Summary




EPA Prevention, Control and Mitigation of Cyanobacteria and Cyanotoxins Webinar

May 14, 2014

Webinar Agenda

TIME	PRESENTATION	SPEAKER
9:30 a.m.–9:45 a.m.	Welcome	Lesley V. D'Anglada, DrPH Health and Ecological Criteria Division, Office of Science and Technology, EPA
9:45 a.m.–10:00 a.m.	Webinar Objectives and Logistics	
10:00 a.m.–11:00 a.m.	Controlling CyanoHABs in a World Experiencing Anthropogenic and Climatic-Induced Change	Hans Paerl, PhD Kenan Professor Marine and Environmental Sciences Institute of Marine Sciences University of North Carolina – Chapel Hill
11:00 a.m.–12:00 p.m.	A Systems Approach to Freshwater Management: Water Body Treatments	Kenneth Hudnell, PhD Vice President and Director of Science GridBee® / SolarBee® Medora Corporation New Bern, North Carolina
12:00 p.m.–1:00 p.m.	**LUNCH**	
1:00 p.m.–2:00 p.m.	Cyanotoxins and Drinking Water Quality: Treatment Options	Judy Westrick, PhD Director of Lumigen Instrument Center Wayne State University
2:00 p.m.–3:00 p.m.	MMIC (Mitigating *Microcystis* in the Chesapeake): Treatment Options For a Cyanotoxin-Impacted Lake in Denton, Maryland	Allen Place, PhD Professor Institute of Marine and Environmental Technology Center for Environmental Sciences University of Maryland
3:00 p.m.–4:00 p.m.	Surface Water Sources and Their Watersheds: Options When You Have to "Drink Downstream From the Herd"	Thomas M. Conry, R.S., CLM Program Manager Production Quality Control and Watershed Programs City of Waco Water Utilities
4:00 p.m.	**ADJOURN**	

Introduction and Welcome

Lesley V. D'Anglada, DrPH, EPA Office of Science and Technology, Health and Ecological Criteria Division

Dr. Lesley D'Anglada welcomed everyone to the U.S. Environmental Protection Agency's (EPA) Prevention, Control and Mitigation of Cyanobacteria and Cyanotoxins Webinar. Dr. D'Anglada noted that all the presentations had been posted to EPA's cyanobacterial harmful algal blooms (cyanoHABs) website (www2.epa.gov/nutrient-policy-data/cyanobacterial-harmful-algal-blooms-cyanohabs) under the Control and Treatment tab. This webinar's objective is to share with interested public health personnel, environmental scientists, and state and federal regulators information on the prevention, control and mitigation activities for cyanobacteria and their toxins in freshwater systems.

Dr. D'Anglada noted that harmful algal blooms (HABs) are a serious and growing threat to freshwaters and marine waters. An increase in the occurrence and intensity of HABs could cause fouling of the beaches and shorelines; taste and other drinking water impairments; and adverse risks to human, fish, and animal health across the United States and around the world. Although the understanding of the causes of HABs is not complete, it is known that the interactions of factors including available nutrients, sunlight, temperature, and ecosystem disturbance can result in optimal conditions for algal growth. Public health officials and water resource managers have had to increasingly respond to the adverse effects of harmful algae by closing beaches, changing or adding new drinking water treatment techniques, tracking algal blooms, and issuing advisories. Therefore, it is crucial to understand the advantages and limitations of prevention, control, and mitigation strategies for dealing with HABs.

One of EPA's strategic goals is to protect our nation's water by protecting human health from contaminants and detecting and restoring watersheds and aquatic ecosystems. EPA's Office of Water, Office of Science and Technology, has undertaken the effort to develop resources; develop criteria for cyanotoxins in drinking water and swimming recreational water; and create collaborations with other EPA offices, states, federal agencies, and organizations. EPA's Office of Science and Technology also develops webinars like this one to increase environmental awareness and provide information and tools to water managers, policymakers, academia, and the public on various HAB topics.

Dr. D'Anglada stated that the focus of the webinar is prevention, control, and mitigation activities for cyanobacteria and their toxins in freshwater systems. During the first presentation, the participants will learn about the different factors that promote bloom formation and proliferation and also about some physical and chemical approaches that have been used to treat and control blooms (using Lake Taihu in China as the case study). Then the participants will hear about a system approach to freshwater management and some cost-effective management technologies. After lunch, the participants will hear about the effectiveness of drinking water treatment processes in removing cyanotoxins. Also, the participants will learn about analytical methods, sample preparation, and a multiplex freshwater and marine method for cyanotoxin detection. Later in the afternoon, the participants will hear about the successes and challenges of watershed management activities. One presentation will focus on using barley straw in a Maryland lake and the other will focus on using dissolved air flotation (DAF) in a drinking water treatment plant in Waco, Texas.

Dr. D'Anglada introduced the first speaker, Dr. Hans Paerl. He will be discussing the control of cyanoHABs in a world experiencing anthropogenic and climatic-induced change.

Controlling CyanoHABs in a World Experiencing Anthropogenic and Climatic-Induced Change

Hans Paerl, Ph.D., Kenan Professor, University of North Carolina – Chapel Hill, Marine and Environmental Sciences, Institute of Marine Sciences

Dr. Hans Paerl thanked everyone and mentioned that he would be discussing nutrients and other factors that control incidences of cyanoHABs. Dr. Paerl mentioned he would also be describing some management strategies for preventing or minimizing cyanoHABs in freshwater. A summary of this information is provided below.

What current anthropogenic and climatic-induced changes would promote cyanoHABs occurrence?

- Factors including nitrogen, phosphorus, hydrologic modification, and climate change affect the occurrence of cyanoHABs.
  - Urban, agricultural, and industrial expansion is leading to more nutrient inputs.
  - Climate change (e.g., warming, hydrologic changes due to changes in rainfall patterns and amounts in systems) plays an increasingly important role.
- CyanoHABs produce compounds that can be toxic to a variety of indigenous biota in systems, including zooplankton, fish, shellfish, domestic animals, and humans.
- Big blooms can lead to big problems.
  - Big swings in oxygen in the system, particularly in bottom water as these blooms die lead to anoxia, hypoxia, and fish kills.
  - They cause odor and taste problems.
  - Sustainability of systems affected by these blooms is adversely affected, including the use of systems for drinking water, recreational use, and fishing.
- Algal blooms are not just a freshwater bloom, although initially problems had been emphasized in freshwater systems.
  - These problems are also found in estuaries and coastal waters and seas.
  - These blooms have also affected the largest estuary in the world, the Baltic Sea, for several hundred years. Human development has affected waters for that long because of agricultural and human expansion in the Baltic Sea watershed.
- Nutrient sources include overland discharge, ground water, and atmospheric inputs.
- Historically, limnologists were concerned about phosphorus inputs because they were initially identified as being the controlling factors for these blooms.
  - A paper published in 2008 entitled *Eutrophication of lakes cannot be controlled by reducing nitrogen input: Results of a 37-year whole-ecosystem experiment* is

being challenged in literature by people looking at diverse lakes and estuarine and coastal systems.

        - The assumption is that nitrogen-fixing cyanobacteria that are capable of using atmospheric nitrogen are providing the nitrogen needs of ecosystems that are plagued by these blooms.
    - Dr. Paerl emphasized that both nitrogen and phosphorus are of concern for a variety of reasons, of which the most important is the incorrect assumption that there is enough nitrogen being fixed by nitrogen-fixers in these systems.

- Dr. Paerl used Lake Taihu as an example of advanced eutrophication because in the last three decades, it has changed from one that was dominated by diatoms and desirable algae to one that now has 9-month-long algal blooms. Lake Taihu is China's third-largest lake. The lake is used as the drinking water supply for about 20 million people in the Taihu Basin.
    - With the cyanoHABs and production of toxins there has been a curtailment of drinking water and recreational use. In 2007 they had an extreme bloom during hot conditions, which essentially led to water supplies being cut off and the Chinese government having to bring in water for 10 million people living in the large cities around Lake Taihu.
    - What's the problem in Lake Taihu, and how is this a looking glass for other lakes that are facing these runaway eutrophication and toxic cyanoHAB problems?
        - About 85 percent of the biomass is *Microcystis* during these blooms; *Microcystis* is not a nitrogen-fixer.
        - Dr. Paerl plotted a 3-year continuous data set of total nitrogen and total phosphorus values in the lake. He showed the Redfield ratio (which is the balance ratio of nitrogen to phosphorus that they would like to have in a system to have a balanced growth of algae) as a red line going across the graph.
        - In the springtime, the lake suffers from extremely high nitrogen inputs mostly from runoff from agriculture and nonpoint sources, leading to a very high nitrogen-to-phosphorus ratio.
        - In the summertime, as the bloom materializes, the nitrogen-to-phosphorus ratio drops below the Redfield ratio.
        - Based on indicators (e.g., chlorophyll *a, mcyE* gene that codes for microcystin production) of algal growth response in the lake itself, phosphorus is limiting in the spring, and in the summer it switches over to nitrogen limitation through the fall.
        - This scenario repeats in the following years. The nutrients are not co-limiting at the same time, but they are on a seasonal basis.
        - There is some variability in the extent to which nitrogen and phosphorus stimulate individually, which has to do with the inputs of nutrients and the

hydrologic conditions in the lake itself. The bottom line is that if you add nitrogen and phosphorus at the same time, you get the largest response.

- Dual nutrient limitation phenomenon is also occurring in other lakes.
  - In the St. Johns River system in Florida, *Cylindrospermopsis raciborskii* is another cyanobacterium that is problematic.
    - *C. raciborskii* has invaded Florida waters and other highly eutrophic systems in the United States and Europe.
      - It can take up phosphorus and nitrogen very efficiently.
    - It is capable of nitrogen fixation, but it will reluctantly do so because it requires a lot of energy that needs to come from light. It would be difficult to fix nitrogen in very turbid waters. When given the option, it will exhaust the nitrogen sources in the water.
    - It tolerates low light intensity. It can come into systems that already have surface blooms like *Anabaena*, *Microcystis*, and so on. It can cohabitate these systems because it actually can bloom underneath the surface blooms.
    - *C. raciborskii* is opportunistic and both nitrogen and phosphorus will need to be controlled even though it is a nitrogen-fixer.
  - Similar dual nutrient limitation relationships are seen in a variety of lakes including experimental lakes in Canada and a lake in Sweden, as well as in the Chesapeake Bay and the Neuse River Estuary in North Carolina.
  - The dual nutrient limitation relationship has been observed in the Himmerfjarden system in Sweden. It is a freshwater to brackish system. The single large nutrient input into the system is a sewage treatment plant.
    - Phosphorus removal practices have been used since the 1970s, including phosphorus detergent bans and improving removal capabilities at the sewage treatment plant. Phosphorus levels have been kept low because of these practices.
    - Nitrogen wasn't recognized as a potentially problematic nutrient. Nitrogen was increasing because of higher population density and more wastewater generation.
    - Denitrification was recently used at the sewage treatment plant to reduce nitrogen loads to the fjord. Then, the sewage treatment plant shut down the nitrogen treatment, which allowed more nitrogen to come into the system again.
      - When nitrogen inputs were reduced, there was a reduction in chlorophyll *a* levels and the blooms were arrested.
      - When nitrogen was reintroduced, there was an increase in chlorophyll *a*.

