Management of Blue Green Algae and Taste and Odor with Cutrine-Plus in McDaniel Lake, Greene Co. Missouri

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Abstract

McDaniel Lake experienced a T & O event in early fall of 1982 following a drought. Extreme measures of distribution flushing and water treatment were ineffective until fresh water from another reservoir was supplied. T & O episodes occurred each year following 1982 until a zero tolerance approach was taken in 2003 to avoid any level of taste and odor compounds. Additional management procedures initiated in 2003 included daily estimation of algal density at the raw water intake and program of measured applications of Cutrine-Plus using GSI mapping techniques and enhanced monitoring of algal populations within the lake in strategic and seasonal locations. Prior to instituting the application of Cutrine-Plus, an algal challenge assessment was undertaken to determine the appropriate concentration that would have an impact on algal populations. Its use has continued since 2003 through the present. Water quality data including algal concentrations, and a variety of chemical parameters were analyzed for three years prior to the initiation of the management program and three years after the program has been ongoing. Specific algal populations at strategic locations and depths were used to guide the program. Algal density, MIB and geosmin concentrations as well as customer complaints have been analyzed. The water quality that has resulted from the program includes a decrease in most parameters including blue green algal counts, MIB, geosmin, taste and odor complaints from customers, cost reduction in water treatment plant operations and continued absences of HABs.

Introduction

Domestic water has for centuries become fouled and Taft (1) referred to Nero and Caesar as the latter carried containers of water on their trips. With the invention of the microscope, water was found to contain a variety of living organisms of both plant and animal origin. In the late 1800's the identification of algae in water samples was being carried out by professional natural historians as well as lay persons having an interest in algae (1). The relationship between algae and bad water was suspected, but only in the mid 1900's and into the 2000's were metabolites obtained from algae that were associated with taste and odor in water (2, 3, 4).

With the increasing reliance on surface water for domestic supplies (5), there is more of an awareness of the need to maintain water quality in the finished product of a water treatment plant (6). The front line of maintaining water quality is the source of the surface water. Watson (2)

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pointed out that "…T/O [taste and odor] monitoring is essential to the proactive management of this resource, for two basic reasons: T/O has (1) profound socioeconomic effects and (2) can be diagnostic of source and supply problems."

While there were attempts to clean reservoirs serving as domestic water supply sources by lowering the water level, removing benthic mud layers and modifying the bottom, chemical methods to reduce algal growth began to appear in the early 1900's (1). One of the chemical algicides was copper sulfate. Experiments by Moore and Kellerman showed that certain blue green algae could be effectively eliminated from the water column by the use of copper sulfate (1). Copper sulfate remained in use as one of the only effective algicides by water treatment plant operators (7). Taste and odor comes in a variety of forms and can be associated with a variety of algae and fungi (7). However, there has been an increased awareness of a correspondence of cyanobacteria and two chemicals that are particularly offensive, MIB and geosmin.

Cyanobacteria, commonly referred to as blue green algae have been shown to be a source of two of the offensive metabolites, geosmin and MIB (4) and in presumptive associations (8). While algae other than blue green algae have been associated with taste and odor problems (1), from the proactive management viewpoint of containing, reducing, and striving for zero tolerance of taste and odor due to metabolites, geosmin and MIB, in surface water domestic water supplies, a focus has been on controlling the abundance of blue green algae in the water source (2).

A water supply reservoir in Greene Co., Missouri, Lake McDaniel, became the source of a major taste and odor event to be followed by other less serious events in 1982. There is also a second lake, Fellows Lake, which provides the majority of potable water to the service area. However, with the 1982 event, attention was placed on improving the water quality of Lake McDaniel (9). Focus was placed on watershed improvements, reduction of nutrient inflow, known to enhance the growth of algae, and on water treatment practices to reduce the offensive taste and odor in the finished water and to eliminate any cyanotoxins associated with harmful algal blooms (HABs) that might be present. Taste and odor events continued through 2002 at which time a program of Zero Tolerance for the presence of MIB and geosmin was initiated.

