WEST PALM BEACH

Expert Panel Review of the City of West Palm Beach's Management of Cyanotoxins SUMMARY REPORT

March 2022

Executive Summary

The City of West Palm Beach (City) Mayor Keith A. James convened the Cyanotoxin Expert Panel to identify proactive and lasting solutions following a May 2021 detection and response to cylindrospermopsin (a cyanotoxin produced by blue-green algae). The City took immediate action to protect public health by isolating and destroying the cyanotoxin when it was discovered in the finished water system at levels exceeding the U.S. Environmental Protection Agency's (EPA) National Health Advisory Levels for vulnerable populations.

The City also brought together the Expert Panel to study the City's available data and apply the best available science to evaluate opportunities to control water quality risks associated with cyanotoxin events. Cyanotoxins are a national concern—not just an issue for West Palm Beach—and a key objective for convening the Panel was to learn from water quality and treatment experts leading the industry response to address cyanotoxins across the U.S.

To complete their work, the Expert Panel performed an incident review with City staff interviews, observed source conditions in the field, reviewed records, and inspected facilities. The Panel then evaluated potential improvements in the context of historical observations to develop recommendations for:

- Source water quality monitoring and management focusing on primary, secondary, and potential alternative source water options.
- Water treatment process optimization to reduce cylindrospermopsin risk.
- Improving communications within the City, with regulators, and with customers.

Through the evaluation, the Expert Panel identified opportunities for proactive cyanobacteria and cylindrospermopsin monitoring, water supply management, treatment optimization, and improved communications to reduce risk if a cylindrospermopsin event were to occur in the coming algae seasons. The City has already implemented many of these recommendations.

The Expert Panel provided further near-term recommendations to the City for additional measures that will enhance the City's ability to detect, react, and control elevated levels of cylindrospermopsin, increasing protection of the City's customers. The Expert Panel also reviewed long-term options to further reduce potential water quality risks associated with cyanotoxins and contaminants of emerging concern (CEC), and recommended the City undertake comprehensive, holistic master planning efforts to ensure sustainable solutions to achieving the City's long-term water quality goals.

An implementation schedule of recommendations is provided in Figure ES-1, with more detail and justification for the recommendations found within this summary report and in Attachments A–F.

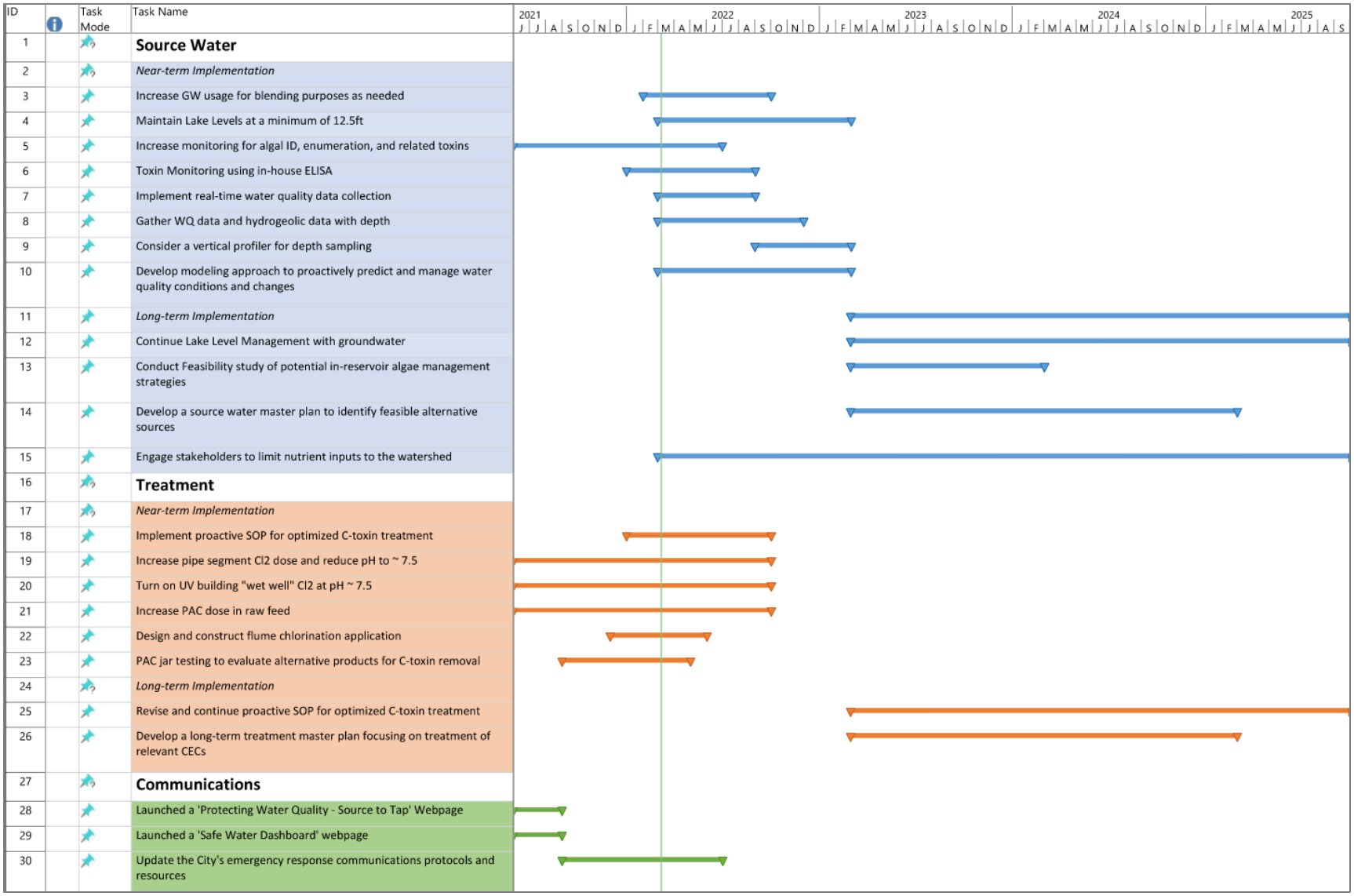

Figure ES-1: Implementation Schedule for Near- and Long-Term Expert Panel Recommendations

1. Introduction

Following the May 2021 cyanotoxin event, Mayor James convened the Expert Panel to use available City data and the best available science to recommend proactive and lasting solutions to address water quality risks from cyanotoxins.