        - Data were used to develop a threshold relationship to show how much nitrogen could be loaded into the system and how much chlorophyll *a* you would get downstream. This relationship was used to develop a nutrient management strategy—if nitrogen loads are kept below 400 tons, the bloom intensity in the system can be controlled.

- Why doesn't nitrogen fixation supply enough nitrogen to continue eutrophication potential?
    - It is not because there is a shortage of nitrogen-fixing taxa.
    - Phosphorus and other constraints to nitrogen fixation include energy, iron, and oxygen.
        - They obtain their energy through photosynthesis, so if there isn't enough light in turbid lakes, light might be limiting.
        - They can fix nitrogen up to a certain point but when the blooms get really thick, oxygen can be inhibitory substance.

- Temperature is increasing; mean temperature in the epilimnion has increased. It creates a stronger temperature gradient, which favors stratification in the water. Mixing becomes more difficult as these systems become more stratified.
    - This favors bloom organisms that like being up at the surface waters. Lake Taihu is an example of this; *Microcystis* can adjust its own buoyancy.
    - In Holland, studies have shown that when the waters warm, it causes strong stratification, and at that time, the dominant cyanobacteria bloom formers do best. *Anabaena* and *Microcystis* are dominant here.
    - Huisman et al. (2004) tested a model that looked at turbulent mixing versus depth and bloom formation. They tested the model by mixing part of the lake and leaving the other part unmixed. They showed that if you had complete mixing, you could change the phytoplankton community to a less cyanobacteria-dominated community.
    - In comparison to diatoms and dinoflagellates, cyanobacteria prefer the warmest temperature conditions. As things get warmer, the preference for cyanobacteria might be increasing in some of these systems. Dutch researchers (Kosten et al. 2012) plotted the relationship of temperature and percent dominance by cyanobacteria and showed a good relationship.
    - In Lake Taihu, using chlorophyll *a* levels in the surface water as an indicator, blooms have increased dramatically in the past 10 to 15 years. Nutrient loads have stabilized, so temperature might be playing a synergistic role.

- Hydrologic conditions are becoming more extreme. In North Carolina, Dr. Paerl noticed that diatom growth in the system coincided with high flow periods. The cyanobacterial blooms in the system occur during periods of lowest flushing. More extreme droughts would favor cyanobacteria.

What land and water management strategies for preventing or minimizing cyanoHABs in freshwater are currently available?

- For Lake Taihu, what have we learned and what management activities have been implemented to try to bring the lake back to a pre-bloom period?
    - They convinced the local, regional, and national managers that it is not just a phosphorus problem and that they also need to control nitrogen.
    - The dual nutrient problem is being addressed with improved wastewater collection and treatment, and vegetative buffer zones are being created around the lake.
    - Some questionable engineering fixes are being used, including dredging, diversion of water from Yangtze River to the lake to enhance flushing, and collecting algae from the lake.
        - Water diversions: In the 1990s it was proposed that Yangtze River water could be forced through the lake, reducing the lake's residence time allowing other algae to compete with cyanobacteria.
            - Yangtze River water is heavily polluted. Input from the Yangtze River adds about 15 percent to the nitrogen and phosphorus loads to the lake; therefore, it is questionable whether this is helping.
            - Physically, the water that moves into the lake doesn't really get into the embayments.
            - Water residence time would be reduced from about 320 days to 220 days at best. This is not short enough to have any effect on bloom organisms whose doubling times are on the order of days.
            - This has been going on for about 10 years, and it hasn't improved the problem. Blooms have been made worse in some areas, including the embayments.
        - Dredging has been attempted in some of the embayments in the lake.
            - Because dredging is not a very clean operation, this is releasing the legacy of nutrients into the water column.
            - The dredged sediments are being deposited in catchments surrounding the lake basin and will eventually leach back into the lake.
        - Physical removal: A lot of people have been employed to physically remove the algal scum from the lake.
            - Only about 1 percent can be removed this way.

            - It might help with the aesthetics but it is not a good long-term strategy.
        - Flocculation and precipitation have been tried.
            - The lake is very exposed so that anything that goes into the lake sediments by flocculation eventually comes back up (resuspension).
            - Costs are prohibitive.
    - About half of the nitrogen and phosphorus loads are coming from nonpoint sources. Buffer zone construction is going into place, but land is very precious in China and there are only a few places where there is enough land to produce these buffer zones. There is a limitation from the spatial aspect.
    - Management ramifications: In most cases, both nitrogen and phosphorus reductions are needed for long-term management.
        - Nutrient bloom thresholds are system-specific because they are related to flushing and other physical factors that interact with nutrient controls.
        - Thresholds might be changing in systems that are warming up, causing increased stratification and hydrologic changes.
        - Long-term, year-round restrictions are needed in large lakes where there is a legacy of nutrients.

Identify research needs to improve land and water management strategies for preventing and minimizing cyanoHABs in freshwaters.

- Additional information is needed on other physical approaches that could be used to control cyanoHABs. These include increasing circulation or ultrasound.
    - In a lake as large as Lake Taihu, which is well-mixed to begin with, increased circulation might not be a protective management strategy. Also, increased circulation in stratified systems might bring more nutrients up to the surface water.
    - Ultrasound works in the lab, but it has not been attempted in large lakes. One of the problems of breaking up cells is that the toxins could be released from the cells into the water. The same problem exists with other treatments including hydrogen peroxide treatment.

- Dr. D'Anglada mentioned that Lake Taihu was a good example to confirm the extent of the problems of HABs and it would be helpful to learn more about the efforts used like the vegetative buffers, buffer zones, and sediment dredging in Lake Taihu because those controls are also used in the United States and it would be good to learn from their experiences.

Questions

Q. Kim Ward: Recent research has shown that microcystins and other toxins and bioactive metabolites can have allelopathic effects. Do these interactions seem to be important in controlling emerging and established cyanoblooms?

A. Hans Paerl: We don't really know why they produce these toxins, but we are starting to learn why, including maybe their roles as antioxidants and in attracting certain microbes and not others. I think they could have allelopathic effects and that those effects might be important in terms of determining the competition among cyanobacteria themselves, and ultimately how that influences the bloom controls and who wins out. Using these compounds in an applied sense right now is very premature. I think we need to learn a whole lot more about their roles. I certainly don't question that those roles might exist.

Q. Kevin Sellner: Regarding the nitrogen-to-phosphorus ratio in Lake Taihu, what were the actual dissolved inorganic nitrogen (DIN) and dissolved inorganic phosphorus (DIP) concentrations in the lake at bloom initiation, bloom peak, and bloom decline?

A. Hans Paerl: The DIN concentration at the beginning of bloom in Lake Taihu can be as high as 1–2 milligrams per liter (mg/L) of nitrate, which is huge. The other impressive thing is that all that DIN basically gets sucked up in the bloom and disappears as the bloom increases in the summertime. The amount of beginning inorganic nitrogen at the beginning of the bloom is probably very critical in determining how large the bloom is going to be in the summertime. At this time, when nitrogen is limiting, there is actually free phosphate in the water itself that is coming from the sediments. That is just another indication of how limiting nitrogen is in that system to have a bloom that thick and still have free orthophosphate in the water. Lake Taihu is an extreme situation, but I think it is a looking glass of how bad things can get.

Q. Ohio EPA: Were cyanotoxins or other concerns associated with the decision to provide bottled water at Lake Taihu?

A. Hans Paerl: Yes.

Q. Kenneth Hudnell: What do you think of the model of cyanobacterial bloom formation that was published this year by the Canadian group (where Molot was the first author), which describes the critical role of anoxia and iron release from sediment and bloom formation?

A. Hans Paerl: I am aware of that publication. I think iron can play a role in some systems but in other systems it is not likely to be important simply because a lot of iron is already available, and Lake Taihu is one of those situations. The lake is very shallow and pretty well-mixed and the soils around Lake Taihu are red from the high iron content. We've actually tested iron limitations. I think that in very high stratified lakes where the epilimnion may in fact become iron limited, if it is isolated long enough there can potentially be some role for iron.

C. Kenneth Hudnell: You talked about circulation potentially bringing up nutrients from the hypolimnion when circulation is applied, and that doesn't happen because the intake to the unit is only from the epiliminion and only the epiliminion is circulated; therefore, no hypolimnetic water is brought up.

C. Hans Paerl: There might be situations where the stratification breaks down or is not always constant. The epilimnion is not always sitting in one place in many shallow waters. So, in those systems, there is actual physical mixing of the algae through the water column so that none of them are light limited, and this might actually enhance production.

C. Kenneth Hudnell: Where it does seem like the thermocline shifts, there's typically monitoring and readjustment of the intake depth if the thermocline moves. Also, how do you describe a lake like Taihu that has a thermocline as well-mixed?

A. Hans Paerl: It doesn't have a well-established thermocline. The mixing there occurs sporadically and during the daytime. The surface waters can warm up a bit and form intermittent stratification, but at nighttime, and on a day-to-day basis, the lake is actually fairly well-mixed. It is also very shallow; it is only 2 meters deep. Even with moderate mixing in Taihu, *Microcystis* is the dominant bloom organism. It is so buoyant that it can overcome moderate mixing. That is another thing to keep in mind.

C. Kenneth Hudnell: Thank you.

C. Hans Paerl: Thank you. If anyone would like any of the papers on Lake Taihu, I'd be glad to send them to you. You can just send me an email.

Q. Hua Jiang: Could you provide your email address? I would also like to have your papers on Lake Taihu please. Thanks.

A. Hans Paerl: hpaerl@email.unc.edu

A Systems Approach to Freshwater Management: Water Body Treatments

Kenneth Hudnell, PhD, Vice President and Director of Science, GridBee® / SolarBee®, Medora Corporation, New Bern, North Carolina

Dr. Kenneth Hudnell thanked everyone and mentioned that he would be talking about examples of water body treatments that can be used in an impaired water body to help it recover. A summary of this information is provided below.

