Developing a Reservoir Algae-Control Plan for Taste & Odor Prevention

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This article is a case history of the planning and implementation process undertaken to create a Cyanobacteria (blue-green algae) control plan for reservoir and source water management at the Beaufort-Jasper Water & Sewer Authority in Beaufort and Jasper counties, South Carolina, in regard to taste and odor (T&O) control in drinking water. It is hoped that our experience will be helpful to other water utilities that are considering similar control strategies, or who may be in the process of improving their current T&O activities. The article focuses on the elements of the plan, not a technical review of data and results. Additional detail may be requested from the authors on any of the specific items covered.

The Beaufort-Jasper Water & Sewer Authority operates two water treatment plants in Beaufort and Jasper counties. The source water for both plants comes from the Savannah River. An 18-mile canal and two reservoirs supply source water to the plants.

The plan discussed in this article pertains to both plants but is aimed primarily at the newer of the two reservoir-water treatment plant pairs, the Purrysburg plant near Hardeeville. The Purrysburg reservoir has had several cyanobacterial blooms since startup in 2004, which at times led to the typical "musty" or "muddy" type of odor in finished water delivered from the Purrysburg plant, most recently in the summer and fall of 2008.

The control plan was created exclusively within the Authority in response to the 2008 event using a team approach that involved several departments and all levels in the organization. The responses taken were successful in 2009, resulting in no significant algal blooms or related T&O events.

Based on the 2009 experience, it is believed that the plan will continue to yield positive results and provides a solid base for continued improvement in the future. Because of the comprehensive nature of the actions considered and reviewed during plan creation, the authors felt that the information would be of interest and assistance to some other utilities.

Water Treatment Plant Overview

The Authority's Purrysburg Water Treatment Plant is rated for 15 million gallons per day (mgd) using a conventional treatment process employing alum flocculation, sand filtration, sodium hypochlorite disinfection via on-site 0.8-percent hypochlorite generation, and lime alkalinity control, a system designed by Jordan, Jones & Goulding Engineers. The Purrysburg plant supplies drinking water primarily to the Bluffton and Hardeeville areas in Beaufort and Jasper counties at an average annual flow of approximately 8 mgd.

Powdered activated carbon (PAC) can be added if needed for T&O control via a bulk-bag dosing system. Although the PAC helps to reduce T&O, the retention time in the plant is minimal for optimum contaminant absorption, and the high concentration required for complete control is too expensive.

The Chelsea Water Treatment Plant is the Authority's other plant and is the original plant, built in 1964. It is also a conventional plant and had on-site hypochlorite generation added in 2009. The Chelsea plant supplies northern Beaufort County, including its military facilities, with an average annual flow of 12 mgd. This plant experienced T&O stemming from Cyanobacteria in the past, but these issues have been almost non-existent since control BMPs (Best Management Practices) were implemented for the supply canal some years ago.

Reservoir & Canal Overview

The supply canal is original to the Chelsea plant system, with the 60-acre, 150-mg reservoir located near the plant added in 2001. The Purrysburg reservoir was built for service to the Purrysburg plant and is quite close to the Savannah River origination point of the supply canal. Both reservoirs are located adjacent to the canal so that water can be directed through the reservoir or bypassed directly to the corresponding treatment plant.

The Purrysburg reservoir is approximately 65 acres in surface area with a capacity of 165 mg and is located in a rural area on private property. Retention time is typically 15 to 20 days. The area is rich in wildlife, including nesting bald eagles on the reservoir property, and the reservoir is designed to provide limited recreational fishing as well as drinking water supply.

The reservoir is fairly shallow, with a depth of eight to 10 feet. It has a complex shape created by site-specific limitations, which leads to stagnant areas. The combination of low turbidity, shallow depth, stagnant areas, long shoreline, and limited flow throughput has been found to lead to algae blooms in the summer months.

