

Harmful Algal Blooms: A Case Study in Two Mesotrophic Drinking Water Supply Reservoirs in South Carolina

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Abstract. Algal blooms can be harmful and a nuisance in a variety of aquatic ecosystems, including reservoirs and lakes. Cyanobacterial (blue-green algae) harmful algal blooms are notorious for producing both taste-and-odor compounds and potent toxins that may affect human health. Taste-and-odor episodes are aesthetic problems often caused by cyanobacterial-produced organic compounds (geosmin and methylisoborneol) and are common in reservoirs and lakes used as source water supplies. The occurrences of these taste-and-odor compounds and toxins (like microcystin) can be sporadic and vary in intensity both spatially and temporally. Recent publications by the U.S. Geological Survey address this complexity and provide protocols for cyanotoxin and taste-and-odor sampling programs.

A case study conducted by the U.S. Geological Survey, in cooperation with Spartanburg Water, monitored two mesotrophic reservoirs that serve as public drinking water supplies in South Carolina. Study objectives were (1) to identify spatial and temporal occurrence of the taste-and-odor compound geosmin and the cyanotoxin microcystin and (2) to assess the associated limnological conditions before, during, and after these occurrences. Temporal and spatial occurrence of geosmin and microcystin were highly variable from 2007 to 2009. The highest geosmin concentrations tended to occur in the spring. Microcystin tended to occur in the late summer and early fall, but occurrence was rare and well below World Health Organization guidelines for finished drinking water and recreational activities. No current U.S. Environmental Protection Agency standards are applicable to cyanotoxins in drinking or ambient water. In general, elevated geosmin and microcystin concentrations were the result of complex interactions between cyanobacterial

community composition, nutrient availability, water clarity, hydraulic residence time, and stratification.

Introduction

This manuscript describes preliminary findings of an ongoing study of Lake William C. Bowen (Lake Bowen) and Municipal Reservoir #1 (Reservoir #1), two drinking-water reservoirs in Spartanburg County, South Carolina. Spartanburg Water treats water from Lake Bowen and Reservoir #1 and distributes the treated drinking water to the Spartanburg area of South Carolina. These reservoirs, which are impoundments of the South Pacolet River, were characterized in 2006 by the South Carolina Department of Health and Environmental Control (SCDHEC) as being fully supporting of all uses based on established criteria. Nonetheless, Spartanburg Water has experienced periodic taste-and-odor problems in their finished water due to the presence of geosmin in the reservoir source water (Journey and Abrahamsen, 2008) and recognized the need for further information on the limnological conditions associated with these taste-and-odor episodes. In addition, Spartanburg Water is concerned about the potential that microcystin, a cyanotoxin, also may be present.

This cooperative U.S. Geological Survey (USGS) and Spartanburg Water study monitored Lake Bowen and Reservoir #1 (1) to identify spatial and temporal occurrence of geosmin and microcystin and (2) to assess the associated limnological conditions before, during, and after these occurrences. Spartanburg Water is using information from this study to develop management strategies to reduce (short-term solution) and prevent

(long-term solution) the occurrence of taste-and-odor episodes and cyanotoxin occurrence.

Background and Related Work

Occasional taste-and-odor episodes in public water systems that use surface-water supplies are common throughout the United States (Taylor and others, 2005). Cyanobacteria and actinomycetes bacteria are both known to be important sources of geosmin and 2-methylisoborneol (MIB), the compounds most frequently associated with taste-and-odor episodes in drinking water supplies (Watson, 2003; Zaitlan and Watson, 2006). Of the two possible sources, most taste-and-odor episodes in lakes and reservoirs are related to cyanobacterial blooms, which are triggered by certain environmental factors, such as elevated nutrients and low light conditions (Izaguirre and others, 1982; Smith, 1983; Downing and others, 2001; Pearl and others, 2001; Havens and others, 2003). Geosmin and MIB are metabolic by-products of cyanobacteria and actinomycetes that have an earthy, musty smell that is detectable to humans at concentrations of about 10 parts per trillion (Wnorowski, 1992). Geosmin and MIB do not pose human health risks, but their presence in drinking water is aesthetically unpleasant. However, some of the same cyanobacteria that produce geosmin and MIB also are capable of producing toxins, commonly called cyanotoxins, which do have known effects on human health (Taylor and others, 2005; Graham and others, 2008).

