Environmental & Water Quality Operational Studies

TECHNICAL REPORT E-80-1

A COMPILATION OF COMMON ALGAL CONTROL AND MANAGEMENT TECHNIQUES

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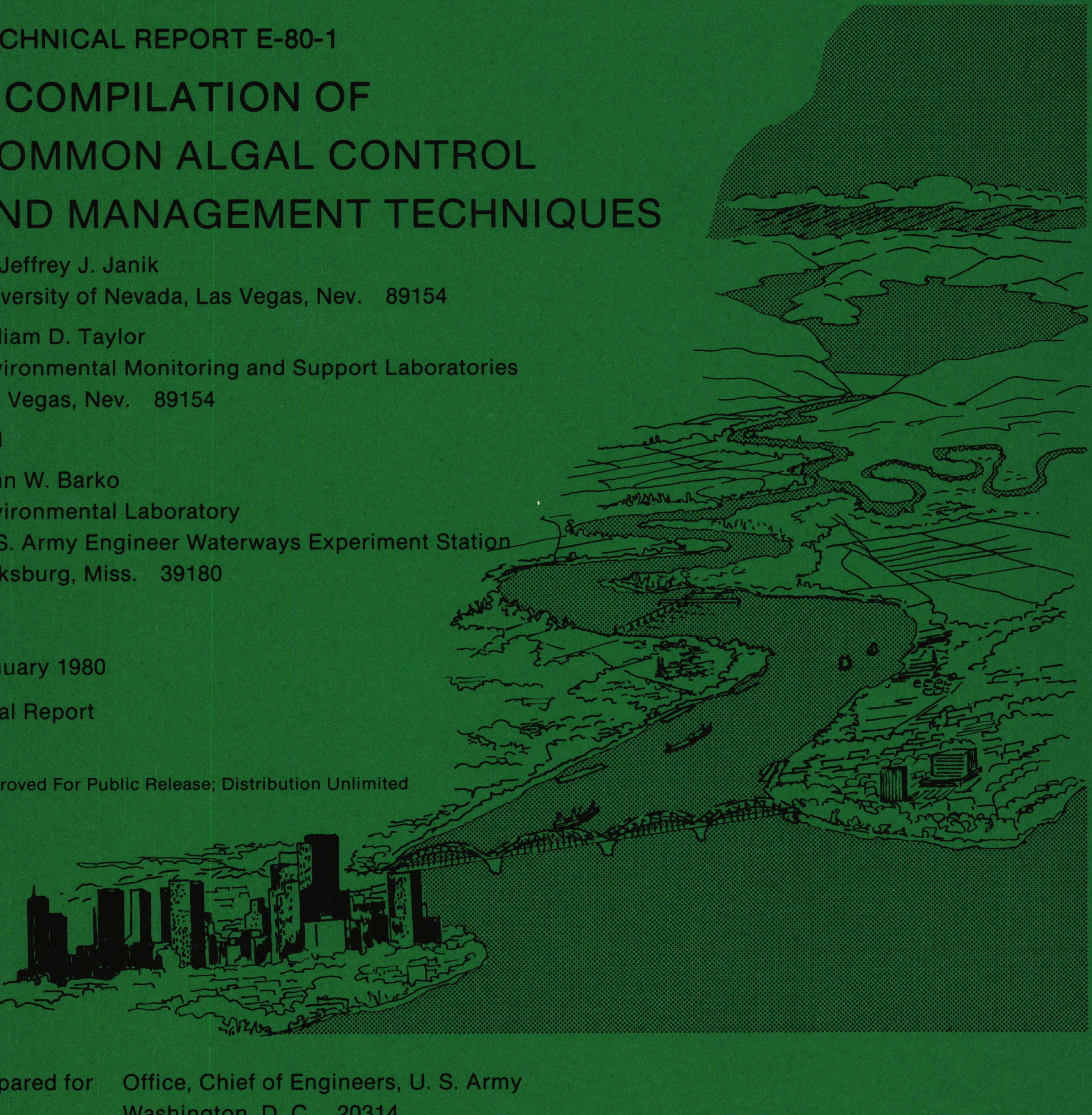
January 1980

Final Report

Approved For Public Release; Distribution Unlimited



Prepared for Office, Chief of Engineers, U. S. Army
Washington, D. C. 20314

Under Interagency Agreement No. EPA-IAG-78-R-X0393
(EWQOS Work Unit IIA.1)

onitored by Environmental Laboratory
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UNITED STATES OF AMERICA

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IN REPLY REFER TO: WESEV

15 March 1980

SUBJECT: Transmittal of Technical Report E-80-1

TO: All Report Recipients

1. The work reported herein was conducted as part of Work Unit 31598 (IIA), "Development and Evaluation of Reservoir Operational and Management Methods for Controlling Algal Blooms," of the Corps of Engineers' Environmental and Water Quality Operational Studies (EWQOS) Program. Work Unit 31598 (IIA) has the objective of developing and evaluating operational and management techniques for the control of nuisance algae.

2. This work involved a survey of literature and other sources of information to compile currently available methods of algal control and management. This information is summarized in an extensive table and is supported by an associated bibliography. This report is intended as a baseline of existing information for use in evaluating algal control methods and developing management policies applicable to Corps impoundments.

3. Future work under the EWQOS Program in this work unit will concentrate on the evaluation of algal control methods with specific consideration given to their ecological and economic appropriateness.

Nelson P. Conover

NELSON P. CONOVER
Colonel, Corps of Engineers
Commander and Director

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE *(When Data Entered)*

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Technical Report E-80-1	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE *(and Subtitle)* A COMPILATION OF COMMON ALGAL CONTROL AND MANAGEMENT TECHNIQUES		5. TYPE OF REPORT & PERIOD COVERED Final report 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Jeffrey J. Janik, William D. Taylor, and John W. Barko		8. CONTRACT OR GRANT NUMBER(s) Interagency Agreement No. EPA-IAG-78-R-X0393
9. PERFORMING ORGANIZATION NAME AND ADDRESS University of Nevada, Las Vegas, Nev. 89154; Environmental Monitoring and Support Laboratories, Las Vegas, Nev. 89154; U. S. Army Engineer Waterways Experiment Station, Vicksburg, Miss. 39180		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS EWQOS Work Unit IIA.1
11. CONTROLLING OFFICE NAME AND ADDRESS Office, Chief of Engineers, U. S. Army Washington, D. C. 20314		12. REPORT DATE January 1980 13. NUMBER OF PAGES 77
14. MONITORING AGENCY NAME & ADDRESS*(if different from Controlling Office)* U. S. Army Engineer Waterways Experiment Station Environmental Laboratory P. O. Box 631, Vicksburg, Miss. 39180		15. SECURITY CLASS. *(of this report)* Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT *(of this Report)*

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT *(of the abstract entered in Block 20, if different from Report)*

18. SUPPLEMENTARY NOTES

19. KEY WORDS *(Continue on reverse side if necessary and identify by block number)*

Algae
Algal control
Aquatic plant control
Impoundments

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

The objective of this survey was to compile the more commonly implemented methods of algal control and management. This information is summarized in an extensive table developed from the literature as well as through communications with individuals in various State agencies. References in the annotated bibliography are appropriate for consideration by individuals desiring direction in developing algal control programs. However, conclusions and recommendations drawn from this survey need to be viewed as preliminary, since the information
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compiled herein does not provide a sufficient basis for detailed discrimination of the relative efficacy of the individual techniques identified. Therefore, the discussion of these techniques is necessarily generalized. This report is intended as a baseline of existing information for use in evaluating algal control methods and management policies applicable to Corps impoundments.

SUMMARY

The objective of this survey was to compile the more commonly implemented methods of algal control and management. This information is summarized in an extensive table developed from the literature as well as through communications with individuals in various State agencies. References in the annotated bibliography are appropriate for consideration by individuals desiring direction in developing algal control programs. However, conclusions and recommendations drawn from this survey need to be viewed as preliminary, since the information compiled herein does not provide a sufficient basis for detailed discrimination of the relative efficacy of the individual techniques identified. Therefore, the discussion of these techniques is necessarily generalized. This report is intended as a baseline of existing information for use in evaluating algal control methods and management policies applicable to Corps impoundments.

Most of the algal control methods identified during this survey can be categorized into one or a number of generalized groups including: biological, chemical, physical, and an additional category of methods providing combined effects on algae. For the most part, these categories are comprised of techniques that afford limited algal control for relatively brief periods of time. Long-term algal management procedures appear to be essentially nonexistent. Most algal control methods are implemented only after a bloom has occurred. Normally the control techniques must be repeated on a regular basis to ensure continued success. Considerable emphasis needs to be placed on determining the constraints and limitations associated with the application of various algal control techniques so that long-term effective control programs and, most importantly, preventive methodologies can be developed.

PREFACE

The work conducted in the preparation of this report was performed under Interagency Agreement No. EPA-IAG-78-R-X0393. The research was conducted as part of the Environmental and Water Quality Operational Studies (EWQOS) Program, sponsored by the U. S. Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi. The work described in this report was performed under EWQOS Work Unit IIA.1.

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A sincere thanks is given to L. S. Blakey and S. S. Jiu who contributed significantly to the organization and preparation of the report. M. L. Campbell provided invaluable assistance in the acquisition of reference materials. In addition, the following individuals are acknowledged for their assistance in this effort: B. Blau, Department of Ecology, Olympia, Washington; C. Branch, Air and Water Pollution Control Commission, Jackson, Mississippi; E. Gertler, Maryland Water Resources Administration, Annapolis, Maryland; J. Giese, Department of Pollution Control and Ecology, Little Rock, Arkansas; J. Greenley, Department of Fish and Game, Boise, Idaho; J. W. Gregory, Virginia State Water Control Board, Richmond, Virginia; L. V. Guerra, Noxious Vegetation Control Program, Texas Parks and Wildlife Department, San Antonio, Texas; D. H. Henegar, Fisheries Division, North Dakota Game and Fish Department, Bismarck, North Dakota; R. C. Hiltibran, Aquatic Biology Section, Illinois Natural History Survey, Urbana, Illinois; G. A. Jackson, Division of Land Resource Programs, Michigan Department of Natural Resources, Lansing, Michigan; J. L. Janisch, Indiana Department of Natural Resources, Indianapolis, Indiana; M. Japhet, Division of Wildlife, Denver, Colorado; F. Jernejcic, Department of Natural Resources, Fairmont, West Virginia; J. S. Kadakia, Division

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General supervision and managerial assistance were provided by R. L. Eley and R. M. Engler, Division and Group Chiefs, respectively, in the ERSD; and V. W. Lambou, Chief, Water and Land Quality Branch, Environmental Monitoring and Support Laboratory, EPA. Chief of the EL was J. Harrison. Program Manager was J. L. Mahloch.

The Commander and Director of WES during the study was COL J. L. Cannon, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

A COMPILATION OF COMMON ALGAL CONTROL AND MANAGEMENT TECHNIQUES

PART I: INTRODUCTION

1. Algae form an essential part of lake and reservoir ecosystems. These organisms photosynthesize and thereby provide both the structure and energy upon which much of the aquatic ecosystem depends; however, excessive populations, especially of undesirable species (e.g., blue-green algae), often interfere with man's use of water. Nuisance algal blooms occur in many Corps of Engineers (CE) impoundments due to excessive nutrient enrichment from various sources within their extensive watersheds. Excessive algal production and the subsequent decay of algal biomass often result in oxygen depletion, fish kills, disagreeable taste and odor problems in water supplies, and unsightly shorelines and surface waters. Algal related problems are a source of considerable public concern.

2. Algal control measures are frequently considered to reduce excessive algal populations or to modify the species composition promoting the occurrence of more desirable forms. Numerous algal control and management techniques have been attempted with varying degrees of success. The more common methods are identified and summarized in this report.

3. The purpose of this survey was to identify algal control methods and management procedures appropriate for CE impoundments. The information collected did not allow a discriminate evaluation of individual techniques. Therefore, discussion is limited to generalized considerations only.

PART II: METHODS

4. Information included in this report was acquired through a systematic literature survey and supplemented through personal communications with individuals from State agencies concerned with water quality management.

5. The literature survey included a computerized search of the following data bases:

Government Research Reports (National Technical Information Service)	1970-1978
Water Pollution Abstracts	1970-1978
Biological Abstracts	1970-1978
Enviroline	1971-1978
Smithsonian Science Information Exchange, Inc. (SSIE)	1975-1978
Water Resources Scientific Information Center (WRSIC)	1968-1978

6. Over 500 articles were requested as a result of the literature search. A number of publications were eliminated as not being pertinent to the subject and others were not available. A total of 219 publications were ultimately considered in the preparation of this report.

7. Appropriate agencies of all states in the continental United States were requested to provide information related specifically to their algal control programs (if any). Twenty-two states responded to the request, and two states indicated that they presently had no active algal control programs.

PART III: RESULTS AND DISCUSSION

8. Biological, chemical, physical, and ecological techniques currently in use or under development for controlling algae in fresh water are tabularly summarized in Appendix A of this report. The appendix is organized according to specific algal control technique, location of the control or management program, species or group of algae causing the problem, and results or remarks summarizing results of the treatment(s). References cited in the table are included in the annotated bibliography section (Part V), where they are organized according to a letter-number system. The letter corresponds to the first letter of the author's last name and the number denotes the alphabetical sequence for each author. Information in the appendix obtained through contact with State agencies is identified accordingly.

Biological Control

9. A wide variety of biological control methods are available or are currently under development. These include the use of pathogens (e.g., viruses, bacteria, and fungi); control through the feeding activities of grazers (e.g., protozoans, zooplankton, and fish); and control by manipulating the interrelationships among plants, animals, and their environment (i.e., biomanipulation).

10. Pathogens potentially serve as highly potent and selective control agents. However, successful results have not yet been reported outside of the laboratory for this control technique.

11. Grazing, the most frequently attempted biological control technique, has not demonstrated conclusive results. However, protozoans and zooplankton appear to have potential as control agents.

12. Biomanipulation has shown promise as an effective algal control technique. The predominant mode of control appears to involve growth-inhibiting compounds, most of which are apparently excreted by algae or aquatic vascular plants. Additionally, the composition of algal populations can apparently be altered through the addition of

chemicals (e.g., HCl, CO_2, and silica) that alter pH or offset specific nutrient limitations.

13. Biological methods offer a most desirable means of controlling nuisance algal problems. The requirements for success of introduced biological control organisms (pathogens and grazers) include high survival under a variety of conditions, an ability to reduce the population of the problem species, and the capability to coexist with native species. Biological control techniques are still in the early developmental stages, with most studies being conducted in the laboratory. Additional information is needed in all areas of biological control before widespread practical applications can be implemented.

Chemical Control

14. Algal control through the application of chemicals (algicides) is the most widely used technique. Application methods vary from dragging a bag of chemicals by boat to spraying them from a boat or helicopter. Results of most treatments have been somewhat inconsistent. Instances of unsuccessful results are probably most often due to incorrect dosages of the control chemicals. Proper dosage is difficult to determine because of the complicating influence of differences in water chemistry and hydrodynamics.

