

# **Treatment Process Performance Evaluation and Investigation of Taste and Odor Problems**

submitted to  
**City of Greenville, Illinois**



**July, 2003**



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## **Background**

In recent summers, the City of Greenville has received complaints of taste and odor in their municipal drinking water. The purpose of this investigation was to evaluate source water quality, treatment plant performance, disinfection practice, and changes in quality during distribution. In particular, the nature and cause of seasonal taste and odor problems was investigated, and alternatives for remediation were evaluated.

## **Governor Bond Lake Water Quality**

Much information on Governor Bond Lake is readily available from IEPA's September 2002 TMDL report. The Executive Summary of that report follows:

### **EXECUTIVE SUMMARY**

Governor Bond Lake in Greenville, Illinois is listed as impaired for recreation, swimming and overall use. Main causes contributing to impairment are identified as nutrients, siltation, suspended solids, and excessive algal growth/chlorophyll-a. This TMDL addresses the nutrient and sediment reductions needed for Governor Bond Lake to comply with Illinois guidelines for nutrients, siltation, suspended solids, and chlorophyll-a concentrations. The specific problems and control action plans associated with nutrient and sediment loads are highlighted below.

#### **Problem No. 1: Nutrients**

Excessive nutrient loading to Governor Bond Lake has resulted in nuisance algal blooms, and consequently, impaired recreation and overall uses. Because there are no point source dischargers in the watershed, nutrient loads are coming from nonpoint sources, such as farming activities, feedlots, septic systems, streambank erosion, and natural processes. Elevated total phosphorus (TP) concentration, a surrogate for nutrients in general, has been measured in both the lake and associated tributaries. Internal cycling (re-release of previously settled out TP) is also implicated as a source of TP. Excessive chlorophyll-a, a surrogate measure of algal growth, has been measured in the lake. Several BMPs will result in nutrient load reductions and consequently, reduced algal growth. Some BMPs include: construction of multi-celled wetlands/extended sedimentation ponds, filter strips,

tillage and nutrient management plans, construction erosion control permits, septic tank setback, sediment sealing, destratifiers, and/or aerators, to name a few. Additionally, continued and increased enrollment in CRP, stream bank stabilization projects, septic system maintenance, tillage and nutrient management education, feedlot management, and other on-going programs will further help reduce nutrient loads to Governor Bond Lake.

**Problem No. 2: Sediment**

Sediment loads to Governor Bond Lake have resulted in lake siltation (in-filling) and elevated non-volatile suspended solids (NVSS) concentrations. About one-half of the sediment load to Governor Bond Lake is from land surface erosion, and the rest is from shoreline and stream bank erosion. High sediment loads from tributaries and high NVSS in the lake have been measured. Practices that reduce erosion will reduce both sediment transport and NVSS concentrations. Most BMPs designed to reduce nutrient transport will also be effective at reducing sediment loads. Stream bank fencing, riprap, and aquascaping are some additional BMPs that can be used to reduce sediment transport to acceptable loads.



**Governor Bond Lake showing near-shore water treatment plant intake structure**

## **Sources of Taste and Odor**

### *Nutrient Sources; Algae*

From the standpoint of drinking water, the most important finding in the IEPA report is that of the excessive nutrient loading in Governor Bond Lake. These nutrients, particularly nitrogen and phosphorous, contribute to the prolific growth of algae, which is most likely the root cause of Greenville's seasonal taste and odor complaints.

Algal cells produce a variety of organic compounds including geosmin and MIB (methyl iso-borneol), which have been identified as taste and odor-causing compounds. While not toxic, these compounds can cause taste and odor problems in concentrations as low as 7 nanograms ( $10^{-9}$ g) per liter.

In addition, as algal cells die and rupture, they release soluble and sometimes toxic organic compounds into the water. As a result, from a taste and odor control standpoint, it is more desirable to *physically* remove algal cells rather than rupture them with a disinfectant or oxidant during treatment. In other words, coagulation, sedimentation and filtration are the preferred methods for removal of the algal cells. Chemical additives that cause cells to rupture (lyse) may only increase taste and odor problems.

## **Laboratory Capabilities for Assessing Lake and Treated Water Quality**

### **Ammonium Ion**

No data on ammonium ion ( $\text{NH}_4^+$ ) was presented in the IEPA report. Knowledge of the amount of ammonium ion in the lake water throughout the year is *critical* to the operation of the Greenville water treatment plant. This is partly due to the fact that liquid ammonia ( $\text{NH}_3$ ) is sometimes fed during treatment to form a chloramine disinfectant residual. Any fluctuating level of ammonium ion in the raw lake water will cause operational problems with maintaining the proper chlorine to ammonia feed ratio.

Until recently, the Greenville water treatment plant laboratory was not equipped to analyze water samples for ammonium ion. Greenville has now obtained and is utilizing the necessary equipment and reagents for performing this important analysis. In fact, the plant staff have already determined that exceptionally high transient concentrations of ammonium ion are passing into the treatment plant.

These results have led Greenville water plant superintendent, Jeff Leidner, to investigate the sources of these transient releases. Sampling of overflow discharges from local animal feedlot waste treatment lagoons to tributary streams in the watershed indicate that, during periods of heavy rainfall or high waste discharge, pond overflow water containing very high concentrations of ammonium ion is released to streams that are tributary to Governor Bond Lake.



**Large-Scale Livestock Production Facility and Animal Waste Storage Lagoon**



**Sampling of Secondary Waste Treatment Cell near overflow point**

### **Total Organic Carbon**

A comparatively advanced measure of the organic content of water is total organic carbon (TOC). While TOC varies markedly with season, nutrient-enriched lake waters have been found to be particularly high in TOC during periods of high water temperatures and algal blooms.

A modified analytical method for analysis of total and dissolved organic matter (TOC, DOC) has recently been developed by Hach Chemical Company (<http://www.hach.com/Spec/toca.htm>). This colorimetric method does not require the purchase of a costly, dedicated organic carbon analyzer and appears to be suitable and cost-effective when only occasional, in-house TOC analyses are required.

For weekly analysis of lake water influent and plant effluent TOC and DOC, this method should be utilized by Greenville on a trial basis to determine whether it will effectively allow monitoring of seasonal changes in lake organic content plus provide a quantitative assessment of the effectiveness of the treatment processes presently used to remove organic matter.

## Microscopic Analysis

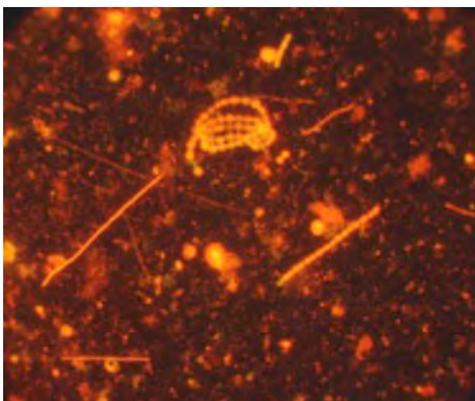
Finally, particularly since Greenville's water source is a lake, the water plant laboratory should be equipped with a compound light microscope. A microscope will allow the staff to observe and identify algae in the lake water as well as enable operators to make numerous other important visual observations throughout the treatment process and in the distribution system.

