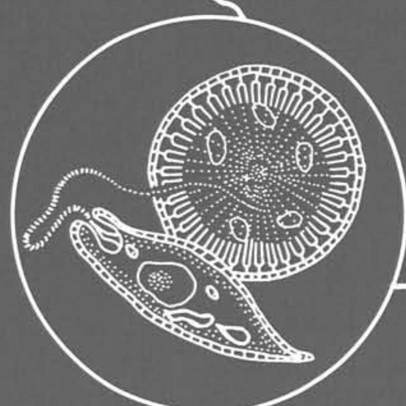
REPORT OF INVESTIGATION 68

STATE OF ILLINOIS
DEPARTMENT OF REGISTRATION AND EDUCATION

# *Algal Removal by Alum Coagulation*

by S. D. LIN, R. L. EVANS, and D. B. BEUSCHER



ILLINOIS STATE WATER SURVEY
URBANA
1971

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# Algal Removal by Alum Coagulation

by S. D. LIN, R. L. EVANS, and D. B. BEUSCHER

Title: Algal Removal by Alum Coagulation

Abstract: The removal of algae in natural waters by coagulation with liquid alum was investigated in the laboratory using the jar test technique. Various amounts of alum (up to 40 mg/l) were added to water samples collected from the Illinois River at Peoria. Algal enumerations as well as some pertinent chemical analyses were performed before and after the process of coagulation and flocculation. The efficiency of algal removal was found to be dependent upon alum dosage, initial algal concentrations, and the types, shapes, and other specific characteristics of the algae. Optimum coagulant dosage for algal reduction was found to be similar to that for turbidity removal. Results should be useful in defining problems encountered in water treatment plants where algae are troublesome.

Reference: Lin, S. D., R. L. Evans, and D. B. Beuscher. Algal Removal by Alum Coagulation. Illinois State Water Survey, Urbana, Report of Investigation 68, 1971.

Indexing Terms: algae, alkalinity, (liquid) alum, aluminum, coagulation, flocculation, Illinois River, jar test, pH, residue, sanitary engineering, turbidity, water temperature, water treatment.

STATE OF ILLINOIS
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DEPARTMENT OF REGISTRATION AND EDUCATION
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## SUMMARY

Twenty-five samples of Illinois River water were subjected to the coagulation process using alum at dosages from 10-40 milligrams per liter. The 38 algal genera detected during the study were divided into seven groups on the basis of apparent susceptibility to reduction by alum coagulation. At a coagulant concentration of 30 mg/l most of the troublesome algae were removed and an overall algal reduction in excess of 85 percent was achieved. The resistance of some genera indicates that coagulant aids or coagulants other than alum may be needed for their removal.

Spine-like algae such as *Scenedesmus* and *Ankistrodesmus* as well as the boat-shaped *Navicula* and the filamentous free-floating *Aphanizomenon* required higher doses for removal. The most persistent organism observed was *Euglena,* a mobile and flexibly encased flagellate.

A quadratic expression (*see equations 1 and 2 in text*) was found to best describe mathematically the relationships between algal or turbidity removal and alum dosage. Coagulant requirements for algae and turbidity were similar although the computed optimum dosage for the removal of each was not the same. Several regression techniques were used in an attempt to define and to predict the effect of several variables to algal reduction at varying coagulant dosages.

The most important factors related to the removal of algae by coagulation appeared to be alum dosage, the initial algae concentration, and the shape and size of the genera encountered. The results suggest the desirability of identifying the predominant species of the troublesome algae for plant design and operations.


## INTRODUCTION

Chemical coagulation is commonly used in the treatment of water. The effective reduction of clay, silt, organic matter, algae, and bacteria in surface waters by coagulation and settling is demonstrated daily in water works operation. Even though the coagulation of clays and other inorganic sols has been reported in detail, similar attention has not been given to the coagulation of algae.

An earlier investigation by the Water Quality Section of the Illinois State Water Survey concerning the operations of a water treatment plant[1,2] suggested the selective removal of planktonic algae in the clarification units. To gain further insight into the phenomena of algal removal by alum coagulation, flocculation, and sedimentation a bench study was undertaken. The investigation did not include the basic kinetics of aluminum absorption by algae, but was designed principally to define the relationships that might be involved between coagulant dosage and other readily measurable factors. Such information is useful to both the water industries and design engineers.

### Literature Review

The mechanism of destabilizing particulate matter in water by the hydrolyzing electrolyte is a function of the electrolyte concentration and pH of the dispersion medium. O'Melia and Stumm[3] have shown that pH, floc age, and anion concentration not only have a demonstrable effect upon the flocculation process but also affect the filtration process. Tenney et al.[4] found that effective algal flocculation occurred during low pH ranges of 2 to 4 while using constant concentrations of a cationic polyelectrolyte (10 mg/l of G-31). However, such a pH range is not practical in the water treatment process. Turbidity studies by Black and Hannah[5] suggested that the optimum coagulation of three types of clays occurred during a pH range of 7.5 to 8.5. Black and Chen[6] found that the pH range for optimum coagulation varied with alum dosage and types of suspended river sediment. Effective flocculation took place within a pH range of 6.5 to 7.5 when the alum dosage was 10 mg/1 or greater. In this range $Al(OH)_3$ is the predominant aluminum species.[7] Sawyer[8] suggested that the optimum pH for the reduction of negatively charged colloids varied with the nature of the water but generally fell within the range of 5.0 to 6.5. The practical pH range for alum usage is generally considered to be 6.5 to 7.5.[9]

Proposed theories for algal removal by chemical coagulants were summarized by Ives.[10] They include the mechanical enmeshments, adsorption, and a protogel theory developed by Hay. None of these theories could satisfy Ives' experimental results. Ives[10] suggested that the removal of algae by a chemical coagulation was due to a form of electrostatic precipitation. He reported that the charge density controlled the algal coagulation and varied with algal species. The amount of chemical required to remove the algae was largely governed by the number and size of the algae present. The size of algal cell had little effect on zeta potential.

The work on algal flocculation with synthetic organic polyelectrolytes by Tenney et al.[4] showed that the optimum condition for the algal flocculation was at the peak range (late log growth and early log decline phases) of the growth curve of the algae. They suggested that the mechanism of algal flocculation is due to a bridging phenomenon between the discrete algal cells and the linearly extended polymer chains, forming a three-dimensional matrix that is capable of settling under quiescent conditions.

The removal of algae by laboratory sand filters with and without a chemical coagulant has been studied at the University of Michigan.[11,12,13] The results of the study by Borchardt and O'Melia[11] may be summarized as follows: 1) the efficiency of the filtration of plain algal suspensions through sand beds decreased with time to a constant minimum value; 2) the size of sand had a distinct effect on the algal removal; 3) no difference in algal removal among the filtration rates of 2.0, 1.0, and 0.2 gpm/sq ft was observed; 4) removal efficiency varied among three tested genera of the algae and were found to be inconsistent from run to run; 5) higher algal removal was achieved with iron coagulation; and 6) a significant number of algae were always present in the filter effluent. In the study by Davis and Borchardt,[12] they concluded that the filtration of plain algal suspensions resulted in sufficient removal after the filtration process had been in operation for a short time. The algal removal was found to be a function of the quantity of coagulant added and dependent on the number of organisms present. Other work by Foess and Borchardt[13] indicated that reducing the repulsive force between algae and sand, by coating the sands with positively charged materials, increased removal efficiencies especially when the pH was lowered.

Plant-scale studies at Cleveland[14,15] revealed that coagulation with alum and subsequent sedimentation reduced the number of algae in water by almost 90 percent before application to the filters. Microstrainers for removing algae, as the sole method of filtration or ahead of slow or of rapid sand filters, have been used in England, Canada, the United States, and many other countries.[16-17] About 25 years ago, the first installation of microstrainers was made in England to provide for the removal of algae ahead of slow sand filters.[17] Taylor[18] reported that microstrainers at Lee Bridge, England, performed most efficiently when the water has a large algal count.

Speedy et al.[19] studied the efficiency of algal removal at the water treatment plant of the University of Iowa. They found that each unit of the treatment process removed different types of algae at varying efficiencies.

The harvesting and processing of algae from waste stabilization ponds has been studied by investigators at the University of California, Berkeley, and at other laboratories. Van Vuuren and van Duuren[20] conducted laboratory jar tests on algae-laden sewage maturation pond effluent in which 110 mg/l of alum was aided by a variety of polyelectrolytes (0.1 to 5.0 mg/l). They found that the polyelectrolytes tested did not significantly affect algal flocculation. Recently a similar study was made by McGarry[21] for separation of algae from the high-rate oxidation pond effluent. It was reported that the efficiency of algal removal was dependent on alum and polyelectrolyte concentrations, time of polyelectrolyte addition, mixing period, and degree of turbulence. Golueke and Oswald[22] used ion exchange columns for removal of pond-grown *Scenedesmus* and laboratory-grown *Chlorella*. They reported that cation resins were effective in algae removal. The aggregated cells were easily removed from the column by backwashing. The aggregation of the cells was promoted within the pH range of 2.8 to 3.5.

## Objectives and Plan

In the Illinois Water Survey study, water samples were used with a laboratory jar test apparatus to determine the following:

1) Whether algal removal is a function of genera.
2) Whether the coagulant dosage is the same for optimum turbidity removal as for optimum algal removal.
3) Whether algal removal efficiencies can be related to water temperature, pH, alkalinity, turbidity, residues, coagulant dosage, and other variables.

This report describes the procedures used in the investigation and presents the results related to these three objectives. Algal counts for 25 runs are given in appendix A and characteristics of observed algae are listed in appendix B.

## Acknowledgments

This study was conducted under the general supervision of Ralph L. Evans, Head of the Water Quality Section, and Dr. William C. Ackermann, Chief, Illinois State Water Survey. William T. Sullivan, Associate Chemist, and David L. Hullinger, Assistant Chemist of the Water Quality Section performed determinations for residue and aluminum concentrations. The computer analyses were programmed by Robert A. Sinclair, System Analyst of the Water Survey. Mrs. J. Loreena Ivens, Technical Editor, edited the final report; Katherine Shemas, Clerk-Typist, typed the original manuscript; and John Brother, Jr., Chief Draftsman, prepared the illustrations.

## MATERIALS AND METHODS

The water samples used during the investigation were collected from the Illinois River at Peoria, Illinois, from June through September 1969. Samples were obtained from that sector of the stream serving as a source of water for the city during summer months. Six portions (999 ml) of the sample were placed in six 1500-ml beakers for each run. The beakers were immersed in a constant temperature tank adjusted to the temperature of the water sample during the time of collection. During the study 25 runs were performed at water temperatures ranging from 18.0 to 28.8 Celsius.

For the coagulant, commercial liquid alum was used. It was applied to the sample at dosages of 10, 20, 25, 30, and 40 mg/1; one beaker was used for control. The coagulant was about 50 percent of alum by weight. Dosage solutions were freshly prepared before each series of runs by diluting the liquid alum with deionized water. The stock solution contained a concentration of 20 g/l of alum and the dosage volume applied to the samples did not exceed 2 ml.

A six-place multiple stirrer (a product of Phipps and Bird, Inc., Richmond, Va.) was used for mixing the contents of the six beakers. The samples were mixed for 30 seconds at 100 rpm after the addition of the coagulant. This was followed by a 30-minute flocculation period at 30 rpm after which the suspension was permitted to settle for 30 minutes. At the end of the settling period a 600-ml portion, from each beaker, was carefully siphoned off so as not to disturb the sediment at the bottom of the beaker.

After the rapid mix period (30 seconds), measurements for pH and the time required for the initial formation of floc were recorded. Other pH measurements were made near the termination of the flocculation period and after settling. A portable meter (Model N pH meter, a product of Beckman Instruments, S. Pasadena, Calif.) was used for all pH determinations. Analyses were performed on the 600-ml portions as well as the raw water for pH, turbidity, alkalinity, aluminum, residues (filterable, nonfilterable, and total), and algal enumeration.