15. The most popular of the chemicals used to control algae are the copper compounds, especially copper sulfate. The use of copper compounds has recently been questioned due to their potential hazard when accumulated in bottom sediments and in associated organisms. Current research into new algicides has provided little advancement in the state of the art of chemical treatment. Some new compounds have been suggested, but their use is not widespread.

16. A successful algicide ideally includes the following properties:

a. Species specific and selective for the nuisance algae.

b. Nontoxic to other organisms in the food chain.

c. Harmless to man and animals.

d. No incorporation into mineral or biological cycles.
e. No adverse effect on water quality.
f. No accumulation in lake sediments.
g. Inexpensive and easy to apply.

Physical Control

17. Physical methods of algae control include the mechanical removal of algae (harvesting); application of dyes (light limitation); the lowering of the water level (drawdown); the removal of bottom sediments (dredging); and the use of explosive charges to burst the vacuoles of blue-green algae (cellular disruption).

18. Mechanical harvesting has demonstrated limited success. However, serious technical difficulties exist due to the small physical size of most individual algal organisms. In general, this technique does not appear to be a practical method for in-lake application.

19. Dyes have been suggested to promote the limitation of algae by reducing light, but their use has not been widespread. The limited findings have been encouraging and suggest that this method may deserve further investigation.

20. Lake drawdown results in the immediate removal of algae. However, the long-term effectiveness of this technique is unknown. Further investigations are needed for a clear understanding of the effects of this technique. In multipurpose reservoirs this technique would not be practical in most cases because of conflicts with other project purposes.

21. Dredging is a frequently successful, but not a widely used, technique for controlling algae. This method is usually economically impractical except where it is implemented for other purposes (e.g., sedimentation control) as well.

22. Explosive charges have been used successfully for bursting the gas vacuoles of blue-green algae subsequently causing them to sink. However, the technique has obvious adverse effects on other aquatic organisms. Cellular disruption through the use of explosives is not considered a viable means to control algae in CE reservoirs.

Control Through Combined Effects

23. Control methods that provide combined effects on algal growth include addition of phosphorus precipitating chemicals (nutrient inactivation); replacement of nutrient-rich with nutrient-poor waters (dilution); increasing water flushing rate; rerouting of waters outside of a lake's drainage basin (diversion); and injection of air into a water body to promote mixing (artificial destratification).

24. The results of several phosphorus inactivation studies have been generally encouraging. However, more information on internal phosphorus cycling in aquatic systems and methods for phosphorus inactivation is needed. The distribution of chemical inactivators and seasonal timing of treatments are additional areas that need more examination and testing.

25. Dilution reduces nutrient concentrations within a lake. Field studies have indicated that algal control can be achieved by this procedure. However, effects on other aspects of lake biology and management may be significant and need to be evaluated before this technique can be implemented on a regular basis.

26. Increased flushing through altered discharge procedures can remove algae from the water body. This method has been proven successful in altering algal species composition within lakes without adversely changing water quality. High flushing rates generally reduce phytoplankton standing crops and favor nannoplankton species over larger nuisance-causing species (e.g., blue-greens).

27. Diversion of nutrients before entry into lake systems has proven successful in reducing nuisance algal abundance. However, the results have not been consistent. Additional data are needed before the applicability of this technique can be adequately evaluated.

28. Artificial destratification has generally been shown to have a positive influence on overall water quality by reducing algal mass and altering species composition. However, the results obtained are often inconsistent, and the effects on phytoplankton require more thorough investigation.

PART IV: CONCLUSIONS AND RECOMMENDATIONS

29. Most algal control methods considered in this report are short term in nature and must be frequently repeated for continued success. More emphasis needs to be placed on determining specific causes of algal problems so that long-term effective control programs and, more importantly, preventive methodologies can be developed. The occurrence of most algal problems can usually be related to increased nutrient input (both internal and external) into a water body. Curbing these fluxes should ultimately result in long-term improvements in water quality and lessened algal growth. However, where such reductions are not possible or are ineffective, the judicious application of control techniques may be a necessity.

30. Many methods now used for algal control may not be acceptable for CE reservoirs. For example, algicides may have significant adverse ecological side effects. Furthermore, algicides, except for localized control, may be difficult to use in large reservoir projects; therefore, controlling algal blooms by reducing growth-promoting factors or through alterations in project operation are attractive alternatives. Previous algal control work has mainly been concentrated on natural lakes. However, reservoirs, in many cases, present significantly different conditions, including greater potential for management by manipulation of water levels and discharge elevations.

31. Specific recommendations based on this survey of algal control and management techniques are enumerated below:

- *a*. There should be a change in emphasis from controlling algal problems after they arise to determining their causes and implementing a preventive program.
- *b*. The application of chemicals, especially copper compounds, should be carefully monitored.
- *c*. There should be better reporting and publication of methods and results of algal control experiences. There is a need for improved phytoplankton surveillance and analysis programs using standardized techniques. Knowledge of the time course of development of algal blooms will allow the more prudent application of algicides.

d. Additional work on nonchemical control methods--especially biological--is needed. Viral control of algae shows good potential; however, it still requires extensive research in order to characterize and isolate additional cyanophages, and study the nature of these unique host-parasite relationships.

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C7. Canter, H. M. 1973a. A guide to the fungi occurring on planktonic blue-green algae. *In*: T. V. Desikachary, (ed.). Taxonomy and Biology of Blue-green Algae. First Intern. Symp. on Taxon. and Biol. of Blue-Green Algae, Univ. of Madras, Madras, India. pp.145-158.

C8. Canter, H. M. 1973b. On *Zygorhizidium venustum* (Canter) n. comb. together with an illustrated list of chytrids occurring on chrysophycean algae. Nova Hedwigia. 21:577-597.

C9. Canter, H. M. and J. W. G. Lund. 1948. Studies on plankton parasites. I. Fluctuations in numbers of *Asterionella formosa* Hass. in relation to fungal epidemics. New Phytol. 47:238-261.

C10. Canter, H. M. and J. W. G. Lund. 1951. Studies on plankton parasites. III. Examples of the interaction between parasitism and other factors determining the growth of diatoms. Ann. Bot., London N. S. 15:359-371.

Discussion of the interrelationships of populations of plankton organisms and their parasites in two English lakes.

C11. Canter, H. M. and J. W. G. Lund. 1953. Studies of the plankton parasites. II. The parasitism of diatoms with special reference to lakes in the English lake district. Trans. Brit. Mycol. Soc. 36:13-37.

Survey of the incidence of parasitism of plankton diatoms by chytridiaceous fungi in the English lake district.

C12. Canter, H. M. and J. W. G. Lund. 1968. The importance of protozoa in controlling the abundance of planktonic algae in lakes. Proc. Linnean Soc. London. 179(2):203-219.

Discussion of the effects of protozoa grazing on colonial green algae.

C13. Clesceri, N. L. 1968. Physical and chemical removal of nutrients. *In*: D. F. Jackson, (ed.). Algae, Man, and the Environment. Syracuse University Press, New York. pp. 413-428.

Compilation of the more pertinent literature regarding physical and chemical means of removing nitrogen and phosphorus from wastewaters.

C14. Cole, G. T. and M. J. Wynne. 1973. Studies of *Microcystis-Ochromonas* interactions. *In*: B. L. Prows and D. W. McIlhenny, (eds.). Development of a Selective Algaecide to Control Nuisance Algal Growth. U.S. Environmental Protection Agency. Ecol. Res. Ser. EPA 660/3-73-006. pp. 110-126.

C15. Cole, G. T. and M. J. Wynne. 1974. Endocytosis of *Microcystis aeruginosa* by *Ochromonas danica*. J. Phycol. 10(4):397-410.

Discussion of endocytic activity of *O. danica* during intracellular digestion.

C16. Cole, G. T. and M. J. Wynne. 1975. Possible utilization of the endocytotic golden alga, *Ochromonas danica* as a means of biological control of nuisance blue-green algae. *In*: P. L. Brezonik and J. L. Fox, (eds.). Proc. Symp. on Water Quality Management Through Biological Control. Univ. of Florida, Gainesville, Jan. 29-31. pp. 118-119.

C17. Cook, G. D., R. T. Heath, R. H. Kennedy and M. R. McComas. 1978. Effects of diversion and alum application on two eutrophic lakes. EPA-600/3-78-003. U. S. Environmental Protection Agency, Ecological Research Series. 114 pp.

C18. Cook, S. F., Jr. and R. L. Moore. 1970. Mississippi silversides, Menidia audens (Atherinidae), established in California. Trans. Amer. Fish. Soc. 99(1):70-73.

Discussion of the effectiveness of the Mississippi silversides as a biological control agent.

C19. Cook, W. L., D. G. Ahearn, D. J. Reinhardt, and R. J. Reiber. 1974. Blooms of an algophorous amoeba associated with Anabaena in a freshwater lake. Water Air Soil Pollut. 3:71-80.

Blooms of the blue-green alga Anabaena planctonica in a freshwater lake in northern Georgia were followed by the massive development of a large algophorous, mayorellid-like amoeba. The algal-amoeba blooms were associated with waters enriched with sewage effluents. The trophozoite and cyst-like stages of the amoeba were examined with phase and light-field microscopy. The use of algophorous amoebae for the natural control of nuisance algal blooms is suggested.

C20. Crance, J. H. 1963. The effects of copper sulfate on Microcystis and zooplankton in ponds. Prog. Fish. Culturist. 25(4):198-202.

Discussion of the effects of low concentrations of copper sulfate on controlling Microcystis and the toxicity on zooplankton.

D1. Daft, M. J., J. Begg, and W. D. P. Stewart. 1970. A virus of blue-green algae from freshwater habitats in Scotland. New Phytol. 69:1029-1038.

Discussion of the effects of a virus which is pathological to certain blue-green algae.

D2. Daft, M. J. and W. D. P. Stewart. 1971. Bacterial pathogens of freshwater blue-green algae. New Phytol. 70:819-829.

Discussion of bacterial isolates which cause lysis of laboratory cultures and natural populations of blue-green algae.

D3. Deegan, U. F. 1976. Certain factors involved in the biological control of Microcystis aeruginosa by Ochromonas danica. J. Phycol. 12(suppl.):8.

The competitive, nutritional, and predatory relationships of O. danica with the bloom-forming cyanophyte M. aeruginosa are investigated in an attempt to identify those conditions favoring optimal phagotrophy.

D4. Denison, J. R. 1974. Limiting nutrient tests used in an investigation of factors controlling phytoplankton development. Water Treat. Exam. 23(1):52-75.

Data are presented showing seasonal variations of phytoplankton in four Manchester reservoirs and relationships are sought with some ecological factors controlling their growth. Selenastrum capricornutum was used as a test species in bioassays to determine the availability of growth-limiting algal nutrients and to quantify the biological response to changes in concentrations of these nutrients. Further study is required before precise interpretation of the bioassay results can be provided, in relation to the naturally occurring algal populations. But the technique promises to be a valuable and versatile tool for studying specific algal problems encountered in waterworks practice.

D5. Desjardins, P. R., M. B. Barkley, S. A. Swiecki, and S. N. West. 1978. Viral control of blue-green algae. California Water Resources Center. Contrib. No. 169. 29 pp.

Description of a method to purify and concentrate cyanophages with discussion of their biological control capabilities.

*D6. Duncan, T. O. 1978. A review of literature on the use of potassium permanganate ($KMNO_4$) in fisheries. Bur. Sport Fisheries and Wildlife. FWS/LR-74/14. F. Fayetteville, Ark. 62 pp.

Discussion of some algal control methods, but mostly a review of the use of $KMNO_4$ in fisheries.

D7. Dunst, R. C., S. M. Born, P. D. Uttormark, S. A. Smith, S. A. Nichols, J. O. Peterson, D. R. Knauer, S. L. Serns, D. R. Winter, and T. L. Wirth. 1974. Survey of lake rehabiliation techniques and experiences. Tech. Bull. No. 75. Department of Natural Resources, Madison, Wisconsin. 179 pp.

E1. Eunpu, F. F. 1973. Control of reservoir eutrophication. J. Am. Wat. Wks. Assoc. 64(4):268-274.

Discussion of aeration system to control algal growths and taste and odor problems.

F1. Fast, A. W. 1971. The effects of artificial aeration on lake ecology. EPA 5501-0232. Washington, D.C. 470 pp.

Discussion of the ecological effects resulting from artificial aeration and a description of the aerators utilized.

F2. Fast, A. W., B. Moss, and R. G. Wetzel. 1973. Effects of artificial aeration on the chemistry and algae of two Michigan lakes. Water Resources Research. 9(3):624-646.

Two lakes were artifically aerated by using compressed air. Section Four Lake, an unproductive lake, was completely mixed, whereas Hemlock Lake, a eutrophic lake, had its hypolimnion aerated but thermal stratification maintained. Chemical and algal changes in Section Four Lake during destratification were not great. Although phytoplanktonic production potentials increased during mixing, the phytoplankton standing crop appeared to decline slightly, possibly due to the increased mixing depth and turbidity. Hemlock Lake hypolimnetic anoxia and conditions associated with it were eliminated during aeration. The lake gradually destratified during aeration due to leaks in the aeration tower. These leaks also released nutrient-rich water into the epilimnion, which promoted algal growth.

F3. Fitzgerald, G. P. 1964a. Laboratory evaluation of potassium permanganate as an algicide for water reservoirs. Southwest Water Works J. 45(10): 16-17.

Discussion of potassium permanganate as an algicide and comparison testing with copper sulfate.

F4. Fitzgerald, G. P. 1964b. Factors in the testing and application of algicides. Appl. Microbiol. 12:247-253.

A review is presented of some of the factors affecting the laboratory testing and practical applications of chemicals toxic to algae. The basic factor demonstrated is that the amount of chemical required to inhibit the growth of algae is dependent on the amount of algae present and not on the volume of water in which the algae are dispersed.

F5. Fitzgerald, G. P. 1964c. The biotic relationships within waterblooms. In: D. F. Jackson, (ed.). Algae and Man. Plenum Press, New York. pp. 300-306.

Discussion of the sequence of algae blooms in aquatic environments.

F6. Fitzgerald, G. P. 1966. Use of potassium permanganate for control of problem algae. J. Am. Wat. Wks. Assoc. 58:609-614.

Discussion of results of a comparative toxicity test of copper sulfate and potassium permanganate on eight species of problem algae.

F7. Fitzgerald, G. P. 1969. Some factors in the competition or antagonism among bacteria, algae, and aquatic weeds. J. Phycol. 5:351-359.

Field observations of changes in the populations of aquatic weeds and phytoplankton have confirmed that aquatic weeds have antagonistic activity toward phytoplankton. Discussed are the ecological implications of associations of certain algae with bacteria that have selective toxicities for other species of algae under certain environmental conditions such as nitrogen-limited growth.

*F8. Fitzgerald, G.P. 1971 . Algicides. Univ. Wis. Water Resource Cent., Eutroph. Inf. Program, Lit. Rev. No. 2. Madison, Wis. 50 pp.

Review of chemicals used for algae control. Includes literature survey, evaluation of algicides, factors in application, and practical uses.

*F9. Fitzgerald, G. P. 1974. Shortcut methods test algicides. Wat. Sewage Wks. 121(9):85-87.

Description of a method to evaluate the effectiveness of algicides.