Microscopes which allow direct observation of bacterial cells commonly cost between \$10,000 and \$20,000. Unlike computers, however, optical microscopes do not become obsolete. We recommend that Greenville purchase a light microscope with phase contrast objectives and an epifluorescence (ultraviolet light) attachment that will allow the observation and photographing of bacteria as well as algae.

Since bacterial regrowth often occurs during water distribution, particularly in system dead-ends, it is anticipated that microscopic evaluation will be useful in responding to consumer complaints where disinfectant residuals may be absent.



**Jeff Leidner examining water samples using a microscope**



**Epifluorescence Micrograph of  
Raw Water from Governor Bond Lake**

# Source Water Protection and Lake Water Quality Management

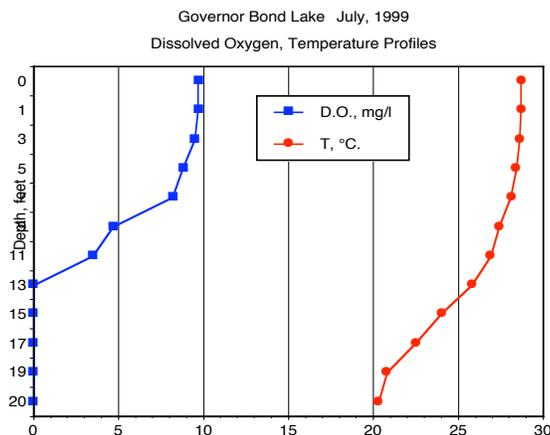
## Lake Water Intake

Portions of the existing raw water intake structure are deteriorated and in need of rehabilitation or replacement. An assessment of whether other portions of the existing intake structure facilities can continue to be utilized and repaired should be conducted. Mitigation of potential winter weather icing problems may also be a significant consideration.



Shallow lake intake withdraws water at 12-foot depth close to shore

Because water quality often varies with depth during periods of reservoir stratification, multi-level withdrawal capability at an intake may be important to allow selection of optimum lake water quality. For example, during periods of lake stratification, dissolved iron ( $\text{Fe}^{2+}$ ) and manganese ( $\text{Mn}^{2+}$ ) concentrations typically increase in the anoxic or low dissolved oxygen (DO), deeper portions of reservoirs. Data from the summer of 1999 show that Governor Bond Lake was anoxic at depths below 13 feet.



## **Destratification**

Many Illinois water utilities utilizing lake water sources provide aeration and/or destratification to mitigate the adverse effects of anoxia and lake stratification. They seek reductions in taste and odor algae concentrations, avoidance of the solution of iron and manganese from sediments, and reduced potential for forming trihalomethanes due to high organic concentrations. From IEPA's September 2002 TMDL report:

### ***Destratifiers***

Destratifiers enhance lake mixing at depths in order to prevent formation of thermal stratification in deep lakes (> 15 foot depth). Thermal stratification sets up the lake with a thermal resistance to mixing, effectively separating the warmer, lighter, well-mixed surface water from the colder, denser, undisturbed deep water. If phosphorus re-release is occurring due to anoxic conditions enhanced by lake stratification, this technique reduce phosphorus re-release by keeping the lake mixed and new oxygen replenishing the depleted supplies. In shallow lakes, however, where anoxic conditions are due to episodic events (sudden senescence of a large amount of aquatic plants) or re-suspension by wind and fish, this technique will not be effective.

Recognizing that significant improvement of Governor Bond Lake water quality might be achieved by installing a system that both aerated and circulated the reservoir water, Greenville previously installed an destratification unit. This particular unit created turbulence in the shallow, offshore water and increased turbidity, thereby making treatment more difficult. In addition, the destratification unit was inherently unstable and tended to twist both the connecting power lines and guy wires. For these reasons, the unit was taken out of service.



**Destratifier removed from service for resuspending sediments**

Greenville's concept of aeration and destratification, although initially unsuccessful, is a good one. It has worked well for many water utilities throughout the region and may, in itself, play a major role in reducing algal activity in the Governor Bond lake. A properly-sized destratifier should be installed in a region of the lake where it would not cause increased turbidity at the intake. Water quality monitoring with depth (dissolved oxygen, temperature profiles) should be conducted to confirm the unit's effectiveness.

An example of such a destratifier unit that has been highly effective in controlling algae is the one operating in Lake Bloomington for the Bloomington water utility. This consists of a pump that forces water through a Venturi injector in the lake, which then aspirates air into the water stream from an air line from the surface.

Alternately, the Solar Bee (pictured at right) is a floating, solar-powered circulator. These units cost approximately \$30,000 each, and it would probably be necessary to install several of them.



**The Solar Bee**

## **Raw Water Intake**

Water from Lake Governor Bond is presently drawn into the plant from the center port of the intake structure at a depth of approximately twelve feet beneath the surface. The upper and lower (3' and 18') intake ports are presently unavailable. While these alternate ports might be returned to service by dredging around the lower intake and restoring the upper intake, it is not certain that this would result in a significant operational benefit because the entire intake structure is located in shallow water in which algal growth may be abundant throughout the water column.



**Rotating microscreens are continuously washed to remove debris**

In addition to the basic facility requirements for adequate water withdrawals, the raw water intake facilities design entails significant process-related considerations. Adequate screening to exclude debris and fish must be provided. In addition, micro-screening either near the intake or at the treatment plant for the physical removal of algae and other organic debris might also be considered as a potential process enhancement to prescreen suspended matter and assist in reducing DBP formation.

## **Lake Source Water Protection Plan**

Overall, source water protection should be a major part of Greenville's plan to control drinking water quality, including taste and odor compounds and disinfection by-products. The IEPA report on Governor Bond Lake, coupled with treatment plant influent monitoring throughout the year, should provide the basis for a long-term program for controlling nutrient discharges to the lake.

In addition to water quality, lake water storage capacity is a valuable asset. Siltation of the lake due to field, stream and bank erosion progressively compromises storage capacity. A program to moderate the loss of soils and sediments to the lake should be undertaken. This might include bank stabilization, conservation tillage, buffer and filter strips and a public relations program aimed at winning the support of both lake users and adjacent landowners in this resource conservation effort.

The Illinois Clean Lakes Program (ICLP) provided assistance for the Governor Bond TMDL Report through a Phase I diagnostic/feasibility study grant. This report scientifically documented the causes, sources, and magnitude of lake impairment and recommended lake protection/restoration practices for future implementation. The City of Greenville should now pursue Phase II implementation project grants to implement the Phase I report recommendations.

## **Water Treatment Plant and Process**



**Greenville has a comprehensive water treatment plant sited on the shore of Governor Bond Lake**

Greenville's water plant has evolved over a long period. Treatment consists of alum coagulation, lime addition, upflow solids contact clarification, dual media filtration, and post-disinfection by chlorine. Supplementary chemical feeds include powdered activated carbon, potassium permanganate, cationic and anionic polymers, carbon dioxide, aqueous ammonia, and fluoride.

### **Chemical Feeds to Influent Water**

Seasonally, an oxidant, potassium permanganate (1-2 mg/l), and an adsorbent, powdered activated carbon (15-20 mg/l), are fed in an attempt to control taste and odor compounds. However, the dosage and contact period for both the permanganate and carbon feeds may be inadequate for taste and odor control during an algal bloom or lake turnover. At these critical times, carbon feed might need to be on the order of 50 mg/l or greater, and the time for adsorption (contact time) should be maximized by feeding PAC as soon as possible after withdrawal. Monitoring of TOC would indicate the relative effectiveness of both the permanganate and PAC feeds and application points.