Turbidity was measured with a photoelectric colorimeter (Evelyn photoelectric colorimeter, a product of Rubicon Co., Philadelphia, Pa.) at 660 n (nanometer = mμ) which had been calibrated with the Jackson candle procedure. Turbidity is expressed in Jackson turbidity units, Jtu. All other determinations were made in accordance with *Standard Methods.*[23]

From each sample 190 ml was preserved with 10 ml of formalin for biological examination. A 50-ml portion of the biological samples was passed through an 0.45-μ membrane filter (a product of Millipore Corporation, Bedford, Mass.). Residue was flushed from the filter by the filtrate into tubes to a volume of 10 ml. Portions from the tubes were used for biological examination. An inverted phase contrast microscope (Unitron Research Model, distributed by Unitron Instrument Co., Newton Highlands, Mass.) equipped with 10X eye-pieces and 20X objectives, in conjunction with a Sedgwick-Rafter counting cell and Whipple disc, was used for counting and identification purposes. All counting procedures followed those outlined in *Standard Methods.*[23]

The algae were identified to genus in all cases and were counted from 10 fields. Enumerations of blue-green algae were made by number of trichomes for all genera observed. The green algae were counted as individual cells except for *Actinastrum, Coelastrum,* and *Pediastrum,* which were counted as one unit for each clump. *Scenedesmus* was recorded as one for each cell packet. The diatoms were counted as one organism regardless of how they were grouped or connected.

## RESULTS AND DISCUSSION

During the chemical coagulation of water, three stages in the process are dominant; each is dependent upon the degree of mixing and time. In the period of rapid mix the destabilization of particulate material is initiated and floc is formed; during the flocculation period the floc increases in density and size; and finally during the sedimentation period the floc settles and leaves a clarified liquid. The addition of alum to water releases hydrogen ions and consequently lowers the pH. Unless the hydrogen ions can be removed, the formation of an effective floc, $Al(OH)_3$, is impossible. The hydrogen ions can be removed by the alkalinity in natural water or by the addition of lime.

In midwestern waters most of the alkalinity is in the form of bicarbonates; to insure effective coagulation the bicarbonates must be in excess of that required for hydrogen ion removal. The total alkalinity of the river waters during the period of study ranged from 153 to 191 mg/1 as $CaCO_3$, which was sufficient to insure proper coagulation without the addition of lime. The range of alkalinity reductions as a function of alum dosage for 25 runs is shown in figure la. For any particular series of samples the reduction in alkalinity varied from about 22 to 33 percent of the alum applied.

The range of pH for 25 runs at varying stages of the coagulation process is depicted in figure lb. During the rapid mix period the pH consistently decreased with an increase in alum dosage. The lowest value recorded, from an initial pH of 7.91, was 7.02 at a dosage of 40 mg/1. During the flocculation period there was the expected increase presumably due to the neutralization of released hydrogen ions by reaction with natural bicarbonates, and during the sedimentation period the pH in each instance rose. Effective coagulation-flocculation occurred with the pH range of 7.1-7.8 and at alum dosages of 25 mg/1 and higher. The floc was large and rigid, and settled well.

Efforts to relate the concentrations of residual aluminum

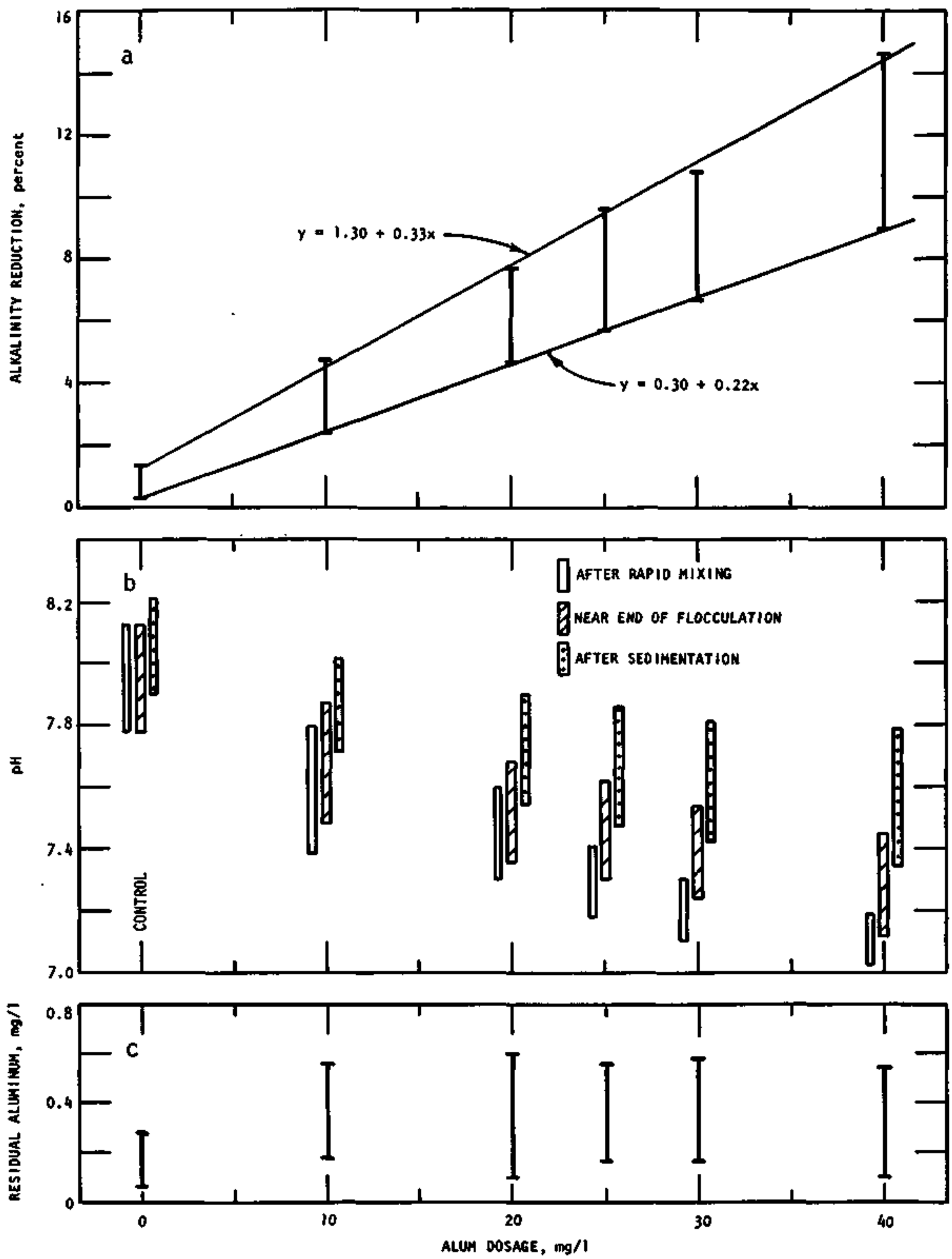


Figure 1. Effect of alum dosage on pH, alkalinity reduction, and residual aluminum

in the clarified water to alum dosage were not successful. As shown by the results in figure 1c, there was no observable trend.

### Genera Removal vs Alum Dosage

Diatoms are the predominant plankton found in midwestern streams, and the Illinois River is no exception. The predominant genera observed during the investigation were *Cyclotella, Navicula, Melosvra,* and *Stephanodiscus.* These organisms constituted about 75 percent of the total algal population; *Cyclotella* alone represented about 60 percent of the total count.

The most prevalent green algae were *Scenedesmus, Chlorella, Ankistrodesmus,* and *Gloeocystis. Euglena* was the only flagellate of importance and appeared in 92 percent of the samples. Although significant numbers of blue-green algae were not observed, *Aphanizomenon* was unexpectedly difficult to remove when subjected to chemical coagulation.

Throughout the study period (June through September) the percentile composition for each genus in the 25 sampling runs was quite consistent. The total number of algae varied from 2500 cells/ml on July 28 to 11,600 cells/ml on September 19. Generally the algal population was highest in September and lowest in July. Algal counts for the 25 test runs are included in appendix A. Some characteristics of algal genera observed during the study are listed in appendix B; descriptions are in accordance with references 24 through 29.

During the period of study 38 algal genera were observed. They are arrayed in table 1 in order of increasing frequency

**Table 1. Algal Occurrences and Average Counts**

| | Number of occurrences in 25 runs | | | | | | | Average algal count per occurrence | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Raw | Water clarified by alum (*mg/l*) | | | | | | Raw | Water clarified by alum (*mg/l*) | | | | | |
| Algal genus* | water | 0 | 10 | 20 | 25 | 30 | 40 | water | 0 | 10 | 20 | 25 | 30 | 40 |
| Group 1 | | | | | | | | | | | | | | |
| *Caloneis* (d) | 3 | | | | | | | 1.3 | | | | | | |
| *Cocconeis* (d) | 2 | | | | | | | 3.0 | | | | | | |
| *Fragilaria* (d) | 1 | | | | | | | 4.0 | | | | | | |
| *Chlorosarcina* (g) | 1 | | | | | | | 1.0 | | | | | | |
| *Clostridium* (g) | 1 | | | | | | | 1.0 | | | | | | |
| *Dispora* (g) | 1 | | | | | | | 1.0 | | | | | | |
| *Neidium* (d) | 1 | | | | | | | 1.0 | | | | | | |
| *Spirogyra* (g) | 1 | | | | | | | 1.0 | | | | | | |
| Group 2 | | | | | | | | | | | | | | |
| *Coelastrum* (g) | 1 | 1 | | | | | | 1.0 | 1.0 | | | | | |
| *Cymbclla* (d) | 1 | 1 | | | | | | 1.0 | 1.0 | | | | | |
| *Anacystis* (bg) | 0 | 1 | | | | | | 0 | 1.0 | | | | | |
| *Lepocinclis* (f) | 0 | 1 | | | | | | 0 | 1.0 | | | | | |
| *Platydorina* (g) | 0 | 1 | | | | | | 0 | 1.0 | | | | | |
| Group 3 | | | | | | | | | | | | | | |
| *Surirella* (d) | 9 | 5 | 2 | | | | | 1.1 | 1.2 | 1.0 | | | | |
| *Phacus* (f) | 5 | 1 | | | | | | 1.0 | 1.0 | 1.0 | | | | |
| *Nitzschia* (d) | 1 | 1 | | | | | | 1.0 | 2.0 | 1.0 | | | | |
| *Asterionella* (d) | 1 | 2 | | | | | | 1.0 | 1.0 | 1.0 | | | | |
| *Diatoma* (d) | 5 | 0 | | | | | | 1.0 | 0 | 1.0 | | | | |
| *Chlamydomonas* (f) | 1 | 0 | | | | | | 3.0 | 0 | 1.0 | | | | |
| *Mougeotia* (g) | 0 | 0 | | | | | | 0 | 0 | 2.0 | | | | |
| Group 4 | | | | | | | | | | | | | | |
| *Anabaena* (bg) | 3 | 2 | 2 | 1 | | | | 1.3 | 1.0 | 1.0 | 1.0 | | | |
| *Ulothrix* (g) | 1 | 1 | 0 | 1 | | | | 1.0 | 2.0 | 0 | 1.0 | | | |
| Group 5 | | | | | | | | | | | | | | |
| *Stephanodiscus* (d) | 10 | 9 | 3 | 2 | 1 | | | 2.5 | 1.5 | 2.3 | 1.0 | 1.0 | | |
| *Oocystis* (g) | 8 | 4 | 3 | 1 | 1 | | | 1.1 | 1.0 | 1.0 | 1.0 | 1.0 | | |
| *Synedra (A)* | 7 | 1 | 1 | 1 | 1 | | | 1.0 | 1.0 | 2.0 | 1.0 | 1.0 | | |
| *Tabellaria* (d) | 7 | 4 | 0 | 0 | 2 | | | 1.4 | 1.5 | 0 | 0 | 1.0 | | |
| *Gyrosigma* (d) | 1 | 2 | 0 | 0 | 1 | | | 1.0 | 1.0 | 0 | 0 | 1.0 | | |
| Group 6 | | | | | | | | | | | | | | |
| *Melosira* (d) | 20 | 14 | 12 | 6 | 4 | 2 | | 2.3 | 2.0 | 1.4 | 1.7 | 1.3 | 1.0 | |
| *Scenedesmus* (g) | 19 | 18 | 10 | 9 | 7 | 4 | | 1.5 | 1.8 | 1.6 | 1.6 | 1.6 | 1.0 | |
| *Chlorella* (g) | 11 | 9 | 12 | 2 | 2 | 2 | | 2.5 | 1.9 | 1.9 | 2.0 | 1.0 | 2.0 | |
| *Ankistrodesmus* (g) | 12 | 8 | 5 | 0 | 4 | 4 | | 1.5 | 2.0 | 1.8 | 0 | 1.0 | 1.0 | |
| *Gloeocystis* (g) | 10 | 10 | 5 | 3 | 6 | 1 | | 2.1 | 1.3 | 1.2 | 1.0 | 1.2 | 2.0 | |
| *Pediastrum* (g) | 8 | 9 | 7 | 4 | 1 | 3 | | 1.6 | 1.1 | 1.0 | 1.3 | 1.0 | 1.3 | |
| *Actinastrum* (g) | 5 | 6 | 4 | 6 | 6 | 1 | | 2.6 | 1.7 | 1.3 | 1.0 | 1.2 | 1.0 | |
| Group 7 | | | | | | | | | | | | | | |
| *Cyclotella* (d) | 25 | 25 | 25 | 22 | 16 | 6 | 2 | 24.9 | 15.6 | 5.5 | 3.6 | 3.3 | 2.5 | 1.5 |
| *Mavicula* (d) | 24 | 16 | 10 | 8 | 5 | 3 | 1 | 3.0 | 2.8 | 1.5 | 1.5 | 1.2 | 1.3 | 1.0 |
| *Aphanizomenon* (bg) | 5 | 6 | 5 | 3 | 2 | 2 | 1 | 1.2 | 1.0 | 1.0 | 1.0 | 1.0 | 2.0 | 1.0 |
| *Euglena* (f) | 23 | 25 | 18 | 15 | 14 | 6 | 6 | 2.6 | 2.2 | 1.9 | 1.5 | 1.3 | 1.3 | 1.0 |