*F10. Fitzerald, G. P. 1975. Are chemicals used in algae control biodegradable. Wat. Sewage. Wks. 122(5):82-85.

Data collected during tests performed over the last 11 years have indicated that the algicides that have been used to control the growth of problem-causing algae, products containing copper, silver, mercuric chloride, phenyl mercuric acetate, and quaternary ammonium compounds, do not pose a threat to aquatic environments if used at the minimal concentrations required to be effective, because these concentrations are biodegraded by the treated algae. However, all chemicals to be added to aquatic environments should be evaluated, since at least one compound--methyl mercuric chloride--is not detoxified by the action of treated algae and its use as an algicide would pose a threat to the general environment.

*F11. Fitzgerald, G. P. and S. L. Faust. 1963. Factors affecting the algicidal and algistatic properties of copper. Appl. Microbiol. 11: 345-351.

Data from laboratory studies are presented to show that, whereas five different sources of copper appear to be equally effective as toxic agents for algae, the medium in which toxicity tests are carried out has a great influence on the toxicity of copper. A technique of subculture is described for determining whether a concentration of a chemical is algicidal, algistatic, or nontoxic in action against a specific alga, and demonstrations are given of tests with algae illustrating each class of action.

F12. Fitzgerald, G. P., G. C. Gerloff, and F. Skoog. 1952. Studies on chemicals with selective toxicity to blue-green algae. Sewage ind. Wastes. 24:888-896.

Discussion of the results of testing 300 organic compounds for toxicity to bloom-producing blue-green algae.

F13. Fitzgerald, G. P. and F. Skoog. 1954. Control of blue-green algae blooms with 2, 3-dichloronophoquinine. Sewage. ind. Wastes. 26(9):1136-1140.

Discussion of the results of an in-lake treatment to determine the effectiveness of 2, 3--DNQ in controlling blue-green algae bloom.

F14. Fox, J. L., P. L. Brezonik, and M. A. Keirn. 1977. Lake drawdown as a method of improving water quality. EPA-600/3-77-005. Corvallis, Oregon. 94 pp.

Discussion of an investigation to determine the feasibility of radical drawdown as a restoration technique for Lake Apopka, Florida.

F15. Frost, T. P. 1960. Practical algal control methods for New Hampshire Water Supplies. J. New Hamp. Wat. Wks. Assoc. 7 pp.

Discussion of the use of copper sulfate as an algicide.

F16. Frost, T. P. 1963. Observations and experience in the control of algae. J. New Hamp. Wat. Wks. Assoc. 6 pp.

Discussion of the use and application of copper sulfate as an algicide.

F17. Frost, T. P., R. E. Towne, and H. J. Turner. 1972. Algae control by mixing. Staff report on Kezar Lake in Sutton, N. H. Staff report No. 59. N. H. Water Supply and Pollution Control Commission. 105 pp.

Discussion of the affects of artifical destratification on the water quality of Kezar Lake.

F18. Fuhs, G. W., S. P. Allen, L. J. Helting, and T. J. Tofflemire. 1977. Restoration of Lower St. Regis Lake (Franklin County, New York) EPA-600/3-77-021. Ecological Research Series. 107 pp.

Discussion of the effects of diversion on the water quality of lower St. Regis Lake.

F19. Fuller, R. H., R. C. Averett, and W. G. Hines. 1975. Problems related to water quality and algal control in Lopez Reservoir, San Luis Obispo County, California. PB-243466. U. S. Geological Survey. 54 pp.

Discussion of possible application rates and methods of determining application rates of copper sulfate for controlling nuisance algae. Description of Monie test for determinations of copper sulfate dosages.

F20. Funk, W. H. and A. R. Gaufin. 1965. Control of taste and odor producing algae in Deer Creek Reservoir. Trans. Am. microsc. Soc. 84(2):263-269.

Field and laboratory comparative testing of the effectiveness of various algicides.

G1. Gibbon, B. 1971. Belleville's microstrainers maintain filter flowrates. Water Pollut. Control. 109(6):24-25.

Description of the use of microstrainers for pretreatment of water.

G2. Gibson, C. E. 1972. Algicidal effect of copper on a green and blue-green alga and some ecological implications. J. Applied Ecol. 9(2): 513-518.

Discussion of the concentrations of copper sulfate needed to control two species of algae.

G3. Goldman, C. R., N. Williams, and A. Horne. 1975. Prospects for micronutrient control of algal populations. In: P. L. Brezonik, and F. L. Fox, (eds.). Proc. Symp. on Water Quality Management Through Biological Control. Univ. of Florida, Gainesville, Jan. 29-31. pp. 97-105.

*G4. Golueke, C. G. and W. J. Oswald. 1965. Harvesting and processing sewage-grown planktonic algae. J. Wat. Pollut. Control Fed. 37:471-498.

Review of methods for algae harvesting and processing.

G5. Granhall, U. 1972. Aphanizomenon flos-aquae, infection by cyanophages. Physiol. Plant. 26:332-337.

This report presents electron microscopic observations of a virus infection of Aphanizomenon flos-aquae (L.) Ralfs and investigations on the presence of the causative cyanophage in a moderately eutrophic lake. The results indicate that the cyanophages regulate termination of the waterbloom of this alga.

G6. Granhall, U. and B. Berg. 1972. Antimicrobial effects of Cellvibrio on blue-green algae. Arch. Microbiol. 84:234-242.

Discussion of the lysing effects of culture fluids from two Cellvibro strains of bacteria on various species of blue-green algae.

G7. Granhall, U. and A. Y. Holsten. 1969. The ultra-structure of a cyanophage attack on Anabaena variabilis. Physiol. Plant. 22:713-722.

Cyanophages multiplying on the nitrogen-fixing blue-green alga Anabaena variabilis Kutz. were revealed by electron microscopy. Severe ultrastructural changes have been observed in the vegetative cells, whereas the heterocysts appeared resistant to the cyanophage. A lytic cycle was observed from adsorption to lysis.

G8. Gratteau, J. C. 1970. Potential algicides for the control of algae. Wat. Sewage Wks. 117:R24-R61.

Review and comparison of 300 algicides. Discussion of physical and ecological control methods.

*G9. Guttman, H. N. 1973. A critical test of methods for the isolation of viruses for use in control of nuisance algae. Illinois Univ., Urbana. OWRR-A-043-Ill. 17 pp.

The objects of this study were a) to compare the two major methods for isolation of blue-green algae viruses in order to determine whether the finding of viruses in any one local depended upon the isolation method used and b) to isolate an array of virulent blue-green algae viruses which could be used for field control of these algal polluters. Since infection of algae with temperature viruses immunizes the algae to infection with closely related virulent viruses, it was concluded that use of virulent viruses to remove blue-green algae from waterways in the greater Chicago metropolitan area is not practical. Virus removal of blue-green algae is only practical in a) areas in which the natural incidence of temperature viruses is low, or b) cases in which non-cross-reacting virulent viruses are available. Virus removal of algae remains an attractive concept because of its specificity but, at the present, may require too much economic investment to locate appropriate viruses.

H1. Harris, D. O. 1971a. Inhibition of oxygen evolution in Volvox globator by culture filtrates from Pandorina morum. Microbios. 3(9): 73-75.

Culture filtrates from Pandorina morum, grown under axenic conditions were inhibitory to most members of the colonial flagellates (green algae). An examination of the filtrate on the rate of photosynthesis (as measured by oxygen evolution) in Volvox globator was conducted. One hour exposure resulted in 65% reduction in photosynthesis which increased to 91% after 12 hours. Respiration rates, as measured by oxygen consumption, were unaffected.

H2. Harris, D. O. 1971b. Growth inhibitors produced by green algae (Volvocaceae). Arch. Microbiologie. 76:47-50.

A complex system of growth inhibition is present in the green algae (Volvocaceae). Inhibitors are found in the culture filtrates of some genera which limit their own growth (autoinhibition) while others in the family produce inhibitors which check the growth of other genera (heteroinhibition). These inhibitors are destroyed by autoclaving.

H3. Harris, D. O. 1972a. Further observations on a growth inhibiting substance produced by *Pandorina morum*. Research Report OWRR-A-018-Ky(3). 20 pp.

These studies clearly show that a substance produced by *Pandorina morum* (a colonial green flagellate) inhibits growth of most members of the Volvocaceae. It is hoped that these studies on the toxin will shed light on a method to control the indiscriminate growth of algae in all water supplies.

H4. Harris, D. O. 1972b. Life history and growth inhibition studies in *Platydorina caudata* (Volvocaceae). Research Report. OWRR-A-018-Ky (4). 33 pp.

Platydorina caudata life history was studied in axenic culture. It was observed by studying many strains that a complex system of growth inhibition is operative in the family Volvocaceae. *Pandorina morum* produced the strongest inhibitor, inhibiting growth of most members of the family and *Volvox tertius* proved to be the most sensitive. These two genera were therefore used as a model system to study the chemical and physical properties of algal growth inhibitors.

H5. Harris, D.O. 1975. Antibiotic production by the green alga, *Pandorina morum*. *In*: P. L. Brezonik and J. L. Fox (eds.). Proc. Symp. on Water Quality Management Through Biological Control. Univ. of Florida, Gainesville. Jan. 29-31. pp. 106-111.

H6. Harris, D. O. and H. D. Caldwell. 1974. A study of naturally occurring algicides produced by freshwater algae. National Technical Information Service. PB-238-349. 39 pp.

The mode of action of the algicide produced by Pandorina morum was examined by exposing Volvox globator and isolates of spinach chloroplasts to a partially purified algicide preparation. Field studies indicate that this algicide has tremendous potential as a control of nuisance algal growth.

H7. Hasler, A. D. and E. Jones. 1949. Demonstration of antagonistic action of large aquatic plants on algae and rotifers. Ecol. 30:359-364.

Discussion of a study to investigate the competitive actions of aquatic plants on algae.

H8. Haynes, R. C. 1973. Some ecological effects of artificial circulation on a small eutrophic lake with particular emphasis on phytoplankton. I. Kezar Lake experiment, 1968. Hydrobiologia. 43(3-4):463-504.

Discusses the effects of artificial circulation on a small eutrophic lake.

H9. Ho, T. S. and M. Alexander. 1974. The feeding of amebae on algae in culture. J. Phycol. 10(1):95-100.

Discussion of the susceptibility of a number of algae to attack by protozoa and to establish some of the variables affecting the rate of predation.

H10. Holcomb, D. E., W. L. Wegener and V. P. Williams. 1975. Lake level fluctuation for habitat management. In: P. L. Brezonik and J. L. Fox (eds.). Proc. Symp. on Water Quality Management Through Biological Control. Univ. of Florida, Gainesville, Jan. 29-31. pp. 151-157.

Review of the biological effects of lake drawdown on a Florida lake.

H11. Holmstrand, L. L. 1971. The role of the rotifer, Lindia euchromata in the ecology of Gloeotrichia blooms. Limresta. 2:24-27.

Discussion of a preliminary study to determine the ecological relationships of the rotifer, Lindia euchromata, with the alga, Gloeotrichia.

H12. Hooper, F. F., R. C. Ball, and H. A. Tanner. 1952. An experiment in the artificial circulation of a small Michigan lake. Trans. Amer. Fish. Soc. 82:222-241.

Discussion of the effects of artificial circulation on improving trout fishing in a small unproductive lake.

*I1. Ingram, W. M. 1954. Selected bibliography of publications relating to the undersirable effects upon aquatic life by algicides, insecticides, and weedicides. PHS-PUB-400, PB-217-414. 32 pp.

Annotated bibliography of algicides.

I2. Irwin, W. H., J. M. Symons, and G. G. Robeck. 1967. Water quality in impoundments and modifications from destratification. Reservoir fisheries Resource Symposium. Southern Division. American Fisheries Society. pp. 131-152.

*I3. Ives, K. J. 1957. Control of algae in reservoirs. Water and Water Eng. 61(737):387-389.

Review of some techniques used to control algae in reservoirs.

J1. Jackson, D. and V. Sladecek. 1970. Algal viruses-euthropication control potential. Yale Scientific Magazine. 44:16-21.

Discussion of algal viruses and their effect on blue-green algae.

J2. Jansen, G. P. and D. L. Parker. 1975. Isolation, purification and partial characterization of a virus infecting certain blue-green algae. Am. Soc. Microbiol. National meeting. New York, N.Y. Apr. 27-May 2 (ABSTR.)

Cyanophage SAM-1, which infects *Synechococcus cedrorum*, *Anacystis nidulans*, and certain strains of *Microcystis aeruginosa* has been isolated from sewage. SAM-1 stocks were concentrated by ultrafiltration and purified by density-gradient and differential centrifugation. Electron micrographs of SAM-1 suspensions show virions with a characteristic morphology. The host range of SAM-1 is demonstrated to differ from those of other reported cyanophages. SAM-1 stocks are rapidly inactivated at temperatures above 45°C or at pH values below pH4 or above pH10. 0.1 M NaCl is required for optimal adsorption of SAM-1 to S. cedrorum.

J3. Jerneloev, A. 1971. Phosphate reduction in lakes by precipitation with aluminum sulfate. In: S. H. Jenkins (ed.). Advances in Water Pollution Research. Pergamon Press, New York. 1(I)15:1-6.

K1. Keating, K. I. 1976. Algal metabolite influence on bloom sequence in eutrophied freshwater ponds. EPA-600/3-76-081. Ecological Research Series. 156 pp.

Biological sequence control of algal blooms is suggested as a relatively inexpensive method of water quality management in moderately sized eutrophic lakes as a practical alternative and/or adjunct to nutrient removal. Monitoring of bloom sequence in Linsley pond, Connecticut, for three years, accompanied by laboratory studies, showed that certain extracellular metabolities in blue-green algae substantially inhibit the growth of planktonic diatoms in cultures and in the pond's natural sequence. A hypothetical sequence control strategy is offered, with a projected cost of about $500 per year for a pond similar to the study site. Using the strategy, winter blue-green blooms would be eliminated by copper sulfate and spring diatom growth enhanced by the addition of silica. The silica would enhance the diatom growth and some other desirable forms and would lessen the effect of the remaining blue-green metabolite inhibition. Such efforts should then increase the period of diatom domination, decrease nutrient levels left in the epilimnion when the diatoms senesce, and decrease the subsequent late summer blue-green bloom. Details are given of the in situ and of the laboratory tests.

K2. Keating, K. I. 1977. Allelopathic influence on blue-green bloom sequence in a eutrophic lake. Science. 196:885-886.

The bloom sequence in a eutrophic lake, Linsley Pond, over a period of three years is correlated to the effects of cell-free filtrates of dominant blue-green algae on both their successors and their predecessors. There is unbroken correspondence between the effects of heat-labile probiotic and antibiotic filtrates and the rise and fall of bloom populations in situ. All organisms in vitro were axenic or unialgal (bacterized) isolates from Linsley Pond.

K3. Keating, K. I. 1978. Blue-green algal inhibition of diatom growth--transition from mesotrophic to eutrophic community structure. Science. 199:971-973.