To assist in operational control, a determination should be made of the effectiveness of the permanganate dose in reducing lake water TOC and DOC. The dosage of permanganate currently used may be insufficient to accomplish significant oxidation of high concentrations of organic matter. Instead, to the disadvantage of the treatment process, permanganate addition may result in the lysing of the algal cells. Finally, the application of permanganate creates a secondary maintenance problem by discoloring the surfaces of the upflow contact clarifiers (ClariCones).

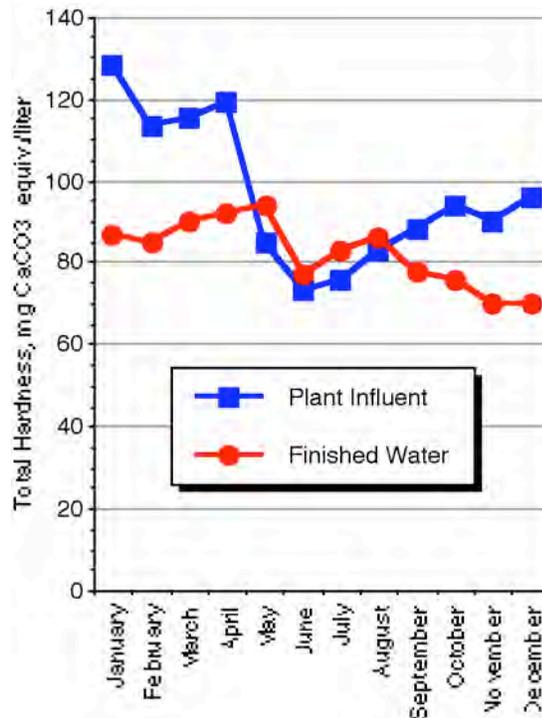
## Lime Softening

The average hardness in the lake water for the year 2002 was 97 mg/l as CaCO<sub>3</sub> equivalent. This was reduced to an average of 82 mg/l as CaCO<sub>3</sub> eq. in the finished water.

In the summer months, when influent hardness was lowest, the plant effluent was equal to or slightly harder than the raw water. Overall, both lake and finished water hardness is satisfactory and the treated water is non-corrosive and stable.

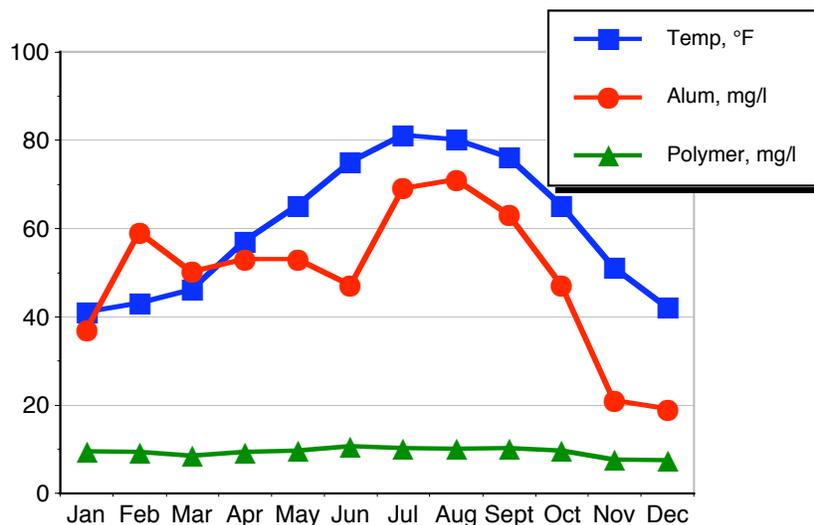
Precipitated solids, incorporating decaying algal matter, tend to accumulate on the sloped walls of the ClariCone. These accumulations should be removed regularly, as the algal decay products could progressively contribute tastes and odors to the water.

2002 Hardness: Lake and Finished Water



## Coagulation

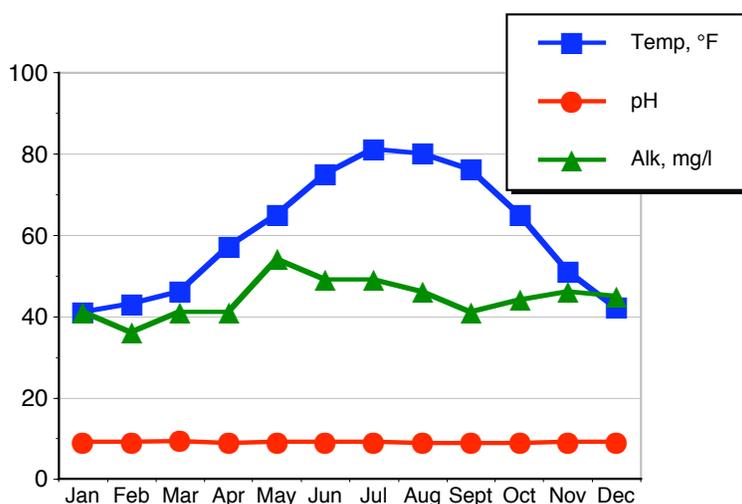
Both aluminum sulfate (alum) and anionic polymer are used as coagulants for the Governor Bond Lake water. In the calendar year 2002, the applied dosage of alum varied with the season while the polymer dosage remained relatively constant. The effectiveness of the coagulation process was indicated by the consistently low settled and finished water turbidity obtained throughout the year.



## Finished Water pH, Alkalinity, TOC

The Greenville plant finished water has sufficient alkalinity to avoid problems with corrosion. However, the finished water pH, with monthly averages ranging from 8.7 to 9.3, could be slightly lower. At pH 9, the supersaturated water deposits calcium carbonate on the filter media and process equipment.

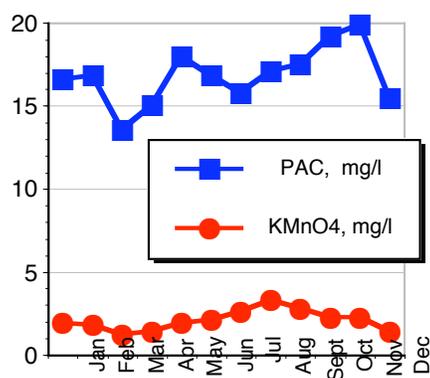
A decrease in the lime feed to maintain a filter influent pH of less than 9 would reduce the finished water's tendency to form scale plus eliminate the need for recarbonation. The water would still be non-corrosive. An additional benefit of lowered pH would be a reduction in the subsequent rate of trihalomethane formation during distribution.



Powdered activated carbon (PAC) and potassium permanganate (KMnO<sub>4</sub>) are applied throughout the year to remove/oxidize organic matter in the lake water source. It is proposed that trials be made to determine how effective permanganate is in achieving significant TOC reductions as compared with coagulation alone. If incremental TOC reductions are minimal, consideration should be given to decreasing or discontinuing the permanganate addition.