Property adjacent to the Purrysburg plant was needed for reservoir construction and was purchased from the Okatie (hunt) Club. During negotiations for the purchase of this property, the Authority agreed to grant the Okatie Club recreational fishing rights, and the reservoir was designed, in part, to optimize the fishery. This, as well as site limitations, led to the complex shape and shallow depth of the reservoir, which includes dikes that extend into the body of the impoundment.

Although the agreements in place require that the primary function of the reservoir is to maintain water quality as a drinking water source, the subordinate fish management aspect of the arrangement creates a somewhat unique situation in regard to reservoir management for algae control.

Definition of the Problem Based on the 2008 Taste & Odor Event

T&O in the drinking water delivered by the Purrysburg plant has been occasional seasonal problem since the plant came on line in the spring of 2004. Despite an extensive evaluation and the implementation of multiple management techniques, it again became an issue in the late summer of 2008.

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This T&O manifests itself as a "dirty" or "musty" taste, odor, or aftertaste degrading perceived water quality by customers of the Authority. These events are caused by algal growth in the Purrysburg reservoir which ultimately produces the compounds MIB (2-methyisoborneol) and geosmin.

MIB is thought to be primarily responsible for the current event, although some past events were identified to be caused by geosmin. We believe the problem is due to the growth of Cyanobacteria, although Actinomycetes bacteria and certain green algae may also contribute based on literature review.

The following reservoir management techniques had been implemented previously:

1. Water Quality monitoring has been conducted in the reservoir since startup in regard to pH, temperature, TOC, UV-254 absorbance, dissolved oxygen, and phosphate, as well as occasionally for chlorophyll a, iron, and manganese. From these parameters (particularly pH and DO), we can predict the onset of algal bloom conditions that can result in T&O problems; however, this by itself will not prevent T&O since it can only be used to trigger other actions. Also, it was desired to have a better "early-warning" capability.
2. Ultrasonic units ("sonic blasters") were installed in the portion of the reservoir near the intake to the treatment plant. While these are believed to help, there are not nearly enough units to control the entire reservoir.
3. Grass carp were added, but the population was relatively small. Although the carp will eat the larger aquatic plants and algae, their effect on cyanobacterial populations and overall planktonic algal populations has been unclear.
4. GreenClean (hydrogen peroxide): Although this kills visible filamentous growth, it is not clear how much this growth contributes to the overall T&O problem. The death of the algae should help limit growth, but also this could result in the liberation of MIB and/or geosmin that is trapped in the growing cells. We believe, however, that the aquatic plants and filamentous mats along the shoreline create a "reservoir" for planktonic growth, and that the environmental conditions and surface area provided by the plants are major initiators for the onset of algal blooms in the body of the reservoir.
5. Manual grass and algae removal: The Authority's field operations group maintains the shore of the reservoir to minimize weed and grass growth along the shoreline, as well as to remove any larger mats of filamentous algal growth manually. These efforts were increased in late 2008 and in 2009. The Authority also considered arrangements to test a floating harvester to help get to filamentous growth that we were unable to reach with existing equipment.
6. An existing reservoir drain was opened to keep up the turnover rate in the reservoir; however, this drain allows flow back to the river, requiring that water be re-pumped. Also, the flow rate was less than desired.

Unfortunately these efforts were not totally successful, and at the time of plan initiation, the reservoir was being bypassed to use river water. Discontinuing the use of the reservoir has the negative consequences of eliminating our primary tool for "turning over" the water, so it became further stagnated. We needed to develop an approach to put it back on line, as well as to prevent and mitigate further outbreaks.

