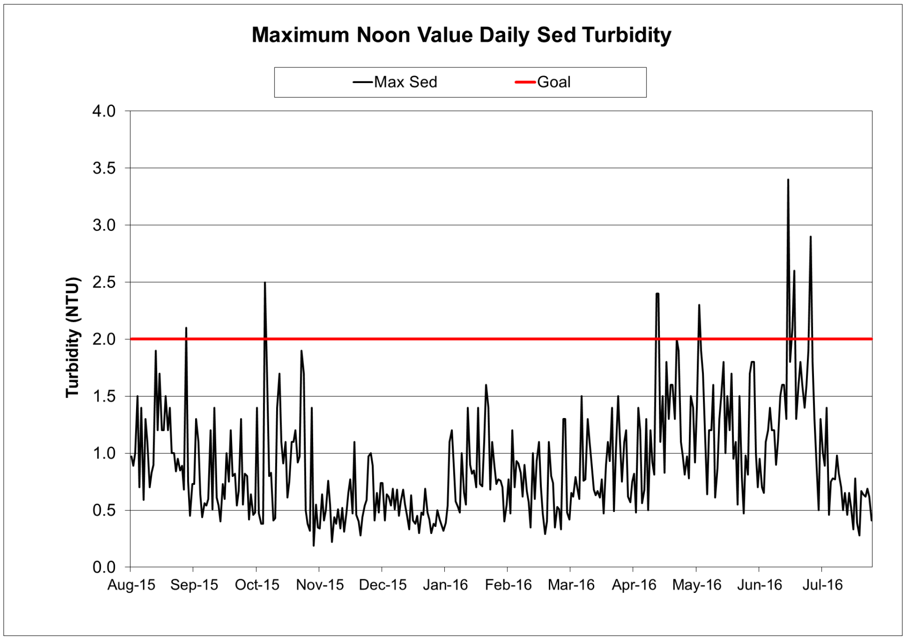


FIGURE 4. Daily Individual Clarifier Effluent Turbidity from 12:00 P.M. Samples.

For filtered water turbidity, the optimization goal is 0.10 NTU or less 95 percent of the time. Table 2 shows that the maximum daily IFE turbidity values met the optimization goal 15 percent of the days analyzed. The maximum IFE values were at 0.52 NTU or less during 95 percent of the days analyzed. Table 2 also shows that the maximum daily CFE values met the optimization goal 88 percent of the days analyzed. The maximum CFE values were at 0.16 NTU or less during 95 percent of the days analyzed.

Figure 5 depicts the maximum daily filtered water turbidity for IFE and CFE turbidity measurements in relation to the optimization goal of 0.10 NTU, represented by the red line. The graph shows the maximum IFE turbidity measurements (dashed lines) mostly above the optimization goal throughout the last year, with significant spikes often exceeding 0.3 NTU. By contrast, the maximum CFE turbidity (solid line) is generally below the optimization goal, although it does exceed the 0.10 NTU goal on several occasions.

Information included in Table 2 above explains that the IFE data stored in the SCADA system and captured in the monthly *"Sanitary Engineers Reports"* are not scrubbed of errant spikes by the SCADA system, as in the case of the CFE values. This was verified when some of the IFE spikes in the *"Sanitary Engineers Reports"* could not be found on the SCADA screen for the same time period. Therefore, the spikes were removed from the visual SCADA readout being monitored by the operators but were captured in the reports.

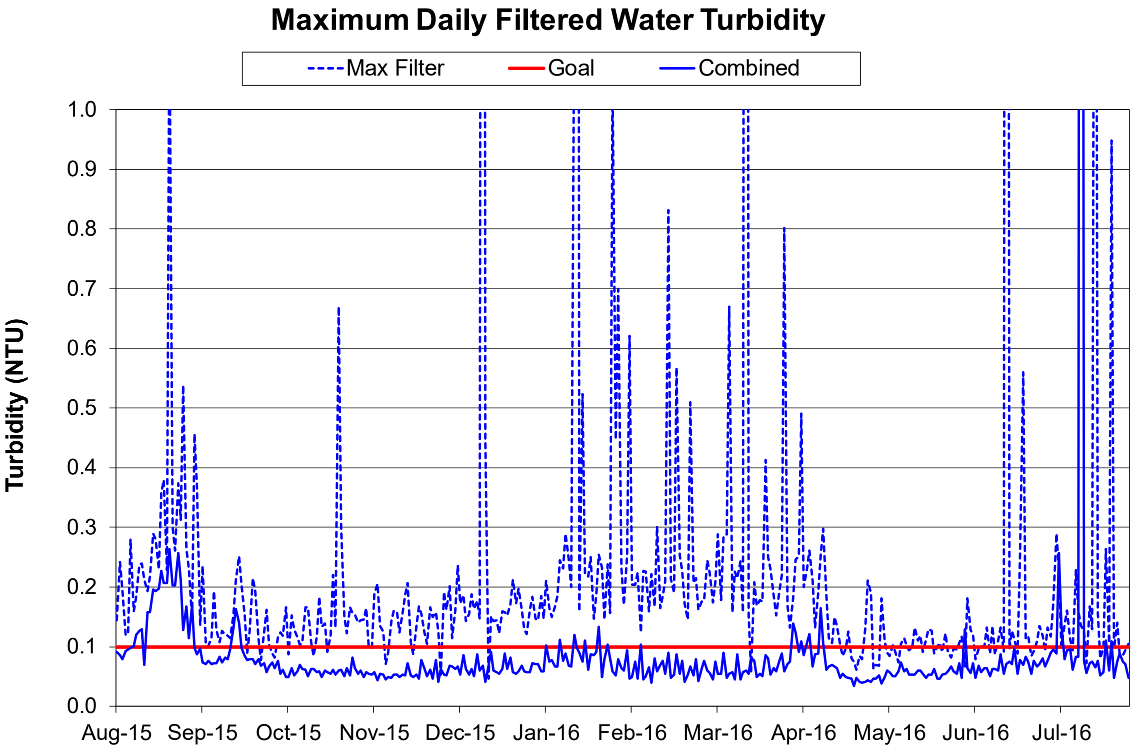


FIGURE 5. Maximum Daily Filtered Water Turbidity (IFE and CFE).

The CPE team performed an onsite study to compare the IFE data that are captured by the Hach SC200 Controller (for filter No. 2 and No. 4) to the IFE data reported in the monthly *"Sanitary Engineers Reports."* The SC200 Controller has limited memory for data storage, but the team was able to access IFE turbidity data for filter No. 4 over the time period of January 26 – July 31, 2016. The results can be found in Table 5. The data from the SC200 Controller represent values obtained directly from the turbidimeter and would include all values, even during filter back-washing, filtering-to-waste, or even during sample pump malfunctions, unless taken offline manually. This study reveals that the data transmitted from the SC200 Controller are being altered in some manner by the SCADA system, even if the SCADA algorithm to *"clean up"* the data has not been applied in the way it has for the CFE data. The data collected by the SC200 Controller revealed higher average and maximum values, which was expected since the SCADA algorithm was likely designed to remove some of the spikes. However, the 95th percentile values are the reverse of what was expected, further indicating that the SCADA influence on the recorded IFE values should be investigated.

TABLE 5. OAS IFE Filter No. 4 Statistics, SCADA vs SC200 Controller

Annual Data	Avg NTU	Min NTU	Max NTU	95% NTU	% Meeting Opt Goal
SCADA values	0.13	0.03	5.00	0.27	80
SC200 values	0.63	0.03	50.77	0.18	86

The OAS also plots the performance of each filter based on IFE turbidity values and is one way of checking to see if certain filters are performing better than others. These data are summarized in Table 6, and they reveal that each filter profile is unique from the others, but that all eight filters experience significant spikes and no individual filter appears to be performing better or worse than the others.

TABLE 6. OAS Optimization Trend – Filtered Water

	Filtered Water Turbidity												
	95th Percentile Values (NTU)										% Values Meeting Goal All Filters		
	Filter 1	Filter 2	Filter 3	Filter 4	Filter 5	Filter 6	Filter 7	Filter 8	Combined	All Filters	0.3	0.2	0.1
Aug-15	0.27	0.32	0.26	0.31	0.23	0.24	**0.40**	0.34	0.24	0.30	95.16	63.31	19.4
Sep-15	0.18	**0.22**	0.13	0.19	0.16	0.17	0.15	0.21	0.14	0.19	100.00	96.67	69.6
Oct-15	0.14	0.16	0.13	0.10	0.17	**0.17**	0.13	0.15	0.07	0.15	99.19	98.79	83.9
Nov-15	0.12	**0.18**	0.12	0.12	0.11	0.18	0.10	0.18	0.08	0.16	100.00	98.75	86.3
Dec-15	0.18	0.19	0.14	0.15	0.13	**0.21**	0.16	0.16	0.09	0.17	99.19	98.39	81.5
Jan-16	0.25	**0.72**	0.34	0.67	0.17	0.21	0.19	0.21	0.12	0.25	95.97	87.90	72.6
Feb-16	0.15	0.22	0.22	0.20	0.20	0.22	0.22	**0.43**	0.09	0.22	97.84	91.38	78.4
Mar-16	0.15	0.29	0.17	**0.35**	0.17	0.22	0.25	0.22	0.09	0.23	97.98	90.73	78.6
Apr-16	0.19	0.15	0.21	0.19	0.14	0.21	0.23	**0.25**	0.13	0.20	99.58	95.00	82.5
May-16	0.10	0.10	0.09	0.09	0.10	0.11	0.10	**0.12**	0.07	0.11	100.00	100.00	92.7
Jun-16	**0.21**	0.10	0.10	0.12	0.10	0.12	0.10	0.13	0.09	0.13	98.33	96.67	88.8
Jul-16	0.16	0.14	0.20	**0.62**	0.08	0.15	0.10	0.12	0.20	0.16	97.98	95.97	85.9
Yr. 95%	0.21	0.24	0.23	0.24	0.19	0.21	0.21	0.22	0.15				
Yr. Goal	78.1%	72.7%	77.3%	73.5%	80.6%	77.0%	80.6%	73.0%	88.0%				

In contrast to the IFE data, spikes in the CFE data are removed from the SWTR MOR data set if there are documented reasons to justify those actions. Table 7 contains some of the CFE values which were removed from the past year's data set. Plant staff review all elevated CFE turbidity values against operator log records and make decisions about the authenticity of the data. Errant spikes are removed from the calculation of the CFE turbidity values reported on the SWTR MOR if it is determined that the elevated values did not represent actual CFE water quality. Turbidity spikes typically occur during maintenance of sample pumps and turbidimeters and plant power outages.

TABLE 7. CFE Data Removal of Errant Spikes

Date	SWTR MOR	*"Sanitary Engineers Reports"*
01/27/2016	0.06	0.64
03/22/2016	0.09	0.41
04/27/2016	0.04	0.61
05/18/2016	0.06	1.43
07/15/2016*	5.00	5.00

* The data for the July SWTR MOR had not yet been edited at the time of the CPE.

Historical Performance Summary

The ABC WTP performance is summarized in Table 8.

TABLE 8. ABC WTP Performance Summary

Barrier	Optimization Goal	Performance
Clarification	Settled water turbidity 1.0 NTU or less 95 percent of the time, based on daily maximum values	The goal was assessed against individual clarifier effluent turbidity values. This is the most effective way to assess the clarification barrier. Plant staff are to be commended for sampling, analyzing, and reporting individual clarifier effluent turbidities. The 95th percentile of the maximum daily individual clarifier effluent turbidity was above the goal, at 3.2 NTU, for the year analyzed. The plant met the 2 NTU goal on 76 percent of the days during the year.
Filtration	IFE and CFE turbidities 0.10 NTU or less 95 percent of the time, based on daily maximum values	The IFE data show performance meeting the optimization goal 15 percent of days analyzed during the year, with an annual 95th percentile of 0.52 NTU. However, the authenticity of the data set is in question, and the data must be *"cleaned up"* in a systematic, well-documented process in order to make appropriate conclusions on IFE performance. The CFE data show performance meeting the optimization goal 88 percent of the days analyzed during the year, with an annual 95th percentile of 0.15 NTU. The performance of the plant, based on CFE data, fails to meet the filtered water optimization goal.

Disinfection

Disinfection is the final barrier in the treatment plant for protection from microbial pathogens. CT represents the disinfection concentration (C) multiplied by the contact time (T) (adjusted for basin hydraulics). The plant operators measure parameters to calculate CT daily, and they use a spreadsheet to compare the daily required CT value to the calculated CT value. The CPE team used the data from the plant CT calculations to evaluate historical disinfection performance. An inactivation ratio is determined by dividing the measured CT value by the required CT value, and the inactivation ratio values for 2015 are plotted in Figure 6. The optimization goal for disinfection is an inactivation ratio of at least 1.0 (demonstrating compliance with the regulatory requirement). Figure 6 shows that the ABC WTP met the goal every day during the year by a wide margin, especially during the summer when disinfectant dosages were increased, presumably as a precaution during a HAB event.

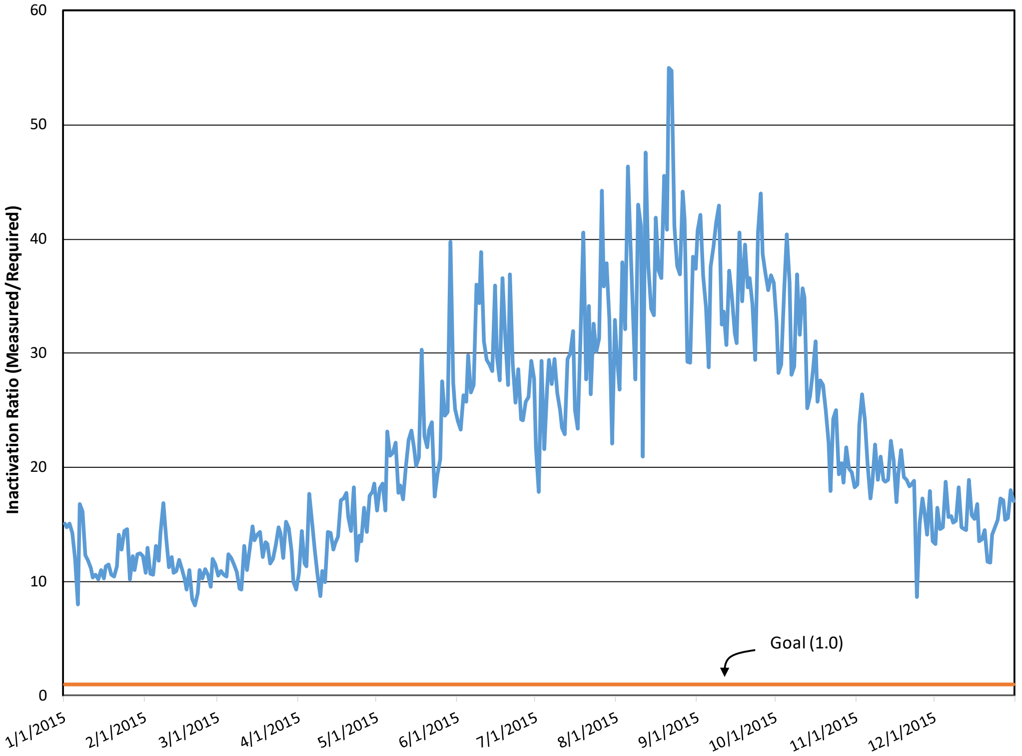


FIGURE 6. Daily Disinfection Inactivation Ratio.

Cyanotoxins

During HAB events, cyanotoxins can enter the plant as either intracellular cyanotoxins (contained within a cyanobacteria; e.g., *Microcystis,* cell) or extracellular cyanotoxins (outside the cell, or free). Intracellular cyanotoxins can also be released from cells if they are lysed (broken apart) during treatment in the plant. Historically, microcystins have only exceeded the current action level and reporting limit of 0.3 µg/L in the finished drinking water on one occasion (0.47 µg/L on September 18, 2013). At that time, raw water microcystins concentrations were reported as exceeding 10 µg/L. Insufficient data are available, however, to evaluate the removal or destruction of cyanotoxins by each of the individual unit processes in the plant.

On-site Studies

During the CPE, several studies were conducted to assess plant performance and process control. These studies included: 1) filter media assessment, bed expansion, and waste backwash profile; 2) filter backwash recovery; 3) assessment of sodium permanganate ($NaMnO_4$) dose on particle removal and cyanobacteria cell lysing; and 4) chlorophyll-*a*, and phycocyanin plant profile.

Study 1: Filter Media Assessment, Bed Expansion, and Waste Backwash Profile

Filter Inspection–

The purpose of the filter inspection is to visually observe physical conditions of the filter media. A visual examination was made of the media once filter No. 4 was drained. The anthracite media appeared to be clean and angular. There didn’t appear to be mudballs or cracks throughout the surface of the media. A small section of the filter bed was excavated by hand to observe the degree of stratification between the anthracite and sand media. Typically, there should be a distinct layer of anthracite over a short depth of intermixed anthracite and sand media, followed by a distinct layer of sand underneath. The excavation in filter No. 4, shown in Figure 7, revealed almost complete mixing of the anthracite and sand layers throughout the depth of the filter bed profile. Re-stratification of media following a backwash cycle is a function of media density, filter bed expansion during backwash, and the approach used to ramp down the backwash flow rate. In filter No. 4, the failure of the anthracite and sand to re-stratify back to their original respective locations following a backwash cycle may be a reflection of poor bed expansion provided during the backwash cycle and the approach used to ramp down the flow rate. It is important to note that these findings only represent the inspection of one of the eight gravity filters at the plant.

Further studies could be pursued by plant staff to assess the condition of the media in the remaining filters. In addition, it may be possible to adjust current backwash procedures and examine the resulting re-stratification until the most effective backwash and re-stratification configuration is found. A possible issue with completely mixed filter media is a more rapid increase in filter headloss and blinding of the filters when operating under high hydraulic and solids loading conditions such as during a HAB event.

Filter Probing–

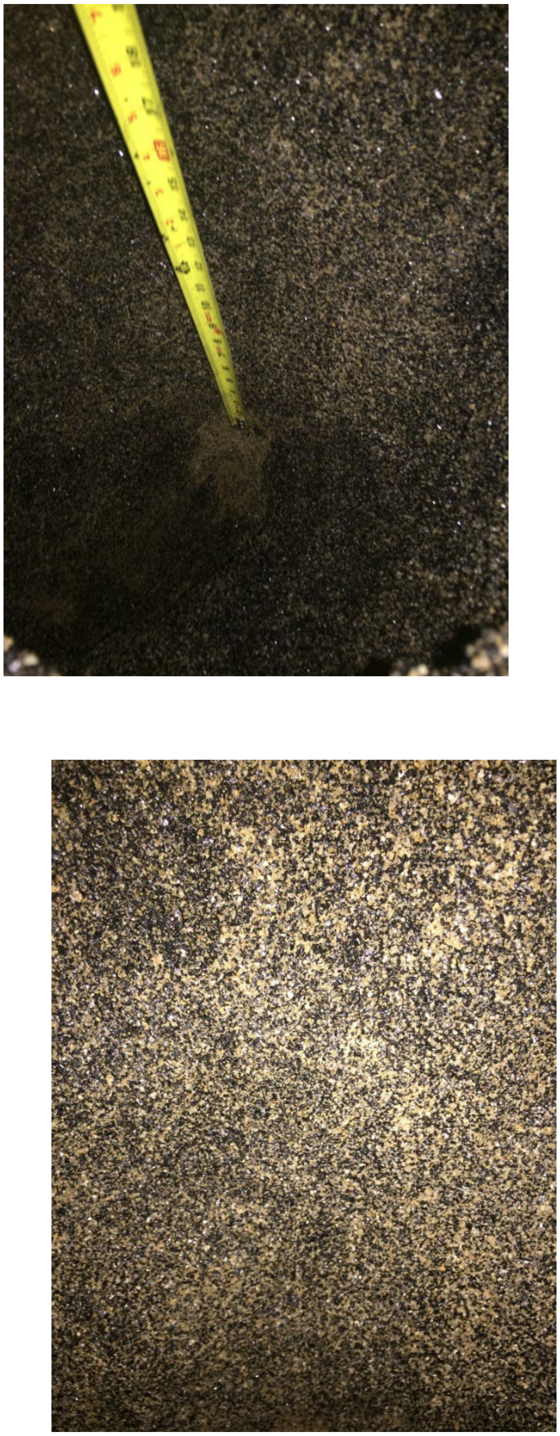


FIGURE 7. Excavated Area of Filter No. 4 Showing Intermixing of Media.

Filter Probing–

The purpose of conducting a filter probing study is to evaluate the overall depth of media in the filter. This is accomplished by probing the filter at approximately equally-spaced distances across the plan area of the filter following a grid-like pattern. Once depths are measured at the various points across the plan area of the filter, the data points can be plotted on a map and used to determine areas where the bed is uneven or where media loss has occurred. The CPE team used a metal rod to manually probe and measure the media depth from the support deck to the top of the media in filter No. 4. The media depth was measured in a grid-like pattern at 24 locations across the area of the filter, and the total depth of media at these locations ranged from 26.75 inches to 29.25 inches. The filter was originally installed with a 15-inch layer of anthracite, followed by a 12-inch layer of sand, and a three-inch layer of torpedo sand, for a total media depth of 30 inches. Therefore, the filter probing study showed a 0.75 to 3.25-inch loss of media in the filter. Figure 8 shows the map of the filter media bed observed in filter No, 4 during the CPE.

Filter No. 4
August 3, 2016

Measurements taken at 4-foot increments measured from the gullet.

Area of Excavation: Anthracite and sand were completely intermixed along profile.

Media depths ranged from 26.75” to 29.25”.

Bed Expansion:
1.5 inches.
5% expansion.

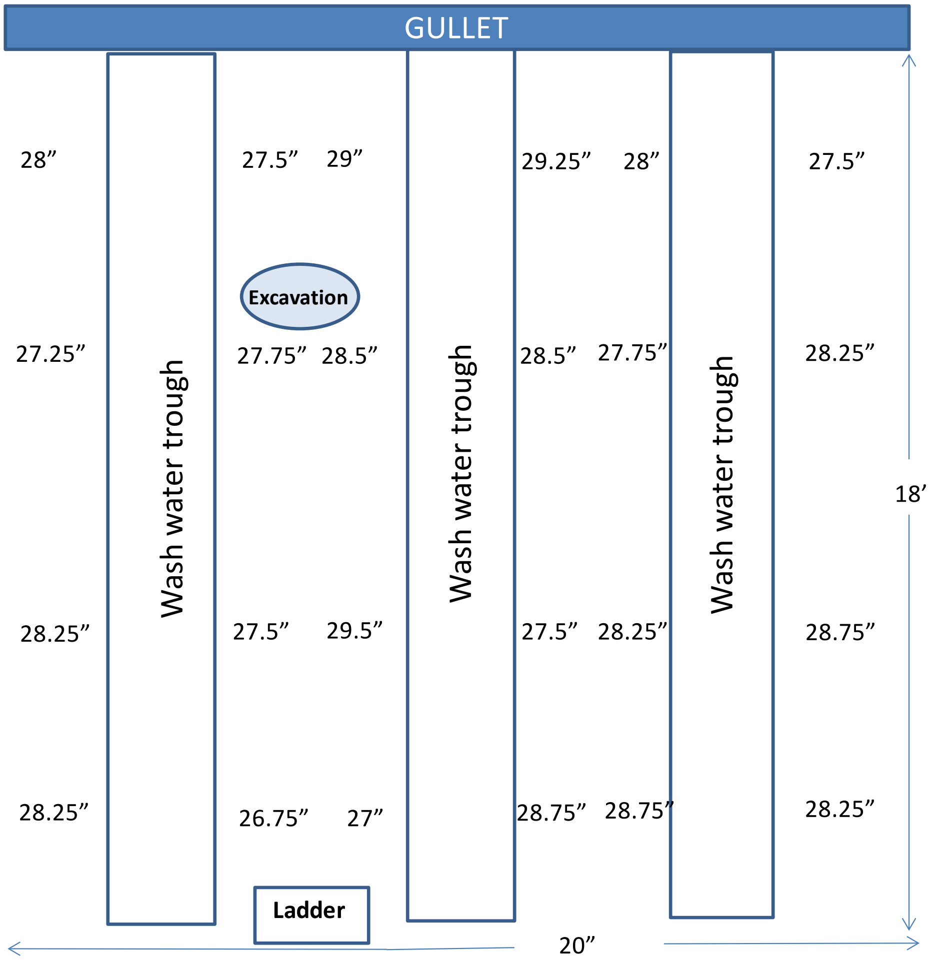


FIGURE 8. Filter No. 4 Filter Probing Map.

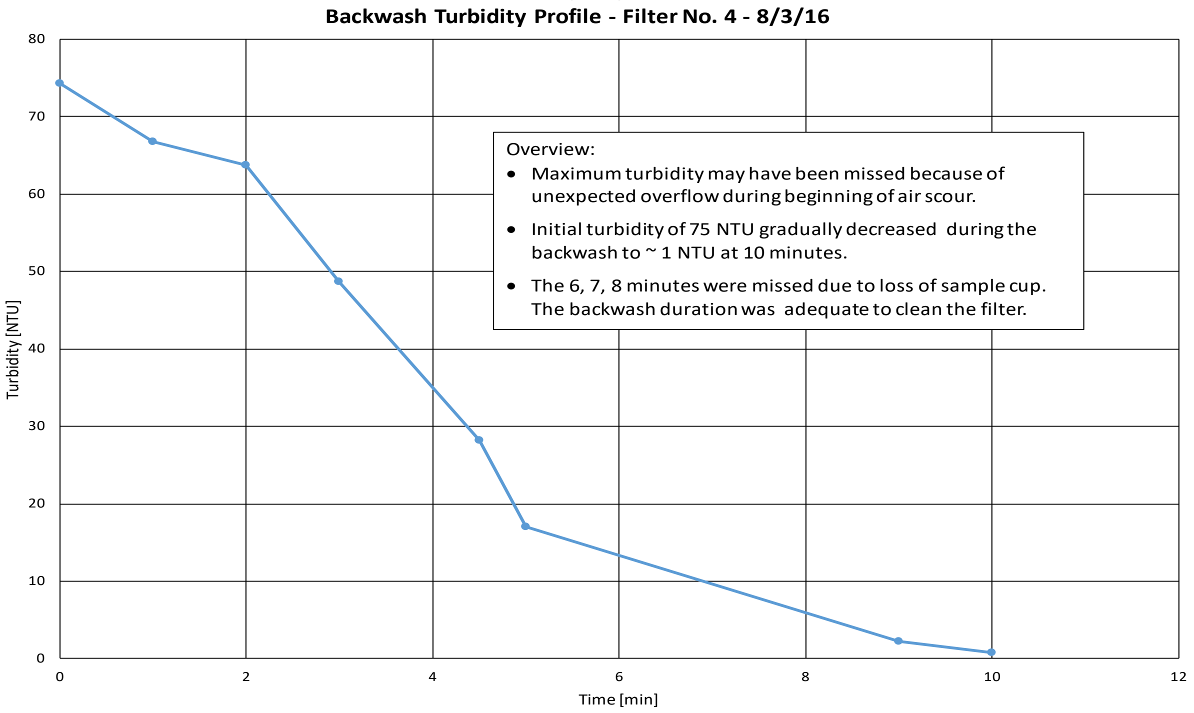
Bed Expansion–

The purpose of conducting the bed expansion study is to determine the depth to which the media expands during a typical backwash cycle being used at the plant. Once the depth of expansion is determined, it can then be used to calculate the bed expansion percentage. Knowing the percent of bed expansion helps operators understand how effective the backwash cycle is in cleaning the media and the ability for the media to re-stratify back to its original location following a backwash. A minimum of 20 percent filter bed expansion is desirable; however, filters using air scour can achieve satisfactory backwashing at lower expansion rates (i.e., 15 percent). The equipment used to conduct the study during the CPE included a Secchi disk attached to a pole. The CPE team marked the pole when it was sitting on the anthracite media before the filter backwash and again at the high backwash flow rate when the Secchi disk was observed to disappear below the fluidized anthracite. The distance between these two marks represents the depth of media expansion.

The CPE team attempted to determine the depth of expansion during the high-rate portion of the filter No. 4 backwash cycle. The initial bed expansion measurement of 1.5 inches indicated a bed expansion rate of only five percent. During an attempt to re-check the bed expansion depth, the Secchi disk detached from the pole and was made unusable. Plant staff members were able to retrieve the Secchi disk from the top of the filter media bed during a subsequent draining of the filter. The plant staff is encouraged to repeat the filter bed expansion study to confirm the bed expansion rate during backwash of each of the filters.

Backwash Waste Turbidity Profile–

The purpose of conducting a waste backwash profile study is to determine the amount of time necessary for effective media cleaning. The equipment used to perform the waste backwash profile study during the CPE included a sample collection device and a turbidimeter. During the filter No. 4 backwash, the CPE team attempted to collect turbidity grab samples from the waste trough using a long pole with a sample bottle attached at the end. The CPE team was able to collect six samples from the start of the backwash cycle through ten minutes into the cycle, at varying intervals. Due to the force of the water from the backwash launders, the sample bottle became detached from the pole and discharged from the filter along with the backwash wastewater. Due to the loss of the sampler, the six, seven, and eight-minute samples were missed, but a ten-minute sample was collected. The backwash waste turbidity profile is shown in Figure 9. These data indicate that the filter was adequately cleaned. This study can also be used to determine an optimum turbidity level to stop backwashing and to determine if excess backwash water is being used during filter backwash. The plant operators are encouraged to periodically conduct this study to support optimization of the filter backwash procedure.



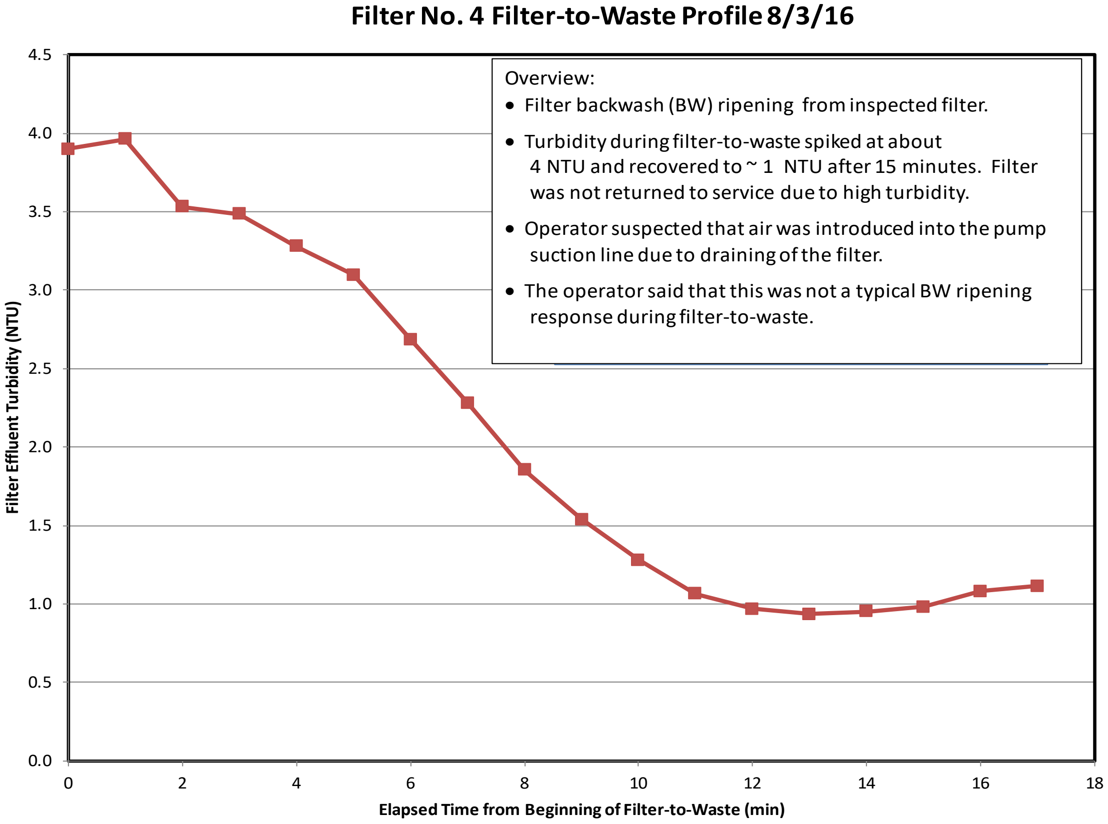
Overview:

- Maximum turbidity may have been missed because of unexpected overflow during beginning of air scour.
- Initial turbidity of 75 NTU gradually decreased during the backwash to ~ 1 NTU at 10 minutes.
- The 6, 7, 8 minutes were missed due to loss of sample cup. The backwash duration was adequate to clean the filter.

