LESSONS LEARNED ON ALGAE CONTROL STRATEGIES – NORTH AMERICAN SURVEY FINDINGS

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ABSTRACT

Algal growth within water treatment plants significantly impacts the finished water quality and treatment plant operations. Although extensive research exists on mitigating algae in source water, traditionally in-house experts and operators have relied on local knowledge and trial and error methodology for algae issues within treatment plants. As many utilities take a closer look at their treatment process for the upcoming Stage 2 D/DBP Rule, some strategies to decrease DBPs may promote unintentional algal growth (e.g. changing the location of chlorine addition to later in the process). For utilities with current algae issues or the potential for algae issues, it is important to understand what problems may arise with algae in treatment plants and what options for mitigation have been utilized.

Towards this goal, the American Water Works Association Research Foundation (AwwaRF) sponsored a research study to document algal mitigation strategies employed by the various water utilities in North America. As part of this study, the research team members conducted a literature review and a survey of 77 water treatment plants in North America. The literature review collected data on various strategies employed by water utilities to control algal growth in their facilities. The survey consisted of a comprehensive 53 question survey which collected information about treatment trains, algae issues, mitigation strategies employed and strategy effectiveness. The survey responses indicate strategies that were successful and unsuccessful for algal mitigation within treatment plants. The study classifies the treatment plants according to region, size, average solar radiation, source water type and impacts, treatment train including chemical additions, types of algae, location of growth within the treatment plant, growth cycles, treatment plant and distribution issues, methods used for mitigation and effectiveness of methods.

This paper will describe the literature review and the following results from the detailed study:

- Utility operational and distribution issues caused by algal growth
- Algae type (floating, attached or benthic) and growth locations within the treatment plant
- Strategies employed by utilities for specific algae types
- Analysis of effective and ineffective strategies utilized in specific treatment trains
- Comparison of treatment plants with similar treatment trains and differing algal mitigation strategies and their effectiveness

Algal control strategies that will be discussed include chemical addition (chlorine, copper sulfate, potassium permanganate), operational practices (scrubbing walls and weirs), design and structural modifications (covering basins, copper plating of weirs and walls) and treatment

processes (dissolved air flotation). The findings of this study will be useful for the treatment plant superintendents and utility managers who are struggling with algal growth issues at their water treatment plants. The survey findings will present a unique opportunity for the utility staff members to compare their current strategies to those used by other utilities facing algae issues and learn from the experiences of others.

KEYWORDS

Algae, algae control, taste and odor control, water treatment, algae characterization

INTRODUCTION

Algae are photosynthetic organisms that occur in freshwater, marine water, snow and sand. Algae vary from small single-celled organisms to complex, multi-cellular organisms. Algae are microorganisms some of which are closely related to protozoa and some of which are closely related to plants. Algae play an important role in lakes/reservoirs and recycling of nutrients. However, algae are known to cause a variety of problems for water treatment facilities, from both the operational and finished water quality standpoints. They can impart taste and odor (T&O) and can be pathogenic to humans. The pathogenic nature of algae arises from the production of algal toxins which may cause gastroenteritis.

A wide variety of algal types are found in water treatment plants, each with different characteristics. Different types of algae grow in different optimum living conditions and thus have different impacts on the treatment plants and finished water quality (AWWA 2004). A relatively small number of algae types cause taste and odor problems in finished waters. Water treatment facilities across the United States struggle with algae issues in terms of operation, performance and finished water quality. The water utilities are always in search of various treatment and operational strategies for the control and mitigation of algae.

This paper provides a discussion of the types of algae, their characteristics, problems they cause, and various treatment strategies used to manage this issue. It also provides a summary of data collected in a nationwide survey of water treatment facilities regarding their issues with algae.

METHODOLOGY

Based on the literature review, 53 questions were identified to fit the following four categories:

- Demographics
- Algae Characterization
- Algae Issues
- Control Strategies

The section on Demographics covered questions on population served, system size, water sources and impacts on water sources. The second section on algae occurs queried on the details of algae occurrences, frequency and the duration of occurrences. Algae characterization identified the types of algae and seasonal occurrences of particular algae type. The last two sections identified the issues in the treatment plant due to algal growth and strategies to control this growth.

The survey was sent to 200 water utilities across the United States. The respondents were given almost two months to respond to the survey questions by taking an online survey. The responses were entered by either checking the appropriate choices or entering brief responses. The final responses were exported into Excel and appropriate graphs and tables were generated to summarize the responses.

The questions were logic based, so all the utilities did not answer every question. The response rates for each question are calculated based on the total number of responses received for each question.