Cell-free filtrates of axenic or bacterized cultures of the dominant blue-green algae from a freshwater lake inhibited the growth of diatoms isolated from the same lake. Lake waters, collected during blue-green algal blooms, also inhibited diatom growth. In situ observations over a five-year period indicate that diatom bloom populations vary inversely with the levels of the preceding blue-green algal populations. Blue-green algal dominance of eutrophic lakes is attributed to this allelopathy, and dilution is proposed as one cause for the limited occurrence of blue-green algal dominance in marine waters.

K4. Kemp, H. T., R. G. Fuller, and R. S. Davidson. 1966. Potassium permanganate as an algicide. J. Am. Wat. Wks. Assoc. 58(2)255-263.

Description of preliminary laboratory studies of the algicidal effect of potassium permanganate along with determination of its toxicity to fish.

K5. Kerst, A. F., J. D. Douros, and M. Brokl. 1973. Controlling algae with 5-(5 barbiturilidene)-rhodanine. Official gazette of the U.S. Patent Office. 915(3):986.

Discussion of a new algicide and a review of its claims and properties.

K6. Khudyakov, I. Y. and B. V. Gromov. 1973. The temperate cyanophage A-4(L) of the blue-green alga Anabaena variabilis. Mikrobiologiya 42:904-970. (Translation)

Description of the cyanophage A-4(L), which is specific for Anabaena variabilis.

K7. Kocurova, E. 1966. The application of algicide CA 350 in the Lubi Reservoir near Trebio, Czechoslovakia. Hydrobiologia. 28(2):223-240.

A discussion of the effects of the algicide CA 350 on blue-green algae blooms (Aphanizomenon flos-aquae).

K8. Kozyakov, S., B. Gromov and I. Khudyakov. 1972. Cyanophage A-1(L) of the blue-green alga Anabaena variabilis. Mikrobiologiya. 41:555-559. (Translation)

Description of the cyanophage A-1(L) which lyses Anabaena variabilis.

K9. Kraus, M. P. 1974. Host range study of blue-green algal viruses. Coll. of Mar. Stud. U. of Delaware. Rep. No. Del-5G-1-74. 30 pp.

Progress report summarizing the information gained on the molecular ecology of a host/virus system covering a rather wide range of blue-green algal viruses and their hosts.

L1. Lackey, R. T. 1973. Artificial reservoir destratification effects on phytoplankton. J. Wat. Pollut. Control Fed. 45(4):668-673.

Discusses the effects of artificial destratification on phytoplankton standing crop and species composition.

*L2. Lawrence, J. M. 1968. Aquatic weed control in fish ponds. Fao Fish Rep. 44(5):76-91.

Results of 30 years of aquatic weed control research in fish ponds at this station are summarized. This summary includes a listing of important algae genera and aquatic weed species and information on pond construction features of significance in aquatic weed control, as well as mechanical, biological, and chemical control techniques. Included in discussions on chemical control techniques are data on fish toxicity of each herbicide as well as effective rates of application for use under pond conditions.

L3. Lawton, G. W. 1961. Limitations of nutrients as a step in ecological control. Algae and metropolitan wastes. Robert A. Taft, Eng. Cent. Tech. Rep. W61-3. Cincinnati, Ohio. pp. 108-117.

*L4. Leach, L. E. and C. C. Harlin. 1970. Induced aeration of small mountain lakes. EPA Project #16080. Washington, D.C. 55 pp.

Summer stratification in small mountain trout fishery lakes restricts trout habitat to the thin layer of surface waters. As atmospheric temperatures increase during later summer months, the epilimnion waters reach temperatures intolerable for trout. A technique of managing trout fishery lakes, through introduction of compressed air, was studied at Lake Roberts in southern New Mexico during the summer of 1969. Research findings and further research required for optimum development of induced aeration systems as management tools for trout-fishery lakes are discussed.

*L5. Lin, S. D. 1977. Tastes and odors in water supplies--A review. National Technical Information Service. PB-273-142. 50 pp.

A literature review comparing experiences and characteristics in the control of tastes and odors in water supplies.

L6. Lond, H. Y. 1969. Optimum operation of microstrainers. Wat. Treat. Exam. 18(3):229-232.

Discussion of the efficiency of microstrainers in removing algae from lake water.

L7. Lorenzen, M. W. 1977. Aeration/circulation keeps algal blooms in check. Water Wastes Engineer. 14(10):69-74.

Discusses the results of aeration/circulation studies aimed at controlling phytoplankton.

L8. Lorenzen, M. W. and R. Mitchell. 1973. Theoretical effects of artificial destratification on algal production in impoundments. Environ. Sci. Technol. 7(10):939-944.

Theoretical models of phytoplankton production are reviewed and a model for application to mixed impoundments is derived.

L9. Lorenzen, M. W. and R. Mitchell. 1975. An evaluation of artificial destratification for control of algal blooms. J. Am. Wat. Wks. Assoc. 67(7):373-376.

Results of a study conducted by the New Hampshire Water Supply and Pollution Control Com. on a New Hampshire lake were used to evaluate a model previously developed to predict the effects of artificial destratification on algal production in impoundments. These results may be of help in water quality management decisionmaking.

*L10. Lueschow, L. A. 1972. Biology and control of selected aquatic nuisances in recreational waters. Tech. Bull. No. 57. Dept. of Natural Resources, Madison, Wisconsin. 36 pp.

The control of aquatic nuisances has been in effect in Wisconsin since the early 1900's. Algae populations that have become so expanded that they contribute odors and unsightly conditions are temporarily abated through the use of copper sulfate. This chemical quickly reacts with natural carbonate ions in the water and precipitates into biologically inactive copper carbonate.

*L11. Lund, J. W. G. 1955. The ecology of algae and waterworks practice. Proc. Soc. Water Treat. Examin. 4(2):83-99.

*L12. Lund, J. W. G. 1966. Limnology and its application to potable water supplies. J. Brit. Waterworks Assoc. 49(424):14-26.

M1. MacKenthun, K. M. 1960. Algae control. Public Works. 91(9):114-116.

Brief discussion of copper sulfate (with dosage chart) as an algicide.

M2. MacKenthun, K. M. 1969. Nuisance organism control. In: The Practice of Water Pollution Biology. U.S. FWPCA, Washington, D.C. 281 pp.

Discussion of algal control techniques.

M3. MacKenthun, K. M. and L. E. Keup. 1970. Biological problems encountered in water supplies. J. Am. Wat. Wks. Assoc. 62(8)520-526.

Compilation of literature dealing with problem organisms in water supplies and methods of control.

*M4. Massey, A. and J. Robinson. 1971. Review of the factors limiting the growth of nuisance algae. Wat. Sewage Wks. 118(11):352-355.

Review of the roles of phosphorus, nitrogen, and carbon as limiting factors for algal growth.

M5. Mattox, K. R. and K. D. Stewart. 1972. probable virus infections in four genera of green algae. Can. J. Microbiol. 18:1620-1621.

Description of virus-like inclusions in four species of filamentous, ulotrichalean algae. Observations suggest that virus infections of green algae are not uncommon.

M6. McBrien, D. C. H. and K. A. Hassall. 1967. The effect of toxic doses of copper upon respiration, photosynthesis and growth of Chlorella vulgaris. Physiol. Pl. 20:113-117.

Description of the effects of toxic doses of copper in aerobic and nonaerobic conditions on Chlorella vulgaris.

M7. McCullough, J. R. 1974. Aeration revitalizes reservoir. Wat. Sewage Wks. 12(6):84-85.

Description of an aeration system and the effects on the water quality of a reservoir.

M8. McGarry, M. G. 1970. Algal flocculation with aluminum sulfate and polyelectrolytes. J. Wat. Pollut. Control Fed. 42(5):191-201.

Discussion of chemical flocculation as a means of harvesting dispersed algae from pond water rich in algal biomass.

*M9. McGarry, M. G. and C. Tonykasame. 1971. Water reclamation and algae harvesting. J. Wat. Pollut. Control Fed. 43(5)824-835.

Discussion of methods of algae removal from wastewaters.

M10. Menday, D. and A. Buck. 1972. A shockwave technique to collapse the vacuoles of blue-green algae. Wat. Res. 6:279-284.

A method is described for controlling blue-green algae by bursting their gas vacuoles, used for buoyancy, by producing pressure waves from explosive charges. The peak pressures required (4.5 kg cm^{-2}) to sink algae can be achieved at a cost of £3.25 ha^{-1} using lines of charge. Adverse effects of explosive systems on trout at pressures greater than 7.0 kg cm^{-2} have been observed and while the method is cheap and easy, such effects and the temporary nature of control must be taken into account.

M11. Monie, W. D. 1956. Algae control with copper sulfate. Wat. Sew. Wks. 103:392-397.

Description of the "D. M. Test," used to determine the amount of copper sulfate necessary in treating a water body regardless of its temperature and chemical composition.

M12. Moriarty, D. J. W. 1973. The physiology of digestion of blue-green algae in the cichlid fish, *Tilapia nilotica*. J. Zool., Lond. 171:25-39.

The cells of blue-green algae are lysed by high concentrations of acid (pH 1.9-1.4) in the stomach of *Tilapia nilotica*. After lysis, cell contents are digested in the intestine. Acid secretion follows a diurnal cycle related to feeding, and thus there is a cycle from zero to maximum digestion each day. Some of the digestive enzymes have been studied.

M13. Moriarty, D. J. W., J. P. E. C. Darlington, I. G. Dunn, C. M. Moriarty, and M. P. Tevlin. 1973. Feeding and grazing in Lake George, Uganda. Proc. R. Soc. Lond. B. 184:229-319.

A study to determine the degree of digestion and assimilation of algae (blue-greens) by herbivores.

M14. Moriarty, D. J. W. and C. M. Moriarty. 1973. The assimilation of carbon from phytoplankton of two herbivorous fishes; *Tilapia nilotica* and *Haplochromis nigripinnis* in Lake George, Uganda. J. Zool., Lond. 171:41-55.

Discussion of the algae assimilation rates of two herbivorous fishes.

M15. Moriarty, C. M. and D. J. W. Moriarty. 1973. Quantitative estimation of daily ingestion of phytoplankton by *Tilapia nilotica* and *Haplochromis nigripinnis* in Lake George, Uganda. J. Zool., Lond. 171:15-23.

A direct method has been used to estimate the amount of phytoplankton ingested per day by herbivorous fish in Lake George, Uganda. The quantities ingested are linearly related to the weight of the fish, as given by the following regression equations for *Tilapia nilotica*: y = 271 +13.3x and for *Haplochromis nigripinnis*: y = -21.9x, where y is the dry weight of phytoplankton (mg) ingested per day and x is the wet weight of the fish (g).

*M16. Muchmore, C. B. 1973. Algae control in water supply reservoirs. Southern Illinois Univ. National Technical Information Service. PB-226-275/6WP. 57 pp.

A literature review of alternative methods to copper sulfate as possible controls for algal growth.

*M17. Mulligan, H. F. 1969. Management of aquatic vascular plants and algae. *In*: Eutrophication: Causes, Consequences, Correctives. Nat. Acad. Sci., Washington. pp. 464-482.

Review of mechanical, biological, and chemical methods of algae control.

N1. New Hampshire Water Supply and Pollution Control Commission. 1971. Algae control by mixing. Concord, N. H. 131 pp.

Discussion of artificial destratification on the limnology of Kezar Lake.

O1. Opuszynski, K. 1972. Use of phytophagous fish to control aquatic plants. Aquaculture. 1(1):61-74.

Discussion of the effectiveness of the grass carp (*Ctenopharyngodon idella*) and the silver carp (*Hypophthalmichthys molitrix*) in the control of algae and aquatic weeds.

O2. Oskam, G. 1971. A kinetic model of phytoplankton growth and its use in algae control by reservoir mixing. *In*: W. C. Ackermann (ed.). Geophysical Monograph 17. Knoxville, Tennessee. pp. 629-631.

Describes a model to predict the effectiveness of applying artificial turbulence as an algal control measure in reservoir management.

O3. Oswald, W. J. 1976. Removal of algae in natural bodies of water. EPA-600/3-76-059. U.S. Environmental Protection Agency, Corvallis, Oregon. 151 pp.

Discussion of the economics and practicability of algal harvesting with a description of the equipment.

*04. Oswald, W. J. and C. G. Golueke. 1968. Harvesting and processing of waste-grown microalgae. _In_: D. F. Jackson (ed.). Algae, Man and the Environment. Syracuse University Press, New York. pp. 371-389.

Discussion of the feasibility of harvesting and processing algae.

*05. Otto, N. E., P. M. Turner, and V. S. Miyahara. 1972. Progress report on aquatic weed and algal control studies. Bur. of Reclamation REC-ERC-72-35. Denver, Colorado. 67 pp. (NTIS-PB-214-643).

Laboratory and field studies report on chemical control methods for aquatic weeds and attached algae.

P1. Padan, E., A. Rimon, D. Ginzburg, and M. Shilo. 1971. A thermosensitive cyanophage (LLP1-G) attacking the blue-green alga _Plectonema boryanum_. Virology. 45:773-776.

P2. Padan, E. and M. Shilo. 1968. Spread of viruses attacking blue-green algae and their interaction with _Plectonema boryanum_. Bamidgeh. 20:77-87.

Discussion of algal host reactions to the infection by viruses.

P3. Padan, E. and M. Shilo. 1969. Distribution of cyanophages in natural habitats. 17th Congress of the International Society for Applied and Theoretical Limnology. Verh. Internat. Verein. Limnol. 17: 747-751.

Discussion of the distribution of cyanophages in natural aquatic habitats together with that of blue-green algal population fluctuations. It was suggested that rapid lysis of the blue-green algae is due to virogenic factors and is not merely the outcome of decline and decay. It is thus highly possible that cyanophages play an important role in the cyclic appearance and disappearance of blue-greens in nature and thus evidently influence the ecology of these aquatic systems.

P4. Padan, E. and M. Shilo. 1973. Cyanophages-viruses attacking blue-green algae. Bacteriol. Reviews. 37:343-370.

A review of the characteristics, morphology, and host range of cyanophage agents which attack and lyse blue-green algae.

*P5. Palmer, C. M. 1957. Evaluation of new algicides for water supply purposes. Taste and Odor Control Journal. 23(1):1-4.

Review of chemicals used to control algae in water supplies.

*P6. Palmer, C. M. 1959. Algae in water supplies. U.S. Public Health Service Publication. No. 657. 88 pp.

Brief review of algae control techniques (Chapter 13).

P7. Panov, D. A., Y. I. Sorokin, and L. G. Motenkova. 1969. Experimental study of young silver carp (_Hypophthalmichthys molitrix_). Prob. of Ichtyol. 9(1):101-112.

The results of C-14 studies of the feeding and food requirements of the white and mottled varieties of _H. molitrix_ at different stages of development are described. The only satisfactory food for the larvae of these fishes in the early stages of their development is small zooplankton, and the optimum concentration of these forms is 1000/liter. In addition to zooplankton, many algae can provide good and suitable food for the young of these fishes at the age of 1.5 months, the optimum concentration being 20 mg/liter, with a minimum of 2-4 mg/liter.

*P8. Patrick, R., T. Bott, and R. Larson. 1975. The role of trace elements in management of nuisance growths. EPA-660/2-75-008. Environmental Research Technical Series. 250 pp.