FIGURE 9. Filter No. 4 Waste Backwash Water Turbidity Profile.

Study 2: Filter Backwash Recovery

The optimization goal for plants with filter-to-waste capability is to return the filter to service at ≤ 0.10 NTU. Following the inspection and backwash of filter No. 4 during the CPE, the turbidity recovery of the filter was monitored during filter-to-waste. The filter-to-waste profile is shown in Figure 10. The turbidity spiked to 4 NTU and gradually decreased to 1 NTU after 12 minutes; however, the turbidity remained around 1 NTU for several more minutes. Because of this high turbidity, the filter was not immediately placed in service. The operator commented that this was not a typical filter-to-waste recovery and thought that the draining of the filter might have resulted in air entrainment in the filter media and underdrain. The operator also commented that the pumping of the filter effluent samples to the turbidimeters has frequently resulted in high turbidity spikes that the operators need to address.



Overview:

- Filter backwash (BW) ripening from inspected filter.
- Turbidity during filter-to-waste spiked at about 4 NTU and recovered to ~ 1 NTU after 15 minutes. Filter was not returned to service due to high turbidity.
- Operator suspected that air was introduced into the pump suction line due to draining of the filter.
- The operator said that this was not a typical BW ripening response during filter-to-waste.

FIGURE 10. Filter-to-Waste Profile for Inspected Filter No. 4.

To assess a normal turbidity recovery following a filter backwash, the CPE team evaluated turbidity data from filter No. 8 that was also backwashed on the same day. These data are shown in Figure 11. During the filter-to-waste period of 15 minutes, the turbidity varied from 0.11 to 0.13 NTU. After the filter was returned to service to the clearwell, the turbidity spiked to 0.14 NTU and did not reach the optimization goal of 0.10 NTU for another 50 minutes. This filter recovery did not meet the optimization goal of achieving ≤ 0.10 NTU by the end of the filter-to-waste period. Achieving this goal following each filter backwash reduces the number of particles (including pathogens and cyanobacteria cells) that pass to the clearwell and, as a result, enhances public health protection.

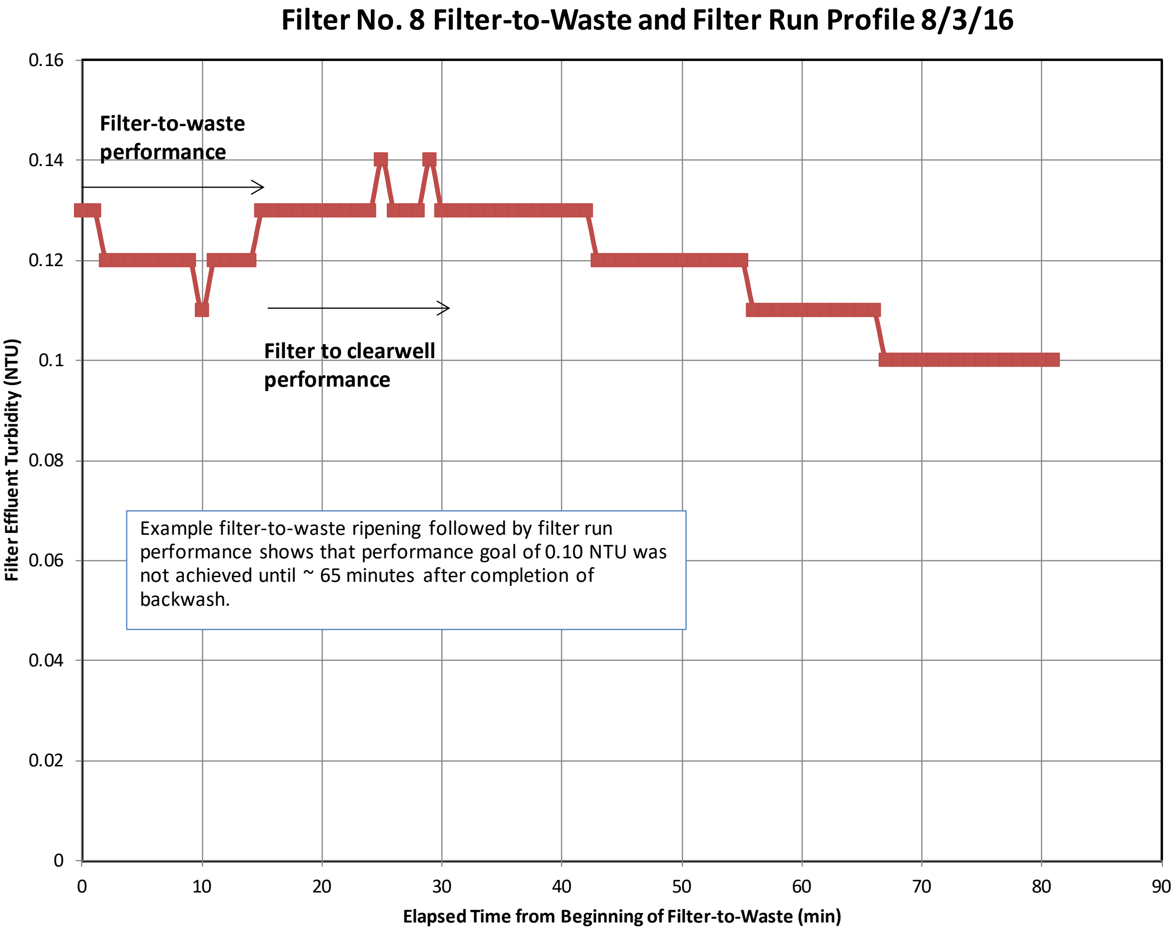


FIGURE 11. Filter-to-Waste Profile for Filter No. 8 Backwash.

Study 3: Assessing $NaMnO_4$ Dose on Particle Removal and Cyanobacteria Cell Lysing

Sodium permanganate ($NaMnO_4$) is added at the raw water pump station as a pre-oxidant to enhance turbidity removal and to oxidize organics to reduce taste and odor in the finished water. While sodium permanganate addition can provide treatment benefits, there could be negative impacts of adding this oxidant to the raw water when cyanobacteria cells are present. The potential exists for the permanganate to disrupt the cyanobacteria cells and release the intracellular cyanotoxin into the water. The ABC operators currently feed permanganate in the range of 0.7 to 1.1 mg/L and target a residual of 0.3 mg/L at the head of the plant just prior to coagulant addition.

The purpose of this study was to assess the benefits and negative impacts of permanganate addition at the ABC WTP. Two study hypotheses were identified:

1. The addition of NaMnO4 to the raw water will improve floc formation through the coagulation process and improve particle settleability through the clarification process.

2. As the $NaMnO_4$ dose increases in the raw water, it will contribute to cell disruption and an increase in extracellular microcystins concentration.

Approach–

This study was conducted using jar testing equipment provided by the plant. Since the raw water microcystis cell concentration was relatively low during the CPE, the evaluation team augmented the cell concentration in the raw water sample. Phycocyanin measurements were taken with a data sonde from both the river intake site (near bank) and raw water wet well in the pump station. Since concentrations were higher in the river, a plankton net was used to concentrate phytoplankton cells from the river source water. The concentrated biomass collected via the plankton net was mixed into approximately four gallons of river water for use in the jar test.

The plant's coagulant, aluminum chlorohydrate (ACH), and $NaMnO_4$ were added to the jars during the test. A micropipette was used to deliver the neat ACH dose to the jars. Knowing that 1 microliter (µL) of water is equal to 1 mg of water, the ACH volume to deliver to the jars was calculated using the ACH specific gravity and jar volume. The following sample calculation for a 24 mg/L ACH dose shows that the required ACH delivered to a 2 liter jar would be 36 µL.

$$\frac{24\,mg}{L} \times \frac{1\ \mu L\ ACH}{1.32\ mg\ ACH} \times\ 2\ L\,jar\ = 36\ \mu L$$

For $NaMnO_4$, a 0.2 percent stock solution of the chemical was prepared. This stock solution concentration resulted in a 1 mg/L $NaMnO_4$ dose to the 2-liter jars for every 1 milliliter of stock solution added.

The jar test settings were estimated based on hydraulic detention time through the plant and the current jar test settings used by the plant staff. The settings used in this study are listed below. The permanganate contact time was reduced from the actual time (approximately one hour) because of the limited time to conduct the study. The jars were sampled for turbidity and total microcystins following the eight-minute settling time.

1. Permanganate contact time – 30 minutes @ 30 rpm
2. Rapid mix – 2 minutes @ 175 rpm
3. Flocculation – 15 minutes @ 30 rpm, then 15 minutes @ 20 rpm
4. Settling time – 8 minutes

In addition to the sampling time of eight minutes that represented the settling rate in the clarifiers, additional sampling times were set for jar No. 2 and No. 3 starting immediately after the mixer was turned off (i.e., time zero minutes) and continuing at one, two, four, six, and ten minutes. These sample times were used to support the development of settling curves from these two jars.

The jars were set up with the following conditions:

Jar 1 – blank (no chemicals)
Jar 2 – ACH dose = 24 ppm (plant dose)
Jar 3 – ACH dose – 24 ppm, $NaMnO_4$ = 1.2 ppm (plant dose)
Jar 4 – ACH dose – 24 ppm, $NaMnO_4$ = 3 ppm (high dose where cyanotoxin release may occur)

Testing from the samples collected from the jars included turbidity, total microcystins, and extracellular microcystins. Turbidity was also measured from Jar No. 2 and No. 3 from the samples collected to develop the settling curves. Following the sampling for turbidity, samples were collected from each of the jars for testing total and extracellular microcystins at the State EPA lab. A small volume of sodium thiosulfate was added to these samples to quench the permanganate residual to stop any further oxidation reactions in the samples.

Results and Conclusions–

To assess the impact of $NaMnO_4$ on the formation and settleability of floc particles, settling curves were developed from samples collected from Jar No. 2 (coagulant only) and No. 3 (coagulant and $NaMnO_4$). Figure 12 shows a plot of settling time versus turbidity for these two jars. Observations of these two jars during the testing showed the formation of higher density, larger diameter floc particles in the jar with permanganate addition. The initial part of the settling curve for the jar with permanganate supports this observation with the jar having higher initial turbidity than Jar No. 2 (time zero samples) and faster settling particles, as indicated by lower turbidity from the two- and four-minute samples. However, this trend reversed in the six- and ten-minute samples. The reason for this trend change is unknown but could be due to some type of sampling or testing error or color interference from the jar with permanganate addition. This trend change makes the study results somewhat inconclusive, and repeating this study would be needed to confirm the impact of $NaMnO_4$ on coagulation and particle settleability.

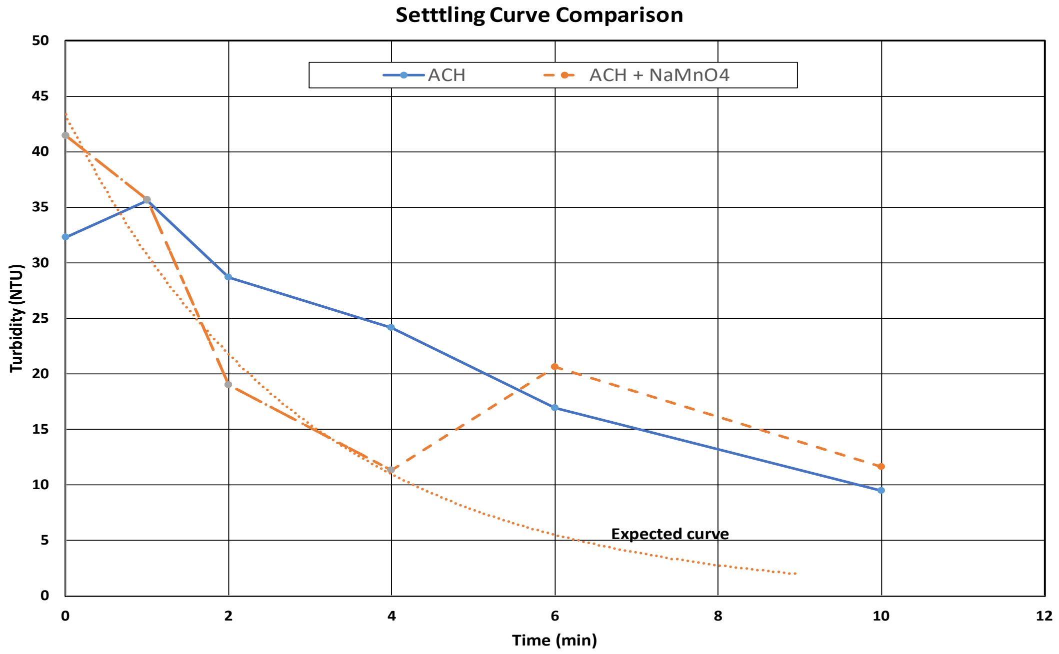


FIGURE 12. Settling Curves for Water Treated With and Without $NaMnO_4$.

The results of the $NaMnO_4$ addition on the potential for cyanobacteria cell lysing and release of microcystins is shown by the results in Figure 13. The first two samples show the total and extracellular microcystins of the augmented raw water sample and another augmented raw water sample that was mixed for 30 minutes. Both show similar results, with the majority of the microcystins being contained within the cells (i.e., intracellular). Sample 3 shows that about 85 percent of the total microcystins were removed through coagulation, flocculation, and sedimentation. Comparing the results from Samples 2, 3, and 4 indicates that, as the $NaMnO_4$ dose was increased in the jars from zero permanganate in Sample 2 to 3 mg/L in Sample 4, the extracellular microcystins concentration increased from about 20 percent of the total concentration to almost 80 percent of the total concentration. The extracellular microcystins concentration increased slightly in the sample, with 1.2 mg/L of permanganate (i.e., plant dose).

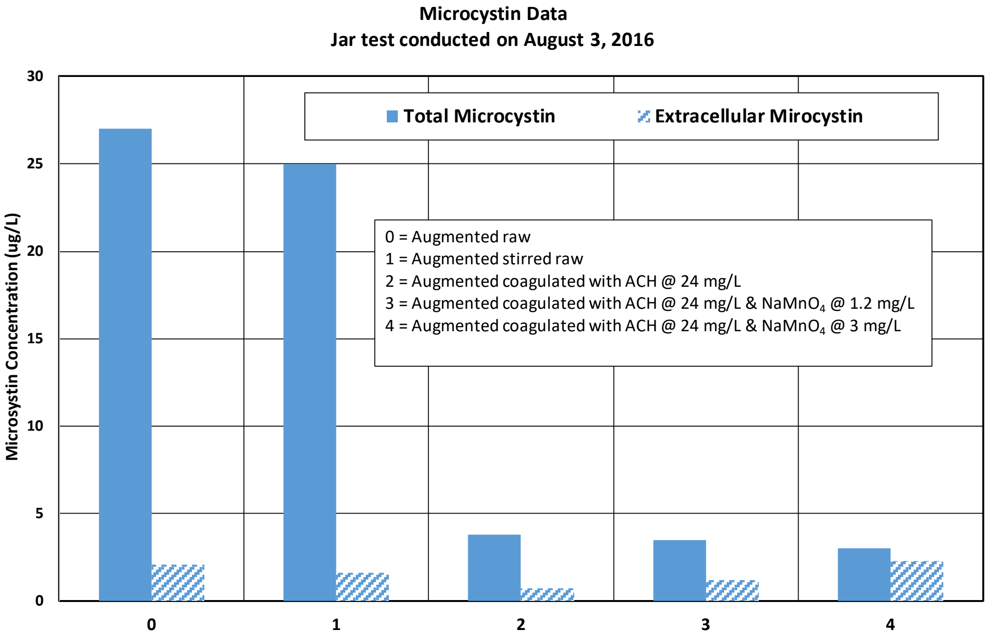


FIGURE 13. Impact of $NaMnO_4$ on Cyanotoxin Release and Extracellular Microcystins Concentration.

Implementation–

The results of this study were inconclusive regarding the benefits of $NaMnO_4$ addition on coagulation and particle removal. Due to conflicting results from the settling curves developed from the jar test, it is recommended that this part of the study be repeated. The development of accurate settling curves requires practice with the sampling techniques used when conducting multiple sampling events from the same jar. When consistent sampling techniques are followed during this study, more reliable settling curves should result.

The microcystins testing conducted as part of this study does support optimization of particle removal as the primary mechanism for removal of total microcystins in the plant. The testing also indicates that extracellular microcystins concentration does increase when $NaMnO_4$ is added to the water; however, the most significant increase occurred at the higher permanganate dose of 3 mg/L. Repeating this study is recommended to confirm these findings.

Study 4: Chlorophyll-a, Phycocyanin, and Microcystins Plant Profile

Process control sampling through the water treatment plant provides information on how each unit process is performing relative to water quality goals or targets. A plant profile is a useful way of trending these process control sampling results. Especially during a harmful algal bloom (HAB), it is important for water utilities to understand how each water treatment unit process is performing at removing cyanobacteria cells and cyanotoxins, while maintaining other treatment objectives, such as turbidity and TOC removal and disinfection. Plant profile trending can provide operators with warning of a source water HAB propagating through the treatment plant such that incremental process control changes can be made to avoid detection of cyanotoxins in the finished water.

Approach–

A plant profile was developed from sampling results obtained from a combination of grab samples and data sonde readings at locations in the water treatment plant indicated in Table 9. Chlorophyll-*a*, phycocyanin, total and extracellular microcystins, temperature, pH, and turbidity data were collected and trended in a spreadsheet. The pigments chlorophyll-*a* and phycocyanin are used as indicators of total algal biomass (chlorophyll-*a*) and cyanobacteria biomass (phycocyanin). It should be noted that each unit process sample was collected in conjunction with the plant's normally scheduled sampling for turbidity. As such, the samples do not represent the same slug of water as it is flowing through the plant. If the water system conducts future unit process sampling, they should consider timing sample collection to mimic flow through the plant, since raw water microcystins concentrations can vary over time. For this profile, raw water samples were collected at the raw water pump station wet well approximately 30 minutes prior to the first unit process sample. The remaining samples were collected sequentially through the plant.

TABLE 9. Plant Profile Sampling Locations

Location	Rationale
Raw water (Lake) (surface grab from wet well prior to sodium permanganate addition)	Determine concentrations of cyanotoxins and cyanobacteria biomass indicators that are entering the water treatment plant.
Pre-sedimentation basin (surface grab from first chamber after inlet from raw water)	To understand the effect of sodium permanganate ($NaMnO_4$) pre-oxidation on total and extracellular cyanotoxin concentrations (and biomass indicators).
Clarifier 1, 2, and 3 effluent	Determine the concentrations of cyanotoxins and indicators leaving each clarifier. Understand the effect of coagulation/flocculation/sedimentation process on cyanobacteria cell removal, cyanotoxin concentrations, and biomass indicators. Sampling each clarifier helps indicate any potential performance issues with individual clarifiers.
Applied/top-of-filter	Represents combined clarifier effluent and is representative of water quality being applied to the filters.
Transfer well/combined filter effluent (microcystins grab sample collected from tap; sonde measurements taken immediately post-chlorine addition).	Determine the concentrations of cyanotoxins and indicators leaving the filters. Understand the effect of the filters on cyanobacteria cell removal, cyanotoxin concentrations, and biomass indicators. Represents the water quality entering the clearwells for the disinfection process.
Plant tap (EP001)	This represents *"finished water."* Determine the concentrations of cyanotoxins entering the water distribution system (if any, at this point). The microcystins grab sample was collected from the tap. No sonde measurements were taken at this location.
Sludge lagoon inlet and outlet, sludge tower No. 2 well	A combination of filter backwash wastewater and clarifier sludge blowdown water. Help understand if cyanobacteria are still viable and potentially producing cyanotoxins in the clarifier sludge and/or filter media. Both inlet and outlet were sampled to understand the effect of the lagoons on improving water quality (specific to HABs) prior to discharge.
River intake (surface grab off of dock adjacent to intake)	Understand potential differences in water quality between the River and Lake intakes.

Samples that were collected at the individual clarifier effluents, applied/top-of-filter, and transfer well/combined filter effluent locations were matched (same location and collection time) with grab samples collected by the operator for turbidity analysis. Plant profile samples were collected at two different times of day to coincide with normal operator sampling: 12:00 noon and 4:00 p.m.

A YSI 6600 multi-parameter data sonde was used to measure pH, temperature, chlorophyll-*a*, and phycocyanin, both as relative fluorescence units (RFU) and estimates of concentration (µg/L of chlorophyll-*a*, and cyanobacteria cells/mL using a pre-programmed phycocyanin calibration curve). The data sonde's calibration was verified with standards for each parameter prior to use. The sonde was allowed to stabilize at each sampling location prior to recording output to minimize any error associated with the sonde's transfer from the previous sampling location. On occasion, the sonde's internal optics cleaning mechanism was utilized to ensure that fouling of the optical sensors was minimized between sampling locations.

Grab samples were collected for total and extracellular microcystins analysis using 125 mL polyethylene terephthalate (PETG) containers. All samples that had been subjected to an oxidant (i.e., sodium permanganate or chlorine) were quenched with a 10 mg sodium thiosulfate tablet. All samples were analyzed using the Ohio EPA Microcystins-ADDA ELISA method[6].

Results and Conclusions–

As expected, the plant profile developed from the sampling results depicts a decreasing trend for all parameters (except pH), indicating that cyanobacteria cell and cyanotoxin removal is occurring through the plant (Figures 14 and 15). The greatest percentage of removals of chlorophyll-*a*, phycocyanin, total and extracellular microcystins occurred during the coagulation/flocculation/sedimentation process (i.e., from pre-sedimentation basins through the clarifiers). This emphasizes the importance of the settling process for removing cyanobacteria cells in conventional water treatment plants (see Figures 16 and 17 for percent removals). Removal of extracellular microcystins also occurred to a significant degree during the settling process, likely because ABC also adds powdered activated carbon (PAC) in the rapid mix prior to the clarifiers. Most microcystins concentrations were below the reporting limit of 0.3 µg/L within the

---

[6] Ohio EPA Total (Extracellular and Intracellular) Microcystins - ADDA by ELISA Analytical Methodology. Ohio EPA DES 701.0. Version 2.2. November 2015. Retrieved April 28, 2016, from http://www.epa.ohio.gov/Portals/28/documents/rules/draft/Ohio%20EPA%20DES%20701.0%20Version%202.2_Dec2015.pdf

treatment plant; however, the State's lab has a Minimum Detection Limit (MDL) of 0.09 µg/L for their ADDA-ELISA method. Therefore, the data are presented here for the sake of understanding the removals being achieved by each unit process. Plant tap samples were analyzed for total and extracellular microcystins concentrations, but data sonde measurements were not collected. Both the 12:00 noon and 4:00 p.m. finished water samples were non-detect based on the 0.3 µg/L reporting limit; however, the concentrations were 0.24 µg/L and 0.14 µg/L.

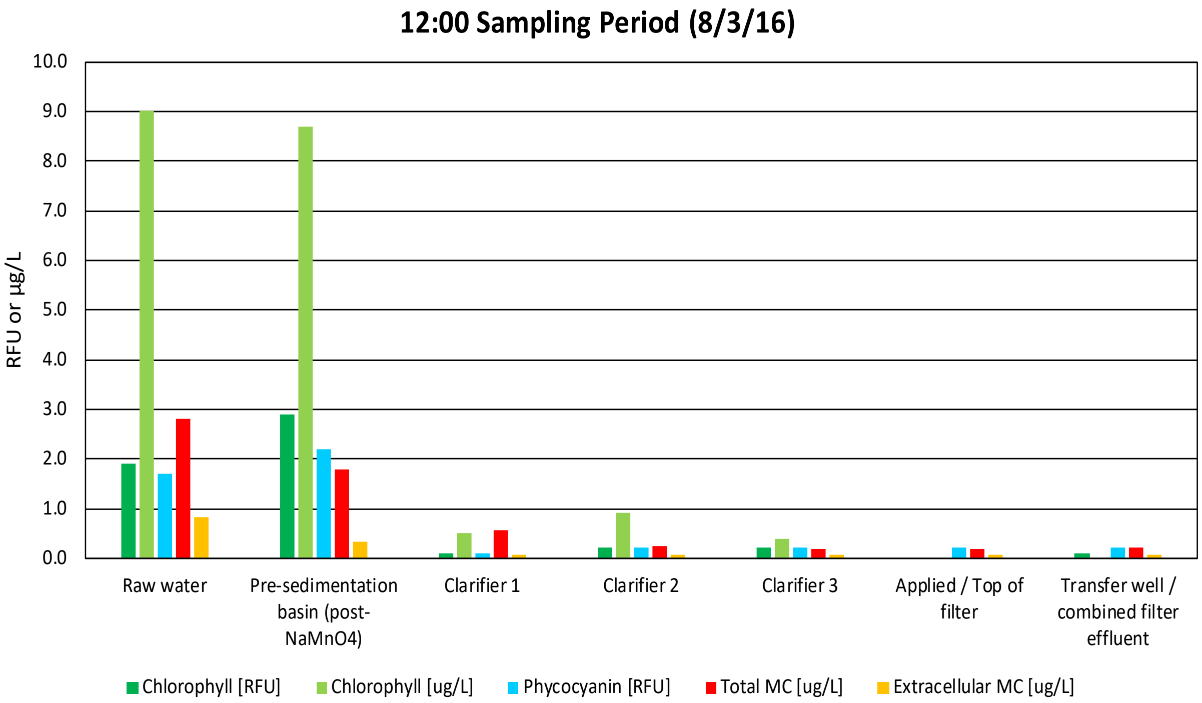


FIGURE 14. Plant Profile for 12:00 Hour Sampling Period on August 3, 2016.

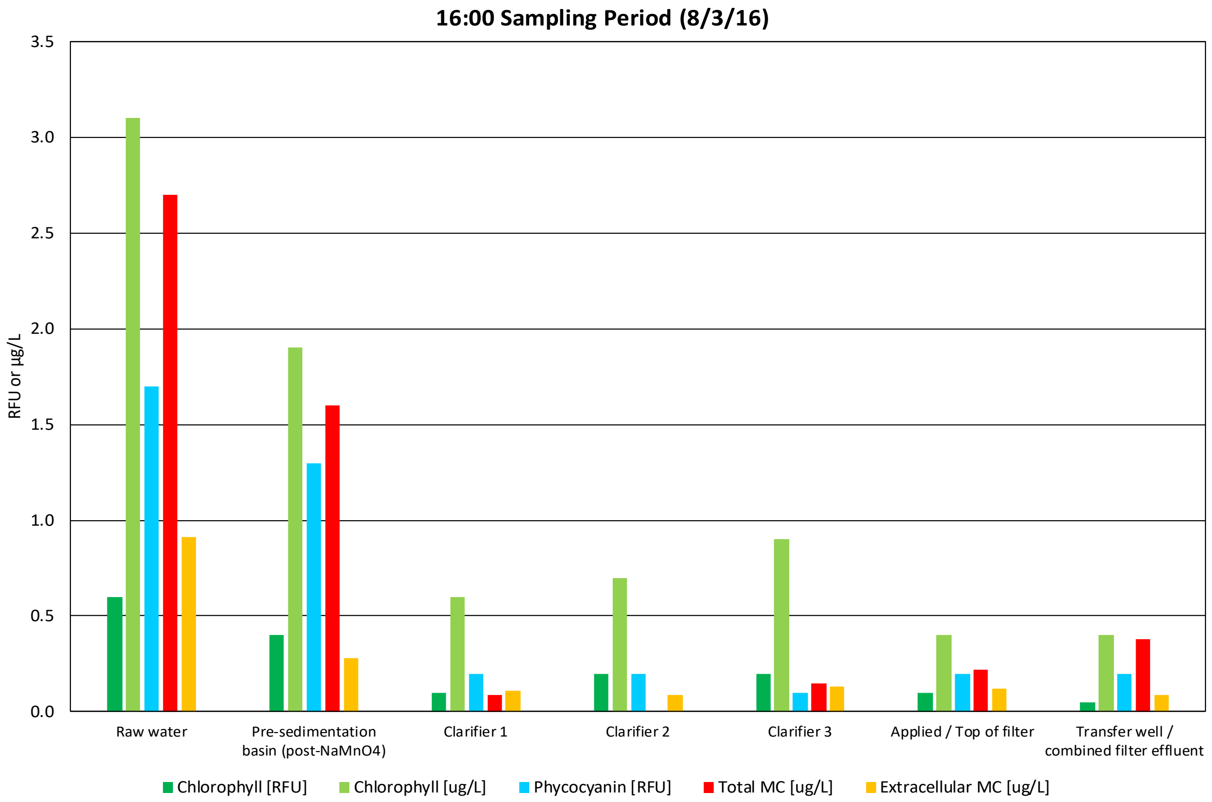


FIGURE 15. Plant Profile for 16:00 Hour Sampling Period on August 3, 2016.

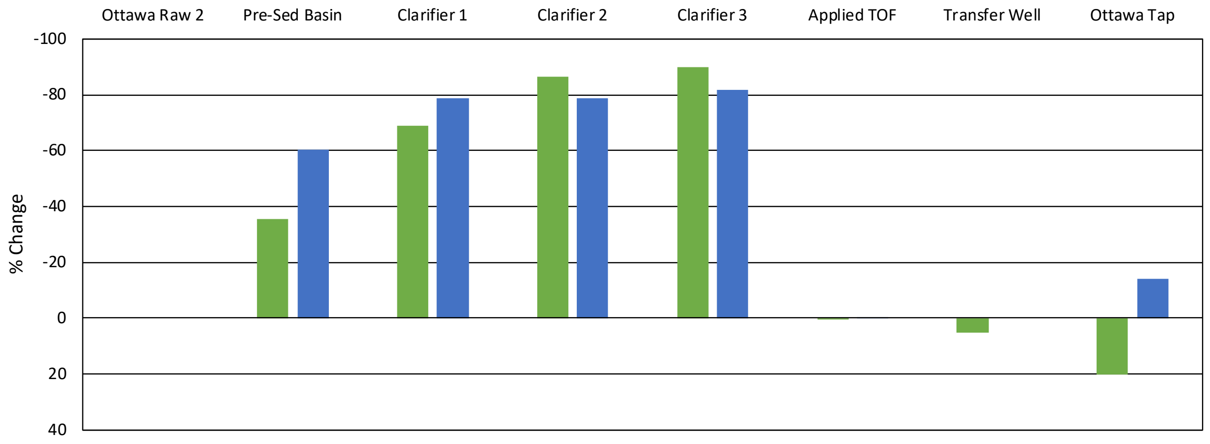


FIGURE 16. Plant Process Percent Removals of Total and Extracellular Microcystins at the 12:00 Hour Sampling Time.

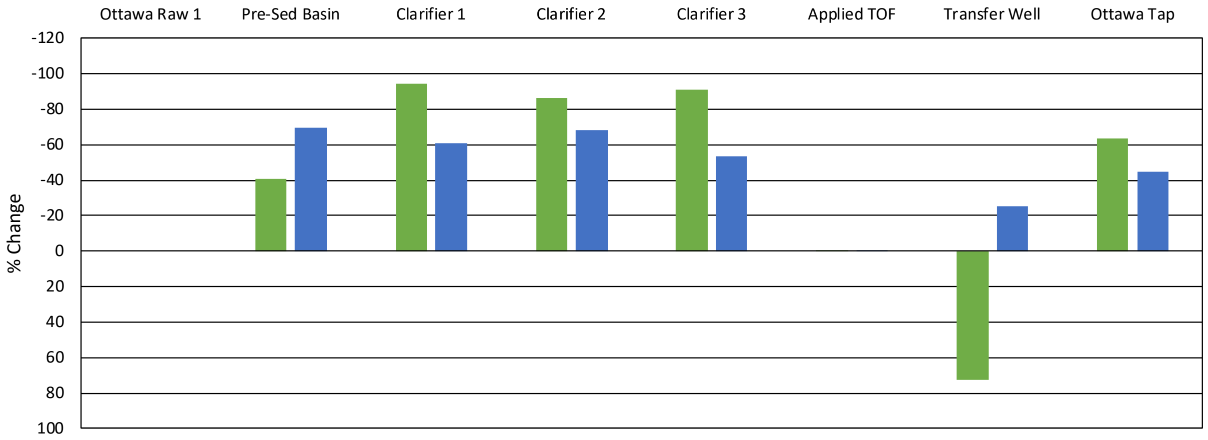


FIGURE 17. Plant Process Percent Removals of Total and Extracellular Microcystins at the 16:00 Hour Sampling Time.

Total microcystins data obtained from the sludge lagoons (supernatant) indicated a decrease from backwash inlet (0.52 µg/L) to outlet (0.15 µg/L). Chlorophyll-*a* and phycocyanin data followed a similar decreasing pattern through the sludge lagoons. Total microcystins were concentrated in the sludge transfer well sampling location (14 µg/L), demonstrating the effectiveness of the clarifiers at removing cyanobacteria cells. Extracellular microcystins were 0.86 µg/L in the sludge transfer well, possibly indicating that some cell death and lysis were occurring. The sludge itself was not sampled, since an analysis method for microcystins in sediments is still under development by the State EPA.