The program was formulated in consultation with and implementation by two companies, Aquatic Control, Inc., Seymour, Indiana and Applied Biochemists, Germantown, Wisconsin, a division of Advantis Technologies. This paper reports on the success of that program in reducing the abundance of blue green algae, geosmin, MIB, customer complaints, operational costs in water treatment, and limiting harmful algal blooms (HABs).

Materials and Methods

Study site

McDaniel Lake was constructed as a domestic water supply reservoir in 1929 and is located in northern part of Greene County Missouri, Lat: 36.9 N, Lon: 90.35 W. The surface area is 300 acres with a volume of 4066 acre-ft. The maximum depth is 30 ft and a depth at Grant Bridge of 20ft. For the summer peak demand of water, 16 MGD can be distributed to the Springfield, Missouri service area of 222,000 persons. McDaniel Lake supplies 27% of the domestic and commercial water to the Springfield service area and is one of two reservoirs in the vicinity of Springfield, the other being Fellows Lake. Both McDaniel and Fellows Lake are municipally owned by City Utilities and Springfield, Missouri.

Data collection

Sampling for phytoplankton abundance, dissolved oxygen, TN, TP, geosmin, MIB, and Secchi depth was conducted at 4 locations on the lake: (1) dam, (2) Grant Street Bridge, (3) Summit Street Bridge, (4) a low water bridge (Fig. 1). Qualitative phytoplankton samples were taken at the raw water intake of the treatment plant using fine mesh (10 u) plankton net.

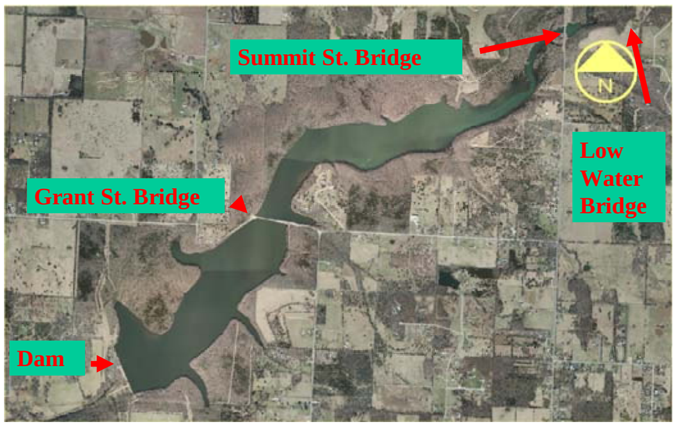


Fig. 1. View of McDaniel Lake, Greene Co. Missouri and the four sampling Sites used for data collection.

At the raw water intake near the dam, phytoplankton was collected with a Kemmerer bottle at either the 7' or the 14' valve intake depending on the depth of the lake. The sampling protocol was dictated by which value is open at the intake structure. At the three other locations a Kemmerer bottle sample was taken as an integrated sample from 1-6' depth. Samples were brought to the lab and l ml sub samples were analyzed using a Sedgwick Rafter cell and a bright field compound microscope at 200X. Organisms were counted as natural units, single cell, colony, or filament at the generic level.

Dissolved oxygen was measured with an YSI Model 58 dissolved oxygen meter. TN, TP, Cu and Secchi depth were measured using Standard Methods (10). Geosmin and MIB were measured using a GC/MS and following Standard Methods (10).

Customer complaints were tallied by phone calls into the operators at the City Utilities main office, Springfield, Missouri. Not all complaints were registered if there was a significant event and/or if calls reached over 100 per event.

Application of Cutrine-Plus

A program of Cutrine-Plus application was based on analyses of total phytoplankton and blue green algal densities and geosmin and MIB concentrations at each of the four sampling sites. Two private companies, Aquatic Control of Seymour, Indiana and Applied Biochemists, Surface Water Products Division, Germantown, Wisconsin. An algal challenge test conducted by personnel associated with Applied Biochemists was used to determine the appropriate concentration and timing of the application of Cutrine-Plus. Transects determined by GIS readings and run perpendicular to the axis of the lake were run for 1/3 of the lake for each of three applications made during the summer. After each application the concentration of residual copper was measured for a 10 day period using a Varian 220 FS Flame Atomic Absorption Spectrometer.