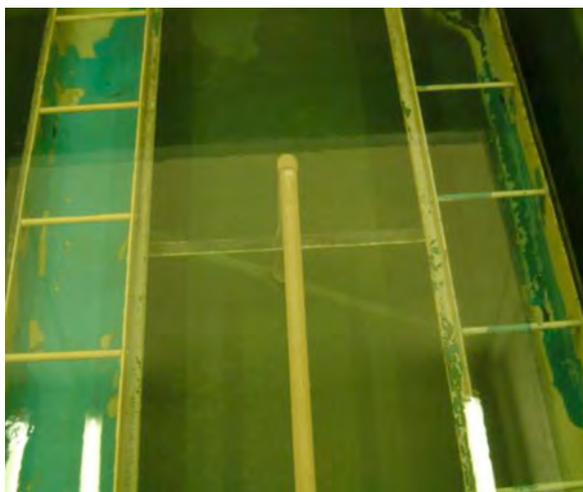
The PAC dosages and contact times required to reduce TOC should also be determined. During periods of algal blooms and high influent TOC, dosages in excess of 50 mg/l may be required.

Alternately, during winter periods, PAC feed may offer little benefit. With a year or more of accumulated data on influent and effluent TOC, a seasonal PAC dose-response protocol should be established.



## Filtration

The filters at the Greenville water treatment plant are dual-media; anthracite over silica sand. Plant staff provided a grab sample from the top of an operating filter. Despite being taken from the filter surface (normally only the lighter anthracite), the sample was found to be comprised of a mix of sand and anthracite. Most of the anthracite was encrusted with what appeared to be calcium carbonate. In order to determine the extent of calcium carbonate encrustation, the sample was repeatedly treated with hydrochloric acid. This acid treatment resulted in a weight loss of 35%.



The photographs shown below illustrate the initial condition of the filter media surface (left), followed by the treatment with acid to dissolve the surface accumulations (center) and, finally, the acid-cleaned media (right). Note the evolution of gas (effervescence) following the addition of acid (center).

**Filter Media (19.6 grams)**



**Acid Treatment**



**After Acid Treatment (12.6 grams)**

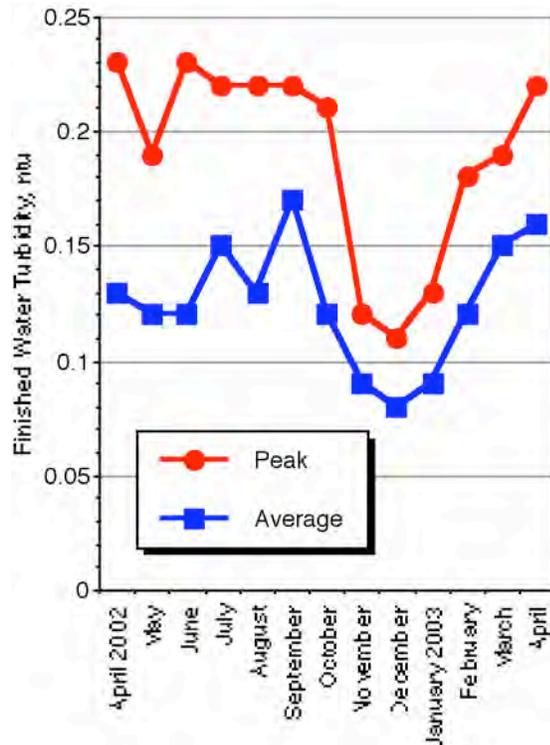


Despite the enlargement of the filter media due to calcium carbonate encrustation, the finished water turbidity was maintained at very low levels, well within regulatory requirements. Still, the enlargement of the filter media over time, due to post-precipitation of calcium carbonate, is to be avoided. An enlarging filter media will allow increasing numbers of fine particles, such as unflocculated algal and bacterial cells, to pass into the finished water. These cells can serve as precursors to the formation of DBPs.

Filter media growth can be minimized by reducing pH in the filter influent, providing more frequent backwash, and installing a compressor and piping for air-assisted backwash. A decrease in lime feed to limit pH to 8.5 or less in the filter influent would be beneficial. Whereas backwash frequency currently seems optimal, the installation of air-scour should increase media cleaning efficiency and reduce backwash water requirements.

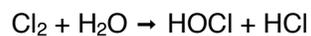
IEPA requires that finished water turbidities remain under 0.3 ntu 95% of the time. For the 12-month period ending April 2003, finished (filtered) water turbidities at the Greenville plant averaged 0.12 ntu and peak values did not exceed 0.23 ntu. Finished water turbidities were highest in the spring and summer months and declined markedly in the winter.

The highest monthly average finished water turbidity, 0.17 ntu, was observed in September. This peak may correspond to a seasonal peak in lake water algal population. If so, further increases in coagulant (alum, polymer) dosages during the period, June through October, may further limit the passage of potential taste and odor-producing organisms into the distribution system.



## Disinfection

Greenville currently uses gaseous chlorine as a primary disinfectant. When adding chlorine gas to water, the following reaction occurs:



An alternative method of chlorine disinfection is liquid sodium hypochlorite (bleach). When adding sodium hypochlorite to water, the following reaction occurs:



Both methods of chlorination produce the same active oxidizing/disinfecting agent, hypochlorous acid (HOCl). The difference is that chlorine gas produces hydrochloric acid (HCl) as a byproduct, whereas bleach produces sodium hydroxide (NaOH), a base.

The advantage of sodium hypochlorite over chlorine gas is risk reduction: safety of plant personnel and neighbors, transport of hazardous chemicals, and concern over terrorist attacks on chemical storage facilities. Sodium hypochlorite can either be purchased or generated on site. Information from USEPA regarding on-site hypochlorite generation is appended.

### *Chloramination*

Chloramines should be consistently used as the disinfectant residual. The Greenville plant is set up to feed aqueous ammonia in order to form chloramines. However, it seems that the laboratory staff has not been provided with the equipment or training to properly monitor the chloramination process. In addition, recent lake water samples have been found to contain widely-varying concentrations of ammonium ion, thus further complicating the chloramination process.

The lab should be equipped with an ion-specific probe for ammonia analysis, and the purchase of an online ammonia/monochloramine analyzer (such as the Hach APA 6000) should be considered.

### *Chlorine Taste and Odor*

The sensory thresholds at which individuals detect odors and tastes due to different disinfectant residuals is given in the following table (after Krasner and Barrett, 1965). For example, tasters detected free chlorine (HOCl) at 0.24 mg Cl/l whereas chloramine (NH<sub>2</sub>Cl) was not detected until the concentration reached 0.48 mg Cl/l. Therefore, the earliest use of chloramines was to mitigate taste and odor complaints.

	<i>Odor</i>	<i>Taste</i>
free chlorine, mg/l	0.20	0.24
chloramine, mg/l	0.65	0.48

### **Plant Maintenance: Coating of Exposed Metal in Treatment Basins**

The extent of in-plant corrosion, rust and metal loss should be assessed as part of an equipment and maintenance evaluation. In addition to the important maintenance aspects, microscopic analysis may show that many particles found in Greenville's treated water originated from the treatment plant system itself. Paint chips, rust, oil droplets, and post-precipitates of calcium carbonate or aluminum oxide are among particles that were not originally in the source water. Diligent plant maintenance can reduce the passage of such recruited particles plus improve overall plant process performance with respect to turbidity reductions.