Phycocyanin correlated relatively well with total microcystins concentration ($R^2 = 0.67$), as demonstrated in Figure 18. This suggests that phycocyanin may be a good indicator of cyanobacteria cell presence and total microcystins concentrations, especially for developing future sampling approaches and plant profiles during a HAB (such that 1 phycocyanin RFU ≈ 0.85 µg/L total microcystins, which is in line with other published studies). A correlation plot was also developed for total microcystin and chlorophyll-*a* (see Figure 19); however, the lower R^2 value for that relationship demonstrated a less direct correlation ($R^2 = 0.49$). Because chlorophyll-*a* is produced by all forms of algae, this less direct correlation with total microcystins may indicate that other forms of algae are also present in the raw water (e.g., green algae, diatoms, etc.).

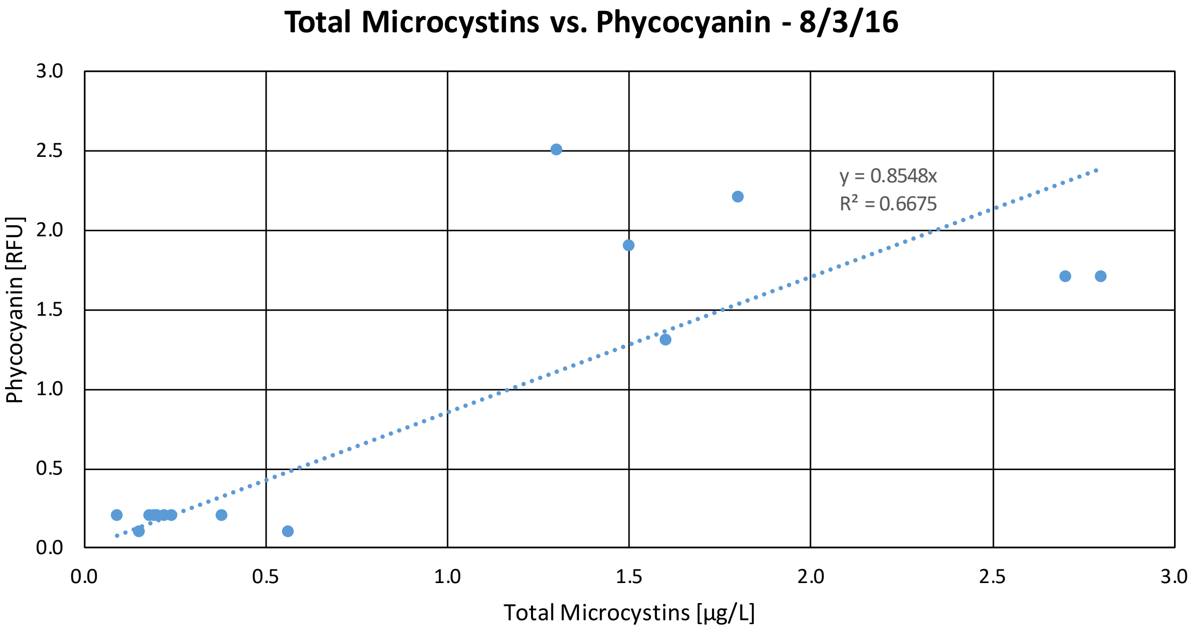


FIGURE 18. Total Microcystins and Phycocyanin Correlation.

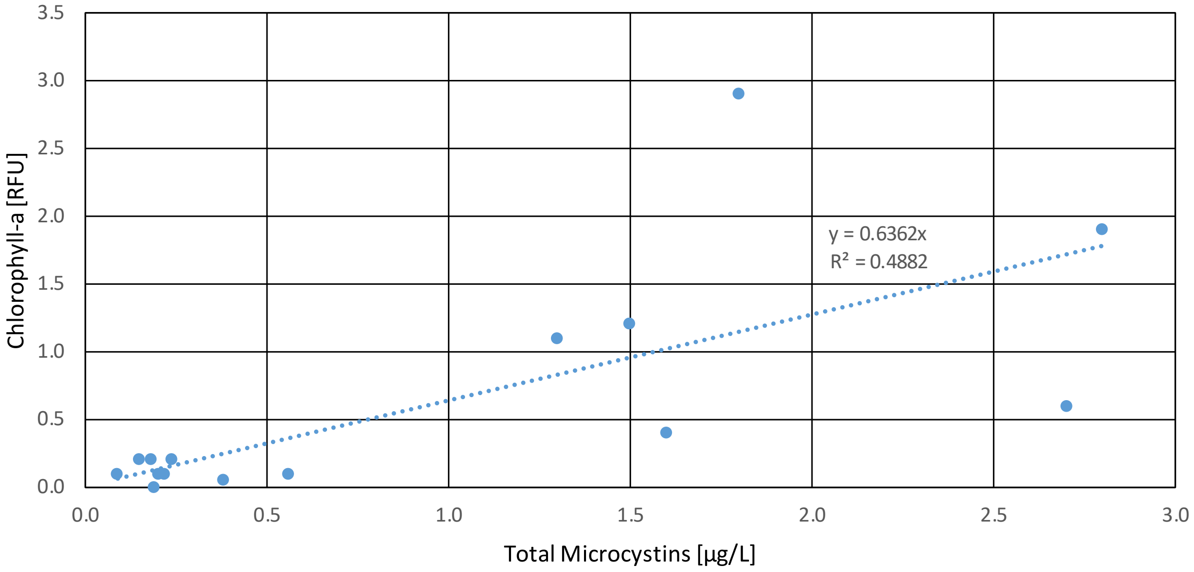


FIGURE 19. Total Microcystins and Chlorophyll-*a* Correlation.

Further Implementation–

ABC may consider repeating the plant profile sampling process; for example, by using phycocyanin as an indicator of cyanobacteria cell removal or determining total and extracellular microcystins concentrations on a regular basis, especially if microcystins concentrations in the raw water increase. It is important to regularly understand each unit process's performance, especially during a HAB, to ensure a robust multiple barrier treatment scheme.

MAJOR UNIT PROCESS EVALUATION

Major unit processes are assessed with respect to their capability to meet the optimized goals for:

- Settled water turbidity
- Filtered water turbidity
- Disinfection (inactivation ratio goal)
- Cyanotoxin adsorption through the use of powdered activated carbon
- Cyanotoxin destruction (oxidation) through the use of chlorination

There is an emphasis on turbidity reduction to remove cyanobacterial cells through the multiple-barrier treatment process; however, recognizing that toxins will likely be in the raw and settled water, toxin removal and destruction are also considered. The capability of each individual unit process is also assessed to verify its capability to provide consistent optimized performance.

Since the treatment processes of the plant must provide multiple effective barriers at all times, a peak instantaneous operating flow is also determined. The peak instantaneous operating flow represents conditions when the treatment processes are the most vulnerable to the passage of parasitic cysts, microorganisms, and toxins. If the treatment processes are adequate at the peak instantaneous flow, then the major unit processes should be capable of providing the necessary effective barriers at lower flow rates. The flow through the plant is controlled by raw water pumps, each equipped with a variable frequency drive that allows operators to adjust the flow rate up to the pump capacity. Through discussions with operators regarding operational policies at the plant as well as the review of plant operating records by the CPE team, the rate of 6 MGD was selected as the peak instantaneous flow rate through the plant under normal operating conditions. This rate was used to assess the capabilities of the major unit processes.

Unit process capability is assessed using performance potential graphs, where the projected treatment capability of each major unit process is compared against the peak instantaneous operating flow rate and the plant design flow for comparison. An individual performance potential graph is developed for each of the treatment objectives evaluated in this report: 1) microbial removal/inactivation and 2) cyanotoxin removal and destruction.

Particle Removal and Microbial Disinfection

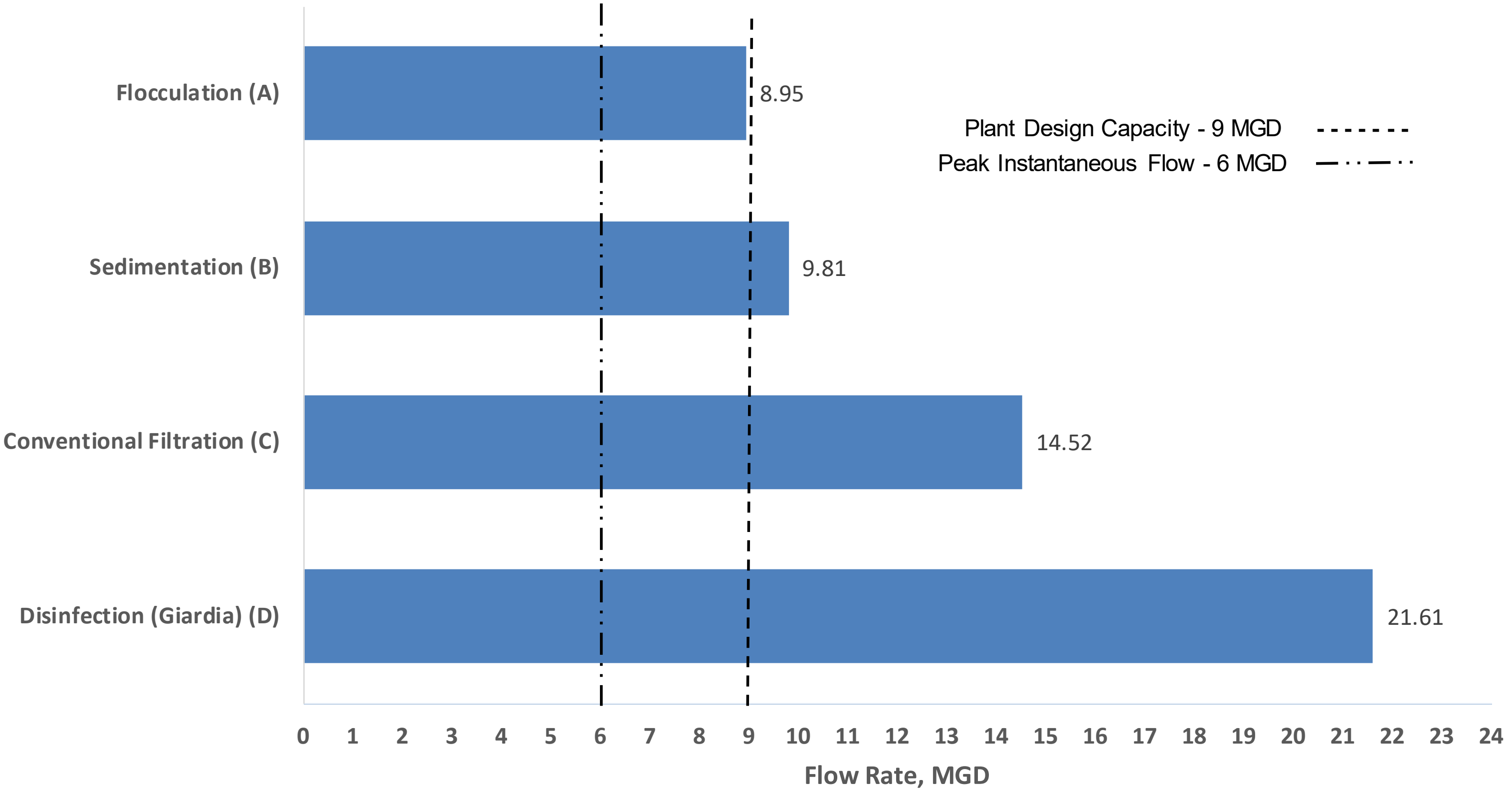
The Major Unit Process Evaluation graph for microbiological treatment through turbidity removal and disinfection, developed for the ABC WTP, is shown in Figure 20. The unit processes evaluated during the CPE are shown along the vertical axis. The horizontal bars on the graph represent the projected peak capability of each unit process that would support achievement of optimized process performance. These capabilities were projected based on several factors, including: the combination of treatment processes at the plant, the CPE team's experience with other similar processes, raw water quality, industry guidelines, the ABC WTP design, and regulatory standards.

Each unit process can fall into one of three categories:

Type 1: Where the bar for the unit process exceeds the peak instantaneous flow (>100 percent of peak flow), the plant should be expected to achieve the performance goals.

Type 2: If the bar for the unit process falls short but is close to the peak instantaneous flow (80 to 100 percent of peak flow), then operational adjustments may still allow the plant to achieve the performance goals.

Type 3: If the bar for a specific unit process falls far short of the peak instantaneous flow (<80 percent of peak flow), then it may not be possible to achieve the performance goals with the existing unit process.



(A) Flocculation: Capacity calculation using the volume under the clarifier sludge recirculation zone, for 30-min detention time.

(B) Sedimentation: Capacity calculation using the SOR average in the clarifier sedimentation zone to achieve a settling velocity of 0.7 gpm/ft^2.

(C) Conventional Filtration: Calculation based on eight 18x20 ft filters with one out of service. Loading rate to achieve 4 gpm/ft^2.

(D) Disinfection (Giardia inactivation): Assumptions - pH 8.2 (HAB conditions), temperature = 0 °C (winter time), 2 mg/L free chlorine residual. Clearwell volume (626,133 gallons) based on minimum level (10 ft) and 73 ft. diameter.

FIGURE 20. Major Unit Process Evaluation Graph – Particle Removal and Microbial Disinfection.

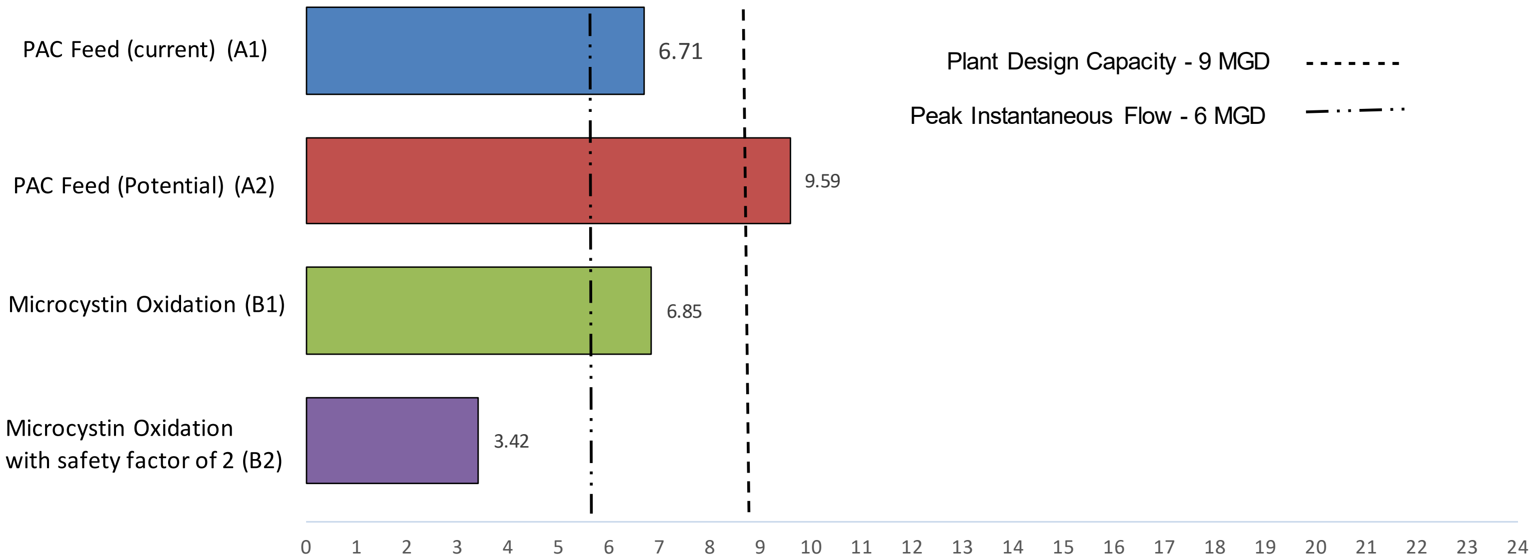
The shortest bar represents the unit process that may limit plant capability the most relative to achieving optimized plant performance. The major unit processes evaluated include: flocculation, sedimentation, filtration, and disinfection. The flocculation and sedimentation processes both occur in the solids contact clarifiers at the ABC WTP, and the disinfection process takes place in the clearwells. The approach and calculations used to determine the rating for each process are provided in Appendix A.

The unit process performance potential for each of the processes summarized in the Figure 20 graph shows that all unit processes are rated as Type 1 processes, capable of meeting the particle removal and microbial treatment objectives at the assigned peak instantaneous flow rate of 6 MGD through the facility. The graph also shows that the major unit processes can achieve the particle removal and disinfection goals at the plant design rate of 9 MGD.

Cyanotoxin Removal and Destruction Treatment

In the event that a HAB occurs at one or both of the ABC WTP sources and cyanotoxins appear in the raw water, the particle removal processes in the water treatment plant would be able to remove the majority of the intracellular cyanotoxins, provided the cells are removed before release the cyanotoxins. The pre-oxidant sodium permanganate feed may also have to be carefully controlled to prevent the cyanotoxins from being released before the cells are removed. The evaluation of the major unit processes in the microbiological (turbidity) control section of this report gives an estimate of the plant capacity to remove cyanobacteria cells through clarification and filtration to control the intracellular cyanotoxins. Any extracellular cyanotoxins present in the raw water or released in the plant would have to be removed primarily through powdered activated carbon (PAC) adsorption or destroyed through chlorine oxidation in the plant. The Major Unit Process Evaluation graph in Figure 20 would apply to ability of the plant to remove intracellular cyanotoxins.

The Major Unit Process Evaluation graph for extracellular cyanotoxin treatment through powdered activated carbon (PAC) adsorption and chlorine oxidation, developed for the ABC WTP, is shown in Figure 21. A target total microcystins concentration of 100 µg/L was used in the evaluation due to historic concentrations observed in the western basin of this lake. The unit processes evaluated during the CPE are shown along the vertical axis.



Assumptions

(A1) PAC Feed (current): Assume 30 mg/L PAC dose is needed to achieve 90% removal during an elevated HAB event (e.g., 100 ug/L microcystins entering the plant), based on Mohamed et. al. equations and Newcombe 2009 charts with a safety factor. Dose was estimated based on medium auger feed rate of 70 lb/hr.

(A2) PAC Feed (potential): Assume 30 mg/L PAC dose is needed to achieve 90% removal during an elevated HAB event (e.g., 100 ug/L microcystins entering the plant), based on Mohamed et. al. equations and Newcombe 2009 charts with a safety factor. Piping and delivery changes may be necessary for this option. Dose was estimated based on a combined feed rate of the medium and small augers of 100 lb/hr, potentially feeding into pre-sed basin and rapid mix simultaneously.

(B1) Cyanotoxin Oxidation: Required CT calculated using the AWWA spreadsheet. Assumptions: microcystins concentrations (10 ug/L entering clearwell, 0.3 ug/L entry point), chlorine residual of 4 mg/L, temperature of 20 °C, and pH of 8.8. Clearwell volume (313,066 gallons) based on minimum level (10 ft) and 73 ft. diameter.

(B2) Same assumptions as B1 but using a safety factor of 2.

FIGURE 21. Cyanotoxin Treatment Major Unit Process Evaluation Graph.

The horizontal bars on the graph represent the projected peak flow capability for each unit process that would support achievement of optimized process performance. These capabilities were projected based on several factors, including:

> <u>PAC Feed Capacity</u>: Discussions with WTP operators and outside experts on PAC feed rates and their feasibility at the ABC WTP considering: safety, chemical storage and acquisition, and the anticipated physical demands on operators of a sustained two- to three-week high feed rate during an extracellular microcystins event.
>
> <u>Microcystins (Cyanotoxin) Oxidation</u>: An estimate was based on the *AWWA Hazen-AdamsCyanoTOX Tool for oxidation kinetics (version 1.0)*[7]. For comparison, the estimate was also performed using a safety factor of 2 to account for uncertainties in applying the AWWA tool to the actual conditions at ABC (i.e., competing oxidant demand such as NOM, pre-oxidants like sodium permanganate, etc.).

In evaluating the microcystins control processes in the ABC WTP, each process is assigned a rated capacity, based on a comparison of the rated capacity to the peak instantaneous flow (6 MGD) at the plant. Results of this evaluation are presented in Figure 21, and each unit process can fall into one of three categories:

Type 1: Where projected peak capability for the unit process exceeds the peak instantaneous flow (>100 percent of peak flow), the plant should be expected to achieve the performance goals.

Type 2: If the projected peak capability for the unit process falls short of, but is close to, the peak instantaneous flow (80 to 100 percent of peak flow), then operational adjustments may still allow the plant to achieve the performance goals.

Type 3: If projected peak capability for a specific unit process falls far short of the peak instantaneous flow (<80 percent of peak flow), then it may not be possible to achieve the performance goals with the existing unit process.

---

[7] AWWA Cyanotoxins resource site: http://www.awwa.org/resources-tools/water-knowledge/cyanotoxins.aspx

The lowest projected process peak capability (flow rate) represents the unit process that may most limit plant capability relative to achieving optimized plant performance. The major unit processes evaluated include PAC feed and oxidation. PAC is fed by two dry chemical feeders (a third spare unit is provided, which is not currently active, but can be placed into service if necessary). Each feeder has a dedicated hopper, filled manually with bags of PAC, which dispenses PAC to the feeders. The feeder meters the PAC into a slurry solution through an auger that can be adjusted to control the PAC feed rate. A carrier, or dilution, water line draws in the PAC to form a slurry that is then carried and fed into the rapid mix basin. Feed lines also exist and can be connected to carry the slurry (or additional slurry from one of the feeders acting independently) to the presedimentation basin, which was originally intended to be a PAC contact basin. The oxidation process takes place through the application of chlorine in the clearwells after the particle removal treatment processes.

The unit process performance potential summarized in Figure 21 shows that the PAC feed and the oxidation processes are rated as a Type 1. However, another bar for the oxidation process shows that this process would be in the Type 3 range, if a safety factor of 2 is applied to account for a lack of real plant data and the uncertainties of applying the AWWA model to predict oxidation. The plant operators could not lower the pH of the water entering the clearwells to try to make the oxidation reaction more efficient, but they could raise the chlorine concentration higher, to 4 mg/L, on a short-term basis if conditions called for it. Considering the uncertainties in the unit process evaluation but the flexibility in raising the chlorine dosage on a short-term basis if necessary, the CPE team rated the oxidation process a Type 2 process. The plant may not have the capability to meet the optimization goals under normal operating conditions, but operational adjustments may make it possible to meet the goals on a short-term basis during a HAB event.

The overall major unit process summary for microbial and cyanotoxin removal and destruction is summarized in Table 10 below. The particle removal and microbial disinfection unit process ratings are all classified as Type 1, indicating that the plant has the capability to achieve the microbial optimization goals when excellent process control skills are applied. Due to uncertainties in the assumptions made during the evaluation, the cyanotoxin removal and destruction processes are rated as a more conservative Type 2, indicating that the plant has the capability of achieving the microcystins finished water target, assuming more aggressive attention is given to plant O&M to prepare for and treat through a significant HAB event.

TABLE 10. Major Unit Process Summary

Microbiological Treatment	
Major Unit Process	**Rating**
Flocculation (1)	Type 1
Sedimentation (1)	Type 1
Filtration (1)	Type 1
Disinfection/Oxidation (1)	Type 1
PAC Adsorption Process (2)	Type 2
Chlorine Oxidation (2)	Type 2

(1) Microbial treatment
(2) Extracellular cyanotoxin removal and destruction

PERFORMANCE-LIMITING FACTORS

The areas of design, operation, maintenance, and administration were evaluated to identify factors that limit performance. These evaluations were based on information obtained from the plant tour, interviews, performance and design assessments, studies, and the judgment of the CPE team. Each of the factors was assessed for the possible classification as A, B, or C according to the following guidelines:

A	Major effect on a long term repetitive basis
B	Moderate effect on a routine basis, or major effect on a periodic basis
C	Minor effect

The performance-limiting factors identified were prioritized as to their relative impact on performance. They are summarized below. While developing the list of factors limiting performance, over 50 potential factors were reviewed, and their impact on the performance of the ABC WTP was assessed. There were three *"A"* factors and two *"B*"* factors identified. Note that the asterisk on the "B" factor (B*) refers to a performance-limiting factor identified for the specific situation when the plant is facing a harmful algal bloom in its source water and must remove cyanobacteria and cyanotoxins during treatment.

Policies – Administration (A)

- The numerical optimization goals for individual clarifier effluent, individual filter effluent, and combined filter effluent turbidity have not been officially adopted.

Application of Concepts and Testing to Process Control – Operations (A)

- Documented operational guidelines identify a target turbidity value of 0.25 NTU for initiating a backwash and returning a filter to service after filtering to waste. These individual filter effluent turbidity values exceed the optimization performance goal of 0.10 NTU.

- Staff are aware of extensive filter media mixing and limited bed expansion, but studies have not been conducted to investigate problems and possible solutions (e.g., assessing alternative air scour and backwash procedures). Mixing of media could limit filter run time and performance during higher hydraulic and solids loading rates (e.g., during HAB event).

- Staff are not trending the daily maximum raw, settled, IFE, and CFE turbidities over time.

- Studies are not being conducted to assess HAB control (e.g., carbon feed, $NaMnO_4$ feed).

- Capability to feed higher carbon doses in the plant for a HAB event has not been adequately tested (i.e., address treatment limitations).

- IFE particle counters are available for process control but are not calibrated (only cleaned). Particle counters can be effective for assessing cyanobacteria cell removal through filters.

Process Instrumentation/Automation – Design (A)

- The location of all IFE and CFE turbidimeters and particle counters and the type of sample pump requires significant suction lift to transport the sample stream to the instruments for analysis, resulting in more frequent interruptions in monitoring and potentially erratic readings.

Reliability – Administration/Design (B*)

- The sustainability of manually adding PAC to the hoppers during a long-term HAB event is questionable.
- The feasibility of adding PAC at rates above 10 mg/L to the rapid mix is limited by the existing design of the supply lines (configuration of supply lines, undersized eductor, and carrier water pressure).
- PAC feed lines to the presedimentation basin are not connected, and the design is prone to excessive plugging.

Process Control Testing – Operations (B*)

- The water system's ability to optimize individual treatment processes during a HAB event is limited by a lack of information concerning concentrations of total and extracellular microcystins throughout the treatment train.
- Phycocyanin measurements are not being obtained throughout the treatment train. This information could assist in optimization of intact cell removal.

EVALUATION FOLLOW-UP

The State EPA has not established an approach for providing follow-up training to CPEs at the current time. Additional HAB-focused developmental CPEs are planned at other water utilities over the next year. Following these events, the State EPA will be considering follow-up strategies to support common CPE findings and performance-limiting factors. Plant staff are encouraged to contact EPA staff regarding any questions or comments they may have regarding specific findings from this CPE.

The ABC WTP staff and management are commended on their proactive approach to operation and maintenance of their treatment plant and to addressing HAB treatment challenges. This CPE has identified further areas that can be pursued to enhance particle removal performance and be better prepared for future HAB events. An excellent place to start the optimization process is collecting and trending optimization data such as the approach demonstrated in the Historical Water Quality Performance Assessment section of this report. The studies conducted during this CPE also demonstrate a structured approach for conducting problem-solving activities by plant staff. The following section includes several study ideas for plant staff to consider and prioritize based on benefits to plant operation and performance, level of complexity, and available staff time.

Ideas for Further Study

Study 1: Optimizing $NaMnO_4$ Dose

- Description:
  - Conduct jar testing using $NaMnO_4$ and determine optimum dose based on oxidant demand.
  - Conduct jar testing using $NaMnO_4$ and assess impact on coagulation and settling (repeat of CPE study).
- Potential Benefits:
  - Determine permanganate demand of raw water.
  - Better understand the benefits of feeding permanganate.
  - Assist with decision making when considering turning off permanganate during a HAB event.
  - The $NaMnO_4$ demand part of the study is a relatively simple topic to learn the study approach (staff develop the study, it is reviewed by EPA, and staff implement and share documented results with the state EPA).

- Obstacles and possible solutions:

Obstacles	Solutions
Finding operator time to conduct studies	Assess priority of study benefits relative to other studies. $NaMnO_4$ demand study very doable by plant staff.
Becoming familiar with preparing permanganate stock solution (use Jar Test spreadsheet)	Obtain training on basic jar test training (local operators, AWWA manuals/video).
Developing settling curves to assess impacts of coagulation/flocculation/sedimentation and pre-oxidation conditions	Practice the sampling and testing techniques by sampling from two jars prepared identical to each other, developing settling curves, and comparing the results.

Study 2: Investigating Filter Backwash Capability to Improve Media Expansion and Stratification

- Description:
  - Conduct studies during routine backwashing to increase backwash flow to improve media expansion.
  - Assess ability to more slowly ramp down high rate wash to better stratify filter media.
- Potential Benefits:
  - Improved media stratification.
  - Longer filter run time during periods with high solids loading to the filters (e.g., during a HAB event).
  - Understand if any design limitations exist.
  - Excellent study to learn problem-solving skills.

- Obstacles and possible solutions:

Obstacles	Solutions
Finding operator time to conduct studies	Assess priority of study benefits relative to other studies. Very doable by plant staff.
Requires a bed expansion measurement tool	Can be constructed by plant staff.

Study 3 – Evaluation of IFE and CFE Sample Pump Operation on Turbidity Spikes

- Description:
  - Collect data to determine the maximum daily IFE and CFE turbidity values.
  - Document turbidity spike occurrences for IFE and CFE samples related to sample pump operation.
  - Identify possible solutions to eliminate turbidity spikes related to pumping of samples.
- Potential Benefits:
  - Provide more reliable IFE and CFE turbidity data to assess filter performance.
  - Reduced operator time addressing sample pumping problems.
  - Excellent study to learn problem-solving skills.
- Obstacles and possible solutions:

Obstacles	Solutions
Finding operator time to conduct studies	Assess priority of study benefits relative to other studies. Very doable by plant staff.
Identification of daily maximum IFE and CFE turbidity values	Determine values from daily review of SCADA screen and compare with SCADA data logs.

Study 4 – Carbon Feed Dose Versus Microcystins Removal

- Description:
  - Conduct jar testing using current carbon type and assess varying doses versus microcystins removal.
- Potential Benefits:
  - Assist staff with determining how much carbon dose would be needed to treat through a HAB event (e.g., up to 100 µg/L extracellular).
  - Supports full-scale study to determine the ability of the plant to feed a higher carbon dose.
- Obstacles and possible solutions:

Obstacles	Solutions
Finding operator time to conduct studies	Assess priority of study benefits relative to other studies (one-time study may be better for others to conduct?).
Microcystins testing	Send to City of Oregon lab (if they have capacity) or send to other certified labs.
Obtaining higher microcystins concentrations for testing (natural versus spiking)	Concentrate sample from natural raw water (more doable by plant staff, less costly). Spike with standards (costly).
Interpreting results and showing relationships between the PAC dosage and performance	Use the AWWA PAC evaluator spreadsheet, available for free download on the AWWA.org website. The spreadsheet will compile the results and develop dosage curves.

Study 5 – Assessing the Impact of Full-Scale Feeding of High Carbon Dose on Plant Performance

- Description:
  - Conduct full-scale study to assess the ability to feed an extended high dose of carbon (supported by previous jar study, determine dose to achieve microcystins performance goal).
- Potential Benefits:
  - Establish capability of plant to feed high carbon dose and assess the impact on clarifier and filter performance and sludge handling capability.
  - Identify plant design limitations.
  - Better able to assess O&M sustainability of feeding high carbon dose.
- Obstacles and possible solutions:

Obstacles	Solutions
Finding operator time to conduct studies	Assess priority of study benefits relative to other studies. Very doable by plant staff (short term).
Cost of study (carbon, extra staffing)	Conduct study during HAB season when higher carbon doses are likely beneficial for water quality.
Potential operation and performance issues	Step up carbon feed rate and assess O&M and performance issues. Stop study if impacts become significant.

Study 6 – Assessing $NaMnO_4$ Feed on Microcystis Cell Disruption and Cyanotoxin Release

- Description:
    - Conduct jar testing using variable $NaMnO_4$ doses to assess impact on microcystins cell disruption and cyanotoxin release (repeat of CPE study).
- Potential Benefits:
    - Better understand potential impacts of feeding permanganate on cyanotoxin release.
    - Determine a permanganate dose (if any) that minimizes cyanotoxin release, such that treatment focus can be on particulate/cell removal.
    - Assist with decision-making when considering turning off or reducing permanganate feed during a HAB event.
- Obstacles and possible solutions:

Obstacles	Solutions
Finding operator time to conduct studies	Assess priority of study benefits relative to other studies (one-time study may be better for others to conduct?).
Becoming familiar with preparing permanganate stock solution (use Jar Test spreadsheet)	Obtain training on basic jar test training (local operators, AWWA manuals/video).
Microcystin testing	Send to city of Oregon lab (if they have capacity) or send to other certified labs.
Obtaining higher microcystin concentrations for testing (natural versus spiking)	Concentrate sample from natural raw water (more doable by plant staff, less costly) or spike with standards (costly).