**d = diatom; g = green, bg = blue-green; f = flagellate* of occurrence in 25 samples. The average number of algae observed per occurrence is also tabulated in table 1. To express the concentration in "average algal cells per milliliter per occurrence," each numerical value must be multiplied by the factor 165.

The seven groupings of algal genera in table 1 reflect the observed persistence of the organisms in water clarified by alum coagulation. The first group appears to be susceptible to reduction solely by mechanical mixing, i.e., they appeared in the raw sample but were not observed in the control jar after the mixing and settling periods. The five genera of group 2 were effectively removed by an alum dosage of 10 mg/l. In this group, as well as some others, the unlikely occurrence of several genera being observed in the control jar, after mixing and settling, but not in the raw sample was experienced. From previous work[2] this was not unexpected; it merely demonstrates the limitation of microscopic examination of a natural population of low algal concentration. Those genera in group 3 were completely removed when subjected to an alum dosage of 20 mg/1, and the two genera in group 4 were not found in suspension after a dosage of 25 mg/1.

The 16 genera included in groups 5, 6, and 7 were the most persistent organisms. It is of interest that 12 of them were also found to be the least susceptible to removal, at a dosage of 25 mg/1 of alum, in the operations of the Peoria Water Company.[2] Unfortunately these 16 genera are the organisms reported to be the most troublesome for water treatment plants in the Midwest. The organisms in group 5 were removed by an alum dosage of 30 mg/1. *Gyrosigma* appeared persistent even in a low frequency of occurrence. *Stephanodiscus* is noted for the "vegetable to oily taste" imported to water, *Tabellaria* produces an aromatic geranium-like odor, and *Synedra* is responsible for an earthy-musty odor.[24]

The seven genera of algae in group 6 were successfully removed at an alum dosage of 40 mg/1. *Scenedesmus* and *Ankistrodesmus* have spine-like tips. The "cigar-shaped" *Actinastrum* is arranged in radiating colonies. Spines of the cells permit these nonswimming green algae to remain suspended in water. The large flat surfaces of the green algae *Pediastrum* and the diatom *Melosira* produce similar results. The ellipsodial *Chlorella* is extremely small, often about 2-5 μ in diameter, and *Gloecystis* cells are not only small but also are enclosed by concentric layers of mucilage. Both are of the free-floating type. All of these algae possess the capability of suspension in water. A high alum dosage of up to 40 mg/1 is required for their removal because of their configuration and density.

The algae in group 7, with the exception of the blue-green *Aphanizomenon*, were the most frequent organisms observed in the 25 samples of river water subjected to chemical coagulation. All four genera persisted in the clarified water with alum dosages as high as 40 mg/1. Although *Cyclotella* was persistent, excellent reduction was achieved at dosages up through 30 mg/1. This reduction efficiency is presumably due to its relatively large size, drum shape, and density. *Navicula*, in spite of its boat-shape and ability to move through water, was also reduced markedly at alum applications up through 30 mg/1. *Aphanizomenon*, on the other hand, appears to be one of the most difficult algae to remove; however, it did not occur frequently, only about 20 percent of the time. It is a filamentous organism formed in plate-like bundles, and is a surface free-floating plant. *Euglena*, a pigmented flagellate, was the most persistent algae of all observed. This is consistent with its structure. Though a rather large organism, its mobility coupled with a nonrigid cell wall that permits flexible changes in form has resulted in passage of the organism tiirough sand filters.[2,19]

The array of algal genera in table 1 is principally a suggestive order of algae persistence with alum coagulation; it has been prepared solely upon frequency of occurrence as observed during the study. It is quite probable that the blue-greens *Anabaena* and *Anacystis* with their low density and large flat surfaces, as well as the flagellates *Chlamydomonas*, *Lepocinclis*, and *Phacus* with dieir mobility, would reflect a greater degree of persistence with alum coagulation than depicted in table 1 if their occurrences were more frequent.

A wide range of removal, expressed as percent, was observed for most genera under varying coagulant dosages during the 25 runs. The inconsistency of algal removal from run to run was also observed by the study of Borchardt and O'Melia.[11] To express removal efficiencies for each series of tests for each genus was considered impractical; average values likewise would not be meaningful. However, the trend of algae reduction as related to alum dosage is indicated by the data in table 2.

### Algae and Turbidity Removal

During the study the turbidity of the Illinois River at Peoria ranged from 60 to 132 Jtu; the range of the algal concentration was 2500 to 11,600 cells/ml. There was no correlation (r = 0.15) between the two. In otiier words the algae in the waterway were not a major constituent of turbidity nor was there visual evidence of an algal bloom.

Three mathematical models were used in an effort to formulate the relationships of algal and turbidity removal to coagulant dosage. They included:

Model 1. $Y = aX^2 + bX + c$ (quadratic)

Model 2. $Y = bX^a$ (geometric)

Model 3. $Y = a \log X + b$ (logarithmic)

where

$Y$ = the percent removal of algae and turbidity

$X$ = the alum dosage in mg/1

$a,b,c$ = constants determined by regression analysis

In the calculations for models 2 and 3 an alum dosage of 0.00001 mg/1 was assumed for the control jar. The regression curves for models 1 and 2, as well as the plotted observed data, are depicted in figure 2. Solely from observations of these curves, model 1 in figure 2a appears to be the best fit

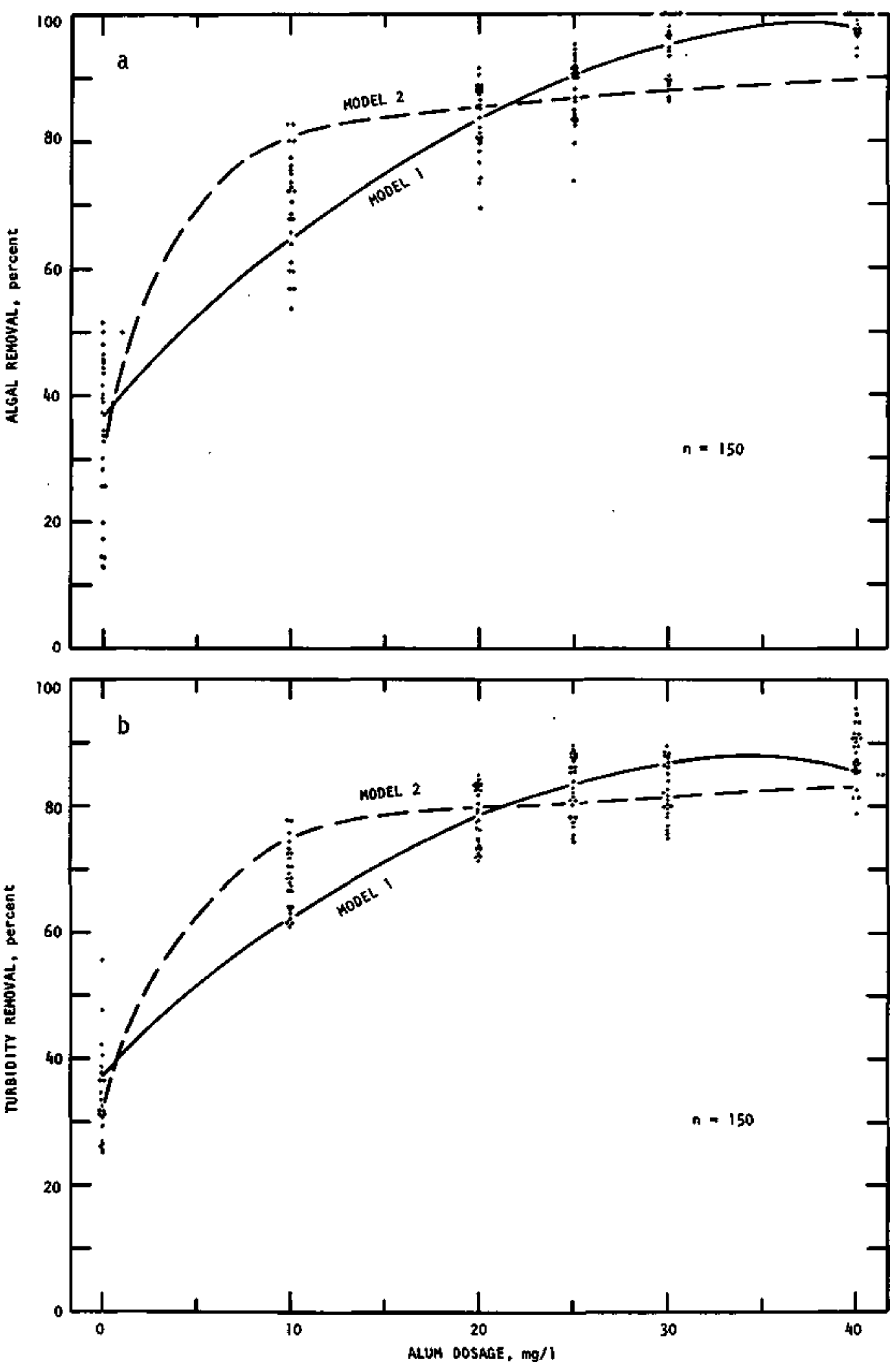


Figure 2. Relationship between algal and turbidity removal and alum dosage

**Table 2. Percent Algae Reduction Related to Alum Dosage**

| Alum dosage (*mg/l*) | Algae reduction (%) |
|---|---|
| 0 | 9—51 |
| 10 | 51—83 |
| 20 | 69—100 |
| 25 | 73—97 |
| 30 | 87—100 |
| 40 | 93—100 |

for algal removal, and model 2 in figure 2b appears to fit the data best for turbidity removal. This is particularly so for the dosage range of 20 to 30 mg/l. A tabulation of the regression analysis is set forth in table 3. High coefficients of correlation were found for each of the models tested. In selecting the model of best fit the correlation coefficient and the standard error of estimate were considered. It was concluded that model 1 expressed best the relationships of algal and turbidity removal with coagulant dosage. The relationships are:

For algal removal

$$Y = 36.54 + 3.2325\ X - 0.04256\ X^2 \quad (1)$$

For turbidity removal

$$Y = 37.08 + 2.9567\ X - 0.04355\ X^2 \quad (2)$$

It seems obvious that for a required reduction in algae concentration or turbidity, the alum dosage is comparable. Chaudhuri[30] found a similar relationship in comparing virus reduction with turbidity removal. There was no significant difference in turbidity removal between dosages of 25 and 30 mg/1 of alum (figure 2). Depending upon the initial turbidity, the residual turbidity for samples treated with 40 mg/1 of alum ranged from 4 to 19 Jtu. Removal efficiencies for algal reduction were similarly high for a 40 mg/1 dosage. Alga was not detected in 16 of the 25 runs at that dosage.