Background

- The Watershed Management Program under the Clean Water Act (CWA) includes implementation of the National Pollutant Discharge Elimination System (NPDES) program to control point sources and implementation of best management practices (BMPs) to control nonpoint sources.
    - Point source control under the NPDES program has been very successful; they now only account for 5 to 10 percent of the nutrient inputs.
    - Nonpoint sources account for 90 to 95 percent of the nutrient inputs into our freshwaters.
- The CWA also described the Clean Lakes Program, under which technologies are used within impaired water bodies to provide therapy and enable them to recover.
    - Water body management is not currently implemented.
    - Only $145 million had been spent from 1972 to 1995 through section 314 grants, and no money has been spent since then.
    - Around 2000 EPA was encouraging people to use up to 5 percent of the section 319 grant funds (that are mainly used for BMPs) for water body management treatments.
        - That emphasis faded in 2002 with the focus placed on nonpoint source BMPs.
        - The Assistant Administrator for Water at that time, Mr. Benjamin Grumbles, said that decision was not based on any scientific or cost-benefit analyses. It was simply made because they didn't have enough money and they thought it would be easier to manage from just the 319 program.
    - Some source water protection funding is available through the Safe Drinking Water Act, but that hasn't been used extensively.
- The current watershed management process begins when there is an impaired water body.
    - The water quality is not thought to be suitable for meeting the water body's designated uses.

- Water quality standards are then developed. It is thought that if these standards are met, the impairments will eventually fade away.
- Then an assessment of the pollutants is done. Total maximum daily loads (TMDLs) are developed that say if inputs are limited, the impairments might fade away over time. A watershed management plan is implemented.
- Monitoring and assessment of results goes on for a while and it is determined whether water quality standards are being attained.
    - They are not often being attained. When they are not, people usually wait and hope that the conditions will improve in the future.
    - It is not often that they go back, reassess water quality standards, and start over.
- The watershed management approach seems to work better for point source-impaired water bodies.
    - In 1972 10–20 percent of U.S. lakes and reservoirs were impaired and in 2007 there were 50 percent impaired from eutrophication. The cyanotoxin health risks in 2007 for these waters were 27–41 percent moderate to high.
    - Rivers and streams with excessive phosphorus in 2004 were 47 percent, and in 2008–2009 they were 66 percent. This is thought to be primarily from agricultural sources.
    - Based on EPA data, no impaired reservoirs greater than or equal to 1,000 acres with 90 percent input from nonpoint sources have attained water quality standards.
- Watershed management drawbacks include the following:
    - Addressing only some new pollutant inputs and missing ground water and atmospheric inputs. It misses the huge internal legacy loads of nutrients that cycle from sediment to the water column, stimulating HABs.
    - Agriculture is exempt from the CWA. Some states are starting to deal with agricultural inputs, but it is dependent on every state addressing that impact themselves. The federal government's hands are tied from doing that.
    - For nonpoint source controls, BMPs are often difficult to implement over very large areas. There are no good cost-benefit analyses for all the BMPs.
        - Some of them are only marginally effective and yet quite expensive to implement.
        - They do not address cyanobacteria's need for quiescent, stagnant water to predominate.
        - If you have a *Microcystis* bloom, and you start to mix that water, the *Microcystis* decreases while the density of diatoms increases.

        - With watershed management only, it is like only giving the sick patient preventive medicine (lowering inputs) and not providing therapy to the impaired water body.

- HAB occurrence is increasing and leads to cyanotoxin exposure, where people can be exposed through inhalation, ingestion, and dermal absorption during recreational activities.
    - Centers for Disease Control and Prevention has shown that the toxins can become airborne, and people living around lakes can be exposed to it. There are studies being done showing increased incidence of diseases, such as amyotrophic lateral sclerosis, among populations living around lakes that repeatedly have cyanobacterial blooms.
    - Data from Florida shows that sometimes the levels of cyanotoxins in finished drinking water are higher than the source water. This is because when water is treated, the cells are lysed and release all their toxins.

What physical, chemical, and biological efforts to minimize and control cyanobacterial blooms in freshwater are available?

- A systems approach to freshwater management starts with an impaired water body. A scientific analysis is performed to determine the basis of impairment.
    - The official impairments for Jordan Lake in North Carolina are excessive levels of chlorophyll *a*, high pH, and high turbidity, all of which are caused by the predominance of cyanobacteria.
        - With a systems approach, the desired future condition for that water body might be to prevent cyanobacteria from predominating.
        - Most importantly, look at every option for suppressing cyanobacteria and removing nutrients from the lake to help stop cyanobacteria domination.
        - Perform a cost-benefit analysis on all of these options.
        - Determine if you have the tools needed and determine whether you can afford to use them. If not, start again and come up with some future desired condition that can be addressed with the available funds and tools.
        - Implement a management plan that involves cost-effective and water body management tools.
        - Monitor and assess results, and then ask again if the desired condition can be obtained. If yes, great; if not, go back to the dynamic process and the scientific process and see what you did wrong. Why didn’t it work? How can it be done better?

- The idea of a systems approach is to combine cost-effective watershed management to provide a preventative management and water body management approach to apply supportive therapy the impaired water body needs to recover more quickly.

- Examples of water body treatments include circulation, aeration, side-stream flow-ways, flocculants and oxidizers, floating artificial wetlands, nitrifying and denitrifying bacteria, biological manipulations, and hydrologic manipulations.
    - These address the problems of suppressing HABs and cyanobacteria. This allows the nutrients to be channeled up trophic levels in the water body.

- Some technologies can also remove or deactivate nutrients in the impaired water in the inlets where those nutrients are easier to access and highly concentrated. The goal is to suppress cyanobacteria to eliminate the water body impairment; remove nutrients to help suppress the cyanobacteria; and help protect downstream waters.

- Solar-powered, long-distance circulation technology (made by Medora Corporation)
    - The prototype was developed in 1999 to replace brush aeration in wastewater. The main markets for this are in wastewater and potable water. However, More than 300 U.S. water bodies and more than 350 worldwide are using these units to suppress cyanobacteria. These units operate 24 hours a day, 7 days a week.
    - The unit has a frame supported by pontoons and an impeller in the center that spins to pull up water. The impeller is powered by solar panels, which charge an underwater battery that drives the engine responsible for turning the impeller.
    - Water comes up the 3-foot-diameter intake hose. Water does not come straight up because a steel plate is suspended 1 foot below the hose. Water comes in radially from all sides in near laminar flow.
    - Water flows from long distances into the tube where 3,000 gallons per minute (gpm) goes up to the surface and another 7,000 gpm of induced flow goes up to the surface outside of the tube.
    - Water comes into the unit from above the thermocline and circulates only the epilimnion. As Dr. Paerl mentioned, you do not want to bring up the cold, dense, nutrient-rich, and hypolimnetic water that might further stimulate cyanobacteria.
    - These units are usually spaced about 35 acres per unit to suppress cyanobacteria.
    - In 2005 a survey of users identified three source water utilities using circulation to suppress cyanobacteria.
        - Data demonstrated cyanobacterial suppression in these source waters. The data indicated that the strength of the suppression increased over time.
        - Two of the facilities previously used algaecides and then cut down or eliminated algaecide treatment.
        - When cyanobacteria is suppressed and algaecides are not used, there are great rebounds in the density of the beneficial edible green algae and diatoms that move nutrients to zooplankton that are eaten by filter feeders and so forth, so that the nutrients are moving up the food web.

- Oxidizers
    - The active ingredient, hydrogen peroxide, is mixed with an inert ingredient, soda ash. When in water, these separate so that the hydrogen peroxide can kill cyanobacterial cells.
    - Oxidizers are used in source waters as a preventative. The idea is not to wait until a big bloom, go out and treat with peroxygen, and have all of those lyse and lose toxins and nutrients.
    - The idea is to repeatedly apply small doses to prevent cyanobacteria from reaching high densities.
    - Hydrogen peroxide will kill cyanobacteria and degrade into water and oxygen.
    - The California Department of Water Resources collected data at Dyer Reservoir.
        - No cyanobacteria was present in early April 2012, but then their monitoring started to show that cyanobacteria was increasing throughout the spring until May 25, when the levels reached almost 30,000 cells per milliliter (mL).
        - The California Department of Water Resources applied 21 pounds/acre-foot of peroxygen and 7 hours later, they found that the levels of cyanobacteria had decreased by an order of magnitude and decreasing for a few days.
        - Concentrations finally reached undetectable levels, but then it started to come back in June.
        - Dr. Hudnell was not sure whether they started treatment again or if they left it untreated. If it was left untreated, it is likely that the cyanobacteria would have become predominant again because peroxygen will not stay around in the water column.

- Ultrasound technology
    - The unit needs to be kept clean so that it can continue to be effective in transmitting the ultrasound waves.
    - The waves are transmitted with enough intensity to kill cyanobacteria to a distance of about 100–150 meters.
    - It uses 24-volt DC power that can be supplied by grid or solar cells.
    - It doesn't use much amperage and it kills cyanobacteria by rupturing their gas vesicles. Therefore, it does not kill all kinds of cyanobacteria. They have to have gas vesicles. It kills many types of cyanobacteria and the frequency of the ultrasound can be changed to best target the types of cyanobacteria that you have.
    - The system must be deployed at least 2 feet below the surface but above the thermocline.

- If a lake is irregularly shaped, sound waves will go out to part of the lake but be blocked from hitting other parts of the lake. A second unit is needed so that the whole lake can be treated.
    - In one case study, it was shown to cause a decrease of *Microcystis* over a 3.5-month period.

- Anionic polyacrylamide
    - It is a polymer that chains together more than 150,000 monomers per molecule.
    - It can be used on land to stop nutrients and other turbidity components from getting to freshwater.
    - When used in the water, it can be used to flocculate suspended material.
    - It can capture dissolved and particulate pollutants through chelation and anionic exchange. Some particulate matter gets trapped in the meshwork through physical entraption.
    - The water needs to be flowing for polyacrylamide to work in freshwater. Molecules of polyacrylamide will then flow through the water body, coagulate particles, and eventually flocculate them out.
    - The Florida Department of Environmental Protection completed a study looking at phosphorus sequestration with circulation and floc logs in Lake Hilaman. There was about an 80 percent reduction of phosphorus in the water column using these technologies.
    - Another study was done in a stormwater pond in Reedy Creek Water District in Florida using circulation and polyacrylamide to both suppress cyanobacteria and remove phosphorus. The data showed about an 85 percent reduction in phosphorus levels and about an 82 percent reduction in chlorophyll *a* concentration or density.

- Floating artificial wetlands
    - Mats constructed out of ethylene vinyl acetate are used. They float very well and react well to waves.
    - There are cups that are at a density of 2.5 holes per square foot. Indigenous plants are put in the holes and take up nutrients in water.
    - To get good results from this technology, the plants must be harvested. If the plants are left to die over winter, the nutrients will go back into the water body.
    - Several publications from Clemson University discuss the effectiveness of this technology. The effectiveness is based on several factors including:
        - What plants are used.
        - The density of the floating artificial wetlands; some people have used the floating artificial wetlands at densities of 10 percent of the water body to get the reductions needed.
        - The flow of water.

