Cyanobacteria & Cyanotoxins

THE CHALLENGE

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

THE RESEARCH

Cyanobacteria continue to be one of the most problematic organisms in our fresh water systems—with nearly a third of the United States reporting blooms—making it a top priority for WRF research. Without clear guidance or consensus regulations in place, many utilities struggle to respond to events. Since 1994, WRF has completed more than 30 research projects on cyanobacteria and the cyanotoxins they produce, helping facilities detect, monitor, and control these nuisance organisms—as well as communicate with the public.

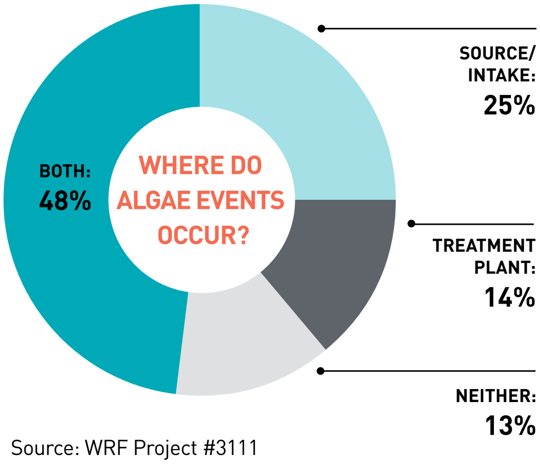
The first related research WRF published was a comprehensive guide for utilities, *Cyanobacterial (Blue-Green Algal) Toxins: A Resource Guide* (925). Since the publication of the guide, WRF has funded additional research on control, treatment, and detection methods for cyanotoxins, much of it in collaboration with research partners.

Treatment

There are several conventional and advanced treatment options available for the removal of cyanotoxins. The key is in understanding 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 to investigate cyanotoxins as a potential threat to U.S. water systems. Published in 2001, the comprehensive study, *Assessment of Blue-Green Algal Toxins in Raw and Finished Drinking Water* (256), assesses microcystin occurrence and treatment removal capabilities. During the project, 45 utilities in the United States and Canada 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 microcystin-LR (MC-LR) (1 µg/L). The study also shows that almost all utilities studied had adequate procedures to reduce microcystin to safe levels in finished water.

Another early project that addresses the removal of cyanotoxins through water treatment was conducted as a Tailored Collaboration project 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



Source: WRF Project #3111

that ozone is an efficient treatment for anatoxin-a and microcystin. However, saxitoxin is not readily destroyed under the same conditions. The study also determines that GAC adsorption is not effective for the removal of microcystins. However, a later study demonstrates 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.

Detection

In response to the increasing frequency of cyanobacterial blooms, greater awareness of toxic cyanobacteria, and new methods of detecting and monitoring cyanotoxins, robust analytical methods must be available to monitor for toxins and assess their significance. These methods either detect specific toxins or measure overall toxicity. There are several detection methods for cyanotoxins: 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. The 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) evaluates the use of surface enhanced Raman spectroscopy to concentrate and quantify cyanobacterial byproducts. The goal of the research was to develop simple and cost-effective detection methods for two common cyanobacterial byproducts—MC-LR and 2-methyl isoborneol—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 suggests 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 water and wastewater utilities, especially as Raman spectrometers are becoming both cheaper and more compact.

Numerous workflows have been developed to quantify MC congeners. The two most common are the ADDA moiety-targeting enzyme-linked immunosorbent assay (ADDA-ELISA), and methods that couple liquid chromatography with tandem mass spectrometry (LC/MS/MS). *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 detection levels in drinking water and source water.

Source Water Control

Cyanobacterial blooms occur seasonally and are generally a result of over-enrichment by plant nutrients, particularly nitrogen and phosphorus. Human influences such as urbanization, increasing population, and agriculture contribute to the incidence of cyanobacterial blooms. However, not all cyanobacterial blooms cause the production of toxins. This uncertainty necessitates active source water control and monitoring of water quality for cyanobacterial toxins.

Reservoir Management Strategies for the Control and Degradation of Algal Toxins (2976), co-sponsored by the Cooperative Research Centre for Water Quality and Treatment (Australia), investigates cyanotoxin degradation in reservoirs by toxin-degrading organisms, developing reservoir management approaches for the control of toxin production using an ecological model. It successfully simulates reservoir hydrodynamics and growth of algal species with a computer model, finding that timing and magnitude of blooms were comparable for field and simulated data sets. The model was extended to include toxin production and degradation, which can predict the risk of cyanobacterial toxins in reservoirs. The study also points out that utilities cannot rely on biodegradation to control microcystin and cylindrospermopsin in drinking water reservoirs because toxins can be present in the water column without toxin-degrading bacteria being present. Cylindrospermopsin can persist for months in the water column, suggesting that biodegradation does not always occur. Additionally, screening with PCR for microcystin-degrading organisms revealed that these organisms were not always present in toxic blooms of *Microcystis aeruginosa*.

Water Utility Guidance

In the early 1990s, several countries, including Canada, Australia, and the United Kingdom, developed health guidance levels for microcystin in drinking water. To manage the potential hazard of cyanobacterial toxins, water suppliers needed knowledge not only of health risks, but also of 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.

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. The purpose of this project was to develop two cyanotoxin utility action guides for use by water utility management and personnel and the drinking water community. These guides synthe-

SOLUTIONS IN THE FIELD: Southern Nevada Water Authority

Serving 2.2M people, Southern Nevada Water Authority (SNWA) has faced challenges associated with algal 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 blue-green algae, which resulted in algal bloom advisories.

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

Dr. Eric Dickenson, Project 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."

size existing knowledge on cyanobacterial and cyanotoxin events and provide 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), is a summary of cyanotoxin occurrence trends, potential health effects, preemptive and mitigation strategies, and potential challenges. This guide includes a short self-assessment, which allows utility managers to assess the vulnerability of their water systems to cyanobacteria 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 utility personnel and the water utility community. It provides information necessary to guide the development of a technically sound evaluation of cyanotoxins as a water quality concern for drinking water supplies and appropriate mitigation measures. The guide summarizes the most recent information about 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. The second guide helps readers make informed decisions about appropriate mitigation measures and how to prepare for potential toxic cyanobacteria blooms.

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

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

LIFT

The Leaders Innovation Forum for Technology (LIFT) helps move water technologies to the field quickly and efficiently. Water resource recovery facilities have an important role to play in reducing the amount of nutrients that make their way into our water bodies. Nutrient treatment and recovery technologies are a key LIFT initiative, which targeted biological nutrient removal as the program's first focus area and helped to advance deammonification technologies. Other nutrient-related focus areas include digestion enhancements and phosphorus recovery, which promoted the launch of TERRY, the *Tool for Evaluating Resource Recovery*, (NTRY1R12t), which helps utilities determine their potential to recover phosphorus.

WHAT'S NEXT?

An Emerging Opportunities project, *Cyanobacterial Blooms and Cyanotoxins: Research Priorities for Drinking Water Protection* (4657), synthesizes existing literature on cyanotoxins into a summary document, which was reviewed during an expert symposium held in Boulder, CO, in June 2016. Workshop participants included leading academics, governmental scientists, water utility representatives, and consultants. During the workshop, the participants identified research gaps and needs related to cyanotoxins in drinking water, which were translated into a multi-year research agenda for WRF's Focus Area, titled *Cyanobacterial Blooms and Cyanotoxins: Monitoring, Control, and Communication Strategies.*