Comparison of Reservoirs & Source Water Conditions

The Chelsea Water Treatment Plant did not experience the same T&O problem as Purrysburg, even though the source water is the same: the Savannah River. The differences between the reservoirs can be used to help identify the problem:

1. The Chelsea reservoir has a higher turnover rate. The design of the reservoir prevents any significant water stagnation, while Purrysburg has a complex shape that results in short circuiting and water stagnation. The depths are similar.
2. A complex shape and low-slope earthen banks at Purrysburg result in much more shoreline where grass can grow, as well as near-shore aquatic plants. The aquatic plants provide a high-surface area environment for algae growth, resulting in a virtual algae nursery. Overall, this means that Purrysburg has a much higher surface area/volume ratio than Chelsea in regard to potential plant growth.
3. The Purrysburg reservoir has a much lower turbidity (5-10 NTU versus 40 NTU or more at Chelsea), which means that the light energy input/volume is also much higher, leading to more photosynthetic activity. Once undesirable species are established, the growth rate can be much faster. The lower turbidity is considered to be the major difference between the source waters for the Purrysburg plant as compared to the Chelsea plant, minimizing algal growth for the Chelsea plant, despite longer retention times because of the long canal transport.
4. Past Chelsea T&O events were believed to be caused primarily by algal growth in the canal, not in the reservoir. Once BMPs were implemented to control growth of vascular plants and macrophytic algae in the canal, T&O events at Chelsea were reduced greatly. These BMPs are physical in nature, including variations in water level and "dragging" heavy chains along the canal to dislodge plant growth, followed by manual removal at collection points.

Factors in common between the reservoirs should point out what is not the cause:

1. Nutrient levels are similar between the reservoirs, and overall N and P concentrations are low. Potassium has not been evaluated, but the level should be similar between the reservoirs and is expected to be fairly low.
2. The depths of the reservoirs are similar. There is little stratification.
3. The source water is the same, and there are no significant inflows other than river water to either reservoir.
4. Of course, the weather is the same.

Even with optimization of the above-mentioned management activities, they were not sufficient to control T&O outbreaks in 2008. We felt that these events would continue to occur, so it was necessary to take additional actions.

T&O Plan Development

Due to the continued T&O issues caused by cyanobacteria blooms, we decided to initiate a more comprehensive study of possible control factors for the Purrysburg reservoir. This began with an extensive literature search via the web and using American Water Works Association publications. Vendors were contacted and their literature was considered. Water samples were taken for algae identification purposes and for MIB/Geosmin analyses.

Ideas were listed from research and the experience of the team using an open-minded approach ("no bad ideas"). One idea is thought to be novel, as no literature was found about it (intentionally increasing turbidity via bentonite addition).

Rough cost estimates for the various possible solutions were generated. A matrix was created, listing the possibilities under consideration. Each item in the matrix was rated for expected efficacy versus approximate cost. Cost versus expected efficacy was plotted for selected items.

Taste & Odor Control Matrix

A core team of managers from the Authority's water treatment operations department reviewed and evaluated the options. Input was solicited from all levels of the organization, from water operators to field operations, finance, and executive levels. A Taste and Odor Control Matrix was developed as a decision-making tool.

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Taste and Odor Control Matrix