RESULTS AND DISCUSSION

The survey responses represent broad geographic, demographic and climatic coverage to address the algae issues and recommend strategies for effective control of algal events. The responses received from the 76 treatment plants classified into following regions: Midwest, Northeast, South, and West (Table 1). Of the 76 respondents, 12 were located in the Midwest, eight in the Northeast, 23 in the South, and the remaining 33 were from the West.

61 utilities of the 200 utilities contacted completed 76 surveys, with some plants providing information on more than one treatment plant.

Table 1 – Regions of the United States

Region			
South	**Midwest**	**West**	**Northeast**
Alabama	Illinois	Alaska	Connecticut
Arkansas	Indiana	Arizona	New Jersey
Washington D.C	Iowa	California	New York
Delaware	Kansas	Colorado	Maine
Florida	Michigan	Hawaii	Massachusetts
Georgia	Minnesota	Idaho	New Hampshire
Kentucky	Missouri	Montana	Pennsylvania
Louisiana	Nebraska	Nevada	Rhode Island
Maryland	North Dakota	New Mexico	Vermont
Mississippi	Ohio	Oregon	
North Carolina	South Dakota	Utah	
Oklahoma	Wisconsin	Washington	
South Carolina		Wyoming	
Tennessee			
Texas			
Virginia			
West Virginia			

Demographics

The population sizes served by the responding utilities ranged from small systems (0-10,000 people) to very large systems (greater than 1,000,000 people). Plant capacities for the responding utilities ranged from 1.5 mgd to 1457.5 mgd. The responding treatment plants were categorized as 0-30 mgd, 31-50 mgd, 51-100 mgd, and >100 mgd. A comparable number of responses were received from plants of each size (approximately 25% each).

Algae Characterization

Blue-green algae are generally blue-green to brown in color. Blue-green algae are also commonly called cyanobacteria due to their prokaryotic cell structure that resembles more closely the structure of bacteria. They are single-celled, colonial, or filamentous bacteria that are often found near the surface of reservoirs (Rusin et al. 1997). Algal blooms may end naturally in the absence of nutrients, if too much sunlight damages the photosynthetic apparatus, when the algae are stranded on shore, or are attacked by viruses or fungi (AWWA 2004). Some algal species like *Aphanizomenon*, are blue-green algae that give off an odor produced by geosmin. This is the cause of T&O episodes in warm temperatures, such as those that occur in late summer or early fall.

The diatoms are brown to light green in color, and the cell wall is very rigid, with regular markings (Hilal et al. 2004). Diatoms may occur as single cells, chains of cells, or in colonies. Diatoms are denser than water and must rely on mixing in water bodies to remain in suspension (AWWA 2004). Diatoms are often a cause of filter clogging in water treatment plants (Scholz 1997; Jun et al. 1999).

Green algae are green to yellow-green in color due to the presence of chlorophylls *a* and *b*. The cell wall is semi-rigid and may be smooth or have spines (Hilal et al. 2004). Green algae can be the dominant species in summer when they commonly occur in eutrophic waters (Horne and Goldman 1994).

Golden algae are mainly unicellular or colonial. The golden color for which they are named is caused by the pigment fucoxanthin in the chloroplasts (AWWA 2004). Golden algae may be the dominant species (at low concentrations) in summer and in waters with pH below 7.5 (AWWA 2004).

Based on the survey responses, algae were characterized based on color, body features, and survival adaptations. Amongst the 58 responses for algae characterization, blue-green algae and green algae are the two dominant species in all the regions. These algae types were identified as cyanobacteria and chlorophyceae. In addition to these species bacillariophyceae (diatoms) are also predominant in all the regions, when characterized by species.

During the summer months, all regions have high temperatures and high solar radiations. Algae growth is favorable in such conditions. The dominance of blue-green and green algae in all the regions possibly explain the dominance of these two species in all the regions. The low pH in the lakes of the Midwest and some rivers of South serve as breeding grounds for golden algae in the summer, making them next dominant species in these regions.

Algae Issues

The survey results showed algal growth in water treatment plants impact water quality (e.g. T&O, DBP formation) and treatment plant operations (e.g. increased filter run time, sedimentation basin disruption). The primary algae issues within the treatment plant are (Figure 1):

- Clogging of raw water intake screens
- Fouling overflow weirs, leading to disruption of flow distribution in settling basins
- Fouling of flow control structures
- Algae "mats" rise and sink in sedimentation basins, affecting settling characteristics of alum floc and decreasing overall particulate removal in sedimentation basins
- Clogging of filter media, increasing headloss, shortening filter of run times, and increasing filter backwash requirements
- Increasing coagulant demand and sludge production.
- Increasing chlorine demand and disinfection by-products (DBPs) formation
- Fluctuations in pH and dissolved oxygen causing undesirable precipitation/dissolution reactions.