Other Plant Studies

- Impact of seasonal adjustments to clarifier sludge blanket level on clarifier performance (winter versus summer).

- Evaluating use of pre-sedimentation basins for PAC addition (including modifications to reduce PAC feed plugging).

- Repeat microcystins plant profile study to assess the ability of the treatment processes to control microcystins breakthrough. This study would be dependent on laboratory support for microcystins analyses and would be conducted during a HAB event.

- Studies to verify the theoretical predictions on microcystins oxidation laid out in this report, and to document the effect that variables, such as pH, have on oxidation performance. Conduct jar tests initially to understand the relationships, the results of which can be used to develop full-scale studies.

Appendix A

Major Unit Process Evaluation Supporting Calculations

FLOCCULATION PROCESS – Particle (Turbidity) Removal

The flocculation process takes place in the three parallel solids contact clarifiers, in the section of the clarifier under the floc recirculation cone that extends down and out from the center of the basins, surrounding the inlet riser pipe. The CPE team used a 30-minute hydraulic detention time (HDT) as a rating criterion for the flocculation process. Many solids contact clarifiers have been found to be more efficient at flocculation than conventional flocculation basins, and the 30-minute HDT parameter typically used to evaluate single stage flocculation basins is conservative for the more efficient solids contact process.

The volume of the flocculation zone in one of the contact clarifiers is the volume under the floc recirculation cone minus the volume of the riser pipe. The operators at the ABC WTP usually maintain a sludge blanket two to four inches above the bottom of the cone. Water passing through the sludge blanket as it travels around the bottom of the cone is an important part of the flocculation process, so the CPE team used the entire volume under the cone as the flocculation volume (minus the riser pipe volume). In the summer, operators sometimes allow the sludge blanket to be lowered to an elevation that is below the bottom of the floc recirculation cone, but that type of operation is not recommended for these types of units. The potential remains for the flocculation process to work more efficiently through the operation of the unit with a sludge blanket that extends above the bottom of the cone. For each of the basins, the equation that defines the volume under the floc recirculation zone is:

$$Volume_{cone} = \frac{\pi(h)}{3}\left[r_1^2+(r_1 r_2)^2+r_2^2\right]$$

Where:

h = the height of the cone (17 feet for each of the basins)
r_1 = the radius of the top of the cone (6.5 feet in each of the basins)
r_2 = the radius of the bottom of the cone (18.25 feet in each of the basins)

The volume under the cone is 8793.2 cubic feet or 65,773.5 gallons in each basin.

The volume of the riser pipe in each basin is defined by the equation:

$$Volume_{riser} = \frac{\pi}{4}(h)d^2$$

Where:

h = the height of the riser (17 feet for each of the basins)
d = the diameter of the riser pipe (6 feet for each of the basins)

The volume of the riser in each of the basins is 480.7 cubic feet or 3595.4 gallons.

The volume of the flocculation zone is:

$$Volume_{cone} - Volume_{riser}$$

= 65773.5 gallons – 3595.4 gallons = 62178.1 gallons.

Using the 30-minute HDT criterion, the potential capacity of each of the units is:

Flocculation Capacity = $\text{Volume}_{\text{flocculation}}$/HDT

$$= \frac{62178.1\ gal}{30\ min} \text{ x } \frac{1{,}440\ min/day}{1{,}000{,}000\ gal/MG}$$

= 2.98 MGD per clarifier. The total capacity for all three clarifiers would be 8.95 MGD, well above the peak instantaneous flow of 6 MGD.

SEDIMENTATION PROCESS – Particle (Turbidity) Removal

The settling processes in the three solids contact clarifiers were evaluated by calculating an average Surface Overflow Rate (SOR,) which would also represent the average settling velocity of a floc particle traveling up through the solids contact settling zone. The average SOR was determined by calculating the settling area at the top of the basin (a larger area because the floc recirculation cone is smaller at the top of the basin, leaving more area for settling) and the settling area at the bottom of the recirculation cone and averaging the two areas. The capacity of the basin is determined by determining the flow through the basin that would result in a SOR of not more than 0.7 gpm/sf, a typical rating value used for solids contact clarifiers greater than 14 feet in depth.

The settling zone area at the top of the clarifier = Area of the clarifier – Area of the top of the cone.

Where, Area of the clarifier = $\frac{\pi}{4}D^2$

Where, D is the Diameter of the basin (70 feet for each basin)

And, Area of the top of the cone = $\frac{\pi}{4}d_1^2$

where d_1 is the diameter of the top of the cone (13 feet for each basin)

The settling zone area at the top of the filter = 3848.45 sf – 132.73 sf = 3715.72 sf.

The settling zone area at the bottom of the floc recirculation cone =
Area of the clarifier – Area of the bottom of the of the floc recirculation cone.

Where, Area of the bottom of the floc recirculation zone = $\frac{\pi}{4}d_2^2$

where d_2 is the diameter of the bottom of the cone (37 feet for each basin)

The settling zone area at the bottom of the floc recirculation zone = 3848.45 sf – 1075.21 sf = 2773.24 sf.

The average settling area of the top and the bottom of the floc recirculation cone =

$\frac{3715.72\ sf + 2773.24\ sf}{2}$ = 3244.48 sf

The rated capacity is calculated by:

Sedimentation Capacity = SOR x average settling area =

0.7 gpm/sf x 3244.48 sf x $\frac{1{,}440\ min/day}{1{,}000{,}000\ MG/Gal}$ = 3.27 MGD

The capacity of the three solids contact units in tandem is 3.27 MGD x 3 = 9.81 MGD, which is well above the peak instantaneous flow of 6 MGD.

FILTRATION PROCESS – Particle (Turbidity) Removal

The ABC WTP filters are dual-media filters, using sand and anthracite as filtration media. The capacity of the filtration process is calculated using a filter loading rate of 4 gpm/sf of filter area, assuming one of the filters is out of service, to account for filtration rates when one of the filters is being backwashed. The water treatment plant has eight filters, all measuring 18 feet by 20 feet. The capacity of the process is calculated by:

Filtration Capacity = 7 x 18 ft x 20 ft x 4 gpm/sf x $\frac{1{,}440\ min/day}{1{,}000{,}000\ gal/MG}$ = 14.52 MGD, well above the peak instantaneous flow of 6 MGD.

DISINFECTION PROCESS – Microbial Treatment

Calculation of plant disinfection capability is based on chlorine CT values (i.e., chlorine concentration multiplied by chlorine contact time) outlined in the USEPA Guidance Manual[8] for meeting disinfection requirements for inactivation of 0.5 log (85 percent) of *Giardia* cysts. (For disinfection with chlorine, the *Giardia* inactivation requirement is more stringent than the virus disinfection requirement.) This assumes that the ABC WTP is well operated and can be credited for 2.5 log (99.7 percent) removal of *Giardia* cysts through the plant's physical treatment processes. This can be achieved by meeting the specified CT required for disinfection with chlorine, as used in the clearwell at the water treatment plant.

For disinfection in the clearwell, a required CT value of 63.7 mg-min/L is obtained from the USEPA Guidance Manual, using a maximum chlorine residual of 3.0 mg/L, a maximum pH of 8.2, and a worst-case temperature of 0 °C for disinfection. These data are obtained from reviewing the previous year of operating data and through discussions with water treatment plant operators. The total volume used for the clearwell is 626,133 gallons, based on two ground storage tanks with 73-foot diameters and a 10-foot minimum operating level in each. A baffling factor of 0.6 was assigned to each of the clearwells, based on their well-baffled configuration.

---

[8] USEPA Guidance Manual for Disinfection Profiling and Benchmarking, Appendix E, EPA 815-R-99-013 (August 1999).

Based on these criteria, the disinfection rating of the clearwell is 21.61 MGD, which is well above the reported peak instantaneous flow of 6 MGD.

PAC ADSORPTION PROCESS – Microcystins Removal

Removal of extracellular microcystins through PAC adsorption would depend on factors not related to design considerations such as type of carbon used and dose, use of pre-oxidants (e.g., $NaMnO_4$), competing compounds in the water (e.g., natural organic matter), and contact time. To accurately estimate a necessary PAC dose and/or most effective type of PAC for a given water, jar tests and/or full-scale studies should be performed. In the absence of these studies, the published research studies may be able to provide an indication of the PAC dose needed. The USEPA *Drinking Water Health Advisory for Cyanobacterial Microcystins Toxins* suggests:

> According to Newcombe et al. (2010), a PAC dose of 20 mg/L and a contact time of at least 45 minutes should be considered for removal of most extracellular microcystins (with the exception of microcystin-LA).

Given the absence of jar test data for the water and the PAC that ABC WTP uses, the initial PAC dose was estimated using isotherm equations and constants, which account for the type of carbon used that has been referenced by the State EPA in their *Draft White Paper on Cyanotoxin Treatment (August 2015)*, based on work from Mohamed et al[9]. However, isotherm data typically underestimate PAC doses required for full-scale water treatment plant operation. Hence, a multiplying (safety) factor was applied to estimate a baseline dose. As shown in Figure 21, the equations can predict the PAC dosage that would achieve 90 percent and 99 percent removal of extracellular microcystins for a range of initial concentrations. In these predictions, the carbon constant used was for a wood/coal blend PAC – similar to that used by the ABC WTP. Also shown is the prediction multiplied by safety factors (two and three). Figure 22 suggests that over 90 percent removal could be achieved for the entire range of initial microcystins concentrations at a PAC dosage less than 30 mg/L, even with an applied safety factor of *"3."* However, the equations predict that is it unlikely that 99 percent removal of

---

[9] Mohamed, Z.A., W.W. Carmichael, J. An, and H.M. El-Sharouny, "Activated Carbon Removal Efficiency of Microcystins in an Aqueous Cell Extract of Microcystis aeruginosa and Oscillatoria tenuis Strains Isolated from Egyptian Freshwaters," Env. Toxicol., 14(5), 197-201 (1999).

microcystins could be achieved if the initial concentration was greater than 50 μg/L, for a safety factor of *"2."* Also, in Figure 21, jar test data from a nearby Lake western basin system test, conducted in the winter of 2015-2016, were added as a point of reference. Those data show consistent removal of microcystins in the 85 to 90 percent range at a 5 mg/L PAC dosage, regardless of initial concentration. The uncertainty in this analysis highlights the importance and need for evaluating the PAC used by the ABC WTP at a range of raw water microcystins concentrations. (the State recommends that systems in the western basin of this Lake be prepared to treat 100 μg/L.)

The contact time at the ABC WTP should be adequate for PAC adsorption of microcystins, since the current feed location in the rapid mix would allow up to two hours of contact in the clarifier plus a small amount of additional contact in the rapid mix basin. However, the presedimentation basin may also need to be used for additional PAC contact time if a high PAC dose is required due to operational constraints (i.e., challenges related to delivering a consistent high dose to one location, difficulty keeping the PAC from immediately settling out, etc.). The team estimated the maximum PAC feed rate possible to be 30 mg/L, assuming the following:

- One feeder is out of service (thus, the one feeder would deliver the entire dose of 30 mg/L).
- The feed system is consistently able to deliver this thick slurry (30 mg/L dose) to a combination of the presedimentation or rapid mix basin.
- An estimate of how much PAC can be stored onsite.
- An assessment of the physical ability of the operators to feed the 50-lb sacks of PAC into the dry chemical hopper.

It is possible that the plant could feed more PAC, but this would need to be assessed through *sustained*, full-scale operation.

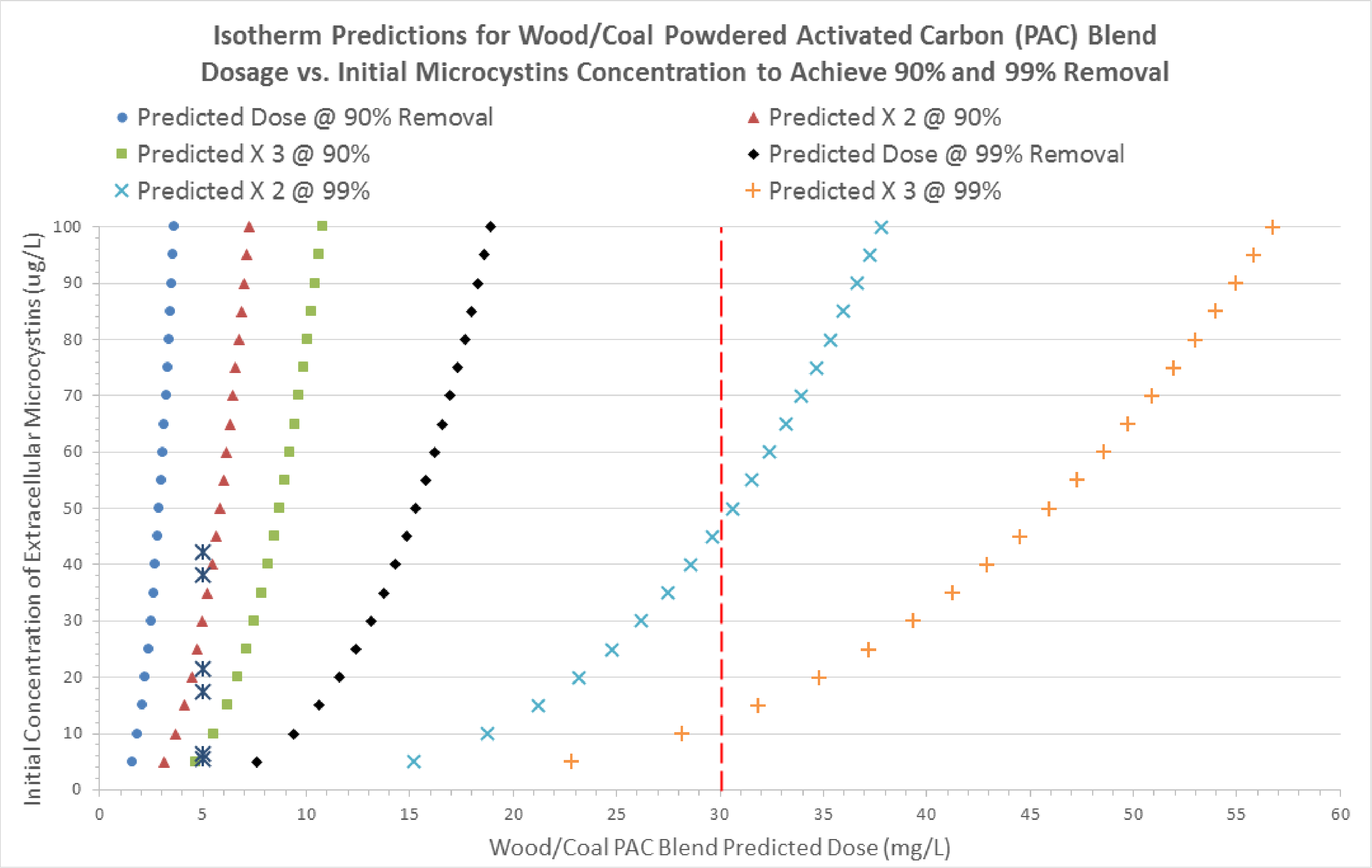


FIGURE 22. Predicted PAC Dose Based on Removal Efficiency and Initial Microcystin Concentration.

Based on the available tools and the data from a nearby system, the team estimated that a maximum feed rate at the water treatment plant of 30 mg/L would likely remove over 90 percent of extracellular microcystins. The PAC feed capacity of the plant currently is about 172 lb/hr, based on a feed rate of 134 lb/hr through the larger auger feeder and 38 lb/hr through the smaller auger. The water treatment plant operators report that they have a third, spare auger feeder that is in between the small and large size, but it has not yet been tested to determine its feed rate. Using the current plant PAC feed design, the feed rate is evaluated based on the largest auger feeder being out of service and replaced by the medium feeder and an estimate that the medium-sized auger feeder can feed at a rate of about 70 lb/hr.

At 70 lb/hr feed, and a 30 mg/L concentration, the plant capacity is:

$$\text{Capacity} = \frac{FR\left(\frac{lb}{day}\right) x\ 453{,}000\ \left(\frac{mg}{lb}\right)}{Dose\frac{mg}{L}\ x\ 3.7854\ \left(\frac{L}{gal}\right) x\ 1{,}000{,}000\ \left(\frac{gal}{MG}\right)}$$

Where:

FR = chemical feed rate (70 lb/hr x 24 hrs = 1,680 lb/day)

Dose = PAC dosage (30 mg/L)

Plant capability = 6.7 MGD, greater than the peak instantaneous flow of 6 MGD

With minor plant improvements, PAC could be fed simultaneously to the presedimentation basin and the rapid mix basin using two of the PAC feeders simultaneously. In this way, the PAC feed rate could be lowered to facilitate slurry travel and dosage optimization. (Water treatment plant operators may find, through studies, that increasing the PAC feed to the presedimentation basin and then adding a lesser amount at the rapid mix is more effective.) Assuming two feeders are used, the combined feed rate might be 100 lb/hr, if the larger auger is out of service and the smaller auger is used with the medium-sized auger. Still targeting 30 mg/L total concentration, the capacity would be calculated to be the same, except that the feed rate would be 100 lb/hr (2,400 lb/day) and the plant capacity would be 9.59 MGD.

While the PAC feed would be rated a Type 1 process based on the sizing of the feeders, concerns would include: the contact time, the ability to feed 30 mg/L with the existing facilities, and the sustainability of adding such a high dosage (approximately thirty 50-lb sacks of PAC into the hopper per day) for a sustained period safely. An additional concern would be the ability of the plant to deliver the slurry to the rapid mix or pre-sedimentation basin at such a high concentration without maintenance problems, such as clogged delivery lines. For this reason, the process has been downgraded to a Type 2 process. In other words, diligent and careful operation would be needed in order for this process to achieve the specified goals (removal of 90 percent of extracellular microcystins).

OXIDATION PROCESS – Microcystins Destruction

Chlorine oxidation can destroy any remaining extracellular microcystins that would not be adsorbed onto the PAC earlier in the treatment processes. Predicting the capacity of the plant to oxidize certain levels of microcystins can be determined using the AWWA *Hazen Adams CyanoTOX (1.0)* calculator spreadsheet. However, the oxidation rate is highly dependent on the pH of the water, and pH during a HAB event could be much higher than the pH observed at the plant under non-HAB conditions. Figure 23 shows a graph of the oxidation capacity of chlorine (from 10 μg/L to 0.3 μg/L, or 97 percent removal) at different flow rates and pH levels, assuming the chlorine concentration was increased to 3 mg/L and 4 mg/L (both of which are above the current operating range of the plant). The target of 0.3 μg/L was chosen because it is identified by the State EPA as the level above which a *Do Not Drink* advisory must be issued. During a HAB event, an anticipated maximum pH is estimated at 8.8 (based on a review of pH data from twelve previous months at the ABC WTP and experiences with HAB events at other locations), which would limit the plant to 6.85 MGD capacity at 4 mg/L chlorine if a concentration of 10 μg/L of extracellular microcystins were entering the clearwells.

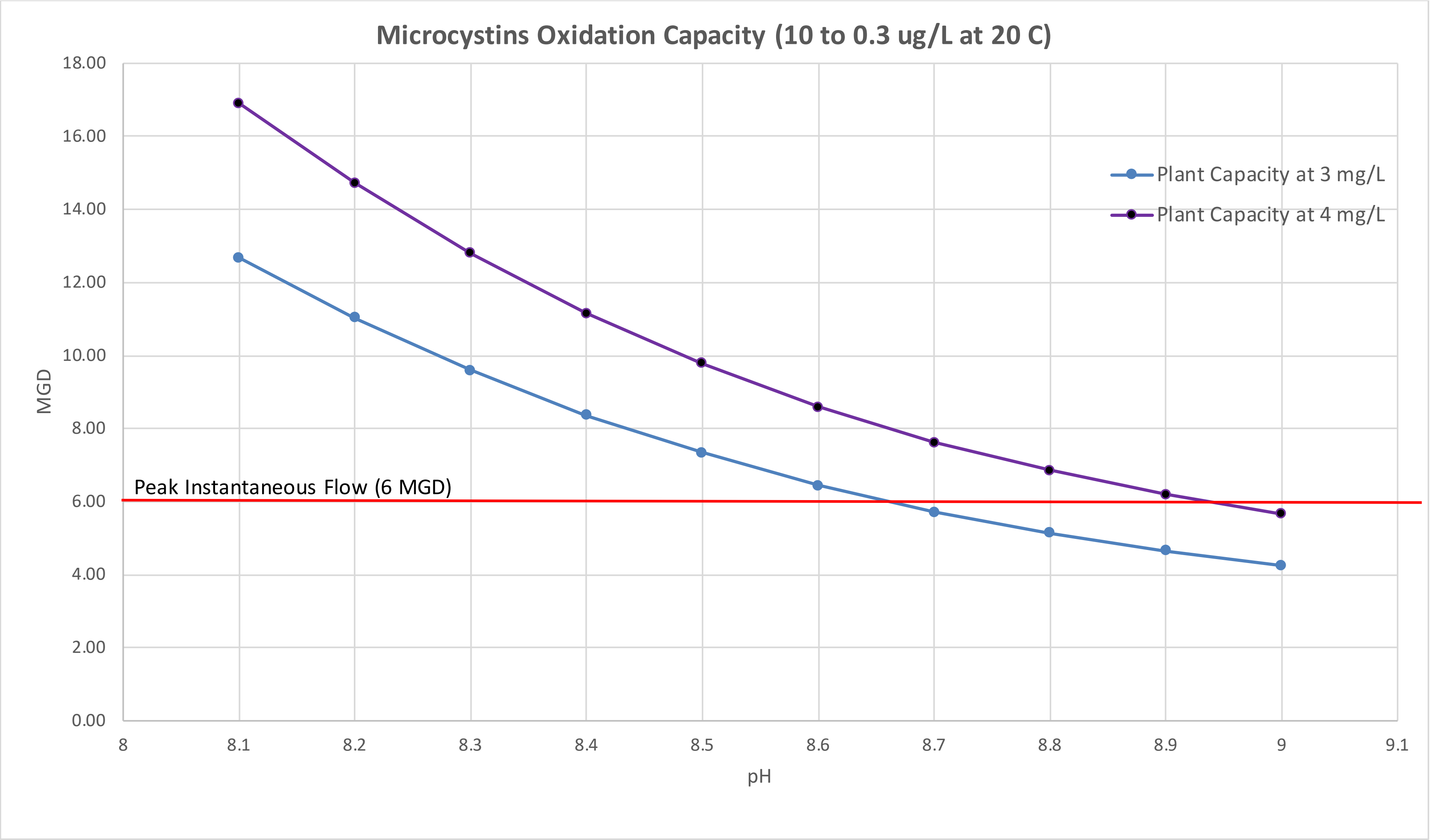


FIGURE 23. Oxidation Capacity Based on 97 Percent Removal Using AWWA Calculator.

Results of the
Harmful Algal Bloom
Comprehensive Performance Evaluation
for the
ABC Water Treatment Plant
Anytown, State

January 23 - 27, 2017

Prepared By:

Process Applications, Inc.
2627 Redwing Road, Suite 340
Fort Collins, Colorado 80526

USEPA Technical Support Center
26 West Martin Luther King Drive
Cincinnati, Ohio 45268

State Environmental Protection Agency

Table of Contents

List of Figures

List of Tables

SITE VISIT INFORMATION

Site and Mailing Address:

Removed

Date of Site Visit:

January 23 - 27, 2017

ABC Water Treatment Plant Personnel Participating:

Mayor
Administrator
Fiscal Officer
Water Billing Clerk

Superintendent
Class 3 Operator (Assist. Supt.)
Class 3 Operator
Operator and Meter Reader

CPE Team:

USEPA Technical Support Center, 26 West Martin Luther King Drive, Cincinnati, OH 45268
Alison Dugan – 513-569-7122; Dugan.Alison@epa.gov
Rick Lieberman – 513-569-7604; Lieberman.Richard@epa.gov
Tom Waters – 513-569-7611; Waters.Tom@epa.gov

USEPA Office of Research & Development, 26 West Martin Luther King Drive, Cincinnati, OH 45268
Craig Patterson – 513-487-2805; Patterson.Craig@epa.gov

Process Applications, Inc., 2627 Redwing Road, Suite 340, Fort Collins, CO 80526
Bill Davis – 469-338-1823; waterbilldavis@gmail.com
Larry DeMers –970-223-5787; ldemersco@aol.com

State Environmental Protection Agency
HAB Engineer
HAB Coordinator
Design Engineer
Field Engineers/Staff/Inspectors

INTRODUCTION

The Composite Correction Program (CCP)[10] is an approach developed by the U. S. Environmental Protection Agency (USEPA) and Process Applications, Inc. (PAI) to improve surface water treatment plant performance and to achieve compliance with the Surface Water Treatment Rule (SWTR). Its development was initiated by PAI and the state of Montana[11], which identified the need for a program to address performance problems at its surface water treatment plants. The approach consists of two components, the Comprehensive Performance Evaluation (CPE) and the Comprehensive Technical Assistance (CTA).

A CPE is a thorough evaluation of an existing treatment plant, resulting in a comprehensive assessment of the unit process capabilities and the impact of the operation, maintenance, and administrative practices on performance of the plant. The results of the evaluation establish the plant capability to meet the optimization goals and list a set of prioritized factors limiting performance. A CTA is used to improve performance of an existing plant by systematically addressing the factors limiting performance identified during the CPE.

The implementation of the Interim Enhanced Surface Water Treatment Rule (IESWTR), promulgated in December 1998, required plants that serve greater than 10,000 customers to achieve less than 0.3 NTU (nephelometric turbidity units) turbidity in 95 percent of the monthly combined filter effluent samples and to monitor individual filter performance. The requirement went into effect for all surface water treatment plants in 2005. Research results and field experience have shown that just meeting the requirements of the IESWTR does not guarantee adequate protection against some pathogenic microorganisms, as evidenced by some waterborne disease outbreaks.

Producing a finished water with a turbidity of less than or equal to 0.10 NTU provides much greater protection against pathogens like *Cryptosporidium.* This microorganism that passed through the public water supply was responsible for a large outbreak of *Cryptosporidiosis* in

---

[10] Hegg, B.A., L.D. DeMers, J.H. Bender, E.M. Bissonette, and R.J. Lieberman, Handbook - Optimizing Water Treatment Plant Performance Using the Composite Correction Program, EPA 625/6-91/027, USEPA, Washington, D.C. (August 1998).

[11] Renner, R.C., B.A. Hegg, and D.F. Fraser, Demonstration of the Comprehensive Performance Evaluation Technique to Assess Montana Surface Water Treatment Plants, Association of State Drinking Water Administration Conference, Tucson, AZ (February 1989).

Milwaukee, Wisconsin in April 1993, where 400,000 people became ill and nearly 100 deaths occurred. *Cryptosporidium* cysts are extremely resistant to chlorine disinfection, necessitating optimization of physical removal of particles.

Since the development of the CCP for optimization of surface water treatment plants for protection from microbial pathogens, PAI and the USEPA's Technical Support Center (TSC) have adapted the CCP protocol to additional public health parameters such as DBP control and distribution system optimization. Given the recent concerns with harmful algal blooms (HABs) and their impact on surface water treatment plants in the State and nationwide, the State EPA, in partnership with TSC, has initiated a project to expand the CCP to include optimization for the removal of cyanobacteria cells and the reduction of associated toxins. This CPE for the XYZ Water Treatment Plant (WTP) represents the second of four developmental CPEs focused on these performance goals that will be conducted in this State.

The following report presents the findings from this CPE, and it will hopefully provide the XYZ Water Department with valuable information that can be used to enhance and maintain water quality. The CPE team would like to thank the plant staff and utility management for hosting this event and for taking the time to assist the team in completing the evaluation. During the evaluation, utility staff members were very accommodating in providing plant information and sharing their experience and knowledge regarding treatment approaches to address HAB events. This type of attitude represents a strong foundation for development of an optimization approach to address HAB events that public water systems may face in the future. This report documents the findings of the CPE.

DESCRIPTION OF WATER TREATMENT PLANT

Overview

The XYZ WTP is the main source of potable water for the City, providing treated drinking water from a nearby lake. The XYZ Water System also has interconnections with a County Water and Sewer Organization to purchase potable water on an emergency basis, but it does not have a contract defining how much can be purchased in case of emergency. XYZ also provides finished water to a nearby Public Water System. Potable water is delivered to approximately 3,857 direct consumers, including water purchased by the neighboring communities.

Source Intake and Pump Station

A schematic of the water treatment plant (removed from Figure 1). The source water is supplied to the plant by two intake structures located ten miles away from the water treatment plant at a Lake. There is an existing backup intake located at a Reservoir, which is currently not approved for use. The two Lake intake structures are located roughly 10 to 13 feet offshore, at a depth of about eight feet, and the intake pumping station building is located on the bank of the Lake adjacent to the intake structures.

Three raw water pumps within the pump station (with one in use) transport the raw water ten miles to the water treatment plant. The plant has facilities to feed potassium permanganate and powdered activated carbon (PAC) at the raw water intake pump station; however, potassium permanganate was not being fed during the CPE. A raw water sample line located in the pump station is used to collect raw water from the wet well prior to PAC addition. However, this must be done manually; hence, water quality for process monitoring (e.g., turbidity) is collected after PAC addition.

Water Treatment Processes

The XYZ WTP utilizes conventional surface water treatment processes, including: aeration, coagulation, flocculation, sedimentation, filtration, and disinfection. The reported plant capacity is 1.1 MGD.

Preceding the conventional treatment, the raw water is dosed with PAC from a hopper auger unit located in the pump station at the raw water source. The water is then sent through roughly nine miles of 12-inch diameter pipe, followed by one mile of eight-inch pipe to the aeration unit at the water treatment facility.

FIGURE 3. Schematic Removed

After the raw water passes through the aeration unit, the water is sent to the first rapid mix where lime and soda ash are added with an alum/polymer blend coagulant. There is a potassium permanganate feed point in the first rapid mix; however, it was not in use at the time of the CPE site visit. Water leaving the first rapid mix is dosed again with PAC. A chlorine addition feed point at this location is currently not used.

Flocculation and sedimentation are accomplished using two flocculation and sedimentation tanks operated in series. The two-stage processes are separated by a second rapid mix with no mixer in operation, and aluminum sulfate is added at this location to further aid coagulation. The sludge from the sedimentation tanks is removed manually and sent to the onsite sludge holding tank. Each sedimentation basin effluent has a sampling point where a grab sample is taken to measure turbidity and pH.

From the last sedimentation tank in series, water bypasses the non-operational recarbonation basin, and flow is distributed by an inlet weir to four dual-media anthracite/sand filters. Each filter effluent is continuously sampled via sample streams that feed turbidimeters located on the operating floor. The backwash supply is provided by the filters in service and supplemented by the high service pump discharge. Figure 2 shows how a higher water elevation in the wet well (compared with the filter being backwashed) is used to provide the backwash supply. Air is also injected during the backwash. Because of the common filter wet well design, the filters do not have filter-to-waste capability.

Filtered water flows to a common transfer wet well, where the combined filter effluent turbidity is sampled and directed to a continuous turbidimeter. Sodium hypochlorite and fluoride are injected in the discharge of the wet well before filtered water is sent to the clearwells. Each clearwell holds a volume of 164,500 gallons of water. Both are constructed of concrete and are subterranean in design. The clearwells are baffled, operate in parallel, and are utilized for disinfection contact time. Treated water is pumped to the distribution system from a 30-inch suction line from the clearwells by way of three horizontal, centrifugal high service pumps. An additional feed point for chlorine also exists on the high-pressure discharge line manifold to boost levels after the clearwells, if needed. A sampling location after the high service pumps is used to measure pH and chlorine residual of the finished water as well as to take other compliance samples.