**Table 3. Regression Analysis for Algal and Turbidity Removal vs Alum Dosage**

| Model | Removal of | *a* | *b* | *c* | *r* | *Se* |
|---|---|---|---|---|---|---|
| 1 | Algae | -0.04256 | 3.2325 | 36.54 | 0.945 | 7.51 |
| | Turbidity | -0.04355 | 2.9567 | 37.08 | 0.945 | 6.26 |
| 2 | Algae | 0.06824 | 69.63 | | 0.876 | 9.88 |
| | Turbidity | 0.06003 | 66.10 | | 0.947 | 6.52 |
| 3 | Algae | 8.52117 | 75.65 | | 0.888 | 10.54 |
| | Turbidity | 7.37550 | 70.19 | | 0.930 | 6.95 |

Note: r = regression correlation coefficient; *Se* = standard error of estimate

For determining the optimum dosage of alum for algal and turbidity removal, equations 1 and 2 were differentiated with respect to the dosage and equated to zero. The results yielded a dosage of about 38.2 mg/1 of alum for 97.9 percent removal of algae and about 34 mg/1 of alum for 87.3 percent removal of turbidity.

### Factors Influencing Algal Removal

It has been demonstrated that the quantity of the coagulant dose is an influential factor in the degree of algal removal attained. In an effort to quantitatively relate algal concentration in the clarified water, for a certain alum dosage, to other characteristics of the untreated water a stepwise multiple linear regression analysis was performed.

The Soupac Program readily available at the University of Illinois was used for computing purposes. Initially 12 independent variables were tested, but only seven were retained after screening within the computer program. Those critical factors retained were 1) time of floc formation, 2) turbidity, 3) total residue, 4) nonfilterable residue, 5) pH of untreated water, 6) temperature, and 7) initial algal concentration. Those dropped out of the program were pH after rapid mixing and after settling, alkalinity, residual aluminum, and filterable residue. The results are tabulated in table 4. The absence of numerical values in several of the columns suggests that the independent variable represented by the column is not an important factor in algal removal at each corresponding alum dosage. It would appear that three independent variables — initial algae concentration $x_7$, nonfilterable residue $x_3$, and temperature $x_5$ — bear the most important relationships to the algae concentration in the clarified water.

A standard multiple linear regression analysis was also tried with the seven variables retained in the computer program. The relationship of algae concentration in clarified water, at a certain alum dosage, with these variables can be expressed as:

$$Y_i = C_i + C_{1i}x_1 + C_{2i}x_2 + C_{3i}x_3 + C_{4i}x_4 + C_{5i}x_5 + C_{6i}x_6 + C_{7i}x_7 \quad (3)$$

where

$Y_i$ = the algae concentration after the coagulation process in cells/ml

$x_1$ = initial turbidity in Jtu

**Table 4. Results of Step-Wise Multiple Regression Analysis**

| Alum dosage (*mg/l*) | *C* | Coefficient of variable $x_2$ | $x_2$ | $x_3$ | $x_4$ | $x_5$ | $x_6$ | $x_7$ | *r* | *Se* |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 1195 | -15.83 | | | | | | 0.687 | 0.877 | 944 |
| 10 | -3451 | | | 10.54 | | 90.2 | 2.42 | 0.302 | 0.779 | 579 |
| 20 | -2538 | | | 7.84 | | 62.0 | 2.00 | 0.187 | 0.755 | 383 |
| 25 | -1686 | | | 5.79 | | 42.4 | | 0.154 | 0.775 | 311 |
| 30 | 6809 | -10.75 | 3.21 | 6.47 | 1138 | | | 0.091 | 0.673 | 327 |
| 40 | -2850 | - 1.55 | -0.55 | 2.87 | 523 | 15.3 | 2.57 | | 0.607 | 98 |

Note: *C* = intercept; $x_1$ = turbidity in Jtu; $x_2$ = total residue in mg/1; $x_2$ = nonfilterable residue in mg/1; $x_4$ = pH; $x_5$ = temperature in °C; $x_6$ = time of floc formation in seconds; $x_7$ = initial algal concentration in cells/ml; r = multiple correlation coefficient; *Se* = standard error of estimate in cells/ml

Table 5. Results of Standard Multiple Linear Regression Analysis

| Alum dosage (mg/l) | C | Coefficient of variable | | | | | | | r | Se |
|---|---|---|---|---|---|---|---|---|---|---|
| | | $x_1$ | $x_2$ | | $x_4$ | $x_5$ | $x_6$ | $x_7$ | | |
| 10 | -12,834 | 7.43 | 0.96 | 4.83 | 1148 | 101.7 | 1.58 | 0.274 | 0.789 | 615 |
| 20 | - 3,907 | 2.81 | -0.45 | 5.94 | 195 | 65.5 | 2.09 | 0.185 | 0.759 | 413 |
| 25 | - 1,697 | 0.22 | 1.41 | 4.43 | - 92 | 47.2 | -0.42 | 0.150 | 0.780 | 343 |
| 30 | 6,034 | -10.24 | 3.59 | 6.08 | -1081 | 7.8 | -0.46 | 0.091 | 0.677 | 345 |
| 40 | 3,513 | - 1.61 | -0.47 | 2.92 | 632 | -18.3 | -2.96 | 0.007 | 0.618 | 100 |

Notations are the same as those in table 4

$x_2$ = total residue in mg/l
$x_3$ = nonfilterable residue in mg/l
$x_4$ = pH of untreated water
$x_5$ = water temperature in degrees Celsius
$x_6$ = time of floc formation in seconds
$x_7$ = initial algae concentration in cells/ml
$C_i$ = the intercept of the regression curve in cells/ml
$C_{1i} .. C_{7i}$ = coefficients of the corresponding independent variables

The intercepts and regression coefficients are tabulated in table 5. Applying the intercept and regression coefficients in either table 4 or 5 to equation 3 would provide an estimate, for a certain alum dosage, of the algae concentration remaining in the treated water. However, the use of seven variables would appear to be impractical.

It would seem that better use could be made of the three most important variables previously mentioned and included in table 4. The three independent variables and alum dosage for all observed data were used with multiple regression techniques to develop the following expression:

$$Z = 1132 - 104.85\, u_1 + 0.23\, u_2 + 1.80\, u_3 + 33.25\, u_4 \quad (4)$$

where

$Z$ = the algae concentration in the treated water in cells/ml
$u_1$ = alum dosage in mg/l
$u_2$ = initial algae concentration in cells/ml
$u_3$ = nonfilterable residue in mg/l
$u_4$ = water temperature in degrees Celsius

The coefficient of correlation was 0.857 and the standard error of estimate was 896 cells/ml.

When we let $r_{zu1}$, $r_{zu2}$, $r_{zu3}$, and $r_{zu4}$ represent the correlation coefficients of the dependent variable and a corresponding independent variable, the values obtained were 0.800, 0.302, 0.028, and —0.069, respectively. This suggests that only alum dosage and possibly the initial algae concentration significantly affect the removal of algae from water in the coagulation process. Further, if we omit the two variables $u_3$ and $u_4$ from equation 4, the expression becomes essentially the same as equation 1. Therefore, for Illinois River conditions in the vicinity of Peoria, the best estimate for algal removal by alum coagulation can be made by using equation 1. It may be written as:

$$\%\ \textit{algal removal} — 36.54 + 3.2352\ (\textit{alum dosage}) — 0.04256\ (\textit{alum dosage})^2$$

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## Appendix A. Algal Counts of Runs 1 through 25

(Values multiplied by a factor of 165 give concentrations in organisms per milliliter)

| | Run 1 | | | | | | | Run 2 | | | | | | | Run 3 | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Raw | Alum dosage (*mg/l*) | | | | | | Raw | Alum dosage (*mg/l*) | | | | | | Raw | Alum dosage (*mg/l*) | | | | | |
| Algal genus | water | 0 | 10 | 20 | 25 | 30 | 40 | water | 0 | 10 | 20 | 25 | 30 | 40 | water | 0 | 10 | 20 | 25 | 30 | 40 |
| Blue-green algae | | | | | | | | | | | | | | | | | | | | | |
| *Anabaena* | | | | | | | | | | | | | | | | | | | | | |
| *Anacystis* | | | | | | | | | | | | | | | | | | | | | |
| *Aphanizomenon* | | | | | | | | | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | |
| Green algae | | | | | | | | | | | | | | | | | | | | | |
| *Actinastrum* | 4 | | | 1 | 1 | | | 1 | 1 | 1 | 1 | 2 | 1 | | 2 | 3 | | | | | |
| *Ankistrodesmus* | 1 | | 2 | | | | | 1 | | | | | | | | | | | | 1 | |
| *Chlorella* | | | | | | | | 1 | 1 | 1 | | | | | | | | | | | |
| *Chlorosarcina* | | | | | | | | | | | | | | | | | | | | | |
| *Closteridium* | | | | | | | | | | | | | | | | | | | | | |
| *Coelastrum* | 1 | | | | | | | | 1 | | | | | | | | | | | | |
| *Dispora* | | | | | | | | | | | | | | | | | | | | | |
| *Gloeocystis* | | | | | 1 | | | | | | | 1 | | | | | | | 1 | | |
| *Mougeotia* | | | | | | | | | | | | | | | | | | | | | |
| *Oocystis* | | | | 1 | | | | | | | | | | | 1 | 1 | | | | | |
| *Pediastrum* | 3 | 1 | | | | | | 3 | 1 | 1 | 2 | | | | | | | | | 2 | |
| *Platydorina* | | | | | | | | | | | | | | | | | | | | | |
| *Scenedesmus* | 1 | 3 | 2 | | | | | 2 | 1 | 1 | 1 | | | | 3 | 3 | 1 | | | | |
| *Spirogyra* | 1 | | | | | | | | | | | | | | | | | | | | |
| *Ulothrix* | | | | | | | | | | | | | | | | | | | | | |
| Diatoms | | | | | | | | | | | | | | | | | | | | | |
| *Asterionella* | | | | | | | | | | | | | | | | 1 | 1 | | | | |
| *Caloneis* | | | | | | | | | | | | | | | | | | | | | |
| *Cocconeis* | | | | | | | | | | | | | | | | | | | | | |
| *Cymbella* | | | | | | | | | | | | | | | | | | | | | |
| *Cyclotella* | 15 | 13 | 5 | 3 | | | | 16 | 11 | 7 | 3 | | | | 17 | 8 | 2 | 2 | 1 | | |
| *Diatoma* | 1 | | | | | | | 1 | | | | | | | | | | | | | |
| *Fragilaria* | | | | | | | | | | | | | | | | | | | | | |
| *Gyrosigma* | | | | | | | | | | | | | | | | | | | | | |
| *Melosira* | | | | | | | | | | | | | | | | 2 | | | | | |
| *Navicula* | 6 | 2 | | | | | | 3 | 3 | | | | | | 2 | | 1 | 1 | | | |
| *Neidium* | | | | | | | | | | | | | | | | | | | | | |
| *Nitzschia* | | | | | | | | | | | | | | | | | | | | | |
| *Stephanodiscus* | | 1 | | | | | | | | | | | | | 5 | 1 | 3 | 1 | 1 | | |
| *Surirella* | 1 | 1 | 1 | | | | | | 2 | 2 | | | | | 2 | | | | | | |
| *Synedra* | 1 | | | | | | | | | | | | | | 1 | | | | | | |
| *Tabellaria* | 2 | | | | | | | | | | | | | | | | | | | | |
| Pigmented flagellates | | | | | | | | | | | | | | | | | | | | | |
| *Chlamydomonas* | | | | | | | | | | | | | | | | | | | | | |
| *Euglena* | 3 | 6 | 3 | | 1 | | | 4 | 2 | 2 | | | 1 | | 5 | 2 | 1 | 1 | 1 | 1 | 1 |
| *Lepocinclis* | | | | | | | | | | | | | | | | | | | | | |
| *Phacus* | | | | | | | | | | | | | | | | | | | | | |
| Total | 41 | 27 | 13 | 5 | 3 | 0 | 0 | 32 | 23 | 15 | 7 | 3 | 2 | 0 | 39 | 22 | 10 | 6 | 5 | 5 | 1 |
| % Reduction | | 34.1 | 68.3 | 87.8 | 92.7 | 100 | 100 | | 28.1 | 51.6 | 78.1 | 90.6 | 93.8 | 100 | | 43.6 | 74.4 | 84.6 | 87.2 | 87.2 | 97.4 |