The major distribution system issues are related to aesthetics and water quality like increased taste and odor and increased turbidity (Figure 2).

Figure 1 - Treatment Plant Issues

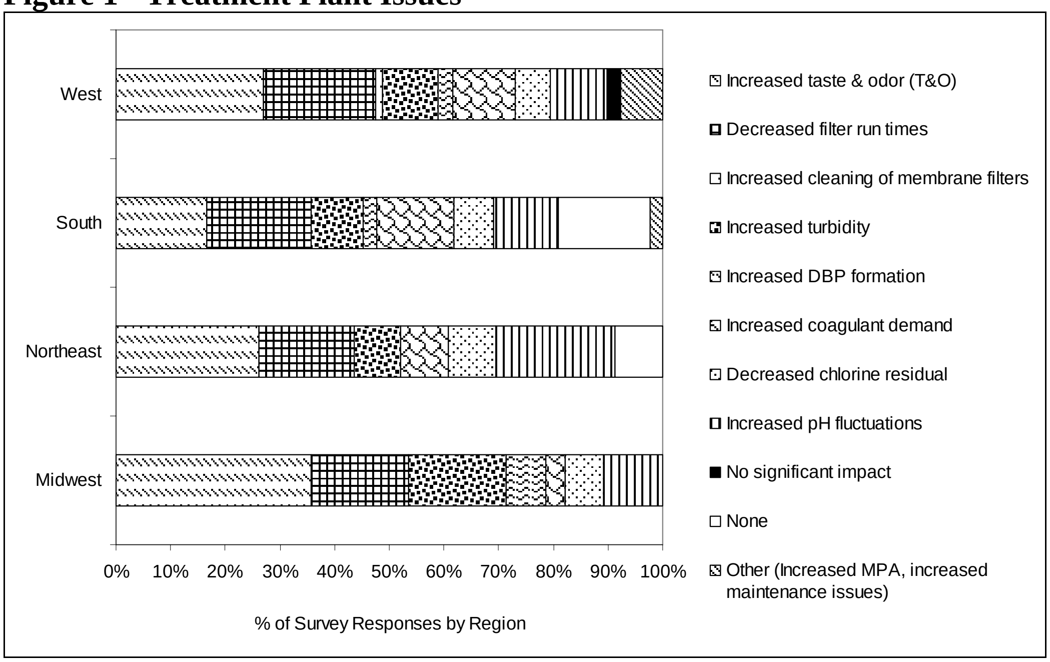
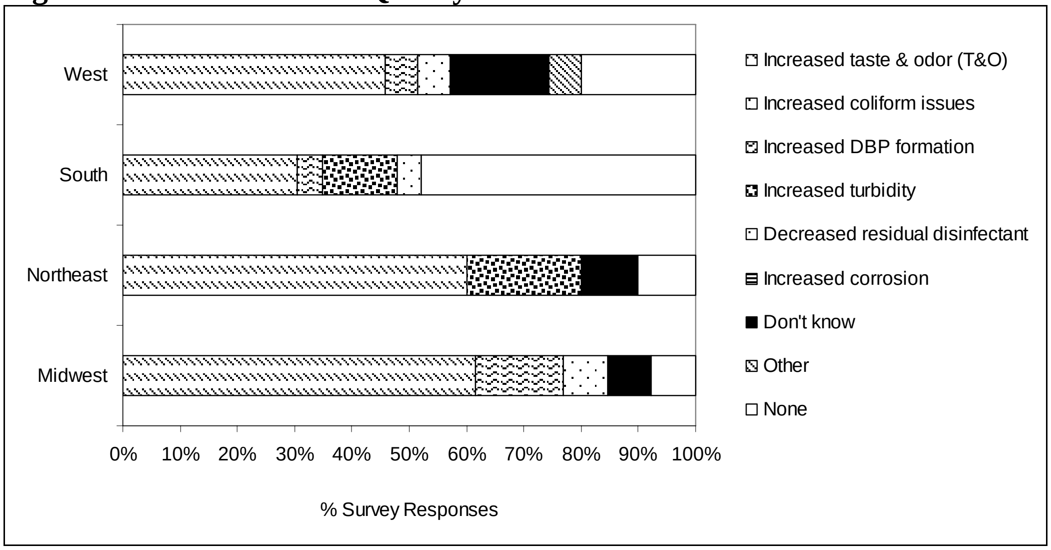


Figure 2 - Finished Water Quality Issues



The presence of algae in plant waters is related to T&O episodes. The earthy and musty odors are a results of (E)-1, 10-dimethyl-9-decalol (geosmin) and 2-methylisoborneol (MIB) compounds. Blue-green algae are associated with the production of MIB and geosmin. Golden algae (*Synura petersenii* and *Dinobryon cylindricum*) are associated with the occurrence of fishy odors, as well as cucumber odors (*Synura petersenii*) (AWWA 2004).

