Taste-and-Odor Control

Evergreen Lake - Autumn, 2004

Evergreen Lake following Autumn 2004 overturn

April, 2005

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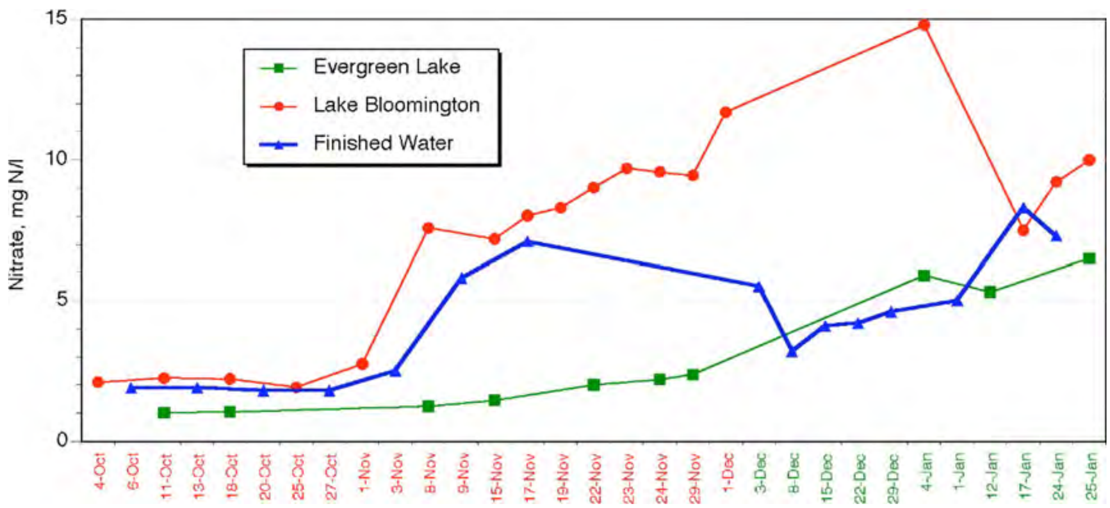
Background: 2004-2005 Odor Episode

Although infrequently in recent years, Bloomington occasionally receives complaints of musty tastes-and-odors in their treated municipal drinking water. The purpose of this present investigation was to evaluate water quality and treatment plant performance in reducing tastes-and-odors that evolved in the Evergreen Lake water source in autumn 2004. In addition, current and potential future treatment alternatives for enhanced odor remediation were evaluated.

Complaints of musty odors in Bloomington's distributed water were first received in November 2004. At the time, Lake Bloomington, thought to be free of noticeable odor, was in use as the sole treatment plant source water. However, weeks of steady rain and snow melt had increased surface infiltration and resulted in the leaching of nitrate from agricultural tiles throughout the Lake Bloomington watershed.

Progressive increases in nitrate levels in Bloomington's lakes and tributary flows were closely monitored. By late November 2004, both lakes were filled to overflowing due to high rates of inflow. Lake Bloomington nitrate levels had increased to just under the 10 mg N/l MCL. Projected further increases necessitated the blending of Evergreen Lake with Lake Bloomington water to dilute and diminish the nitrate ion concentration in Bloomington's finished water.



Accordingly, on December 2, the influent to Bloomington's treatment plant was adjusted to a blend of 60% Lake Bloomington and 40% Evergreen Lake water. While effectively reducing nitrate levels, noticeable odors from Evergreen Lake water were detected in the plant's finished water within a day.

The odor exhibited by the Evergreen Lake water was typically described as musty or earthy. However, the taste-and-odor was undetectable to many, if not most, of the plant personnel who sniffed or tasted the water. This limited the pool of potential evaluators of the effectiveness of treatment techniques for reducing tastes-and-odors. As tastes-and-odors are notoriously difficult to quantify, this marked difference in olfactory sensitivity creates a continuing problem in assessing remedial treatment effectiveness.

Pumping facilities at Evergreen Lake - High lake stage due to rain and snow, December, 2004

Nutrient Sources, Organism Growth

Nutrients in agricultural runoff and drainage, particularly nitrogen and phosphorous, contribute to the prolific growth (blooms) of microorganisms, such as algae, fungi and bacteria. These blooms are believed to be the root causes of Evergreen Lake's occasional musty taste-and-odor character. Microorganisms, such as cyanobacteria and actinomycetes, produce a wide variety of volatile organic compounds (Silvey and Roach, 1964). From these organisms, geosmin and 2-methyl isoborneol (MIB), have been identified as taste-and-odor-causing compounds (Gerber, 1979). While not toxic, these specific compounds reportedly impart threshold odors at concentrations in the range of 10 to 200 nanograms (10^{-9} g) per liter (*Advances in Taste-and-Odor Treatment and Control, AWWARF, 1995; Table 5-2*). Fortunately, the compounds produced by cyanobacteria and actinomycetes can be degraded by bacteria. In 1965, Hoehn demonstrated the control of earthy-musty tastes by adding bacteria to Lake Hefner in Oklahoma City.

As algal and bacterial cells die and rupture (lyse), they release soluble internal cellular organic compounds into the water. As a result, from a taste-and-odor control standpoint, it is considered more desirable to *physically* remove microorganisms rather than rupture them with a disinfectant or oxidant during pretreatment. In other words, coagulation, sedimentation and filtration are among the preferred methods for removal of the algal cells. Chemicals that cause cells to lyse and release their organic content may have the potential to further increase taste-and-odor problems.

Laboratory Capabilities for Assessing Lake and Treated Water Quality

Total Organic Carbon

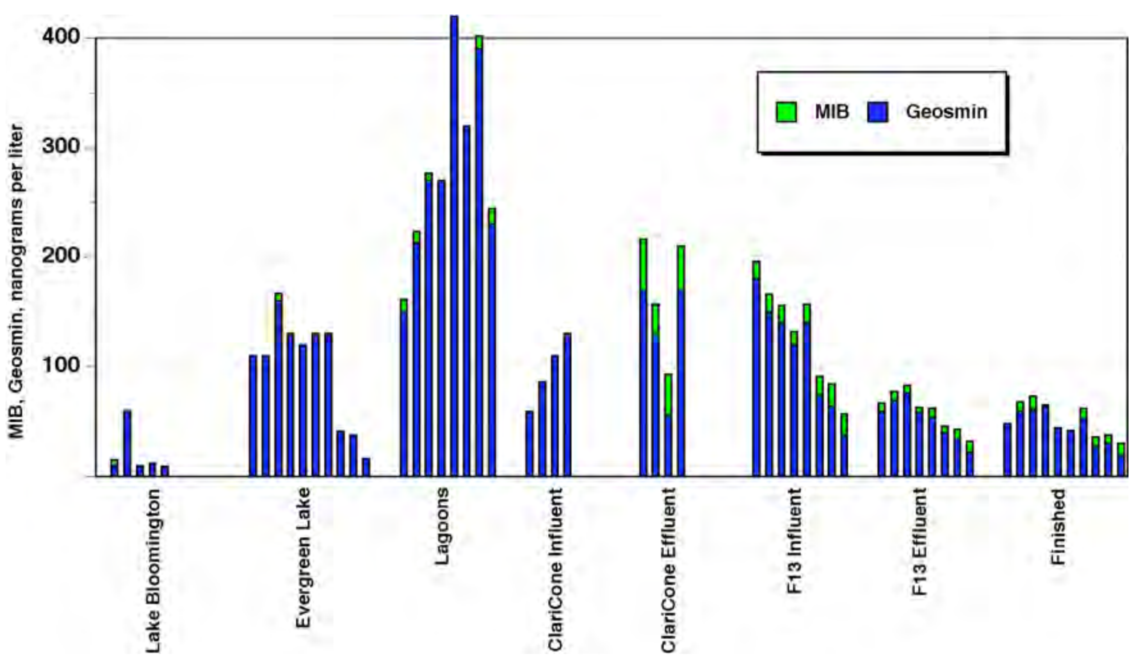
An advanced measure of the organic content of water is total organic carbon (TOC). While TOC may vary with season, nutrient-enriched lake waters may be particularly high in TOC during periods of stagnation, high water temperatures and algal blooms. The Bloomington water treatment plant laboratory is equipped with a state-of-the-art facility for the measurement of total organic and inorganic carbon.

Measurements (2004) indicated that Bloomington's treatment process was achieving approximately 57% TOC removal. This exceeded the USEPA regulatory requirement of 35% TOC removal.