- Using bacteria to reduce nutrients
    - A process can be used that involves fermentation, followed by photosynthesis in a multistage process using 29 species of bacteria, including purple sulfur-eating bacteria.
        - Some of the bacteria are aerobic, some are facultative, some are anaerobic, and some are photosynthetic.
        - These bacteria enhance organic matter and sludge digestion.
    - Very good results can be seen over a short amount of time.
        - This can enhance ammonia conversion to nitrate and denitrification, where the nitrate is converted to nitrogen gas in anoxic areas.
        - Hydrogen sulfide is converted to nontoxic sulfate by the purple sulfur-eating bacteria.
    - Data collected in China show that biochemical oxygen demand decreased steadily over a 3-month period using this technology. There was a decrease in nitrogen and turbidity over this same time frame, but little reduction in phosphorus (although other studies have shown this). Cyanobacterial density also decreased during this time.
    - Side-stream flow-ways as exemplified by algal turf scrubbers.
        - Freshwater is pumped up to the high end of an acre-sized inclined plane and trickles down the whole surface.
            - When the water trickles down this surface, and with sunlight, a native mixture of algae is grown.
            - Algae takes up the nitrogen and phosphorus, adding dissolved oxygen to the water body.
        - The algae needs to be harvested regularly to maintain a high growth rate and nutrient removal rate on these inclined platforms.
            - The harvested material can be used for producing animal feedstock, fertilizer, or even biofuels.
            - Removal depends on the growth rates of the algae and how much of the nutrients the cells contain. Factors that can affect growth rate include the nutrient concentrations in the water, the temperature, the amount of incident sunlight, and the carbon availability in the source water.
- Will Jordan Lake become the first large eutrophic water body to attain water quality standards?
    - Jordan Lake is about 14,000 acres or 22 square miles, but it is small compared to the size of the watershed, which is about 1,700 square miles.
    - The U.S. Army Corps of Engineers completed it to provide flood control. Its designated uses include drinking source water, wildlife habitat, and recreation.

- It was built on low-lying farm land and high-nutrient input water.
- EPA and scientists predicted that it would be eutrophic even before it was filled and in fact, it has been eutrophic ever since it was filled.
- It is impaired by high levels of chlorophyll *a*, pH, and turbidity because cyanobacteria are predominant in Jordan Lake.
- North Carolina Department of Environment and Natural Resources (NCDENR) has developed TMDLs and designed Nutrient Strategy Rules.
    - Eight of the nine rules to reduce nutrient input were for nonpoint sources. Estimated implementation cost would be up to $2 billion.
    - Last summer the North Carolina general assembly did not think that reducing phosphorus input in two inlets in Jordan Lake by only 5 percent would make much difference in lake's water quality.
        - The general assembly suspended eight of the strategy rules for 3 years and they called for a demonstration project in Jordan Lake to directly suppress cyanobacteria.
        - The demonstration project will start this summer using SolarBee® units in two test areas.
        - It is critical that they use a systems approach to use the best cost-effective watershed management upstream BMPs as well as technologies within Jordan Lake to suppress cyanobacteria, remove nutrients from the lake, and help protect downstream waters.
            - Phosphorus levels, chlorophyll *a*, and phycocyanin levels in the water will be quantified using satellite data.
            - High levels of chlorophyll *a* are seen in the inlets as it warms up. Much of that chlorophyll *a* is in cyanobacteria.
            - NCDENR data show that cyanobacteria predominate in Jordan Lake.
        - The 2-year demonstration project is going to test circulation in its suppression of cyanobacteria in Morgan Creek Arm, where 24 units will be placed.
            - Units will be spaced 35 acres apart. In the more shallow portions, the spacing will be 15 acres apart.
            - Water that enters the top part of Jordan Lake takes more than a year to reach the dam at the southern end of the lake.
            - For the Haw River Arm in the south, the water comes in with high nutrient concentrations and stays in the lake for 7 days before it exits the dam. It does not really affect the upper part of Jordan Lake, but it does cause water quality

exceedances in the southern area where 12 SolarBee® units will be placed.

    - The goal is to suppress the cyanobacteria and stop the chlorophyll *a* exceedances.
- It is important that NCDENR develops a systems approach to manage the cyanobacteria in Jordan Lake and the nutrients entering the lake.
    - The plan is to protect the lake with approximately 155 circulation units in the inlets. These are areas where high phosphorus and nitrogen waters enter the lake, where chlorophyll *a* levels are high, and where cyanobacteria begin to predominate and seed the rest of the lake.
    - It is thought that 155 units in these inlets would be sufficient to eliminate the chlorophyll *a* impairments throughout the lake.
    - In these same areas, hopefully some other technologies will be implemented to help suppress cyanobacteria. These treatments could include circulation, flocculants, bacteria, floating artificial wetlands, and side-stream flow-ways.
- The hope is that Jordan Lake will become the first large reservoir to attain water quality standards using a systems-based approach in which the most cost-effective watershed and water body management approaches are used to unimpair Jordan Lake, enabling it to meet water quality standards and protecting downstream waters.

Identify research needs to improve control and mitigation strategies for cyanobacterial blooms in freshwater systems.

- There is a lack of research grant funding to develop and assess these treatment technologies.
    - Hydrogen peroxide: The effects of oxidation on the overall health of aquatic ecosystems are not known. It is thought that hydrogen peroxide does not harm shellfish and fish; however, research on what it does to smaller single-celled organisms has not been performed.
    - Ultrasound technology: There are not a lot of good data available that show the amount of decrease in cyanobacteria using this technology. Most of the case studies simply show before and after pictures.
    - Using bacteria to reduce nutrients: There are not a lot of good quantitative data available to demonstrate efficacy.

- A dedicated research grant program is necessary to address issues concerning controlling cyanoHABs.

- The Harmful Algal Bloom and Hypoxia Research and Control Act (HABHRCA) provided some funding for research.
  - Funding was initiated in 1998 and it provided funding for research on HABs in coastal waters for the National Oceanic and Atmospheric Administration, but it did not include any such funding for EPA and all freshwater.
  - This year the Senate has advanced a bill to do that and reauthorize HABHRCA.
  - The hope is that the House will soon come out with a companion bill and this will be the year where EPA and freshwater is included in HABHRCA, so that there will be research grant funding for developing and accessing technologies for controlling HABs in freshwater.

Questions

Q. Lesley D'Anglada: One of the worries that we always have when we use algaecides is release of toxins. You had mentioned other technologies like ultrasound, hydrogen peroxide, and solar power circulation. In your opinion, which technology will result in the least release of toxins?

A. Kenneth Hudnell: It is pretty much the same for all of the technologies if they are used correctly. The idea is not to wait until you have a bloom of cyanobacteria and then have the potential for high toxin release. Don't wait until there's a bloom and then create a high toxin release. The idea is to continually treat the water body, whether it is with circulation, ultrasound, or peroxygen, to prevent cyanobacterial densities from getting high. I use peroxygen as an example of an algaecide because I think it is more sustainable algaecide than things like copper sulfate that lead to copper buildup and potential problems in the lake. All of these technologies, if used properly, will prevent cyanobacteria densities from ever reaching high levels so that there would not be a problem with a sudden large release of cyanotoxins.

Q. Mike Archer: What is the durability of the floating treatment wetlands in northern climates (i.e., winter)?

A. Kenneth Hudnell: Steve Beaman can certainly tell you more about this and provide you with case studies, but my impression is that these floating islands made out of the ethylene vinyl acetate are extremely durable and have no problems going through winters where there is no ice covering the water body. I think if there is ice, you might want to remove them. SolarBees® are left iced over in lakes but these floating mats might not do so well in an iced-over condition.

Q. Frank Anscombe: Will a copy of this wonderful presentation be made available by EPA's organizer?

A. Kenneth Hudnell: I can send a link to Lesley and she can send the link to everyone.

A. Lesley D'Anglada: Your presentation has been posted on EPA's CyanoHABs website on the Control and Treatment tab at http://www2.epa.gov/nutrient-policy-data/cyanobacterial-harmful-algal-blooms-cyanohabs

Q. Participant: Some studies have shown that polyacrylamide breaks down into neurotoxic acrylamide over time. Has anyone studied the long-term fate of the polyacrylamide polymers added to these water bodies?

A. Kenneth Hudnell: We need a dedicated research grant program so that issues like this can be addressed. I have not seen data on whether this breaks down into acrylamide. It certainly would not be good for the aquatic ecosystem and might have potential health risks if it did break down to acrylamide, but I don't have any evidence that this happens. Polymers are usually quite stable over time so I am hoping that does not happen.

Q. Kristin Larson: You mentioned a 10 percent surface area of a water body for effectiveness of the floating wetland. Did I understand you right?

A. Kenneth Hudnell: That is a figure that has often come up as the amount of coverage needed to produce the amount of nutrient removal lake users need to meet things like discharge limits in stormwater ponds. It is not a hard-and-fast rule, but with 10 percent coverage you end up with a very nice looking lake with plants and flowers and such, and lots of nutrient removal. But you need to look at every situation individually. You might need more or less coverage.

Q. Jianfeng Peng: What were the effects of season on different control methods considered in your research?

A. Kenneth Hudnell: Season does apply to anything where temperature and perhaps sunlight are important. I haven't shown any data on the effects of seasonality on things like the algal turf scrubber or the artificial floating wetlands. I'm not sure if there are data that show how much variance in performance there is with variations in these parameters. These technologies need more research to better describe their benefits and identify any drawbacks they might have.

C. Seva: Anionic water-soluble polyacrylamide must be used that has .05 percent or less unreacted acrylamide. This breaks down in the environment within 48 hours. It does not break down into acrylamide.

C. Kenneth Hudnell: This is a comment from Seva from Applied Polymer Systems. Based on her information, there isn't a problem with acrylamide.

Q. Lesley D'Anglada: You talked about the proposed system approach in Jordan Lake. Do you have an estimate of how much it would cost to implement that system approach?

A. Kenneth Hudnell: The suspended rules are expected to cost up to $2 billion for the watershed BMPs. For the inlake treatments, if you applied circulation to suppress cyanobacteria over the whole lake, and you put in treatments like bacteria, floating artificial wetlands, side-stream flow-ways, and some of the other technologies I mentioned to suppress cyanobacteria in the water body and remove nutrients from its inlets and the water body itself, it would cost about $50 million. That would leave a great part of the $2 billion to use the most cost-effective parts of it upstream. It is hoped and thought that if you develop and apply a good systems approach, you might be able to restore Jordan Lake in the near term at maybe half or less of that $2 billion. This is all untried. The plan is not developed yet, so I cannot give any definitive answers. If a systems approach is applied to a large water body and watershed like Jordan Lake, it could cut costs in half and instead of waiting decades for improvement in water quality, you would see the removal of impairments within a couple of years.