## Granular Activated Carbon Filter Caps

With the exception of seasonal taste and odor excursions, the composition of Greenville's finished water appears good. The treated water is low in turbidity, moderate in hardness and alkalinity, non-corrosive, properly disinfected and fluoridated. However, extracellular solutes from lake water algae plus high summer water temperatures may exacerbate tastes and odors, undermining confidence in overall water quality.

Potential treatment process modifications and in-plant procedures to remove organic materials and reduce tastes and odors at Greenville range from:

- lake water quality management (limit algal nutrients)
- installation of a modified destratifier (reduce algal growth)
- prescreening (remove larger algal cells, filaments and organic debris)
- monitoring organic matter (TOC, DOC) to further optimize current chemical application rates
- maintain chloramine residual in distribution system (reduced chlorinous taste)
- installation of granular activated carbon (GAC) filter caps to adsorb organic compounds.

The use of GAC filter caps is increasingly commonplace for taste and odor control. GAC caps may be observed atop the sixteen filters of the Bloomington, Illinois, water treatment plant.



**18" GAC Filter Cap - Bloomington, Illinois; Replacement of GAC media (in black totes)**

When used to remove taste and odor-producing compounds, GAC filter media may be rented from a supplier and replaced on a two to four year schedule. The use of GAC should obviate the need for feeding PAC and potassium permanganate. Additional reductions in the use of lime and carbon dioxide to lower filtered water pH should further offset the cost of utilizing GAC filter caps.

## Seasonal Variation in Chemical Usage

Greenville treatment plant chemical usage varies with seasonal changes in source water quality and water consumption. As an example, the table below contrasts the the amounts and costs of chemicals used in January and July 2002.

<i>Chemical</i>	January, 2002 (1.3 mgd) 41 deg. F.; 8 ntu Turb.		July, 2002 (1.6 mgd) 81 deg. F.; 17 ntu Turb.	
	<i>Dosage, mg/l</i>	<i>Cost, \$</i>	<i>Dosage, mg/l</i>	<i>Cost, \$</i>
PAC	17	86	16	117
Alum	37	37	69	99
KMnO <sub>4</sub>	2	33	3	64
Lime, CaO	97	47	90	61
Cat. Polymer	9	38	10	58
Chlorine	4	9	5	16
Carbon Dioxide	9	5	10	8
Fluoride	1	5	1	8
Aq. Ammonia	0	0	1	1
<i>Monthly Cost</i>	-	<i>\$262</i>	-	<i>\$433</i>

The major difference in chemical use is with respect to the coagulant, alum. This is due, in part, to the fact that lake water turbidities averaged 8 ntu in January as opposed to 17 ntu in July. To a degree, this variation in turbidity may be a measure of the effect of temperature on algal populations.

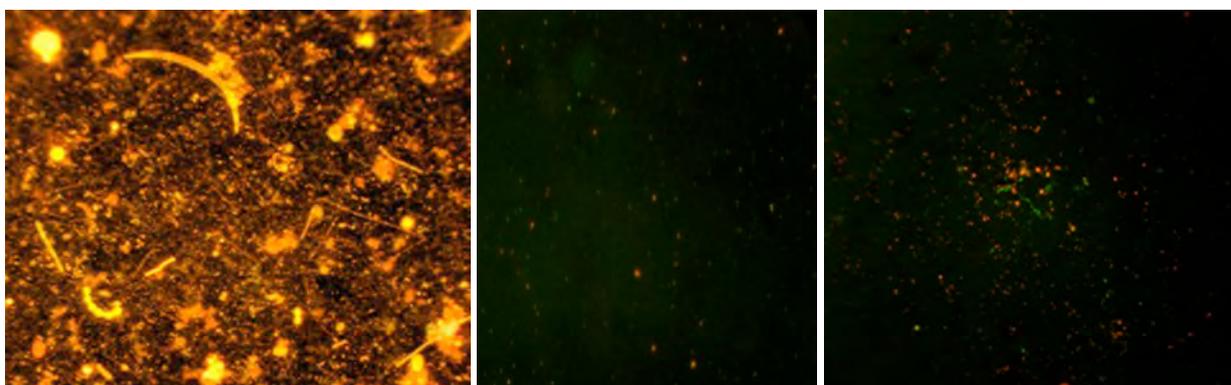
Overall chemical costs are modest, approximately \$250 per million gallons or \$0.25 per 1,000 gallons. About 30% of this cost is for PAC. If TOC data indicates that a doubling of the use of PAC is desirable throughout the spring and summer, even while diminishing its use in the winter, chemical costs might increase to about \$350 per million gallons. For the average householder, this approach to taste and odor control might increase the monthly water bill by \$0.40.

## Distributed Water

### Bacterial Regrowth

Greenville water samples (lake, finished, and distributed) were examined under epifluorescence microscopy. As expected, the raw lake water was full of bacteria and algae. The vast majority of these organisms were physically removed or inactivated during treatment, as the plant finished water micrograph indicates.

A water distribution system sample showed a limited amount of bacterial regrowth. More extensive observation of distribution system samples, particularly at remote regions, should be conducted to ensure that bacterial regrowth is not contributing to the source of taste and odor complaints.