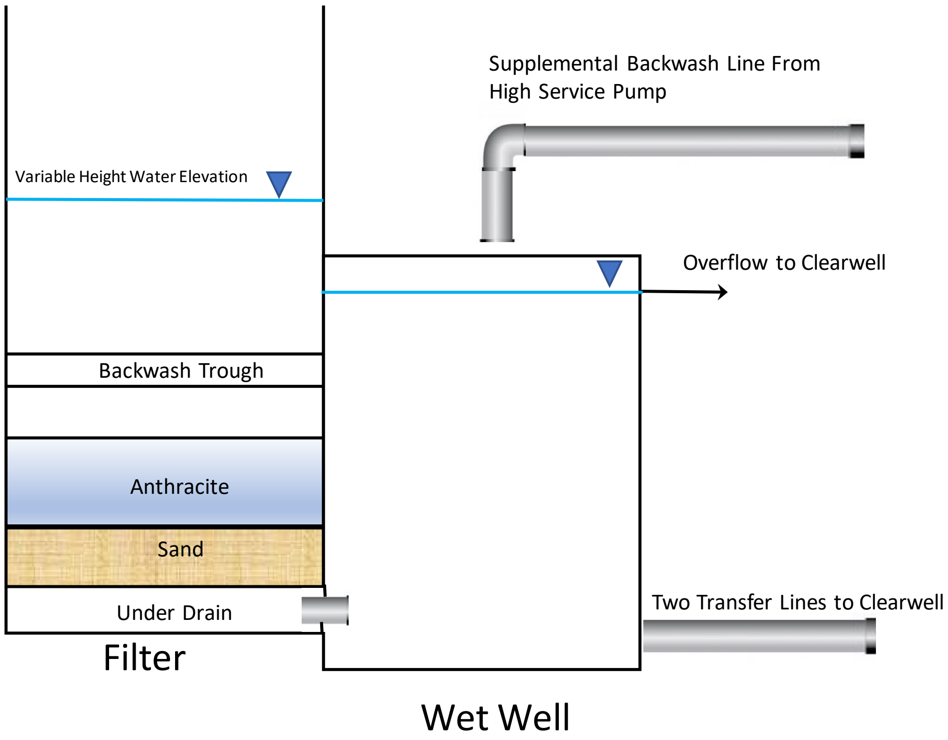


FIGURE 4. Typical filter layout in relation to common filter wet well.

PERFORMANCE ASSESSMENT

Historical Performance Assessment

Optimized performance, for the purposes of this CPE report, represents performance beyond the Surface Water Treatment Rule (SWTR) requirements. To achieve optimized performance, a water treatment plant must demonstrate that it can take a raw water source of variable quality and produce consistent, high quality finished water. In addition, the performance of each treatment unit process must demonstrate its capability to act as a barrier against the passage of particles at all times.

Administration Assessment

An assessment of the administration of the XYZ WTP and its possible effect on plant performance was performed by collecting information through interviews in the following general areas: utility structure, vision, mission, water quality goals, reporting, data review, management style, communications, planning, plant coverage, financial management, and spending authority. Two possible administrative issues were identified that could potentially affect performance. These issues, as well as others, are considered in subsequent sections of the report:

- Formal adoption of optimization turbidity goals for unit process performance.
- Staffing issues that may affect performance and innovation within the water treatment plant processes.

Historical Water Quality Performance Assessment: Turbidity

Historical turbidity data were collected from laboratory data sheets and from SCADA files provided by the Operator of Record. These reports were provided to the CPE team, and the data were entered in an Optimization Assessment Spreadsheet (OAS) that was used to assess performance against the optimization goals for turbidity.

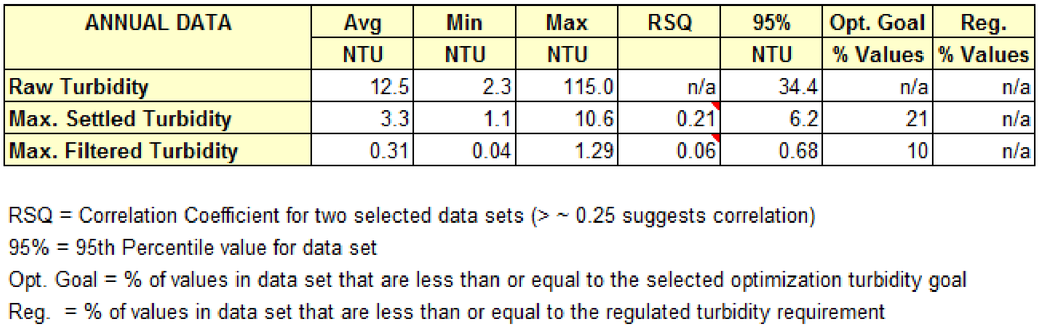
Historical performance was assessed over a 12-month period, starting on January 1, 2016 and ending on December 31, 2016. Table 1 describes in more detail the exact source of the data used in the CPE performance assessment. As indicated in Table 1, the plant raw water sampling site is not a *"true"* raw water since the sampling location is downstream of the PAC addition at the intake. Only the effluent of sedimentation Basin 2 was used to assess performance of the sedimentation treatment process.

TABLE 2. CPE Turbidity Performance Analysis; Data Acquisition Description

Performance Parameter	Data Used in the CPE Performance Analysis
Maximum Daily Raw Water Turbidity Entering the Plant	Maximum daily plant raw water turbidity data were determined from data recorded on paper laboratory bench sheets. The plant raw water turbidity values are obtained by benchtop turbidimeter measurements of grab samples from the plant raw water tap at the laboratory sink. The plant raw water sample tap is upstream of rapid mix Tank 1 and approximately ten miles downstream of the intake chamber, where PAC is being fed. Therefore, the plant raw water samples contain PAC.
Individual Sedimentation Basin Effluent, or *"Settled Water"* Turbidity	Operator logs of settled water turbidity test results were used to determine the maximum turbidity value for each day, using the effluent of each sedimentation basin and top of the filter box which is above the filter media. These values were used for comparison, but the daily maximum individual sedimentation effluent values obtained from sedimentation Basin 2 were used to assess performance against the optimization goals.
IFE Turbidity	The individual filter effluent (IFE) daily maximum turbidity records were obtained in electronic CSV format from the SCADA system. The system obtains continuous turbidity readings from individual Hach 1720E turbidimeters and stores one value from each individual filter turbidimeter every 15 minutes into an electronic *Microsoft Excel* file. Each of these *Excel* files are named with a T followed by the four-digit calendar year and one or two digits for each month. Each file contains the title, MONTHLY FILE - FILTER TURBIDITY 15 MINUTE SAMPLES and stores 15-minute readings for each of the four filters for each day of the month.
CFE Turbidity	The combined filter effluent (CFE) sampling location is not being used for compliance nor is it actively recording data. Therefore, CFE turbidity performance was not assessed.

Maximum daily raw, settled, and filtered turbidity data were entered in an Optimization Assessment Spreadsheet (OAS). These data were analyzed through the spreadsheet calculations and charts which compare historical plant performance to optimization goals. Settled water turbidity values were obtained from plant bench sheets, while filtered turbidity was collected from the SCADA system. Individual Filter Effluent (IFE) turbidity data is collected every 15 minutes by the SCADA system during plant production. From this SCADA database, maximum daily turbidity values were determined for each filter. Table 2 shows the OAS summary statistics for the plant, and Figures 3 and 4 display turbidity profiles that are graphical descriptions of water treatment plant performance over the past year (2016).

TABLE 3. OAS Summary Statistics



ANNUAL DATA	Avg	Min	Max	RSQ	95%	Opt. Goal	Reg.
	NTU	NTU	NTU		NTU	% Values	% Values
Raw Turbidity	12.5	2.3	115.0	n/a	34.4	n/a	n/a
Max. Settled Turbidity	3.3	1.1	10.6	0.21	6.2	21	n/a
Max. Filtered Turbidity	0.31	0.04	1.29	0.06	0.68	10	n/a

RSQ = Correlation Coefficient for two selected data sets (> ~ 0.25 suggests correlation)
95% = 95th Percentile value for data set
Opt. Goal = % of values in data set that are less than or equal to the selected optimization turbidity goal
Reg. = % of values in data set that are less than or equal to the regulated turbidity requirement

The statistics in Table 2 are based on the maximum daily turbidity values for raw water, sedimentation Basin 2 effluent, and IFE turbidity during the period of January 1, 2016 to December 31, 2016. These statistics are then compared to optimization goals. The optimization program utilizes the *"maximum"* daily turbidity readings to assess worst-case performance by each of the barriers. If the plant can perform within the optimization goals at the time of its worst daily performance, then the plant staff can be assured that the plant is maximizing its ability to protect public health against the passage of pathogens and cyanobacteria. Table 2 shows that the daily maximum raw water turbidity average for the XYZ WTP was 12.5 NTU. For raw water conditions where the average maximum daily raw water turbidity is greater than 10 NTU, the optimization goal for settled water turbidity is 2 NTU. The optimization goal for individual filter effluent and combined filter effluent turbidity is 0.10 NTU.

The maximum daily settled water effluent turbidity, as measured with grab samples from the effluent of Basin 2, met the optimization goal 21 percent of the time. The maximum settled water effluent turbidity was 6.2 NTU or lower 95 percent of the days during the evaluation period. Figure 3 offers a closer look at the settled water turbidity, as measured with grab samples from the effluent of Basin 2. The red line in the graph represents 2.0 NTU, the optimization goal for settled water turbidity. It is apparent that sedimentation performance appeared to be the best during the late summer and autumn months, as compared to the winter and spring months. In addition, sedimentation Basin 2 performance appeared to generally meet the optimization goal during the late summer and autumn months of 2016, but it did not approach the goal during other parts of the year.

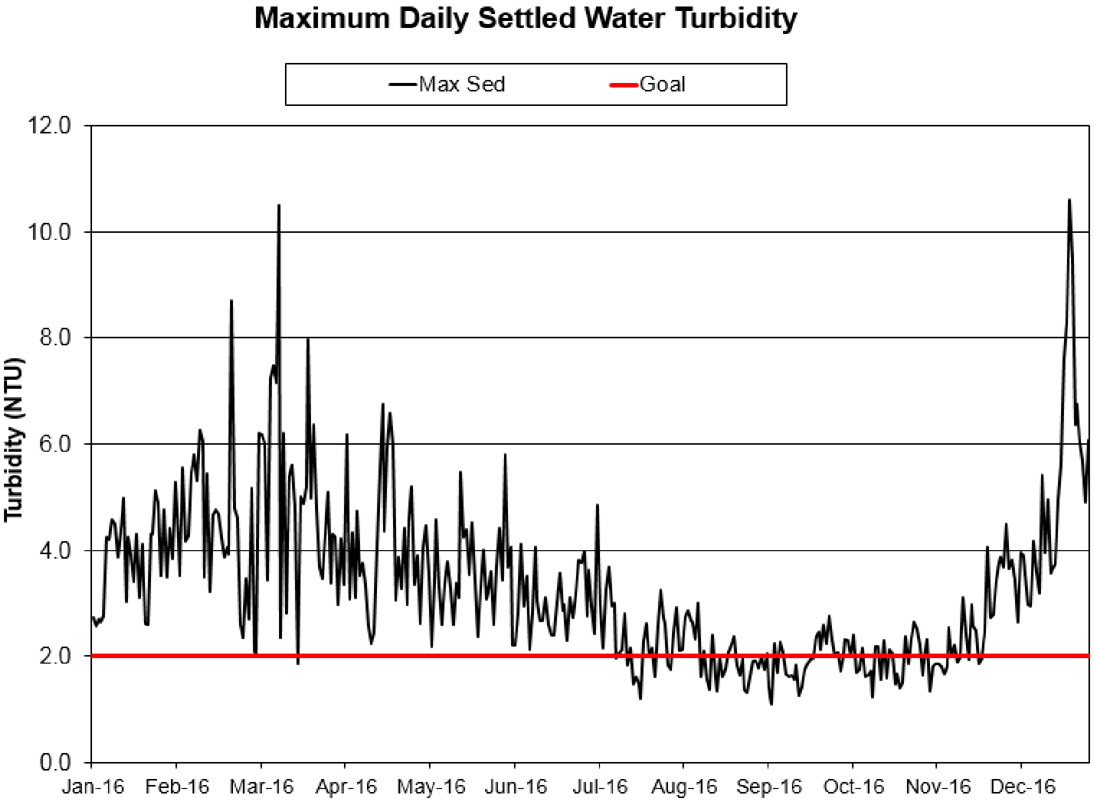


FIGURE 5. Maximum daily sedimentation Basin 2 effluent turbidity.

Table 2 also shows that the maximum daily IFE turbidity values met the optimization goal 10 percent of the days analyzed. The maximum IFE values were at 0.68 NTU or less during 95 percent of the days analyzed.

The R-squared (RSQ) value in Table 2 above represents the correlation coefficient for two selected data sets. The lower the values, the less carry-through between treatment barriers and the greater each barrier's efficiency. A value greater than 0.25 suggests a correlation. The raw turbidity and maximum settled turbidity data sets have an RSQ value of 0.21, which suggests some carry-over of turbidity from the raw water through the sedimentation process. However, the RSQ value between the maximum settled turbidity and maximum filtered turbidity is much lower, and it reveals that filter performance is not closely associated with sedimentation basin performance.

Figure 4 provides a turbidity profile of plant performance over a 12-month period. The raw water turbidity, depicted by the solid red line, seems to exhibit an increase in the spring and drop during the summer months, with spikes in June and October. The settled water data represented by the solid black line generally trends with the raw water turbidity, especially at the end of 2016. A visual observation of the IFE turbidity data suggests a slight inverse relationship with the settled water turbidity data, where the filters appear to have the worst performance over the summer months, even though the settled water turbidity is the lowest during this period. Again, the combined, solid blue line is not represented in Figure 4 because the XYZ plant does not collect data nor use the CFE sampling point.

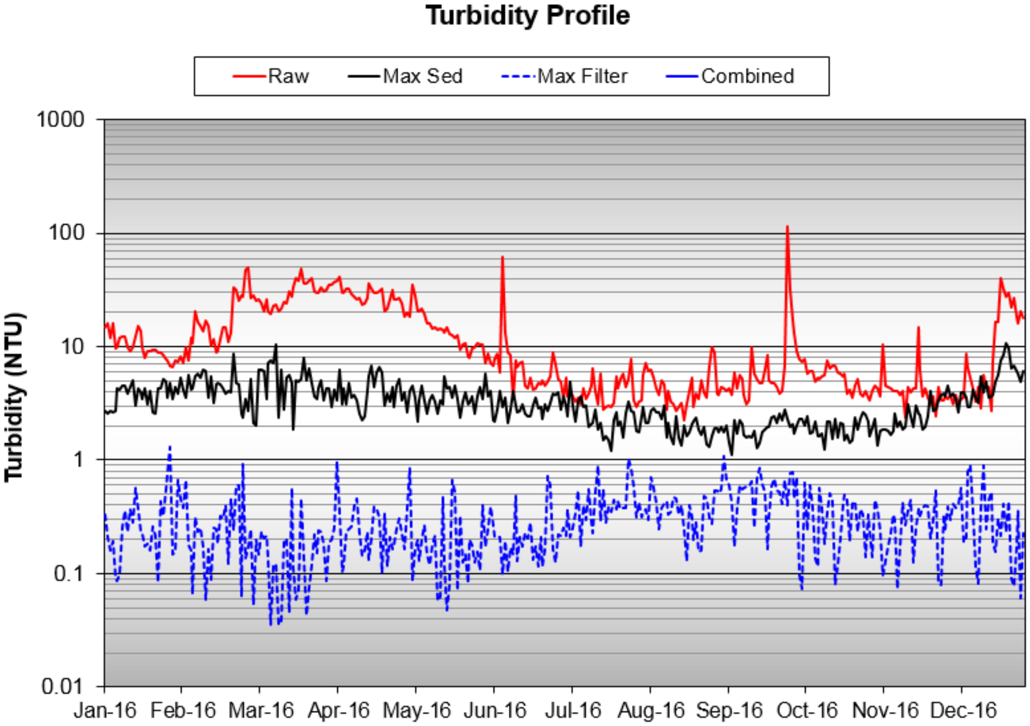


FIGURE 6. XYZ WTP turbidity profile.

Figure 5 depicts the maximum daily filtered water turbidity for IFE measurements in relation to the optimization goal of 0.10 NTU, represented by the red line. The graph shows the maximum IFE turbidity measurements (dashed blue lines) mostly above the optimization goal throughout the last year, with significant spikes up to 1.0 NTU at times. A seasonal influence on performance occurs during the late summer and autumn time frame.

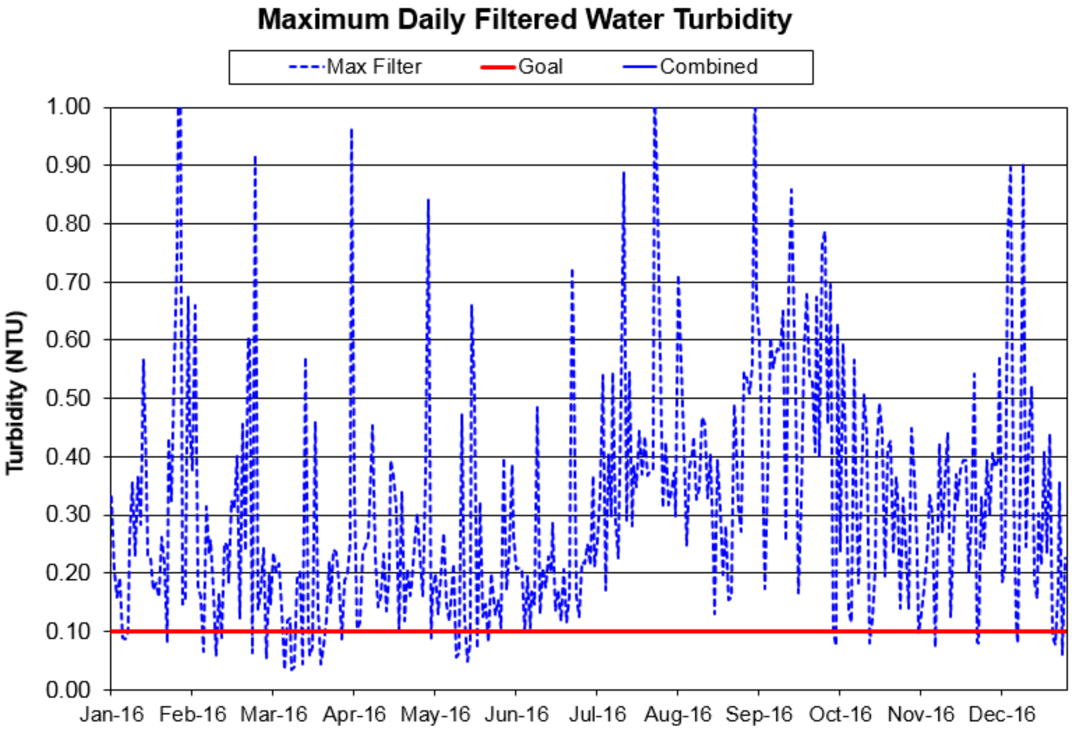
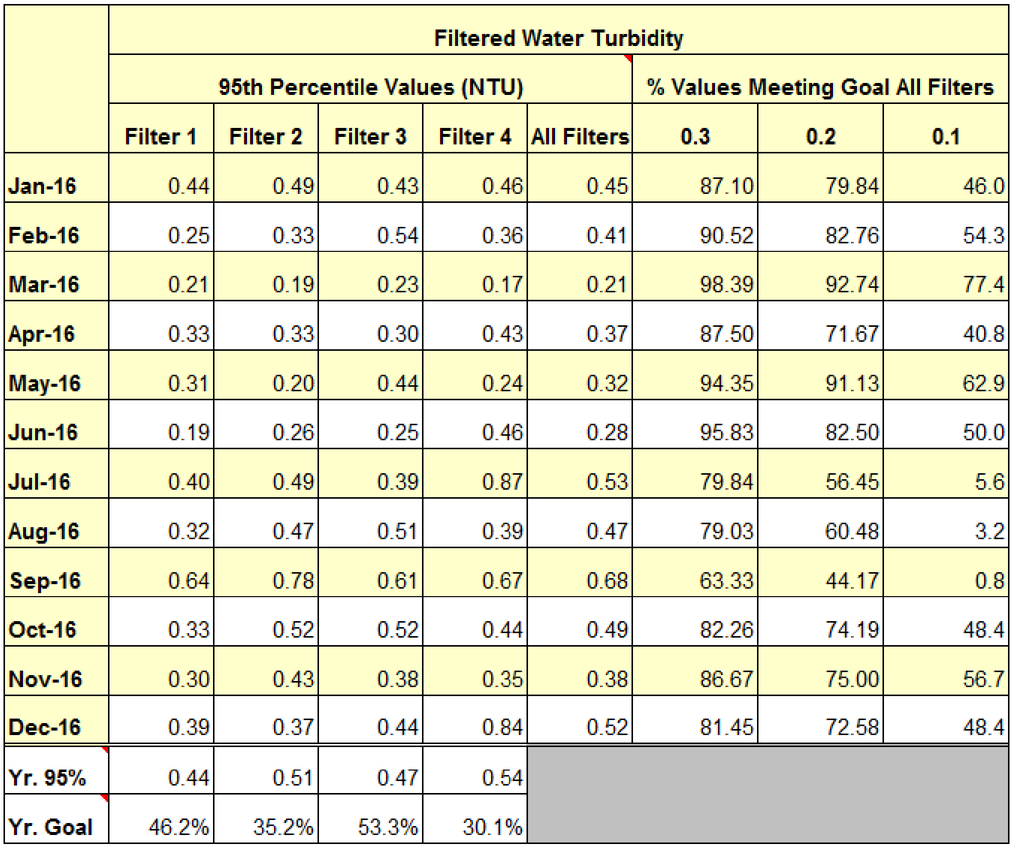


FIGURE 7. Maximum daily filtered water turbidity (IFE only).

The data used to develop the profile in Figure 5 are the maximum daily IFE values from all four filters. However, Table 3 offers a closer look at the individual filtered water turbidity data. The OAS also plots the performance of each filter based on IFE turbidity values, and it is one way of checking to see if certain filters are performing better than others. These data are summarized in Table 3, and they reveal the worst performing filter is Filter 4, meeting the 0.10 NTU optimization goal 30.1 percent of the time. Filter 2 experiences similar performance to Filter 4, followed by Filter 1 and Filter 3 in order of increasing efficiency. It is important to note that Filter 3 contains the oldest media, yet it met the optimization goal more than the other filters with a value of 53.3 percent of the time in 2016.

TABLE 4. OAS Optimization Trend – Filtered Water



	Filtered Water Turbidity							
	95th Percentile Values (NTU)					% Values Meeting Goal All Filters		
	Filter 1	Filter 2	Filter 3	Filter 4	All Filters	0.3	0.2	0.1
Jan-16	0.44	0.49	0.43	0.46	0.45	87.10	79.84	46.0
Feb-16	0.25	0.33	0.54	0.36	0.41	90.52	82.76	54.3
Mar-16	0.21	0.19	0.23	0.17	0.21	98.39	92.74	77.4
Apr-16	0.33	0.33	0.30	0.43	0.37	87.50	71.67	40.8
May-16	0.31	0.20	0.44	0.24	0.32	94.35	91.13	62.9
Jun-16	0.19	0.26	0.25	0.46	0.28	95.83	82.50	50.0
Jul-16	0.40	0.49	0.39	0.87	0.53	79.84	56.45	5.6
Aug-16	0.32	0.47	0.51	0.39	0.47	79.03	60.48	3.2
Sep-16	0.64	0.78	0.61	0.67	0.68	63.33	44.17	0.8
Oct-16	0.33	0.52	0.52	0.44	0.49	82.26	74.19	48.4
Nov-16	0.30	0.43	0.38	0.35	0.38	86.67	75.00	56.7
Dec-16	0.39	0.37	0.44	0.84	0.52	81.45	72.58	48.4
Yr. 95%	0.44	0.51	0.47	0.54				
Yr. Goal	46.2%	35.2%	53.3%	30.1%				

Historical Performance Summary

The XYZ WTP performance is summarized in Table 4.

TABLE 5. XYZ WTP Performance Summary

Barrier	Optimization Goal	Performance
Clarification	Settled water turbidity 2.0 NTU or less 95 percent of the time, based on daily maximum values	The goal was assessed against sedimentation Basin 2 effluent turbidity values. The 95th percentile of the maximum daily individual clarifier effluent turbidity was above the goal, at 6.2 NTU, for the year analyzed. The plant met the 2.0 NTU goal on 21 percent of the days during the year.
Filtration	IFE and CFE turbidities 0.10 NTU or less 95 percent of the time, based on daily maximum values	The IFE data show performance meeting the optimization goal 10 percent of days analyzed during the year, with an annual 95th percentile of 0.68 NTU. The performance of the plant, based on IFE data, fails to meet the filtered water optimization goal.

Additional Performance Observations

Sedimentation

For settled water turbidity, data were analyzed for each day of calendar year 2016 from the plant bench sheets, and the maximum values from each day were collected. Turbidity data were collected from sedimentation Basin 1, sedimentation Basin 2, and the *"top of filter"* (TOF) location, depicted in Figures 6, 7, and 8 respectively. Figure 6 reveals relatively high turbidity values leaving sedimentation Basin 1 that are comparable to raw water turbidities and, thus, indicate little removal across sedimentation Basin 1. Sedimentation Basin 2 provides the bulk of the turbidity removal, as shown by Figure 7. The TOF samples are another way of measuring settled water performance and should be essentially the same as the sedimentation Basin 2 effluent samples. Slightly elevated turbidities were observed from the TOF with higher values in Figure 8 than in Figure 7, even though the profiles were very similar. These elevated turbidity values could be due to the sampling method followed at the TOF location. The evaluation team could have used either the TOF data or the values from sedimentation Basin 2. They chose the latter in order to develop the performance summaries reported in the previous section to represent the overall turbidity reduction from the sedimentation process.

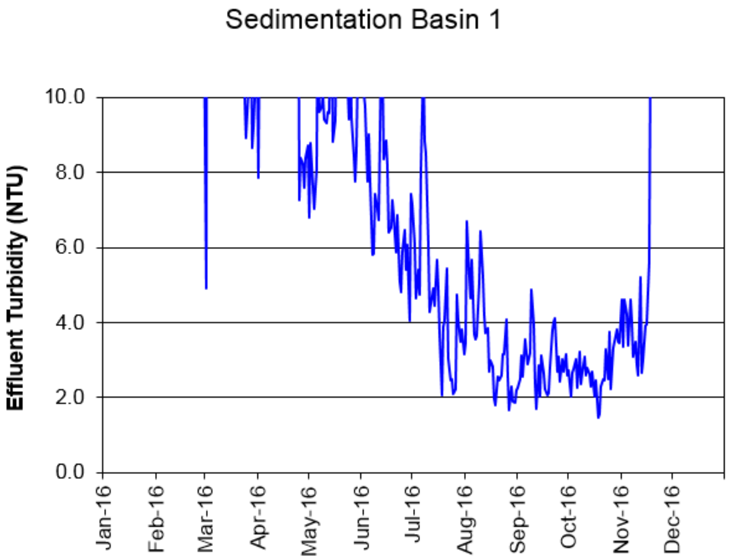


FIGURE 8. Sedimentation Basin 1 turbidity 2016.

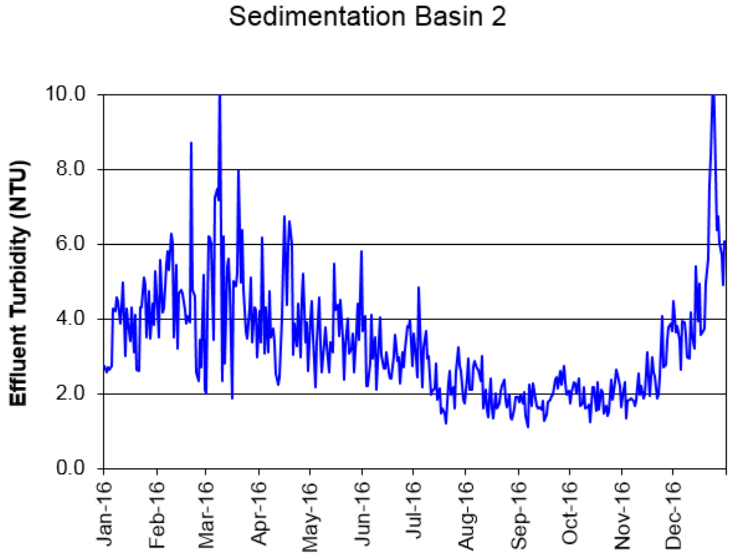


FIGURE 9. Sedimentation Basin 2 turbidity 2016.

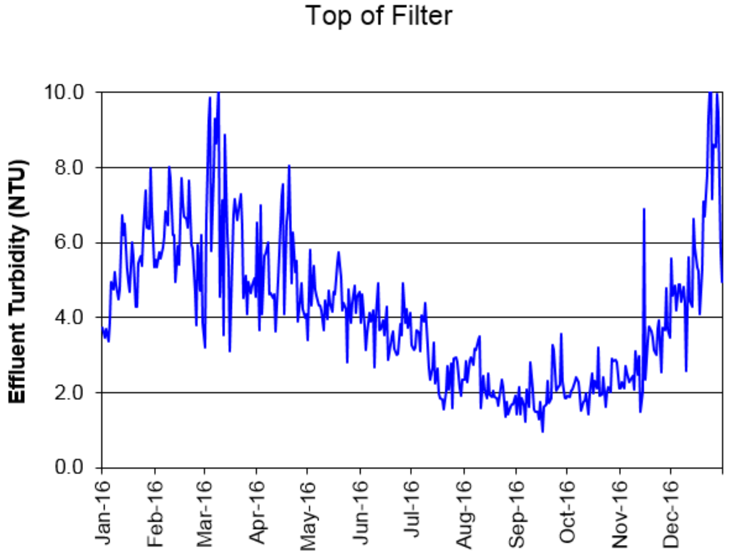


FIGURE 10. Top of filter turbidity 2016.

Filtration

On several days, the maximum daily filter turbidity occurred in the morning at plant startup. Figure 9 below is a graph of the Filter 4 daily turbidity data for four days in January 2016 that support this observation. The absence of filter-to-waste capability means that these turbidity spikes are being measured on water going to the clearwell. Filter performance following these plant start-up turbidity spikes often meets the optimization goal of ≤ 0.10 NTU for the remainder of each day.

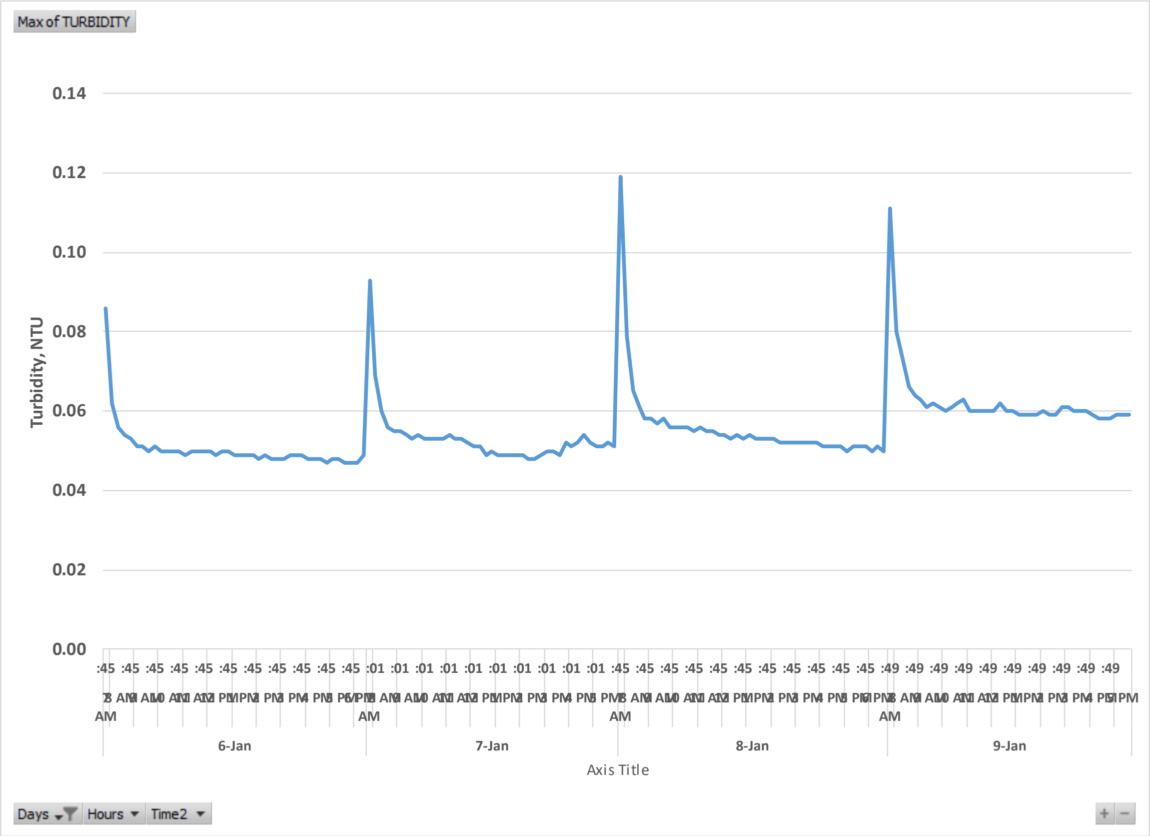


FIGURE 11. Filter 4 effluent turbidity profile showing spikes at plant startup.