TOC, mg C/l / Date	Lake Bloomington	Finished Water	% Removal
11/5/2004	3.4	1.4	59
12/1/2004	2.9	1.3	55

Repetitive analyses during the taste-and-odor episode indicated that the Bloomington plant influent exhibited a total organic carbon concentration around 4.1 mg C/l. About half of this organic matter was removed during lime softening and clarification. Despite this removal with the sludge, the recycled water from the lagoon, which had become far higher in geosmin, was 20% lower in TOC than the lake influents.

Filtration through the GAC-capped filters, while reducing geosmin concentrations by 50%, removed just 16% of the TOC applied to the filters. Finally, the filtered, finished and distributed waters averaged about 2.1 mg C/l.



Microscopic Analysis

The Bloomington laboratory is also equipped with a compound light microscope having an epifluorescence (ultraviolet light) attachment that allows the observation and photographing of bacteria, protozoans, fungi and algae. This microscope permits laboratory personnel to make visual observations of organisms in the lake water and assess their removal throughout the treatment process. They can also utilize the equipment to make and archive photomicrographs of the particles and organisms observed.

Tannins and Lignins

Bloomington has recently acquired laboratory capabilities for measuring the combined tannin and lignin concentration of their source waters. This capability was utilized for the first time in the current evaluation of the lake water sources. The method is simple, rapid, inexpensive and can be used in the field. It was hoped that this measure might serve as a useful adjunct to the direct measurement of TOC.

The first results of tannin/lignin analyses are shown in the following table. Bloomington's lakes were sampled and aliquots drawn through a 0.22 μm neutron-track-etched polycarbonate membrane. The initial results indicated that there was little, if any, removal of tannins and lignins due to membrane filtration. This confirmed the expectation that these compounds are in true solution and that, if anything, this analysis might best relate to dissolved, rather than total, organic carbon.

Future analyses for tannins/lignins might be accompanied by parallel analyses for dissolved organic carbon to determine whether a significant relationship exists between the two parameters.

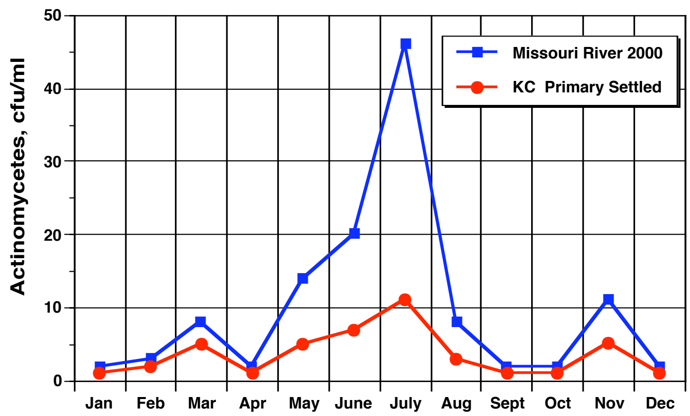
Sample Date / Tannin/Lignin, mg/l	Evergreen Lake	Evergreen Lake 0.22 μm filtered	Lake Bloomington	Lake Bloomington, 0.22 μm filtered
11/30/2004	1.2	-	0.7	-
12/1/2004	0.9	1.0	0.8	0.7

Actinomycetes

The Bloomington laboratory is in the process of acquiring media and supplies for the identification and enumeration of *actinomycetes*, a filamentous, branching bacterium associated with earthy/musty tastes and odors. As organisms possessing properties intermediate between fungi and bacteria, actinomycetes are sometimes called 'higher bacteria'. They are gram-positive organisms that tend to grow slowly as branching filaments, resembling fungi, as their filamentous growth forms mycelial colonies. They were long regarded as fungi, as is reflected in their name: aktino (ray), mykes (mushroom or fungus).

Little data is available on the source water abundance, physical removal and inactivation of actinomycetes. However, the Kansas City (Missouri) Water Department has long monitored for these organisms in Missouri River water as part of their effort to avoid musty odors in their distributed water. A year of average monthly data from Kansas City is shown below. The results are based on bacterial plate counts and expressed as colony-forming-units per milliliter.

As with most bacterial growth, including coliform, abundance is highest during warm weather months. This is why the situation in Bloomington, occurring when water temperatures were lower, appear to be an anomaly. However, this autumn peak may be a recurring feature resulting from a seasonal influx of nutrients.



Actinomycetes in Missouri River water and its removal at KCMO

Micrographs of Actinomycetes: filaments, hyphae

Geosmin, Methyl Isoborneol (MIB)

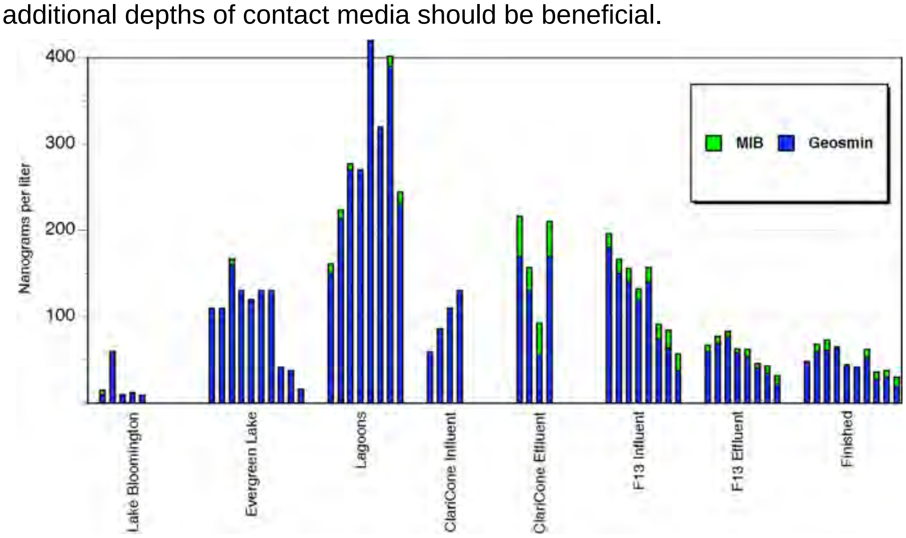
Analysis for the known odor-producing compounds, *geosmin*, an alicyclic alcohol, and *2-methylisoborneol (MIB)*, which is similar in structure to camphor, were conducted on samples collected on November 9, 2004, in response to limited taste-and-odor complaints.

Concentration, ng/l	Lake Bloomington	Finished Water	Distributed Water
Geosmin	10	7.2	11
2 - Methyl Isoborneol	0.7	5.3	5.5

Subsequently, throughout December, with the onset of odors, Bloomington Water increased geosmin and MIB monitoring efforts markedly. The analytical results, illustrated in the bar graph, below, confirm that detectable odors had developed in Evergreen Lake. The lake destratifier was inoperative during the summer of 2004. In addition, an exceptionally wet autumn and winter contributed to the influx of nutrient-rich tile drainage from the watershed.

Although they reduced TOC substantially, coagulation and lime softening did not appear to reduce odor concentrations significantly. Instead, softened and settled (ClariCone) effluents sometimes appeared to exhibit far higher concentrations of geosmin and MIB than influents. Whether this increase is an artifact of high pH or is an inherent inaccuracy in sampling and measurement is unknown.

However, within the plant, approximately half of the odorous compounds were found to be removed during filtration through the GAC-capped sand filters. Earlier studies (June, 2002) of Bloomington's filters had shown that both the GAC and filter sand support a thriving biological community. The diverse community of organisms on the filter media consisted primarily of attached bacterial cells. This evidence suggests that the odor-producing compounds may be partially biodegraded during their passage through the filter media. Accordingly, Bloomington operators slowed the passage of water through the filter media to allow extended contact time with the active microbial community. This was accomplished by extending filter runs and placing all operational filters into service to minimize filter loading rates. Based on these observations, additional depths of contact media should be beneficial.



Oxygen, Hydrogen Sulfide

Analyses were conducted to determine whether there was oxygen depletion or the presence of reducing agents, such as hydrogen sulfide, in the lake waters. Both lake waters were found to be fully oxygenated and hydrogen sulfide was measured at an insignificant 0.02 mg/l. These results are consistent with lakes which have undergone the turbulence and destratification of their autumn turnover.

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 populations, avoidance of anoxia and the dissolution of iron and manganese from sediments, and reduced potential for forming trihalomethanes due to high organic concentrations. A prime example of such a destratifier unit that has been highly effective in controlling anoxia and algal blooms is the one operating in Lake Bloomington. Operated since 1997, this compact unit consists of a submerged pump that forces water through a Venturi injector, which, in turn, aspirates air into the water stream from an air line to the lake surface.