The purposes of these studies were to examine the effects of various kinds and amounts of trace metals on the structure of algal communities and their possible subsequent effect upon the productivity of the aquatic ecosystem. The results of these experiments indicate the concentration and form of a trace metal may have a definite effect upon which algal species can out-compete others.

P9. Peelen, R. 1969. Possibilities to prevent blue-green algal growth in the delta region of the Netherlands. Verh. Internat. Verein. Limnol. 17:763-766.

Discussion of proposed techniques to control algae in the delta region of The Netherlands.

P10. Peterka, J. J. and J. W. Held. 1972. Causes and control of algal blooms in Spiritwood Lake, North Dakota. National Technical Information Service. PB-227-675. 18 pp.

P11. Peterson, S. A., W. D. Sanville, F. S. Stay, and C. F. Powers. 1974. Nutrient inactivation as a lake restoration procedure. Laboratory procedures. National Technical Information Service. PB-239-969. 130 pp.

P12. Pickett-Heaps, J. D. 1972. A possible virus infection in the green alga _Oedogonium_. J. Phycol. 8:44-47.

Developing germlings of the green alga (_Oedogonium_) were found to contain particles presumed to be those of a virus.

P13. Pierce, P. C. and H. M. Yawn. 1965. Six field tests using two species of _Tilapia_ for controlling aquatic vegetation. Proc. South. Weed. Conf. 18:582-583.

Discussion of the effectiveness of two species of herbivorous fish as biological control agents of filamentous algae.

P14. Porter, K. B. 1972. Control of natural phytoplankton populations by grazing zooplankton. Bull. Ecol. Soc. Am. 53:9 (Abstract).

Discussion of the effect of zooplankton grazing on the species composition and standing crop of phytoplankton. Grazers can suppress the numbers of select algal species thereby regulating the relative proportions of algal groups and reducing the total number of phytoplankton.

*P15. Powers, C. F., D. W. Schults, K. W. Malueg, R. M. Brice, and M. D. Schuldt. 1972. Algal responses to nutrient additions in natural waters. II. Field experiments. Nutrients and Eutrophication. Spec. Symp. Limnol. Oceanogr. 1:141-154.

Bioassay experiments to determine the effects of various nutrient additions on growth of natural algal populations were carried out.

Discussion of some implications of the experimental results.

P16. Pratt, R. and J. Fong. 1940. Studies on Chlorella vulgaris II. Further evidence that Chlorella cells form a growth-inhibiting substance. Amer. J. Bot. 27:431-436.

Evidence is presented that indicates that Chlorella cells produce and liberate into the external solution a substance that tends to retard their growth.

P17. Prows, B. L. and W. F. McIlhenny. 1973. Development of a selective algaecide to control nuisance algal growth. EPA-660/3-73-006. Washington, D.C. 126 pp.

Discusses the results of surveying more than 100,000 compounds for properties most effective and economical for controlling the growth of nuisance species of blue-green algae (with a minimum impact on nontarget organisms).

P18. Prows, B. L. and W. F. McIlhenny. 1974. Research and development of a selective algaecide to control nuisance algal growth. EPA-660/3-74-019. Washington, D.C. 221 pp.

Discussion of the effectiveness of two algaecides under natural, open-field conditions.

P19. Prowse, G. A. 1969. The role of cultured pond fish in the control of eutrophication in lakes and dams. Verh. Internat. Verein. Limnol. 17:714-718.

Discussion and review of the literature on the use of fish as biological control agents.

R1. Robinson, E. L., W. H. Irwin, and J. M. Symons. 1969. Influence of artificial destratification on plankton populations in impoundments. Trans. Kentucky Acad. Sci. 30(1 & 2):1-18.

Discussion of the effects of artificial destratification by mechanical pumping and diffused air systems on the limnology of two lakes in Kentucky. The total algal counts, the counts of various types of algae (green, blue-green, etc.), and the number of occurrences of various species of algae are reported.

S1. Safferman, R. S. 1968. Virus disease in blue-green algae. In: D. F. Jackson (ed.). Algae, Man, and the Environment. Syracuse University Press, New York. pp. 429-439.

Discussion of techniques to isolate and culture cyanophages.

S2. Safferman, R. S. 1973. Phycoviruses. In: N. G. Carr and B. A. Whitton (eds.). The Biology of Blue-Green Algae. Blackwell Scientific Publishers. pp. 214-237.

Review of phycoviruses and their possible application as biological controls for algal growth.

S3. Safferman, R. S., T. O. Diener, P. R. Desjardins, and M. E. Morris. 1972. Isolation and characterization of AS-1, a phycovirus infecting the blue-green algae, Anacystis nidulans and Synechococcus cedrorum. Virology. 47:105-113.

Description of a virus isolated from a waste stabilization pond that infects only unicellular algae.

S4. Safferman, R. S. and M. E. Morris. 1962. Evaluation of natural products for algicidal properties. Appl. Microbiol. 10:289-292.

A method for screening of anti-algae substances is evaluated with specific reference to microbial products.

S5. Safferman, R. S. and M. E. Morris. 1963. Algal virus: isolation. Science. 140:674-680.

Freshwater blue-green algae of the genera Lyngbya, Plectonema, and Phormidium are susceptible to a virus recently isolated from a waste-stabilization pond. Electron micrographs of a partially purified preparation show that the viral particle has an icosahedral structure about 66 μm in diameter.

S6. Safferman, R. S. and M. E. Morris. 1964. Control of algae with viruses. J. Am. Wat. Wks. Assoc. 56(9):1217-1224.

Discussion of algal viruses as a possible control technique for blue-green algae.

S7. Safferman, R. S. and M. E. Morris. 1967. Observations on the occurrence, distribution, and seasonal incidence of blue-green algal viruses. Appl. Microbiol. 15:1219-1222.

Phycovirus populations were found in 11 of the 12 waste stabilization ponds studied. These populations were comprised solely of blue-green algal (BGA) viruses. Two virus types were observed, one of which was related to the previously reported LPP-1 virus. The incidence and magnitude of the LPP group indicated that several of the ponds supported well-established BGA virus populations of this type. Counts as high as 270 plaque-forming units/ml were noted; however, marked differences in the nature and magnitude of these BGA viruses were apparent even in geographically related ponds of similar design. Of the algal strains found dominant in these ponds, none was of the type reported susceptible to the LPP viruses.

*S8. Safferman, R. S. and M. E. Morris. 1977. Phycovirus bibliography. EPA-600/9-77-008. Cincinnati, Ohio. 18 pp.

The volume comprises a comprehensive survey of the phycovirus literature. It covers the period from their isolation to the present time.

S9. Safferman, R. S., M. E. Morris, L. A. Sherman, and R. Haselkorn. 1969. Serological and electron microscope characterization of a new group of blue-green algal viruses (LPP-2). Virology. 39:775-780.

Description of a new LPP class of blue-green algal viruses distinguishable from LPP-1 virus in its failure to cross-react serologically. The average edge-to-edge distance of head capsides of the LPP-1 viruses measured 586 ± 27Å. The general morphology of the two classes was indistinguishable.

S10. Safferman, R. S., I. R. Schneider, R. L. Steere, M. E. Morris, and T. O. Diener. 1969. Phycovirus SM-1: a virus infecting unicellular blue-green algae. Virology. 37:386-395.

Describes the purification of a new blue-green algal virus SM-1, which infects only unicellular forms. The new virus appears to be a polyhedron with no obvious tail and with an average diameter of about 88 μm. Several characteristics indicate that this virus is distinct from the blue-green algal virus LPP-1.

*S11. Sailer, R. I. 1975. Principals and techniques of biological control. *In:* P. L. Brezonik and J. L. Fox (eds.). Proc. Symp. on Water Quality Management Through Biological Control. Univ. of Florida, Gainesville, Jan. 29-31. pp. 8-14.

S12. Sanville, W. D., A. R. Gahler, J. A. Searcy, and C. F. Powers. 1976. Studies on lake restoration by phosphorus inactivation. EPA-600/3-76-041. Ecological Research Series. 53 pp.

Evaluation of the nutrient inactivation technique to control excessive eutrophication.

S13. Sawyer, P. J. 1970. The effects of copper sulfate on certain algae and zooplankters in Winnisquam Lake, New Hampshire. Completion Rep. Proj. No. A-004-NH, Water Resour. Res. Cent., Univ. of N. H. 29 pp.

Description of the effects of copper sulfate on certain algal and zooplankton populations in Winnisquam Lake, New Hampshire.

S14. Sawyer, P. J., J. J. Gentile, and J. Sasner. 1968. Demonstration of a toxin from *Aphanizomenon flos-aquae* (L.) Ralfs. Can. J. Microbiol. 14:1199-1204.

A potent toxin was extracted from a natural population of the blue-green alga, *Aphanizomenon flos-aquae*. The toxin is thermo- and acid-stable; alkaline labile; soluble in water and ethanol; insoluble in acetone, ether, and chloroform; and readily dialyzable. Preliminary studies show that the alga contains a toxin that, when released from lysed cells, operates at the membrane level, destroying excitability without alteration of the transmembrane resting potential.

S15. Schulte, T. L. and R. T. Lackey. 1973. Effect of rate of water discharge on phytoplankton in Claytor Lake, Virginia. Proc. 27th Conf. Southeastern Assoc. Game and Fish Comm. pp. 402-414.

Description of a study to determine the effect of water discharge on reservoir phytoplankton. Number/litre, areal units/litre, average cell size, and chlorophyll *a* content were used as measures of phytoplankton abundance. Rate of water discharge had an adverse effect on reservoir phytoplankton during spring and summer. Although increased rate of water discharge caused increased phytoplankton loss, the adverse effect of rate of water discharge on reservoir phytoplankton populations was probably at least partially due to additional discharge of nutrients. The inverse relationship between rate of water discharge and reservoir phytoplankton populations decreased in the uplake direction.

*S16. Schuytema, G. S. 1977. Biological control of aquatic nuisances--A review. EPA-600/3-77-084. Ecological Research Series. 101 pp.

Includes 532 references on biological control of macrophytes, algae, fish, and insect populations.

S17. Shapiro, J., V. Lamarra, and M. Lynch. 1975. Biomanipulation: An ecosystem approach to lake restoration. In: P. L. Brezonik and J. L. Fox (eds.). Proc. Symp. on Water Quality Management Through Biological Control. Univ. of Florida, Gainesville, Jan. 29-31. pp. 85-96.

S18. Shane, M. S. 1971. Distribution of blue-green algal viruses in various types of natural waters. Water Research. 5:711-716.

LPP blue-green algal viruses have been isolated from rivers, streams, lakes, farm and residential ponds, oxidation and stabilization lagoons, and industrial storage waters. Results of this survey showed that the virus is widely distributed in nature and is stable throughout the year in three oxidation ponds examined in the Delaware-Maryland area.

S19. Shane, M. S., R. E. Cannon, and E. DeMichele. 1972. Pollution effects on phycovirus and host algae ecology. J. Wat. Pollut. Control Fed. 44:2294-2302.

A comprehensive ecological and chemical study of the Christina River from its source to 1 mile (1.6 km) above the mouth is reported herein in an attempt to correlate pollution and the presence of LPP viruses and host algae.

S20. Shilo, M. 1970. Lysis of blue-green algae by myxobacter. J. Bacteriol. 104:453-461.

Description of the enrichment, isolation, and characterization of a myxobacter which lyses blue-green algae and the mode of lysis.

S21. Shilo, M. 1971. Biological agents which cause lysis of blue-green algae. Mitt. Internat. Verein. Limnol. 19:206-213.

Discussion of the possible role of viruses and bacteria in lysing blue-green algae, the spectrum of biological activity, their distribution, seasonal fluctuations, and use as biological control agents.

S22. Shilo, M. 1972. The ecology of cyanophages. Bamidgeh. 24:76-82.

Discussion of the ecology of cyanophages and their interaction with blue-green algal blooms and the practicability of biological control.

S23. Sills, J. B. 1964. A report on the use of Karmex to control filamentous algae in fish ponds. Proc. Ann. Conf. Southeast Assoc. Game and Fish Comm. 18:474-479.

Several chemicals that have been used in fish culture for the control of filamentous algae are discussed. Their effects on fish and fish-food organisms in ponds are reviewed.
Results obtained from applications of Karmex to 26 ponds are presented. Data show that Karmex was effective against several forms of filamentous algae at rates above one half pound per surface acre. Rates up to three pounds per surface acre had no adverse effects on fish or fish-food organisms.

S24. Singh, P. K. 1974. Isolation and characterization of a new virus infecting the blue-green alga Plectonema boryanum. Virology. 58:586-588.

Isolation of the first long, contractile-tailed virus infecting Plectonema is reported. The virus has the shortest latent period of the known blue-green algae viruses.

S25. Singh, R. N. and P. K. Singh. 1967. Isolation of cyanophages from India. Nature. 216:1020-1021.

Discussion of cyanophage attacks on blue-green algae.

*S26. Sirenko, L. A., P. S. Vovk, A. YA. Malyarevskaya, and T. I. Birger. 1976. Control of eutrophication of the Dnieper Reservoir by algae removal and herbivorous fishes introduction. Limnologica. 10(2): 603-606.

Discussion of the effects of fish harvesting on the algae community.

S27. Sladeckova, A. and V. Sladecek. 1968. Algicides-friends or foes. In: D. F. Jackson (ed.). Algae, Man, and the Environment. Syracuse Univ. Press, New York. pp. 441-458.

Compilation of literature dealing with the control of algal blooms and heavy growths of filamentous green algae. Special attention is given to European papers.

S28. Stefan, H., T. Skoglund, and R. O. Megard. 1976. Wind control of algae growth in eutrophic lakes. J. Env. Eng. Div., Proc. Am. Soc. Civil Eng. 102(EEG):1201-1213.

Review of reasons for algal blooms in lakes and suggestions to control algae.

S29. Stewart, J. R. and R. M. Brown. 1969. Cytophaga that kills or lyses algae. Science. 164:1523-1524.

A myxobacterium (Cytophaga N-5) isolated from sewage kills or lyses an array of living green and blue-green algae. When assayed with Nostoc muscorum or Plectonema boryanum, plaques form like those caused by the blue-green algal virus LPP-1. This isolate lyses or inhibits mutually Gram-positive and Gram-negative eubacteria.

*S30. Stewart, K. and G. A. Rohlich. 1967. Eutrophication - a review. State Water Qual. Control Bd. Publ. No. 34., State of California. 188 pp.

S31. Stewart, W. D. P. and M. J. Daft. 1976. Algal lysing agents of freshwater habitats. In: F. A. Skinner and J. G. Carr (eds.). Microbiology in Agriculture, Fisheries and Food Symposium, Series #4, Academic Press, New York, pp. 63-90.

Discussion of the viruses and bacteria (including actinomycetes) which occur in aquatic habitats as pathogens of the prokaryotic blue-green algae. The various algal lysing agents are distributed widely in freshwater and marine habitats, and the available evidence suggests that they may play an important, but as yet poorly understood, role in regulating growth in aquatic environments.

S32. Symons, J. M., J. K. Carswell, and G. G. Robeck. 1970. Mixing of Water supply reservoirs for quality control. J. Am. Wat. Wks. Assoc. 59(10):322-334.

