GEOSMIN OCCURRENCE IN LAKE WILLIAM C. BOWEN AND MUNICIPAL RESERVOIR #1, SPARTANBURG COUNTY, SOUTH CAROLINA, 2005 TO 2006

Celeste A. Journey, Jane M. Arrington, Rebecca West, John W. Westcott, and Ken Tuck

AUTHORS: Celeste A. Journey, U.S. Geological Survey, South Carolina Water Science Center, Stephenson Center, Suite 129, Columbia, SC, 29210; 803-750-6141; cjourney@usgs.gov; Jane M. Arrington, Ph.D.,Technical Services Project Manager, Spartanburg Water, P.O. Box 251, Spartanburg, SC, 29304, 864-580-5690; jarrington@spartanburgwater.org; Rebecca West, Director of Technical Services, Spartanburg Water, P.O. Box 251, Spartanburg, SC, 29304, 864-580-5648; John W. Westcott, Water Quality Manager, Spartanburg Water, 297 South Avenue, Spartanburg, SC, 29306, 864-253-9304; and Ken Tuck, Water Resources Manager, Spartanburg Water, 390 Spartanburg Waterworks Road, Chesnee, SC, 29323, 864-578-2764.

REFERENCE: Proceedings of the 2008 South Carolina Water Resources Conference, held October 14-15, 2008, at the Charleston Area Event Center

Abstract. The U.S. Geological Survey, in cooperation with the Spartanburg Water, conducted water-quality monitoring in Lake William C. Bowen (Lake Bowen) and Municipal Reservoir #1 (Reservoir #1), Spartanburg County, South Carolina, periodically from August 2005 to October 2006. Both reservoirs serve as public drinking water supplies. The focus of the monitoring was to identify spatial occurrence and distribution of geosmin, a taste-and-odor compound, and to assess associated limnological conditions at the time of sampling. Findings from the monitoring effort demonstrated that trophic state parameters (total phosphorus, transparency, and chlorophyll a) and established numerical nutrient criteria traditionally used in evaluating source-water conditions did not correlate with the phytoplankton community structure, specifically, cyanobacterial (blue-green algae) dominance and potential geosmin production, in these reservoirs.

During the surveys, Lake Bowen and Reservoir #1 had nutrient and chlorophyll *a* concentrations well within the South Carolina Department of Health and Environmental Control established numerical criteria for lakes and reservoirs. Computed trophic state indices estimated the trophic status of Lake Bowen and Reservoir #1 as mesotrophic. The total nitrogen to total phosphorus ratios in Lake Bowen and Reservoir #1 varied among seasons and among sites. The total nitrogen to total phosphorus ratios often were above 22:1, which indicated less probability of dominance by nitrogen-fixing cyanobacteria. However, cyanobacteria consistently dominated the phytoplankton community (based on abundance) and several known geosmin-producing genera of cyanobacteria were identified in Lake Bowen and Reservoir #1, with the most abundant being *Synechococcus sp.1* and *Lyngbya limnetica*.

Although known geosmin-producing cyanobacteria were identified throughout Lake Bowen and Reservoir #1, the spatial occurrence and level of geosmin were highly variable within and among sampling events and did not correspond directly to cyanobacterial densities. Geosmin concentrations were lower in samples from sites in Reservoir #1 compared to Lake Bowen. The highest geosmin concentration of 0.039 microgram per liter (between 0.002 to 0.010 microgram per liter cause noticeable levels of taste and odor) was measured near the lake bottom in Lake Bowen during August 2005 when stratified conditions existed; the second highest gesomin concentration of 0.030 micrograms per liter was measured near the lake surface in Lake Bowen during May 2006 when the degree of stratification was weak. In general, elevated geosmin concentrations appeared to be complexly interrelated with nutrient dynamics (especially the type and concentration of the inorganic nitrogen), type and density of cyanobacterial species, water temperature, and the degree of stratification.