Based on the success of the destratifier in Lake Bloomington, a similar destratifier was installed in Evergreen Lake. This destratifier was not operational during the past summer. However, at the time of the onset of tastes-and-odors, Evergreen Lake was fully oxygenated owing to its autumn turnover.

Bloomington operational staff have suggested that the destratifier pumps be relocated on-shore to facilitate maintenance and repair. As matters stand, a diver is needed for inspection and repair.

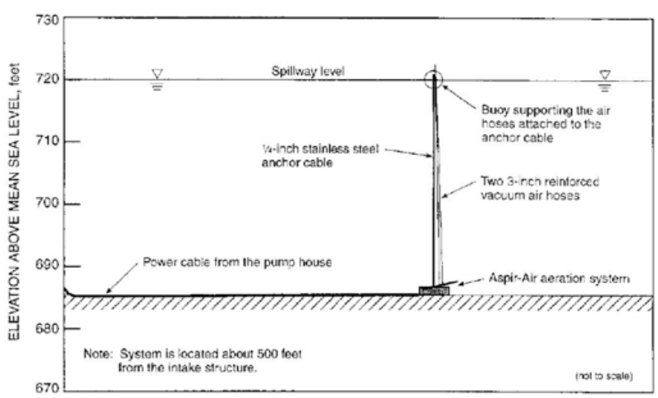
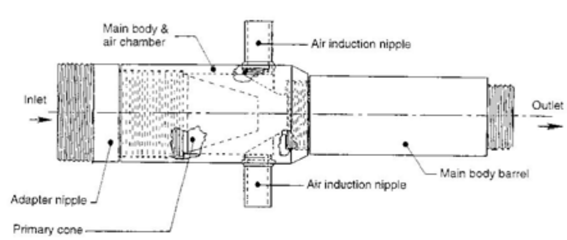


Figure 3. A schematic of the aeration system in Lake Evergreen



Lake Source Water Protection

Source water protection is a major part of Bloomington's efforts to control drinking water quality, including taste and odor compounds. In addition to on-going, long-term field studies of nutrients in agricultural drainage plus an intensive program of lake water monitoring, Bloomington Water is currently implementing a shoreline stabilization project to prevent further erosion along the Lake Bloomington shoreline.

Rick Twait, plant superintendent and a limnologist, has determined the influence of rainfall and runoff on the residence time of water in each of the water supply lakes. Lake Bloomington, a smaller lake in a larger watershed, provides a shorter in-lake residence time for equivalent precipitation. Heavy rains in the winter of 2004-2005 were estimated to have displaced Lake Bloomington water twice over whereas only 60% to 70% of Evergreen Lake was displaced. "As a result, conditions that favored high geosmin concentrations in Lake Bloomington may have diminished more rapidly than in Evergreen Lake."

Rick Twait has also reported that blending of the lake waters is hampered by the configuration of the pumping facilities. Evergreen Lake has large pumps that supply a high proportion of the plant water demand. Fine tuning of the blend between the two lake water supplies is not readily achieved. Accordingly, the design and installation of additional, smaller capacity pumps at Evergreen would be beneficial to plant operation during periods when it is desirable to limit the input from that source.

Construction of seawall to protect shoreline along Lake Bloomington

Winter 2005 precipitation led to lake overflows

Water Treatment Plant Odor-Control: Procedures and Processes

Bloomington treatment processes and in-plant procedures utilized to control organic materials and reduce tastes-and-odors have included:

- ☑ blending of Lake Bloomington and Evergreen Lake waters to minimize nitrates and odors,
- ☑ lake water quality and watershed management to limit the influx of algal nutrients,
- ☑ installation of destratifiers to reduce algal growths and maintain aerobic conditions,
- ☑ lake water pretreatment with cationic polymer for enhanced particle removals,
- ☑ monitoring of organic matter (TOC, DOC) to optimize current chemical application rates,
- ☑ powdered activated carbon (PAC) feed to increase short-term organic adsorption capacity,
- ☑ granular activated carbon (GAC) filter caps on all 16 (bio)filters to degrade organic compounds,
- ☑ chloramine residuals in distribution system to reduce chlorinous tastes.

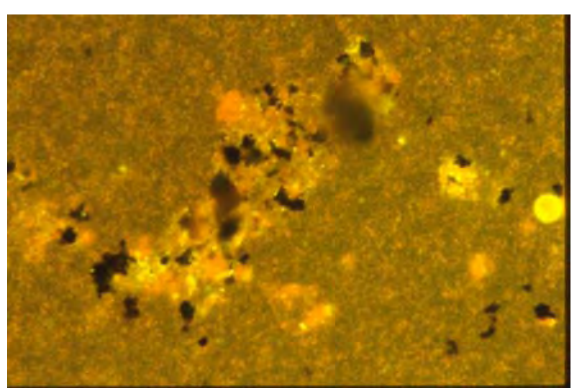
Powdered Activated Carbon

In response to the switch to Evergreen Lake water, Bloomington's powdered activated carbon (PAC) feeders were started at their maximum rates, feeding about 5 mg/l. Initial problems with blockages of the PAC feeder ports were quickly overcome. However, after the initiation of feed, operators noted increases in effluent turbidities from the ClariCones. This was noticeable because, normally, water exiting the clarifiers has exceptionally low turbidity, in the range of 0.2 to 0.7 ntu, so that upsets are readily detected.

The turbidity increases were attributed to the PAC feed. In addition, there was concern over the passage of PAC fines though the filter. This is due to the fact that USEPA characterizes escaped PAC particles as *'particles of potential health significance.'* This is because microorganisms that colonize PAC, a chemical reducing agent, may be protected from inactivation by disinfectant residuals.

To assess the effectiveness of PAC dosages *and available contact time* in controlling odors, a jar test series was conducted on Evergreen Lake water using dosages of PAC ranging up to 20 mg/l. After a 20 minute rapid mix, the PAC was allowed to settle overnight. The following day, similar odors were detected in each of the six test beakers indicating that little odor reduction had been accomplished. Also, tannins/lignins were not measurably reduced by PAC treatment.

PAC is fed at In-Line Static Mixer



µm-sized PAC embedded in - and outside of floc

Granular Activated Carbon Filter Caps

In the late 1980's, the City of Bloomington had several taste-and-odor episodes. These episodes were caused by drought, excessive algal growth in the lakes, zones of anaerobic conditions, lime feed failures, the less-efficient basins used at the time, and the lack of lake destratification. When powdered activated carbon and potassium permanganate failed to control tastes and odors, the City decided to use granular activated carbon in their filters. After pilot testing, GAC caps were added to all filters in 1994. Until the recently, there had been no significant taste-and-odor episodes in the finished water.

Calgon Carbon Warranty

The City of Bloomington is currently renting GAC from Calgon Corporation. The warranty provided by Calgon Carbon in *Exhibit C of the Potable Water Service Agreement* stipulates that their Filtrasorb GAC *"will perform the function of adsorption of dissolved organics which contribute to taste and odors during the life of the warranty... the threshold odor number... shall not persistently exceed two (2) in the carbon-filtered plant effluent for five consecutive days with the treatment plant in normal operation at the time during the first 48 months."*

While Calgon's warranty provides a four-year performance guarantee for their carbon's taste-and-odor removal, Bloomington's GAC is changed out more frequently; every two years in filters in the Main (new) filter building and every three years in the filters in the Annex (old) filter building. Nominally, if all the GAC was effective for a full four years, Bloomington's annual carbon cost might be cut nearly in half.

Effectiveness and Duration of TOC Reduction

Since GAC adsorption capacity is exhausted within months, it is assumed that longer-term removal of dissolved organic matter occurs as the result of biodegradation by the attached biological community that colonizes the carbon. Based on limited testing in the summer of 2002, Filter 14 (containing two-year-old carbon) removed an average of 10% of the filter influent dissolved organic carbon, presumably, by biodegradation, while Filter 15 (containing fresh, new carbon) removed 30% by adsorption.