	Control Method	Additional Information	Efficacy rating (1-5)*	Cost rating (1-5) **
	Diagnostic			
1	Dye tracer flow study	Diagnostic re reservoir mods, stagnant areas.	2	1
2	ID of organisms	Diagnostic tool to aid in reservoir management when a bloom occurs.	1	1
3	Reservoir monitoring	Early detection as a trigger for other actions. Examples: DO, pH, alk, BacT, TOC, UV 254.	2	1
4	Enhanced monitoring	Fluorometry B-G algae detection, B-G algae count, chlorophyll a, "fluid imaging", taste & odor panel, [MIB], [geosmin].	2	2
	Prevention Techniques & Reservoir Management			
5	Manual algae/grass removal	Cutting, harvesting, etc.	2	2
6	Sonic blasters	May need more or different type.	2	2
7	Grass Carp	How effective? Will they add to nutrient load that could be negative? Need more fish/acre.	1	1
8	Reservoir modifications	To improve flow patterns (e.g., remove fingers).	2	4
9	Aeration/mixing	To prevent stratification.	1	3
10	Chemical addition: algicides/algistat	Primarily copper sulfate or chelated copper products (less than 0.5 mg/l Cu, vs MCL of 1.3 mg/l Cu).	4	1
11	Chemical addition: "Green Clean" peroxide	Effective killing of algae. Can it be used preventively?	2	1
12	Nutrient removal (mainly P)	To limit growth, but P is low already. There is some possibility that high winds that stir up sediment may lead to increased P levels that, if followed by intense sunny and hot conditions, may trigger a bloom event.	1	2
13	Water level changes	Control grass by changing level seasonally.	2	1
14	Turbidity increase	Add bentonite, etc. to shade out algae. May have additional treatment benefits.	3	2
15	Colored dye	Used to shade out algae.	3	2
16	pH adjustment	BG algae growth rate is slower at low pH, <6.	1	2
17	Parasitic species	Some research suggests that the use of organisms that prey on cyanobacteria could be effective, but this appears to be unproven.	2	1
18	Barley straw	Barley straw inhibits algal growth, used in UK, but more suitable for small ponds. Seems infeasible for reservoir.	1	1
	Treatment Technologies			
19	PAC or GAC	Reduction in MIB & Geosmin concentrations, modify PAC system and consider GAC system.	4	3
20	UV + peroxide	Disinfection and T&O removal. High cost but high efficacy.	5	5
21	Ozone + Peroxide	Disinfection and T&O removal. High cost but high efficacy.	5	5
22	Ozone	Disinfection and T&O removal. High cost but high efficacy.	5	5
23	Biofiltration, or biofiltration+ozone	T&O removal. May not be reliable.	4	4
24	Membrane technologies	Can remove T&O via nanofiltration.	5	5
25	Ultrasound for MIB	High intensity ultrasound degrades MIB, could be an emerging technology but unproven.	?	?
26	MIEX ion-exchange	Some info says it can work on T&O but it is primarily for color removal.	2	4
27	Air stripping	MIB & Geosmin are not readily strippable.	0	3

**Total cost rating Key	*Efficacy Rating Key
1= 0 - 25K	1=we think it helps
2 = 25 - 100K	2=definitely helps, part of solution
3 = 100 - 250K	3=clearly an important management tool
4 = 250 - 500K	4=key method of control
5 = >500K	5=totally eliminates the problem

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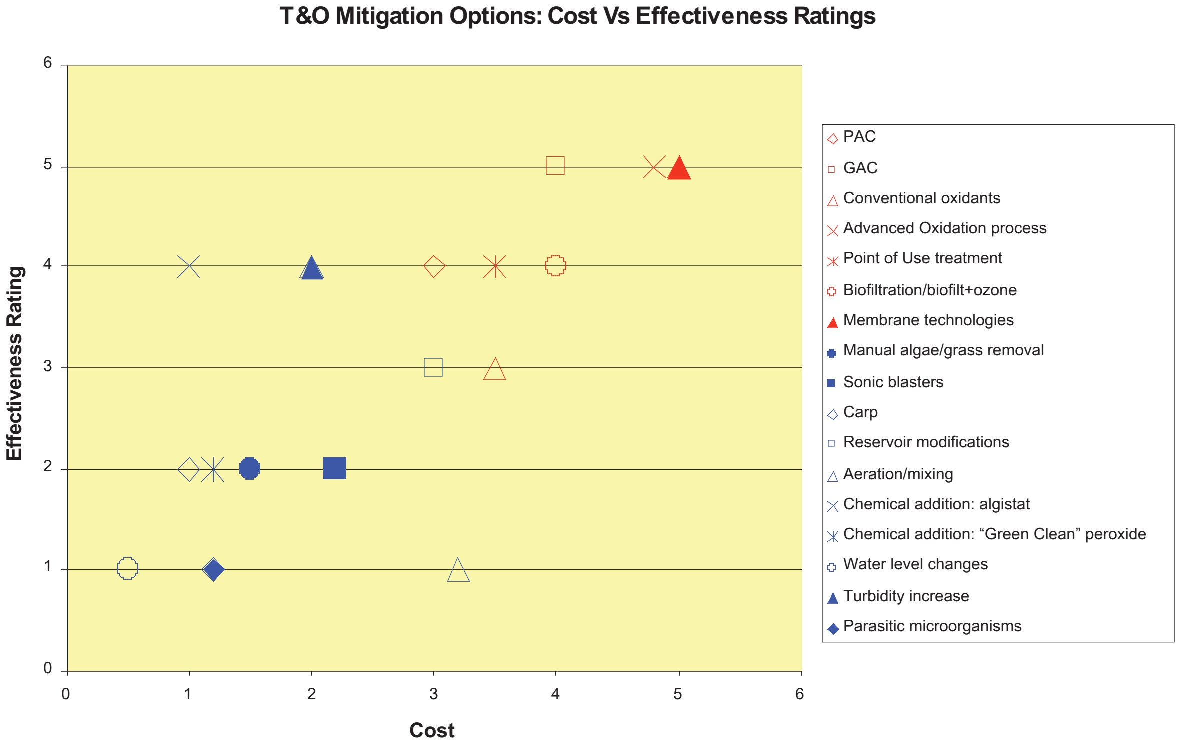
Taste & Odor Solution Cost Versus Expected Efficacy

