Vertical Profiling Safeguards Drinking Water and Sheds Light on Cyanobacteria

A search for algal toxins in North Carolina reservoirs has evolved into an ongoing early warning system for three important drinking water reservoirs—which serve two large cities—and yielded a greater understanding of the dynamics of blue-green algae, or cyanobacteria, in the state's reservoir system.

Building on a pair of grants from the Centers for Disease Control (CDC) to explore key reservoirs for cyanotoxins, the Center for Applied Aquatic Ecology (CAAE) directed by Dr. JoAnn Burkholder at North Carolina State University in Raleigh, NC has teamed up with the City of Raleigh and the City of High Point to track cyanobacteria blooms throughout the water column.

This algae bloom in a North Carolina retention pond was growing at a rate of several feet of surface diameter per hour. Differentiating between these algae and potentially harmful cyanobacteria—and tracking the blooms throughout the water column—helps drinking water plant operators select intake levels and treatment strategies to ensure healthy, good-tasting water.

Photo courtesy William Frazier

Based on continuous *in situ* water quality monitoring of the water column near the water intake structures in three reservoirs, treatment plant operators can vary the depth at which they draw water into their plants, avoiding cyanobacteria blooms that can introduce toxins or impact taste and odor. The *in situ* data, as well as manually collected measurements and grab samples, are also providing insight on the impact of weather and land use on cyanobacteria.

"We're trying to get a handle on water treatment on one hand and on the other hand, a better understanding of the relationship between nutrients and algal blooms," says George Rogers, Environmental Coordinator for the City of Raleigh's Public Utilities Department. "The past approach in water treatment has been that whatever you get at the intake is what you've got. Now we're starting to see the watershed, reservoirs and treatment plants as integral parts of the system."

Cyanotoxin Threat

Cyanobacteria are common in the silty, eutrophic reservoirs of North Carolina, as well as in lakes around the world. Some produce cyanotoxins, a suite of potent neurotoxins and compounds that can cause liver damage, gastrointestinal illness and, at low chronic levels, promote tumors. Dogs, fish and livestock often fall prey to the cyanotoxins after exposure to contaminated water. Though documented cases of human fatalities from cyanotoxins are rare, the deaths of 76 Brazilian patients from cyanotoxin-contaminated water in their dialysis treatments in 1996 thrust the toxins into the spotlight.

"In North Carolina," Dr. Burkholder explains, "cyanobacteria commonly comprise 75 to 95 percent of the phytoplankton in the summer blooms that occur in Falls Lake, which supplies drinking water to more than 450,000 people." The algae sometimes tightly adsorb to clay particles suspended in the water column. In shallow systems like Falls Lake and many other North Carolina reservoirs, she notes, the algae and clay can sink to the bottom and still receive enough sunlight to serve as seed populations for future blooms. Conditions in and around the lakes portend future cyanobacteria challenges—farming and growing development in the watersheds around the reservoirs contribute heavy loads of sediments and nutrients.

In 2002, CDC funded a study through the North Carolina Department of Health and Human Services to sample 29 reservoirs, including 12 potable water supply reservoirs and the drinking water processed from them, for two potent families of cyanotoxins—microcystins and cylindrospermopsin. Funds from the state and area cities supported continued monitoring in 2003, and a second CDC grant from 2004 through 2007 expanded the survey. Cities such as Raleigh and High Point have provided the funding to continue the studies on selected reservoirs, including Falls Lake, funded by the City of Raleigh, and on the City of High Point's City Lake and Oak Hollow Lake.

Some cyanotoxins were detected, but peak levels during the drought of 2002 were 0.8 µg/L, below the World Health Organization 1.0 µg/L standard for human health, according to Elle Allen, a CAAE research specialist.