Discussion of results of artificial aeration on water quality in reservoirs.

S33. Symons, J. M., W. H. Irwin, E. L. Robinson, and G. G. Robeck. 1967. Impoundment destratification for raw water quality control using either mechanical - or diffused-air-pumping. J. Am. Wat. Wks. Assoc. 59(10):1268-1291.

Discussion of the effects of artificial destratification on water quality in reservoirs.

T1. Tassigny, M. and M. Lefevre. 1971. Autoantagonism, heteroantagonism and other consequences of the excretions of algae from fresh or thermal water. Verh. Int. Verein. Limnol. 19:26-38. (English summary: Algal abstracts)

Different species of algae compete directly for nutrients or indirectly by the production of substances that inhibit the growth of competitors (Heteroantagonism). Lefevre also recognizes autoantagonism, the inhibition of the growth of species by its own excretory products. Certain algae in culture reach a stage where growth ceases although there appears to be no lack of nutrients and growth cannot be restarted by the addition of nutrients. It is observed in nature that, as one species becomes particularly abundant, other species become scare. When the abundant species declines, the others resume active multiplication. Experimentally, it was shown that species cultured in the water feeding a certain canal flourished, whereas those cultured in filtered water from the canal, where there was a large population of Aphanizomenon gracile, did not. Bacteria and fungi were eliminated in a dense population of an alga, and heteroantagonism was demonstrated in the laboratory with strains cultured free of bacteria and fungi. The substances produced by some species occasionally stimulate the growth of others. The effect of one species upon another varies according to the medium.

T2. Telitchenko, M. M., G. V. Tsytsarin, and Ye. I. Shirokova. 1970. Trace elements and algal "bloom." Hydrobiologia. 6:1-6.

It has been established that the algae *Aphanizomenon flos-aquae* and *Microcystis aeruginosa* (Cyanophyceae) concentrate 18 trace elements from water, one of which is copper. When copper stocks are exhausted the bloom of Cyanophyceae in the body of water ceases. Repeated blooms are noted only when the water is enriched with copper by the death of the previous generation of algae. It is therefore concluded that the bloom should not be combatted by treatment with copper sulfate.

T3. Toetz, D. W. 1977. Effects of lake mixing with an axial flow pump on water chemistry and phytoplankton. Hydrobiologia. 55(2):129-138.

Describes the changes due to total lake mixing with an axial flow pump on the algal biomass, species composition, and limnology of two Oklahoma lakes.

*U1. U.S. Environmental Protection Agency. 1973. Measures for the restoration and enhancement of quality of freshwater lakes. EPA-430/9-73-005. Washington, D.C. 238 pp.

V1. Venkataraman, G. S., B. D. Kaushik, G. Subramanian, S. Shanmugasundaram, and A. Govindarajan. 1973. Cyanophage AC-1: a phage infecting unicellular and colonial blue-green algae. Current Sci. (India) 42:104-105.

V2. Verigin, B. V. 1971. Results of work on acclimatization of Far Eastern phytophagous fishes and measures for their further assimilation and study in new regions. (Sport Fish. Abstr. 14417, 1972).

Discussion of the progress on acclimatization of phytophagous fishes.

V3. Vestnik Akademii Nauk. USSR. 1970. The use of herbivorous fish in fish farming and the weeding of reservoirs. 11:26-30. (Sport Fish. Abstr. 14055, 1971).

Discussion of research needs and present knowledge of herbivorous fishes.

V4. Vigon, B. W. and D. E. Armstrong. 1977. The role of silica and the vernal diatom bloom in controlling the growth of nuisance algal populations in lakes. OWRT-A-061-WIS. Washington, D.C. 126 pp.

The role of the vernal diatom population in the removal of P and Si from the lake water was evaluated for Lake Mendota, Madison, Wisconsin, in 1974. The results of the investigation show that the vernal diatom population can substantially reduce the amounts of P available to support the growth of nuisance blue-green algae during the summer.

W1. Walsby, A. E. 1970. The nuisance algae: Curiosities in the biology of planktonic blue-green algae. J. Soc. Wat. Treat. Examin. 19(4): 359-373.

Methods of controlling blue-green algal blooms are discussed.

W2. Walters, P. A., E. A. Abbot, and A. J. Isquith. 1973. Algicidal activity of a surface-bonded organosilicon quaternary ammonium chloride. Applied Microbiology. 25(2):253-256.

The hydrolysis product of a quaternary amine-containing organosilicon salt, 3-(trimethoxysilyl) -propyldimethyloctadecyl ammonium chloride, was found to exhibit algicidal activity while chemically bonded to a variety of substrates. Six representative species of Chlorophyta, Cyanophyta, and Chrysophyta were used to evaluate the algicidal activity. Substrate-bonded, ^{14}C-labeled organosilicon quaternary ammonium salt when attached to nonwoven fibers was durable to repeated washings, and algicidal activity could not be attributed to slow release of the chemical.

W3. Welch, E. B., J. A. Buckley, and R. M. Bush. 1972. Dilution as an algal bloom control. J. Wat. Pollut. Control Fed. 44(12):2245-2265.

Discusses the effects of diluting lake water with low nutrient water on the growth rate and maximum biomass of nuisance blue-green algae.

W4. Williams, L. R. 1975. Heteroinhibition as a factor in *Anabaena flos-aquae* waterbloom production. *In*: Proceedings: Biostimulation and Nutrient Assessment Workshop. EPA 660/3-75-034. Ecological Research Series. pp. 275-317.

W5. Wilson, C. G. 1977. Method of controlling growth of aquatic plants. Official Gazette of the U.S. Patent Office. 961(3):1240.

Description of a method for controlling the growth of aquatic plants in a body of water by coloring the water with a blue pigment. Light is absorbed by the pigment in the wavelength around 6500 Angstroms which is used by plants for photosynthesis.

*W6. Wixon, B. G., D. E. Modesitt, P. H. Cheng, and W. H. Zachritz. 1977. Control of algae in lakes, lagoons, and small reservoirs with biogrowth partitions. National Technical Information Service. PB-270-775. 60 pp.

Research was carried out on the control of algae from small lagoons through laboratory and field studies of man-made biogrowth surfaces for removing or controlling algae.

APPENDIX A: ALGAE CONTROL AND MANAGEMENT TECHNIQUES

Biological Control - Pathogens

TECHNIQUES	LOCATION	PROBLEM	RESULTS OR REMARKS	REFERENCES*
VIRUSES				
Viruses	Lake, USSR	Blue-green algae	Blue-green algae forming scums were lysed as a result of spraying cyanophages (only in-lake treatment reported in the literature).	P9
Viruses	Lake, Netherlands	*Microcystis aeruginosa*	Cleared areas reported within a bloom of the algae.	D7
Viruses	Lake Erken, Sweden	*Aphanizomenon flos-aquae*	Observations of the naturally occurring cyanophage Ap-1 suggest that this virus regulates the termination of the water-bloom of this species (under study).	G5
Viruses	--	Blue-green algae	Suggested as control for blue-green algae (under study).	B14, C1, D5, G7, J1, K6, K8, K9, P3, P4, S1, S2, S3, S4, S6, S21, S22, S31, V1, W1
Cyanophage N-1	Laboratory	*Nostoc muscorum*	Under study.	A1, A2, A3
Cyanophage LPP	Laboratory	*Plectonema boryanum* *Phormidium* *Lyngbya*	Lysed algae, further study underway.	C2, D1, P1, P2, S5, S7, S9, S18, S19, S24, S25
Cyanophage SAM-1	Laboratory	*Synechococcus* *Anacystis* *Microcystis*	Lysed algae, under study.	J2, S10
Virus	Laboratory	Green algae	Viruses reported, under study.	M5, P12

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* Entries correspond to Part V of the main text, "Annotated Bibliography."

(Continued)

ALGAE CONTROL AND MANAGEMENT TECHNIQUES (Continued)

Biological Control - Pathogens (Continued)

TECHNIQUES	LOCATION	PROBLEM	RESULTS OR REMARKS	REFERENCES
BACTERIA				
Bdellovibrio bacteriovorus	Laboratory	Blue-green algae	Has potential as an effective control agent (under study).	B15, B16, B17
Myxobacter	Laboratory	Blue-green algae	Lysed unicellular and filamentous species (under study).	S21
Bacteria	Laboratory	*Anabaena flos-aquae* *A. circinalis* *Aphanizomenon flos-aquae* *Microcystis aeruginosa*	Algae were lysed quickly and completely. Under further study.	D2
Cellvibrio	Laboratory	*Anabaena inequalis*	Substances from this bacteria lyse vegetative cells.	G6
Bacteria	Laboratory	*Anabaena cylindrica* *Oscillatoria prolifica*	The bacteria was capable of lysing many species of filamentous and unicellular blue-green algae.	S20
Cytophaga	Laboratory	*Nostoc muscorum* *Plectonema boryanum* Green algae	This bacteria killed or lysed these algae.	S29
FUNGI				
Fungi	English Lakes District	*Anabaena*, *Lyngbya* *Microcystis*, *Oscillatoria* *Aphanizomenon* *Gomphosphaeria*	Observations suggested that these parasites may delay or decrease the size of the maximum population.	C3, C4, C5, C6, C7, C8, C9, C10, C11

(Continued)

ALGAE CONTROL AND MANAGEMENT TECHNIQUES (Continued)

Biological Control - Grazing and Predation

TECHNIQUES	LOCATION	PROBLEM	RESULTS OR REMARKS	REFERENCES
PROTOZOA				
Psuedospora	English Lakes District	*Gemellicystis*	Infestation often followed by a rapid decrease in the algal population.	C12
Amoebae	Lake Sidney Lanier, Georgia, and Laboratory	*Anabaena planctonica*	The use of algophorus amoeba was suggested as a natural control for blooms of nuisance algae. Under laboratory study.	A4, C19
Amoebae	Laboratory	*Anabaena*	Protozoans differed greatly in the ability to prey on algae. Further study underway.	H9
Ciliates	Laboratory	*Navicula dicephala* *Nitzschia palea*	Certain ciliates (*Chilodon* and *Oxytricha*) consumed large quantities of diatoms.	B13
ZOOPLANKTON				
Zooplankton	Westhampton Lake, Richmond, Virginia	*Asterionella* *Anabaena spiroides* *Oscillatoria tenuis* *Ceratium hirundinella*	Suggested as control (under study).	B9
Zooplankton (Rotifers)	Fish Lake, Duluth, Minnesota	*Gloeotrichia*	Under further study.	H11
Copepod (*Thermocyclops hyalinus*)	Lake George, Uganda	*Microcystis*	Ingests the blue-green alga and can assimilate 35-80% of the ingested carbon.	M13
Zooplankton (*Daphnia*)	In situ - lake	Algae	Selective reduction and significant suppression of phytoplankton (under study).	P14

(Continued)

ALGAE CONTROL AND MANAGEMENT TECHNIQUES (Continued)

Biological Control - Grazing and Predation (Continued)

TECHNIQUES	LOCATION	PROBLEM	RESULTS OR REMARKS	REFERENCES
FISH				
Silver carp (*Hypophthalmichthys molitrix*) and Thickhead (*Aristichthys nobilis*)	USSR	Phytoplankton	Proposed control.	V2
Silver carp	Dnieper Reservoir, USSR	*Microcystis aeruginosa* *Aphanizomenon flos-aquae* *Anabaena* spp. *Oscillatoria agardhii*	Assimilated blue-green algae. Studies continuing.	S26
Silver carp	Experimental ponds, USSR	*Aphanizomenon flos-aquae* *Anabaena spiroides* *Anabaena variabilis*	The algae were ingested and assimilated.	P7, V3
Tilapia spp. and Silver carp	Lakes	Diatoms	Freely digested.	P19
		Anabaenopsis raciborskii	Freely digested.	
		Anabaena flos-aquae	Not digested.	
		Microcystis aeruginosa	Not digested.	
Mississippi silversides (*Menidia audens*)	Blue and Clear Lakes, California	Planktonic algae	Inconclusive	C18
Tilapia (*Tilapia nilotica*) and (*Haplochromis nigripinnis*)	Lake George, Uganda	*Microcystis* *Anabaena*	Blue-green algae digested and 70-80% of the carbon assimilated.	M12, M13, M14, M15
Grass carp (*Ctenopharyngodon idella*) and Silver carp	Ponds, Warsaw, Poland	*Hydrodictyon*	Generally ineffective in controlling algal growth.	O1
Grass carp (*Ctenopharyngodon idella*) and Silver carp	Cooling Towers, USSR	Weeds and algae	Suggested for use.	V3

(Continued)

Biological Control - Grazing and Predation (Continued)

TECHNIQUES	LOCATION	PROBLEMS	RESULTS OR REMARKS	REFERENCES
FISH (Continued)				
Mullet (*Mugil cephalus*)	Lake Kinneret, Israel	Dinoflagellate blooms	Inconclusive.	P19, D7
Mugil spp.	Brackish water lakes	Benthic and planktonic algae	Suggested for use.	P19
White amur (*Ctenopharyngodon idella*)	Ponds and lakes, Arkansas	*Pithophora*, *Chara* *Nitella*, *Spirogyra*	Algae were controlled (stocking rate of fish: 100-500/fingerlings per acre).	B1
Blue tilapia (*Tilapia aurea*)	Lake Kinneret, Israel	Algae	Inconclusive	D7
Congo tilapia (*Tilapia melanopleura*)	Artificial pools, Auburn, Alabama	*Spirogyra* *Rhizoclonium*	Effective in controlling algae (studies continuing).	A14
Tilapia nilotica *Tilapia melanopleura*	Ponds, Brunswick, Georgia	*Pithophora*	Excellent control.	P13
Tilapia	Hatchery drains, Buhl, Idaho	Algae	Not furnished.	State Agency
ALGAE				
Algae (*Ochromonas danica*)	Laboratory	*Microcystis aeruginosa*	Has potential, under study.	C14, C15, C16, D3
Algae (*Ochromonas danica*)	Laboratory	*Microcystis aeruginosa*	*Ochromonas ovalis* was most voracious in its attack of the several species of *Ochromonas* studied (under study).	P17
Algae (*Ochromonas danica*)	Natural ponds	*Microcystis aeruginosa*	*Ochromonas* was unable to cope with the new environmental conditions. Studies continuing.	P18

(Continued)

Biological Control - Biomanipulation

TECHNIQUES	LOCATION	PROBLEM	RESULTS OR REMARKS	REFERENCES
Growth inhibitors	Laboratory	Algae	The growth-inhibiting substance produced by *Chlorella vulgaris* inhibits this species and others.	P16
Growth inhibitors produced by Volvocaceae	Laboratory	Algae	Substances produced by these algae inhibit the growth of most members of the Volvocaceae. It is hoped that these studies will shed light on a method to control the indiscriminate growth of nuisance algae in water supplies.	H1, H2, H3, H4, H5, H6
Growth inhibitors	Laboratory and study pond	*Anabaena flos-aquae*	A heteroinhibitory or allelopathic compound secreted by this alga appears to be an important factor in its bloom formation; it prevents cell division and inhibits the growth of other algae in the community.	W4
Growth inhibitors	Experimental ponds, Wisconsin	Phytoplankton	It was observed that dense growths of macrophytes had a significant inhibitory effect upon phytoplankton populations.	H7
Growth inhibitors	Laboratory	*Cladophora* *Pithophora*	Antagonistic activity exists between aquatic weeds and filamentous green algae.	F7
Growth inhibitors	Natural lakes	Blue-green algae	It was observed that algal-produced inhibitory secretions influenced the ecology of water blooms.	F5
Growth inhibitors	Laboratory	Green algae	The growth of several species of green algae was inhibited when cultured with blue-greens. Inhibitory substances are an important factor in the development of relatively unialgal blooms of various species.	B10