C. Lesley D'Anglada: Thank you for the interesting talk. You gave a great description of the different water management technologies and I think they will be very useful for water managers dealing with this issue.

Cyanotoxins and Drinking Water Quality: Treatment Options

Judy Westrick, Ph.D., Director of the Lumigen Instrument Center, Wayne State University

Dr. Judy Westrick thanked everyone and noted that she would be talking about cyanotoxins and drinking water quality, including treatment options, and instrumentation and methodology to detect the toxins.

Background

- The view of how to treat cyanotoxins has changed and developed over time.
  - Dr. Westrick noted that EPA's Contaminant Candidate List 1 (CCL1) initially named "cyanobacteria and their toxins." The first concern was that the cyanobacteria were listed as the toxin.
  - Today, they are presented as a list of chemicals—microcystins, anatoxin, and cylindrospermopsin.

- When thinking about the toxins and where they are located, Dr. Westrick noted that we need to think in two dimensions. The toxins will be either inside the cell or outside the cell.
  - Intracellular toxin is inside the cell.
  - Extracellular toxin is outside the cell.
  - The toxins inside the cell can frequently be removed by physical removal processes such as filtration and membrane technologies.
  - Extracellular toxins are removed through different mechanisms including oxidation, physical removal such as adsorption, or biological activity, which will break down the compounds.

- When removing living organisms, people usually think about removing pathogenic bacteria or microorganisms.
  - They can be removed by making them nonviable or nonliving, and then the problem is solved.
  - In the case of cyanobacteria, making a nonviable cyanobacterial cell does not necessarily remove the toxins. The toxins could be released or the toxins could stay close to the cell wall until the cell breaks down, and then the toxins would be released.

What watershed activities (e.g., using algaecide) help or impede the effectiveness of drinking water treatment process to remove cyanotoxins?

- How are blooms removed from source water?
  - Flushing: The lack of flow in a river system can cause cyanobacterial blooms.

- Harvesting: Removing algae from the area.
- Diversion: Frequently surface waters will have more than one source and hopefully all the sources are not having cyanobacteria issues at the same time.
- Flocculent: These can be added to cause coagulation and settling of cyanobacteria.
- Algaecides: At low levels the cells are not lysed.
  - Cells can be caused to precipitate out without enough damage to release the toxins.
  - High levels of algaecides should not be used because the cells could lyse and release the toxins. When dissolved toxins are released, removal becomes more complicated.
- Ultrasound: This has been used successfully. It can also be used inside the drinking water plant.
- Extracellular toxins: Not much can be done at this stage.

How effective are the drinking water treatment processes in removing cyanobacterial toxins?

- What are options at the intake for intracellular toxins?
  - Usually, the types of algae that produce toxins travel up and down the water column.
  - Determine where the algae are relative to the intake and the time of day the water is taken.
    - Adjust the intake to various levels if that capability is available.
    - Many operators will take water at night to save money. If water is taken at night and the algae have surfaced, there could be problems. If the water is being taken at night, where is the bloom?

- What are options at the intake for extracellular toxins?
  - If there are extracellular toxins at the intake, low levels of oxidants like permanganate and chlorine could be used, but the operator needs to be careful to ensure that cells are not being lysed.
  - Inline powdered activated carbon (PAC) is very safe because it is not going to cause the cells to lyse; however, it will adsorb the toxins.
    - Some literature is available on this, which shows that the best PAC would be wood-based. This would be more effective than a coconut- or bituminous-based PAC in removing microcystins.
    - Microcystin has a molecular weight of about 1,000 whereas anatoxin is a smaller molecule between 100 and 200 molecular weight. For anatoxin, a smaller-pore carbon might work better.
    - How do you determine which carbon works best for you?

                - Enzyme-Linked Immunosorbent Assay (ELISA) kits will allow you to view the removal when spiking PACs with algal toxins. ELISA kits are relatively inexpensive and can be used in-house. The operator would not have to send samples away for liquid chromatography/mass spectrometry (LC/MS) or high-performance liquid chromatography (HPLC).
            - Prechlorination is not recommended before using PAC because the PAC will absorb it.

- Treatment processes for intact algal cell removal include coagulation/sedimentation, DAF/rapid sand filtration, or lime precipitation/sedimentation/rapid sand filtration.
    - Two log removal or better of intact cells is observed with these processes.
    - For microfiltration/ultrafiltration, 75 percent or better removal has been observed.
    - Filtration processes include conventional, biologically active, granular activated carbon (GAC), and low-pressure membrane filtration. These processes are all capable of helping remove the cells from the water.
        - Biologically active filters remove the intracellular toxins.
        - Biologically active sand and GAC filters can remove MCY-LR, MCY-LA, cylindrospermopsin, and anatoxin-a.
        - GAC filtration better adsorbs LA versus LR, which probably has to do with the charge potential. Saxitoxins and anatoxin-a are more readily adsorbed than microcystins, probably because of the size difference. Taste and odor compounds that are removed using GAC filtration are small molecules, similar to the size of anatoxin and saxitoxin.
        - Pore size
            - Micropore used for taste and odor, industry spills, solvents, and anatoxin-a.
            - Mesopore are medium-sized and are often used for total organic carbon removal and microcystins, cylindrospermopsin, and saxitoxin are readily removed. Contact time is usually less than an hour. Large pore volume is more effective at removing the microcystins and cylindrospermopsin.
    - There could be a good spot for ultrasonic technology treatment within the drinking water treatment plant.
        - Two technologies (Sonic Solutions and AlgaeSonic) could be used.
        - Typical operating parameters are 18 watts and 28 kilohertz.
        - It is a low-power ultrasound that shakes the gas vesicle inside the cell but will not cause cavitation.
        - The frequencies are tunable because certain frequencies are better for treating certain cyanobacteria.

        - The critical resonance is for gas vesicles. Success has been seen for *Microcystis*, *Anabaena*, and *Lyngba*.

- Oxidation processes are used to treat extracellular toxins.
    - Chlorine, ozone, hydroxyl radical, and potassium permanganate are effective in treating microcystins.
    - Chlorine is the most effective for treating microcystins. A pH of 6–8, a chlorine residual of 0.5 milligrams or higher, and 30 minutes contact time are used.
    - Anatoxin-a (a much smaller molecule than microcystin), has a double-bond ketone with a double bond, so it is called an enone. Chlorine is not effective in treating anatoxin-a but ozone, hydroxyl radical, and potassium permanganate are effective.
    - Chlorine, ozone, and hydroxyl radical are effective for treating cylindrospermopsin.
    - Chlorine is effective for treating saxitoxin. Chloramine, chlorine dioxide, and hydroxyl radical have not been investigated for effectiveness in treating saxitoxin.
    - Euglenophycin is not made by a cyanobacterium; it is made by a *Euglena*. Not much is known about it, but it is a neurotoxin that has made it through treatment processes, and it has been detected in the United States. It is expected that chlorine would be able to break down the double bonds and deactivate it. It is also expected that ozone, hydroxyl radical, and potassium permanganate would be effective in treating it. It is similar to what we would expect to see for microcystin; however, this research has not been done.

- From a drinking water treatment perspective, operators sometimes need to increase the pH of water that makes it into the distribution system to keep lead levels low, and they use chloramines so that fewer trihalomethanes or haloacetic acids are created. These treatment decisions are based on EPA's regulations.
    - Drinking water is treated to get log deactivation of *Giardia* cysts.
    - Between pH 6 and 7, if you are disinfecting for *Giardia*, you will also be inactivating microcystin.
    - As pH gets to 8, there is less inactivation of microcystin.
    - At pH 9, there is very little inactivation of microcystin.
    - Microcystin inactivation is not only dependent on chlorine; it also depends on pH and the temperature of the water.

- UV treatment is used for *Cryptosporidium* (about 40 milliJoules/square-centimeter) but it will not treat microcystin, cylindrospermopsin, anatoxin-a, and saxitoxin at the same level. Much higher levels (1,530 to 20,000 mJ/cm^2) would be needed to break down these toxins.

- Photolysis and advanced oxidation processes are early on in the development stage and are not at the stage of being used in treatment processes.
    - For photolysis, light would be absorbed by something like phycocyanin. After being excited, there would be intersystem transfer and the excited molecule can break down microcystin.
    - UV/hydrogen peroxide (H_2O_2) uses UV to create a peroxide radical that works as an oxidative breakdown process. It is often used for taste and odor and can be expensive.
    - Fenton reagent uses iron (Fe^{+2}) and allows energy to be transferred.
    - Radiolysis is the addition of high energy, such as gamma rays, which allow the water to be split into hydrogen radical and hydroxyl radical for reaction.
    - Ultrasonic degradation is done by acoustic cavitation, in which the formation and collapse of microbubbles can bring temperatures up to > 5,000 °K and high pressure (> 1,000 atm). This would be very localized. The process generates reactive species including hydroxyl radicals, hydrogen radicals, and oxygen radicals. These radicals will react with cyanotoxins. It is expensive because of the energy needed.
    - Titanium photocatalysis can be used to absorb energy. It is a semiconductor, so once it absorbs light energy, it can then transfer that to electron energy and those electrons can create molecules, which will react with pollutants and break them down. Active species of hydroxyl and oxygen are generated. UV 254 light is used for this. The surface itself changes based on the pH. So sometimes they will be sticky for certain toxins, and if you change the pH, they will be sticky for other toxins.

- It is important to look at the full-treatment process and evaluate each process in the treatment plant.

Analytical methods

- Determine what you need to treat up front.
    - If a liter of water is poured through a glass filter, it will have the attached cells at the top of the filter and then the extracellular toxins will go through. An operator can measure what is in the intact cells and then measure the microcystins in the filtered water, or an operator could measure a total and then measure the intact cells and subtract them.
    - For in situ monitoring, basically take the water, lyse it and measure. Sonication, chemicals, or freeze/thaw could be used for cell lysing.
    - Water can be brought through vacuum filtration through a fiber glass filter or centrifuged and concentrated at the bottom.