1.1. Purpose, Goals, and Guiding Principles

The Expert Panel was brought together to make recommendations to the City to help address the impacts of blue-green algal toxins in the raw water supply on the City's water treatment plant (WTP). More specifically, the goals of the Expert Panel evaluation included:

- Manage source waters to make sure the best water quality enters the WTP
- Optimize performance of multi-barrier treatment steps at the WTP
- Maintain water quality in the distribution system

In achieving these goals, the Expert Panel employed a series of guiding principles, including:

- Strive to produce the highest quality water
- Maintain a holistic source-to-tap perspective
- Leverage multiple treatment barriers

1.2. Expert Panel Members

The Expert Panel was comprised of drinking water quality and treatment experts well versed in cyanotoxin challenges, representing national environmental consulting firms.

- **Dr. Robert Cushing**, PE, BCEE, is a nationally recognized expert with more than 30 years of water quality and water treatment experience. As a senior vice president with Carollo Engineers, Dr. Cushing has worked with large water utilities on numerous successful treatment facility planning and design projects, as well as studies and programs to improve distribution system water.
- **Dr. William Becker**, PE, BCEE, has more than 30 years of drinking water treatment experience, including pilot studies and treatment optimization. He directs Hazen and Sawyer's drinking water practice, working with some of the largest utilities in the country to solve water quality and treatment challenges. Dr. Becker teaches courses on water treatment at the University of Colorado, Boulder, and is affiliated with the Columbia Water Center at Columbia University. He has authored hundreds of technical presentations and publications.
- **Dr. Chandra Mysore**, PE, BCEE, has more than 30 years of drinking water quality and treatment experience. He is a Vice President and Regional Drinking Water lead with Jacobs Engineering, and has partnered with utilities to design water treatment systems and evaluate feasibility of emerging treatment technologies. Dr. Mysore has provided technical direction and senior review of projects around the globe that address

cyanotoxins and other source water quality concerns. He has authored more than a hundred technical publications and is an active committee member with American Water Works Association (AWWA) and Water Research Foundation. He is also the Chair of the AWWA Membrane Process and Research Committee.

- **Dr. Erik Rosenfeldt,** PE, is Hazen and Sawyer's Director of Drinking Water Process Technologies and Director of Innovations–Drinking Water. He has more than 20 years of drinking water treatment experience focusing on optimizing conventional treatment and implementing advanced treatment for addressing CECs. Dr. Rosenfeldt brings experience from algal metabolite focused projects from around the country and has served as a principal investigator on research projects focused on reducing cyanotoxins and other CECs in water resources.

1.3. Scope of Services

To achieve the objective of the evaluation, the Panel was tasked with the following assignments:

- Review the recent event associated with cylindrospermopsin detection, including monitoring and detection methods deployed, source water control, treatment, and overall management response.
- Analyze source water and treatment infrastructure and operations with respect to cylindrospermopsin formation, control, and risk reduction, including conditions surrounding source water quantity and quality of the City's groundwater and surface water supplies, along with permit conditions for source water system and WTP operations.
- Provide near- and long-term recommendations to meaningfully reduce risk of a repeat cylindrospermopsin event, focusing on physical/institutions changes required (if any) to address future cyanobacteria events.

From July to August 2021, the Panel completed an incident review and additional studies to analyze source water, treatment infrastructure, and operations and recommend near-term actions for the City to help reduce water quality risks. These actions were presented to the City Council and other stakeholders on August 26 during a Mayor Commission Meeting.

Then from September 2021 to February 2022, the Panel completed additional analysis and studies to confirm preliminary findings and identify recommendations for future actions. This work was supported by technical subgroups in collaboration with City staff. Throughout, the Expert Panel met with City staff and Town of Palm Beach representatives during monthly technical work sessions to share updates and discuss findings.

Attachment A contains the contracted scope of services. Attachment B contains the presentation slides from the Expert Panel Work Session held on July 9, 2021.

The results of the evaluation are summarized in this document, and include:

- Section 1: Introduction
- Section 2: Incident Review
- Section 3: Expert Panel Evaluation
- Section 4: Charting Future Actions

Further detail is provided in attachments to this summary report, including slides from technical work sessions and other important documents. The included attachments are:

- Attachment A: Expert Panel contracted scope of work
- Attachment B: Presentation from July 9, 2021, Expert Panel work session #1
- Attachment C: 2021 Cylindrospermopsin Incident Operational Evaluation
- Attachment D: Presentation from October 12, 2021, Expert Panel work session #6
- Attachment E: Presentation from September 14, 2021, Expert Panel work session #5
- Attachment F: Presentation from November 9, 2021, Expert Panel work session #7

2. Incident Review

The City owns and operates a public water system providing potable water to the residents, visitors, and businesses of West Palm Beach and the towns of Palm Beach and South Palm Beach. The water system includes the source water facilities, the WTP, the remote storage and pumping facilities, and the distribution system. The City's drinking water treatment processes have been designed and constructed to meet or exceed the requirements of existing federal, state, and local drinking water regulations.

In May 2021, the City detected cylindrospermopsin in the finished drinking water at concentrations above the EPA health advisory level for certain vulnerable populations. Based on confirmation sample results, and in consultation with the Florida Department of Health (FDOH), a health advisory was issued to water customers. In response to the cyanotoxin, the City took immediate action to isolate the harmful algal bloom in the source water and to remove and destroy cyanotoxins at the WTP. The "Do Not Drink–Do Not Boil" advisory was in effect from May 28 until June 4, 2021, when additional sample results confirmed cylindrospermopsin levels were below the health advisory levels.

The following incident review observations stem from the Panel's interviews with City staff, review of records and data, and inspection of facilities completed in 2021. Attachment C contains the 2021 Operational Evaluation providing a comprehensive data set and analysis of the incident.

2.1 Monitoring

The Expert Panel reviewed the City's program for source water, process water, and finished water monitoring to confirm the program incorporates best practices and appropriate monitoring steps. The City is currently following the FDOH recommended sampling schedule. As a result of the May 2021 event, the City increased water quality monitoring and acquired the in-house capability to screen source waters for the cylindrospermopsin and microcystin using the enzyme-linked immunosorbent assay (ELISA) method. This capability allows for early warning screening with more frequent sampling and a shorter turnaround time for sample results. Testing is also completed through a contract laboratory with both ELISA and liquid chromatography with mass spectrometry (LC/MS) capabilities to analyze for microcystin and cylindrospermopsin, respectively. ELISA testing is subject to interferences and potential for false positive and negative results, so it is typically now used as an early warning screening method in raw, process, or finished water samples. The LC/MS testing is the official result for regulatory purposes.

Source Waters

The Expert Panel reviewed historical source water quality data gathered by the City. Between August 2016 and April 2021, 60 sampling events were completed with varying extracellular and Total cylindrospermopsin levels. The removal rates averaged 43 percent and 49 percent for extracellular and total cylindrospermopsin, respectively, with all finished water leaving the WTP below the EPA's Health Advisory levels.