The data indicate that there were some days when a turbidity spike at plant startup did not occur at all or the spike occurred later during the day. Figure 10 shows a two-day turbidity profile of Filter 1. On January 10th, a spike occurs later in the day, and on January 11th there are no spikes or much smaller ones. At the time of the spike on January 10th, there is about an hour of missing turbidity data, suggesting that this time corresponds to a filter backwash during which time the 15-minute turbidity data are not being captured in the SCADA monthly turbidity files. Similar observations were documented for Filters 2, 3, and 4 as well. For each observation, an hour or more of data is missing prior to the spike, and the following day shows few to no spikes for that individual filter. Therefore, the largest turbidity spike of the day can be associated with plant startup or filter recovery following a backwash event.

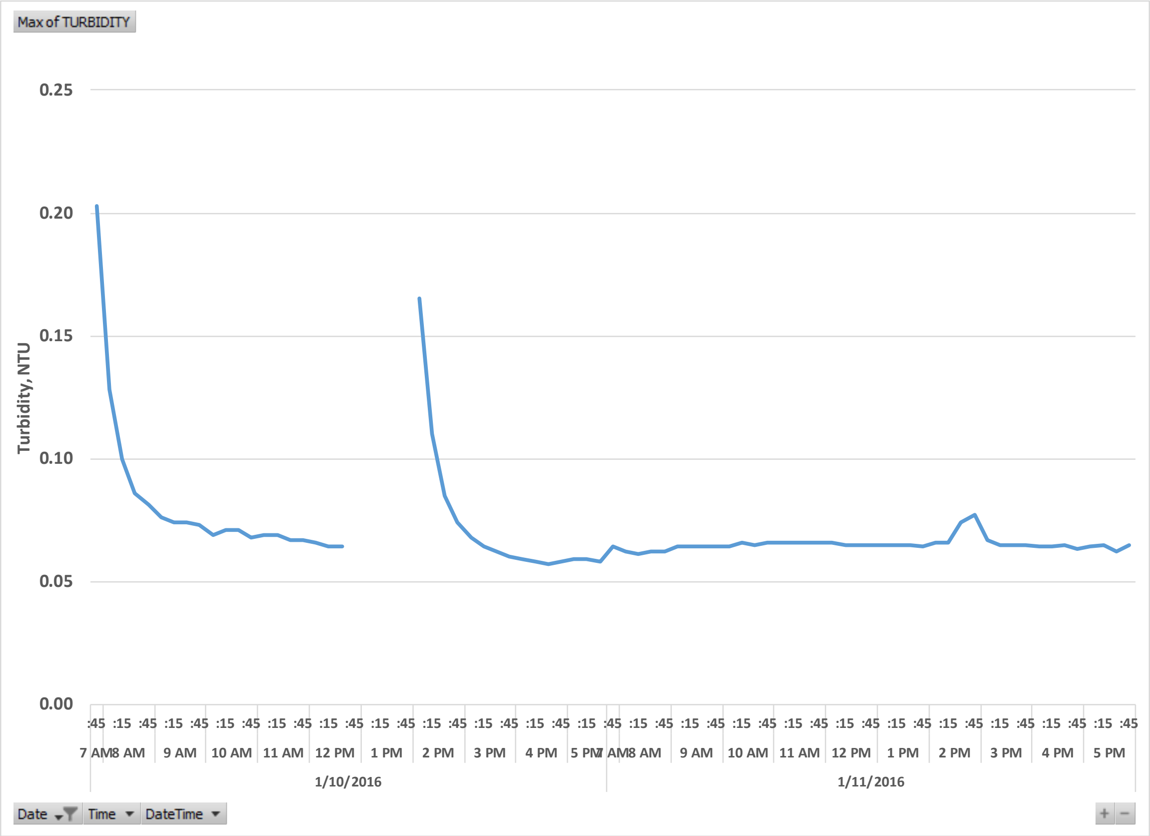


FIGURE 12. Filter 1 effluent turbidity profile showing post-backwash spike.

It is difficult to understand the magnitude and duration of the post-backwash turbidity spikes, since the reported backwash time and/or amount of missing data for an individual filter varies. This corresponds with different operators overseeing the backwash and potentially clicking the IFE *"start"* button on the SCADA turbidity collection at different times. Therefore, the exact time period when data were captured by the SCADA system during the filter ripening period following backwash is unknown.

Filter performance appeared to be inversely proportional to sedimentation basin performance. The plant staff mentioned that IFE turbidity seemed to degrade when *"top of filter"* turbidity values approached 1 NTU or less. This trend appears in Figure 4 above, where sedimentation

Basin 2 effluent and IFE data are plotted together. This trend is even more apparent in Figure 11, which depicts daily maximum TOF data versus daily maximum IFE data.

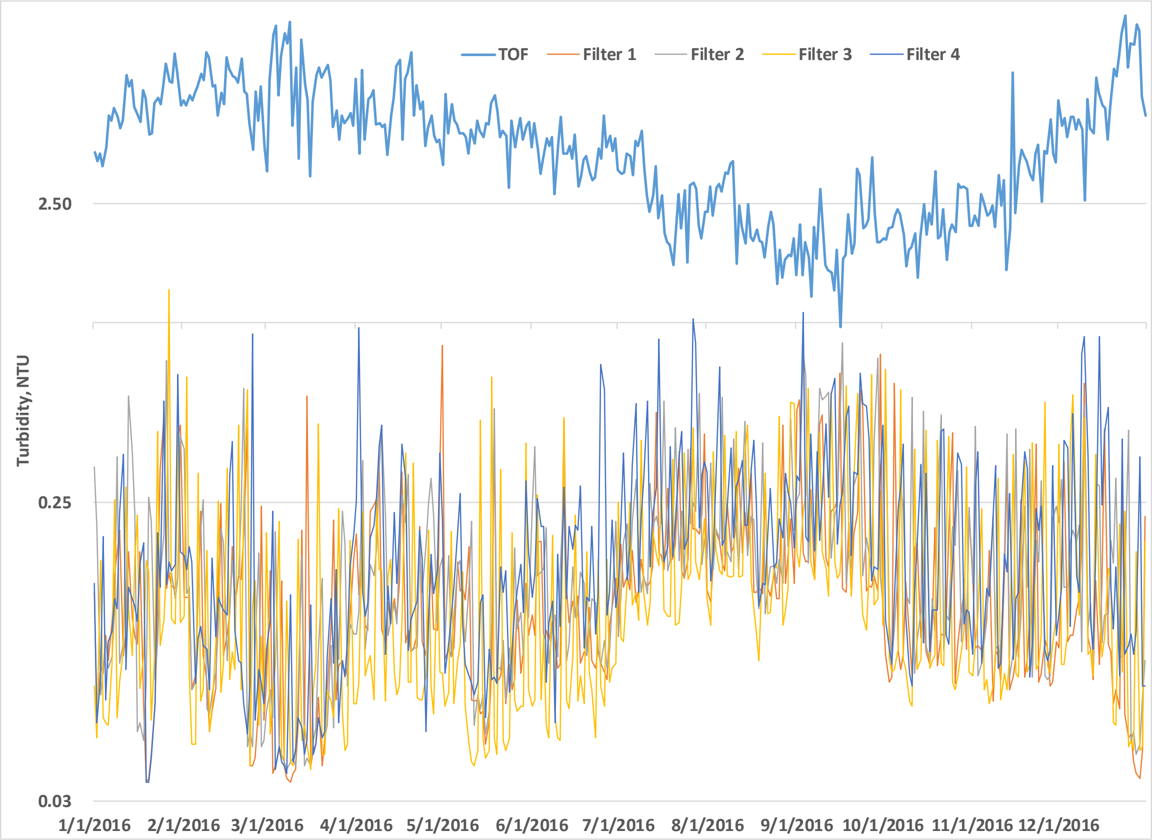


FIGURE 13. Top of filter turbidity profile versus IFE turbidity for each filter.

Because this observation is counterintuitive and unique to the evaluation team, an additional analysis was performed using the 15-minute IFE turbidity data rather than the daily maximum values. Figure 12 displays data that were observed for several days during the months of April and October, representing times when the settled water turbidity data were generally characterized by high and low values, respectively. This analysis compared performance of sedimentation Basin 2 to each individual filter for approximately the same time period that the sedimentation basin samples were measured. This analysis reveals that Filters 2, 3, and 4 performed better in the month of April, which is when settled water turbidity values were high. Only Filter 1 performed better in October, when the settled water turbidity data was lower. It is possible that turbidity carryover from the sedimentation process could act as a *"filter aid"* that enhances filter performance; however, that turbidity carryover could also contain pathogens. The goal in optimization is to optimize each treatment barrier for pathogen removal, including sedimentation and filtration. If low settled water turbidity contributes to higher filter effluent turbidity, areas of filter operation and backwashing should be investigated to identify potential causes and solutions to the filter performance issue.

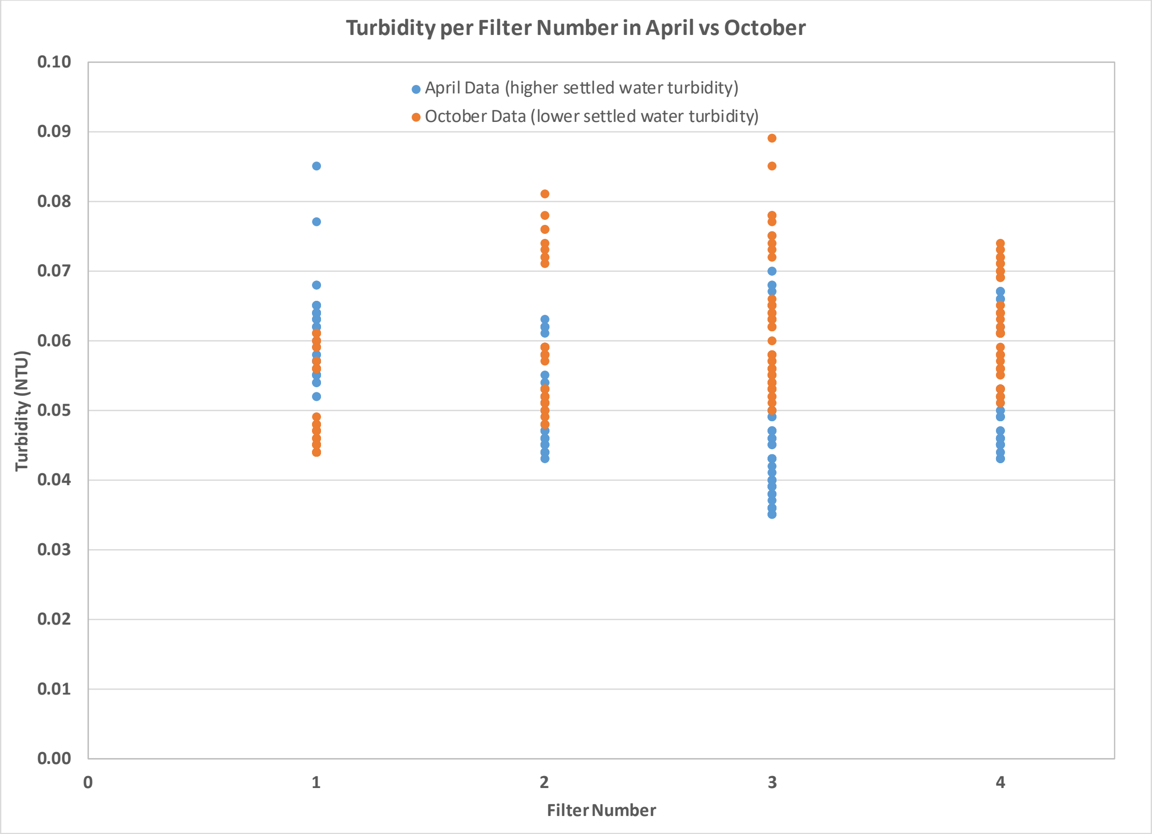


FIGURE 14. Seasonal settled water turbidity versus IFE turbidity for each filter.

Disinfection

Disinfection is the final barrier in the treatment plant for protection from microbial pathogens. CT represents the disinfection concentration (C) multiplied by the contact time (T) (adjusted for basin hydraulics). The plant operators measure parameters to calculate CT daily, and they use a spreadsheet to compare the daily required CT value to the calculated CT value. The CPE team used the data from the plant CT calculations to evaluate historical disinfection performance. An inactivation ratio is determined by dividing the measured CT value by the required CT value, and the inactivation ratio values for 2016 are plotted in Figure 13. The optimization goal for disinfection is an inactivation ratio of at least 1.0 (demonstrating compliance with the regulatory requirement). Figure 13 shows that the XYZ WTP met the goal every day during the year by a wide margin. Although the goal was met, the CPE team noted that a report from June 2016 found an average of five feet of sediment in the bottom of both clear wells. Had the volumes of the clear wells been decreased accordingly in the calculations, the margin of exceeding the goal would have been less, but the trend still would have showed the goal to be attained consistently.

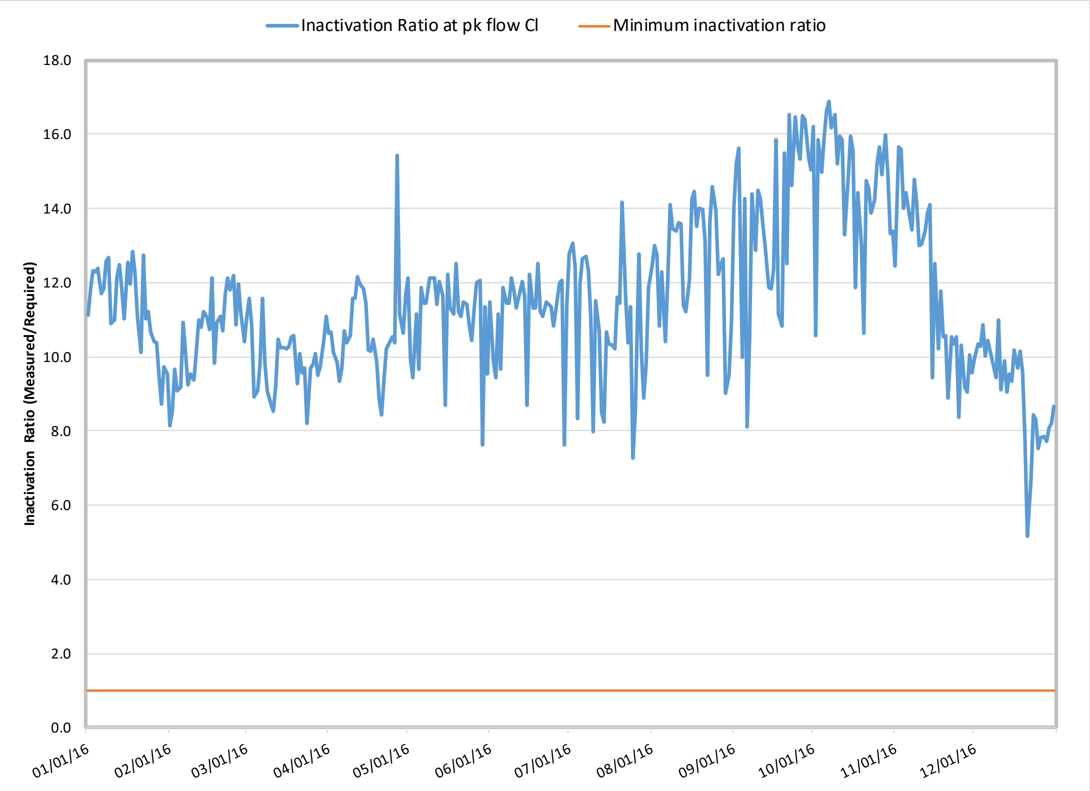


FIGURE 15. Daily disinfection inactivation ratio.

Cyanotoxins

During HAB events, cyanotoxins can enter the plant as either intracellular cyanotoxins (contained within a cyanobacteria cell, or *"cell-bound"* [e.g., in *Microcystis*]) or extracellular cyanotoxins (outside the cell, or dissolved). Intracellular cyanotoxins can also be released from cells if they are lysed (broken apart) or stressed during treatment in the plant. Total microcystins refers to the sum of both intracellular and extracellular microcystins.

Over the past three years total microcystins have peaked in XYZ's raw water in late May and again in late November – early December, as shown in Figure 14. XYZ experienced a finished water microcystins detection of 3.4 ug/L on May 7, 2015, but a drinking water advisory was not issued since microcystins were not detected in repeat finished water or distribution system samples. Resample results showed that extracellular microcystins were between 8-40% of the total microcystins concentration in the raw water on May 8, 2015.

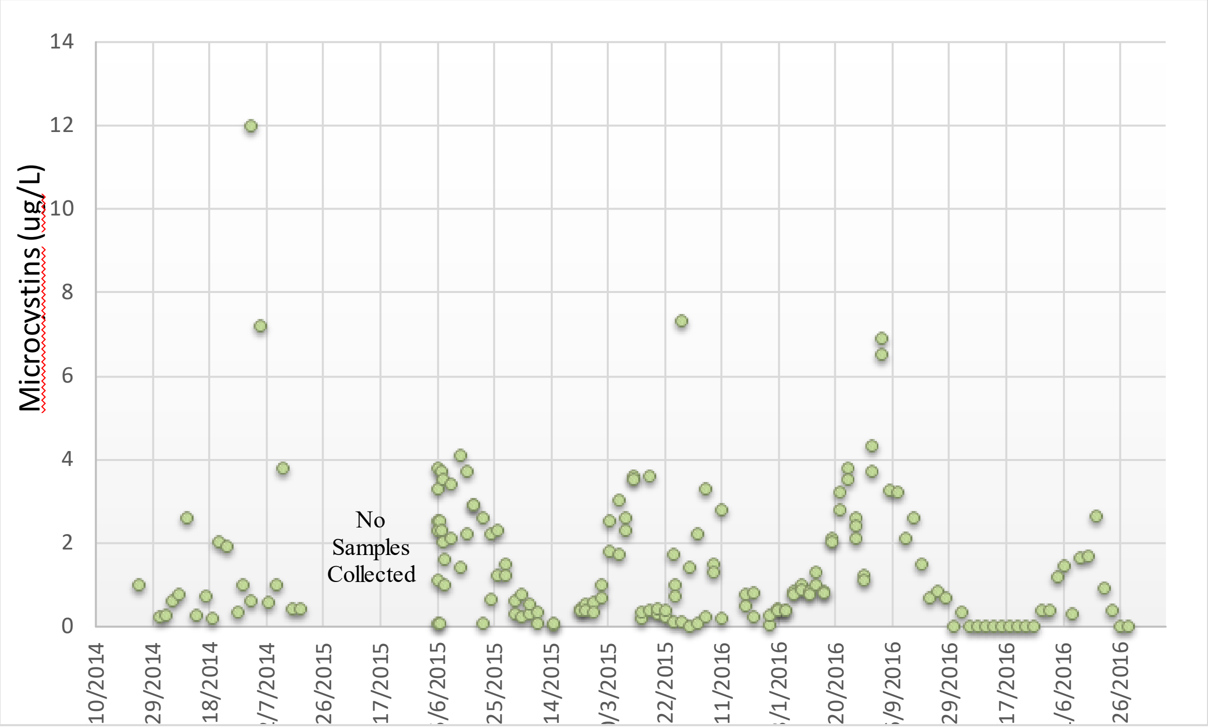


FIGURE 14. Raw water microcystins concentrations at XYZ WTP, 2014 – 2016.

Treatment train sampling was conducted on May 9, 2015 (see Figure 15) and showed 0-52% removal of total microcystins following powdered activated carbon addition at intake (assuming either blend of lower and upper intake or just the lower intake was in use at the time). The "In-Plant 1" sampling location is post powdered activated carbon addition. An additional 72% removal was achieved through settling processes and 68% removal was achieved through filtration and chlorine disinfection. The 0.1 ug/L of microcystins present in the finished water on May 9 is below State EPA's microcystins reporting limit of 0.3 ug/L. Following the initial finished water microcystins detection, Cadiz increased their powdered activated carbon dose and has not had any repeat finished water microcystins detections above State EPA's reporting limit.

State EPA conducted additional treatment train sampling during bloom events in May 2016 and in December 2016. During the December sampling event, 92-95% of the microcystins were intracellular in the raw water, and microcystins were reduced to non-detectable concentrations following sedimentation.

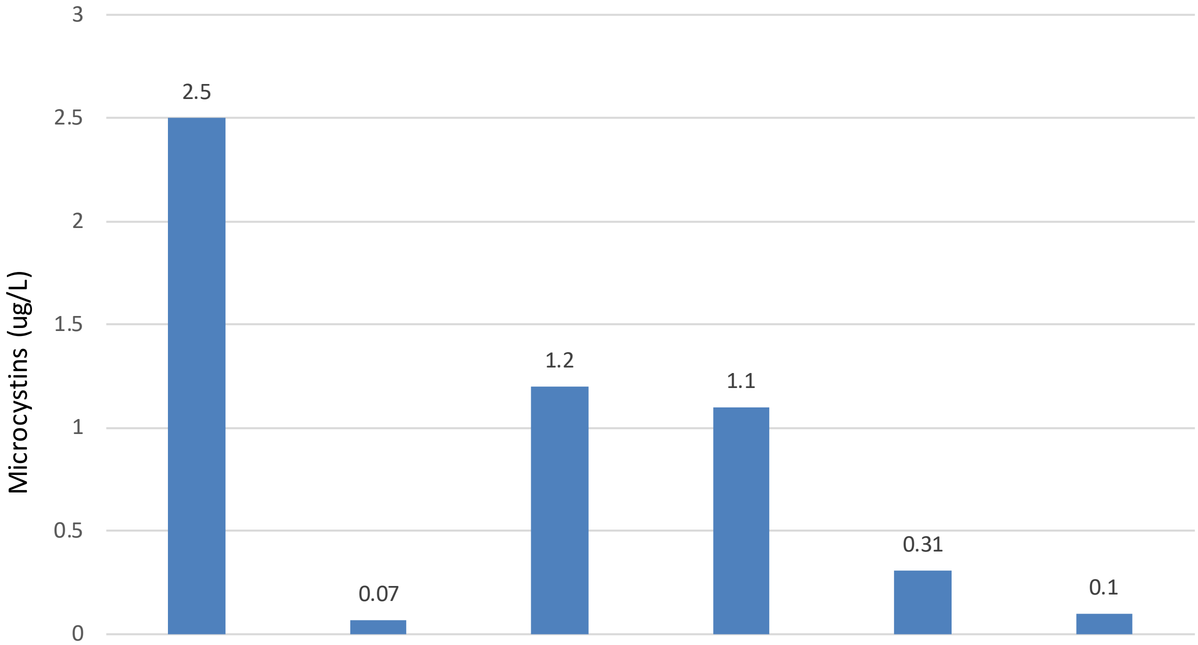


FIGURE 15. XYZ WTP microcystins profile on May 9, 2015.

It is not known if the plant was just utilizing the lower intake or a blend of the upper and lower intake at the time.

On-site Studies

During the CPE, several studies were conducted to assess current plant performance and process control. These studies included: 1) filter probing, media assessment, bed expansion, and backwash waste turbidity profile; 2) filter backwash recovery; 3) online turbidimeter flow rate and sample time assessment; 4) chemical feeder calibration check, and 5) jar testing to assess impact of PAC addition on cyanotoxin removal.

Study 1: Filter Probing, Media Assessment, Bed Expansion, and Waste Backwash Profile

During the CPE, Filter 4 was drained by the plant staff to allow the CPE team to conduct filter evaluation studies. Each of the studies is described in the sections that follow.

Filter Probing–

The purpose of conducting a filter probing study is to evaluate the overall depth of media in the filter. This is accomplished by probing the filter at approximately equally-spaced distances in a grid-like pattern across the plan area of the filter. Once depths are measured, the data points can be plotted and used to determine areas where the bed is uneven or where media loss has occurred. However, due to the design of XYZ's filters, a complete filter probe study could not be conducted. As seen in Figure 16, the backwash collection troughs have shrouds in place to keep media from being lost over the trough. These shrouds covered a large area of the filter, making maneuverability across the filter bed difficult. Therefore, only the center-line was probed in six-inch to one-foot increments, as shown in Figure 16. The filter was originally installed with a 3-inch layer of torpedo sand followed by a 12-inch layer of sand and then a 15-inch layer of anthracite, for a total media depth of 30 inches. At no point were team members able to probe down to the full depth of the media, due to the tightness of the media.

FIGURE 16. Filter 4 plan view.

Filter Inspection–

The purpose of the filter inspection is to observe physical conditions of the filter media. A visual examination was made of the media once Filter 4 was drained. The media was excavated to depths ranging from 30 to 34 inches. No mudballs or cracks were observed throughout the media. Two small sections of the filter bed were excavated by hand to observe the degree of stratification between the anthracite and sand media. The excavation sites selected were areas of the filter that exhibited the most resistance when inserting the probe. These locations were at eight inches from the right wall and at two feet from the left wall, as shown in Figure 17. According to the filter design, there should be a distinct layer of anthracite over a layer of sand, typically with a small layer of intermixing between the two distinct layers. The excavation in Filter 4, shown in Figure 18, revealed almost complete intermixing of the anthracite and sand layers throughout the depth of the filter bed profile. Also, lime particles were found throughout the media.

Filter 4
January 25, 2017

Probed 15 areas along centerline of filter.

Area of Excavation: Highest area of resistance to probing found approximately 8 inches from right wall and 2 feet from left wall.

Top several inches showed mostly anthracite but some sand mixed in.

As depth progressed the anthracite and sand were completely intermixed along profile.

Excavated media depths ranged from 30” at Site 1 to 34” at Site 2.

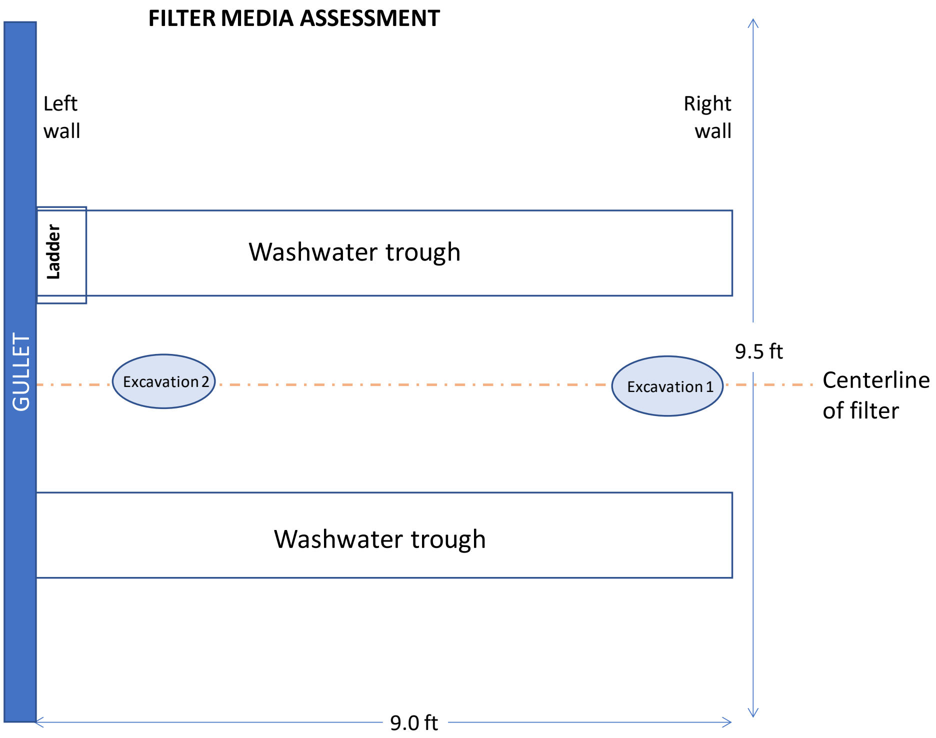


FIGURE 17. Filter 4 probing and excavation locations.

FIGURE 18. Pictures of mixed media found in Filter 4 bed during excavation.

Re-stratification of media following a backwash cycle is a function of media density and size, filter bed expansion during backwash, and the approach used to ramp down the backwash flow rate. In Filter 4, the failure of the anthracite and sand to re-stratify back to their distinct layers following a backwash cycle could be due to low bed expansion provided during the backwash cycle. As observed from the backwash study, only one inch of bed expansion was achieved during backwash (see further discussion of bed expansion below). The current bed expansion is limited by the backwash system design. The flow rate available for backwashing is determined from the water level in the filter effluent wet well. Also, the backwash flow rate cannot be ramped down since there is no automatic control of the rate in the system design.

A possible issue with completely mixed filter media is more rapid increase in filter headloss and binding of the filters when operating under high hydraulic and solids loading conditions. Under normal operating conditions, this can potentially be managed operationally, by reducing hydraulic loading and reducing filter run times. However, the mixed filter media could be challenged to produce optimized water quality (turbidity) when operating with higher hydraulic rates and solids loading conditions (e.g., during a HAB event). Instead, the achievable rate of filtration (gpm/sf) would likely decrease, and shorter filter run times may result.

During this CPE, only Filter 4 was evaluated; however, the media condition could be similar in the other filters. Also, additional studies to optimize filter run times to improve filter performance and to optimize backwash duration to improve filter return to service can be conducted. Design modifications to allow for further adjustment of backwash flow rate and to improve re-stratification of the media may be an option.

Bed Expansion–

The purpose of conducting the bed expansion study is to determine the extent to which the filter media expands during a typical backwash cycle. The percent bed expansion can be calculated from the measurement of media expansion. The percent of bed expansion helps operators understand the effectiveness of the backwash cycle in cleaning the media and the ability for media re-stratification following a backwash. A minimum of 20 percent filter bed expansion is desirable; however, filters using air scour can achieve satisfactory backwashing at lower expansion rates (i.e., 15 percent). During this study, a Secchi disk attached to a pole was used to measure the extent of media expansion. The CPE team marked the pole when the Secchi disk was sitting on the media before the filter backwash and again at the high backwash flow rate when the Secchi disk was observed to disappear below the fluidized media. The distance between these two marks represents the depth of media expansion.

The CPE team attempted to determine the extent of expansion during the high-rate portion of the Filter 4 backwash cycle. Due to the depth of the filter and limited light in the filter, determining the top of the media layer was difficult. Through a combination of visual observation and feeling the difference in water density at the media interface, a bed expansion of about one inch was estimated. Based on 30 inches of filter media, the bed expansion was approximately 3 percent. This bed expansion is at the low end of the typical range, even for filters with combined air and water backwash. Due to the challenges of measuring the bed expansion, a repeat of the study is suggested for all of the filters. Alternative bed expansion measurement tools, such as the one shown in Figure 19, may provide more conclusive results for the XYZ filter design.

FIGURE 19. Filter bed expansion tool.

Backwash Waste Turbidity Profile–
The purpose of conducting a backwash waste turbidity profile study is to determine the amount of time necessary for effective media cleaning. The equipment used to perform this study

included a sample collection device for grab samples, a YSI EXO sonde, and a portable turbidimeter. During the Filter 4 backwash, the CPE team collected eight turbidity grab samples at varied times from the discharge of the waste trough, using a long pole with a sample bucket attached at the end. In addition, the EXO sonde was lowered into the filter and placed in the water on top of the filter, next to the washwater launder. The continuous turbidity data from the EXO sonde and the turbidity data from the grab samples are shown below in Figure 20. These data show that the waste backwash water turbidity spiked to about 400 NTU immediately after the start of the backwash and gradually decreased to the 100 NTU range. After the blower was turned on, the turbidity spiked to the 150 NTU range and then gradually decreased to the end of the backwash when the turbidity was less than 5 NTU. The results suggest that most of the particles trapped in the filter have been removed during the backwash.