Lake Water

Plant Finished Water

Distributed Water

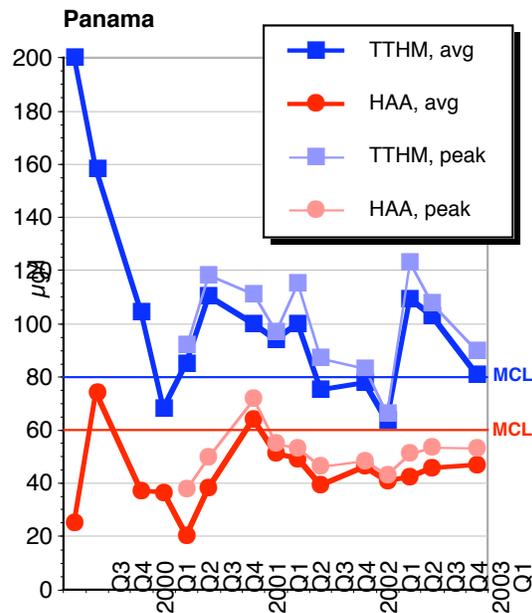
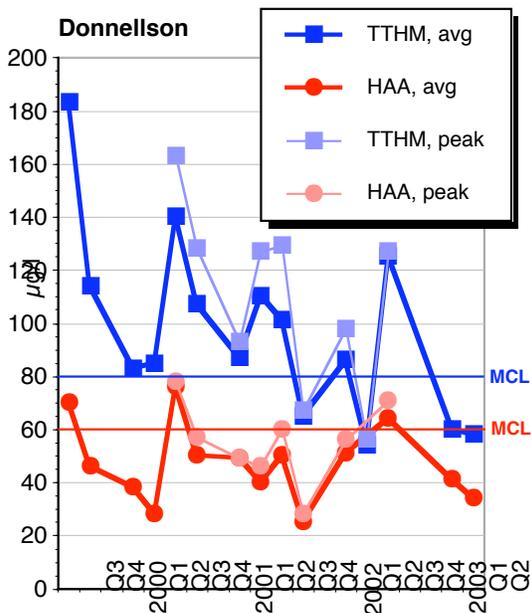
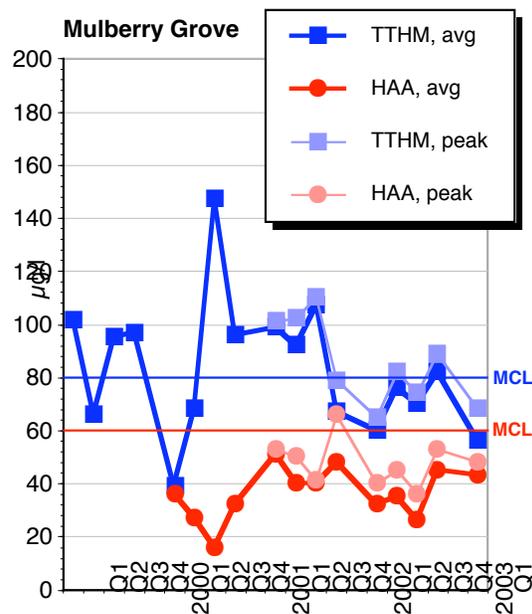
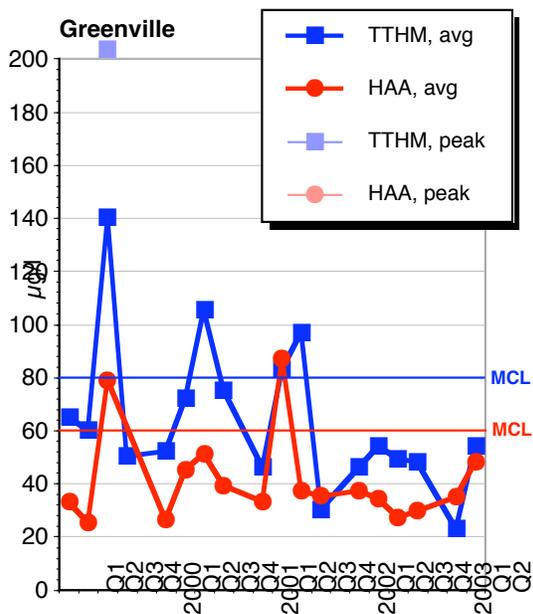
### Disinfection By-Products: Trihalomethanes, Haloacetic Acids

When waters high in organic content, as indicated by high TOC, are chlorinated, the disinfection by-products, trihalomethanes and haloacetic acids (THM, HAA) are slowly formed over a period of hours to days. These groups of compounds are regulated in finished drinking water at levels of 80 and 60  $\mu\text{g/l}$ , respectively. As a result, their concentrations are being monitored on a quarterly basis by the Illinois EPA for regulatory purposes.

A summary of all recorded values of THM and HAA is appended to this report. In addition to Greenville, monitoring results are included for Donnellson, Mulberry Grove and Panama. In general, THM and HAA tend to be higher at more remote points in a distribution system owing to longer contact time between the organic matter and the disinfectant residual.

Trihalomethanes (THMs) and haloacetic acids (HAAs) are the DBPs of concern at Greenville. HAAs and THMs are in compliance but increase with residence time during distribution.

All available results of IEPA monitoring (1999-2003) for the regulated parameters, THM and HAA, have been tabulated and plotted in the following figures. In general, DBP samplings are conducted on a quarterly basis. Whereas Greenville has generally been within the maximum contaminant levels (MCLs) of 80  $\mu\text{g/l}$  for THM and 60  $\mu\text{g/l}$  for HAA, Donnellson, Mulberry Grove and Panama consistently exhibit concentrations of THM in excess of the MCL. Peak THM values often appear to occur in the second- and third quarter samplings.



The formation of disinfection by-products (DBPs) from organic precursors following the addition of chlorine to filtered water is affected by:

- DOC concentration
- DOC source / type
- chlorine dose
- bromide ion
- pH
- time of formation (distribution system))
- temperature
- sunlight - UV considerations

Sunlight, high (summer) temperatures, high DOC concentrations, high pH and prolonged contact times all increase DBP yields. The slow reactions between chlorine and organic precursors often result in the continued formation of DBP during distribution. Alternately, less reactive forms of chlorine, such as the chloramines, markedly reduce both the rate and extent of DBP formation. The use of chloramines in the distribution system is, by far, the most common means employed by U.S. water utilities to meet current drinking water MCLs for DBPs.

The principal measures considered for controlling tastes and odors and DBPs include:

#### 1. Control of Source Water Quality (lake and watershed management)

- lake aeration/destratification,
- nutrient monitoring and control,
- erosion control; construction erosion control permits,
- construction of multi-celled wetlands/extended sedimentation ponds,
- buffer and filter strips,
- tillage and nutrient management plans,
- septic tank setback,
- sediment sealing.

#### 2. Optimized Removal of TOC and THM Precursors and Control of THM Formation

- microstraining for partial removal of organic debris,
- algal cell physical removal: coagulation, sedimentation and filtration,
- permanganate oxidation of precursors,
- adsorption on PAC, seasonally applied,
- GAC-capped filters,
- chloramination,
- lowered finished water pH.

#### 3. Alternate Disinfectants

In selecting a disinfectant, it must be noted that alternative disinfectants create alternative DBPs that must be monitored and controlled. In the case of ozone, bromates are formed from bromide ion in the source water. The production of chlorine dioxide produces residuals of chlorite and chlorate ions which are also regulated in the distribution system.

#### 4. Enhanced Coagulation

Studies on the USEPA-proposed “enhanced coagulation” (Clinton, MO 1998) indicate that the procedure has limited application in high alkalinity, Midwestern waters. Enhanced coagulation requires that the alkalinity be largely destroyed by the addition of acid, then restored to avoid corrosion. This makes enhanced coagulation both costly and difficult to control. Moreover, only marginal improvements in DOC removals and THM-forming potentials were observed. Enhanced coagulation can pose filterability and related finished water turbidity problems, as well as added sludge quantities and disposal problems.

#### **Decomposing Sludges**

Consideration must be given to the timely removal of accumulated sludges in the clarification basins since the decomposition of organic matter in these sludges are known to produce precursors to DBP formation as well as create undesirable tastes-and-odors. For purposes of planning, plant operation and future design modifications, measures should be made of the proportion of DBP formation that occurs within the plant as opposed to their formation during distribution.

#### **Powdered Activated Carbon**

Adequate dosages of PAC, adequate contact times for adsorption, plus retention in the existing sludge blanket-type clarification unit of the primary basins provide advantages for PAC contact and organics removal. PAC dosages should be tailored to seasonal variations of the influent water DOC, taste and odor, and degree of removals to be achieved. For example, the City of Chicago feeds PAC to Lake Michigan water for taste-and-odor control, but only between May and September.