INTRODUCTION

The U.S. Geological Survey (USGS), in cooperation with Spartanburg Water, conducted three spatial surveys of limnological conditions, which included sampling and analysis for geosmin and 2-methylisoborneol (MIB), in Lake William C. Bowen (Lake Bowen) and Municipal Reservoir #1 (Reservoir #1), Spartanburg County, South Carolina, from August 2005 to October 2006. The focus of the surveys was to identify spatial distribution and occurrence of geosmin and MIB. Associated limnological conditions at the time of sampling, including common trophic state indicator constituents (nutrients, transparency, and chlorophyll *a*), algal community structure, and the degree of stratification, also were evaluated. The purpose of this paper is to describe the findings from the three surveys of limnological conditions related to geosmin and MIB occurrence in Lake Bowen and Reservoir #1.

BACKGROUND

Throughout the United States, occasional taste-and-odor episodes in public water systems that use surface-water supplies are common (Paerl and others, 2001; Smith and others, 2002; Havens and others, 2003; Graham and others, 2004; Westerhoff and others, 2005; Zaitlin and Watson, 2005; Taylor and others, 2006; Christiansen and others, 2006). Compounds that produce taste and odor in drinking water are not harmful; therefore, taste-and-odor problems are a palatability, rather than health, issue for drinking water systems.

Second to chlorine, earthy, musty odors produced by the compounds geosmin and MIB are responsible for repeated taste-and-odor problems in drinking water (Suffet and others, 1996). Geosmin and MIB are produced by certain algae and bacteria. Human sensitivity for these compounds is extremely low; human taste-and-odor threshold is from 2 to 10 parts per trillion (nanograms per liter) for geosmin and 15 parts per trillion for MIB (Wnorowski, 1992; Young and others, 1996, respectively).

Most surface-water taste-and-odor episodes are related to algal blooms, which are triggered by environmental conditions. Certain genera of Cyanophyta are known to be important sources of geosmin and MIB (Taylor and others, 2006; Christiansen and others, 2006). Cyanobacterial blooms can be stimulated by human activity that introduces excessive nutrients or modifies the water residence time in a lake or reservoir (Christensen and others, 2006; Graham and others, 2004; Havens and others, 2003; Downing and others, 2001; Paerl and others, 2001). Changes in release patterns from existing reservoirs may reduce the flow and mixing of water, leading to stronger temperature stratification during the hotter months of the year. Human activity that contributes nutrients, mainly phosphorus and nitrogen, to reservoirs can fuel the growth of algae and the development of blooms. The nutrients may come from a variety of sources in a watershed, including soil erosion, urban runoff, irrigation drainage, failing septic or sewer systems, or point sources such as wastewater-treatment-plant outfalls or animal feedlots. Additionally, three genera of Actinomycetes, a type of bacteria that is found ubiquitously in soils but also occurs in the aquatic environment, is an important source of geosmin and MIB (Zaitlin and Watson, 2005).

APPROACH AND METHODS

Because past research identified water-column stability as a possible factor related to the occurrence of cyanobacterial blooms, the depth profiles of water temperature, specific conductance, dissolved oxygen, and pH were used to evaluate degree of stratification at the time of sampling. Additionally, *in vivo* fluorescence as total chlorophyll was measured. These characteristics were measured at the time of sampling in 1-meter depth intervals at three to five points along the transect at each site.