Statistics

Trends in total phytoplankton and blue-green algae abundance were examined in two ways. Changes in abundance by year were examined using a general linear model with square-root-transformed data. Second, all measurements were combined for three years prior to Cutrine-Plus application (2000-2002, "pre-treatment") and were compared to measurements for the following three years when Cutrine-Plus was applied (2003-2005, "treatment"). Pre-treatment and treatment abundances were compared using a one-way ANOVA on log-transformed data. To determine associations between blue-green algae abundance and concentrations of geosmin and MIB, correlations between the metrics over the six-year study period were examined using Minitab version 14.12.0 (Minitab, Inc., State College, Pennsylvania, USA).

Results

Plankton and taste and odor compounds

Abundance of total phytoplankton and blue-green algae varied annually and over the six-year period (Fig. 2; total phytoplankton: range = 0-117,000 L^{-1}, mean = 22.6 L^{-1}; blue-green algae: range = 0-91,000 L^{-1}, mean 8.0 L^{-1}). Total phytoplankton abundance peaked in 2002 and blue-green abundance peaked during 2001 (Fig. 2).

Geosmin and MIB peaked during 2002 when total phytoplankton abundance was highest (Fig. 3). A Pearson correlation between geosmin and blue-green algae abundance measured on the same day revealed a significant association (Fig. 3; $r = 0.25$, $p = 0.008$). A Pearson correlation between MIB concentration and blue-green algae abundance was not significant ($r = 0.12$, $p = 0.21$). However, peaks in MIB clearly occur during years when blue-green algae abundance is highest (Fig. 3).

Cutrine-Plus treatment

After the application of Cutrine-Plus began, total phytoplankton and blue-green algae abundances declined. A one-way ANOVA revealed this decline was significant for both groups (Fig. 4; total phytoplankton: $F = 25.95$, $p<0.001$; blue-green: $F = 24.23$, $p<0.001$). Upon further inspection of these plots, a larger decline in blue-green algae abundance than total phytoplankton abundance during treatment is revealed. Indeed, mean total phytoplankton declined by 35%, while mean blue-green abundance declined by more than four times. In addition, maxima for blue-green algae never reached the same levels during treatment (70,000 L-1) as they did prior to treatment (91,000 L^{-1}).

Taste and odor compounds also declined during treatment, and a Kruskal-Wallis test revealed these declines were significant (Fig. 5; geosmin: $H=11.43$, $p=0.001$; MIB: $H=12.74$, $p<0.001$). Concentrations for both compounds were reduced to nearly zero, and showed little fluctuation during treatment (Fig. 5).

Customer Complaints

Following the post treatment period the reduction of customer complaints was evident (Fig. 6).

Costs of water treatment plant operations

Analyses of pre- and post treatment costs in water treatment plant operations focused on both chemicals used and in salaries of personnel. There was an annual savings in the post treatment period of $20,000 per year in the reduction of the use of powered activated charcoal in the water treatment plant. While not calculated there was also savings in the reduction of water for back flushing processes in the plant. A portion of $50,000 in overhead salaries annually paid to personnel for pretreatment processing time spent in the removal of geosmin and MIB was also reduced in the post treatment period of three years.

Discussion

The public often do not think about how water quality can affect their drinking water supply. As Taft (1) stated, "…If, however, something happens …that alters the palatability of the water, the protests by the consumer are immediate and voluble…". Taste and odor events are also not limited to a given region. Baker, et al. (11) reported on the extensive and cooperative efforts of various agencies in the Phoenix, Arizona area to reduce the distribution of domestic water containing geosmin and MIB. Similar efforts have occurred in Indiana (12) and elsewhere.