Additional steps during the incident review included:

- Field observations, within the canals and lakes, for visual signs of blue-green algae within the source waters by staff.
- Physical samples from the lakes and canals analyzed under a microscope by a trained biologist within the PUD laboratory for specific algal species.
- Physical samples from the lakes and canals shipped to an offsite laboratory for speciation and cell counts of the specific algal species.
- Raw water samples from the WTP's North Raw Water Pump Station collected monthly and shipped to an offsite laboratory for analysis using ELISA.

Process Waters

Prior to May 2021, the City did not conduct process sampling for cyanotoxins. During the event, the City initiated process sampling to help evaluate the effectiveness of the various treatment process.

The City now has the in-house capability to screen process waters for cylindrospermopsin and microcystin using the ELISA method. This provides a short turnaround period of less than 24 hours during an emergency to make sure the treatment processes are performing as needed.

Finished Water

Prior to May 2021, the City collected finished water samples representing the point-of-entry to the drinking water system on a monthly basis and shipped them to an offsite laboratory for cyanotoxin analysis. The samples were analyzed using the ELISA method with a typical turnaround of three to five days.

Since the event, finished water samples are sent offsite to a certified laboratory that uses the LC/MS method for cylindrospermopsin and ELISA for microcystin. Turnaround time is typically two to four days.

2.2 Treatment

The Panel reviewed performance of the City's existing treatment processes at the WTP. Overall, the treatment systems at the WTP are designed with sufficient redundancy and capacity to allow variations within the operating levels to ensure compliance with the applicable federal, state, and local regulatory standards. No exceptional events or conditions were noted during the sampling events that resulted in exceedance of the existing regulatory standards.

Additional observations about specific processes included:

- The pre-chlorination system did not appear to impact observed cylindrospermopsin removal based on the low free chlorine levels and high raw water pH as noted in the historical data and during the May 2021 event. Jar testing indicated that at the free chlorine levels needed to effectively reduce the cylindrospermopsin, disinfection byproduct (DBP) formation would likely approach or exceed regulated limits.
- The Powdered Activated Carbon (PAC) system was not in use during the historical sampling events however process sampling and jar testing indicated that the PAC is effective at reducing the cylindrospermopsin.
- The recarbonation/flume systems did not appear to directly impact observed cylindrospermopsin removal. However, the system provides the benefit of reducing the treated water pH improving the effectiveness of the free chlorine in the post-chlorination process. The reduced Total Organic Carbon (TOC) within the flume provides an additional potential treatment segment for free chlorine.
- The post-chlorination system contact time was changed with the construction of the UV system. This impacted the treatment capacity for cylindrospermopsin based primarily on the reduced contact time with free chlorine levels. Increasing the free chlorine residual provides increased cylindrospermopsin removal. The existing capability to dose free chlorine into the UV wet wells provides an additional barrier along with the existing pipe segment.
- The response capability to switch to free chlorine has a significant impact on the contact time that will effectively reduce cylindrospermopsin levels. The use of free chlorine within the final treatment stages and the distribution system has the negative impact of increased levels of regulated DBPs.

Based on these initial observations, the Expert Panel undertook studies to evaluate the robustness of the City's cylindrospermopsin treatment barriers and identify opportunities for treatment process optimization. These included an evaluation of field collected process data to understand removal by existing WTP processes, use of the AWWA CyanoTOX model to evaluate chlorination and pH practices, and bench testing to confirm and optimize performance of PAC and chlorination, and identify a new chlorination practice to enhance oxidation.

2.3 Communications

The Panel also reviewed the communication steps the City took during the May 2021 event. The City followed available and applicable state and federal guidelines in its reporting, response, and public notification of a cyanotoxin produced by blue-green algae in its finished water. However, there are opportunities to improve ongoing customer communications about drinking water quality and treatment and to develop written procedures for appropriate public notification steps during a potential future event.

3. Expert Panel Evaluation

Cyanotoxins are a contaminant of emerging concern nationwide and the regulatory framework and scientific understanding of cyanotoxins are dynamic. Several states are implementing standards or guidelines that apply to cyanotoxins, but not all. There are currently no drinking water regulations or monitoring requirements for cyanotoxins in Florida.

Addressing cyanotoxins effectively with a holistic approach requires a source-to-tap approach to maximize risk reduction. The Panel reviewed options for improving cyanotoxin control and communications through:

- Source Water Monitoring and Management
- Near-term and Long-term Cyanotoxin Treatment

During the course of the Expert Panel's evaluation, the City undertook several of the recommended actions described in this section.

3.1. Source Water Monitoring and Management

The City owns and maintains an intricate network of monitoring stations in various aquatic sources, including canals, lakes, stormwater, and wetlands. The City conducts water quality and hydrologic monitoring for resource protection, water production, and permit compliance. These various water sources provide raw water to the City's WTP on Clear Lake. Clear Lake is the most downstream waterbody with a series of water bodies upstream of it. Clear Lake is fed by Lake Mangonia, wetlands (Apoxee wetland, Grassy Water Preserve-GWP), and M-Canal. Other controlled inputs to this source water network are upstream including the South Florida Water Management District L-8 tieback canal which receives water from L-8 canal with Lake Okeechobee as the primary source and L8 basin and L8 reservoir as supplemental sources

(regional sources) which are also connected to Everglades agricultural area. Figure 1 provides an overview of the City's source water system.

The flow from the L8 canal is conveyed into the City's system via the L-8 tieback canal through the City's Control-2 structure. From there, the flow enters the City's M-canal passing through Control-3, crossing Grassy Waters Preserve, flowing through Control-4 and into Lake Mangonia. Flow from Lake Mangonia travels through a canal into the main body of Clear Lake and then into the East Lobe of Clear Lake where the two raw water intakes for the WTP are located. During abnormal water quality events (e.g., chemical spills, Harmful Algal Blooms [HAB]), these control structures assist the City in isolating and treating these water bodies.

The East Lobe control system has two locations on Australian Avenue where raw water can enter from Clear Lake into the East Lobe of Clear Lake i.e., a) divide structure/Australian Avenue gate with three gates and b) control structure with pump station and a long chute submerged in the water. These control systems were designed primarily for drought protection and to avoid contamination events (e.g., chemical spills, sewage spills, HABs). The submerged chute with pump station provides flexibility to draw water at a deeper depth from Clear Lake into the East Lobe of Clear Lake under abnormal conditions (e.g., poor water quality event such as HABs that occurred in 2021). L-8, GWP, M-Canal, Lake Mangonia, and Clear Lake are considered as primary sources of water to the WTP.

Secondary sources of water include the C-17 canal (stormwater), C-51 canal (Renaissance Treatment train to treat stormwater), and South Clear Lake and groundwater. The City can convey flow from the C-17 canal via a pump station into the M-Canal. The City uses groundwater to supplement water levels during droughts and includes the Eastern and Western well fields (EWFs and WWFs) and Aquifer Storage and Recharge well located at the WTP.