(Continued)

ALGAE CONTROL AND MANAGEMENT TECHNIQUES (Continued)

Biological Control - Biomanipulation (Continued)

TECHNIQUES	LOCATION	PROBLEM	RESULTS OR REMARKS	REFERENCES
pH alteration	Laboratory	Blue-green algae	Additions of HCl, CO_2, or Cl_2 or other substances might help shift algal populations from blue-greens to greens. Zooplankton might be increased and algae subsequently decreased by lowering pH.	S17
Pantothenic acid	Laboratory	Algae	Suggested as a means to increase zooplankton.	S17
Zooplanktivorous fish	Laboratory	Algae	Suggested as means to allow selected zooplankton to increase and consume phytoplankton.	S17
Daphnia _magna_	Laboratory	Algae	Suggested as an algal controller after zooplanktivores carnivorous on _Daphnia magna_ have been reduced.	S17
Biomanipulation	Proposed	Blue-green algae	Control strategy would be to eliminate winter blue-green blooms with copper sulfate and enhance spring diatom growth by the addition of silica. The silica would enhance diatom growth and some other desirable forms and would lessen the effect of the remaining inhibitory metabolites produced by the blue-green algae. Such efforts should then increase the period of diatom domination, decrease nutrient levels left in the epilimnion when the diatoms senesce, and inhibit the subsequent late summer blue-green bloom.	K1, K2, K3
Biomanipulation	Proposed	Blue-green algae	It is suggested that augmenting the dissolved silica reserves during the critical growth period of diatoms can substantially reduce the amounts of phosphorus available to support the growth of nuisance blue-green algae during the summer.	V4

(Continued)

ALGAE CONTROL AND MANAGEMENT TECHNIQUES (Continued)

Biological Control - Biomanipulation (Continued)

TECHNIQUES	LOCATION	PROBLEM	RESULTS OR REMARKS	REFERENCES
Mild acidification	Proposed	Blue-green algae	Blue-green algae are completely absent from habitats in which the pH is less than 4 or 5 and uncommon in mildly acidic waters (pH 5 or 6). It is suggested that mild acidification of lakes may control or eliminate blue-green algal blooms.	B12
Silica enrichment (proposed)	Harvey's Lake, Vermont	*Oscillatoria rubescens* and other blue-green algae	Enhancement of diatom competitive capabilities by silica enrichment for blue-green algal control.	State Agency

(Continued)

ALGAE CONTROL AND MANAGEMENT TECHNIQUES (Continued)

Chemical Control - Algicides

TECHNIQUES	LOCATION	PROBLEM	RESULTS OR REMARKS	REFERENCES
Cutrine-Plus	Lakes	Planktonic and filamentous algae	Application at a rate of 0.6 gallons per acre-foot of water is effective in controlling algae.	A11
Copper sulfate	Carleton Pond, Augusta, Maine	*Synura* *Asterionella*	Concentration of 0.35 mg/l in the pond was sufficient to eliminate the problem algae.	A12
Copper sulfate	James River, Richmond, Virginia	Nuisance algae	Concentration of 0.10-0.15 mg/l in the colder months and 0.15-0.20 mg/l in the warmer months retarded algal growth.	A6
Copper sulfate	Meadow Lake, Flushing Meadows, New York	*Coelosphaerium* *Aphanizomenon* *Staurastrum*	Apparently effective at initial concentrations of 12 mg/l and 1 mg/l after 24 hours.	A5
Cutrine	Delavan Lake, Wisconsin	*Anacystis*	Chemical treatment eliminated the nuisance algae.	A9
Copper	Laboratory	*Selenastrum capricornutum*	Algicidal at concentrations of 0.30 mg/l.	B3
Zinc	Laboratory	*Selenastrum capricornutum*	Algicidal at concentrations of 0.70 mg/l.	B3
Cadmium	Laboratory	*Selenastrum capricornutum*	Algicidal at concentrations of 0.65 mg/l.	B3
Copper sulfate	(Five) Ponds, Auburn, Alabama	*Microcystis aeruginosa*	Copper sulfate concentrations (0.05-0.08 mg/l) reduced the populations to a controlled status for up to 25 days. In most cases the alga was reduced to a lesser degree after successive treatments suggesting a possible resistance to the chemical.	C20
Copper sulfate	Laboratory	*Chlorella pyrenoidosa* *Microcystis aeruginosa*	Concentrations of (0.05-0.4 mg/l) were algicidal.	F11

(Continued)

Chemical Control - Algicides (Continued)

TECHNIQUES	LOCATION	PROBLEM	RESULTS OR REMARKS	REFERENCES
Copper sulfate	New Hampshire lakes	Nuisance blue-green algae	Effective control.	F15, F16
Copper sulfate	Mozhaysk Reservoir, USSR	*Aphanizomenon flos-aquae* *Microcystis aeruginosa*	Copper was found to be a necessary "trace element" for algal growth. When the copper content of lake water falls to 1 µg/l,the bloom ceases. It was recommended that treatment with copper sulfate will fertilize the water for many years, thus promoting algae growth.	T2
Copper	Bioassay using water from Clear Lake, California	Effect of micronutrient (copper) on phytoplankton	Below 10 µg/l,copper stimulated primary production and nitrogen fixation in blue-green algae. Additions of 10 µg/l or more were inhibitory.	G3
Copper sulfate	Laboratory	*Anabaena flos-aquae* *Scenedesmus quadricauda*	Concentration needed to control *A. flos-aquae* was 0.1-0.25 mg/l, and 0.8-1.0 mg/l was required for *S. quadricauda*. Young cultures require lower concentrations to be controlled.	G2
CA-350 (copper sulfate and silver nitrate)	Lubi Reservoir, Trebic, Czechoslovakia	*Aphanizomenon flos-aquae*	The algae bloom disappeared during the 24 hours after application with no marked biological or chemical changes in the reservoir water and without the toxic side effects of copper.	K7
Copper sulfate	Winnisquam Lake, New Hampshire	*Anabaena circinalis*	Application rate of 4 lbs/acre controlled the algal bloom.	S13
Chelated copper sulfate	Lopez Reservoir, San Luis Obispo County, California	*Anabaena*	Copper sulfate at concentrations of 1.1-1.73 lbs/acre did not significantly affect algal-growth trends. The growth remained exponential even after application of the algicide.	F19

(Continued)

ALGAE CONTROL AND MANAGEMENT TECHNIQUES (Continued)

Chemical Control - Algicides (Continued)

TECHNIQUES	LOCATION	PROBLEM	RESULTS OR REMARKS	REFERENCES
Cutrine-Plus	Chalk Cliffs Trout Rearing Unit, Colorado	Filamentous algae	High nutrient load in water, only marginally effective. Used only after trout were removed from ponds. One treatment annually.	State Agency
Copper complexes and sterilants, specifically: A&V70 Algaecide, Komeen, 3M System M, Aquazine, Diuron, and Endothall	Florida	*Pithophora* spp. *Hydrodictyon* spp.	Not furnished.	State Agency
Cutrine	Fish ponds and ornamental ponds, Idaho	Algae	Recommended for use in this state.	State Agency
Copper sulfate	Various public water supplies, Illinois	Blue-green algae	Very successful in controlling algae. The maximum allowable dosage is 1.0 mg/l and in general the concentration applied was less than 0.5 mg/l.	State Agency
Copper sulfate or cutrine	Maryland	Nuisance algal growth	Not furnished.	State Agency
Copper sulfate, chelated copper products, amine salts of endothall	Michigan	Nuisance algal growth	For the years 1972-1977 the overall success of the control was between fair (50-60%) and good (70-100%) with a few reports of poor and ineffective treatment.	State Agency
Copper sulfate, Cutrine-Plus	Minnesota	No specific information on the algae causing the problem in each lake, but principal species are blue-green algae such as *Anabaena*, *Aphanizomenon*, *Anacystis*, and *Microcystis*.	Results of these treatments range from poor to excellent, with most permittees reporting satisfactory results.	State Agency

(Continued)

Chemical Control - Algicides (Continued)

TECHNIQUES	LOCATION	PROBLEM	RESULTS OR REMARKS	REFERENCES
Copper sulfate	Ponds, Mississippi	Nuisance algae	Some algal control is practiced. Further information not furnished.	State Agency
Copper sulfate	Togus Pond, Kennebec County, Maine	Filamentous, periphytic, and planktonic algae	Not successful; dense bloom of <u>Anabaena circinalis</u> occurred after chemical application.	State Agency
Copper compounds (copper sulfate)	Maine	Nuisance algae	The Division of Lakes and Biological Studies recommends that the application of copper compounds for cosmetic control of nuisance algae be discontinued. No information furnished on alternative control techniques.	State Agency, A10
Copper sulfate	New Jersey	Not furnished	Successful control, provided that the treatment is started early enough before the algae become too dense, and a regular application schedule is maintained throughout the growing season.	State Agency
Chelated copper compounds	New Jersey	Not furnished	Results inconsistent. Suggests that the failures have been due to improper application or waiting until the algal growth became too dense.	State Agency
Copper sulfate applied at not more than 0.3 mg/l in the upper 6 ft. layer of water (0.8 lb/acre-ft)	Non-trout lakes and ponds with hardness greater than 100 mg/l, New York	Filamentous and planktonic algae	Specifics not provided. Results usually reported as partial or temporary control.	State Agency
Cutrine-Plus (liquid) same dosage as copper - (0.23 gal/acre-ft)	Non-trout lakes and ponds with hardness greater than 100 mg/l, New York	Filamentous and planktonic algae	Specifics not provided. Results usually reported as partial or temporary control.	State Agency

(Continued)

ALGAE CONTROL AND MANAGEMENT TECHNIQUES (Continued)

Chemical Control - Algicides (Continued)

TECHNIQUES	LOCATION	PROBLEM	RESULTS OR REMARKS	REFERENCES
Mariner-A (liquid) same dosage as copper (0.27 gal/acre-ft)	Nontrout lakes and ponds with hardness greater than 100 mg/l, New York	Filamentous and planktonic algae	Specifics not provided. Results usually reported as partial or temporary control.	State Agency
Mariner-M (dicopper carbonate) same dosage as above (1.45 lb/acre-ft)	Nontrout lakes and ponds with hardness greater than 100 mg/l, New York	Filamentous and planktonic algae	Specifics not provided. Results usually reported as partial or temporary control.	State Agency
Copper sulfate	Lake Morey, Vermont	Excessive *Spirogyra* Growth along shoreline.	Generally effective control.	State Agency
Copper sulfate	Weathersfield, Vermont (public water supply)	Unidentified bloom	Effective control.	State Agency
Copper sulfate	St. Albans Bay, Lake Champlain, Vermont	*Aphanizomenon*	Effective control.	State Agency
Copper sulfate	Occoquan Reservoir, Virginia	*Anacystis*	Caused fish kills in 6/71 and 6/77 due to miscalculation. Use of copper sulfate for algal control is widespread in water supplies and recreation lakes.	State Agency
Copper sulfate	Lake Chesdin, Virginia	*Anacystis* *Oscillatoria*	Inconclusive.	State Agency

(Continued)

ALGAE CONTROL AND MANAGEMENT TECHNIQUES (Continued)

Chemical Control - Algicides (Continued)

TECHNIQUES	LOCATION	PROBLEM	RESULTS OR REMARKS	REFERENCES
Copper sulfate (dosage rate 5.4 lbs/suface acre)	Wisconsin	Planktonic algae	For the years 1975 and 1976 an estimated 400 chemical treatments were successfully made. Most of the bodies of water were treated both years.	State Agency
Copper sulfate (dosage rate 10 lbs/surface acre)	Wisconsin	Filamentous algae	Specific information for nuisance forms were not discussed.	State Agency
Copper sulfate and Karmex	McClintic Wildlife Station fishing ponds, Pt. Pleasant, West Virginia	Algae (exact species unknown)	Algae turns brown and sinks to pond bottom after each application. Good algae control with copper sulfate 1.3 lb/acre and/or Karmex 1 lb/3 acre-ft.	State Agency
Copper sulfate (coarse)	Sebbins Pond, Beford, New Hampshire	*Oscillatoria* spp.	Cleared after bag-dragging (100 lbs).	State Agency
Copper sulfate (coarse)	Enfield Reservoir, Enfield, New Hampshire	*Anabaena circinalis* *Anabaena circinalis*	July 29, 1977 - cleared after bag-dragging (70 lbs). August 24, 1978 - cleared after bag-dragging (70 lbs).	State Agency
Copper sulfate (coarse)	Lake Winnisquam, Merideth, New Hampshire	*Mougeotia* spp. *Gloeotrichia* spp. *Gloeotrichia* spp.	July 11, 1978 - cleared after bag-dragging (100 lbs). July 24, 1978 - cleared after bag-dragging (1 ton). August 17, 1978 - reduced numbers after bag-dragging (1 ton).	State Agency
Copper sulfate (coarse)	Kelly's Falls, Goffstown, New Hampshire	*Anabaena circinalis*	Cleared after bag-dragging (430 lbs).	State Agency
Copper sulfate (coarse)	Webster Lake, Franklin, New Hampshire	*Spirogyra* spp. *Spirogyra* spp.	August 10, 1977 - cleared after bag-dragging (800 lbs). August 14, 1977 - cleared after bag-dragging (200 lbs).	State Agency

(Continued)

ALGAE CONTROL AND MANAGEMENT TECHNIQUES (Continued)

Chemical Control - Algicides (Continued)

TECHNIQUES	LOCATION	PROBLEM	RESULTS OR REMARKS	REFERENCES
Copper sulfate (coarse)	Fulton Pond, Deering, New Hampshire	*Anabaena* spp.	Cleared after bag-dragging (30 lbs).	State Agency
Copper sulfate (coarse)	Glen Lake, Goffstown, New Hampshire	*Anabaena* spp. *Anabaena circinalis*	August 5, 1977 - cleared after bag-dragging (700 lbs). August 4, 1978 - cleared after bag-dragging (700 lbs).	State Agency
Copper sulfate (coarse)	Wild Goose Pond, Pittsfield, New Hampshire	*Zygnema* spp.	Cleared after bag-dragging (Amount unknown).	State Agency
Copper sulfate (coarse)	Jackson Pond, New Hampton, New Hampshire	*Anabaena* spp.	Cleared after bag-dragging (100 lbs).	State Agency
Copper sulfate (coarse)	Pearly Lake, Rindge, New Hampshire	*Anabaena circinalis* *Anabaena circinalis*	July 19, 1977 - cleared after bag-dragging (700 lbs). July 13, 1978 - cleared after bag-dragging (700 lbs).	State Agency
Copper sulfate (coarse)	Mascoma Lake, Enfield, New Hampshire	*Anabaena circinalis* *Anabaena circinalis*	August 8, 1977 - cleared after bag-dragging (6,500 lbs). July 7, 1978 - cleared after bag-dragging (6,500 lbs).	State Agency
Copper sulfate (coarse)	Big Willey Pond, Strafford, New Hampshire	*Zygnema* spp.	Cleared after bag-dragging (200 lbs).	State Agency