18" GAC Filter Caps - replacement of GAC media (virgin GAC in black totes)

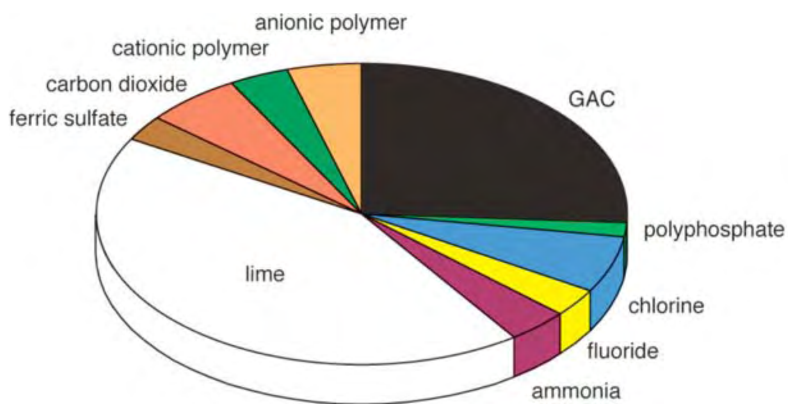
Carbon Costs

Under the current contract, the City of Bloomington pays Calgon $132,300/year for carbon. This includes pickup of used carbon and delivery of 160,000 pounds of new carbon. City staff are responsible for labor associated with the annual changeout of the material.

During the GAC replacement, six city employees work for approximately 108 hours for a total of 648 man-hours. Assuming total labor costs of $50/hour, this represents a cost of $32,400. However, approximately 25% of the laborer's time is spent on other concurrent projects, so $24,300 would be considered the GAC changeout labor expense. Divided by seven filter changeouts per year, labor costs amount to $3,471 per filter.

As a comparison, the Bloomington Water Department received a bid of $9,572.87 for changeout of one filter from All Service Contracting Corp. (May, 1999). This bid included only labor and the use of a vacuum truck.

At $132,300 per year, the cost of carbon accounts for 26% of the total annual chemical cost of $510,751 (FY '03-'04).



Finished Water Taste-and-Odor Monitoring

Every few hours, Bloomington's plant operator on duty samples finished water from a continuously flowing tap (tap 01) in the operator's control laboratory. Analyses are conducted for disinfectant residuals, fluorine, alkalinity, pH, and other parameters, as necessary. An enhanced program of finished water odor detection has evolved as part of their effort to detect changing odor conditions before water reaches the distribution system.

When Bloomington operators become aware of increasing tastes-and-odors in the finished water, they notify laboratory personnel. Presently, analysis for known odor-producing compounds has shown that water withdrawn (recycled) from the lime softening sludge lagoon contributes the highest concentration of odorous materials to the influent water.

Current Operational Alternatives

Alternative operational steps that have been taken to control tastes-and-odors have included:

- ☑ increased dosages of cationic polymer at lake intakes to improve particle, including algal cell, removals.

- ☑ add to number of filters in operation to reduce filtration rates and increase contact time with GAC.
  Since the filters in the 1929 (old) plant provide a longer EBCT at lower filter loadings, these filters may be placed in service in lieu of those in the main building. However, reduced flow rates on all filters will provide longer contact times with the GAC caps.

- ☑ cease prechlorination to avoid compounding of tastes by chlorine.

- ☑ initiate feed of powdered activated carbon, approximately 42 pounds per million gallons (5 mg/l).
  The PAC feed equipment should be inspected regularly to ensure it is operational when an odor emergency arises. However, the benefits of PAC addition are under question.

- ☑ lake water samples for microscopic analysis for organisms and lab testing for organic compounds.
  Determine relationship, if any, between TOC, UV and odor. Depending on filamentous appearance of microorganisms, possibly initiate plate count for actinomycetes (taste and odor-causing bacteria).

Evaluation of Potential for Modified or Enhanced Treatment Process

Testing of alternative treatment processes has been initiated and is continuing in Bloomington's laboratory. Presently, efforts are being made to take additional advantage of the microbial biodegradation of taste-and-odor producing compounds on the biologically active GAC filters available in the plant. With the initial testing showing that geosmin and MIB are currently being reduced by about 50%, efforts are being directed at developing procedures for enhancing biodegradation.

Other laboratory trials involve aeration for stripping of volatile compounds and the use of chemical oxidants, such as potassium permanganate, ozone, chlorine dioxide and hydrogen peroxide (Fenton's reagent) to convert odorous compounds to odor-free constituents.

Still other biological and chemical efforts are directed at controlling odorous compounds directly at the lakes and lagoons. The lagoons, in particular, have been shown to be a major source of odorous compounds. A large portion of the organic matter entering the plant is removed by softening and transferred with the softening sludge to the lagoons. Upon storage, it appears that this material spawns the development of odorous compounds. Instead, water from the storage lagoons should be discharged.

Aeration

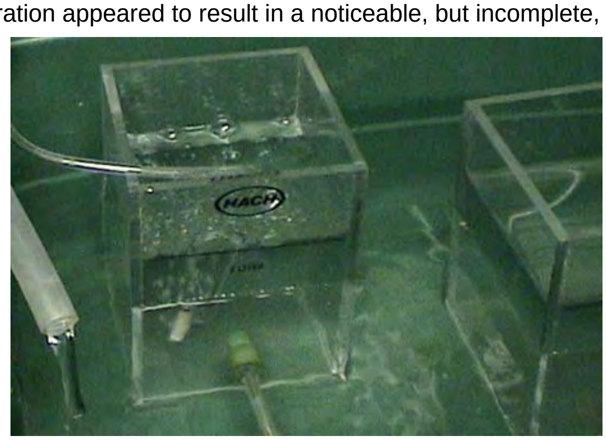
A sample of water from the sludge lagoon was aerated overnight with a small air pump and diffuser stone. A second sample was used as a control. Both samples were kept in a cold water bath. In the morning, the aerated sample smelled ‘fresher’.

Owing to the in-house capability of the Bloomington water department laboratory, the effectiveness of aeration was evaluated by measuring the total organic carbon of the lagoon water before and after aeration. Nominally, this should be a measure of *purgeable* organic carbon. However, TOC is a relatively insensitive measure for this purpose because most of the compounds present in lake waters are relatively non-volatile. Inexplicably, prolonged aeration of the lagoon water appeared to result in an increase in TOC, but a decrease in detectable odor. It is not known whether organic additional matter was introduced with the diffuser, container, pump or laboratory air.

Geosmin and MIB would be better measures of the removal of volatile compounds. However, in the absence of a clear indication of the marked effectiveness of aeration in decreasing odors in the most odorous (lagoon) water, these costly analyses were not conducted.

Parameter	**aerated lagoon**	**lagoon (control)**
TOC, mg/l	3.9	3.0
odor	moderate	strong

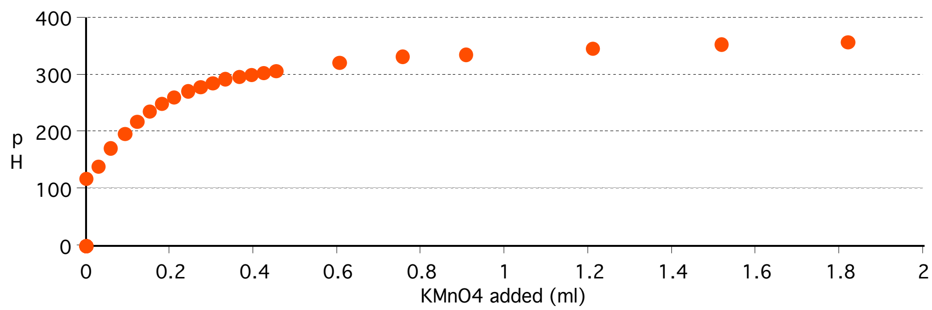
Prolonged aeration appeared to result in a noticeable, but incomplete, odor reduction

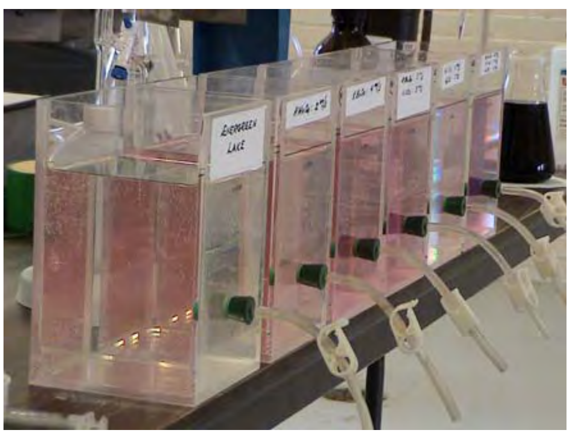


Temperature controlled in water bath

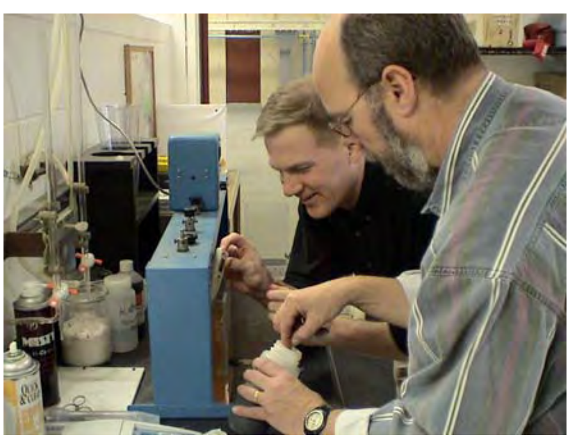
Potassium Permanganate and other Oxidizing Agents

Preliminary tests using lagoon water indicated that moderate dosages of potassium permanganate (1-2 mg/l) may have either decreased or. perhaps, altered odors. This initial test was followed by an evaluation of the change in oxidation-reduction potential (ORP) with titration using a 1 mg/ml permanganate solution. While its significance is not known, the ORP response curve increased and reached a plateau at a permanganate dose of about 1 mg/l. Preliminary tests with moderate dosages of oxidants, such as sodium chlorite, chlorine dioxide, hydrogen peroxide and, for good measure, Fenton's reagent, failed to result in detectable odor decreases.