The City's source water can be susceptible to HABs due to the diverse supply of surface waters with conditions that support algal growth (e.g., water age, quiescent conditions, nutrient load (N,P), sunlight, warmer temperatures, sediment release and biological interactions). Within the water quality monitoring program, the City has incorporated a robust algae monitoring and treatment program in the primary sources of water to the WTP. In the past, City staff have detected the cyanotoxin (i.e., microcystin) at levels below the EPA health advisory levels in several locations (e.g., Lake Okeechobee, M-Canal). Hydrogen peroxide as an algicide is applied at various times of the year to treat algal blooms based on visual observations in the field. The City can isolate various upstream water bodies (e.g., isolate sections of M-Canal by shutting control structures) for treating algal blooms.

The City's Water Use Permit operational protocols restrict discharges through Control-4 to the City's lakes when lake stages are greater than 12.5 feet NGVD and GWP is above 18.4 feet NGVD. The Water Use Permit limitation has resulted in overall significantly lower lake stages compared to historic values in 2021. These operational protocols also limit groundwater withdrawals for lake recharge from the EWF to when Clear Lake is below 10.5 feet NGVD and GWP is below 17.25 feet NGVD, and further restricts the use of the WWF, when Clear Lake is below 9.0 feet NGVD.

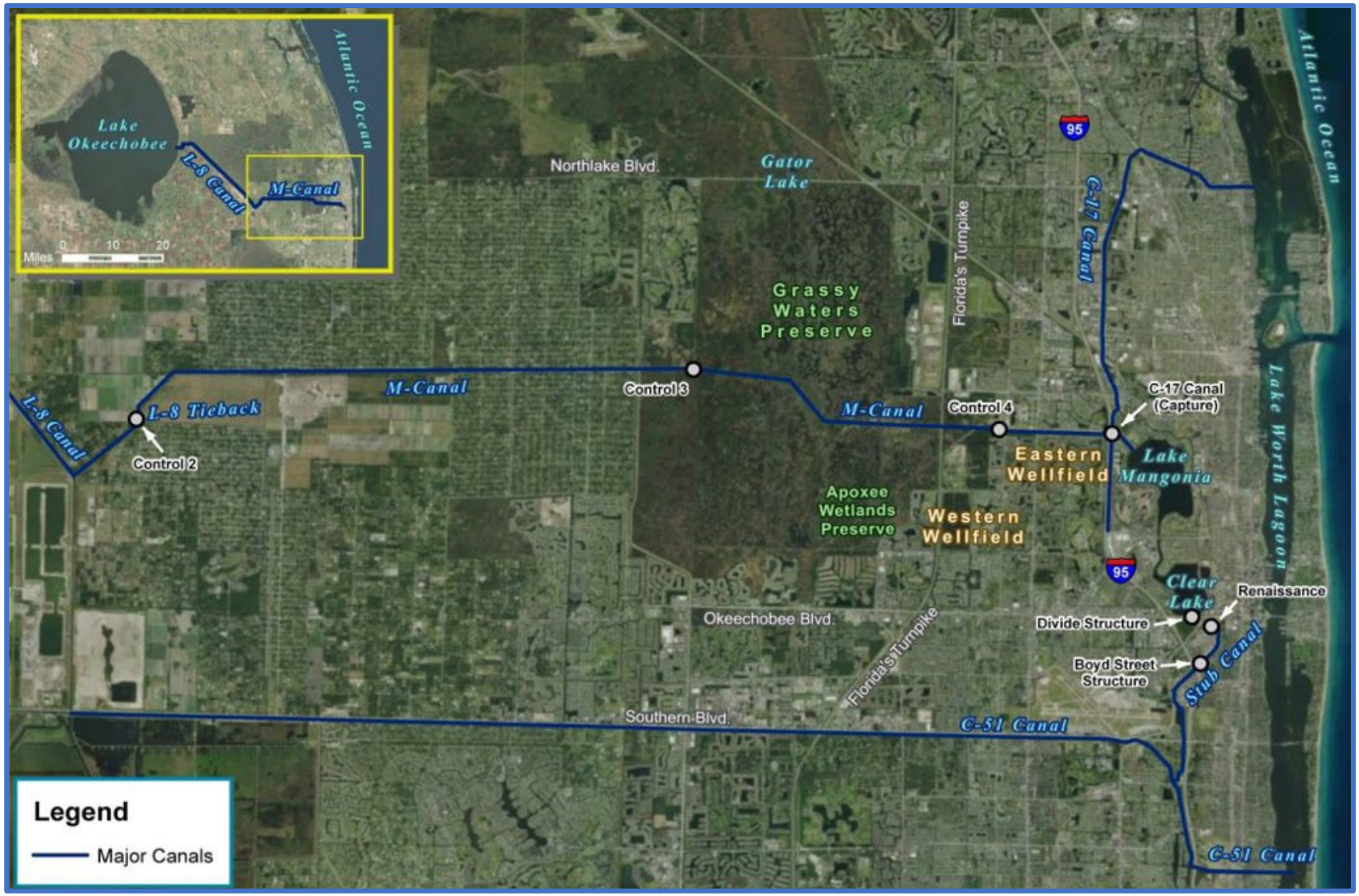

Figure 1: Overview of the City of West Palm Beach Source Water System (Source: 2019 Baseline Water Quality Report)

Objectives

The objectives of the source water monitoring and control evaluation were to identify water quality trends correlating with increased cylindrospermopsin levels in the City's source waters and identify recommended actions to:

- Optimize source water quantity and quality to minimize cyanotoxins and maximize treatment performance.
- Reduce likelihood and magnitude of algal blooms.
- Evaluate active water quantity, quality, and source management strategies (in collaboration with the City's modeling team).

Evaluation Approach

To meet these objectives, the Panel reviewed water quantity and quality data for the City's surface water and groundwater supplies, including seasonal and drought-related variations. The City's comprehensive database, which includes more than 20 years of data, facilitated the evaluation. Correlations between source water quantity and quality (e.g., pH, temperature, conductivity, chloride, algal cell counts, algal toxins) were developed. Additional studies were performed in Clear Lake where data sondes were placed at two different locations and water quality and hydrologic data (pH, temperature, DO, chlorophyll-a, ORP, wind speed) were collected as a function of depth (August-September 2021).

Attachment D contains presentation slides from the Expert Panel Work Session 6 held on October 12, 2021, providing a detailed review of the data review and analysis.