The proactive management described by Watson (2) was earlier echoed by Means and McGuire (13) when they stated, "…Control strategy with the greatest potential for success requires regular treatment of all areas containing MIB producing algae…" and by Palmer (7).
The approach that was and continues to be used to collect data from Lake McDaniel by the personnel of the Blackman Laboratory of City Utilities of Springfield, Missouri mirror these strategies. The program planned to achieve Zero Tolerance of geosmin and MIB in McDaniel Lake and in the finished water product enabled the water treatment plant personnel of City Utilities to achieve their goal. The comparison of pretreatment and post treatment data clearly show that the program of Cutrine-Plus application was a success.

The reduction of MIB for the past two years to below detection limit and the significant reduction of geosmin during the post treatment period have both led to the continuing decline of customer complaints. A taste and odor panel was used 3 times per week to assess the finished water quality and no off tastes and odors were recorded during this period.

In dealing with T and O events one of the effective chemicals used to adsorb the offensive water inclusions has been powered activated charcoal (PAC).As an added benefit to the successful program initiated at City Utilities to reduce T and O events, the reduction in the use of powered activated charcoal, reduction in the loss of water previously used for flushing of mains, and overtime paid to personnel in handling T and O events have offset the costs of the Cutrine-Plus program.

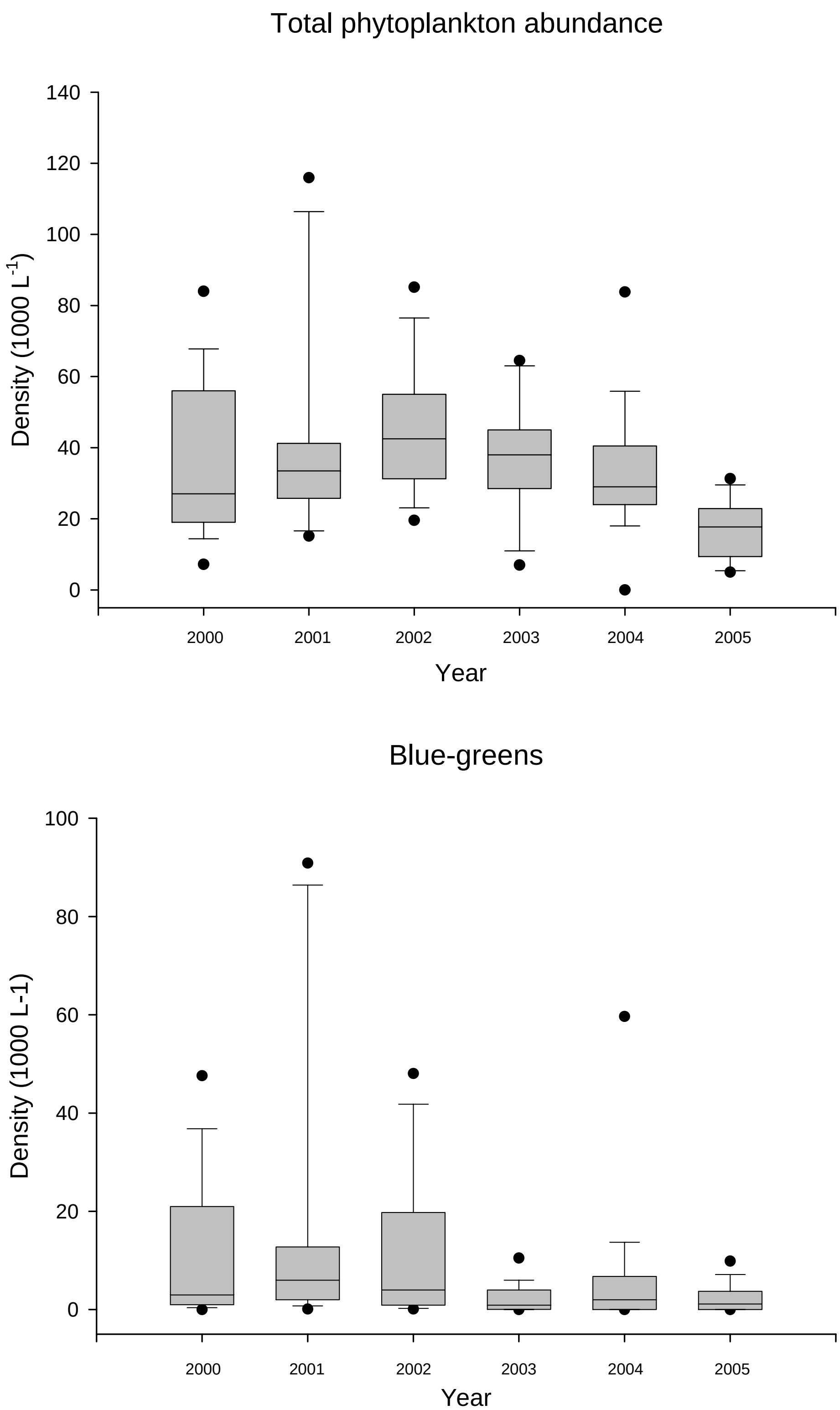
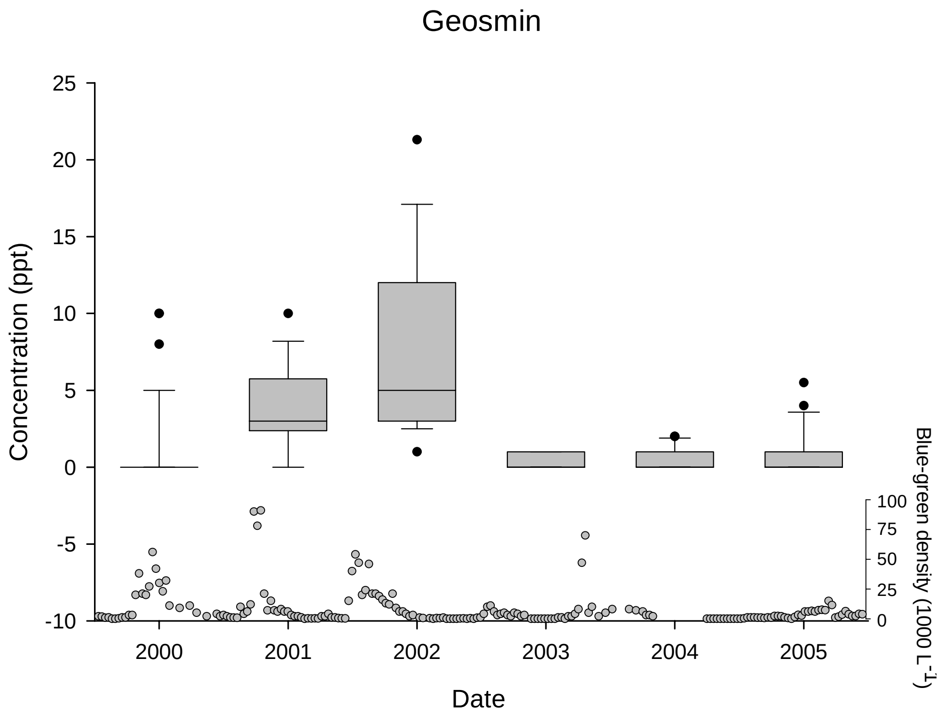