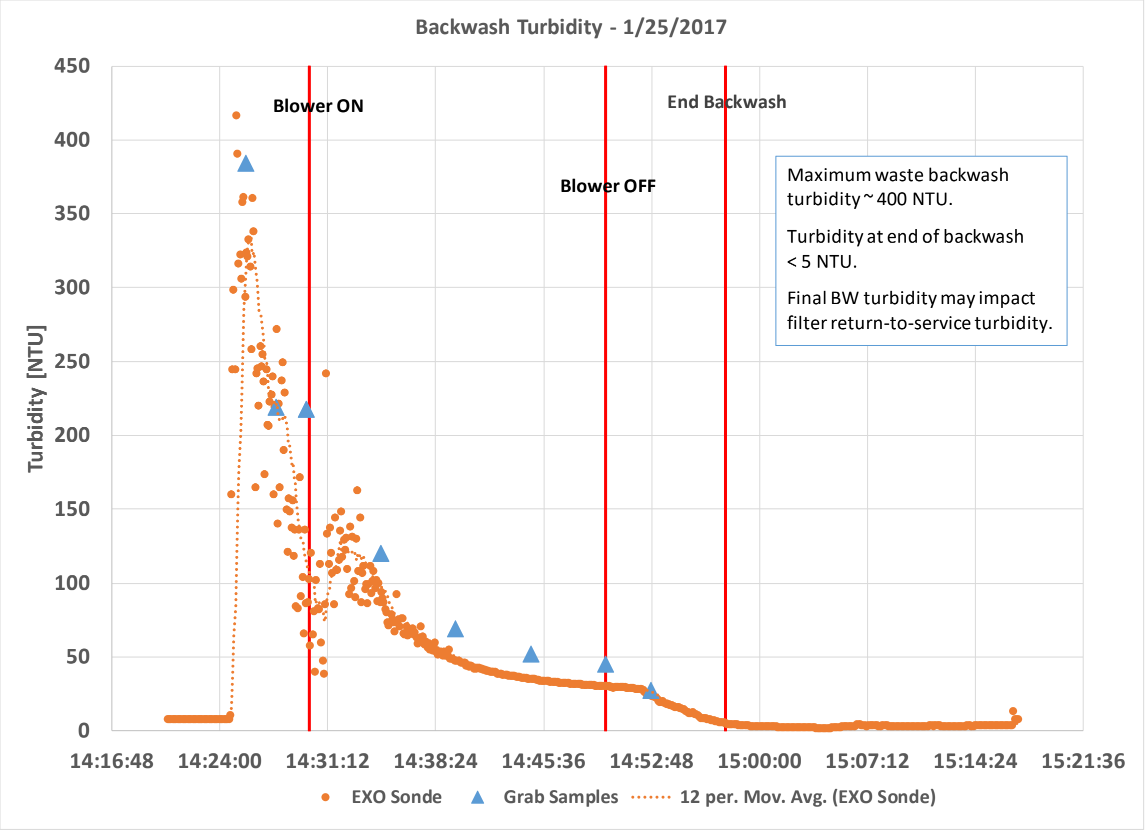


FIGURE 20. Filter 4 waste backwash water turbidity profile.

This study approach can be used by plant staff to determine an optimum turbidity level to stop backwashing and to determine if inadequate or excess backwash water is being used during filter backwash. The plant operators are encouraged to periodically conduct this study to support optimization of the filter backwash procedure.

Study 2: Filter Backwash Recovery

The optimization goal for plants with filter-to-waste capability is to return the filter to service at ≤ 0.10 NTU. Following the inspection and backwash of Filter 4, the filter effluent turbidity was monitored as the filter was returned to service, and these performance data from the continuous turbidimeter are shown in Figure 21. The challenge with the XYZ filter backwash design is knowing when the filter returns to filtering mode. Based on discussions with the plant staff, it was estimated that this occurs about ten minutes after the backwash waste valve closes and the filter begins to fill. The blue data points in Figure 21 represent turbidity from the Filter 4 turbidimeter when backwash is occurring, while the red data points represent turbidity from the filter when the water is going to the combined filter wet well (i.e., return to service). During return to service, the turbidity spiked to 0.7 NTU and gradually decreased to 0.22 NTU after 35 minutes. For filters without filter-to-waste capability, the optimization goal is to limit the turbidity spike to less than 0.30 NTU and return to ≤ 0.10 NTU within 15 minutes. These goals were not achieved during this filter backwash. Achieving these goals following each filter backwash can reduce the number of particles (including pathogens and cyanobacteria cells) that pass to the clearwell and, as a result, can enhance public health protection.

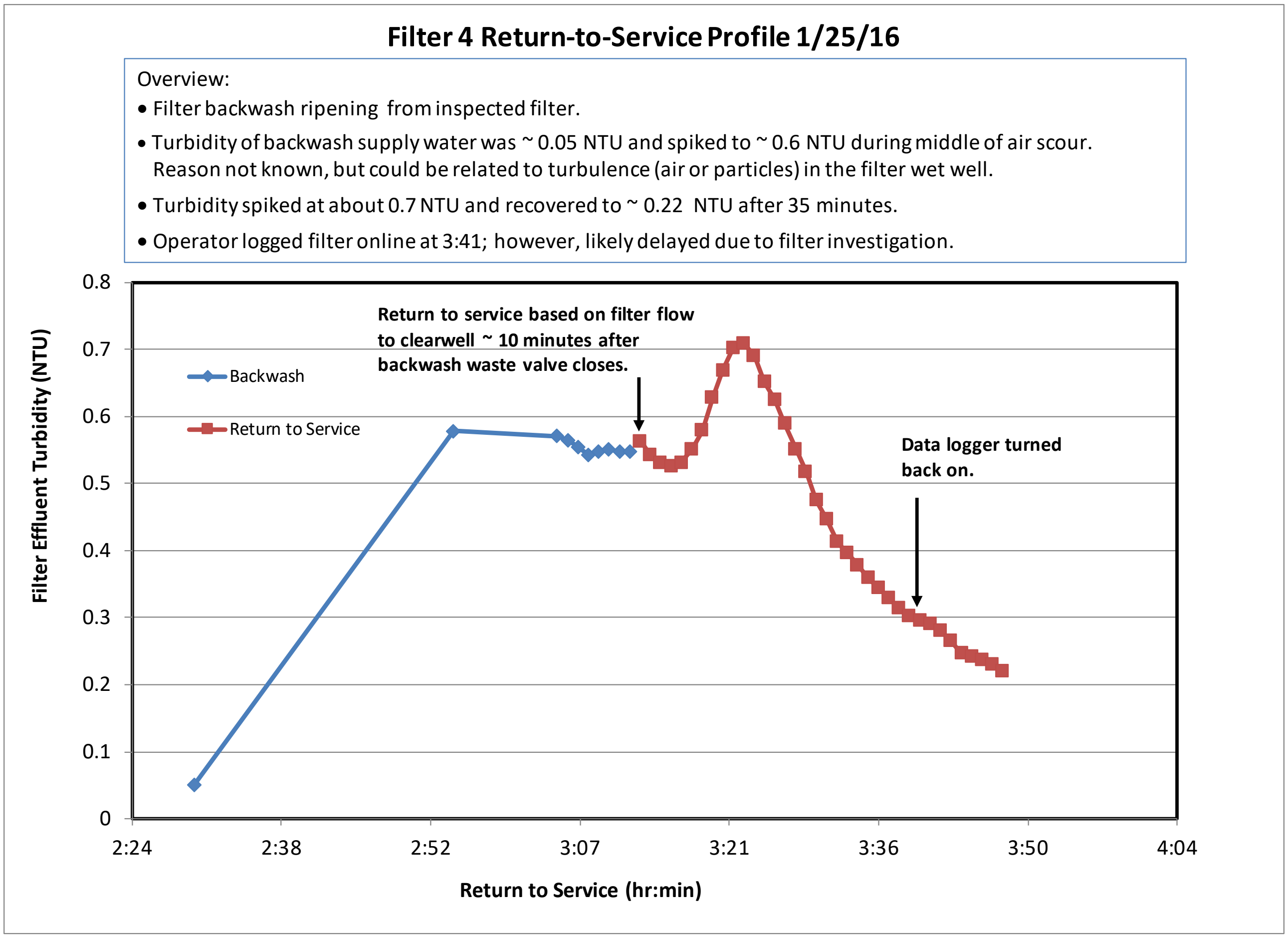


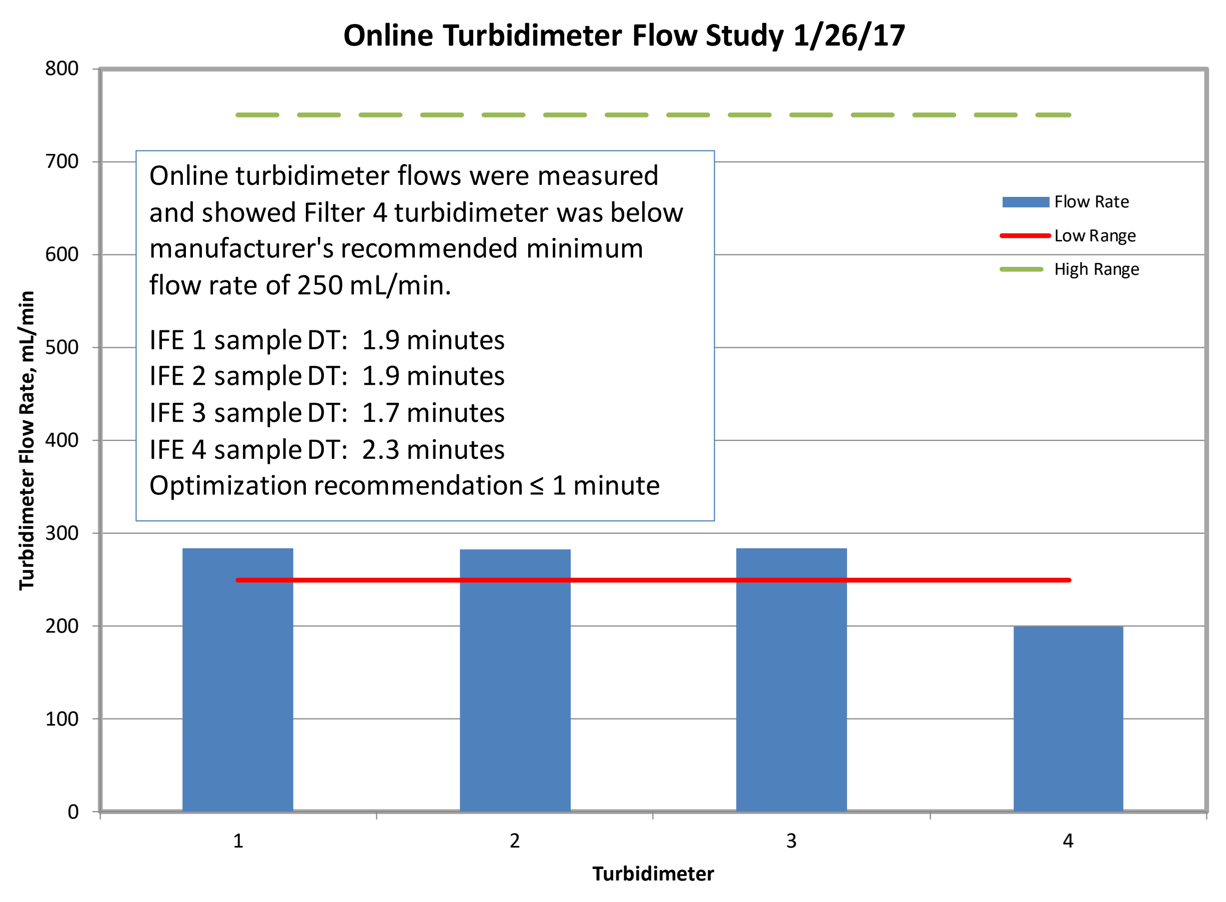
FIGURE 21. Return-to-service profile for inspected Filter 4.

The time when the data logger was turned back on in the SCADA system is also shown in Figure 21. It should be noted that the operator was likely delayed in completing this final backwash activity due to the study that was occurring at the time. However, through discussions and interviews with plant staff, it was determined that there was not a consistent approach for determining when the data logger is turned back on in the SCADA system (e.g., one hour after filter backwash starts, after a downward trend is observed on the turbidimeter). Establishing a consistent, data-based approach for completing this task is important for monitoring water quality that is representative of all water going to the combined filter wet well.

Study 3: Online Turbidimeter Flow Rate and Sample Detention Time Assessment

To assess the flow rate of the online Hach 1720E turbidimeters in the filter gallery, the CPE team used a graduated cylinder and a stop watch to measure the flow rates from the individual filter effluent (IFE) turbidimeter drain lines (Figure 22). IFE Turbidimeter 1 (284 mL/min), Turbidimeter 2 (282 mL/min), and Turbidimeter 3 (284 mL/min) fell within the manufacturer's recommended flow rate range of 250 to 750 mL/minute, as shown in Figure 23. The flow rate of IFE Turbidimeter 4 (200 mL/min) fell below the manufacturer's recommended minimum flow rate of 250 mL/minute. With the flow rate below minimum, the particles in the turbidimeter sample line and meter may settle out, causing a slightly lower effluent turbidity reading for Filter 4 (i.e., false low value).

FIGURE 22. Online turbidimeters with SC200 controllers on the operating floor of the filter gallery.



Online turbidimeter flows were measured and showed Filter 4 turbidimeter was below manufacturer's recommended minimum flow rate of 250 mL/min.

IFE 1 sample DT: 1.9 minutes
IFE 2 sample DT: 1.9 minutes
IFE 3 sample DT: 1.7 minutes
IFE 4 sample DT: 2.3 minutes
Optimization recommendation ≤ 1 minute

FIGURE 23. Online turbidimeter flow check and sample line detention time.

The CPE team calculated the sample detention time of the online Hach 1720E turbidimeters in the filter gallery. The CPE team estimated and measured the distance from the effluent ports of individual filter underdrain pipes to the influent ports of the online turbidimeters. The sample lines are comprised of 1/2-inch and 1/4-inch tubing. The length of 1/2-inch tubing from the effluent ports of individual filter underdrain pipes to a 1/2-inch tubing manifold on the basement floor of the filter gallery was estimated using XYZ plant design plans. A tape measure was then used to measure the remaining length of 1/2-inch tubing from the tubing manifold to the influent ports of four Pulsafeeder Chemtech mechanical metering pumps on the basement wall of the filter gallery. The length of 1/4-inch tubing was then measured from the effluent ports of the metering pumps through the operating floor of the filter gallery to the influent ports of the online IFE turbidimeters. Using the distances and flow rates from the filter underdrain pipes to the turbidimeters, a detention time was calculated for each individual filter as listed in the legend box in Figure 23. The detention times varied between 1.9 and 2.3 minutes, which is greater than the recommended sample travel time of one minute or less for IFE turbidimeters. The sample line distances have already been minimized at the XYZ plant; however, the sample detention time can be reduced by increasing the flow rate settings on the metering pumps or adjusting flow control valves.

The CPE team checked the settings on the online Hach 1720E turbidimeter SC200 controllers, as listed in Table 5. Each SC200 controller communicates with two turbidimeters. A source of historical turbidity data is available from the controller, which stores IFE turbidity values based on the selected datalogging interval (30 seconds, 1 minute, 5 minutes, 10 minutes, or 15 minutes). All four turbidimeters were set on a datalogging frequency of 15 minutes (the Hach default value), allowing storage of about four to six months of data. These data can be downloaded from the controller using an SD card and used to compare the IFE SC200 turbidity values against the IFE turbidity values in the SCADA system. While the turbidimeter controller is storing data in 15-minute increments, the controller transmits continuous data (i.e., value approximately every second) to the plant SCADA system, where it is displayed on the control screen and used to generate reports.

Signal averaging was set on 90 seconds (the Hach default value is 30 seconds) on all four turbidimeters. Signal averaging every 90 seconds reduces the impact of outliers by averaging datasets over a 90-second period. Higher signal averaging values produce a smoother signal but increase the time it takes for a signal to respond to a change in the process value. All four turbidimeters had their bubble reject value on (the Hach default setting) to prevent the recording of erratic readings caused by air in the sample lines. Error Hold Mode and Output Span are explained in detail in the notes listed below Table 5. The XYZ plant has good operation and maintenance practices for their turbidimeters, with replacement of sample lines every three months and cleaning of turbidimeters monthly. Turbidimeters are also calibrated quarterly by operators and verified monthly with a Hach Ice Pic, as confirmed in the XYZ plant calibration history.

TABLE 6. Data Integrity Study: Turbidimeter Settings

Turbidimeter Location	**Filter Effluent No. 1**	**Filter Effluent No. 2**	**Filter Effluent No. 3**	**Filter Effluent No. 4**
Turbidimeter Model	1720 E	1720 E	1720 E	1720 E
Controller Model and Data Logging Setting (1)	SC200 15 minutes	SC200 15 minutes	SC200 15 minutes	SC200 15 minutes
Signal Averaging (2)	90 seconds	90 seconds	90 seconds	90 seconds
Bubble Reject (3)	On	On	On	On
Error Hold Mode (4)	Hold Outputs	Hold Outputs	Hold Outputs	Hold Outputs
Output Span (5)	0 to 100 NTU	0 to 100 NTU	0 to 100 NTU	0 to 100 NTU
Other	Date stamp check: Off by 1 hour Operational practices: • Replace sample lines every three months • Clean turbidimeters monthly • Calibration quarterly by operators and verification monthly with Ice Pic (confirmed in Calibration History)			

(1) Check to see if current data and time are correct. Check frequency of data logging. Default is 15 minutes for Hach models.

(2) Default for Hach models is 30 seconds. This is acceptable in most cases.

(3) Default is *On* for Hach models. This is acceptable in most cases.

(4) Specific to Hach 1720E and FilterTrak 660 models. Default is to Hold Outputs (*HO*) and send last known value to SCADA when turbidimeter loses communication with controller. Better option is Transfer Outputs (*TO*) to send an operator-selected value to SCADA (e.g., 0, 99) to make operator aware of problem.

(5) To avoid *"capping"* of data to SCADA, the output span should be at least 0 to 5.1 NTU (applicable to analog signals). Span for all XYZ IFE turbidimeters 0 to 100 NTU (no data capping issues).
Accessing output span for Hach SC200 controller: Menu/SC200 setup/Output setup (select *1* or *2*; select *Source* to see which turbidimeter is highlighted and then *Back* button)/Activation (low value; high value).

Study 4: Chemical Feeder Calibration Check

A study was conducted to determine the feed rate and dose of chemical additions in the plant. Results are summarized in Table 6. The CPE team collected powdered activated carbon (PAC), lime, and soda ash from their respective feeding points over a measured time period and weighed the samples on a triple beam balance available in the plant's laboratory. The weight of PAC at the in-plant and at the Lake intake were found to be 58.4 grams per two minutes and 174 grams per five minutes, respectively. Based on a plant flow of 0.79 MGD, this equated to a PAC dose of 14 mg/L in-plant and 17 mg/L at the intake. The PAC feed rates were comparable to the total usage over time reported by the operators.

Lime and soda ash additions were measured in a similar fashion and were found to be 262 grams per two minutes for lime and 473 grams per two minutes for soda ash. This equated to a 63 mg/L lime dose and a 114 mg/L dose of soda ash.

In addition to the dry chemical additives, the CPE team also measured the liquid coagulant and alum feeds. The coagulant (AS3040) is added at the primary rapid mix and was measured at 103 mL per 30 seconds for a dose of 130 mg/L. Alum is added at the second-stage rapid mix basin. Alum was measured at 12 mL per minute for a dose of 7.6 mg/L.

The operators do not routinely check their chemical feed dosage rates, and they also reported that chemical feed dosages are seldom changed. Routinely recording and confirming plant chemical feed dosages can provide useful information to support plant optimization.

TABLE 7. Summary of Chemical Feeder Calibration and Dose Results

Chemical Feeder	Feed Rate, g/min or mL/min	Feed Rate, lb/day (24 hr basis)	Flow Rate, MGD	*Chemical Dose, mg/L
PAC plant (small pulley)	58.4 grams/ 2 minutes	93	0.79	14
PAC at lake (small pulley)	174 grams/ 5 minutes	110	0.79	17
Coagulant (AS3040) (1)	103 mLs/ 30 seconds	860 (wet basis)	0.79	130
Alum(2)	12 mLs/ 1 minute	50 (wet basis)	0.79	7.6
Lime	262 grams/ 2 minutes	416	0.79	63
Soda Ash	473 grams/ 2 minutes	749	0.79	114

(1) Reported specific gravity = 1.31; wet weight = 10.93 lb/gal

(2) Reported specific gravity = 1.307; wet weight = 10.9 lb/gal

Study 5: Jar Testing to Assess Impact of PAC Addition on Cyanotoxin Removal

Introduction–

Jar testing is a valuable tool for assessing and optimizing water treatment plant chemical dosing, especially during a harmful algal bloom (HAB) event. When source water quality changes, it is important to determine if chemical dosing needs to be adjusted or added to remove cyanotoxins while maintaining other treatment objectives, such as turbidity and TOC removal. Operators can conduct jar testing in advance of, or during, the initial stages of HAB occurrences. Utilizing concentrated raw water samples or spiking commercially-available stock cyanotoxins can be beneficial to prepare for the changes in chemical dosing that may be necessary to address the HAB.

Jar testing simulates the water treatment plant's processes by setting mixer speeds. Current plant chemical dosing performance can be evaluated and compared with alternative chemical dosing scenarios for changing raw water quality. A simple jar test was conducted to simulate the addition of powdered activated carbon (PAC) at the raw water pumping station and the 10-mile raw water transmission main to the plant. Various PAC doses were evaluated to assess cyanotoxin removal.

Approach–

<u>*Raw water and concentrated sample*</u>

To mimic the conditions XYZ might experience during a HAB event, including elevated microcystins and natural organic matter (NOM), a composite sample was prepared using raw water from XYZ's Lake and raw water from another lake. Cyanobacteria and their associated intracellular cyanotoxins were concentrated from another lake source water using a phytoplankton net, and they were transferred to four unpreserved 1-liter (L) amber glass jars on December 19, 2016. Based on historic sampling data, the cyanobacteria genera and microcystin variants present in the lake water are similar to those present in XYZ's lake water. Total microcystins concentrations in the other lake concentrated samples ranged from 100 to 200 µg/L, and extracellular microcystins ranged from 2.2 to 2.7 µg/L. The samples were frozen to lyse (break apart) cyanobacteria cells and increase the extracellular percentage of microcystins in the sample, to better evaluate extracellular microcystins removal by PAC. The samples were held frozen, then thawed the day prior to the jar test. Equal volumes of raw water from the XYZ's upper and lower Lake intakes were collected in one-gallon amber glass jars on January 24, 2017. Equal volumes of upper and lower intake water were combined with the concentrated alternate Lake samples. A sample of this prepared raw water was determined by ADDA-ELISA to be 23 µg/L total microcystins concentration, with 11 µg/L being in the form of extracellular microcystins. This composite sample was stirred using a metal spoon to keep the cellular matter suspended, and it was split between the six jars utilized for the jar test.

Jar test settings determination

The jar test was set up to replicate the dosing of PAC at the raw water pump station at XYZ's lake and the travel time in the 12-inch/8-inch transmission main to the water treatment plant (Figure 24). The jar test time was based on the volume of the 12-inch and 8-inch pipe diameter lengths of pipe estimated at 42,103 ft^3. Mixing energy in the jars was assumed to be equivalent to the headloss in the transmission line. Using the average flow rate in the raw water line of 550 gpm (or 0.8 MGD), headloss was calculated to be approximately 44 feet. This results in a mixing energy expressed as velocity gradient (G) of 52 sec^{-1}. Table 7 below summarizes the calculated values for the jar test settings. Using Figure 25 below and a velocity gradient (G) of 52, a jar test setting of 61 rpm was determined to replicate the mixing in the raw water line. The calculated detention time in the transmission main, assuming a 550 gpm average flow rate, is 9.6 hours. The jar test was run for 24 hours at 61 rpm, with samples taken at times 0, 1, 2, 4, 9.6 (detention time), and 24 hours. The jar test was extended beyond the detention time in the pipe (9.6 hours) to determine if additional contact time with PAC affects the adsorption of microcystins for this prepared raw water.

FIGURE 24. Jar testing to simulate impact of variable PAC dosages and contact times on microcystins concentrations.

TABLE 8. Summary of Jar Test Settings to Replicate Raw Water Transmission Line

Parameter	Input	Units
Raw Water Line Volume	42,103	ft^3
Flow Rate	0.8	MGD
Detention Time	9.6	Hr
Head Loss	44	Ft
Velocity Gradient (1)	52	Sec^{-1}
Jar Mixer Speed	61	RPM

(1) Based on water temperature of 8°C.

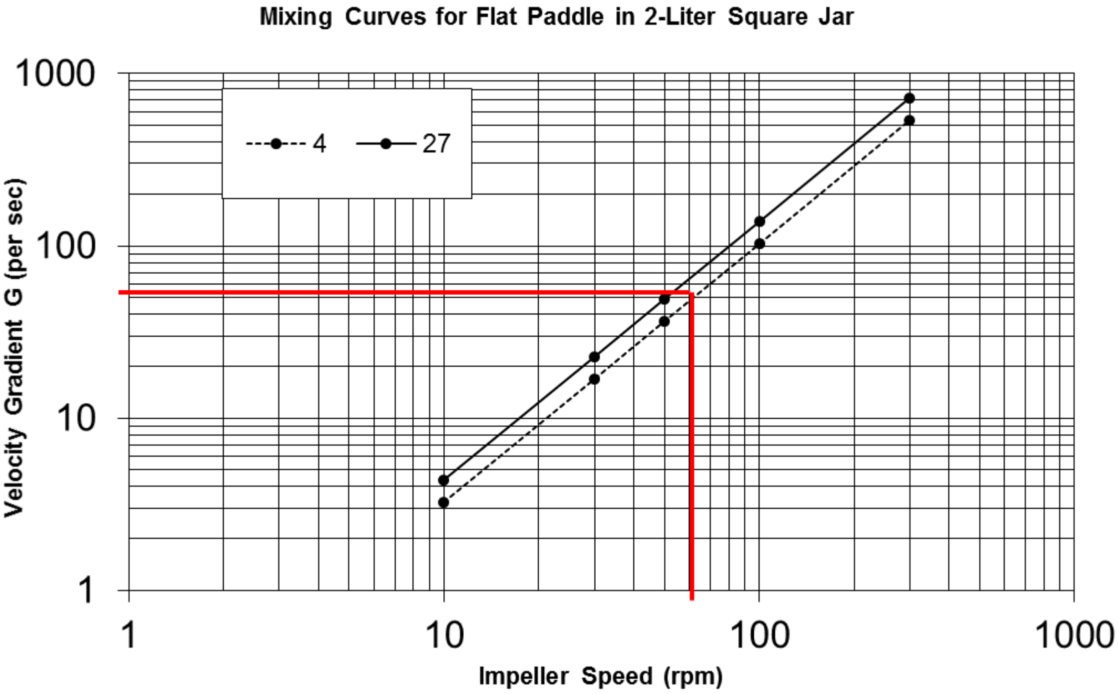


FIGURE 25. Velocity gradient versus mixer speed in 2-liter square jar.

PAC slurry and jar dosing

A stock PAC slurry was created using the plant's PAC and deionized (DI) water at a concentration of 10 mg/mL such that each 1 mL of slurry equaled 5 mg/L PAC concentration in the 2-liter (L) jars. A total of six 2-liter Phipps & Bird jars were run using a Phipps & Bird PB-900 Programmable Jar Tester with the following concentrations of PAC: 0, 10, 20, 30, and 40 mg/L. The jar with zero PAC added was the control jar. A duplicate 20 mg/L PAC jar was run for quality assurance. Table 8 on the following page summarizes the PAC dosing regimen for the jar test.

TABLE 9. Jar Test PAC Dosing Regimen

Jar No.	PAC Dose	PAC Slurry Dose
	mg/L	mL
1	0	0
2	10	2
3	20	4
4	20	4
5	30	6
6	40	8

Each jar was dosed, as described above, at 10-minute staggered intervals to allow time for sample processing from each jar (i.e. vacuum filtration, glassware rinsing, and pH determination) at the specified time intervals.

Jar Sampling–

Approximately 90 mL of sample was collected from each jar at each time interval, vacuum filtered with 0.6-micron glass fiber filters (Whatman, grade GF/F), and transferred to 125 mL PETG containers. Samples were then analyzed using the Ohio EPA ADDA-ELISA method[12] for determining extracellular microcystins. The initial composite sample was analyzed for both total and extracellular microcystins (23 µg/L total microcystins, 11 µg/L extracellular microcystins – see discussion above). pH was analyzed using a Hach SL1000 handheld instrument on an additional 30 mL of sample that was collected from each jar at each time step through four hours.

---

[12] Ohio EPA Total (Extracellular and Intracellular) Microcystins – ADDA by ELISA Analytical Methodology. Ohio EPA DES 701.0. Version 2.2. November 2015. Retrieved April 28, 2016, from http://www.epa.ohio.gov/Portals/28/documents/rules/draft/Ohio%20EPA%20DES%20701.0%20Version%202.2_Dec2015.pdf

PAC jar test troubleshooting

- When conducting jar tests with PAC for extended periods (i.e. greater than four hours, as observed during this study), PAC can accumulate in the jar sampling ports and cause a slug of high-concentration PAC to come through the sampling line during sampling at later time steps. This is likely because the mixing paddles are at the same level as the sampling port. To avoid taking unrepresentative samples with high concentrations of PAC, the sampling line was flushed of the high-concentration PAC and poured back into the jar prior to taking a sample for cyanotoxin and pH analysis.

- When using a concentrated raw water sample for jar testing, ensure the sample is well-mixed prior to adding to the jars. With high concentrations of cyanobacteria cells and other algae or organic matter, it is important to add equal concentrations in each jar. These suspended materials may begin to settle out, resulting in varied concentrations added to each jar if the stock raw water sample is not well-mixed.

- Staggering the PAC dosing by five to ten minutes is recommended to provide time in between taking jar samples for any sample processing, such as filtering the sample to remove PAC, taking measurements on the sample (pH, temperature, turbidity, TOC/DOC, etc.), and cleaning sampling or filtration glassware and other sampling equipment.

Results and Discussion–

For this section, refer to Figures 26 and 27, which are different graphical representations of the same data. PAC performance varied based on dose and, in some cases, time. At the lowest dose evaluated, 10 mg/L PAC, extracellular microcystins were not appreciably reduced throughout the course of the experiment. At the 20 mg/L dose, reduction in extracellular microcystins was observed, with additional reduction at later time steps in one jar, but not the other. At the 30 and 40 mg/L PAC doses, microcystins removal occurred more rapidly, with little difference between one hour and 24-hour time steps. The 40 mg/L PAC dose was most effective at microcystins removal, achieving an 86 – 95% reduction.

The concentration of extracellular microcystins increased over time in the control jar, and increased between the 9.5 and 24-hour time points in 4 of the 5 jars dosed with PAC. This may be due to degradation of *Planktothrix* filaments in the jars over time, causing additional cell lysis and microcystins release. Visual microscopic observation of *Planktothrix* filaments from the control sample show cell rupture and degradation (see images Figure 28). The concentration of microcystins in the initial composite sample was 23 µg/L total (intra- and extracellular) and 11 µg/L extracellular. Some of the microcystins that were still in an intracellular form at the beginning of the experiment could have leached from these degraded filaments and entered an extracellular form by the end of the experiment, as evidenced by an increase from 5.6 to 9.9 µg/L extracellular microcystins concentration in the control jar from hour 0 to hour 24.

The initial concentration of extracellular microcystins for each jar varied (4.7 to 8.5 µg/L), and there are multiple hypotheses for this variability. First, *Planktothrix* filaments are quite variable in length, and even a well-mixed sample is difficult to proportion evenly. This variability may be reduced if the concentrated sample was added as a spike to each jar instead of mixed into the raw water sample prior to splitting into the individual jars. Alternatively, the filaments may be filtered out prior to adding extracellular microcystins to the water sample; however, this will also remove organic matter that may affect PAC removal capacity. pH was also analyzed in the jar test samples to determine if the addition of PAC to the raw water impacts pH. Results through four hours indicate that pH is likely not affected by the PAC.

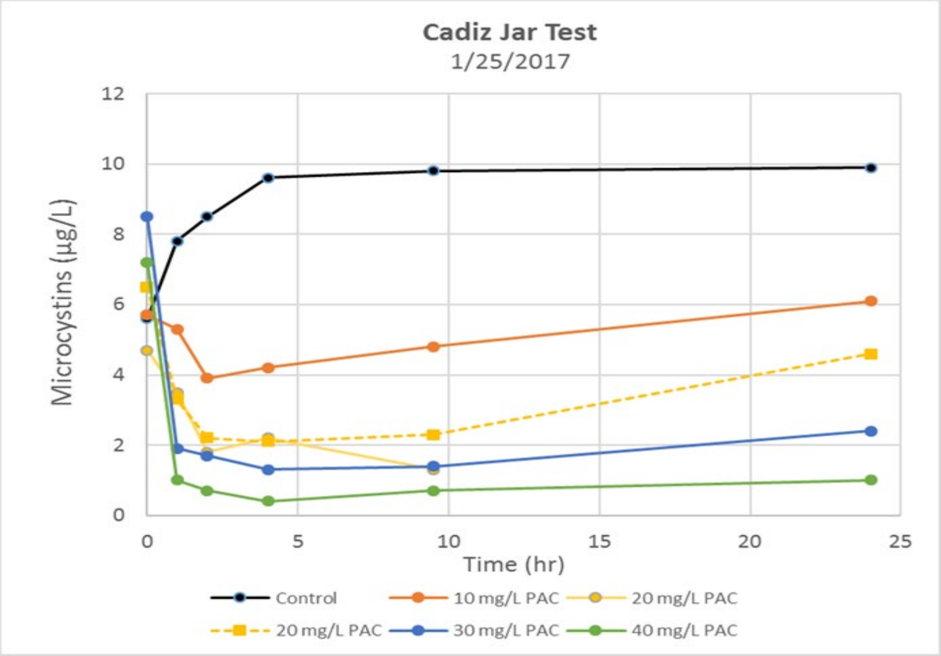


FIGURE 26. Graph showing jar test results for microcystin concentration versus PAC dose and time.