Summary of Findings

Based on the data reviewed and analyzed, preliminary findings are presented below:

- Preliminary data analysis implicates Clear Lake and Lake Mangonia in cyanotoxin production. Two probable hydrological conditions favoring excessive cyanobacteria growth include low water elevation and water age.
- The most common genus of cyanobacteria that produce the toxin cylindrospermopsin include *Cylindrospermopsis*, *Aphanizomenon*, and *Lyngbya*. It was found that *Cylindrospermopsis* and *Lyngbya* are the major toxin-producing algae in Clear Lake and East Lobe, which are the nearest sources to the intake.
- High toxin levels (cylindrospermopsin) can be correlated to higher concentration of the toxin-forming algae (i.e., *Cylindrospermopsis*) in 2021 as compared to 2020. Toxin-forming algae dynamics are enhanced by conditions that include:
    - Low water levels in Clear Lake lasting longer in 2021 compared to 2020; lake levels were down to 10 feet from normal levels of 12.5 feet in 2021.
    - Water age, quiescent conditions, high water temperature, high pH, and nutrients (N,P).

  - Stratification and anoxia in some locations as evidenced by additional studies conducted in Clear Lake.

- Using a greater quantity of groundwater in the source water blend helps to lower the toxin concentration as evidenced by the lowered cylindrospermopsin concentrations in latter parts of May and in June 2021. However, attention should be paid to water quality (e.g., conductivity) and treatment.
- C-17 impacts on overall water quality appear to be minimal as less quantity contributed to the blend in 2021 compared to 2020 (26 percent versus 6 percent); however more data is needed to confirm (e.g., algae and toxins).
- Clear Lake studies (August-September 2021) showed some promise of gathering and using water quality data as a function of depth to manage water quality.

3.2. Cyanotoxin Treatment

The City owns and operates a conventional surface WTP that meets all federal and Florida regulations governing drinking water quality. The WTP has recently undergone upgrades to provide for post-filter UV treatment along with raw water PAC treatment. While these upgrades were designed to improve process reliability and provide an additional treatment barrier for microbial pathogens (UV) and raw water organics (PAC), they were not designed specifically for cylindrospermopsin removal, and the PAC facilities were not in use during the 2021 incident. Figure 2 presents a process flow diagram and facilities map, detailing location and flow through the City's treatment facilities.

Objectives

The objectives of the cyanotoxin treatment evaluation were to identify potential treatment enhancements that could be implemented to maximize risk reduction. The evaluation of near-term risk reduction measures focused on optimizing or expanding use of existing processes, including PAC and free chlorine usage (Cl_2), as well as controlling pH for improved cylindrospermopsin (CYL) oxidation.

Evaluation Approach

The Expert Panel performed an in-depth review of collected process data to benchmark current process performance and followed this evaluation with process modeling and bench testing to evaluate potential process optimization strategies. The process modeling used the AWWA CyanoTOX® model (Version 3.0)[1], an internationally recognized tool designed to assess how treatment adjustments (such as pH, oxidant dose, and contact time) may influence degradation of cyanotoxins. Bench testing to evaluate performance of PAC and chlorination processes was conducted at the Hazen Environmental Lab at Manhattan College.

Attachment E contains presentation slides from the Expert Panel Work Session 5 held on September 14, 2021, which provide further details of the treatment evaluation.

[1] Cyanobacteria/Cyanotoxins | American Water Works Association (awwa.org)

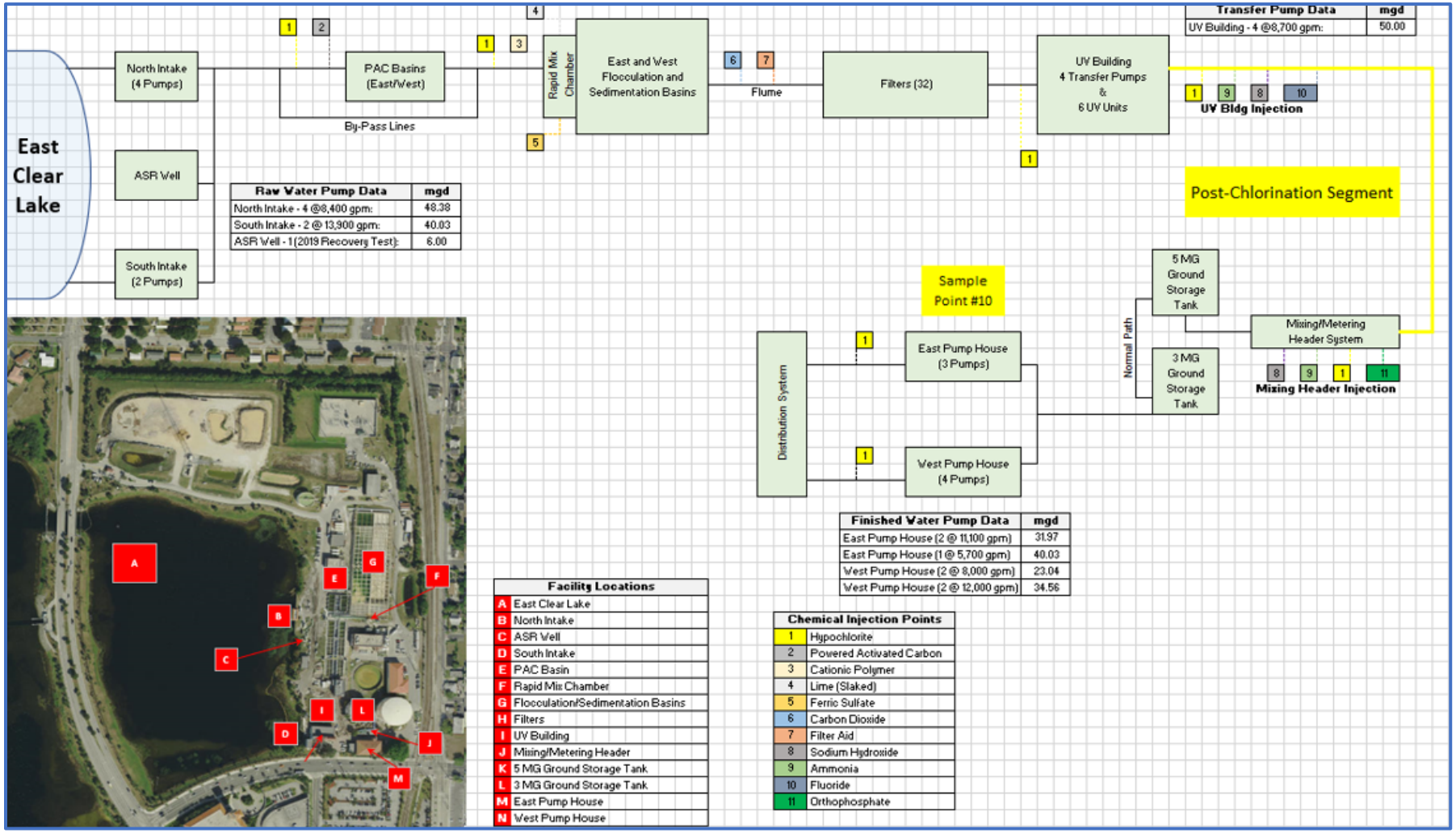

Figure 2: The City of West Palm Beach WTP Process

Summary of Findings

The key findings from this evaluation were that optimization of current treatment was capable of significantly reducing risk from cylindrospermopsin. In addition, the Expert Panel identified a treatment modification (flume chlorination) that could further reduce risk. Even though the risk of a repeat event has been significantly reduced, it is prudent to further evaluate long-term options such as identifying treatment technologies capable of further reducing risk from cylindrospermopsin and additional CECs. These long-term options should be further studied as part of a holistic system evaluation for addressing future treatment challenges and CECs.