## **Summary of Recommendations**

### **Source Water Protection and Lake Water Quality Management**

1. Installation of a lake aerator/mixer/destratifier
2. Appointment of a Water Advisory Committee
3. Development of a Watershed Management Plan
4. Pursuit of IEPA Clean Lakes Program Phase II Funding to Implement Watershed Management Plan
5. Periodic application of chelated copper sulfate to the lake for algae control
6. Continuous monitoring of the hog farm and any other identifiable point sources (Obtain copies of operating permit and compliance monitoring from IEPA; perform in-house testing)
7. Rehabilitation of the raw water intake to enable selective withdrawal

### **Laboratory**

1. The lake water influent should be monitored daily for ammonium ion, dissolved oxygen, and iron.
2. Occasional monitoring to observe the effects of the hog farm should be performed upstream and downstream of the facility's discharge point (BOD, fecal coliform). [~\$4,000 for laboratory equipment, or analyze at wastewater lab.]
3. The laboratory should also be upgraded to include the following analysis capabilities:
  - a. Microscopy: Regularly, lake water algae should be observed, identified, and quantified. When algal populations start to increase significantly, the lake should be treated with copper sulfate. Plant performance should be monitored microscopically. Distribution system samples should be observed for signs of bacterial regrowth. [~\$10,000]
  - b. Total and Dissolved Organic Carbon Analysis: For a period of one year, TOC and DOC in lake water influent and plant effluent should be determined weekly, using the Hach simplified organic carbon method. [\$500]
  - c. Ammonium Ion: Ion-specific probe [\$400] or inline chloramine/ammonia monitor [ \$ ]

## **Treatment System Modifications**

1. Chloramines should be consistently used as the final disinfectant residual. The chlorine to ammonia ratio should be continually adjusted towards a goal of 4:1 by weight. Influent ammonium ion monitoring should enable plant operators to make more precise adjustments of ammonia additions. Finally, plant effluent monitoring should be conducted to ensure that no uncombined (free) ammonium ion enters the distribution system.
2. Chlorine gas detectors should be installed in the plant to ensure that workers are not exposed to excessive levels of chlorine gas. [~\$2,000]
3. Filter media should be replaced. Granular activated carbon for taste-and-odor control should be used in place of the existing anthracite layer, with the consent of IEPA. [~\$8,000]. This will eliminate the need for feeding powdered activated carbon.
4. An air scour (air-assisted) backwash system should be installed to prevent future media encrustation. Air scour will not only provide improved backwashing but will also reduce backwash water requirements.
5. Deposits on ClariCone walls should be physically removed on a routine basis.
6. Lime feed should be reduced to that required to neutralize the acid from the alum coagulant addition.
7. The effectiveness of the potassium permanganate feed should be evaluated with respect to reductions in tastes and odors and DOC concentrations.

## **Distribution System**

A computer-based hydraulic model of the distribution system using EPANET should be constructed. Distribution system operations should be evaluated and alternate scenarios investigated in an attempt to reduce water residence times (stagnation) in storage facilities. The model should also be used to assist in the development of the optimal unidirectional flushing protocol. [~\$10,000]

Subsequently, it may be necessary to install in-tank mixers in some or all of the storage facilities.

## **Appendices**

EPA Guidance Manual, August 1999, M-DBP Simultaneous Compliance, section 6.5: Tastes and Odors

EPA Guidance Manual, September 1998, Small System Compliance Technology List for the Surface Water Treatment Rule and Total Coliform Rule

## 6.5 Tastes and Odors

Changes in oxidants or disinfectants used in a treatment process to control the formation of DBPs may also result in the formation of new tastes and odors in the finished water. The implementation of process modifications can change the intensity and character of historic tastes and odor episodes, or change the way a facility must treat a chronic taste and odor problem. It has been well documented that there are many causes of tastes and odors in finished water, and the intensity and character of specific taste and odor episodes have proven to be highly variable and often difficult to trace (AWWARF and Lyonnaise des Eaux, 1995). Tastes and odors are common in surface water sources, and are typically caused by decaying vegetation, algae, or industrial and municipal wastes. Finished water tastes and odors can also be caused by biological activity in distribution systems and in-storage reservoirs.

The treatment of tastes and odors is commonly accomplished by either the application of an oxidant to raw water prior to treatment, or by the use of an adsorbing media such as activated carbon. The chemicals used for pre-oxidation may also be the primary disinfectant used for microbial inactivation. Many odor causing compounds present in surface water, such as 2- methylisoborneol (MIB) and geosmin, are resistant to oxidation and can have competing chemical reactions with certain oxidants that can create new tastes and odors or worsen existing conditions. DBPs such as aldehydes, phenols, chlorophenols, and trihalomethanes can also impart distinct tastes and odors (AWWARF and Lyonnaise des Eaux, 1995).

Most of the disinfectants and oxidants in use today are effective in reducing and controlling specific taste and odor episodes. Stronger oxidants like ozone, potassium permanganate, and chlorine dioxide are more effective in oxidizing odor-causing compounds, but may form additional tastes and odors at high residual concentrations, or form byproducts. Chloramines have proven more effective in controlling tastes and odors when strong taste and odor precursors are present.

### 6.5.1 Taste and Odor Sources

Tastes and odors are caused by many sources. Geosmin and MIB result in earthy and musty odors in water supplies. These compounds are naturally occurring, and are primarily formed by the metabolism of many forms of algae (AWWARF and Lyonnaise des Eaux, 1995). Tastes and odors can also be created in the distribution system by a variety of causes including biological sources like fungi and bacteria from biofilms, or chemical sources like disinfectants, construction materials, corrosion, and DBPs. System design and operation can also lead to tastes and odors created in areas with long residence times, or by the blending of differing sources and by the presence of cross-connections.

Chlorine has also been the source of many taste and odor complaints. The tastes and odors are often described as bleach-like, or similar to swimming pool odors, resulting from the use of free chlorine or chloramines (AWWARF and Lyonnaise des Eaux, 1995). Monochloramine rarely has been found to result in significant taste and odor problems, but it is not as easy to detect as dichloramine and trichloramine. Dichloramine has been described as a swimming pool or bleach odor, while trichloramine has been described as chlorinous and fragrant (AWWARF and Lyonnaise des Eaux, 1995). These two chloramines are prevalent at lower pH levels. In addition to the tastes and odors imparted by free chlorine and chloramines, tastes and odors can be created from byproducts produced when these disinfectants are applied to water. The reaction of free chlorine with amino acids or organic nitrogen present in water can form aldehydes, which have been associated with taste and odor. Aldehydes have complex tastes and odor characteristics, but have been described as chlorinous, earthy, stale, disinfectant, bitter, ammonia, organic, muddy, moldy, and bleach-like (AWWARF and Lyonnaise des Eaux, 1995). Phenols present in water can also react with chlorine to produce chlorophenol, which have medicinal tastes and odors. In addition, trihalomethanes can have strong medicinal tastes and odors.

Chloramines can have the same reactions with amino acids, organic nitrogen, and phenols to create taste and odor causing compounds. Since chloramines are much weaker oxidants than free chlorine, the reaction time to form taste and odor causing compounds is much longer, resulting in a reduced potential for taste and odor production.

Chlorine dioxide can form detectable tastes and odors when residual concentrations reach 0.20 mg/L to 0.25 mg/L (AWWARF and Lyonnaise des Eaux, 1995). Secondary odors have also been reported due to reactions between chlorine dioxide and household products and from the gaseous release when taps are opened.

Ozone is effective in oxidizing organic compounds responsible for many tastes and odors, and is highly effective when combined with hydrogen peroxide or UV light to form an advanced oxidation process. However, ozone has been reported to impart an “oxidant” or “ozonous” odor to waters, even when an ozone residual is not present. Aldehyde byproducts formed from the reaction of ozone in water have also been associated with odors ranging from fruity to sickening. Tastes and odors have not been identified with other ozone byproducts (AWWARF and Lyonnaise des Eaux, 1995).