Tests of chemical oxidation with permanganate, chlorite, chlorine dioxide and hydrogen peroxide



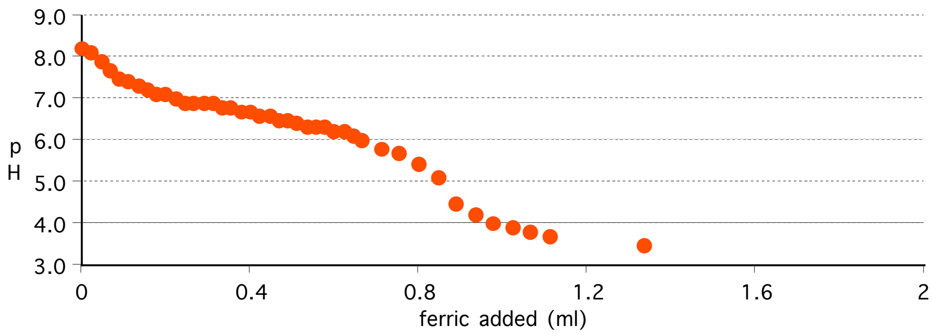
Jar testing of oxidant dose-response;

Analysis for total organic and inorganic carbon

Fenton's Reagent

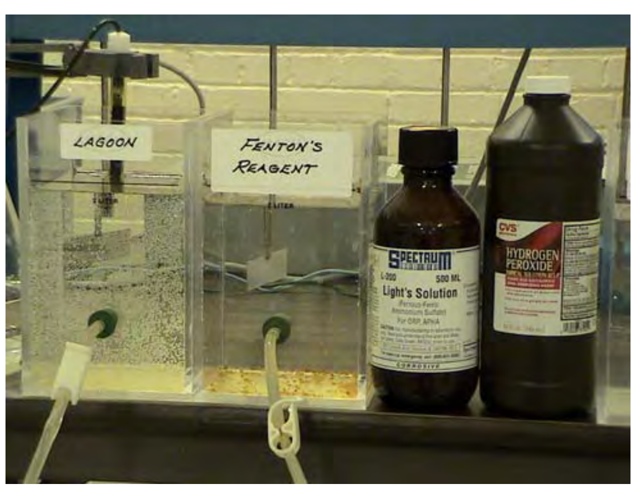
Fenton's Reagent is a combination of iron and hydrogen peroxide that is reported to generate highly reactive hydroxyl radicals, which in turn remove odor and color (among other things). A primer on Fenton's Reagent is appended.

Upon review, it was found that Fenton's process requires a pH of 3 to 5. Titrations were performed to determine how much ferric sulfate and/or hydrochloric acid would be required to decrease the odorous lagoon water to these pH levels.



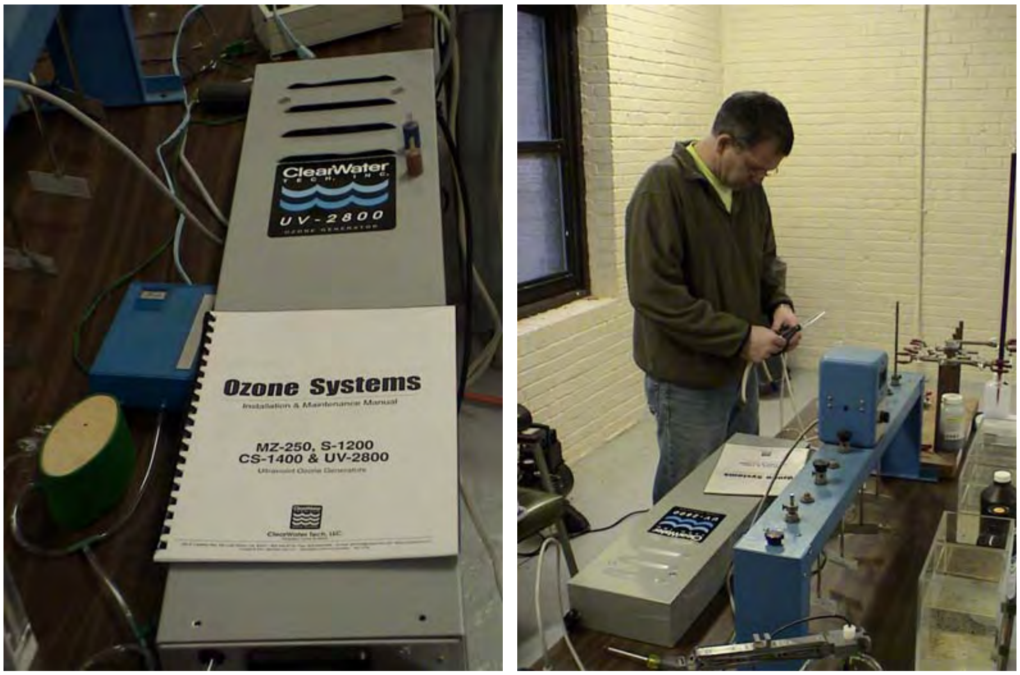
Achieving a pH of 6 in a two-liter Lake Evergreen water sample required the addition of 0.67 ml of ferric sulfate. This corresponds to a full-scale feed rate of 335 gallons of ferric solution per million gallons. Thereafter, ferrous ion and hydrogen peroxide were applied for the oxidation of organic matter. While laboratory measurements indicate that the TOC of the Lake water was reduced from 3.7 to 2.5 mg/l, this treatment did not appear to achieve significant odor reduction. The precipitation of a substantial amount of hydrous ferric oxide may have helped remove some of the particulate fraction of the TOC.

A controlled replicate of this study should be conducted using strong acid for pH adjustment plus a dosage of 4 to 5 mg/l of ferrous or ferric ion prior to the addition of oxidant.

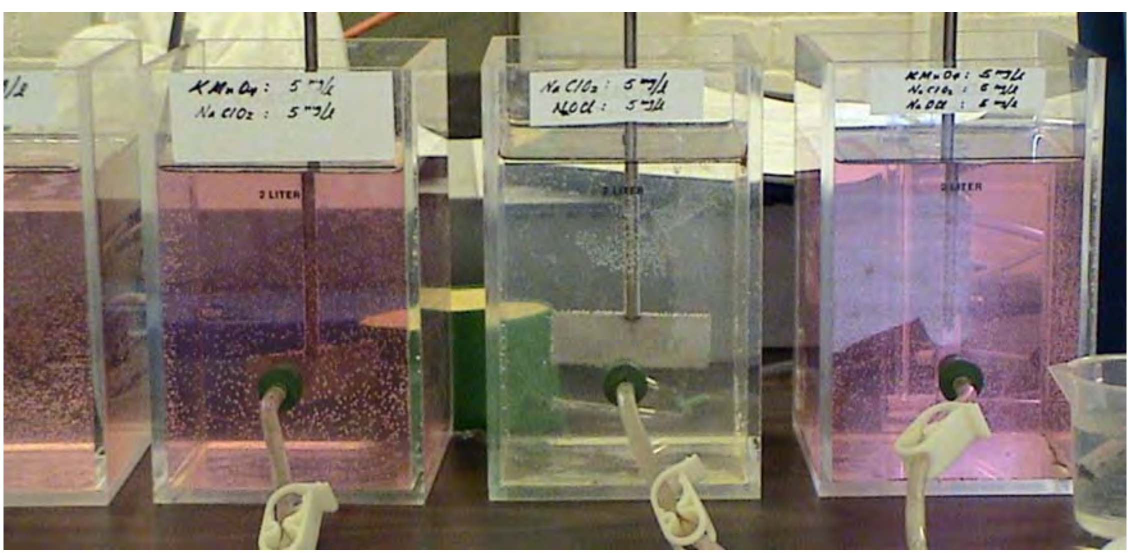


Ozonation

Preparations were made for small-scale, laboratory studies using an ozonater powered by ultraviolet lamps. To facilitate this, efforts were made to prepare the apparatus for determining ozone output and the ozone demand of the lagoon and lake waters. If significant odor reduction can be demonstrated, some estimates may be made of the capital and operating costs of full-scale ozonation.