The ratings for relative cost and expected efficacy were plotted to aid in decision-making.



No.	Action	Notes
1	Update Reservoir Management Plan and Taste & Odor SOPs and related documentation.	Develop an enhanced monitoring plan for reservoir, update plan for management of T&O events, and draft a procedure for use of Cu products.
2	Relocate sonic blasters.	Moving units farther away from shore may improve performance.
3	Purchase spreader for in-house application of "GreenClean" granular product.	To allow more rapid response to localized outbreaks as compared to scheduling outside contractors for application of liquid product.
4	Install drain from reservoir to canal (existing drain is too small and goes back to the river, thus wasting water).	To allow increased flow through reservoir by incorporating flow that ultimately goes to Chelsea.
6	Purchase Fluorometer for phycocyanin detection.	Phycocyanin is a pigment specific to cyanobacteria that can be detected *in vivo* using fluorometry.
7	Install culverts through dike.	To attempt to eliminate a major stagnant area by allowing flow through dike.
8	Arrange visit by Dr. Rodgers of Clemson.	Dr. Rodgers conducts research on algae blooms and prevention via copper compounds.
9	Evaluate mixing to resolve stagnation.	Mixing can eliminate stratification that encourages growth, and may disrupt algal growth processes.
	a. "Solarbee" solar-powered mixers	May be better for deeper reservoirs. Cost is reasonable but it is another thing to maintain.
	b. Manifolding influent line	To move influent into stagnant areas. Cannot reach the other side of reservoir.
	c. Airlift pumps arranged to move water	To move water into stagnant areas to promote mixing. Requires power for compressor.
	d. Removal of dikes	Large project, fairly expensive and disruptive. May degrade fishery.

Selection of Possible Solutions for Implementation

Through a series of meetings, items with the best expected results that also had reasonable cost and a fairly short completion timeline were selected for implementation.

The table on the left shows the items selected and why:

Item	Notes
PAC or GAC	Maintain current PAC capability. GAC considered too expensive and complex.
UV + peroxide	Tabled advanced oxidation methods until future upgrade.
Ozone + Peroxide	Tabled advanced oxidation methods until future upgrade.
Ozone	Tabled advanced oxidation methods until future upgrade.
Biofiltration, or biofiltration+ozone	May not be reliable. Research looks good but there are few installations. Rejected.
Membrane technologies	Tabled until possible future plant upgrade.
Ultrasound for MIB	High-intensity ultrasound degrades MIB; could be an emerging technology but unproven. Rejected.
MIEX ion-exchange	Some info says it can work on T&O but it is primarily for color removal. Rejected.
Air stripping	MIB & Geosmin are not readily strippable. Rejected.
Turbidity increase (intentionally muddy up the water to shade out algal growth via dilute bentonite suspension additions)	Bentonite is self-suspending at fairly low concentrations due to near-colloidal size and interparticle interactions, but at the very low levels desired, settling rate was excessive in lab studies. Thus, mixing might be required and it was rejected.
Colored dye (to shade out algae)	Rejected due to possible interference with fishery or treatment and as incompatible with natural setting.
pH adjustment	Cyanobacterial growth rate is slower at low pH, <6. Rejected due to possible damage to fishery.
Parasitic species	Some research suggests that the use of organisms that prey on cyanobacteria could be effective, but this appears to be unproven, therefore impractical. Rejected.
Sonic blasters	Move current units and maintain, but significant electrical installation and many more units would be required for complete coverage. Tabled for future consideration.
Reservoir modifications	Implement modest changes (new drain to canal and culverts under biggest dike) but major modifications were rejected.
Nutrient removal (mainly P)	Overall levels are low and not considered a primary driver of algal blooms. Rejected.
Barley straw	Barley straw inhibits algal growth, used in UK, but is more suitable for small ponds. Rejected.