- Other preparation methods include lyophilization, using immunocolumn, and solid phase extraction.
- The analytical method with the best selectivity and sensitivity is LC/MS.
- For bioassays, protein phosphatase inhibition assay has a good correlation in comparison to HPLC results.
- ELISA comes in tube kits, plate kits, strips, and so on. There are antibody-based kits for microcystin, cylindrospermopsin, and saxitoxin. The anatoxin-a kit is based on a receptor.
- Liquid chromatography with various detectors can be used. The standards and surrogates used for analyte verification need to be considered.
- Liquid chromatography/mass spectrometry (mass spectrometry) (LC/MS[MS]) can be used to detect cylindrospermopsin, anatoxin, several microcystins, and euglenophycin in one run in less than 9 minutes. It can be used to run approximately four samples per hour for all of the toxins of concern.
- DNA-based technologies include polymerase chain reaction (PCR)/quantitative PCR (qPCR). The gene clusters for microcystin, cylindrospermopsin, anatoxin, and saxitoxin can be identified.

- Dr. Westrick is looking into the development of a multiplex freshwater and marine method for cyanotoxin and euglenophycin detection. She would like to use PCR to determine the potential risk of the natural waters and through the drinking water process. There can be multiple toxins. How do multiple toxins affect people's health?
  - Project aims include:
    1. Develop multiplex PCR method patterned after published research.
    2. Alter PCR method to detect anatoxin-a.
    3. Look at making a multiplex euglenophycin.
  - The initial results show a nice correlation between microcystin analytical and PCR results and with the cylindrospermopsin and the cylindrospermopsin gene.
  - With the qPCR multiplex, Dr. Westrick is looking at three studies using cyanotoxin qPCR.
    - Differences between summers and winters genetically at different depths of the water and sediment.
    - Multivariate toxin and evaluation of those in source waters: Looking at gene production, the toxin levels, the cyanobacteria enumeration, nutrients, and water chemistries including trace metals.
    - Evaluating 10 drinking water treatment plants through the drinking water process, including Lake Winnipeg. She knew this lake had microcystin from MS results; the cylindrospermopsin gene and saxitoxin gene are present in both the summer and the fall.

- For the natural water studies project, Dr. Westrick is collecting water samples around the Great Lakes and in the Florida area.
  - They have not performed the gene analysis for this study.
  - Microcystins have been detected in St. Johns.
  - Anatoxins and microcystins have been detected in Lake Huron.
  - Anatoxin, cylindrospermopsin, and microcystins have been detected in Grand Lake St. Marys.
  - Anatoxin and microcystins have been detected in Lake Erie.
  - Anatoxins have been detected in Lake Michigan.

Questions

Q. Frank Anscombe: The presentation includes mentions of sound waves. Slide 4 mentions ultrasound. This seems to involve preventing intact bacterial cells from entering drinking water systems by removing them (by sinking them via sound waves). This might correspond to slide 10, which shows before-and-after pictures of treatment with “low power” to collapse gas vesicles. At slides 21 and 22, there is mention of processes to degrade cyanotoxin molecules with acoustic cavitation. These seem like two different contexts for using sound waves, which apply different sound energy intensities and durations. Am I understanding this correctly?

A. Judy Westrick: Yes, there are two different concepts. The frequencies are very different. One of them is high intensity and causes cavitation. Energy cost is going to be high around that. For the low one, I like to think of it as basically shaking up of the insides of the cell by moving the gas vesicle around with the low sound.

Q. Hua Jiang: How widespread is the cyanotoxin problem nationwide from a drinking water perspective?

A. Judy Westrick: There are a lot of opinions on this. In my opinion, we know we have a lot of toxins in a lot of source waters. They are frequently reported low. There is a different perspective of just having a toxin versus having huge blooms all the time. What makes it through the drinking water plant? In my experience, very little has made it to the plant. We know it has happened because Ohio EPA has seen it happen, but because we have no levels to determine what is or is not safe, and ideally we know we’d like to remove it all, we do have to deal with it. We know it is widespread in source waters. It is widespread from a low level. We can pick up repetitive blooms in waters, but as far as the drinking water perspective and how successful we are at treating it, it goes back to if we intentionally treat to remove the toxins, I think we will be very successful. When you don’t know what you are treating and you occasionally change something in your system such as pH, because it is better for your lead and copper rule to be at a high pH, all of a sudden what wasn’t making it through the plant might be making it through. We need to understand the system so that we can optimize it and make sure it isn’t getting into the final product.

Q. Hua Jiang: Why is wood-based GAC more effective for microcystins?

A. Judy Westrick: It has a larger pore. Wood-based GAC typically has more of a mesopore than a bituminous GAC.

Q. Kim Ward: How sensitive are currently available analytic methods to the 90+ congeners of microcystin?

A. Judy Westrick: At any given time, you can purchase anywhere between three and nine microcystins. From a 90 congener perspective, we're not sure about the other ones out there and how to identify them from an analytical perspective. People are developing screening methods where they go through and look for anatoxin first, and once they see the 135 group, they go back and look for the rest of the microcystins. Right now we are focused on the four that EPA put out there and the others that have been isolated. The four that are out there from EPA are RR, LR, LA, and YR.

Q. Lesley D'Anglada: Analytical methods like LC/MS(MS) can cost a lot. Same thing with advanced treatment with PAC. For those treatment plants with low resources that cannot afford sampling and using analytical methods and treatment, in your opinion, what would you suggest to guide the treatment?

A. Judy Westrick: ELISA kits for 96 plates will cost anywhere between $300 to $600, depending on which kit you use. You don't quite get 96 samples from this because you have to set up a standard curve and you have to do them at least in duplicate. Looking at it from that perspective, you probably could get 30 samples per kit. It would cost anywhere from $10 to $20 per sample, with labor included. You would have to buy the plate reader, which could cost anywhere from $8,000 to $30,000, depending on how good of a plate reader you want. A good solution is to use the different kits. Some of the kits (e.g., for microcystin) also come in tubes and dipsticks. Another method that people are starting to look into is HPLC because now you can buy one between $30,000 to $80,000. You can basically run all of those in an hour and actually quantify. The microcystins have very unique spectra on them. Those would be your two options in that respect. Prepping your samples for HPLC is not much different than running your ELISA kits. These are the most inexpensive ways. Anyone can run the ELISA kit if they can follow directions. For HPLC, you would need some training but if you are buying your HPLC to run one thing, you can say "I'm going to purchase this from you and I want this method running before you leave."

Q. Lesley D'Anglada: In the previous two presentations, they mentioned that chlorophyll *a* might be a good indicator that could be correlated with microcystins. In your opinion, when you have high levels of chlorophyll *a* in water, would you treat the water or do you suggest more testing on specific toxins?

C. Judy Westrick: If you have no mechanism at all, you have to treat it as though as it is toxic. If you have no mechanism, the best you can do is buy yourself a microscope and learn a little bit about identifying algae. Every other year at the Water Quality Technology Conference we offer an identification of algae workshop. You would at least have an idea of whether you are dealing with potentially toxic algae or not. Yes, you want to remove your chlorophyll *a* and yes I've used it to determine how well the treatment plant is functioning. I think that if you think you have a problem, you need to determine whether you even have cyanobacteria. If you do have cyanobacteria, you need to figure out which ones you have, so you will want to use ELISA or send your samples out for analysis.

Q. Regina Guthenbirg: Have you heard about microcystins being transported by ground water or into drinking water through well contamination?

A. Judy Westrick: Studies have shown that it is possible but not likely. The bacteria that outlines rivers and lakes tend to do a good job of biologically inactivating it. There might be instances where these could be changed or altered because of dredging, and then you do run a risk.

Q. Representative from Ohio EPA: What is the detection limit for the HPLC method?

A. Judy Westrick: The dynamic range is 0.1 parts per million (ppm) but frequently for HPLC, you can concentrate. Oftentimes HPLC might be looking at intact cell concentrations or they might be looking at lyophilized, so they'll concentrate that two or three orders. So they'll go from 1,000 mL to 1 mL or 100 mL to 1 mL.

C. Rocio Aranda-Rodriguez: However, using HPLC-photodiode array (PDA) won't attain the detection limits achieved by ELISA.

C. Judy Westrick: No, being at 0.1 ppm and then if you do the two or three orders of magnitude concentration, you can see what they are. You won't get a false positive with the PDA, which can happen with an ELISA. I consider both of these to be screening methods. They are something that allows you to come to a decision without having to wait for LC/MS(MS) and 2 days to get your results back.

Q. Jake Kann from Aquatic Ecosystem Sciences: What is the effectiveness of direct filtration as opposed to rapid sand filtration (meaning dual media sand and coal with perforated plate underneath)?

C. Hua Jiang: I think direct filtration means no sedimentation.

A. Judy Westrick: If you do direct filtration and you don't have any sedimentation, you will have a high load on your filters. To really remove the algae, you will have to make sure you are using really good coagulants to make sure you get a nice floc and sedimentation. Otherwise, if you go directly onto your filter, you are going to be backwashing regularly and too quickly and you are going to have breakthrough.

MMIC (Mitigating *Microcystis* in the Chesapeake): Treatment Options For a Cyanotoxin-Impacted Lake in Denton, Maryland

Allen Place, PhD, Professor, Institute of Marine and Environmental Technology, University of Maryland Center for Environmental Sciences Columbus Center

Dr. Allen Place thanked everyone and noted that he would be discussing the treatment options for a cyanotoxin-impacted lake in Denton, Maryland. During this 3-year grant of which Dr. Price is in a no-cost extension, he looked at various treatment options. He mentioned that he would talk about something that looked like it worked.

What are the successes and challenges of the mitigation effort of Microcystis in Chesapeake Bay and how do they help minimize and control cyanotoxins?

- Engaging all the players: Early on, it is important to engage all the players that you want to mitigate a lake with so that they have a full understanding of what you are attempting to do. The most important player for us was Bob Foote, the manager of the Girl Scouts camp on Lake Williston.

- Lake Willison: The Girl Scouts had owned this lake since 1935 and it was closed in 2010 and 2011 because of a *Microcystis* bloom that elevated the levels of cyanotoxins in the lake such that girls could no longer swim or canoe in it.
    - There was a complete dominance in August of *Microcystis*. From June through August, *Anabaena* dominated.
    - In this small 65-acre lake, 5 sampling sites were sampled every 2 weeks for 3 years. This lake runs across Route 16, which has a dam. When a storm comes through with sufficient rain, the dam will have to be opened or the road would be washed out.
    - Nutrients were coming from two feeder streams, Mill Creek and Beauchamp Branch.
    - The problem is nutrients.
        - 600 micromolar (µM) nitrate is coming into the lake every minute. This is in farmland that is well-managed with cover crops rotated. This probably is both a legacy issue as well as current practices of fertilizers being applied.
        - Phosphate levels are reasonably high but not ridiculously high.
        - The *Microcystis* and algae growing in the lake actually took the nitrate level from 600 to 0 µM over the summer for 2 years in a row. That drop changed in the third year of our study.
        - This 600 µM level is not unexpected based on the literature. Tom Fisher had shown in the coastal lagoons that depending on the percent watershed

that is in agricultural lands, 300–400 µM is expected. The watershed for this lake is about 60–80 percent agricultural land.