Near-term Risk Reduction Measures

The evaluation of near-term risk reduction measures focused on understanding performance of existing technologies at the WTP and evaluating options for optimizing or expanding use of effective technologies to reduce risk. The Panel collected and analyzed data from literature review, in-plant testing, and modeling and bench testing of promising approaches.

The Panel's review of data from the WTP showed existing treatment steps are removing the low levels of cyanotoxins in the source water, particularly PAC and use of free chlorine (Cl_2). Modeling using a calibrated version of the AWWA CyanoTOX 3.0 tool and additional bench testing suggested that adjustments to optimize the multi-barrier process may make the WTP even more effective at removal. The City has used these findings to inform development of a monitoring and treatment protocol designed to reduce risk of cylindrospermopsin in drinking water.

PAC Optimization

The City recently built a raw water PAC feed and contact system. This system can provide adequate contact time and PAC doses to achieve significant adsorption of cylindrospermopsin. The Panel's evaluation therefore focused on testing alternate products from those currently in use at the WTP and evaluating optimal doses of PAC for handling elevated cylindrospermopsin levels in the raw water.

The findings from this evaluation include:

- Jar testing confirmed that addition of PAC in pre-treatment helps reduce cylindrospermopsin, and that the City's PAC system provides adequate contact time for effective cylindrospermopsin adsorption.
- Jar testing identified a wood-based product which could potentially improve cylindrospermopsin removal at the WTP.
- However, the testing also identified a potential challenge of PAC carryover to and through filters, which may limit dose or product. This phenomenon is being further studied through follow-up jar testing currently ongoing.

Optimization and Expansion of Cl_2

The City historically has maintained a free chlorine residual at one location in the WTP, in a segment of pipe between the UV reactors and the ammonia feed addition, prior to finished water storage. This short segment resulted in minutes of free chlorine residual, occurring at

finished water pH (pH 8.5+), which are known to be less effective for cylindrospermopsin oxidation.

Impacts of chlorinating in this segment at a lower pH, as well as considering impacts of adding free chlorine in the UV system wet well (providing longer contact time), were evaluated using modeling and jar testing methods. Additionally, benefits associated with installing a new pre-filter flume location were quantified and balanced with risks of potential increases in DBPs.

The findings from these evaluations include:

- Reducing pH within the CT segment improved free chlorine performance for cylindrospermopsin oxidation and provided a modest amount of risk reduction.
- Adding free chlorine to the UV building wet well, particularly when coupled with pH reduction, provided significant improvement in overall plant cylindrospermopsin oxidation and further reduced risk.
- Building a new "flume-chlorination" system would provide significantly more oxidation of cylindrospermopsin and greatly reduce risk. Jar testing also indicated that the process change would likely not increase DBPs to unacceptable levels.
- Feeding free chlorine to the raw water could provide significant additional oxidation of cylindrospermopsin, but formation of DBPs to unacceptable levels was identified as a concern.

Long-term Risk Reduction Measures

The evaluation provided confidence in the available treatment processes to adequately reduce risk if levels of cylindrospermopsin in the City's source water increase periodically. As a result, it does not appear that the City is in immediate need of investing in advanced treatment to address water quality concerns associated with cylindrospermopsin.

However, it is also recognized that water supplies may be at risk of contamination from additional known and unknown CECs which may become of concern in the future. As a result, the Expert Panel felt it useful to consider potential options for future treatment which would increase the robustness of the multi-barrier approach for cyanotoxin control and provide additional benefits for controlling potential future CECs if and when they may be identified.

Technologies were identified through literature review which could provide for additional robust cylindrospermopsin barriers as well as enhanced treatment of additional CECs. Table 1 identifies potential benefits of the advanced treatment processes considered as potential additional treatment barriers.

Permanganate (MnO_4)

Permanganate (potassium or sodium) is a strong oxidizer used often in pretreatment to address dissolved metals or for oxidizing bulk organics. Permanganate has shown limited effectiveness for cylindrospermopsin but is effective for mycrocystin and possibly for Anatoxin-A and taste and odor compounds. Permanganate has not been shown effective for disinfection or oxidation of CECs.

Chlorine Dioxide (ClO_2)

Chlorine dioxide is a strong oxidizer used often in pretreatment to address dissolved metals, oxidizing bulk organics, or as a primary disinfectant. Chlorine dioxide has shown limited effectiveness for cylindrospermopsin, additional cyanotoxins, MIB and geosmin, and CECs.

Ozone

Ozone is a highly reactive form of oxygen, used in water treatment as a strong disinfectant and oxidizer. Ozone is capable of rapidly oxidizing cylindrospermopsin, additional algae toxins of concern (mycrocystin, Anatoxin-A, Nodularins, but less effective for Saxitoxins), MIB and geosmin, and additional CECs. Ozone does not provide an effective barrier for oxidizing-resistant compounds, including synthetic flame retardants (such as PFAS).

Ultraviolet Advanced Oxidation Process (UV AOP)

The use of high doses of UV in combination with hydrogen peroxide or free chlorine produces UV AOP. AOP is capable of rapidly oxidizing cylindrospermopsin, additional algae toxins of concern (mycrocystin, Anatoxin-A, Nodularins, but with unknown effectiveness for Saxitoxins), MIB and geosmin, and additional CECs. UV AOP does not provide an effective barrier for oxidizing-resistant compounds, including synthetic flame retardants (such as PFAS).

Granular Activated Carbon (GAC)

Post-filter GAC uses highly hydrophobic GAC media to adsorb (and remove from water) organic compounds. Fresh GAC is capable of removing cylindrospermopsin, additional algae toxins of concern, MIB and geosmin, DBP precursors, and additional hydrophobic CECs including PFAS. The capacity of GAC for removing contaminants from water exhausts over time, so GAC needs to be periodically replaced or regenerated to maintain effective treatment.