Preparation of apparatus for ozonation of Evergreen Lake water



Testing Combinations of Oxidants: Chlorite, Hypochlorite and Permanganate

Biodegradation

Columns were also prepared for preliminary studies of *biodegradation* of odorous compounds on GAC removed from Filter #15. In addition to varying the EBCT and media content, it was proposed that some of Bloomington's filter media be sterilized (e.g., microwaved or washed) and utilized as a biologically inert control. The qualitative difference in odor reduction performance could then, presumably, be attributed to the effect of aerobic biodegradation.

Biodegradation: Apparatus for Comparison of GAC empty bed contact times

Biodegradation - Bloomington's Water Treatment Plant Operations Manual

Earlier, in June 2002, a detailed study of Bloomington's filtration practice was undertaken as part of an on-going effort to develop a comprehensive *Water Treatment Plant Operations Manual.* The *Filter Surveillance and Operation Manual* (attached) outlines the design, installation and configuration of Bloomington's 18 filters. It describes proper filter operation (per senior plant operators); USEPA filtration requirements and the Bloomington's SCADA monitoring of individual filter performance.

The *Manual* further details Bloomington's program of media replacement, contrasting the spent versus virgin GAC and the condition of the underlying sand. Of special interest are the micrographs showing the extensive development of microbial growth on both GAC and sand media.

Comparative operational data on the removal of total (primarily, dissolved) organic carbon by the virgin and in-service GAC is also presented in the *Manual*. This illustrates the greatly reduced removal of TOC on GAC after one year of service and confirms that the adsorptive (chemical) capacity of the carbon is exhausted within months only to be supplanted by the removal of organic compounds by aerobic microbial respiration.

Recognizing the biological nature of the TOC removal process, a caution is included as a result of these early media studies. When a filter is taken out of service for 6 to 24 hours, oxygen is found to decrease within hours. While DOC, ammonium and nitrite ion concentrations in the filter pore water increase, attached microbial cell mass deteriorates under the anaerobic conditions. As a result, water quality degradation is observed upon start-up. To avoid this deterioration and restore the aerobic biodegradation performance of the filters, the idle filters are backwashed before being returned to service.

Microscopic Examination and Description of Micrographs

Microorganisms are believed to be the root cause of the earthy/musty tastes and odors emanating from Bloomington's water sources (Evergreen Lake, Lake Bloomington, and lagoon recycle which is approximately 10% of the total plant influent). Accordingly, samples were taken of each of the source waters as well as through the treatment process in an effort to obtain some evidence of the removal, disintegration or destruction of the odor-producing organisms during treatment.

As part of this evaluation, samples were collected, membrane-filtered through a 0.22 µm polycarbonate membrane, treated with live-dead fluorescent stain and prepared for microscopic examination by ultraviolet fluorescence microscopy. Bloomington's research-grade microscope facilitates organism identification and quantification. In addition, it allows high-quality micrographs to be prepared and archived for future reference.

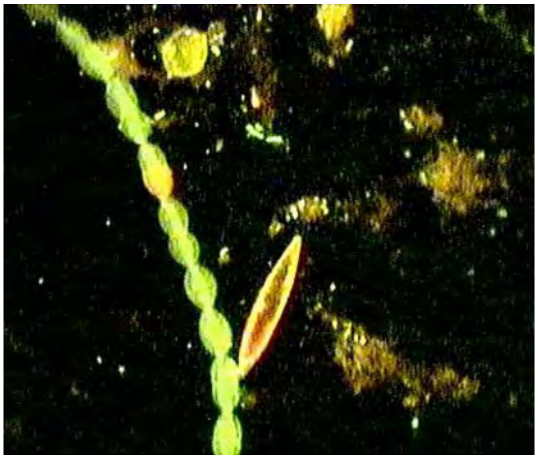
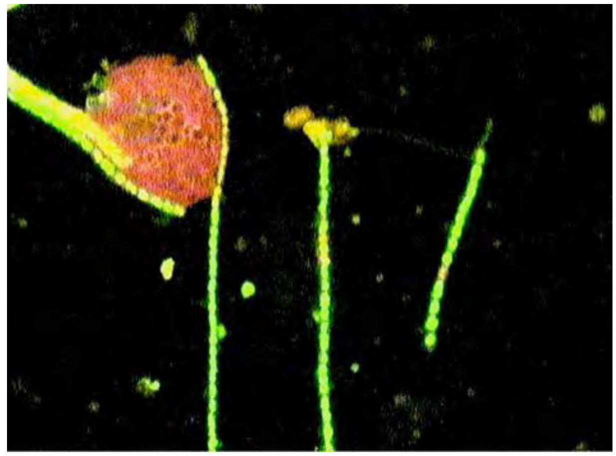
During the current taste-and-odor episode, hundreds of representative micrographs were prepared and an classification system was devised to describe the relative abundance of the particles appearing in the micrographs.

Olympus light microscope with epifluorescence attachment,
video camera and computer monitor

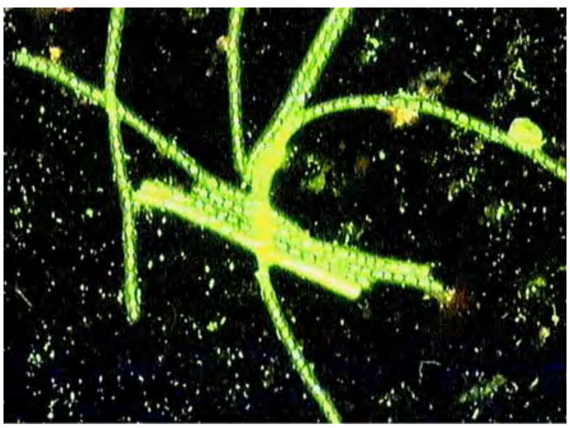
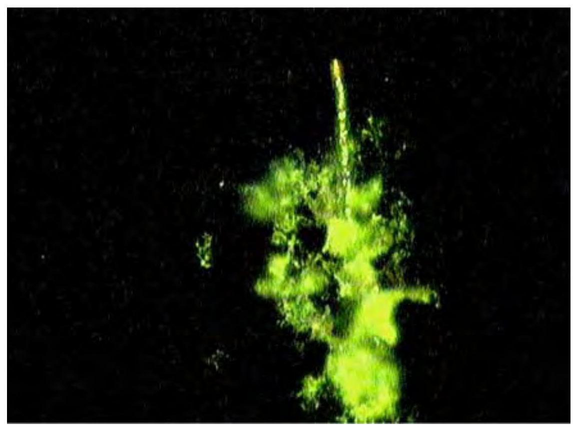
Twait's Classification of Microscopic Particle Abundance (Scale: 1 [low] to 5 [high])

January 11, 2005	*Bacteria*	*Algae*	*Diatoms*	*Inorganic*
Mackinaw River	2	1	1	3
Evergreen Lake	3	3	3	3
Lake Bloomington	3	2	1-2	4
Lagoon Recycle	3	4	3	4
In-Line Mixer	4	1	4	2
Clarifier Effluent	3	1	0	4
Filter Influent	2	2-3	1	3-4
Filter Effluent	2	0	0	0
Finished Water	2	0	0	1

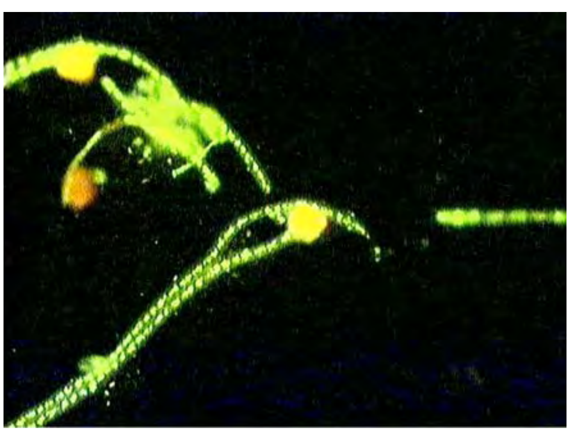
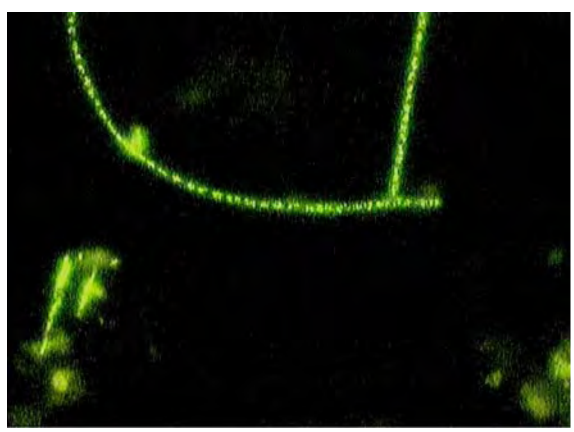
Micrographic Survey of Particles in Bloomington’s Lake and Treated Waters - December, 2004