**Appendiix A (Contiinued)**

(Values multiplied by a factor of 165 give (:oncentrations in organisms per milliliter)

| | **Run 4** | | | | | | | **Run 5** | | | | | | | **Run 6** | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Raw | Alum dosage (*mg/l*) | | | | | | Raw | Alum dosage (*mg/l*) | | | | | | Raw | Alum dosage (*mg/l*) | | | | | |
| Algal genus | water | 0 | 10 | 20 | 25 | 30 | 40 | water | 0 | 10 | 20 | 25 | 30 | 40 | water | 0 | 10 | 20 | 25 | 30 | 40 |
| Blue-green algae | | | | | | | | | | | | | | | | | | | | | |
| *Anabaena* | | | | | | | | | | | | | | | | | | | | | |
| *Anacystis* | | | | | | | | | | | | | | | | | | | | | |
| *Aphanizomenon* | | | | | | | | | | | | | | | 2 | | | | | | |
| Green algae | | | | | | | | | | | | | | | | | | | | | |
| *Aclinastrum* | | 3 | | | | | | 1 | | | 1 | | | | | | | 1 | | | |
| *Ankistrodesmus* | 2 | 2 | 2 | | 1 | | | 4 | 4 | | | | | | 3 | 2 | 1 | | | 1 | |
| *Chlorella* | 2 | | | | | | | 3 | 2 | 1 | | | | | 7 | 4 | 1 | | | | |
| *Chlorosarcina* | | | | | | | | | | | | | | | | | | | | | |
| *Closteridium* | | | | | | | | | | | | | | | | | | | | | |
| *Coelastrum* | | | | | | | | | | | | | | | | | | | | | |
| *Dispora* | | | | | | | | | | | | | | | | | | | | | |
| *Gloeocystis* | | | | | 2 | | | | | | | | | | | 1 | 1 | 1 | | | |
| *Mougeotia* | | | | | | | | | | | | | | | | | | | | | |
| *Oocystis* | | | | | | | | | | | | | | | 1 | | | | | | |
| *Pediaslrum* | | | | | | | | 2 | 1 | | 1 | 1 | | | 1 | 1 | 1 | | | | |
| *Platydorina* | | | | | | | | | | | | | | | | | | | | | |
| *Scenedesmus* | 2 | 3 | 1 | | | | | 1 | 1 | 4 | 3 | 2 | 1 | | 3 | 3 | 3 | 1 | 4 | 1 | |
| *Spirogyra* | | | | | | | | | | | | | | | | | | | | | |
| *Ulothrix* | | | | | | | | | | | | | | | | | | 1 | | | |
| Diatoms | | | | | | | | | | | | | | | | | | | | | |
| *Asterionella* | | 1 | | | | | | | | | | | | | | | | | | | |
| *Caloneis* | | | | | | | | | | | | | | | | | | | | | |
| *Cocconeis* | | | | | | | | | | | | | | | | | | | | | |
| *Cymbella* | | | | | | | | | | | | | | | | 1 | | | | | |
| *Cyclotella* | 27 | 7 | 3 | 4 | | | | 15 | 13 | 7 | 3 | 3 | 3 | 1 | 31 | 14 | 5 | 5 | 5 | 1 | |
| *Diatoma* | | | | | | | | | | 1 | | | | | 1 | | | | | | |
| *Fragilaria* | | | | | | | | 4 | | | | | | | | | | | | | |
| *Gyrosigma* | | | | | | | | | | | | | | | | | | | | | |
| *Melosira* | 2 | | | | | | | 2 | 2 | 2 | 1 | | | | 1 | | | | | | |
| *Navicula* | | | | | | | | 3 | 3 | | | 1 | | | 5 | | | 1 | | | |
| *Neidium* | | | | | | | | | | | | | | | | | | | | | |
| *Nitzschia* | | | | | | | | | | | | | | | | 2 | | | | | |
| *Stephanodiscus* | | | 2 | | | | | | | | | | | | | 1 | | | | | |
| *Surirella* | | | | | | | | | | 1 | | | | | | | | | | | |
| *Synedra* | | | | | | | | 1 | | | | | | | | | | | | | |
| *Tabellaria* | | | | | | | | | | | | | | | | | | 1 | | | |
| Pigmented flagellates | | | | | | | | | | | | | | | | | | | | | |
| *Chlamydomonas* | | | | | | | | | | | | | | | | | | | | | |
| *Euglena* | 2 | 2 | 3 | 3 | | | | 3 | 3 | 3 | 3 | 1 | | | 2 | 2 | | | | | |
| *Lepocinclis* | | | | | | | | | | | | | | | | | | | | | |
| *Phacus* | | | | | | | | | | | | | | | | | | | | | |
| Total | 37 | 18 | 11 | 7 | 3 | 0 | 0 | 39 | 29 | 19 | 12 | 8 | 4 | 1 | 57 | 31 | 12 | 11 | 9 | 3 | 0 |
| % Reduction | | 51.4 | 70.3 | 81.1 | 91.9 | 100 | 100 | | 25.7 | 51.3 | 69.2 | 79.5 | 89.8 | 97.4 | | 45.6 | 79.0 | 80.7 | 84.2 | 94.7 | 100 |

## Append ix A (Continued)

**(Values multiplied by a factor of 165 give concentrations in organisms per milliliter)**

| | **Run 7** | | | | | | | **Run 8** | | | | | | | **Run 9** | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Raw** | | **Alum dosage (*mg/l*)** | | | | | **Raw** | | **Alum dosage (*mg/l*)** | | | | | **Raw** | | **Alum dosage (*mg/l*)** | | | | |
| **Algal genus** | **water** | **0** | **10** | **20** | **25** | **30** | **40** | **water** | **0** | **10** | **20** | **25** | **30** | **40** | **water** | **0** | **10** | **20** | **25** | **30** | **40** |
| **Blue-green algae** | | | | | | | | | | | | | | | | | | | | | |
| *Anabaena* | | | | | | | | 1 | 1 | 1 | 1 | | | | | | | | | | |
| *Anacystis* | | | | | | | | | | | | | | | | | | | | | |
| *Aphanizomenon* | | | | | | | | | 1 | | | | | 1 | 1 | 1 | 1 | | 1 | 3 | |
| **Green algae** | | | | | | | | | | | | | | | | | | | | | |
| *Actinastrum* | | | | | | | | | | | | | | | 5 | | | | | | |
| *Ankistrodesmus* | 1 | 1 | | | | 1 | | | | 2 | | 1 | | | | 2 | | | | 1 | |
| *Chlorella* | 4 | 3 | 1 | | | | | | | 1 | | | | | | | 3 | | | | |
| *Chlorosarcina* | | | | | | | | | | | | | | | | | | | | | |
| *Closteridium* | | | | | | | | | | | | | | | | | | | | | |
| *Coelastrum* | | | | | | | | | | | | | | | | | | | | | |
| *Dispora* | | | | | | | | | | | | | | | | | | | | | |
| *Gloeocystis* | | | | | | | | 2 | 1 | 1 | | | | | | | | | | | |
| *Mougeotia* | | | 2 | | | | | | | | | | | | | | | | | | |
| *Oocystis* | | | | | | | | | | 1 | | | | | | | | | | | |
| *Pediastrum* | 1 | 1 | | | | | | 1 | 1 | 1 | | | 1 | | | 1 | | | | | |
| *Platydorina* | | | | | | | | | | | | | | | | | | | | | |
| *Scenedesmus* | 2 | 3 | | | | | | | 1 | | 1 | 1 | | | | | | | | | |
| *Spirogyra* | | | | | | | | | | | | | | | | | | | | | |
| *Ulothrix* | | | | | | | | 1 | | | | | | | | | | | | | |
| **Diatoms** | | | | | | | | | | | | | | | | | | | | | |
| *Asterionella* | 1 | | | | | | | | | | | | | | | | | | | | |
| *Caloneis* | 2 | | | | | | | | | | | | | | | | | | | | |
| *Cocconeis* | | | | | | | | | 1 | | | | | | | | | | | | |
| *Cymbella* | | | | | | | | | | | | | | | | | | | | | |
| *Cyclotella* | 6 | 3 | 3 | | | 1 | | 21 | 7 | 4 | 3 | | | | 18 | 16 | 4 | 3 | | | |
| *Diatoma* | | | | | | | | | | | | | | | 1 | | | | | | |
| *Fragilaria* | | | | | | | | | | | | | | | | | | | | | |
| *Gyrosigma* | | | | | | | | | | | | | | | | | | | 1 | | |
| *Melosira* | 3 | | | | | | | 2 | 2 | 1 | | | | | 2 | 2 | 2 | | | | |
| *Navicula* | 3 | 1 | | | 1 | | | 4 | 2 | | | | | | 3 | | | | | | |
| *Neidium* | | | | | | | | | | | | | | | | | | | | | |
| *Nitzschia* | | | 1 | | | | | | | | | | | | | | | | | | |
| *Stephanodiscus* | | | | | | | | 1 | | | | | | | 2 | 2 | | | | | |
| *Surirella* | | | | | | | | | 1 | | | | | | | | | | | | |
| *Synedra* | | | | | | | | | | | | | | | 1 | | | | | | |
| *Tabellaria* | 3 | | | | | | | | | | | | | | | | | | | | |
| **Pigmented flagellates** | | | | | | | | | | | | | | | | | | | | | |
| *Chlamydomonas* | | | | | | | | | | | | | | | | | | | | | |
| *Euglena* | 4 | 5 | | | | | | 3 | 3 | 1 | | 1 | | 1 | 2 | 2 | 2 | | | | |
| *Lepocinclis* | | | | | | | | | | | | | | | | | | | | | |
| *Phacus* | 1 | | | | | | | | | | | | | | | | | | | | |
| **Total** | 31 | 17 | 7 | 0 | 1 | 2 | 0 | 36 | 21 | 13 | 5 | 3 | 1 | 2 | 35 | 26 | 12 | 3 | 2 | 4 | 0 |
| **% Reduction** | | 45.2 | 77.4 | 100 | 96.8 | 93.5 | 100 | | 41.7 | 63.9 | 86.1 | 91.7 | 97.2 | 94.5 | | 25.7 | 65.7 | 91.4 | 94.3 | 88.6 | 100 |

