Cyanobacteria & Cyanotoxins

THE CHALLENGE

Cyanobacteria (formerly known as blue-green algae) occur naturally in most freshwaters; however, excess nitrogen and phosphorus, along with warmer temperatures, can cause them to multiply rapidly, leading to "blooms," often referred to as cyanobacterial harmful algal blooms (cHABs). Some species of cyanobacteria produce secondary metabolites or cyanotoxins, which may pose health risks to humans and animals. Even when cyanobacteria are not toxic, they can produce taste-and-odor-causing compounds such as geosmin and 2-methylisoborneol.

THE RESEARCH

Cyanobacteria are among the most problematic organisms in freshwater systems, making them top research priorities for The Water Research Foundation (WRF). Without clear guidance or consensus regulations in place, many utilities struggle to respond to cHAB events. Since 1994, WRF has completed more than 40 research projects on cyanobacteria and the cyanotoxins they produce, helping facilities detect, monitor, control, and communicate about these organisms.

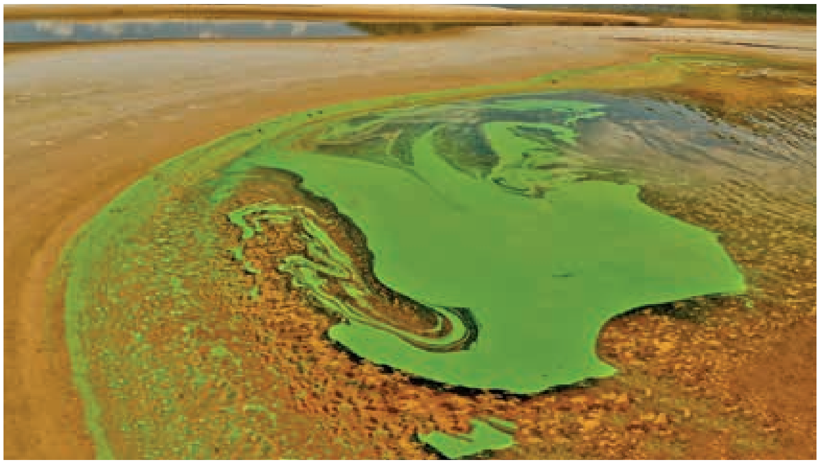
The first related research WRF published was a comprehensive guide for utilities, *Cyanobacterial (Blue-Green Algal) Toxins: A Resource Guide* (925). Since then, WRF has funded additional research on the detection, control, and treatment of cyanotoxins, much of it in collaboration with research partners. In 2019, WRF published *Managing Cyanotoxins*, a state of the science document providing an overview of the issues surrounding cyanobacteria and cyanotoxins, and highlighting some of WRF's cyanobacteria research.

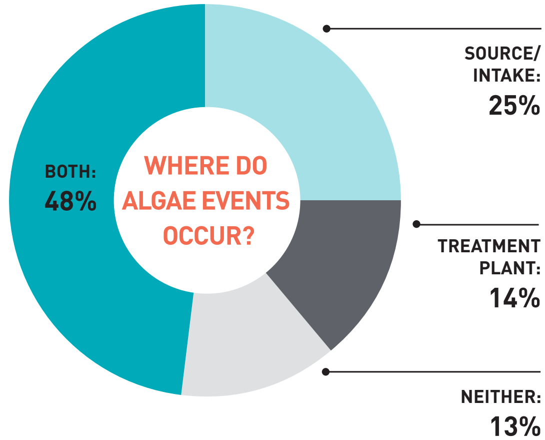
Detection

Cyanobacterial blooms occur seasonally, generally due to the presence of excess nutrients. Human influences such as urbanization, increasing population, and agriculture contribute to the incidence of cyanobacterial blooms. However, not all cyanobacterial blooms produce toxins. This uncertainty necessitates active monitoring of water quality for cyanobacterial toxins.

Robust analytical methods must be available to monitor for toxins and assess their significance. These methods either detect specific toxins or measure overall toxicity. Detection methods for cyanotoxins include high-performance liquid chromatography (HPLC), gas chromatography coupled with mass spectrometry (GC/MS), liquid chromatography coupled with mass spectrometry or tandem mass spectrometry (LC/MS and LC/MS/MS), and enzyme-linked immunosorbent assay (ELISA). The toxicity assays include the neuro-blastoma assay and the phosphatase inhibition (PIP) assays. ELISA and PIP are currently commercially available. Depending on the cyanotoxin, one method may be preferable over another. More recently, molecular methods have been developed to identify the genes controlling toxin production.

Rapid Detection of Cyanobacterial By-Products in Drinking Water (4212) evaluated the use of surface-enhanced Raman spectroscopy to concentrate and quantify cyanobacterial byproducts. The project goal was to develop simple and cost-effective detection methods for two common cyano-





Source: WRF project 3111

bacterial byproducts—microcystin-LR (MC-LR) and 2-methylisoborneol—that could be implemented in a water treatment facility. The study shows that drop coating decomposition Raman spectroscopy (DCDR) can be a powerful detection tool for MC-LR. Data suggest that DCDR can successfully identify MC-LR within a dissolved organic matter matrix, yield reproducible spectra for samples up to 6 months old, and quantify MC-LR in samples of 2–100 ng. Findings also highlight the ability of Raman spectroscopy to distinguish between similarly structured contaminants—a breakthrough for drinking water and wastewater utilities, especially as Raman spectrometers are becoming less expensive and more compact.