In addition to thermal stratification and other physical processes, water-quality conditions, such as transparency, concentrations and ratios of major nutrients, and suspended solids concentrations, can favor or inhibit cyanobacterial dominance and subsequent geosmin or MIB production in reservoirs. Long-term monitoring is required to capture the seasonal and annual variability in limnological conditions and associated in-lake algal response and to accurately assess the influence of these factors on cyanobacterial dominance. This USGS study monitored Lake Bowen and Reservoir #1 over a 2.5 year period to assess the conditions associated with cyanobacterial abundance and the occurrence of geosmin, microcystin, and MIB.

Water samples were collected at locations near the surface and near the bottom below thermocline along two transects in Lake Bowen and three transects in Reservoir #1 from May 2007 through June 2009. Water samples were analyzed for nutrients, total suspended solids, dissolved organic carbon, chlorophyll *a* and algal biomass, major ions, iron, and manganese by the USGS National Water Quality Laboratory in Denver, Colorado.

At least 36 states in the United States have anecdotal reports of poisonings of wild and domestic animals and/or humans associated with toxins produced by cyanobacterial blooms (Graham and others, 2009). Cyanotoxins are harmful to a wide range of aquatic and terrestrial organisms and can affect the liver, nerves, skin or gastrointestinal tract of mammals, including humans. The 2007 National Lake Assessment by the U.S. Environmental Protection Agency detected microcystin, a common cyanotoxin, in almost every state in the Midwestern and Eastern United States. In September 2009, the U.S. Environmental Protection Agency placed three cyanotoxins (anatoxin, cylindrospermopsin, and microcystin) on the Contaminant Candidate List 3 for the development of drinking water standards (U.S. Environmental Protection Agency, 2009). A study in the Midwestern United States demonstrated that geosmin and MIB frequently co-occur with cyanotoxins in lakes and reservoirs, though most species of cyanobacteria are not capable of producing both taste-and-odor compounds and cyanotoxins simultaneously (Graham and others, 2009). The occurrences of these toxic and taste-and-odor compounds can be sporadic and vary in intensity both spatially and temporally. Recent publications by the U.S. Geological Survey address this complexity and provide protocols for cyanotoxin and taste-and-odor sampling programs (Graham and others, 2008; Graham and others, 2009).

Experimental Design

Additionally, samples were analyzed for geosmin, MIB, and microcystin by the USGS Kansas Organic Geochemistry Research Laboratory and for algal taxonomy by a private contract laboratory. Reservoir samples were collected and processed using USGS protocols and guidelines to ensure high quality, representative samples (U.S. Geological Survey, variously dated; Graham and others, 2008). The samples were collected using pre-cleaned Van Dorn samplers. Each depth sample was composited in pre-cleaned depth-delegated churns to ensure adequate mixing. Transparency (Secchi disk depth) and light attenuation were measured at the time of sampling. Field properties of fluorescence (total chlorophyll), specific conductance, pH, dissolved oxygen, and water temperature were measured at 1-meter (3.3 feet) intervals, including the sampled depths, at each transect at the time of sampling using a field-calibrated multi-parameter sonde. The sampling frequency was seasonally variable – a greater number of samples were collected during the peak algal growth period (spring to late summer).

Discussion

Lake Bowen and Reservoir #1 are relatively small and shallow (1,534 acres and 16 feet mean depth; 272 acres and 8 feet mean depth, respectively), with short residence times (mean of 254 and 35 days, respectively). Both reservoirs are classified as mesotrophic, with nutrient levels that tend to be below 0.02 and 0.40 milligram per liter (mg/L) for total phosphorus and total nitrogen, respectively, and surface chlorophyll *a* concentrations that tend to be below 10 micrograms per liter ($\mu\text{g/L}$). Low total-nitrogen-to-total-phosphorus ratios (below 29:1) were consistent with environmental conditions reported to favor cyanobacterial dominance (Smith, 1983; Havens and others, 2003). Reservoir #1 has higher total phosphorus, shorter residence times, and lower transparency than Lake Bowen, but other characteristics (for example, phytoplankton biovolumes, chlorophyll *a*, nitrogen species, and basic water chemistry) were similar between reservoirs.