Sample collection activities were conducted in August to September 2005, May 2006, and October 2006. Water-column samples were collected at a near-surface depth (1 meter) and bottom depth (2.5 to 7 meters) using a point sampler (an acrylic Kemmerer). For each depth, the collected subsamples were composited to ensure the sample was representative of the entire transect and the composited sample was mixed in plastic churns to ensure adequate sampling of the particulate material. Water samples were analyzed for total and dissolved forms of nutrients, dissolved organic carbon, chlorophyll *a*, and phytoplankton ash-free dry mass (as estimate of algal biomass) by the USGS National Water Quality Laboratory (NWQL) in Denver, Colorado. Water samples also were analyzed for geosmin and MIB by the USGS Organic Geochemistry Research Laboratory (ORGL) in Lawrence, Kansas. Samples that were used to enumerate and identify phytoplankton were collected simultaneously with water samples for the other constituents. Taxonomic characterization and enumeration of phytoplankton in samples were conducted and classified at the species level, when possible, to identify blue-green algae that were potential geosmin producers. Phytoplankton data were analyzed to determine if the algal community structure corresponded to the indicated trophic status based on nutrient and chlorophyll *a* levels at the time of sampling.

Total nitrogen (TN), total phosphorus (TP), and chlorophyll *a* concentrations were compared to established numerical criteria and trophic state indices to assess the limnological conditions in the reservoirs. The South Carolina Department of Health and Environmental Control (SCDHEC) has established numerical nutrient criteria to evaluate the water quality in lakes and reservoirs: TP concentrations less than 0.06 mg/L (milligrams per liter); TN concentrations less than 1.50 mg/L, chlorophyll *a* concentrations less than 40 µg/L (microgram per liter), and turbidity less than 25 NTUs (nephelometric turbidity units) (South Carolina Department of Health and Environmental Control, 2004). Lakes and reservoirs that have nutrient and chlorophyll concentrations that exceed these criteria are considered to be impaired due to nutrient enrichment. Nutrient concentrations, chlorophyll *a* concentrations, and transparency were applied to empirically derived trophic state indices (TSIs) developed by Carlson (1977) that use log transformations of these constituent concentrations as estimates of algal biomass on a scale of 0 to 110.

RESULTS

The degree of stratification was demonstrated by temperature-depth profiles and computed relative thermal resistance to mixing. Higher thermal resistance to mixing between the epilimnion and hypolminion indicated more stable water column conditions and stronger degree of stratification. Seasonal occurrence of thermal stratification (August to Septmber 2005; May 2006) and de-stratification (October 2006) was evident in the depth profiles of water temperature in Lake Bowen. The most stable water-column conditions occurred in Lake Bowen during the August to September 2005 survey. The least stable water-column conditions (de-stratified) occurred in Lake Bowen during the October 2006 survey and in Reservoir #1 during all three surveys. In stratified areas of the lake, the thermocline was located at a lower depth (between 5 and 6 meters) during the May 2006 survey than during the August to September 2005 survey (between 4 and 5 meters).

Changes with depth in dissolved-oxygen concentrations (decreased to near anoxic conditions in the hypolimnion), pH (decreased), and specific conductance (increased) with thermal stratification indicate that Lake Bowen was exhibiting characteristics common to both mesotrophic and eutrophic conditions. During stratified periods, increases in pH near the surface can be explained by increased photosynthetic activity in the epilimnion. Decreased pH and dissolved oxygen in the hypolimnion often are related to increased activity of respiration and decomposition processes. Increased specific conductance could be related to remobilizaiton of phosphorus, trace elements, and ammonia in the anoxic hypoliminion.

For the three limnological surveys, surface concentrations of chlorophyll *a* and TP met all established numerical criteria for South Carolina, indicating good water-quality conditions. Overall, the computed trophic state indices indicated that mesotrophic conditions were present in Lake Bowen and Reservoir #1. Total organic nitrogen concentrations (total Kjeldahl nitrogen minus ammonia) remained relatively constant within the surveys and ranged from 0.15 to 0.36 mg/L during the period of study. Nitrate was the dominant inorganic species of nitrogen during May 2006; ammonia was the dominant species during the August to September 2005 and October 2006 surveys. In Lake Bowen, TP concentrations in bottom samples during the May 2006 and October 2006 surveys (0.009 to 0.014 mg/L) were lower than those identified for the August to September 2005 survey (0.022 to 0.034 mg/L). Greater chlorophyll *a* concentrations were identified in samples from the May 2006 survey (6.8 to 15 μg/L) than in the August to September 2005 (1.2 to 6.4 μg/L) and October surveys (5.6 to 8.2 μg/L) at all sites in Lake Bowen and Reservoir #1. The TN to TP ratios in Lake Bowen and Reservoir #1 varied among seasons and among sites. The TN:TP ratios often were above 22:1, which indicated less probability of dominance by nitrogen-fixing cyanobacteria (Smith and others, 2002).