In addition to the T&O compounds, many freshwater blue-green algae can produce powerful toxins that are harmful to humans and animals. Heptotoxins can cause death in humans and animals by liver hemorrhage. Anatoxins detected in freshwaters are powerful neurotoxins that can cause death through muscular paralysis and ultimately respiratory arrest (Knappe et al. 2004).

Control Strategies

The most commonly used source water management techniques include the addition of algaecides or other chemicals like potassium permanganate, copper sulfate, and hydrogen peroxide to control algal growth.

Base of the survey 46 responded have source water algal control strategies in place while 28 had no control strategy. Sixty percent of responses from the Northeast plants add potassium permanganate to their source water to control algae. Other regions also used this technique to some extent. Copper sulfate, a known algaecide, was the next most prevalent choice in all the regions. Aeration, mechanical mixing, physical removal, and mixing waters with waters of lower or negligible algae concentrations were other most commonly practiced techniques for source water management.

Chemical Strategies

Pre-oxidation with chlorine enhances coagulation of algal cells and causes algal cell lysis and release of metabolites. It is only an acceptable treatment option for algae if subsequent treatment processes are able to remove the algal toxins released when cell lysis occurs (AWWA 2004).

Coagulation and flocculation are more effective at removing actual algal cells than their associated toxins (Steffensen et al. 1998). While the addition of chlorine serves many purposes, chlorine (or other strong oxidant) addition is not recommended before flocculation, due to its tendency to disrupt the algal cells. At application rates between 0.5 and 2 mg/L, chlorine was found to cause increased inhibition of nitrogen fixation as well as increased release of potassium, dissolved organic carbon (DOC), and geosmin (Peterson et al. 1995).

Potassium permanganate combined with alum was a more effective oxidant than iodine and ozone for the removal of algae from Nile River water (Shehata et al. 2002). Rastogi and Knappe (2000) evaluated the impact of potassium permanganate preoxidation on algal cell removal. Removal of algae was upto 20% primarily due to cell lysis.

Another alternative preoxidant to chlorine and potassium permanganate is chlorine dioxide (ClO_2). ClO_2 has been shown to remove 91 percent of microcystin. Gregory (2005) reported that the application of ClO_2 as a pre-oxidant before the coagulation step led to the reduction of algal concentrations measured in chlorophyll *a* levels.

The survey indicated utilities use similar chemicals for in-plant control as the source water control. Thus copper sulfate, potassium permanganate, and algaecides were commonly used to control algal growth. In addition to these chemicals, some responding utilities also used enhanced coagulation, activated carbon adsorption, lime softening, and residual disinfectant maintenance within the treatment process for additional control.

Design Strategies

Limiting the sunlight can control in algal growth, thus reducing the light reaching the reservoir can limit algal growth. Covering the reservoir or basin is one of the successful design strategies. Another option to reduce algal growth is the application of an algaecide coating to surfaces where algae tend to grow. Copper sheeting has also been tested in several treatment plants to evaluate its ability to prevent the growth of attached algae. Finally covering filter cells and using concrete deck covers are other successful design alternatives for reducing algal growth.

Operational Strategies

Power washing is a practice which is commonly employed by treatment plants for the removal of periphytic algae. Many utilities prefer to use power washing where possible, at times when water flows are low and some of the basins may be taken offline. The surveys conducted as a part of this project found 60% of the responding water treatment facilities used this technique in their utility. Scrubbing and power washing was the second most successful strategy for controlling algal growth according to the survey. A few more operational strategies include using coagulation and flocculation, dissolved air flotation and sonication techniques.

CONCLUSIONS

Algae issues occur in many water treatment plants. The main algae types typically detected are blue-green algae (C*yanobacteria*), green algae (*Chlorophyceae*), diatoms, golden algae (*Chrysophyceae*), eugleonoids (*Euglenophyceae*), and cryptomonads (*Cryptophyceae*). The algae growth subsequently leads to problems within the treatment plant and ultimately leads to problems in the distribution system. Water quality from the treatment plant is impacted due to algal growth. Water quality parameters in terms of TOC and DBPs increase with the presence of algae. The instances of T&O episodes increase with algae growth. Algal toxins are another issue that needs attention in algae control.

Based on literature case studies and utility surveys, designing covered sedimentation basins and filters, using algaecide coatings on walls, and applying algaecides like copper sulfate and potassium permanganate help in controlling algae to some extent. Operational practices like scrubbing walls, cleaning with a power hose, peroxidation using strong oxidants like ozone or chlorine dioxide also aid in algae control.

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