### Appendix A (Continued)

(Values multiplied by a factor of 165 give concentrations in organisms per milliliter)

| Algal genus | Run 10 Raw water | Run 10 Alum dosage (mg/l) 0 | 10 | 20 | 25 | 30 | 40 | Run 11 Raw water | Run 11 Alum dosage (mg/l) 0 | 10 | 20 | 25 | 30 | 40 | Run 12 Raw water | Run 12 Alum dosage (mg/l) 0 | 10 | 20 | 25 | 30 | 40 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Blue-green algae | | | | | | | | | | | | | | | | | | | | | |
| *Anabaena* | | | | | | | | | | | | | | | 2 | 1 | | | | | |
| *Anacystis* | | | | | | | | | | | | | | | | | | | | | |
| *Aphanizomenon* | | 1 | | 1 | | | | | | 1 | | | | | | | | | | | |
| Green algae | | | | | | | | | | | | | | | | | | | | | |
| *Actinastrum* | | | | | | | | | | 2 | 1 | | | | | 1 | | | 1 | | |
| *Ankistrodesmus* | | 3 | | | | | | | | | | 1 | | | 1 | | | | | | |
| *Chlorella* | | | | | 1 | 1 | | 2 | | 5 | 1 | | | | | | | | | | |
| *Chlorosarcina* | | | | | | | | | | | | | | | | | | | | | |
| *Closteridium* | | | | | | | | | | | | | | | | | | | | | |
| *Coelastrum* | | | | | | | | | 2 | | | | | | | | | | | | |
| *Dispora* | | | | | | | | | | | | | | | | | | | | | |
| *Gloeocystis* | 2 | | | | | | | 2 | 1 | | | 1 | | | | | | | | | |
| *Mougeotia* | | | | | | | | | | | | | | | | | | | | | |
| *Oocystis* | 1 | | 1 | | | | | 1 | | | | | | | | | | | | | |
| *Pediastrum* | | | 1 | 1 | | | | | 2 | | | | | | | | 1 | 1 | | | |
| *Platydorina* | | | | | | | | | 1 | | | | | | | | | | | | |
| *Scenedesmus* | 1 | | | | | 1 | | 1 | | | | | | | 2 | | | 1 | 1 | | |
| *Spirogyra* | | | | | | | | | | | | | | | | | | | | | |
| *Ulothrix* | | | | | | | | | | | | | | | | 2 | | | | | |
| Diatoms | | | | | | | | | | | | | | | | | | | | | |
| *Asterionella* | | | | | | | | | | | | | | | | | | | | | |
| *Caloneis* | | | | | | | | | | | | | | | 1 | | | | | | |
| *Cocconeis* | | | | | | | | | | | | | | | | | | | | | |
| *Cymbella* | | | | | | | | | | | | | | | | | | | | | |
| *Cyclotella* | 14 | 8 | 4 | 1 | 3 | | | 17 | 13 | 3 | 2 | 2 | | | 5 | 5 | 1 | | | | |
| *Diatoma* | | | | | | | | | | | | | | | | | | | | | |
| *Fragilaria* | | | | | | | | | | | | | | | | | | | | | |
| *Gyrosigma* | | | | | | | | | | | | | | | | | | | | | |
| *Melosira* | 3 | 2 | | | | | | | 1 | | 2 | | | | 1 | | 1 | | | 1 | |
| *Navicula* | 1 | | 2 | | | | | 1 | 2 | | | | | | 1 | | 2 | | | | |
| *Neidium* | | | | | | | | | | | | | | | | | | | | | |
| *Nitzschia* | | | | | | | | | | | | | | | | | | | | | |
| *Stephanodiscus* | 2 | | | | | | | | | | | | | | | | | | | | |
| *Surirella* | | | | | | | | 1 | | | | | | | 1 | | | | | | |
| *Synedra* | | | | 1 | | | | 1 | | | | | | | | | | | | | |
| *Tabellaria* | | | | | | | | 1 | | | | | | | | | | | | | |
| Pigmented flagellates | | | | | | | | | | | | | | | | | | | | | |
| *Chlamydomonas* | | | | | | | | | | | | | | | | | | | | | |
| *Euglena* | 4 | 2 | | | 1 | | 1 | 2 | 2 | 2 | 2 | | | | 1 | 1 | 2 | 1 | 2 | 1 | 1 |
| *Leponcinclis* | | | | | | | | | | | | | | | | | | | | | |
| *Phacus* | | | | | | | | 1 | | | | | | | | | | | | | |
| Total | 28 | 17 | 8 | 4 | 5 | 2 | 1 | 30 | 24 | 13 | 8 | 4 | 0 | 0 | 15 | 10 | 7 | 3 | 4 | 2 | 1 |
| % Reduction | | 39.3 | 71.4 | 85.7 | 83.2 | 92.9 | 96.4 | | 20.0 | 56.7 | 73.3 | 86.7 | 100 | 100 | | 33.3 | 53.3 | 80.0 | 73.3 | 86.7 | 93.3 |

## Appendix A (Continued)

(Values multiplied by a factor of 165 give concentrations in organisms per milliliter)

| | Run 13 | | | | | | | Run 14 | | | | | | | Run 15 | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Raw | Alum dosage (*mg/l*) | | | | | | Raw | Alum dosage (*mg/l*) | | | | | | Raw | Alum dosage (*mg/l*) | | | | | |
| Algal genus | water | 0 | 10 | 20 | 25 | 30 | 40 | water | 0 | 10 | 20 | 25 | 30 | 40 | water | 0 | 10 | 20 | 25 | 30 | 40 |
| Blue-green algae | | | | | | | | | | | | | | | | | | | | | |
| *Anabaena* | | | | | | | | | | | | | | | | | | | | | |
| *Anacystis* | | | | | | | | | | | | | | | | | | | | | |
| *Aphanizomenon* | | | | | | | | 1 | 1 | | | | | | | | | | | | |
| Green algae | | | | | | | | | | | | | | | | | | | | | |
| *Actinastrum* | | | | | | | | | | | | | | | | | | | | | |
| *Ankistrodesmus* | | | | | | | | | | | | 1 | | | 1 | | | | | | |
| *Chlorella* | | | | | | | | 3 | | | | | | | | | | | | | |
| *Chlorosarcina* | | | | | | | | | | | | | | | | | | | | | |
| *Closteridium* | | | | | | | | | | | | | | | | | | | | | |
| *Coelastrum* | | | | | | | | | | | | | | | | | | | | | |
| *Dispora* | | | | | | | | | | | | | | | | | | | | | |
| *Gloeocystis* | | | | | | | | | | | | | | | 1 | 1 | 1 | | | | |
| *Mougeotia* | | | | | | | | | | | | | | | | | | | | | |
| *Oocystis* | | | | | | | | | | | | | | | | | | | | | |
| *Pediastrum* | | | 1 | | | | | | | | | | | | | | | | | | |
| *Platydorina* | | | | | | | | | | | | | | | | | | | | | |
| *Scenedesmus* | 1 | | | | | | | 1 | 1 | | | 1 | | | 1 | | | | | | |
| *Spirogyra* | | | | | | | | | | | | | | | | | | | | | |
| *Ulothrix* | | | | | | | | | | | | | | | | | | | | | |
| Diatoms | | | | | | | | | | | | | | | | | | | | | |
| *Asterionella* | | | | | | | | | | | | | | | | | | | | | |
| *Caloneis* | | | | | | | | | 1 | | | | | | | | | | | | |
| *Cocconeis* | | | | | | | | 5 | | | | | | | 1 | | | | | | |
| *Cymbella* | | | | | | | | | | | | | | | | | | | | | |
| *Cyclotella* | 13 | 5 | 3 | 1 | 2 | | | 19 | 14 | 5 | 3 | | | | 29 | 27 | 3 | 3 | 1 | | |
| *Diatoma* | | | | | | | | | | | | | | | | | | | | | |
| *Fragilaria* | | | | | | | | | | | | | | | | | | | | | |
| *Gyrosigma* | | | | | | | | | | | | | | | | | | | | | |
| *Melosira* | 1 | | | 2 | | | | 4 | 2 | 1 | | | | | 2 | 2 | 1 | 1 | | | |
| *Navicula* | 4 | 4 | | | | | | 2 | 2 | | | | | | 3 | 3 | 1 | | | | |
| *Neidium* | | | | | | | | | | | | | | | | | | | | | |
| *Nitzschia* | | | | | | | | | | | | | | | | | | | | | |
| *Stephanodiscus* | | | | | | | | | | | | | | | | | | | | | |
| *Surirella* | 1 | 1 | | | | | | 1 | | | | | | | 1 | | | | | | |
| *Synedra* | 1 | | | | | | | | | | | 1 | | | | | | | | | |
| *Tabellaria* | | 1 | | | | | | | | | | | | | 1 | 1 | | | | | |
| Pigmented flagellates | | | | | | | | | | | | | | | | | | | | | |
| *Chlamydomonas* | | | | | | | | | | | | | | | | | | | | | |
| *Euglena* | | 3 | 1 | | | | | | 1 | 1 | 1 | | | | 1 | 1 | 1 | 1 | 1 | | |
| *Lepocinclis* | | | | | | | | | | | | | | | | | | | | | |
| *Phacus* | | | | | | | | | | | | | | | | | | | | | |
| Total | 21 | 14 | 5 | 3 | 2 | 0 | 0 | 36 | 22 | 7 | 4 | 3 | 0 | 0 | 41 | 35 | 7 | 5 | 2 | 0 | 0 |
| % Reduction | | 33.3 | 76.2 | 85.7 | 90.5 | 100 | 100 | | 38.9 | 80.6 | 88.9 | 91.7 | 100 | 100 | | 14.6 | 82.9 | 87.8 | 95.1 | 100 | 100 |