Biologically Aerated Filter (BAF)

The City's filters are filled with biologically active carbon filter media, which serves as an effective barrier for turbidity and pathogen removal, and also as a structure to support biological activity which can support transformation of some organic chemicals. When the media in the filter is freshly replaced with active GAC, the filters will serve to remove organics similar to GAC. However, the carbon quickly exhausts and the resulting steady-state biological activity can remove some algae toxins of concern, partially remove MIB and geosmin, DBP precursors, and some CECs (excluding PFAS). The efficiency of BAF increases when combined with pre-filter ozonation.

Reverse Osmosis (RO) Nanofiltration (NF)

High pressure membranes (NF or RO) are semi-permeable barriers utilized often for treating saline groundwater in Florida, as the technology is capable of passing water but rejecting many constituents within the water including organics, metals, and ions (Ca^{2+}, Cl^-). High pressure membranes are an effective barrier available for providing high removal of organics, including cylindrospermopsin, additional algal toxins of concern, MIB and geosmin, DBP precursors, and additional CECs including PFAS. The process results in a highly concentrated reject stream, requiring special consideration.

Table 1: Identifying Potential Treatment Options for Cylindrospermopsin and Additional Water Quality Benefits

Technology	Cylindrospermopsin	Additional cyanotoxins	Taste and Odor	CECs	Pathogens	"As Needed" Operations
MnO_4	Not Effective	Variable	Inconclusive	Not Effective	Not Effective	Capable
ClO_2	Not Effective	Not Effective	Not Effective	Not Effective	Effective	Capable
Ozone	Effective	Effective	Effective	Effective	Effective	Incapable
UV AOP	Effective	Effective	Effective	Effective	Effective	Capable
GAC	Effective	Effective	Effective	Effective	Not Effective	Incapable
BAF	Inconclusive	Variable	Variable	Variable	Effective	Incapable
RO/NF	Effective	Effective	Effective	Effective	Effective	Incapable

4. Charting Future Actions

The actions the City has taken to enhance source water monitoring and optimize the existing water treatment process have greatly reduced the risk of elevated levels of cylindrospermopsin reaching the distribution system and consumer taps. To further manage and reduce risk, the Panel recommended additional near-term and long-term actions related to source water monitoring and management, treatment optimization, and communications, summarized as follows.

Near-term Recommendations

The Panel recommended ongoing and additional near-term steps the City can take related to source water, treatment, and communications.

Source Water

The Expert Panel reviewed and evaluated source water quantity and quality data for correlations with observed elevated levels of cylindrospermopsin. To optimize source water quantity and quality entering the WTP, the Expert Panel recommends the City:

- Continuously maintain lake level stages greater than 12.5 feet NGVD as lower stages contribute to the formation of algal blooms and subsequent algal toxin formations, especially in warmer months.

- Use more groundwater for surface water blending, as the findings support that the introduction of groundwater with low potential for algal growth can further reduce cyanotoxins in the City's source water.
- As part of an early warning system, increase monitoring for algal identification, enumeration (e.g., genus and species) and related toxins, using the following:
    - Conduct toxin monitoring and sampling within the primary and secondary source waters using the in-house ELISA method.
    - Implement devices that help in detection of contaminants and water quality characteristics in real-time at select locations in the source water network (in-situ monitoring).
    - Consider investing in a vertical profiler system which samples and analyzes water samples throughout the depth of the lake, assisting operators to know the depth of the best quality water.
- Continue to gather water quality and hydrologic data as a function of depth in select locations to better understand Lake Mangonia and Clear Lake characteristics and internal water quality dynamics including seasonal impacts (e.g., water age and stratification).
- Continue modeling of the City's water sources to help proactively manage and predict water quality conditions and changes. Along with the City's robust sampling program, modeling will help the City make decisions on what water sources to use based on real-time conditions.

Treatment

The Expert Panel performed extensive review of existing treatment data, modeling, and bench testing to evaluate potential treatment optimization strategies targeting cylindrospermopsin at the WTP.

To provide meaningful risk reduction for cylindrospermopsin in treatment, the Expert Panel recommends the City:

- Continue with measures the City has implemented to date for reducing cylindrospermopsin risk in treatment including wet well chlorination and increased chlorine doses in the pipe segment which were effective for reducing cylindrospermopsin when applied at lower pH (~7.5).
- Incorporate treatment optimization findings into a standard operating procedure for proactive optimization of PAC and Cl_2 treatment. This operating procedure can be documented in the City's Harmful Algae Response Plan to significantly reduce risk from cylindrospermopsin, focusing on chlorination pH and doses, and PAC doses and contact time.

- Increase the treatment robustness with an additional barrier for cylindrospermopsin by designing and constructing a flume chlorination application point to increase reliability of cylindrospermopsin treatment.

Communications

The Expert Panel recommended the following communications actions to keep the public and other interested stakeholders informed on steps the City is taking to protect water quality.

Ongoing Customer Communications

The Panel recommended options to provide ongoing, timely information to customers interested in learning more about the City's drinking water quality and treatment. In August 2021, the City launched two information webpages:

- A 'Protecting Water Quality—Source to Tap' webpage where community members can find information about the City's drinking water quality, sources, and treatment steps.
- A 'Safe Water Dashboard' webpage where interested community members can learn about routine water quality sampling and find current test results.

Seasonal Customer Communications

The Panel recommended the City incorporate proactive information in early spring customer communications about water quality and treatment steps the City is taking to address potential cyanotoxin concerns.

Public Notification Protocols

The Panel recommended the City document communications protocols and prepare notification templates as part of a written response plan. The City took action on this recommendation and developed a Harmful Algae Response Plan that identifies communications groups, activities, methods, and timing based on condition levels.

Communications groups:

- Residents, customers, and visitors, including vulnerable facilities and populations with access to the City's drinking water supply
- City of West Palm Beach
- Palm Beach County, Town of Palm Beach, and Town South Palm Beach
- Regulatory agencies

Activities:

- Health Advisory/Do Not Drink
- Emergency disinfectant switch
- City-wide Boil Water Advisory
- General status update

Communication Methods:

- News media release
- Palm Beach County Emergency Operations Center
- Direct contact to key stakeholders involved in the decision process or with the potential for additional impacts
- Social media
- Print media

Long-Term Recommendations

The near-term improvements recommended to bolster the City's monitoring, treatment, and source water management will significantly reduce the immediate threat from cylindrospermopsin in the future. The City can also take future actions to reduce risk from cyanotoxins or additional potential CECs. These actions will take more time to implement, and require significant science- and engineering-based evaluation to first identify potential CECs and then ensure that the incorporated actions meet appropriate challenges in a sustainable fashion. The following long-term recommendations will provide the City with opportunities to proactively plan for future cyanotoxin and other CEC challenges.