- The nutrients gave rise to the algal problem.
  - He put in for all 3 years SPATT samplers. Those were sampled every 2 weeks. Microcystins and anatoxin-a were detected in the lake.
  - They saw a drop in microcystins during that period of time.
    - Over the period of time of the study, about a million *Microcystis* cells were detected in periods when the lake was fully dead.
    - The level dropped to 10,000 *Microcystis* cells.
    - *Microcystis* was not eliminated but there was a 1–2 order of magnitude drop both in the level of microcystins and *Microcystis*.
    - The lake looks much cleaner now.

- What was the answer?
  - Nature supplied part of it through hydraulic flushing. Three major storm events (i.e., Hurricane Irene, Tropical Storm Sandy, and Tropical Storm Andrea) occurred during the period of study. The dam had to be opened during those three events.
    - After Dr. Place met with Kevin and Bob Foote, they decided to keep the lake emptied over the winter.
    - There were three lake emptyings and three lake fillings.
  - There was a green layer in the sediment of the drained lake.
    - In 2011 prior to the water temperature coming up, *Microcystis* came up as a mat off the sediment.
    - The hope was that by exposing the sediment to the full sun and by freezing (although it was not a very cold winter), the inoculum for the next bloom that might occur would be knocked down.
  - With the two drainings, there was an 80 percent volume flushout essentially of what was in the water system as well as what was on the sediment. This lake is about 0.5 million square meters in volume.
  - Dr. Place and his associates took sediments that following spring, after the sediment had been exposed to determine whether *Microcystis* could be recovered out of the sediment cores.
    - Cores were gradually warmed in the lab where sufficient nutrients were given and sufficient conditions were given for *Microcystis* to bloom.
    - *Microcystis* was not detected in the sediment after this full exposure in any of the cores (about 30 to 35 cores) from various sites. They saw *Synechococcus*, *Pseudanabaena*, and *Geitlerinema acutissimum*.
  - By allowing the sediment to be exposed, grasses regrew.
  - They planted barley bales along the feeder stream.

- There was a farm pond less than 0.25 miles from Lake Williston for which the farmer had deployed barley bales. The farmer had read the British literature on this.
    - The nutrients in the farm pond that is about 140 feet in length never developed *Microcystis* blooms.
    - They took the water from the farm pond, brought it to Williston, inoculated the bloom that had been occurring in 2011, and found that it basically killed *Microcystis*.
    - The same thing was observed in the laboratory culture. There was complete growth suppression from barley bale that had been deployed in the farm pond.
    - There are several British publications on using barley straw and also more recently, the characterization of the nature of the polyphenols being produced during fermentation.
- They deployed 550 bales of barley by summer interns along the feeder streams.
    - They chose feeder streams with the idea that as they rotted, the material would find its way into the lake.
    - The concern about putting in that amount of organic material is whether there would be big dissolved oxygen issues in the lake.
- During this same period of time, they had continuous monitoring on a daily basis from the start of the season to the end through Department of Natural Resources YSI monitoring. They could see the data online.
- A barley bale was put by a small substream (i.e., Willston footbridge site). It was shown that 10 percent of that water added to a culture medium basically inhibited the growth of *Microcystis*, except when the water temperatures started getting colder in September.
- Barley bales need to be deployed before the bloom. If the bloom is already occurring, they are not going to be very effective.
- The optimal temperature for producing this in situ is in the warmer range, from 23–28°C.

o One of the products that has been found in the fermentation of barley is pyrogallol. It is one of about 110 products from barley fermentation.
- They used this because the literature mentioned that if you take *Microcystis* and treat it with pyrogallol, it will actually induce an oxidative stress. The stress is shown with an increase in a particular gene, the peroxiredoxin gene.

- They envision what's occurring is that both the exposure of sediments to full sun and the molecules coming from barley straw fermentation are further stressing *Microcystis.*
    - *Microcystis* is already stressed out because of being at the surface with the games that they play in terms of shading everyone else in the process.
    - This effectively inhibits or potentially kills them outright in the field.

- Can we enhance this activity?
    - They looked into using two different varieties of white rot fungus. One of them is responsible for complete degradation of cellulose in lignin and the other only degrades the cellulose part of the lignin and actually leaves the polyolignols.
        - They inoculated about 12 bales with white rot fungus strain. They thought they saw 10-fold higher production of inhibitory activity with that inoculation.
        - With this, they hopefully would not have to use 550 bales. They might be able to get down to 50 bales in the process.
    - Bales need to be in open sunny areas so that their temperatures get up to 25 °C and they cannot get completely wet.

- Through natural processes of hydraulic flushing and the constant addition of an inhibitory molecule coming from degradation of barley, the Girl Scouts can now use the lake.

Questions

Q. Lesley D'Anglada: How do you discard the barley bales? What do you do with them when you are done?

A. Allen Place: They are more or less degraded. With natural fermentation and everything else, it becomes organic material that gets added to the lake when the lake is refilled. I can't say whether the hydraulic flushing with the 80 percent reduction of the inoculum was the major cause for the reduction in microcystin. There has been no reduction in nutrient input into the lake during the 3 years. The chlorophyll *a* that I use are as high as they were before. If you just go by chlorophyll *a* there has been a complete change in the assemblage. *Microcystis* is no longer dominant; it is less than 1 percent of the assemblage. We are starting to see more cryptophytes (hence the phycocyanin signal) and the diatom blooms earlier in the season.

Q. Lesley D'Anglada: What is the cost of using barley bales in this particular lake?

A. Allen Place: It was $1,000; it is $250 a barrel.

C. Lesley D'Anglada: That's good that it is effective and cheap.

C. Allen Place: The lake is currently still drained because a natural weir is being put in place that will maintain the depth of the lake. He will no longer have to open the sloughway. If a hurricane comes through, it will naturally empty. The next part of the experiment of not draining will happen in 2015.

C. Lesley D’Anglada: Thank you for sharing this preventative measure, since it needs to be applied before the blooms occur.

C. Hans Paerl: The nitrate decrease in Allen’s lake is very similar to what happened at Lake Taihu, and there it was inversely related to the size of the *Microcystis* blooms.

C. Allen Place: We have calculated the depletion rate of nitrate per day for chlorophyll *a*. It was 10 times higher in the first year than the second year. In the third year, we never saw complete reduction of the nitrate to 0. When nitrate gets taken up by algae, they have to secrete a hydroxyl group. When you have 600 µM nitrate, that is also going to be responsible for a large pH change.

Q. Kim Ward: Has the barley bale treatment method been shown to be potentially inhibitory to the proliferation of other potentially toxic genera such as *Anabaena*, *Planktothrix*, and *Aphanizomenon* or has this not been evaluated?

A. Kevin S.: Yes, but barley straw inhibition is species-specific. We have a list.

Q. Judy Westrick: Could Kevin share the list with everyone?

A. Kevin S.: It is in a publication from the mid-1990s and yes, I’ll make it available. There is more current information on species, but I do not have those (perhaps check Google Scholar).

A. Allen Place: There is very little effect on diatoms.

Q. Judy Westrick: What is the concentration of the pyrogallol?

A. Allen Place: We used 1 milligram per milliliter for pyrogallol content we used.

C. Kevin S.: We are also using barley straw in a brackish system and it also appears to inhibit *M. aeruginosa.*

Q. Representative from Ohio EPA: Does barley straw have algaecidic effects on *Planktothrix*?

A. Allen Place: We didn’t necessarily have *Planktothrix* in our lake, so I don’t know to what extent it has algaesidic effects. It’s not universal. *Microcystis* plays the game of coming to the surface. It is known to produce mycosporine amino acid because it is already dealing with heavy UV input. I think in some ways this is specific. We didn’t see a reduction in other algae.

I think Kevin has talked about using a clay flocculation strategy. The main take-home from that is that we would have to use at least 10-times higher levels than what have been described in the literature, and you have to do repeated treatments. We’ve also tried Phoslock in terms of removing phosphorus. Again, it works, but you have to do repeated treatments. We’ve also tried peroxide and it works, but you had to do repeated treatments.

Q. Regina Guthenbirg: Was there a noticeable change in lake color or total organic carbon? In other words, could the carbon from the barley be shading the bloom?

A. Allen Place: Yes, the lake is much more tannin in color. There was no reduction in chlorophyll *a* content in the lake with the barley treatment. Yes, there is a change in the color but the chlorophyll *a* content measured by the continuous monitoring system was more or less almost exactly identical.

Surface Water Sources and Their Watersheds: Options When You Have to "Drink Downstream from the Herd"

Thomas M. Conry, R.S., CLM, Program Manager, Production Quality Control and Watershed Programs, City of Waco Water Utilities

Mr. Thomas Conry thanked everyone. Mr. Conry noted that an old axiom is to not "drink downstream from the herd" so that you don't have hooves and other things in your water. He said that they can no longer begin worrying about source water quality. They have to know what changes are affecting Lake Waco.

What strategies have been implemented to improve Lake Waco drinking water quality?

- The taste and odor issues for Lake Waco water were pretty serious.
  - There was a lot of publicity about this.
  - Customers were very upset.
  - One customer left town and another threatened to leave because of the taste and odor episodes.
  - Because the taste and odor started to become infamous, the issue became very political.
  - When the subject of algal toxins entered the discussion, they actually reached a critical mass that required spending additional money as the problem developed.
  - The city and others were actively seeking the watershed resolution that was really too distant a solution time wise (in decades really).
  - In-lake management could address some of these symptoms successfully within a couple of years.

- Lake Waco provides adequate drinking water to meet the needs of Waco and the surrounding communities for the next 50 years. Few places in Texas have that luxury.
  - In 1872 Waco basically depended on shallow wells and springs.
  - In 1896 a well was drilled and water was hit in 1,830 feet, which is in the second trinity sands. That was the source of water for several years until about 1929, when Lake Waco was built. It was controversial.
  - In 1966 they had a new dam built. Many PL566 detention areas were built; they are erosion control structures.
  - There are about 40 PL566 structures in the watershed with an expected life of about 50 years. Most of them were put in during the 1960s, so they are in trouble.
  - The watershed is 1,640 square miles and to put it in perspective, Rhode Island is about 1,214 square miles and Delaware is about 2,489 square miles. The North Bosque River is 70 percent of the overall watershed of Lake Waco. That is where most of the confined animal feeding operations (CAFOs) or dairies are located. It has a significant influence on the lake.

- They have been monitoring Lake Waco since 1968 and they have been involved in the watershed since 1995.

- They used one of the first three chlorination systems in Texas. They have used monochloramines for more than 40 years and they have been proactive in the water arena.