## Appendiix A (Continued)

(Values multiplied by a factor of 165 give concentrations in organisms **per** milliliter)

| | Run 16 | | | | | | | Run 17 | | | | | | | Run 18 | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Raw | Alum dosage (*mg/l*) | | | | | | Raw | Alum dosage (*mg/l*) | | | | | | Raw | Alum dosage (*mg/l*) | | | | | |
| Algal genus | water | 0 | 10 | 20 | 25 | 30 | 40 | water | 0 | 10 | 20 | 25 | 30 | 40 | water | 0 | 10 | 20 | 25 | 30 | 40 |
| Blue-green algae | | | | | | | | | | | | | | | | | | | | | |
| *Anabaena* | | | | | | | | | | | | | | | | | | | | | |
| *Anacystis* | | | | | | | | | | | | | | | | | | | | | |
| *Aphanizomenon* | | | | | | | | 1 | | | | | | | | | | | | | |
| Green algae | | | | | | | | | | | | | | | | | | | | | |
| *Actinastrum* | | | 1 | | | | | | | | | | | | | | | | | | |
| *Ankistrodesmus* | 1 | | | | | | | | | | | | | | | | | | | | |
| *Chlorella* | 1 | 1 | 1 | | | | | 1 | 1 | 3 | | 1 | | | | | | | | | |
| *Chlorosartina* | | | | | | | | | | | | | | | | | | | | | |
| *Closteridium* | | | | | | | | | | | | | | | | | | | | | |
| *Coelastrum* | | | | | | | | | | | | | | | | | | | | | |
| *Dispora* | | | | | | | | | | | | | | | | | | | | | |
| *Gloeocystis* | | | | | | | | 1 | 1 | | | | 2 | | 1 | | | | | | |
| *Mougeotia* | | | | | | | | | | | | | | | | | | | | | |
| *Oocystis* | | | | | | | | | | | | | | | 1 | | | | | | |
| *Pediastrum* | | | | | | | | 1 | 1 | | | | 1 | | | | | | | | |
| *Platydorina* | | | | | | | | | | | | | | | | | | | | | |
| *Scenedesmus* | | 1 | | | | | | 1 | 2 | 1 | 3 | | | | | 1 | 1 | 1 | | | |
| *Spirogyra* | | | | | | | | | | | | | | | | | | | | | |
| *Ulothrix* | | | | | | | | | | | | | | | | | | | | | |
| Diatoms | | | | | | | | | | | | | | | | | | | | | |
| *Asterionella* | | | | | | | | | | | | | | | | | | | | | |
| *Caloneis* | | | | | | | | | | | | | | | | | | | | | |
| *Cocconeis* | | | | | | | | | | | | | | | | | | | | | |
| *Cymbella* | | | | | | | | | | | | | | | | | | | | | |
| *Cyclotella* | 20 | 19 | 5 | 5 | 3 | | | 48 | 44 | 10 | 7 | 7 | | | 21 | 11 | 3 | 1 | 1 | | |
| *Diatoma* | 1 | | | | | | | | | | | | | | | | | | | | |
| *Fragilana* | | | | | | | | | | | | | | | | | | | | | |
| *Gyrosigma* | | 1 | | | | | | | | | | | | | | | | | | | |
| *Melosira* | 3 | | | | | | | 1 | 1 | | | | | | 2 | | 1 | | 1 | | |
| *Navicula* | 3 | 3 | 2 | | 2 | 1 | | 3 | 3 | 1 | 1 | | 1 | | 4 | 3 | | | | | |
| *Neidium* | | | | | | | | | | | | | | | | | | | | | |
| *Nitzschia* | 1 | | | | | | | | | | | | | | | | | | | | |
| *Stephanodiscus* | | | | 1 | | | | 3 | | | | | | | 4 | | | | | | |
| *Surirella* | | 1 | | | | | | 1 | | | | | | | | | | | | | |
| *Synedra* | | | | | | | | | | | | | | | | | | | | | |
| *Tabellaria* | | | | | | | | 1 | | | | | | | | 3 | | | | | |
| Pigmented flagellates | | | | | | | | | | | | | | | | | | | | | |
| *Chlamydomonas* | | | | | | | | | | | | | | | | | | | | | |
| *Euglena* | 1 | 1 | 1 | | | | | 2 | 1 | | 2 | 2 | 3 | | 2 | 3 | 2 | 1 | 1 | | |
| *Lepocinclis* | | | | | | | | | | | | | | | | | | | | | |
| *Phacus* | | | | | | | | | | | | | | | | | | | | | |
| Total | 31 | 21 | 10 | 6 | 5 | 1 | 0 | 64 | 54 | 15 | 13 | 10 | 7 | 0 | 35 | 21 | 7 | 3 | 3 | 0 | 0 |
| % Reduction | | 32.3 | 67.8 | 80.7 | 83.9 | 96.8 | 100 | | 15.6 | 76.6 | 79.7 | 84.4 | 89.1 | 100 | | 40.0 | 80.0 | 91.4 | 91.4 | 100 | 100 |

## Appendiix A (Continued)

(Values multiplied by a factor of 165 give concentrations in organisms per milliliter)

| | Run 19 | | | | | | | Run 20 | | | | | | | Run 21 | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Raw | Alum dosage *(mg/l)* | | | | | | Raw | Alum dosage *(mg/l)* | | | | | | Raw | Alum dosage *(mg/l)* | | | | | |
| Algal genus | water | 0 | 10 | 20 | 25 | 30 | 40 | water | 0 | 10 | 20 | 25 | 30 | 40 | water | 0 | 10 | 20 | 25 | 30 | 40 |
| Blue-green algae | | | | | | | | | | | | | | | | | | | | | |
| *Anabaena* | | | | | | | | | | 1 | | | | | | | | | | | |
| *Anacystis* | | | | | | | | | | | | | | | | | | | | | |
| *Aphanizomenon* | | 1 | 1 | | | | | | | | | | | | | | | | | | |
| Green algae | | | | | | | | | | | | | | | | | | | | | |
| *Actinastrum* | | 1 | 1 | | | | | | | | | | | | | | | | | | |
| *Ankistrodesmus* | 1 | | | | | | | 1 | 1 | | | | | | | | | | 1 | | |
| *Chlorella* | | | | | | | | 2 | 2 | 2 | | | | | | | | | | | |
| *Chlorosarcina* | | | | | | | | | | | | | | | | | | | | | |
| *Closteridium* | | | | | | | | | | | | | | | | | | | | | |
| *Coelastrum* | | | | | | | | | | | | | | | | | | | | | |
| *Dispora* | | | | | | | | | | | | | | | | | | | | | |
| *Gloeocystis* | 2 | | | | | | | 4 | 3 | | 1 | | | | | 1 | | 1 | | | |
| *Mougeotia* | | | | | | | | | | | | | | | | | | | | | |
| *Oocystis* | | 1 | | | | | | 1 | 1 | | | | | | 2 | | | | | | |
| *Pediastrum* | 1 | | | | | | | | | | | | | | | | | | | | |
| *Platydorina* | | | | | | | | | | | | | | | | | | | | | |
| *Scenedesmus* | 2 | | | | | | | 2 | 1 | | 2 | | | | | 2 | | | 1 | | |
| *Spirogyra* | | | | | | | | | | | | | | | | | | | | | |
| *Ulothrix* | | | | | | | | | | | | | | | | | | | | | |
| Diatoms | | | | | | | | | | | | | | | | | | | | | |
| *Asterionella* | | | | | | | | | | | | | | | | | | | | | |
| *Caloneis* | | | | | | | | | | | | | | | | | | | | | |
| *Cocconeis* | | | | | | | | | | | | | | | | 1 | | | | | |
| *Cymbella* | | | | | | | | | | | | | | | | | | | | | |
| *Cyclotella* | 34 | 14 | 8 | 8 | 5 | | | 14 | 5 | 5 | | 4 | | | 38 | 17 | 16 | 10 | 4 | 2 | |
| *Diatoma* | | | | | | | | | | | | | | | | | | | | | |
| *Fragilaria* | | | | | | | | | | | | | | | | | | | | | |
| *Gyrosigma* | | | | | | | | 1 | | | | | | | 1 | | | | | | |
| *Melosira* | | 5 | 1 | | | | | 2 | 1 | | 3 | | | | 3 | 1 | 1 | 1 | | | |
| *Navicula* | 2 | | | | | | | | | | | | | | 2 | | | 1 | 1 | | |
| *Neidium* | 1 | | | | | | | | | | | | | | | | | | | | |
| *Nitzschia* | | | | | | | | | | | | | | | | | | | | | |
| *Stephanodiscus* | 2 | | | | | | | 1 | 1 | | | | | | 2 | 2 | 2 | | | | |
| *Surirella* | | | | | | | | | | | | | | | | | | | | | |
| *Synedra* | | | | | | | | | | | | | | | | | | | | | |
| *Tabellaria* | | | | | | | | 1 | 1 | | | 1 | | | | | | | | | |
| Pigmented flagellates | | | | | | | | | | | | | | | | | | | | | |
| *Chlamydomonas* | 3 | | | | | | | | | | | | | | | | | | | | |
| *Euglena* | 2 | 2 | 1 | 1 | 1 | | | 1 | 1 | | 1 | | | | 6 | 5 | 3 | 1 | 2 | | |
| *Lepocinclis* | | 1 | | | | | | | | | | | | | | | | | | | |
| *Phacus* | | 1 | | | | | | | | | | | | | | | | | | | |
| Total | 50 | 26 | 12 | 9 | 6 | 0 | 0 | 30 | 17 | 8 | 7 | 5 | 0 | 0 | 54 | 29 | 22 | 14 | 9 | 2 | 0 |
| % Reduction | | 48.0 | 76.0 | 82.0 | 88.0 | 100 | 100 | | 43.3 | 73.3 | 76.7 | 83.3 | 100 | 100 | | 46.3 | 59.3 | 74.1 | 84.3 | 96.3 | 100 |

## Appendix A (Continued)

(Values multiplied by a factor of 165 give concentrations in organisms per milliliter)

| | **Run 22** | | | | | | | **Run 23** | | | | | | | **Run 24** | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Raw | Alum dosage (*mg/l*) | | | | | | Raw | Alum dosage (*mg/l*) | | | | | | Raw | Alum dosage (*mg/l*) | | | | | |
| Algal genus | water | 0 | 10 | 20 | 25 | 30 | 40 | water | 0 | 10 | 20 | 25 | 30 | 40 | water | 0 | 10 | 20 | 25 | 30 | 40 |
| Blue-green algae | | | | | | | | | | | | | | | | | | | | | |
| *Anabaena* | | | | | | | | | | | | | | | | | | | | | |
| *Anacyslis* | | | | | | | | | | | | | | | | | | | | | |
| *Aphanizomenon* | | | | | | | | | | | | | | | | | 1 | | | | |
| Green algae | | | | | | | | | | | | | | | | | | | | | |
| *Actinastrum* | | | | | | | | | 1 | | | 1 | | | | | | 1 | 1 | | |
| *Ankistrodesmus* | | 1 | 2 | | | | | 1 | | | | | | | | | | | | | |
| *Chlorella* | | | | | | | | | | | 3 | | 3 | | | | 3 | | | | |
| *Chlorosarcina* | | | | | | | | 1 | | | | | | | | | | | | | |
| *Closteridium* | | | | | | | | | | | | | | | | | | | | | |
| *Coelastrum* | | | | | | | | | | | | | | | | | | | | | |
| *Dispora* | | | | | | | | | | | | | | | 1 | | | | | | |
| *Gloeocystis* | 5 | | 1 | | 1 | | | | 1 | 2 | | | | | 1 | 2 | | | | | |
| *Mougeotia* | | | | | | | | | | | | | | | | | | | | | |
| *Oocystis* | | | | | | | | | | | | | | | | | | | | | |
| *Pediastrum* | | | | | | | | | | | | | | | | | 1 | | | | |
| *Platydorina* | | | | | | | | | | | | | | | | | | | | | |
| *Scenedesmus* | 1 | 1 | | | | | | 1 | 1 | | 1 | | 1 | | 1 | 3 | 1 | | 1 | | |
| *Spirogyra* | | | | | | | | | | | | | | | | | | | | | |
| *Ulothrix* | | | | | | | | | | | | | | | | | | | | | |
| Diatoms | | | | | | | | | | | | | | | | | | | | | |
| *Asterionella* | | | | | | | | | | | | | | | | | | | | | |
| *Caloneis* | | | | | | | | | | | | | | | | 1 | | | | | |
| *Cocconeis* | | | | | | | | | | | | | | | | | | | | | |
| *Cymbella* | | | | | | | | 1 | | | | | | | | | | | | | |
| *Cyclolella* | 28 | 18 | 8 | 3 | | | | 49 | 31 | 8 | 1 | 2 | | | 51 | 44 | 11 | 5 | 5 | 6 | 2 |
| *Diatoma* | | | | | | | | | | | | | | | | | | | | | |
| *Fragilaria* | | | | | | | | | | | | | | | | | | | | | |
| *Gyrosigma* | | | | | | | | | 1 | | | | | | | | | | | | |
| *Melosira* | 2 | | | | 1 | | | 3 | 2 | 2 | | 1 | 2 | | 5 | 2 | 2 | | 2 | | |
| *Navicula* | 2 | 1 | 1 | 2 | 1 | | 1 | 5 | 3 | 1 | 2 | | | | 2 | 4 | 3 | 2 | | | |
| *Neidium* | | | | | | | | | | | | | | | | | | | | | |
| *Nitzschia* | | | | | | | | | | | | | | | | | | | | | |
| *Stephanodiscus* | 3 | 1 | | | | | | | 2 | | | | | | | 2 | | | | | |
| *Surirella* | | | | | | | | | | | | | | | | | | | | | |
| *Synedra* | | 1 | | | | | | | | | | | | | 1 | | | | | | |
| *Tabellaria* | | | | | | | | | | | | 1 | | | | | | | | | |
| Pigmented flagellates | | | | | | | | | | | | | | | | | | | | | |
| *Chlamydomonas* | | | | | | | | | | | | | | | | | | | | | |
| *Euglena* | 1 | 1 | | | | | | 2 | 1 | 3 | 1 | 1 | 1 | 1 | 4 | 2 | | 1 | 1 | 1 | |
| *Lepocinclis* | | | | | | | | | | | | | | | | | | | | | |
| *Phacus* | 1 | | | | | | | 1 | | | | | | | | | | | | | |
| Total | 43 | 24 | 12 | 5 | 3 | 0 | 1 | 64 | 43 | 16 | 8 | 6 | 7 | 1 | 66 | 60 | 22 | 10 | 10 | 7 | 2 |
| % Reduction | | 44.2 | 72.1 | 88.4 | 93.0 | 100 | 97.7 | | 32.8 | 75.0 | 87.5 | 90.6 | 89.1 | 98.4 | | 9.1 | 66.7 | 84.9 | 84.9 | 89.4 | 97.0 |