Source Water Monitoring and Management

Long-term improvement in source water quality and quantity can improve reliability and quality of the water provided to the City's WTP. These improvements are potentially expensive and must be considered within the context of addressing the City's water quality goals in a holistic fashion. To actively address source water improvements and make sound, sustainable decisions for long-term source water improvements, the Expert Panel recommends the City:

- Conduct feasibility studies that will help implement potential in-reservoir management strategies to further reduce likelihood and magnitude of potential algal blooms. These feasibility studies will assist in evaluating alternatives, compare merits and demerits, and develop lifecycle costs. Such alternatives could include:
    - Destratification
    - Hypolimnetic oxygenation
    - Floating covers
    - Biological control/bio-manipulation
    - Ultrasound
- Develop a source water master plan that will help select a source water and blending program based on best available water. A comprehensive and systematic approach will help to establish priorities and develop recommendations for a Capital

Improvement Program for a 20-year planning horizon. This could include evaluation of various source waters:

  - Additional groundwater wells to augment the Eastern Wellfield
  - Alternative water supply such as new brackish groundwater wells
  - Seawater desalination

- Engage stakeholders (point and non-point source dischargers) to protect the watershed from nutrients including minimizing nutrients in stormwater discharges. It is acknowledged that these options may not be in the City's direct control, but can be much more economical than future investments to address blooms.

Treatment

Long-term treatment improvement can improve water quality reliability by incorporating additional barriers within treatment for cyanotoxins and other CECs. These improvements, identified in Section 3, are likely expensive and must be considered within the context of addressing the City's long-term water quality goals. To make sound, sustainable decisions for long-term treatment improvements, the Expert Panel recommends the City:

- Develop a treatment master plan that will inform selection of appropriate treatment barriers to meet the City's long-term water quality goals. A comprehensive and systematic approach will help to establish priorities and develop recommendations for a Capital Improvement Program for a 20-year planning horizon. The evaluation should include:
  - Identify future regulatory considerations for a robust treatment process.
  - Identify and monitor CECs that present potential science-based and/or regulatory concern for the City's drinking water customers.
  - Evaluate advanced treatment options for the City's current source water portfolio, focusing on feasibility, rate impacts, and sustainability of technologies for meeting long-term water quality goals.
  - Evaluate treatment requirements for identified alternate sources, focusing on feasibility, rate impacts, and sustainability of technologies for meeting long-term water quality goals.

Schedule of Implementation

Figure 3 provides a graphical summary of the timeline to implementation of the Expert Panel's recommendations. The City has already implemented many of the near-term recommendations or laid the groundwork for implementation based on the work with the Expert Panel. The remaining near-term recommendations should be implemented within one year of Expert Panel completion. Beyond this one-year period, long-term recommendations are suggested to continue the holistic evaluation of improvements to the City's drinking water source and treatment systems.

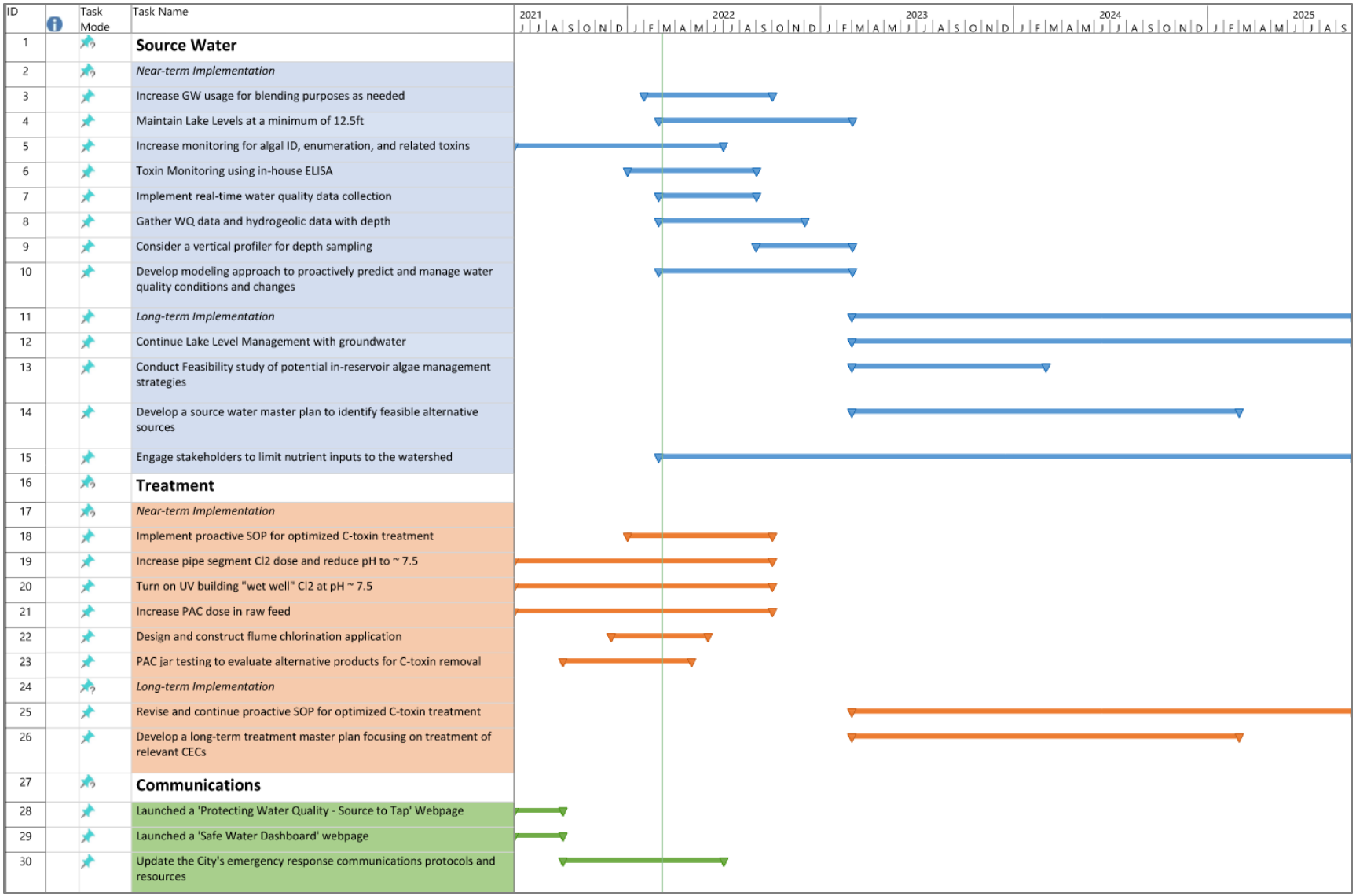

Figure 3: Implementation Schedule for Near- and Long-Term Expert Panel Recommendations

Attachments