(Continued)

Chemical Control - Algicides (Continued)

TECHNIQUES	LOCATION	PROBLEM	RESULTS OR REMARKS	REFERENCES
Potassium permanganate	Laboratory	Microcystis aeruginosa Anabaena circinalis Gloeotrichia echinulata Aphanizomenon flos-aquae	Concentrations of 0.5-2.0 mg/l gave the same results as 0.025-0.10 mg/l of copper sulfate in controlling the problem species.	F3
Potassium permanganate	Laboratory	Microcystis aeruginosa Anabaena circinalis Gloeotrichia echinulata Oscillatoria rubescens Oscillatoria chalybia	Potassium permanganate controlled the problem algae. It was recommended that this chemical be used in treating raw water reservoirs where the species of algae are unknown or where several species with different chemical susceptibilities are present.	F6
Potassium permanganate	Laboratory	Algae (20 species)	Less toxic to the algae studied than copper sulfate. A 16-mg/l concentration was required for complete algal control.	K4
300 Algicides	Laboratory	Planktonic algae	Bioassay testing was performed (see publication).	G8
300 Algicides	Laboratory	Microcystis aeruginosa	After bioassay tests 2-3-dichloronaphthoquinone was found to be the most effective and was lethal at concentrations as low as 2 g/l. Additional testing under field conditions is needed.	F12
2-3-dichloronaphthoquinone	Spauldings Pond, Jonesville, Wisconsin	Microcystis Aphanizomenon	Spray applications of 2-3-DNQ at concentrations of 0.03-0.05 mg/l effectively killed heavy growths of blue-green algae with no observable harmful effects to green algae, higher aquatic plants, fish, and zooplankton.	F13
Various chemicals	Deer Creek Reservoir, Salt Lake City, Utah	Planktonic algal blooms	Field investigations showed that the most effective algicides were rendered useless in waters of total alkalinity of over 300 ppm. Copper sulfate and its chelated forms are the only algicides tested that are economically feasible for extensive reservoir treatment. An extensive summary is presented in the publication.	F20

(Continued)

ALGAE CONTROL AND MANAGEMENT TECHNIQUES (Continued)

Chemical Control - Algicides (Continued)

TECHNIQUES	LOCATION	PROBLEM	RESULTS OR REMARKS	REFERENCE
Compound No. 73: p-Chlorophenyl-2-thienyl-iodonium chloride	Lakes and laboratory	*Anabaena*, *Microcystis*, *Aphanizomenon*, and *Oscillatoria*	Effective chemical for algae control, and exhibited a high degree of specificity for the target organisms.	P17, P18
Phenylureas (diuron)	Ponds	*Cladophora* *Enteromorpha* *Vaucheria*	Concentrations of 0.2-0.4 mg/l controlled algae.	B18
Halogens	Laboratory	*Cladophora*	Halogens, especially chlorine, killed algal cells at concentrations of 10 mg/l in 2-hour contact time. Copper sulfate required 10 mg/l for 4 days for similar results.	B8
3-(trimethoxysilyl)-propyldimethyloctadecyl ammonium chloride	Laboratory	*Oscillatoria borneti* *Anabaena cylindrica* *Selenastrum gracile* *Gonium*, *Volvox* *Pluerococcus*	Controlled algae. The ability of Si-QAC to form durable algicidal surfaces, without release of chemical to the surrounding environment, offers a new approach to water treatment.	W2
Karmex 3-(3,4-dichlorophenyl)-1,1-dimethylurea	26 Ponds	*Spirogyra* *Oedogonium* *Cladophora* *Pithophora*	All species were controlled with no detrimental effects to fish or fish-food organisms.	S23
5-(5 Barbiturilidene)-Rhodanine	Laboratory	*Scenedesmus*, *Plectonema* *Anabaena*, *Ankistrodesmus* *Oscillatoria*, *Coccochloris* *Chlamydomonas*, *Lyngbya* *Synura*, *Chlorella*	This compound was reported to control algae at concentrations from 0.1 to 100 mg/l (preferred range is 10-20 mg/l) with none of the degradation products being toxic to fish and most fish-food organisms at algae-killing concentrations.	K5
Endothall	Lakes and ponds	Floating algal mats	Good control at dosage of 2-3 mg/l of active ingredient.	A13
Monuron and diuron	Dordrecht Reservoirs, Netherlands	*Aphanizomenon flos-aquae* *Microcystis aeruginosa* *Oscillatoria agardhii*	High cost of such treatment is a disadvantage. Concentration of 1 mg/l required. Experiments with diuron continuing. Treatment of the reservoir is proposed.	P9

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ALGAE CONTROL AND MANAGEMENT TECHNIQUES (Continued)

Chemical Control - Algicides (Continued)

TECHNIQUES	LOCATION	PROBLEM	RESULTS OR REMARKS	REFERENCES
Simazine	Lakes, Illinois	Filamentous algae	Application rate of 0.5 mg/l successfully controlled algae.	State Agency
Simazine	New Jersey	Not furnished	Very successful results.	State Agency
Diuron	Two water bodies, Illinois	Filamentous algae	Effective in controlling algae at a rate of 1 lb. of 80-wp formulation per acre of water surface.	State Agency
Calcium sulfate applied at 0.1 mg/l when dissolved oxygen is > 5.0 mg/l	Hampton Manor Lake (8 acres), New York	Nuisance blue-green and green algae	Not available. Monitoring to be undertaken.	State Agency
Karmex	Fork Creek PHFA pond, West Virginia	Algae (exact species unknown)	Algae turns brownish and sinks to pond bottom after each application. Good algae control with copper sulfate 1.3 lb/acre and/or Karmex 1 lb/3 acre-ft.	State Agency
Karmex (diuron)	Bear Rocks Lakes, Wheeling, West Virginia	Dense growths of Cladophora	Growth effectively reduced each summer permiting bank fishing.	State Agency

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ALGAE CONTROL AND MANAGEMENT TECHNIQUES (Continued)

Physical Control

TECHNIQUES	LOCATION	PROBLEM	RESULTS OR REMARKS	REFERENCES
Microstrainers	Queen Mary Reservoir, England	Phytoplankton	Removal of up to 50% of the larger algal cells.	B5
Microstrainers	Bay of Quinte, Lake Ontario, Canada	*Anabaena* *Oscillatoria*	Effective in removing algae during periods of high algae concentrations.	G1
Microstrainers	Ulemiste Lake, USSR	*Microcystis*, *Anabaena* *Oscillatoria*, *Lyngbya*	Removed 74% of blue-green algae.	L6
Microstrainers	Clear Lake, California	*Aphanizomenon*	*Aphanizomenon* was removed for cosmetic purposes in small bays. An oil skimmer was used to collect floating blue-green algae which was pumped through a microstrainer for removal. Results were inconclusive.	D7
Harvesting	Clear Lake, California	*Aphanizomenon* *Anabaena*, *Microcystis*	More efficient pickup system needed for the system to be economically feasible (under study).	O3
Explosive charges (to burst gas vacuoles)	Water supply reservoirs, South Wales, England	*Microcystis* *Anabaena*	This technique provides a drastic but quick and cheap control method; it is recommended that explosives should not be used as a regular means of algal control.	M10
Aquashade (water dye)	Lakes (proposed)	Algae	Coloring of the water would reduce light penetration in the wavelengths used by plants for photosynthesis (proposed method).	W5
Aquashade	Michigan	Nuisance algae	Used by a few commercial applicators in combination with other algicides. This is an effective treatment when applied early in the year and if the algae problem is not too severe.	State Agency
Lake drawdown circulation/aeration	North Dakota	Not furnished	Inconsistent results.	State Agency
Lake drawdown	Lake Apopka, Florida	Poor water quality	Following drawdown, phytoplankton were less numerous and contained fewer blue-greens.	F14

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ALGAE CONTROL AND MANAGEMENT TECHNIQUES (Continued)

Physical Control (Continued)

TECHNIQUES	LOCATION	PROBLEM	RESULTS OR REMARKS	REFERENCES
Lake drawdown	Lake Tohopekaliga, Florida	Aphanizomenon Anabaena Microcystis	No significant algal blooms have occurred since lake drawdown.	H10
Dredging	Lake Trummen, Sweden	Aphanizomenon flos-aquae Microcystis aeruginosa Oscillatoria	Summer phytoplankton biomass has been reduced by nearly 60% and the troublesome blue-green algae has nearly disappeared.	A7

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ALGAE CONTROL AND MANAGEMENT TECHNIQUES (Continued)

Control Through Combined Effects

TECHNIQUES	LOCATION	PROBLEM	RESULTS OR REMARKS	REFERENCES
Nutrient diversion and alum application	Twin Lakes, Ohio	Algal blooms	Plankton biomass declined after diversion.	C17
Aluminum sulfate	Lake Långsjön, Sweden	Nuisance algae	No change in the algal biomass was evident.	J3
Chelating agents and aluminum sulfate	Fish rearing ponds, Minnesota	Blue-green algae	The response to reduced phosphorus levels was variable. The chelating agents were ineffective in reducing algal growth.	B2
Nutrient removal (alum and sodium aluminate)	Annabessacook Lake, Kennebec County, Maine	Annual algal blooms from internal phosphorus loading	A significant reduction in total phosphorus has been observed. Project will continue next year (1979) to determine effects on phytoplankton.	State Agency
Nutrient inactivation with aluminum sulfate	Medical Lake, Spokane County, Washington	Nuisance blue-green algae	Preliminary results indicate that the treatment was at least initially successful in reducing algae. A two-year study is currently underway to determine results.	State Agency
Ferrichloride ($FeCl_2$)	Dordrecht Reservoir, Netherlands	Blue-green algae	Changes in plankton biomass noted. Results inconclusive.	P9
Sodium aluminate	Clines Pond, Oregon	*Anabaena*	The algae appeared to shift from a predominantly blue-green to a green community and there was no indication of reduced algal standing crop.	S12
Phosphate removal, salts of lanthanum, zirconium, and aluminum	Laboratory	Phytoplankton	Depression of algal growth was evident.	P11

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ALGAE CONTROL AND MANAGEMENT TECHNIQUES (Continued)

Control Through Combined Effects (Continued)

TECHNIQUES	LOCATION	PROBLEM	RESULTS OR REMARKS	REFERENCES
Proposed reduction of nutrients	Spiritwood Lake, North Dakota	*Lyngbya*, *Gomphosphaeria* *Aphanizomenon*, *Microcystis*	Suggested that once the nutrient inputs into the lake are reduced, the algal bloom will be reduced.	P10
Dilution	Moses Lake, Washington	*Aphanizomenon*	The addition of low-nutrient Columbia River water to the lake reduced the subsequent maximum biomass of nuisance blue-green algae in direct proportion to the amount of dilution water added.	W3
Diversion and phosphate removal	Lower St. Regis Lake, New York	*Anabaena* *Anacystis*	Summer blooms were reduced in duration and intensity and the annual spring bloom did not occur.	F18
Diversion	Lake Waubesa, Lake Monona, and Lake Kegonsa Wisconsin	Blue-green algae	In general, the number of species and changes in dominant species have not changed in Monona and Kegonsa. The importance of *Microcystis* in the plankton of Waubesa decreased sharply, whereas, the number of species increased since diversion.	L3
Water discharge	Claytor Lake, Virginia	Phytoplankton	(1) Increased rate of discharge did increase the amount of phytoplankton removed from the reservoir. (2) Rate of water discharge had less effect on removal of reservoir phytoplankton from locations further uplake. (3) Increase in rate of water discharge had an adverse effect on reservoir phytoplankton populations during spring and summer.	S15

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ALGAE CONTROL AND MANAGEMENT TECHNIQUES (Continued)

Control Through Combined Effects (Continued)

TECHNIQUES	LOCATION	PROBLEM	RESULTS OR REMARKS	REFERENCES
Artificial destratification	Wahnbach Reservoir, Sieburg, Germany	*Oscillatoria rubescens*	Reduction in blue-green algal population with an increase in the diatom *Melosira granulata* v. *angustissima*.	B7
Artificial aeration	Occoquan Reservoir, Alexandria, Virginia	Excessive algae	No evidence of any prolific algal growths since the aeration system began operation.	E1
Artificial aeration and hypolimnion destratification	Hemlock Lake, Section Four Lake, Michigan	Poor water quality	Phytoplankton standing crop declined slightly following aeration.	F1, F2
Artificial destratification	Kezar Lake, New Hampshire	*Aphanizomenon flos-aquae*	Algal succession was modified. The summer bloom of *Aphanizomenon* occurred earlier than in previous years. Total peak algal biomass was reduced slightly.	F17, N1
Artificial circulation	Kezar Lake, New Hampshire	*Aphanizomenon flos-aquae*	Mixing caused a uniform vertical distribution of this alga. Its population eventually dissipated and chlorophycean taxa became dominant.	H8
Artificial circulation (partial destratification)	West Lost Lake, Michigan	Low productivity	Blue-green algae increased. Results indicate that the timing of the onset of destratification was of great importance in determining algal response.	H12
Artificial destratification	Parvin Lake, Colorado	*Anabaena flos-aquae* *Aphanizomenon flos-aquae* *Gomphosphaeria lacustris*	Total phytoplankton abundance decreased but the decrease was not uniform among all algal groups. The blue-greens increased in numbers.	L1
Artificial destratification (theoretical models)	Lakes	Algal blooms	Destratification to control algal blooms is only appropriate under certain circumstances and requires high energy systems sufficient to redistribute algal cells throughout the water column.	L7, L8

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ALGAE CONTROL AND MANAGEMENT TECHNIQUES (Concluded)

Control Through Combined Effects (Continued)

TECHNIQUES	LOCATION	PROBLEM	RESULTS OR REMARKS	REFERENCES
Artificial aeration	Prompton Lake, Pennsylvainia	Algal blooms	Algal blooms were completely controlled in the lower reaches of this reservoir.	M7
Artificial destratification	Boltz Lake, Falmouth Lake, Kentucky	Poor water quality	Total phytoplankton biomass did not change, blue-green algae were reduced to a greater extent than green algae and diatoms. The total number of plankton species remained the same or increased slightly.	R1, I2
Artificial destratification	Lakes	Poor water quality	Plankton populations decreased temporarily during reservoir mixing and the species composition shifted in predominance to green algae.	S32
Artificial destratification	Lakes	Poor water quality	Blue-green algal populations declined more than green algae.	S33
Artificial destratification	Hams Lake, Oklahoma	Poor water quality	Algal biomass declined, numbers of species of green algae increased while blue-green algal species did not change.	T3
Artificial destratification	Arbuckle Lake, Oklahoma	Poor water quality	Algal biomass was not affected.	T3
Artificial destratification (models)	--	Control phytoplankton	Suggested that artificial mixing can significantly reduce peak algal biomass.	S28, 02, L9