For all three surveys, MIB concentrations were below the detection level of 0.005 μg/L. Of the three surveys, the highest concentrations of geosmin were measured during the August to September 2005 survey in samples collected near the bottom of Lake Bowen when stratified conditions existed. Elevated geosmin concentrations ranged from 0.016 to 0.039 μg/L at sites and depths that had elevated ammonia and TP concentrations in Lake Bowen. Geosmin levels were lower in samples from sites in Reservoir #1 than those from Lake Bowen. The lowest geosmin concentrations for Lake Bowen were measured during the October 2006 survey (less than 0.005 to 0.007 μg/L) when de-stratified conditions existed.

Total phytoplankton densities were similar in samples collected near the surface and bottom depths at each site. Members of the division Cyanophyta (also known as cyanobacteria or blue-green algae) were present in the greatest abundance of all the phytoplankton communities in Lake Bowen and Reservoir #1 at all sites and sampling depths during all three surveys. For the three surveys, the abundance of cyanobacterial cells in the Cyanophyta division as part of the total phytoplankton community ranged from 91 to 99 percent among all sites and depths. Even with the removal of the picoplankton species (species that have extremely small cell sizes) from consideration, the percentage of cyanobacterial cells in the Cyanophyta division as part of the total phytoplankton community was greater (45 to 97 percent) than the percentage of other algal divisions.

Several known geosmin-producing genera were identified in Lake Bowen and Reservoir #1, with the most abundant being *Synechococcus sp.1* and *Lyngbya limnetica*. Overall, the members of the division Cyanophyta identified in these samples were dominated by the picoplankton members of the algal family Chroococaceae (especially species within the genus *Synechococcus)*, *Cyanogranis ferruginea*, and *Lyngbya limnetica*. No pattern was identified between algal cell density of known geosmin-producing genera of cyanobacteria and the geosmin occurrence during the three surveys.

DISCUSSION

During the surveys, Lake Bowen and Reservoir #1 had nutrient and chlorophyll *a* concentrations well within numerical criteria for lakes and reservoirs established by the SCDHEC. Computed trophic state indices estimated the trophic status of Lake Bowen and Reservoir #1 as mesotrophic. The TN to TP ratios in Lake Bowen and Reservoir #1 usually were above 22:1, which indicated less probability of dominance by nitrogen-fixing cyanobacteria. However, cyanobacteria consistently dominated the phytoplankton community (based on abundance) and several genera of cyanobacteria that are known geosmin producers were identified in Lake Bowen and Reservoir #1. The most abundant geosmin-producing cyanobacteria were *Synechococcus sp.1* and *Lyngbya limnetica*.

Although known geosmin-producing cyanobacteria were identified throughout Lake Bowen and Reservoir #1, the spatial occurrence and level of geosmin were highly variable within and among sampling events and did not correspond directly to cyanobacterial densities. Geosmin concentrations were lower in samples from sites in Reservoir #1 compared to Lake Bowen. The highest geosmin concentration of 0.039 μg/L (between 0.002 to 0.010 μg/L cause noticeable levels of taste and odor) was measured near the lake bottom in Lake Bowen during August 2005 when stratified conditions existed; the second highest gesomin concentration of 0.030 μg/L was measured near the lake surface in Lake Bowen during May 2006 when degree of stratification was weak.