Fig. 2. Total phytoplankton (top) and blue-green algae (bottom) abundance by year. Each box represents 1st and 3rd quartiles, and the line inside the box represents the median. Whiskers represent one standard error, black dots represent the 5th and 95th percentiles.



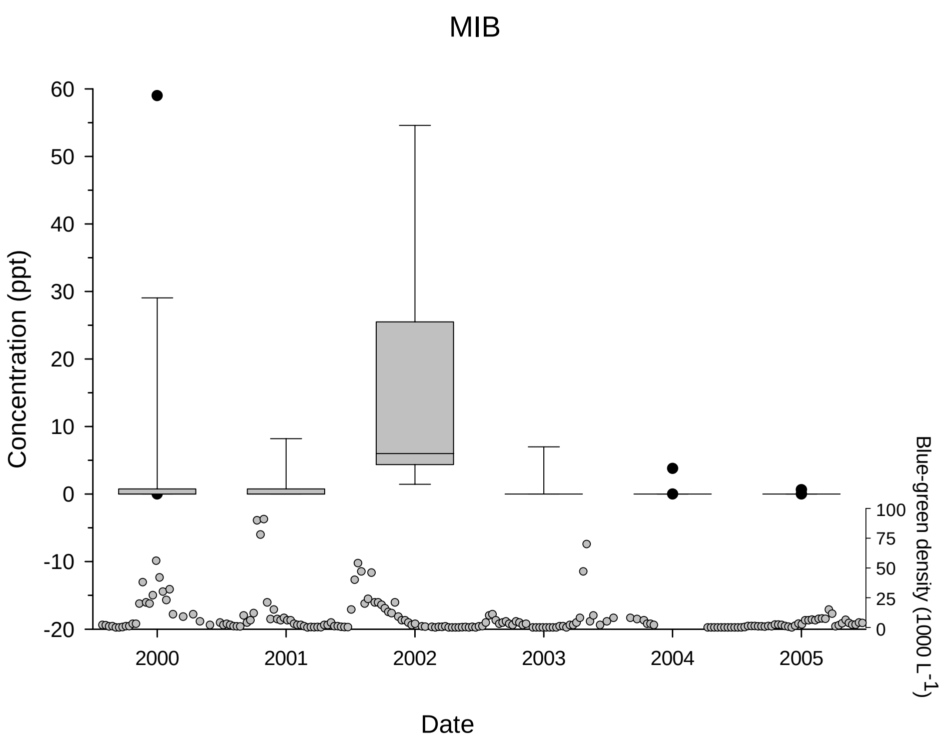


Fig. 3. Geosmin (top) and MIB (bottom) concentrations for each year. Boxes represent 1st and 3rd quartiles and the horizontal line represents the median value among three years of data. Whiskers represent one standard error. Dots represent 5th and 95th percentile. Blue-green algae abundances are provided at the bottom of each plot. Year labels are placed in the mid-point of each year.