Looming Regulatory Issues

Listed in the U.S. Environmental Protection Agency's Candidate Contaminant Lists (CCLs) 1 and 2, cyanobacteria and cyanotoxins could become significant regulatory challenges for drinking water utilities in the future. The ability to track algal blooms in real-time and adjust water intake along the water column could become a key strategy for dealing with cyanobacteria—especially if EPA makes a regulatory determination that requires public water systems to treat for the algae, notes Bill Frazier, Manager of the Water Quality Lab and Pretreatment for the City of High Point's Public Services Department.

Cyanobacteria have been on Frazier's radar screen throughout his 24-year career with the City of High Point, and the problem continues to grow as the city's watershed becomes increasingly impacted by industrial and residential activities. The 62-square-mile watershed is home to three interstate highways, several heavily traveled state roads, a huge petroleum depot and a FedEx hub. Aeration, settling ponds, protective booms pre-located at the reservoir, BMPs in the watershed—High Point is implementing an array of measures to protect its drinking water, and is constantly alert to challenges.

"We're constantly in a response mode, and you can bet that we keep a close eye on cyanobacteria," Frazier says.

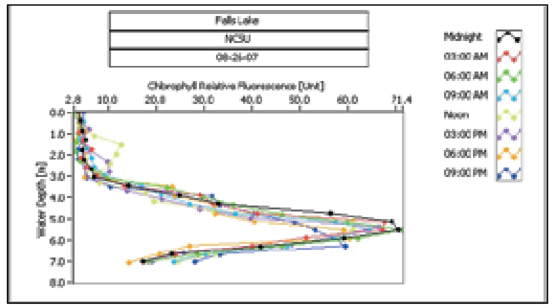
"We participated in a national round-robin study on cyanobacteria, and the results suggested that we would have to add 70 to 90 parts per billion (ppb) of powdered activated charcoal to our water to address a bloom," he adds. "That would force us to increase the cost of treating our water by a power of 3 to 10, depending on the source of the powdered activated carbon. If you can avoid that by taking water through a different intake, it makes a lot of sense."

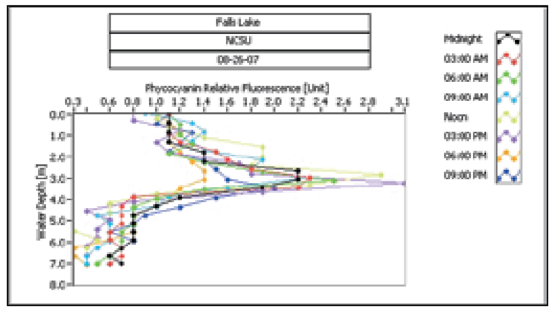
Building understanding of cyanobacteria and cyanotoxins is a vital step in managing them in drinking water systems, he notes —regulated or not.

In Situ and Manual Monitoring

Through its studies, Burkholder's team has built a five-year database on cyanobacteria through floods and droughts—an invaluable resource in building an understanding of blue-green algae, toxic or not.

The ongoing research combines the data from YSI automatic vertical profiling systems at the reservoirs' water treatment plant intakes as well as manual water column profiling and grab samples.





Readings every three hours from in situ *vertical profilers track algal blooms spatially and temporally. YSI sondes measure both phycocyanin—characteristic of blue-green algae—and chlorophyll a to differentiate among algae. The data help drinking water plant operators anticipate blooms at reservoir intake structures, and yield important insights on cyanobacteria.*

Images courtesy NCSU CAAE

The *in situ* vertical profilers include YSI 6600V2 sondes that monitor dissolved oxygen (DO), conductivity, water temperature, pH, depth, chlorophyll a and phycocyanin, an accessory pigment unique to cyanobacteria. Readings are taken every three hours, with the sonde automatically sampling every half-meter. Data are collected by a Campbell Scientific datalogger and a transmitted via cell phone modem to the CAAE lab, where it is posted to www.ncsu.edu/wq for public access.