Findings from the surveys demonstrated that trophic state parameters (TP, transparency, and chlorophyll *a*) and established numerical nutrient criteria traditionally used in evaluating source-water conditions did not correlate with the phytoplankton community structure, specifically, cyanobacterial (blue-green algae) dominance and potential geosmin production, in these reservoirs. In general, elevated geosmin concentrations appeared to be complexly interrelated with nutrient dynamics (especially the type and concentration of the inorganic nitrogen), type and density of cyanobacterial species, water temperature, and degree of stratification.

LITERATURE CITED

Carlson, R.E., 1977, A trophic state index for lakes: *Limnology and Oceanography*, v. 22, no. 2, p. 361-369.

Christensen, V.G., Graham, J.L., Milligan, C.R., Pope, L.M., and Ziegler, A.C., 2006, Water quality and relation to taste and odor compounds in the North Fork Ninnescah River and Cheney Reservoir, south-central Kansas, 1997–2003: *U.S. Geological Survey Scientific Investigations Report* 2006-5095, 43 p.

Downing, J.A., Watson, S.B., and McCauley, E., 2001, Predicting cyanobacteria dominance in lakes: *Canadian Journal of Fishery and Aquatic Sciences*, no. 58, p. 1905-1908.

Graham, J.L., Jones, J.R., Jones, S.B., Downing, J.A., and Clevenger, T.E., 2004, Environmental factors influencing microcystin distribution and concentration in the Midwestern United States: *Water Research*, no. 38, p. 4395 – 4404.

Havens, K.E., James, R.T., East, T.L., and Smith, V.H., 2003, N:P ratios, light limitation, and cyanobacterial dominance in a subtropical lake impacted by non-point source nutrient pollution: *Environmental Pollution*, no. 122, p. 379–390.

Paerl, H.W., Fulton, R.S., Moisander, P.H., and Dyble, J., 2001, Harmful freshwater algal blooms, with an emphasis on cyanobacterial: *Science World*, v. 1, p. 76-113.

South Carolina Department of Health and Environmental Control, 2004, Water Classifications and Standards: South Carolina Department of Health and Environmental Control, Code of Regulations, State Register, Regulation 61-68, accessed on January 3, 2007 at http://www.scdhec.net/environment/water/regs/r61-68.doc.

Smith, V. H., Sieber-Denlinger, J., deNoyelles, Jr., F., Campbell, S., Pan, S., Randke, S. J., Blain, G. T. , and Strasser, V. A., 2002, Managing taste and odor problems in a eutrophic drinking water reservoir: *Lake and Reservoir Management*, v. 18, no. 4, p. 319-323.

Suffet, I.H., Corado, A., Chou, D., Butterworth, S., and Macguire, M.J., 1996, AWWA taste and odor survey: *Journal of American Water Works Association*, v. 88, no. 4, p. 168-190.

Taylor, W.D., Losee, R.F., Torobin, M., Izaguirre, G., Sass, D., Khiari, D., and Atasi, K., 2006, Early warning and management of surface water taste-and-odor events: *American Water Works Association Research Foundation Reports*, 268 p.

Westerhoff, P., Rodriguez-Hernandez, M., Baker, L. and Sommerfield, M., 2005, Seasonal occurrence and degradation of 2-methylisoborneol in water supply reservoirs: *Water Research*, no. 39, p. 4899-4912.

Wnorowski, A.U., 1992, Tastes and odors in the aquatic environment—a review: *Water South Africa*, v. 18, no. 3, p. 203–214.

Young, W.F., Horth, H., Crane, R., Ogden, T., and Arnott, M., 1996, Taste and odour threshold concentrations of potential potable water contaminants: *Water Research*, v. 30, no. 2, p. 331-340.

Zaitlin, B., and Watson, S.B., 2005, Actinomycetes in relation to taste and odour in drinking water: myths, tenets and truths; *Water Research*, 40, p. 1741-1753.