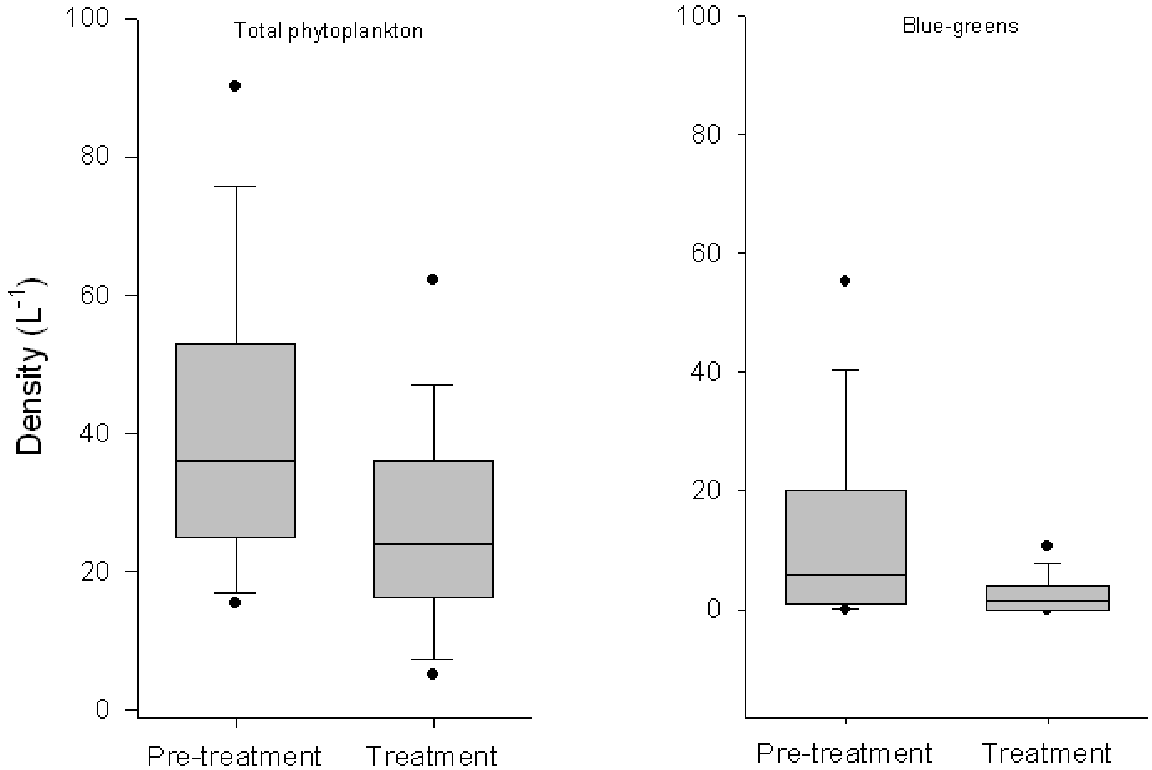


Fig. 4. Total phytoplankton and blue-green algae abundance before application of Cutrine-Plus (2000-2002) and after treatment began (2003-2005). A one-way ANOVA revealed both groups were significantly reduced after treatment began (total: $F = 25.95$, $p<0.001$; blue-green: $F = 24.23$, $p<0.001$). Boxes represent 1st and 3rd quartiles and the horizontal line represents the median value among three years of data. Whiskers represent one standard error. Dots represent 5th and 95th percentile.

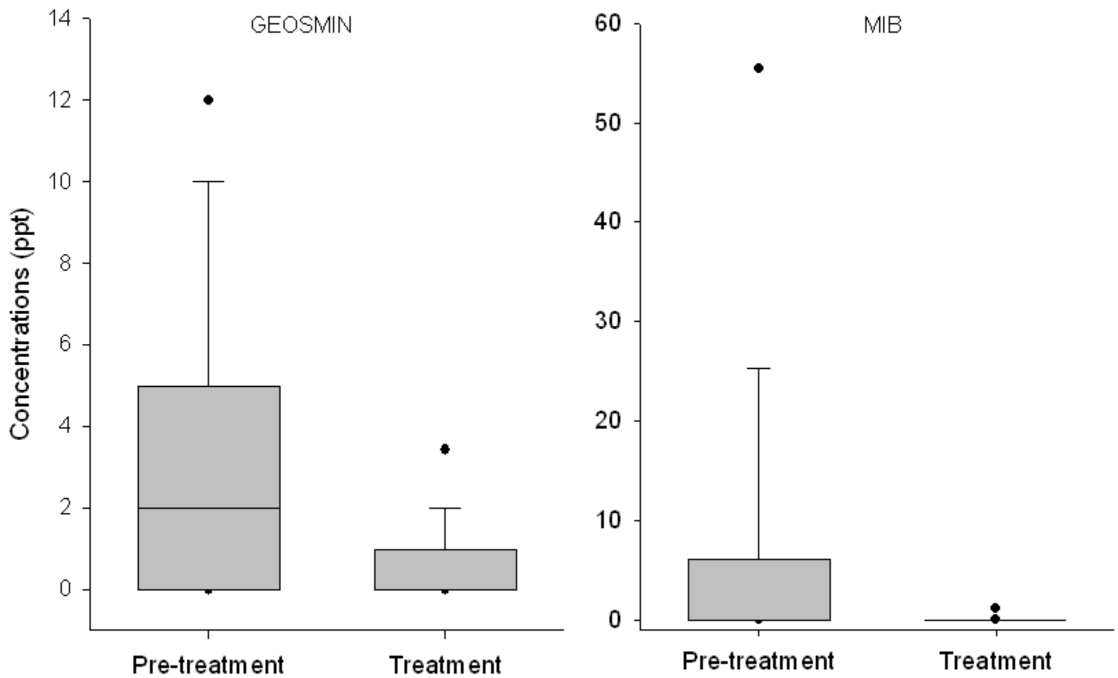


Fig. 5. Geosmin and MIB concentrations before application of Cutrine-Plus (2000-2002) and after treatment began (2003-2005). A Kruskal Wallis test revealed the concentration of both compounds was significantly reduced after treatment began (geosmin: $H=11.43$, $p=0.001$; MIB: $H=12.74$, $p<0.001$). Boxes represent 1st and 3rd quartiles and the horizontal line represents the median value among three years of data. Whiskers represent one standard error.