Items rejected or Tabled for Future Consideration

The following items were rejected for implementation. The table lists these items and some of the reasoning for rejection.

Implementation & Status

The items implemented and comments on their current status are shown below:

- An algal-growth prevention plan was devised that includes physical, biological, and chemical controls, as well as enhanced monitoring.
  - ➢ Physical: Continue manual shoreline grass and aquatic plant removal.
  - ➢ Biological: Increase Triploid Grass Carp to recommended levels.
  - ➢ Chemical: Aggressively use granular "GreenClean" peroxide to treat localized filamentous growth outbreaks as they occur. If a planktonic bloom is detected, initiate copper algaecide application for short-term control.
  - ➢ Monitoring: Increase reservoir site visits and monitor specific shoreline sampling sites with fluorometer readings for phycocyanin detection. Monitor raw water to water treatment plant daily with fluorometer. Conduct regular "Taste & Odor Panel" finished water testing during the warm months with staff personnel. Also conduct hourly T&O evaluations by operators running water samples from March to October. This is in addition to normal monitoring parameters.
- A phased response plan was devised if cyanobacteria and T&O are detected at levels considered to be unacceptable:
  1. Increase granular GreenClean treatments.
  2. Initiate PAC treatments at the water treatment plant.
  3. Initiate copper algaecide treatments. This step is to be used only if considered absolutely necessary, and only for short-term use to prevent a major outbreak.
- An additional reservoir drain was installed that goes to the canal, such that water pumped into the Purrysburg reservoir and drained to the canal will continue on to the Chelsea plant. This allowed a flow increase of about 2 mgd and therefore a reduction in retention time of 20 to 25 percent. Although we believe that this is a substantial help and an improvement in our reservoir management capabilities, probably if conditions are such that a serious algal outbreak is imminent, this reduction in retention time will not be enough to prevent it (growth rate would be faster than the retention time).
- Grass carp: Additional carp were stocked to achieve the density recommended by Jack Whetstone of Clemson Extension, who visited the reservoir in 2007 and made recommendations. The grass carp, when stocked to sufficient density, did a great job in minimizing aquatic plants around the shoreline of the reservoir. In our opinion, this was by far the biggest reason for our success in preventing T&O outbreaks due to algal growth in 2009.
- Fluorometry for Cyanobacteria detection: A Turner Designs Aquafluor dual-channel handheld fluorometer was purchased with one channel designed for phycocyanin (pigment specific to Cyanobacteria) and the other designed for rhodamine dye (intended for dye flow studies). The unit can also be supplied with the other channel designed for chlorophyll detection for green algae. This might be more useful for early detection, since some literature indicates that green algae commonly increase before Cyanobacteria during the onset of a bloom event. Pure isolated phycocyanin was purchased for initial instrument stan-

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dardization. This step proved to be tricky because the technique is still early in its use history for Cyanobacteria detection. The unit proved to be very sensitive to Cyanobacteria and a strong response was found when algae-laden samples were intentionally selected. The instrument is used for routine raw water testing on a daily basis at the Purrysburg plant. The technique has good potential and is easy to run, once the initial standardization hurdles are overcome. It is an additional tool for algae bloom detection, but it is unclear whether this provides an improvement over simple reservoir inspections and microscopic examination. In regard to its use as an early-warning technique, our results are inconclusive at present, requiring additional experience and data. Certainly it is a tool that helps focus additional scrutiny regarding Cyanobacteria proliferation in the source water, which may lead to more rapid response when an event occurs.