In general, temporal occurrence of geosmin and microcystin were highly variable from May 2007 to June 2009, with the highest geosmin concentrations for the period of this study occurring in April and May of 2008 in both reservoirs. MIB rarely was detected, and when present was detected at very low concentrations. During the study period, higher geosmin concentrations occurred in the spring (March-May). Cyanobacteria were present in both reservoirs during this peak geosmin period, but did not dominate the algal community (less than 20 percent of total algal biovolume). However, during the period of highest geosmin concentrations in April and May 2008, cyanobacterial genera with known geosmin-producing species comprised about 80 percent of the total cyanobacterial biovolume. This pattern tended to recur during spring months in 2007 and 2009 along with corresponding increases in geosmin. These data suggest that the growth of geosmin-producing genera over non-geosmin-producing genera of cyanobacteria is favored during the spring months. However, greater cyanobacterial abundances did not co-occur with higher geosmin concentrations.

Microcystin rarely was detected in either reservoir, but microcystin concentrations of 0.30 and 0.40 $\mu\text{g/L}$ in Lake Bowen and Reservoir #1, respectively, were observed during the summer immediately following the spring peak in geosmin in 2008. Microcystin concentrations were below the World Health Organization (WHO) finished drinking water guidelines of 1.0 $\mu\text{g/L}$ and well below the WHO recreational guidelines of 20 $\mu\text{g/L}$ (Chorus and Bartram, 1999). During the time period of detectable microcystin in 2008, cyanobacteria dominated the algal community, comprising greater than 50 percent of total algal

biovolume. Periods of greater cyanobacterial abundances in Lake Bowen and Reservoir #1 occurred with warm water temperatures, stable water column, low nitrogen concentrations, low total nitrogen to total phosphorus ratios, and high hypolimnetic total phosphorus concentrations.

In Lake Bowen, higher geosmin concentrations were observed during periods of deeper transparencies (especially transparencies greater than 2 meters (6.6 feet)) and greater euphotic zone depths. Reservoir #1 had a similar relation between euphotic zone depth and geosmin, but not with transparency. These deeper transparencies in the spring were consistent with a “clear water phase” commonly attributed to heavy zooplankton grazing – a process common to mesotrophic reservoirs (Scheffer, 2004). Zooplankton grazing has been reported to induce stress in cyanobacteria and may trigger the release of cellular geosmin, either as a defense mechanism or as a result of cell lysis (Durrer and others, 1999; Jüttner and Watson, 2007). Slower flushing rates and longer residence times have been reported to promote zooplankton community growth, thereby enhancing the clear-water phase (Durrer and others, 1999; Jüttner and Watson, 2007). Although the mean annual residence time of water in Lake Bowen was 0.69 year – complete reservoir flushing about once every 7 months – in 2008, the residence time was a year because of an extended drought. Zooplankton data are not available for Lake Bowen and Reservoir #1 to directly confirm this process.

Ongoing Work

Although Lake Bowen and Reservoir #1 exhibit good water quality and meet SCDHEC nutrient and chlorophyll numeric criteria for lakes and reservoirs, periodically the aesthetic problem of taste and odor occurs in these reservoirs. In general, cyanobacterial abundance and elevated geosmin and microcystin concentrations appeared to be complexly interrelated with nutrient availability, type and density of cyanobacterial species, transparency, mean residence time, and degree of reservoir stratification. Further analysis of the complex relations among geosmin and microcystin occurrence and associated environmental conditions in Lake Bowen and Reservoir #1 is ongoing. At present, bivariate and multivariate relations are being explored among chemical, biological, and physical factors and geosmin concentrations and cyanobacteria abundance.

In response to the aesthetic problem of taste and odor, Spartanburg Water began this study to understand the limnological conditions of their source water and use that knowledge to design appropriate treatment systems and management strategies, following guidelines from

American Water Works Association for integrated taste-and-odor management (Taylor and others, 2006). Integrated watershed management plans designed to control the environmental conditions that promote the occurrence of cyanobacteria and associated nuisance compounds have been reported to serve as a proactive means of reducing future problems with harmful algal blooms (Brookes, J.D., Daly, R., Regel, R.H., Burch, M., Ho, L., Newcombe, G., Hoefel, D., Saint, C., Meyne, T., Buford, M., Smith, M., Shaw, G., Guo, P.P., Lewis, D., Hipsey, M., 2008, Reservoir Management Strategies for Control and Degradation of Algal Toxins: American Water Works Association, 241 p.

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