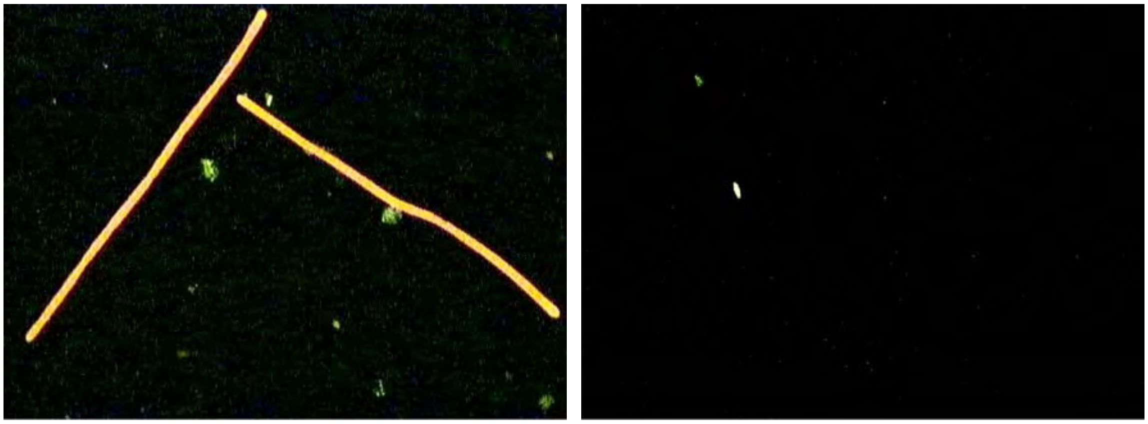
Bloomington and Evergreen Lakes exhibit particle and organism diversity; many filaments.
Many small bacteria (yellow dots) attached to non-fluorescing particles; diatoms.
Bacterial filaments may be odor-producing actinomycetes and their fruiting bodies (red).
Note: PAC was being fed to the plant influent at the inline mixer during this period.

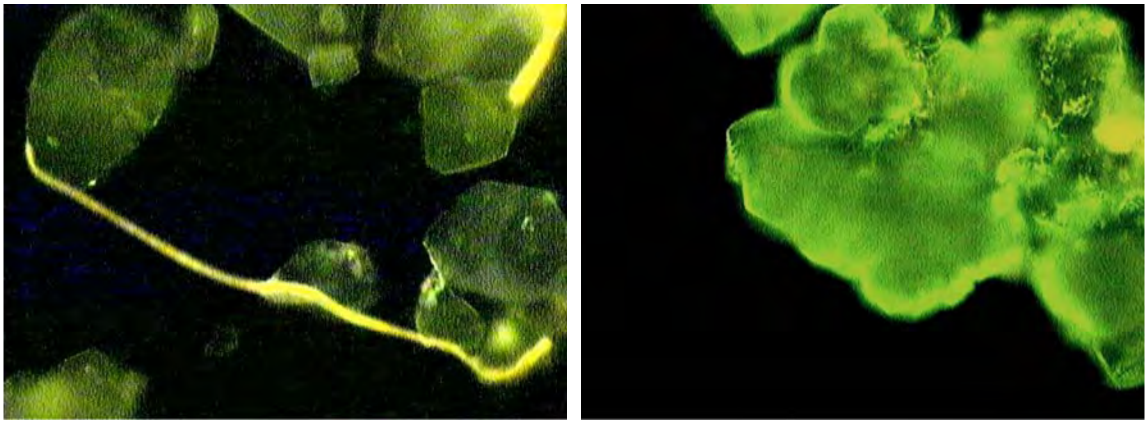
ClariCone Influent (left) shows long filaments and numerous planktonic bacteria;
Clarified effluent (right) shows few planktonic cells; flocculated aggregates.
Bacterial cells and filaments appear to be encapsulated in $CaCO_3$ crystals.
Note: High numbers of filamentous organisms may have caused problems with adequate coagulation.

Filter Influent (left) shows filaments, relatively few planktonic bacteria, $CaCO_3$ crystals absent;
Filter effluent (right) shows fewer and smaller filaments, few planktonic bacteria, some $CaCO_3$.
Note: The actual particle content of finished (tap) water was far less than illustrated.

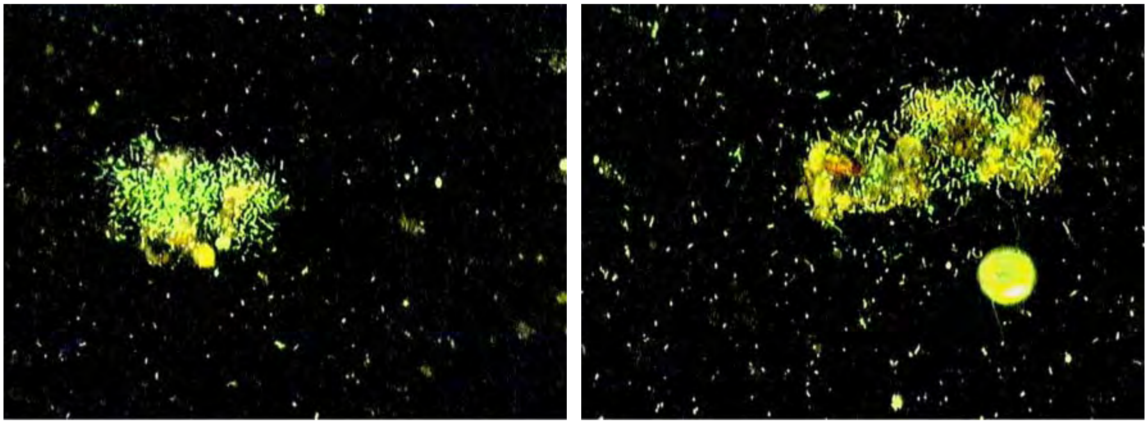


Chlorinated finished water (left) exhibits red-fluorescing (injured?) filaments; few tiny crystals;
Water from distribution system (right) is virtually free of particles of all types.

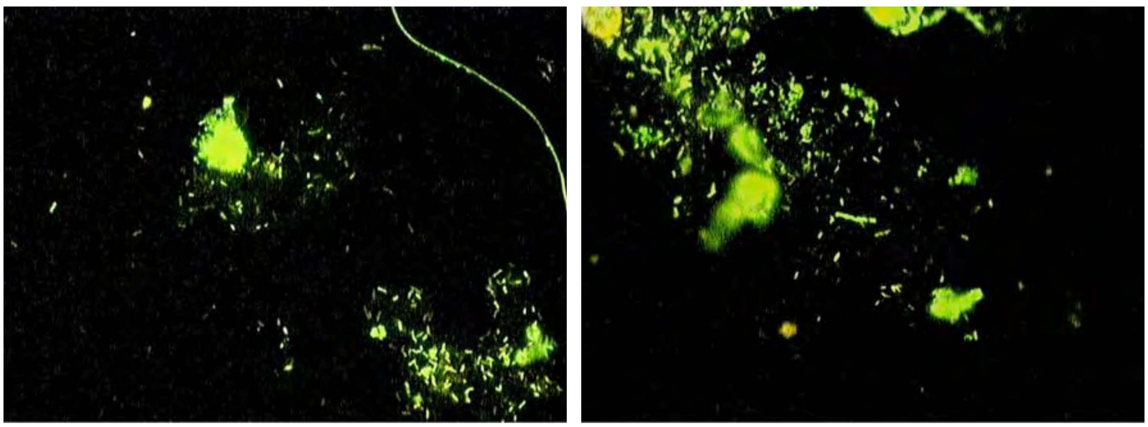


By contrast, water recycled from lime softening sludge lagoon exhibits numerous large, well-formed $CaCO_3$ crystals with securely attached or embedded filaments (left);
Micrograph (right) shows inclusion of numerous bacterial cells within $CaCO_3$ crystals.
Absence of planktonic cells indicates that most organisms are particle-associated.