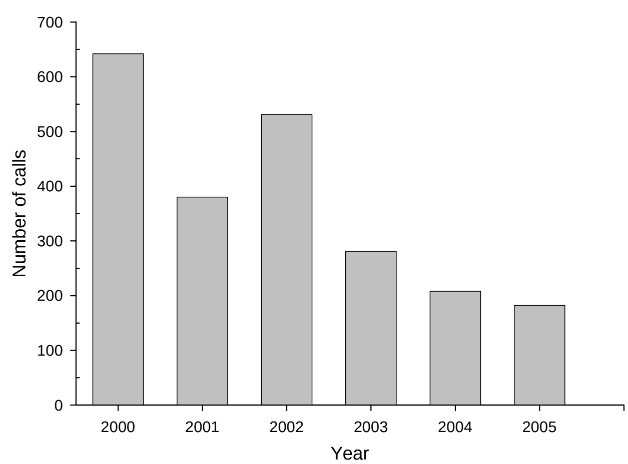


Fig. 6. Total number of phoned-in complaints received annually during the six-year period. Total complaints declined after the use of Cutrine-Plus began.

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References

1. Taft, C. E. 1965. Water and Algae~World Problems. Educational Publishers, Inc. Chicago, Il. 236 p.

2. Watson, S. B. 2004. Aquatic taste and odor: a primary signal of drinking-water integrity. J. Toxicology and Environmental Health Part A, 67:1779-1795

3. Schrader, K. 2005. Evaluation of several commercial algicides for control of odor-producing cyanobacteria. J.Aquatic Plant Management. 43: 100-102.

4. Sommerfield, M., P. Westerhoff, and L. Baker. 2002. Reducing Taste and Odor and other Algae Related Problems for Surface Water Supplies in Arid Environments. Final Report, Arizona State University (http://www4.eas.asu.edu/pwest/tasteandodor.htm

5. Westrick, J. A. 2003. Manager to Manager: Everything a manager should know about algal toxins but was afraid to ask. J. AWWA. September: pp26-34.

6. Watson, S. B. and J. Lawrence. 2003. Drinking water quality and sustainability. Water Quality Res J Canada 38:3-13.

7. Palmer, C. M. 1962. Algae in Water Supplies. Division of Water Supply and Pollution Control (HEW) and Robert A. Taft Sanitary Engineering Center. Cincinnati, Ohio. 88p.

8. Smith, V. H., F. deNoyelles, D. W. Graham, and S. J. Randtke. 2001. A Comparative Water Quality Study of Cheney Reservoir, Kansas. Final Report to the City of Wichita Water and Sewer Department.
https://wichita.gov/NR/rdonlyres/E617DB85-D3F6-42C9-BE95-B39E3AE8A11A/0/A_Comparative_Water_Quality_Study_of_Cheney_Reservoir_Kansas_20d.pdf

9. APHA. 2005. Standard Methods for the Examination of Water and Wastewater. American Public Health Association, American Waterworks Association and Water Environment Federation. 1368 p.

10. Baker, L. A., P. Westerhoff, and M. Sommerfield. 2006. Adaptive management using multiple barriers to control tastes and odors. J. AWWA 98:113-126.

11. CEES Publication 2003-01. Center for Earth and Environmental Science Indiana University~Purdue University, Indianapolis. Central Indiana Water Resource Partnership. http://www.cees.iupui.edu/Research/Water_Resources/CIWRP/Publications/Reports/Watersheds-2003/previous_work.htm

12. Means, E. G. and M. J. McGuire. 1986. An early warning system for taste and odor control. J. AWWA, March 1986:77-83.

13. Youngsteadt, N. W. 2005. Factors that influence phosphorus, filamentous cyanobacteria, and odor in McDaniel Lake, a Southwest Missouri water supply reservoir, 1983-2002. Lake and Reservoir Management 21:453-464.