Numerous workflows have been developed to quantify MC congeners. The two most common are LC/MS/MS and the (2S, 3S, 8S, 9S)-3-amino-9-methoxy-2,6,8-trimethyl-10-phenyldeca-4,6-dienoic acid enzyme-linked immunosorbent assay (ADDA-ELISA). *Evaluation and Optimization of Microcystin Analytical Methods* (4647) compares the strengths and weaknesses of each, focusing on whether the method can precisely quantify microcystins at part-per-trillion levels in drinking water and source water.

While knowledge about cyanobacteria has increased over the years, there is not much research specific to benthic species of cyanobacteria. Benthic cyanobacteria are not typically included in current monitoring practices; therefore, their growth and impacts on water quality and human and animal health are not fully understood. *Benthic Cyanobacteria: An Aesthetic and Toxic Risk to Be Evaluated* (4738), conducted in partnership with Water Research Australia, investigated the incidence of benthic cyanobacteria and associated secondary metabolites and whether environmental conditions impact taste and odor and toxin production in these strains and in natural biofilms. The research results can be used to increase understanding of potential growth peak and monitoring periods.

Treatment

Once cyanobacteria and cyanotoxins are detected, utilities must address any related risks or regulations. There are several conventional and advanced treatment options available for the removal of cyanotoxins. The key is to understand the specific toxin of concern, because different toxins are removed or inactivated at varying degrees by different treatment technologies.

WRF, in partnership with the U.S. Environmental Protection Agency (EPA), funded one of the first projects investigating cyanotoxins as potential threats to North American water systems. Published in 2001, the comprehensive study, *Assessment of Blue-Green Algal Toxins in Raw and Finished Drinking Water* (256), assessed microcystin occurrence and treatment removal capabilities. During the project, 45 utilities in North America were surveyed for two years during cyanobacterial blooms. While microcystin was found in 80% of the source waters, only two of the finished water samples contained levels above the World Health Organization guidelines for MC-LR (1 µg/L). Furthermore, almost all of the utilities studied had adequate procedures to reduce microcystin to safe levels in finished water.

Another early project addressing the removal of cyanotoxins through water treatment was conducted with United Water International (Australia). *Removal of Algal Toxins from Drinking Water Using Ozone and GAC* (446) conducted lab and pilot-plant tests for the control of cyanotoxins through advanced treatment (ozone, granular activated carbon [GAC], biological filtration) to assess the optimal conditions under which microcystin, anatoxin-a, and saxitoxin are inactivated. Findings show that ozone is an efficient treatment option for anatoxin-a and microcystin, but not saxitoxin. The study also determined that GAC adsorption is not effective for the removal of microcystins. However, a later study demonstrated that GAC is effective if it is replaced frequently. In addition, excellent removal is achieved when GAC is operated in the biological mode. Effective removal of toxicity can also be accomplished with GAC for saxitoxin, but biological filtration did not effectively remove saxitoxin.

Water Utility Guidance

To manage the potential hazards of cyanobacterial toxins, water suppliers need to understand the nature and causes of cyanobacterial blooms, the methods of monitoring and controlling toxins, the effectiveness of water treatment practices in removing toxins, and strategies for preventing and mitigating toxic bloom development.

To aid utilities in this effort, in 2014, WRF and the American Water Works Association (AWWA) co-sponsored the project *Cyanotoxin Guides for Water Utility Managers* (4548), which distills information from the previous 25 years of cyanotoxin research. This project developed two action guides for use by water utility personnel and the drinking water community, synthesizing existing knowledge on cyanobacterial and cyanotoxin events and providing practical tools to help the water community prepare for, and respond effectively to, potential events.

The first manual, *A Water Utility Manager's Guide to Cyanotoxins* (4548a) summarizes cyanotoxin occurrence trends, potential health effects, preemptive and mitigation strategies, and potential challenges. This guide includes a short self-assessment that allows utility managers to assess the vulnerability of their water systems to cyanobacterial and cyanotoxin events and, when needed, directs utilities on where to find additional information, available resources, and necessary guidance. The second guide, *Managing Cyanotoxins in Drinking Water: A Technical Guidance Manual for Drinking Water Professionals* (4548b), is an action-oriented synthesis of relevant literature for the water utility community. It provides information to guide the development of a technically sound evaluation of cyanotoxins and appropriate

SOLUTIONS IN THE FIELD: Southern Nevada Water Authority

Serving 2.2 million people, Southern Nevada Water Authority (SNWA) has faced challenges associated with cyanobacterial blooms and cyanotoxins. Southern Nevada's chief source of water is Lake Mead, the largest manmade reservoir in the United States. In the spring and summer of 2015, Lake Mead experienced elevated concentrations of cyanobacteria, which resulted in cyanobacterial bloom advisories.