The sondes have proven to be durable in the field. "We have the extended-deployment sondes, the wipered version," explains Dr. Robert E. Reed, research scientist at CAAE. "The wipers help immensely in waterbodies that have a lot of growth. Moving to the optical dissolved oxygen sensors has been great, too—hydrogen sulfide produced under hypoxic and anoxic conditions don't damage the optical sensors, which is important to us, because DO will get down to zero sometimes."

Chlorophyll a and phycocyanin are measured with fluorescence sensors, which are sensitive enough to detect algae at low natural levels, without the need for lab techniques such as concentration or extraction. The sensors deliver values that allow the CAAE team, water treatment plant operators, Health and Human Services specialists, and other users of the data to track the relative increase and decrease of the total algal population (from chlorophyll) and cyanobacteria-specific biomass (from phycocyanin).

"We can pick up blooms and identify where the chlorophyll maximum is in the water column," says Reed. That information guides the team on where to draw samples during its manual sampling trips to the lakes. "Though we typically sample on a two-week schedule, we've gone out there because of big spikes that we've seen from the profilers," Reed notes. "We want to see what's happening in real time."

Most of those spikes in chlorophyll or phycocyanin would have been missed in the past, notes Rogers from the utilities department. "These blooms might come up and be gone in a few weeks, or even a few days," he points out. "Unless you're out there all the time, you'd never see it. And if you miss the peak, your numbers would be low."

In fact, the City of Raleigh has found the vertical profiling data so valuable that it is funding the deployment of a second automated vertical profiler off a bridge located about halfway up the lake from the treatment plant intake in Falls Lake. There, the lake changes from a shallow, highly eutrophic system to a deeper, more river-like bathymetry—a significant change in conditions that affects nutrient concentrations and algal blooms. "Once that second profiler goes in, we'll have a temporal and spatial look at what's going on out there," says Allen.

A Deeper Look

Every two weeks, Burkholder and her colleagues collect an integrated water column sample from the photic zone for bench analysis. In addition to gathering quantitative data on chlorophyll and phycocyanin, the team is growing out cultures in the lab and sending samples to Dr. Parke Rublee of the University of North Carolina in Greensboro, who is analyzing DNA on microarrays to better understand the community dynamics within the blooms.

Using nutrient analyzers—which will soon also be handled by long-term unattended monitoring stations—the team also gathers data on phosphate, ammonia nitrogen, nitrate and silicate.

Burkholder, Reed, Allen and their colleagues at CAAE are analyzing nutrient and vertical profiling data now, using contour graphing and other techniques to spot trends and relationships. "We're seeing where the blooms are in the water column and seeing what, biologically, is causing that," says Allen. "Remote monitoring has allowed us to detect blooms of cyanobacteria earlier in the spring, before the typical growing season when we would regularly sample. And we have seen effects from storm events and very large rain input that result in chlorophyll peaks that we can clearly see on the plots."

Rogers appreciates the chance to watch changes in the lake in real time, both to better track its ecological cycles and to help treatment plant operators plot cost-effective strategies to deliver clean drinking water to the city.

"Real-time information is incredibly important—this is really valuable information about water quality at various depths, and changes in the water quality that could affect drinking water," Rogers says. "We're just now starting to use it as effectively as we can.

"What's really made this work is the phycocyanin probe," he adds. "We can watch the chlorophyll, but it doesn't tell the whole story. The blue-greens are incredibly important, and the ratio between phycocyanin and chlorophyll becomes important because of the tendency of blue-green algae to come with taste and odor problems. The operators have a bench instrument to measure phycocyanin, but now we can see these blooms as they're coming. It gives us a warning that there might be odor and taste issues."

That warning allows plant operators to change which intakes they use to bring water into the plant, says Rogers. They can also choose among preoxidants, alter the dose of coagulant, or use powdered activated carbon.

"It's expensive to put in this vertical profiler platform, but you could spend more than that on powdered activated carbon in a month," Rogers says. "It's a tremendously valuable piece of equipment. To have a view of a lake as a system, and to work towards treatment strategies based on what the patterns are revealing, that's cutting-edge stuff."