### 6.5.2 Taste and Odor Controls

Taste and odor episodes respond in various ways to different treatments. Free chlorine application or ozonation can effectively remove some odors, such as those characterized as fishy. Other constituents like geosmin and MIB are difficult to oxidize. In planning for the implementation of any process modifications, incorporating flexibility in the treatment process to allow the application of differing oxidants at various points in the treatment process for the control of tastes and odors should be considered.

Bench-scale and pilot studies may be required to develop treatment schemes that will minimize byproduct formation and provide taste and odor control without reducing the microbial protection. Chemical analyses can also be performed to determine the causes of tastes and odors. The Flavor Profile Analysis (FPA) approach can be used to define sensory responses to tastes and odors to better understand their character and intensity. Once known, treatment and control strategies can be developed to address specific applications. Further information describing taste and odor identification and treatment strategies can be found in the publications *Identification and Treatment of Tastes and Odors in Drinking Water* (AWWARF, 1996) and *Advances in Taste and Odor Treatment and Control* (AWWARF and Lyonnaise des Eaux, 1995).

In addition to oxidation, treatment schemes utilizing activated carbon may be necessary to control tastes and odors and minimize byproduct formation. Activated carbon is typically applied as powdered activated carbon (PAC) or as granular activated carbon (GAC). Activated carbon is an adsorbent, and its efficiency is determined by contact time and the presence of organic constituents in the water competing for adsorbent sites.

PAC is generally injected into raw water as a slurry prior to treatment, and is useful for occasional control of recurring taste and odor events. The PAC is captured through sedimentation, regenerated, and recycled. GAC is typically used after sedimentation, and typically in a GAC-filled basin used as a contactor. GAC contactors are normally used for control of chronic tastes and odors. It should be noted that activated carbon has other uses in water treatment, including the removal of natural organic matter and synthetic organic compounds.

Activated carbon has been proven effective for the control of many tastes and odors, but the effectiveness and economic impacts are application-specific. Bench and or pilot testing is normally required to determine the recommended configuration, especially for the design of GAC contactors.

Biological treatment has also been examined in Europe, but has not received wide attention in the United States. Biological treatment utilizes slow sand filtration and attempts to control tastes and odors by achieving biological stability of water through the removal of biological organic matter. Biological treatment may have other benefits by controlling biological regrowth in the distribution system, thus reducing the requirements for secondary disinfectants. The effectiveness and application of biological treatment is not fully known at this time, but research continues to examine its use and evaluate the benefits to be gained in the control of tastes and odors.

### 6.5.3 Recommendations

Tastes and odors in the distribution system and treatment facility should be continually monitored to ensure that high quality, stable water is being delivered. Systems should consider the following to control taste and odor problems:

- Reviewing customer complaints to best determine the cause of tastes and odors so that corrective action can be taken
- Considering changing the secondary disinfectant to control regrowth
- Making a pH adjustment or applying a corrosion inhibitor to address corrosion problems

- Rehabilitating water mains to replace existing, unlined corrosion surfaces in the distribution system
- Examining the construction materials used in the distribution system, including coatings and linings in both piping and storage facilities
- Revising the system operations to reduce residence times in storage facilities
- Implementing a water main flushing program
- Maintaining an adequate disinfectant residual to control regrowth.

**On-Site Oxidant Generation** (Also known as anodic oxidation and salt brine electrolysis) On-site oxidant generation may be accomplished by an electrolytic process which generates a concentrated solution of oxidants, mainly free chlorine. This process involves passage of an electric current through a continuous-flow brine (salt) solution within a cell. The electrolyzed brine solution containing the concentrated disinfectant is injected into water for treatment. The concentrated solution is diluted approximately one hundred-fold in drinking water treatment. EPA's previous listing included "mixed oxidant disinfection," and the Agency has decided to characterize this technology in another manner. Recently completed research, as discussed below, has not determined that additional oxidants (other than free chlorine) are produced to a significant degree by the electrolytic action within this process. In its application this treatment is similar to chlorination, however rather than apply commercially available gaseous, solid or liquid forms of chlorine, the process produces a strong disinfectant solution on-site. This treatment method has been successfully tested, applied, and accepted mainly due to the convenience, ease of operation, and basic level of operator skill required.

On-site oxidant generators have been reported to produce multiple oxidants. However, the individual oxidants in solution have proven to be difficult to characterize. Recent research, sponsored by EPA, investigated the composition of the generated solutions as well as the analytical techniques available for measurement of the individual species. Lab and full-scale units were studied, and a variety of analytical methods and chemical masking techniques were tested for blocking the interference of free chlorine in the measurement of ozone in solution. The experiments confirmed that chlorine is the primary oxidant in the electrolyzed solution (measured at 200 to 400 mg/L), with ozone, hydrogen peroxide, and chlorine dioxide undetected. Lab-prepared solutions containing free chlorine and ozone were also tested and it was shown that, due to the rapid rate of reaction between the two oxidants (in the millisecond time-scale), any ozone that may be in solution becomes, in a very short time, unavailable for the purpose of disinfection. Based on kinetic studies, ozone levels were calculated by researchers to be less than 0.5 mg/L immediately following generation.

It may be assumed until further investigations bear results that units of this type may use various grades of raw material, salt, and this may in turn result in differing amounts of oxidants and associated byproducts in solution. It is noteworthy that this process may also produce chlorate ( $\text{ClO}_3^-$ ) and bromate ( $\text{BrO}_3^-$ ) in solution: the former species being a function of free chlorine decomposition, the latter, a human carcinogen, is produced as a result of reactions with bromide in the salt used in preparation of the electrolytic solution. The above-cited study reported relatively low levels of chlorite, chlorate and bromate ions in solution in concentrated anolyte liquor (less than 0.05 mg/L chlorite, and 1 to 2 mg/L both chlorate and bromate in full-scale system); the study also detected bromate in finished water but was not specific about concentration.

Researchers have studied the effects on-site electrolyzed salt brine disinfection in relation to *Cryptosporidium* oocysts and *Clostridium perfringens* spores as an indicator of oocyst inactivation: at a dosage of 5 mg/L, mixed oxidation achieved greater than 2-log *Cryptosporidium* inactivation at 1-hour contact time. A technical report by the Los Alamos Technical Associates, Inc., reported a 4-log inactivation of f-2 bacteriophage in water at a relatively short contact time, i.e., CT of 4. In order to provide a complete and useful set of data, studies on inactivation of *Cryptosporidium* are under way by EPA and by others, including the American Water Works Research Foundation, with results anticipated in 1999.

On-site oxidant generation for disinfection purposes has been used in full scale water treatment applications at a variety of locations. Field applications have indicated the ease of operation and effectiveness of these systems. Examples of full-scale applications of on-site generation of disinfectants, in several U.S. states, may provide some guidance to interested parties on the use and efficacy of this technology.

Given that on-site generation of oxidants may have advantages over other treatment methods, EPA suggests that small systems consider this disinfection technique for compliance purposes. Given information regarding the disinfectant generated, EPA suggests taking a course of utilizing **chlorination** CT tables when designating chemical dosing for these systems. Additional studies in 1998-99 may yield appropriate data on CT requirements for this technology.