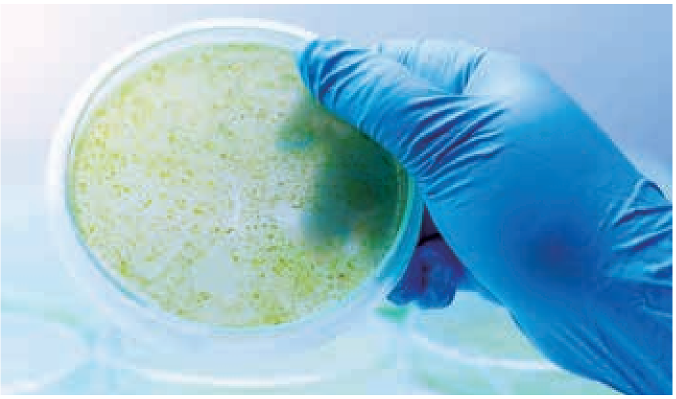
Recognizing that cyanobacterial blooms are, and will continue to be, critical issues, SNWA has been heavily involved in WRF research projects investigating cyanobacterial blooms and cyanotoxins. One recent project, *Refinement and Standardization of Cyanotoxin Analytical Techniques for Drinking Water* (4716), evaluated existing methods for the analysis of cyanotoxins at extremely low detection levels in raw and finished drinking water. The end products of this project include standardized and streamlined procedures to increase the accuracy, precision, and overall quality of cyanotoxin monitoring. This research provides water utilities with a clear path forward and helps provide a solid foundation for future cyanotoxin research and regulatory decisions.

Dr. Eric Wert, Water Quality Research & Development Manager at SNWA, says, "Our involvement in WRF research allows us to address public inquiries about emerging topics like cyanotoxins. We can address those questions really appropriately and speak to the state of the science on particular topics."

mitigation measures. The guide summarizes the most recent information on cyanotoxin occurrence, analytical methods and monitoring, and management strategies. Like the first guide, it is intended to benefit water utility managers, operators, and consultants. More specifically, it is intended for users working for, or with, water utilities that are at risk of having cyanobacteria and possibly cyanotoxin issues. This guide helps readers make informed decisions about appropriate mitigation measures and how to prepare for potential cHABs.

Published in 2018, *Four Steps to Effective Cyanotoxin Communications: A Risk Communication Toolkit* (4697) provides templates and tools for utilities, regulatory agencies, and other water professionals to better communicate about the risks associated with cyanotoxins in water supplies. The report describes attributes of a cyanotoxin risk management framework that can create potential communication barriers; for example, the complexity of health guidance and the uncertainty inherent in monitoring and testing protocols. The report also includes linguistic research, which was used to develop recommended health advisory and alert language.

More recently, *Developing Guidance for Evaluation and Implementation for Control of HABs in Source Water* (4912), reviewed published information, surveyed utilities regarding practices, and evaluated existing and innovative monitoring and treatment technologies. This information was synthesized into a guidance document and decision trees utility managers can use to address potential cHAB events. Another project completed in 2023, *Utility Responses to Cyanobacterial/Cyanotoxin Events: Case Studies and Lessons Learned* (4914), gathered case studies illustrating drinking water utility experiences with, and responses to, cyanobacterial and cyanotoxin events, and developed actionable steps utilities can take to both help prevent these events and address them when they occur.



WRF's research on cyanobacteria helps utilities detect, monitor, and manage these microorganisms—as well as communicate about potential impacts.

WHAT'S NEXT?

Despite the wealth of research related to cyanobacteria and cyanotoxins, utility personnel face challenges in deciding which monitoring methods to use and how to interpret data. Guidance on designing effective site-specific monitoring programs for source water, in-plant, and finished water analyses and subsequent data interpretation is imperative. *Utility Field Guide for Developing a Cyanobacteria and Cyanotoxin Monitoring Program* (5120) will develop a field guide and best practices that utilities can use to develop cyanobacteria and cyanotoxin monitoring strategies. These tools will help utilities characterize risk, understand their risk tolerances, develop efficient and cost-effective monitoring plans, and interpret data to obtain actionable intelligence for proactive source water management and treatment plant operations.

As utilities gather more data, they are increasingly considering how technology can support data management and analysis. *Assessment of Vulnerability of Source Waters to Toxic Cyanobacterial Outbreaks* (5080) is advancing new methods from interpretable artificial intelligence (IAI) to better understand how seasonal and temporal combinations of nutrient concentrations, temperatures, thermal stratification, and sunlight levels impact cyanobacterial growth. The IAI will utilize user-provided water quality data and publicly available data to compute risk metrics of cHABs forming in a given waterbody. An interactive web and mobile application will be developed for users to explore the results, including estimating the effect of specific events on future cHAB risks. *Autonomous in situ Monitoring of Harmful Algal Blooms* (5154), conducted in partnership with Great Lakes Water Authority, is also using AI and will develop the Autonomous Real-Time Microbial Scope (ARTiMiS) device for in situ and low-cost monitoring of cHABs. This project will develop a training dataset for algal species of relevance, optimize machine learning approaches to identify and quantify algal species, and field test ARTiMiS.

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