- What were the major concerns?
    - The geosmin scum was a major problem.
        - They used PAC. Through trial and error they found one made with a wood that was relatively effective.
            - It could remove 40 to 80 percent of the taste and odor, but they had 1,600 ppm (and that really is the correct unit of measure) coming in.
            - When PAC is added, it creates a very short filter run. There are a lot of problems associated with the filter.
        - They would receive water from the intake on Lake Waco and then transport it via pipelines to their two water treatment plants. The geosmin levels at the intake were always lower than those in the inflow to the treatment plant.
            - Obviously they had cell lysing and things going on like that.
            - Getting rid of the algae while the algal cell is intact is very important.
        - Fifty percent of their budget annually was in response to taste and odor episodes.
        - In 2000 they had a stakeholder group that couldn't reach consensus.
        - The Texas Natural Resource Conservation Commission (which is the predecessor agency to Texas Commission on Environmental Quality), prepared a nutrient TMDL. The watershed was listed for both bacterial and nutrient effects.
        - In 2004–2008 they performed a comprehensive lake study and in 2005 they began 10 years of DAF planned pilot tests.
    - They have point source and nonpoint source pollution, manmade and natural pollution, and baseflows and stormflows. Mr. Conry is not aware of any mechanism that addresses all of these equitably to reduce effects.
        - For nonpoint source pollution, sources include lawns, septic systems, and agricultural fields. It is very difficult to monitor if there is variability of pollution contributions based on rainfall runoff.
        - Arsenic is naturally found in ground water.
        - The biggest issue and challenge is how a TMDL can be developed when the major effect is just less than 10 percent of the time through significant

stormflows. In Texas there is either very little water or way too much water. It is a complete flash flood scenario for flows.

- They started looking at the cost to address the algal toxins and to meet some of the upcoming regulations and items of concern that were being discussed in journals and by regulatory agencies.
    - They passed an $85 million bond. Part of that was to upgrade the filters at their two existing treatment plants and also to build a DAF.
    - EPA Region 6 has provided help in figuring out their treatment costs.
    - They found out that once they had the DAF, they actually were gaining about $10 million in revenue from neighboring communities that would buy wholesale water from them. That made the $85 million a little easier to pay back.

- The continuous mixing and increasing the predatory fish populations have been implemented.
    - It is the first lake in Texas to use aeration to have water column mixing.
    - The hybrid striped bass was a top-down biomanipulation that they have tried. They have stocked 43,000 fry per year since 2009. They are of legal limit and there is great fishing right now.

- They have not figured out how they can add calcium during storms because they would need train cars full of calcium to bind the orthophosphate so that it would not be such a problem. Dr. Ken Wagner found that they are actually getting four to five times the amount of phosphorus into the system than the lake can actually assimilate. They need to do something to reduce the phosphorus in the lake.
    - They have covered DAF cells because of the odor.
        - They create a slight vacuum and pump that air up and into the aerators in the lake itself.
        - They are getting rid of the odor issue that would be associated with a DAF process if it were uncovered, and they also get the benefit of having the aeration across the face of the dam.

- They found some watershed options, including urban runoff controls. They are looking at manure management with CAFOs.

- They have the issue of reservoir maintenance with the PL566s. So far, they've done really well but they are not sure what will happen when they are gone.

- The following are benefits of using DAF with ozone:
    - Removing some micropollutants.
    - Taking the trihalomethanes below 40 parts per billion (ppb). (They are about 9 ppb now.) Taking the haloacetic acids to 20 ppb.

- Overall geosmin is much lower.
- They no longer have taste and odor issues because they started using ozone coupled with DAF.
  - The *Waco Tribune Herald* held a water tasting contest, including bottled water, just as they had put the DAF online. They did not have the ozone going at the time and they we were still trying to dial in on the DAF process. They won the contest.
  - Aeration and flotation are good because geosmin is a semivolatile oil, so they are stripping the column of that oil. There is a significant decrease in the amount of organics and the influence on the taste.
  - It's great when something actually works out and things exceed your expectations.
- Water sales are up, complaints are gone, they are using less chemicals, their filter run times are 100+ hours (which is great), and no cyanotoxins have been detected (they test on the inflow to the DAF and the outflow from the DAF) except for a couple of times when the ozone was on the blink, but that happens infrequently.

- The bad news is:
  - They are in debt.
  - They had a steep learning curve because it took them 2 years to be very comfortable with the DAF ozone process.
  - They've addressed some of the issues in the lake and they've resolved the taste and odor issues, but they still have cyanotoxins.
    - They are performing increased monitoring and working closely to resolve public health concerns.
    - They still have watershed problems.
    - The lake is still basically an algae factory, so they have fixed the symptoms but maybe not the source.

- DAF is used in a lot of treatment plants; this is the only one in Texas and the fourth one in the United States, but there could be more.
  - They get 90 million gallons per day treatment capacity; previously this was about 60. This is important because the construction costs for the DAF were roughly 60 cents per gallon. So, 60 cents per gallon and 90 million gallons is about $54 million, and that is about what this cost.
  - If they were to build a conventional system, it would cost $1.50 a gallon, so that 90 million gallons would have been closer to about $140 million just because of the extra size needed for sedimentation, concrete, and so on.
  - Supervisory control and data acquisition (SCADA) operates the DAF. The DAF is only staffed 8 hours per day, which is primarily for routine maintenance.

- To remove almost all of the organic material, the DAF takes about 30 minutes whereas the conventional sedimentation basin takes about 6 hours.
- The nephelometric turbidity unit (NTU) turbidity at the end of the DAF treatment process is usually in the 0.7 to 0.5 range.

Questions

Q. Lesley D'Anglada: Thank you for the new perspective on drinking water treatment dealing with taste and odor problems. How many people does this plant serve?

A. Thomas Conry: The plant serves 135,000 in our city but we also provide water to several communities around us, so we provide water for 200,000 to 250,000 people.

Q. Hua Jiang: What was your typical geosmin level at your plant influent? How much wood-based GAC did you use, in mg/L?

A. Thomas Conry: Our geosmin levels fluctuate even hourly. We were normally in the 100 ppb range and then we would go up to 1.6 ppm, so that was pretty high. For the PAC, we were limited by our equipment, so we were pumping in about 40 ppm. It was really ugly. We had a ring around our treatment basins. It was a very high concentration. Then, of course, you have to drop everything out so once the DAF came in and we turned it online, we were able to completely stop using the PAC and started taking all of the basins downs and cleaning them out.

Q. Representative from Ohio EPA: What concentration of cyanotoxins are you seeing in your lake? What toxins are you seeing in your lake (added by Lesley)?

A. Thomas Conry: We have the privilege of having just about every kind of cyanotoxin and cyanobacteria that there is. We have *C. raciborskii*, which is one of the algae du jour. We do have microcystins, cylindrospermopsin and we are testing for those. We have recently gotten the saxitoxin, so we are using that. We haven't used the euglenophycin that Judy mentioned; we haven't tried to do any of that. Most of our stuff is the antibody reaction, so that we are looking at a quick-and-dirty survey with a fairly rapid result, so we have a chance to do something if we find something. It has been very encouraging to not find anything post-DAF treatment.

Q. Lesley D'Anglada: What concentrations did you detect?

A. Thomas Conry: We were pretty much all over the board with that. I really don't remember what it was but it was much higher than the detection limit.

Q. Hua Jiang: Which filter media are you using and are you considering your filters to be biofilters?

A. Thomas Conry: We are using anthracite and sand. At this point we are not using biofiltration. We are doing pilot tests and the DAF with two columns we constructed, which are 1 square foot and 10 feet tall. We are taking DAF water and looking at the transition process and then this equilibration of the community going to a biological filtration. We are working with both Baylor University and University of Massachusetts professors. We are going to use biological filters. I see that as the best opportunity to provide our customers with the best product, but we are not there yet.

C. Kevin S.: If the lake (1,000 acres) is an "algae factory," placing > 5,000 barley straw bales (approximately $15,000–$20,000) upstream of the algae might be a cheap exploratory approach.

C. Thomas Conry: The lake's surface area is more than 9,000 acres, so with a 1,640 square-mile watershed, I don't think we can get enough barley straw.

Q. Kim Ward: From your experience so far, does it seem that ozone destroys cyanotoxins more efficiently than DAF?

A. Thomas Conry: Yes, I think the ozone is tearing the molecules apart. With aeration, these things are amazing. It looks almost like milk with the bubbles in the water. There really is a tremendous amount of flotation that occurs. I really do think that this is like aeration on steroids. We have not done a sample between the DAF process and the ozone process. We could go ahead and get a couple of samples and do that—and I think we probably will do that. I have not separated those two processes. We've just had inflow and outflow. I think it is ozone.

Q. Hua Jiang: Tulsa did quite a bit of work on biofiltration pilot studies and I will be very happy to share some of our experience with you if you want. hjiang@cityoftulsa.org.

A. Thomas Conry: I'd really like to talk to you. If the climate is nice, I can come up there or vice versa.

C. Hua Jiang: Sounds good.

Q. Jianwei Yu: Have you detected the extracellular geosmin concentration? In most cases, geosmin was retained in the intracellular form.

A. Thomas Conry: Yes, we actually did. Dr. Landover at Baylor had theorized that this geosmin might be a defense mechanism for the algae. We just don't know. We looked and we didn't see any other sources of geosmin. The literature often refers to the actinomycetes as a source. Ken Wagner rigged an underwater camera and television screen where we could go along in a boat and look for some actinomycetes mats, and we didn't find any at all. I don't know. I think there is an extracellular portion to this, but our work is mainly trying to figure out what is going on and what to do about it.

C. Lesley D'Anglada: Thank you very much, Tom.

C. Thomas Conry: Thank you.

Closing Remarks

Lesley V. D'Anglada, DrPH, EPA Office of Science and Technology, Health and Ecological Criteria Division

Dr. D'Anglada hoped that all the participants received a good overview of the factors that promote algal blooms and the different techniques that can be used to control and mitigate algal blooms and cyanotoxins in surface waters and drinking waters. The presenters also gave us information on what has been successful in controlling algal blooms and cyanotoxins in surface water and in drinking water. The presentations are posted on EPA's CyanoHABs website under the "Control and Treatment" tab at: http://www2.epa.gov/nutrient-policy-data/cyanobacterial-harmful-algal-blooms-cyanohabs. She thanked the speakers for their great presentations and the participants for their interest in the presentations and discussions. Dr. D'Anglada is looking forward to receiving feedback on the webinar. She asked the participants to send her an email with their comments on what worked, what didn't work, what can be improved, and what other topics she can prepare and share with them in the future. Dr. D'Anglada thanked everyone for joining her today.