Coagulation of Evergreen Lake Water, Aggregation of Filter Influent Particles



Evergreen Lake water contains numerous planktonic as well as particle-associated bacteria.



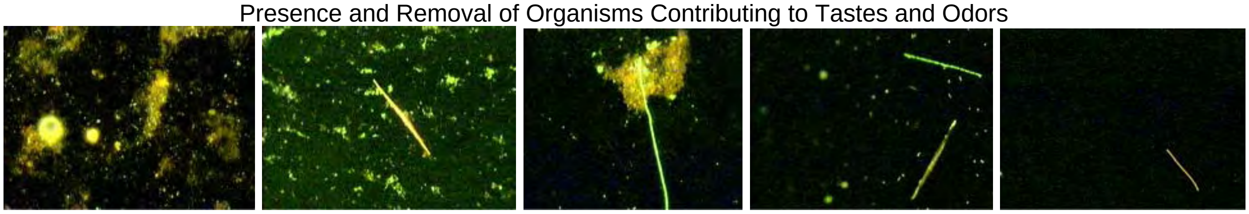
Filter Influent: Following coagulant and lime addition, planktonic bacteria are entrained in floc.
Well-defined floc is evident from outlines formed by fluorescing bacteria and entrained particles.

Analytical Services Utilized in the Evaluation of Taste-and-Odor Removal

Geosmin and MIB Analyses: ($350 per sample)	Environmental Health Laboratories 11 South Hill Street South Bend, Indiana 46617
Primary Analytical Facility:	Bloomington Water Treatment Plant Laboratory 25515 Waterside Way Hudson, Illinois 61748
Microscopic Analysis; Micrographs	Rick Twait
Nitrate Analyses (lakes, tributaries)	Jill Mayes, Ron Stanley
Total Organic and Inorganic Carbon	Ron Stanley
Tannins/Lignins	John O’Connor
Nitrate Analyses (finished water)	PDC Laboratories Peoria, Illinois

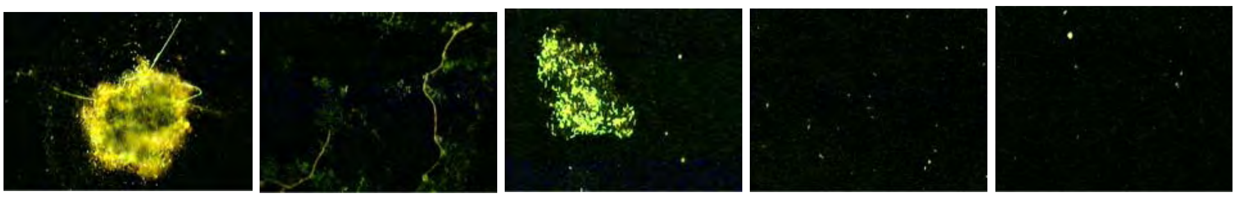
R. M. Twait's Micrographic Process Evaluation: Time Series, Source to Tap

Presence and Removal of Organisms Contributing to Tastes and Odors



Lake Evergreen **Lagoons** **Filter Influent** **Filter Effluent** **Tap** ***January 26***

*Heavy rain results in 109 ntu turbidity (**LB**), 23 ntu (**EL**), cyclotella, melosira, oscillatoria, navicula, bacteria; **lagoon** musty/fishy odor, algae; **filter influent** musty, 6.5 ntu, filamentous algae; **filter effluent** musty, 0.17 ntu, planktonic bacteria, sparse filaments; **tap water** musty, 0.17 ntu, clean, small filament lysing.*

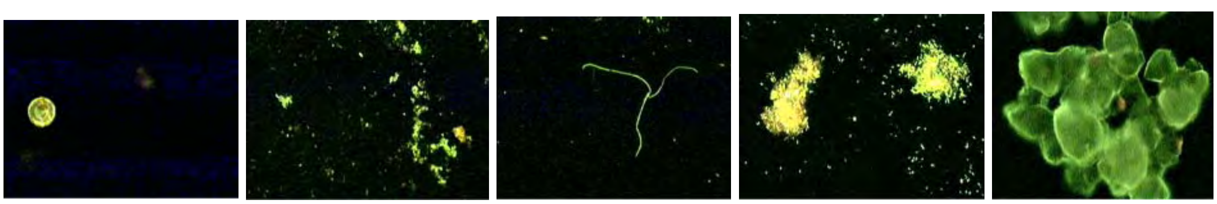


Lake Evergreen **Lagoons** **Filter Influent** **Filter Effluent** **Tap** ***January 31***

***LB** (97 ntu) stronger (fishy) odor than **EL** (23 ntu), diatoms, agglomerated bacteria, melosira colony, cyclotella; **lagoon** strong fishy odor, (1.7 ntu), decomposing filament; **filter influent** bacteria, filaments, agglomerated particles; **filter effluent** clean, planktonic bacteria; **tap water** fishy/musty, chlorinous.*

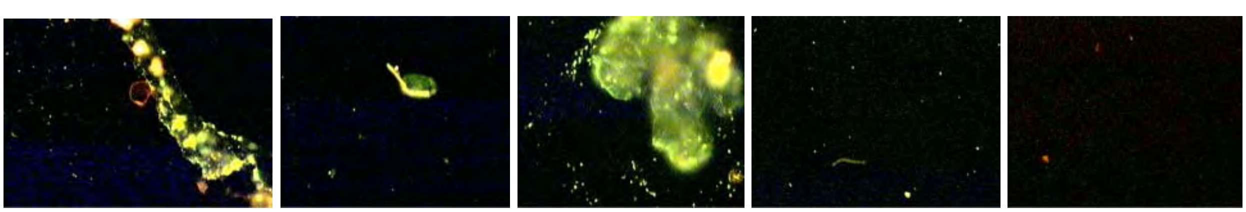
Lake Evergreen **Lagoons** **Filter Influent** **Filter Effluent** **Tap** ***February 8***

***LB** (70 ntu) earthy, **EL** (20 ntu) diatoms, filaments, melosira colony, cyclotella, asterionella, spherical bodies, fishy; **lagoon** very strong musty/fishy, filaments (1.2 ntu); **filter effluent** planktonic & agglomerated bacteria, filaments; **tap water** slight musty odor, particle-free, very clean.*



Lake Evergreen **Lagoons** **Filter Influent** **Filter Effluent** **Tap** ***February 16***

***LB** (50 ntu) no odor, **EL** (20 ntu) astringent odor; **filter influent** long spiral bacteria, centric diatoms, melosira,cyclotella, fragillaria colony, crystals; **filter effluent** musty/fishy, planktonic & agglomerated bacteria; **tap water** strong chlorinous odor, carbonate crystals (particles absent in most fields).*



Lake Evergreen **Lagoons** **Filter Influent** **Filter Effluent** **Tap** ***February 22***

***LB** (38 ntu) no odor, **EL** (13 ntu) astringent odor, melosira, cyclotella, synedra, Nitzschia, blue-green algae, asterionella, trachelomonas; **lagoon** (2 ntu) strong fishy odor, planktonic bacteria; **filter influent** fishy/musty, sloughed matter, planktonic bacteria, algae; **filter effluent** musty/fishy, cymbella; **tap water** musty odor.*

Potential Future Trials

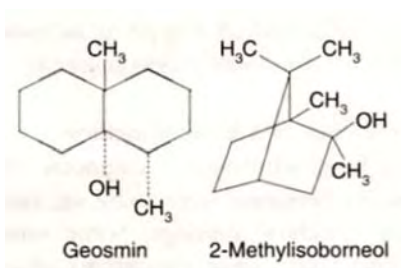
Titanium Dioxide Adsorption

Scottish researchers at Robert Gordon University (Aberdeen) have reported the successful removal of earthy-musty tastes and odors from surface waters using titanium dioxide and ultraviolet light. (AWWA MainStream, v.49, no. 1, Jan., 2005). Details should be obtained and laboratory trials made with Bloomington waters.

Biodegradation

Biodegradation appears to be the most promising method for destroying geosmin and 2-MIB. Even after the adsorption capacity of the GAC had been exhausted, passage through Bloomington's microbially-colonized filters were found to have removed about one-half of the geosmin in the filter influent.

Additional testing should be conducted using *operating* filters in an effort to increase and maximize the aerobic biodegradation.



Bloomington's 2004-2005 episode would clearly have been far more severe if microbial degradation of the taste-and-odor-producing compounds had not occurred on the filter media.