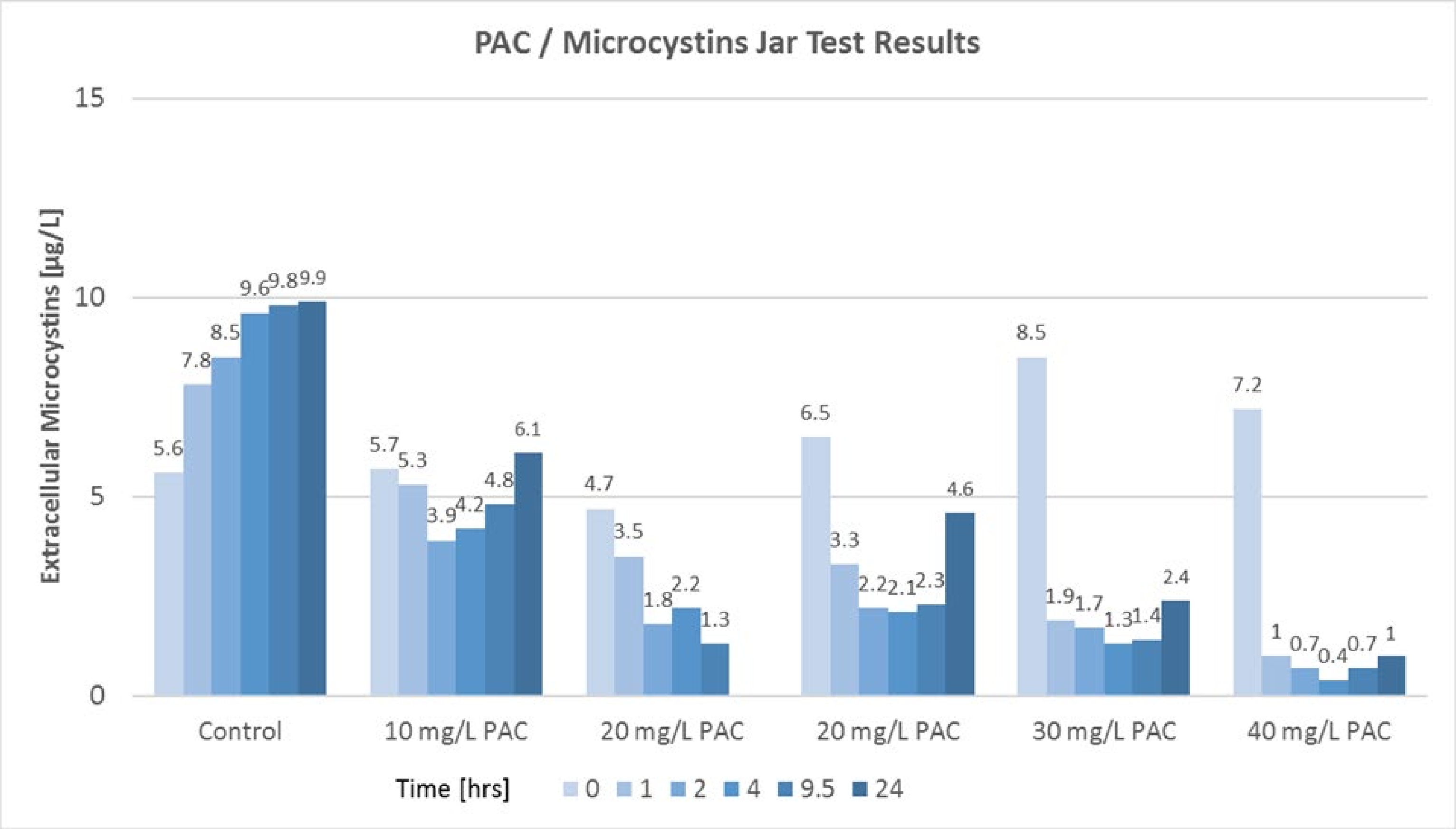
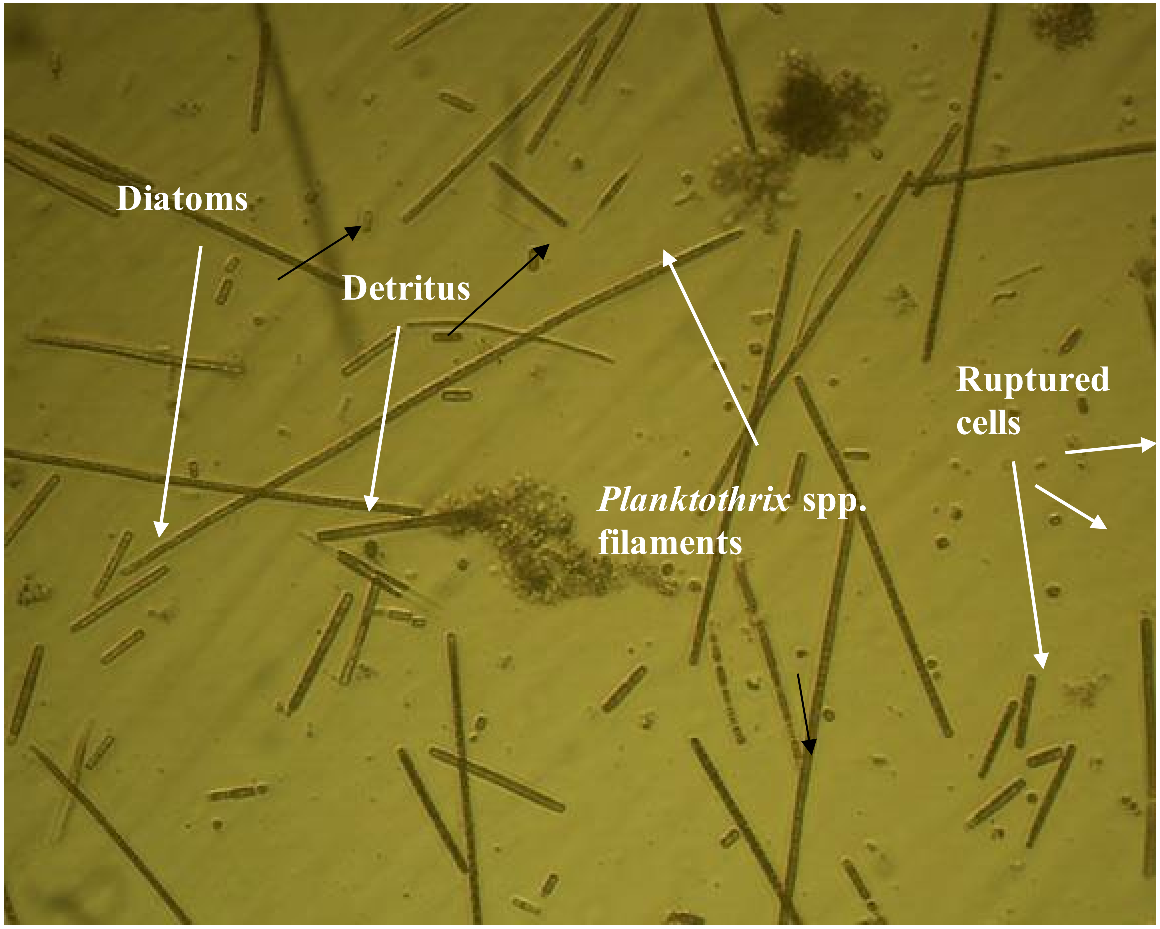
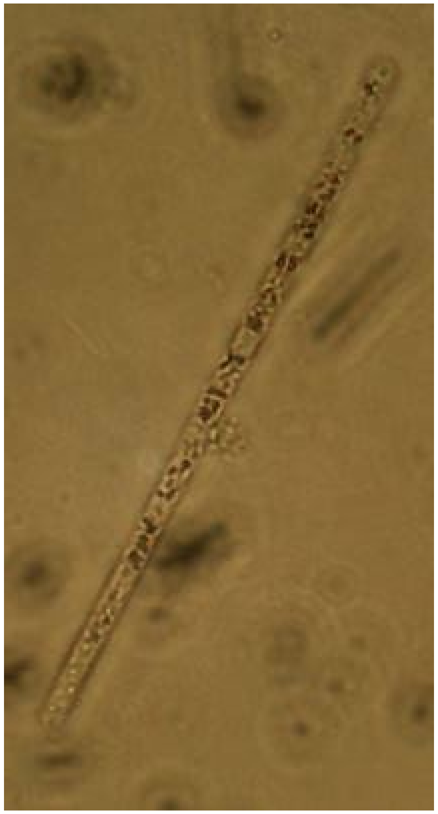


FIGURE 27. Bar chart showing jar test results for microcystins concentration versus PAC dose and time.


Diatoms
Detritus
Planktothrix spp. filaments
Ruptured cells



Pictures of phytoplankton from control sample preserved with Lugol's iodine solution. Left image shows phytoplankton community is dominated by Planktothrix spp. filaments (280x magnification). Right panel shows a partially degraded filament of Planktothrix with ruptured cells (560x magnification).

FIGURE 28. Pictures of phytoplankton from control sample.

MAJOR UNIT PROCESS EVALUATION

The plant's major unit processes are assessed with respect to their capability to meet the optimized goals for:

- Settled water turbidity
- Filtered water turbidity
- Disinfection (inactivation ratio goal)
- Cyanotoxin adsorption with powdered activated carbon
- Cyanotoxin oxidation with chlorination

There is an emphasis on turbidity reduction to remove cyanobacterial cells through the multiple-barriers of the treatment process; however, recognizing that toxins will likely be in the raw and settled water, toxin removal and destruction are also considered. The capability of each individual unit process is assessed to estimate its ability to provide water that consistently meets the optimized performance goals.

Since the treatment processes of the plant must provide multiple effective barriers at all times, a peak instantaneous operating flow is also determined. The peak instantaneous operating flow represents conditions when the treatment processes are the most vulnerable to the passage of parasitic cysts, microorganisms, and toxins. If the treatment processes are adequate at the peak instantaneous flow, then the major unit processes should be capable of providing the necessary effective barriers at lower flow rates. The flow through the plant is controlled by the raw water pumps, and each of the pumps is rated at about 570 gpm. Through discussions with operators regarding operational policies at the plant as well as the review of plant operating records by the CPE team, the equivalent flow rate of 0.8 MGD was selected as the peak instantaneous flow rate through the plant under normal operating conditions. This rate was used to assess the capabilities of all the major unit processes except for disinfection, which was established by the high service pumps since they control the detention time in the clearwell. The peak instantaneous flow of the high service pumps to be used in the disinfection evaluation was determined to be 1.1 MGD, based on a review of recent pumping records at the plant.

Unit process capability is assessed using performance potential graphs, where the projected treatment capability of each major unit process is compared against the peak instantaneous operating flow rate and the plant design flow for comparison. An individual performance potential graph is developed for each of the treatment objectives evaluated in this report: 1) microbial removal/inactivation and 2) cyanotoxin removal and destruction.

Each unit process can fall into one of three categories:

Type 1: Where projected peak capability for the unit process exceeds the peak instantaneous flow (>100 percent of peak flow), the plant should be expected to achieve the performance goals.

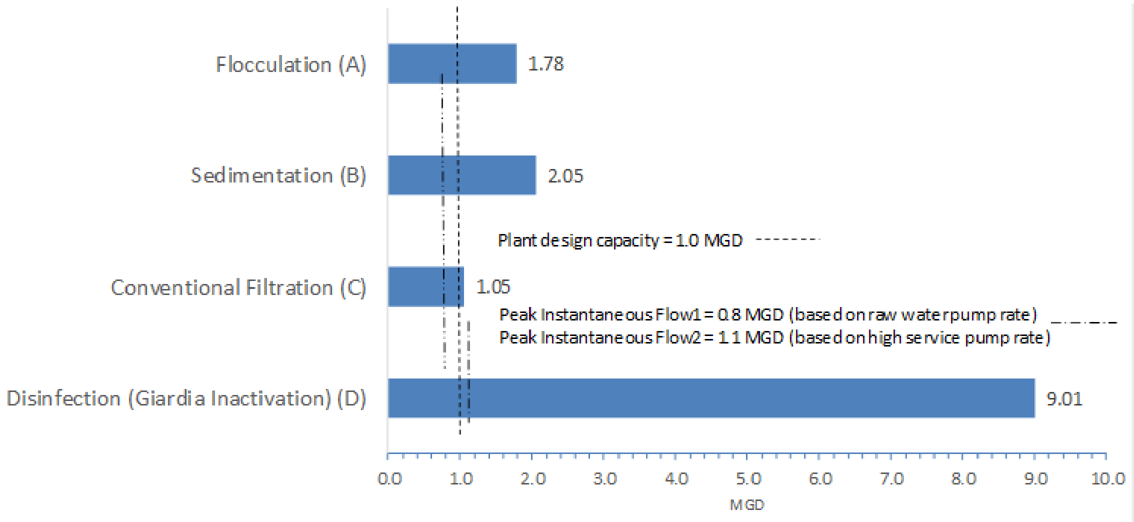
Type 2: If the projected peak capability for the unit process falls short of, but is close to, the peak instantaneous flow (80 to 100 percent of peak flow), then operational adjustments may still allow the plant to achieve the performance goals.

Type 3: If projected peak capability for a specific unit process falls far short of the peak instantaneous flow (<80 percent of peak flow), then it may not be possible to achieve the performance goals with the existing unit process.

The results of the assessment, relative to these categories, are discussed below.

<u>Particle Removal and Microbial Disinfection</u>

The Major Unit Process Evaluation graph for microbiological treatment through turbidity removal and disinfection, developed for the XYZ WTP, is shown in Figure 29. The unit processes evaluated during the CPE are shown along the vertical axis. The horizontal bars on the graph represent the projected peak capability of each unit process that would support achievement of optimized process performance. These capabilities were projected based on several factors, including: the combination of treatment processes at the plant, the CPE team's experience with other similar processes, raw water quality, industry guidelines, the XYZ WTP design, and regulatory standards and guidelines.



<u>Assumptions</u>:

(A) Flocculation: Assume both clarifier processes could be run in parallel or could be run in series as independent processes. Selected 20-minute HDT to allow adequate floc buildup and softening.

(B) Sedimentation: Selected 10 gpm/ft^2 SOR for softening clarification process, and the depth is greater than 14 ft in both basins.

(C) Conventional Filtration: Assume one filter is out of service. Selected 2 gpm/ft^2 loading rate since filter inspection indicated that filter media was mixed, low backwash rate, inability to ramp backwash to stratify in dual-media filter, and limited bed expansion during backwash.

(D) Disinfection (*Giardia* inactivation): Volume is based on a 12.85 ft lowest operating level. Baffling factor is assigned at 0.6 by State EPA. Assumed pH of 9 and a maximum residual of 4 mg/L.

FIGURE 29. Major Unit Process Evaluation - XYZ Water Treatment Plant turbidity removal (microbes, cells) and disinfection.

The major unit processes evaluated include: flocculation, sedimentation, filtration, and disinfection. The flocculation and sedimentation processes are both in series, and the disinfection process takes place in the clearwells. The shortest bar represents the unit process that may limit plant capability the most relative to achieving optimized plant performance; and, in this case, it is associated with filtration. The flocculation, sedimentation, and disinfection processes are rated as Type 1, indicating that they should be capable of meeting the particle removal and microbial treatment objectives at the assigned peak instantaneous flow rate of 0.8 and 1.1 MGD through the facility. The filtration process is also rated Type 1, but it is the process that limits plant capacity and would require careful operation to meet the optimization goals for particle removal at the peak flow.

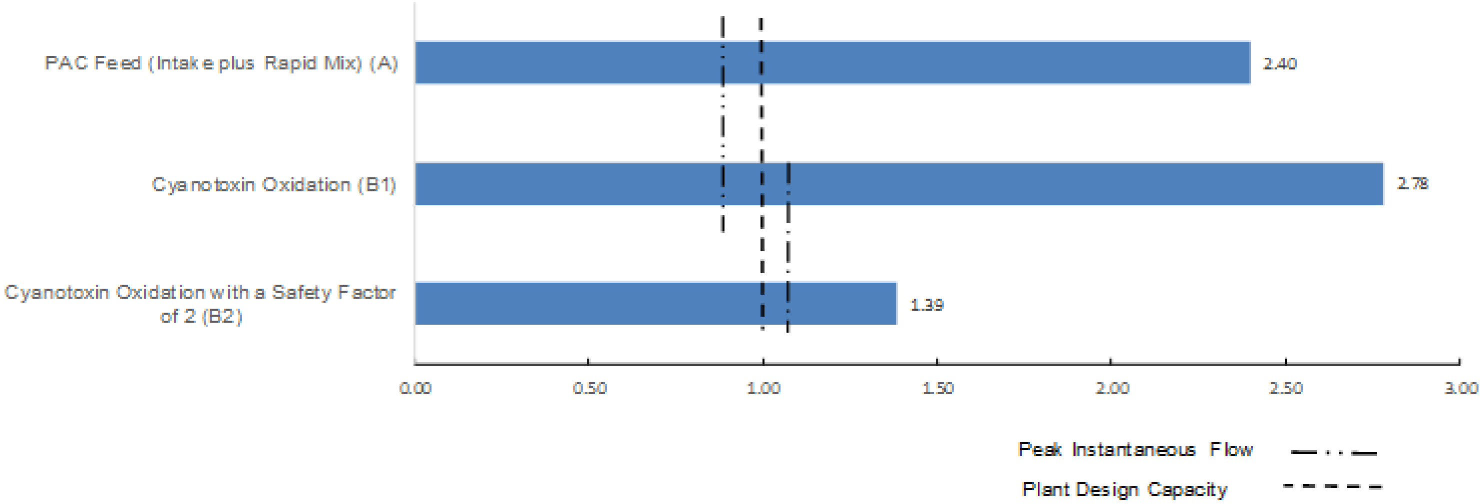
Cyanotoxin Removal and Destruction Treatment

If a HAB occurs in the XYZ WTP source and cyanotoxins appear in the raw water, the particle removal processes in the water treatment plant would be able to remove most of the intracellular cyanotoxins, provided the cells are removed before release of the cyanotoxins. The evaluation of the major unit processes in the microbiological (turbidity) control section of this report gives an estimate of the plant capacity to remove cyanobacteria cells through clarification and filtration to control the intracellular cyanotoxins (Figure 29). Any extracellular cyanotoxins present in the raw water or released in the plant would have to be removed primarily through powdered activated carbon (PAC) adsorption or destroyed through chlorine oxidation in the plant clearwell.

The Major Unit Process Evaluation graph for extracellular cyanotoxin treatment through powdered activated carbon (PAC) adsorption and chlorine oxidation, developed for the XYZ WTP, is shown in Figure 30. A challenge target of 50 µg/L microcystins at the raw water intake was used in the evaluation, with the assumption that all of the toxins are extracellular. This assumption was based on anticipated baseline occurrence data for inland lakes per State EPA's *Guidance for Developing a Harmful Algal Bloom General Plan*[13]. The unit processes evaluated during the CPE are shown along the vertical axis.

---

[13] Guidance for Public Water Systems; Developing a Harmful Algal Bloom (HAB) General Plan, State EPA, Division of Drinking and Ground Waters, Version 1.0, September 2016. http://epa.ohio.gov/Portals/28/documents/habs/HABGeneralPlanGuidance.pdf.



<u>Assumptions</u>:

(A) PAC feed is based on 40 mg/L. Dose is split between intake and rapid mix locations. Intake feed rate assumption (174 lb/day) will require management of clogging issues. In-plant feed rate assumption (224 lb/day) is projected based on feeder potential.

(B1) Assumes plant effluent residual = 4.0 mg/L, pH = 9, and temp. = 10°C. AWWA CyanoTOX calculations for MC-LR are used to support this assessment.

(B2) Same assumptions with Safety Factor of 2 applied. Basis for this is extrapolating the required CT to a higher pH (9.5) and lower temperature (5°C) than the CyanoTOX spreadsheet can support.

FIGURE 30. Major Unit Process Evaluation - XYZ Water Treatment Plant microcystins adsorption and destruction.

The horizontal bars on the graph represent the projected peak flow capability for each unit process that would support achievement of optimized process performance. These capabilities were projected based on several factors, including:

- PAC Feed Capacity: PAC is fed by two dry chemical feeders – one at the intake and one at the rapid mix. The State EPA's *Guidance for Developing a Harmful Algal Bloom General Plan* recommends that plants be capable of feeding a minimum of 40 mg/L of PAC and have two feed locations. The XYZ WTP PAC feeds can be split between the intake and the rapid mix locations. However, during the CPE site visit, the intake feeder was measured to be operating at about 17.6 mg/L and was experiencing clogging issues that necessitated daily manual unclogging by operators. To reach a total dose of 40 mg/L, the intake feeder may not be able to function at a higher rate, but the remaining dose (22.4 mg/L) could be added at the plant where operators would be onsite to manually address clogging issues on a temporary basis during the HAB event. The two PAC feeders are identical, and they were estimated to each have a feed capacity of 34 mg/L notwithstanding the clogging that might occur. The PAC would have over two hours' detention time even from the in-plant feeder, which should be adequate for microcystin adsorption. Operating at such a high dose (40 mg/L) would require careful oversight and management to prevent clogging of the feed system.

- Microcystins (Cyanotoxin) Oxidation: The oxidation process takes place through the application of chlorine in the clearwells after the particle removal treatment processes. An estimate was based on the *AWWA Hazen-Adams CyanoTOX Tool for Oxidation Kinetics (Version 1.0)*[14] for microcystin-LR. However, since the calculator doesn't apply in the pH and temperature range that XYZ's water treatment plant sometimes experiences during a HAB, a safety factor of *"2"* was also applied to this estimate to account for these parameters. Additionally, the team assumed that the plant could run with a plant effluent residual of 4.0 mg/L, which is higher than normal but operationally possible.

---

[14] AWWA Cyanotoxins resource site: http://www.awwa.org/resources-tools/water-knowledge/cyanotoxins.aspx

Similar to the turbidity assessment, in evaluating the microcystins control processes in the XYZ WTP, each process is assigned a rated capacity, based on a comparison of the rated capacity to the peak instantaneous flows at the plant (using the raw water flow for the PAC assessment and the high service flow for the oxidation assessment). The lowest projected process peak capability (flow rate) represents the unit process that may most limit plant capability relative to achieving optimized plant performance. Both the PAC adsorption process and the toxin oxidation process were rated as Type 1. However, many operational assumptions were made for the PAC assessment, and the oxidation estimates were made by extrapolation of the *CyanoTOX* calculator results for MC-LR only and may not be reliable. A more reliable assessment of the adsorption and oxidation processes could be made through in-house studies to evaluate the removal and destruction efficiency of the plant processes on its unique water quality.

The overall major unit process summary for microbial and cyanotoxin removal and destruction is summarized in Table 9 on the following page. The particle removal, microbial disinfection, cyanotoxin adsorption, and chlorine cyanotoxin oxidation process ratings are all classified as Type 1, indicating that the plant has the capability to achieve the microbial and cyanotoxin optimization goals when excellent process control skills are applied. The filtration process in particular would have to be carefully operated to reliably and consistently meet the filtration goals. Due to uncertainties in the assumptions made during the evaluation, the cyanotoxin removal and destruction processes are rated as a more conservative Type 2, indicating that the plant has the capability of achieving the microcystins finished water target, assuming careful attention is given to plant O&M to prepare for and treat through a significant HAB event.

TABLE 10. Major Unit Process Summary

Major Unit Process	Rating
Flocculation (1)	Type 1
Sedimentation (1)	Type 1
Filtration (1)	Type 1 (with careful operation)
Disinfection/Oxidation (1)	Type 1
PAC Adsorption Process (2)	Type 2
Chlorine Oxidation (2)	Type 2

(3) Microbial treatment
(4) Extracellular cyanotoxin removal and destruction

PERFORMANCE-LIMITING FACTORS

The areas of design, operation, maintenance, and administration were evaluated to identify factors that limit performance. These evaluations were based on information obtained from the plant tour, interviews, performance and design assessments, studies, and the judgment of the CPE team. Each of the factors were assessed for the possible classification as A, B, or C according to the following guidelines:

A	Major effect on a long term repetitive basis
B	Moderate effect on a routine basis, or major effect on a periodic basis
C	Minor effect

The performance-limiting factors (PLFs) identified were prioritized as to their relative impact on performance. They are summarized below. While developing the list of factors limiting performance, over 50 potential factors were reviewed, and their impact on the performance of the XYZ WTP was assessed. There were three *"A"* factors, three *"B"* factors, and one *"C"* factor identified. Note that the asterisk on one "B" factor (B*) refers to a performance-limiting factor identified for the specific situation when the plant is facing a harmful algal bloom in its source water and must remove cyanobacteria and cyanotoxins during treatment. All other factors that are listed apply to performance limitations for reduction of turbidity, which can also impact the ability of the water treatment plant to perform during a HAB event. Specific impacts on the ability of the water treatment plant to perform during a HAB event are also indicated in the description of each PLF.

Policies – Administration (A)

- The numerical optimization goals for individual clarifier effluent, individual filter effluent, and combined filter effluent turbidity have not been established and relayed to staff. The commitment to produce water quality that is not only required by regulation, but is the best quality that the plant can produce, must typically be embraced by the top administrators to create the culture needed to optimize treatment processes.

- Due to the existence of a consistent quality source water, plant staff are not typically challenged to make significant process control changes which can lead to a lack of preparedness for a HAB event. Striving to meet the water quality goals associated with optimized treatment and empowering staff to achieve those goals can keep staff skills sharp and enhance preparedness for potential HAB events.

- Plant staff confidence and capability to respond to unusual water quality conditions exists primarily with the Operator of Record (e.g., the superintendent who is soon retiring has the most institutional and operational knowledge at the plant; however, there is no detailed procedure in place to transfer this capability to other members of the plant staff).

- The utility is limited to one water source during a HAB event. Availability of the alternate water source, Sparrow Reservoir, is uncertain because it has been inactive since April 2013, and a policy has not been established to pursue developing this source.

Application of Concepts and Testing to Process Control (Operations) (A)

- Plant staff do not perform jar testing to determine optimum softening and coagulant dosages for different water quality conditions.

- Plant staff do not perform studies to determine most effective PAC type, dose, and mixing energy to treat for HABs (e.g., wood-based versus coal).

- Studies are not conducted to evaluate treatment options to optimize plant performance and consider simultaneous treatment objectives.

- Plant staff do not calculate chemical dosages on a routine basis.

- Plant staff do not change chemical feed systems to respond to changes in raw water quality (e.g., constant PAC feed at lake and plant).

- Filters are backwashed based on time in service or headloss rather than on optimized performance goals for turbidity and particle removal.

- The depth of sludge in the clearwell and storage tanks is not monitored and removed on a regular basis.

- The second-stage rapid mix is out of service, without plans for replacement. This may limit the ability to optimize softening and coagulation.

- The recarbonation basin is out of service, without plans for replacement. This may limit the ability to stabilize the water following softening and reduce calcium carbonate deposition in filters and clearwell. Lower pH water would also be more effective for disinfection and would be more effective for oxidizing cyanotoxins.

- Data logging may not accurately capture the turbidity when water is going to the clearwell at plant startup and immediately after returning to service after a backwash.

Operational Guidelines/Procedures (Operations) (A)

- Inconsistent approaches are used by staff for logging turbidity data following backwash (i.e., one hour following start of the backwash versus when turbidity starts to trend down).

- There is not a consistent procedure used by operators to perform chemical feed pump calibrations and determine chemical dosages.

- There is no operational procedure describing the process for completing monthly reporting.

Staffing/Number (Administration) (B)

- Plant staff are responsible for operation and maintenance of both the water treatment and wastewater treatment plants as well as distribution system maintenance, revenue collection, and meter reading. This limits their availability for process control improvements and adjustments.

- During emergency conditions, such as distribution system line breaks, personnel are asked to work long hours which stretch staff resources.

- The current pay scale is not comparable to that offered by the surrounding water systems which are competing for personnel with the same level of experience.

Process Controllability (Design) (B)

- The filter design limits the backwash rate and does not allow the backwash flow rate to be ramped up and down during a backwash.

- There are no rate-of-flow controllers to limit the filtration rate of the filters.

Alarm Systems (Design) (B*)

- There is no alarm system to notify operators if the PAC feed at the lake fails. The PAC feed may be critical to remove cyanotoxins.

Sample Tap (Design) (C)

- Each clear well receives a separate chlorine dose, resulting in two separate disinfection zones. The current monitoring location does not monitor each clear well separately. Each disinfection zone should be monitored and controlled to optimize its performance.

EVALUATION FOLLOW-UP

State EPA has not established an approach for providing follow-up training to CPEs at the current time. Additional HAB-focused developmental CPEs are planned at other the State's water utilities over the next several months. Following these events, State EPA will be considering follow-up strategies to support common CPE findings and performance-limiting factors. Plant staff are encouraged to contact the state EPA staff regarding any questions or comments they may have regarding specific findings from this CPE.

The XYZ WTP staff and management have specific challenges outlined in the Performance Limiting Factors section above. Other issues pertaining to compliance were found that are outside the scope of the CPE, which will be addressed separately.

This CPE has identified further areas that can be pursued to enhance particle removal performance and be better prepared for future HAB events. An excellent place to start the optimization process is collecting and trending optimization data such as the approach demonstrated in the Historical Water Quality Performance Assessment section of this report. The studies conducted during this CPE also demonstrate a structured approach for conducting problem-solving activities by plant staff. The following section includes several study ideas for plant staff to consider and prioritize, based on benefits to plant operation and performance, level of complexity, and available staff time.

Study Ideas

Study No. 1 – Investigating Impact of Filter Run Time on Filter Return to Service Turbidity

- Description:
  - Conduct study to assess impact of reducing filter run time on filter backwash turbidity recovery.
  - Current run time on filters with newest media is about 80 hours.
- Benefits:
  - Reduced solids loading to the filter media.

  - Potential for lower backwash recovery turbidity spikes.
  - Understand if any design limitations exist.

Challenges	Solutions
None identified	Very doable by plant staff

Study No. 2 – Investigating Filter Backwash Procedure to Improve Filter Return-to-Service Turbidity

- Description:
  - Conduct study during routine backwashing to optimize backwash duration.
  - Assess impact of longer filter backwash duration on filter recovery.
- Benefits:
  - Potential for lower backwash recovery turbidity spikes
  - Understand if any design limitations exist.

Challenges	Solutions
None identified	Very doable by plant staff

Study No. 3 – Determine Optimal PAC Dose and/or Type for a HAB Event

- Description:
  - Conduct a simplified version of a PAC study which would evaluate treatment effectiveness of PAC feed at the intake location accounting for the calculated approximate 9.5-hour detention time in the raw water transmission main. All four jars would have the same detention time of 9.5 hours, but the PAC dosages could vary between jars. For example, doses of 10, 20, 30, and 40 mg/L PAC could be evaluated. Samples could be pulled and filtered at the 9.5-hour time step and analyzed for microcystins.

  - This exercise could also be repeated with different types of PAC. The type of PAC currently being used at the plant is a coal-based PAC, but studies have shown different treatment performance based on the type of PAC being used.

  - If cyanotoxins are only present at lower concentrations (<5 µg/L), the cyanobacteria in the raw water could be concentrated using a phytoplankton net or similar device, and then the concentrated sample could be added to the raw water sample used in the jar test.

  - In addition to microcystins testing, testing for pH, turbidity, TOC/DOC, phycocyanin, etc. can be included to better understand the PAC performance for other water quality parameters.

- Benefits:
  - This approach could help determine optimal PAC dosage and/or PAC type for a HAB event with higher microcystins concentration prior to a more severe event occurring.

Challenges	Solutions
Learning jar testing techniques	Obtain instructional videos (AWWA, others). Obtain support from local water treatment plants. Review jar testing spreadsheet provided by HAB CPE team. Review PAC Jar Testing Protocol developed by AWWA (provided by HAB CPE team).
Obtaining samples of different types of PAC to evaluate (coal, wood-based, coconut-based)	Reach out to PAC vendors for samples.
Lab support for microcystins analysis	Obtain training on ELISA procedure and develop in-house capability. State EPA or contract lab – Check State EPA's website for list of contract labs.

More Advanced Plant Studies

- Investigating first-stage softening treatment followed by second-stage coagulation using jar testing.

- Investigating impacts of recarbonation on settled water turbidity and stability (pH).

- Determining optimum in-plant PAC, softening, and coagulant dosages.