- Culvert installation: Two culverts were installed to provide some water flow through the largest of the dikes that extend into the body of the reservoir. This was done in an attempt to mitigate the effects of one of the worst stagnant areas. Although this action may have helped, it is believed that not very much water flows through the culverts (flow rate has not been quantified).
- Sonic blasters: The existing ultrasonic units were relocated by moving them out from the bank by a few feet, based on a recommendation from the supplier. This probably helped the efficacy somewhat. Although we have been uncertain about the overall effectiveness of the ultrasonic technique for algae control, our opinion is that it definitely helps, and given enough units for good coverage, it might be effective as the only preventive technique. It is clear from visual reservoir observation over time that the area with the sonic blasters (the portion of the reservoir near the source water intake for the plant) has less algal growth than the portions of the reservoir without sonic blasters. Although it was decided not to increase the number of units because of cost, this may be a viable option in the future.
- Mixing: It was decided to not move ahead with reservoir mixing because of cost, maintenance concerns, and uncertainty regarding effectiveness.
- Copper algaecides: Two suppliers of copper algaecides were contacted, samples obtained and literature reviewed. Many papers were read on the subject, some of which are not referenced. More details can be supplied on request. Dr. John Rodgers of Clemson University visited the reservoir and a small study was conducted with certain copper-based products. One product was selected for application, if needed, but actual application to the reservoir has not been necessary. The use of copper for algae control is a complex subject that will not be covered in detail. In general, we have concluded that low levels of copper can be highly effective in preventing algal blooms, or stopping blooms once they have started, without exceeding the MCL for copper. Our final decision was to use copper as a short-term response solution to algal blooms associated with T&O events if other measures have failed. More information about our conclusions and reasoning on this subject can be supplied on request.

Discussion of Results

Results in the summer and fall of 2009 were much more favorable than in 2008, which we attribute primarily to the controls implemented, since the weather and source water were reasonably comparable to 2008.

1. Complaints from our complaint-tracking database that were attributable to cyanobacterial T&O declined dramatically as shown:
   - 2008: 29 complaints
   - 2009: no complaints
2. No major algae blooms were detected in the reservoir. Minor green algae outbreaks in stagnant areas were identified quickly and controlled with granular GreenClean applications. Some elevation of fluorometer values for phycocyanin indicated Cyanobacteria increases but these were not excessive and did not result in T&O issues. No large filamentous algae mats occurred in 2009.
3. No PAC was used in 2009 for T&O control.
4. Grass carp clearly were active and were often observed eating all shoreline aquatic plants.
5. Minor algae outbreaks occurred only in stagnant areas in the sections of the reservoir that have no sonic blasters installed, suggesting that the ultrasonic treatment is working.

Conclusions & Recommendations

What we learned:

- Considering options in an open-minded, comprehensive way was valuable in generating effective solutions, as compared to a "shotgun" approach based on opinions, or whatever you heard from the last consultant or vendor presentation.
- Involve the organization from top to bottom in order to foster teamwork, gather all pertinent information and ideas, to create "buy-in" and ownership as well as to acknowledge contributions.
- Solutions should be tailored to your particular source water and reservoir situation. A deeper, larger reservoir, or one with significant nutrient loading, might require a totally different solution.
- There is no substitute for effective monitoring and consistent response with appropriate BMPs.
- A phased approach to response plan actions leads to confidence and success.

What we plan to do going forward:

- Continue the current program.
- Consider further reservoir modifications and other identified BMPs.
- Consider advanced treatment technologies for future water treatment plant upgrades.

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Note: numerous supplier literature and other minor references were consulted and are not specifically listed. More details can be supplied to interested individuals.

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