## Appendix A (Concluded)

(Values multiplied by a factor of 165 give concentrations in organisms per milliliter)

### Run 25

| Algal genus | Raw water | Alum dosage (*mg/l*) 0 | 10 | 20 | 25 | 30 | 40 |
|---|---|---|---|---|---|---|---|
| Blue-green algae | | | | | | | |
| *Anabaena* | | | | | | | |
| *Anacystis* | | 1 | | | | | |
| *Aphanizomenon* | | | | | | | |
| Green algae | | | | | | | |
| *Actinastrum* | | | | | | | |
| *Ankistrodesmus* | | | | | | | |
| *Chlorella* | 1 | 1 | 1 | | | | |
| *Chlorosarcina* | | | | | | | |
| *Closteridium* | | | | | | | |
| *Coelastrum* | | | | | | | |
| *Dispora* | | | | | | | |
| *Gloeocystis* | | | | | | | |
| *Mougeotia* | | | | | | | |
| *Oocystis* | 1 | 1 | 1 | | 1 | | |
| *Pediastrum* | | | | | | | |
| *Platydorina* | | | | | | | |
| *Scenedesmus* | | 2 | 1 | | | | |
| *Spirogyra* | | | | | | | |
| *Ulothrix* | | | | | | | |
| Diatoms | | | | | | | |
| *Asterionella* | | | | | | | |
| *Caloneis* | 1 | | | | | | |
| *Cocconeis* | | | | | | | |
| *Cymbella* | | | | | | | |
| *Cyclotella* | 55 | 21 | 4 | 4 | 4 | | |
| *Diatoma* | | | | | | | |
| *Fragilaria* | | | | | | | |
| *Gyrosigma* | | | | | | | |
| *Melosira* | 2 | 2 | 2 | | | | |
| *Navicula* | 5 | 5 | 1 | 2 | | | |
| *Neidium* | | | | | | | |
| *Nitzschia* | | | | | | | |
| *Stephanodiscus* | | | | | | | |
| *Surirella* | 1 | | | | | | |
| *Synedra* | | | | | | | |
| *Tabellaria* | 1 | | | | | | |
| Pigmented flagellates | | | | | | | |
| *Chlamydomonas* | | | | | | | |
| *Euglena* | 2 | 2 | 2 | 2 | 2 | | 1 |
| *Lepocinclis* | | | | | | | |
| *Phacus* | 1 | | | | | | |
| Total | 70 | 35 | 12 | 8 | 7 | 0 | 1 |
| % Reduction | | 50.0 | 82.9 | 88.6 | 90.0 | 100 | 98.0 |

# Appendix B. Some Characteristics of Observed Algae

| Algal genus | Significance: T and odor | Sand filter | Surface water | Clean water | Polluted water | Attached | Ceusize (μ): Length | Width | Diameter | Shape | General description |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Blue-green algae** | | | | | | | | | | | |
| *Anabaena* | x | x | x | | x | | 17-90 | | 6-22 | Barrel-shaped, ovoid, cylindrical | Mobile; filamentous, solitary and planktonic in a few species; the colonial mass is soft |
| *Anacystis* | x | x | | | | | 4-8 | | 2-35 | Marble-like cells | Cells very numerous and crowded within the colonial mucilage; irregularly arranged |
| *Aphanizomenon* | x | | | | | | 5-15 | 4-6 | | Rectangular fusiform or plate-like | Filamentous, laterally jointed to one another |
| **Green algae** | | | | | | | | | | | |
| *Actinastrum* | | | x | | | | 10-32 | 1.5-6 | | Cylindrical, cigar-shaped | 4, 8, or 16 elongate cells that radiate in all directions from a common center |
| *Ankistrodesmus* | | | x | x | | | 15-150 | | 2-10 | Straight | Nonmobile; spine-like tips; *A.falcatus* is probably the one most frequently occurring in the U.S. |
| *Cklorella* | x | x | x | | x | | | | 1.5-10 | Round or ellipsoid | Unicellular, solitary, or aggregated in irregular clumps; size variable in the same habitat |
| *Chlorosarcina* | | | | x | | | | | | Spherical to subspherical | Nonmobile; colonies, compact packets; free-living or endophytic within aquatic plants |
| *Closteridium* | | | | | | | | | | Arcuate to lunate with spines | Nonmobile; solitary and free-floating; celli bearing a stout spine at either end |
| *Coelastrum* | | | x | | | | | | 3-24 | Hollow spherical, ovoid | Free-floating colony; cells compact, united by short or long process, 2, 4, 8, 16, . . . , 128 cells |
| *Dispora* | | | | x | | | 4-6 | | 3-5 | Oval, forming a fiat plate | Nonmobile; free-floating plate-like colonies, one cell in thickness; rare, found in soft water |
| *Gloeocystis* | x | | | | | x | | | 7.5-17 | Globose, ellipsoid | Colony 45-135 μ in diameter, in a gelatinous sheath |
| *Mougeotia* | | x | x | | | | 25-225 | | 3.5-24 | Cylindrical | Simple filaments, 1 or 2 branches, many species separable by zygospore shape and wall markings |
| *Oocystis* | | | x | | | | 8-52 | | 3-35 | Ovoid, ellipsoid | Unicellular in colonies.of 2-16 individuals enclosed by several generations |
| *Pedtastrum* | x | | x | | | | 15-45 | | 7-32 | Lens-shaped, perforate | Nonmobile; thick-walled aplanospores, outer half of marginal cells with 2 short projections |
| *Platydorina* | | | | | | | 10-24 | 10-24 | | Spheroid, bifiagellate | Mobile; colonies flat, twisted with 16-32 cells in one layer; horseshoe-shaped |
| *Scenedesmus* | x | | x | | x | | 7-40 | 3-9 | | Crescent-shaped, with spines | Nonmobile; colonies of 2-4-8-32 ovoid fusiform, cells lying side by side in a single series or double row |
| *Spirogyra* | x | x | x | | x | | | | 0.3-30 | Cylindrical, short | Filamentous, unbranched, straight or spirally arranged |
| *Ulothrix* | x | x | x | x | | x | 6-100 | | 5-45 | Cylindrical, girdle-shaped | Cells are united end to end, simple unbranched filaments, some free-floating |
| **Diatoms** | | | | | | | | | | | |
| *Asterionella* | x | x | | | | x | 40-130 | 1-2 | | Frustules (g)*, linear (v) | Nonmobile; cells radiate from a common center like spokes of a wheel |
| *Caloneis* | | | x | | x | | 15-120 | 4-20 | | Cigar-shaped, rectangular (g) | Cells solitary, free-floating; many species in both fresh and salt waters |
| *Cocconeis* | | | | x | | x | 11-70 | 8-40 | | Rectangular (g) | Cells transversely curved in girdle view, solitary, epiphytic |
| *Cymbella* | | x | | x | | x | 15-265 | 4-50 | | Straight or convex (v) | Cells solitary and free-floating or attached at the end of gelatinous stalks |
| *Cyclotella* | x | x | x | x | | | | | 5-80 | Drum-shaped, pronounced rim | Nonmobile; solitary or united into filamentous or zigzag colonies; widely distributed |
| *Diatoma* | x | x | | | | | 15-100 | 4-13 | | Rectangular (g), fusiform (v) | Attached side by side to form ribbons, zigzag chain; prefer cool flowing waters |
| *Fragilaria* | x | x | x | | | | 7-100 | 2-16 | | Rectangular (g), fusiform (v) | Nonmobile; attached side by side to form ribbons, zigzag chain; widely distributed in fresh water |
| *Gyrosigma* | | | x | | | | 25-240 | 5-30 | | Elliptic (g) | Solitary and free-floating, sometimes in gelatinous tubes |
| *Melosira* | x | x | x | | x | | 3-13 | | 4-25 | Capsule-like cylindrical | End to end in long filaments (g), with short marginal teeth (v) |
| *Navicula* | | x | x | x | x | | 10-170 | 4-37 | | Wedge-shaped, valves elongated | Solitary and free-floating, or aggregated into irregularly radiating clusters |
| *Neidium* | | | x | | x | | 30-200 | 10-30 | | Rectangular (g), boat-shaped (v) | Solitary and free-floating; in rivers and lakes |
| *Nitzschia* | | x | | x | x | | 20-500 | 4-26 | | Rectangular (g), linear elliptic (v) | Solitary and free-floating, or band-like within gelatinous tubes, elongated |
| *Stephanodiscus* | x | x | x | | x | | | | 8-80 | Discoid, drum-shaped, cylindrical | Solitary and free-floating; common in hard water lakes |
| *Surirella* | | | | x | x | | 18-350 | 17-80 | | Boat-shaped, rectangular (g), ovoid (v) | Solitary and free-floating; found in fresh, brackish, and salt waters |
| *Synedra* | x | x | x | x | | | 10-500 | 2-16 | | Needle-shaped in both views | Frustules elongated and straight, with capitate poles, single or in clumps; passes through sand filter |
| *Tabellaria* | x | x | x | | | | 12-140 | 3-16 | | Tabular (g), elongated (v) | Frustules forming zigzag or straight filaments; widely distributed |
| **Flagellates** | | | | | | | | | | | |
| *Chlamydomonas* | x | | | | x | | | | 5-10 | Ovoid, spherical, fusiform | Mobile; unicellular, passes through slow sand filter |
| *Euglena* | x | | x | x | x | | 55-490 | 6-55 | | Spindle-shaped, elongated | Mobile; flexible cell wall, uninucleate flagellated; one or more centractile vacuoles; passes through sand filter |
| *Lepocinclis* | | | | | x | | 30-38 | 15-18 | | Ovoid, circular, or pear-shaped | Mobile; a short, sharp projection from the posterior end; rigid and fixed in shape when swimming |
| *Phacus* | | | | x | x | x | 25-170 | 13-70 | | Pancake-like, flattened | Mobile; solitary, often twisted along the longitudinal axis, with a tailpiece |

* *For diatoms: g = girdle view; v = valve view*