United States
Environmental Protection
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Great Lakes
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536 South Clark Street
Chicago, Illinois 60605

EPA-905/3-79-003
April 1979

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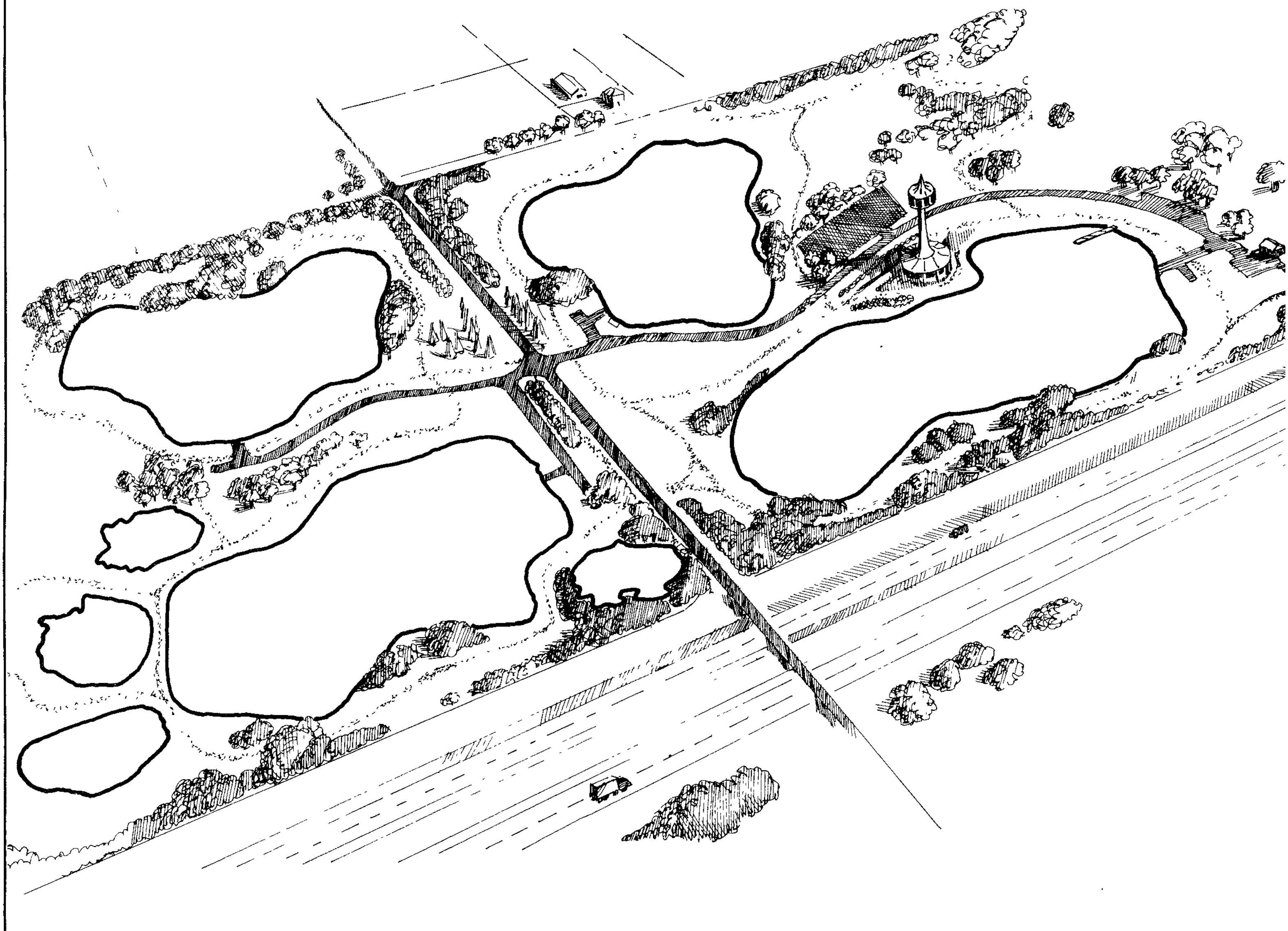
Utilization of Natural Ecosystems for Wastewater Renovation



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UTILIZATION OF NATURAL ECOSYSTEMS FOR WASTEWATER RENOVATION

by

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Comprehensive
Grant No. Y005065

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On behalf of
City of East Lansing
East Lansing, Michigan 48823

for

REGION V
GREAT LAKES NATIONAL PROGRAM OFFICE
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536 SOUTH CLARK STREET, ROOM 932

DISCLAIMER

FOREWORD

This was a Comprehensive Grant involving coordinated support of a USEPA Construction Grant, a Research Grant, and a Section 108a Great Lakes Demonstration Program Grant. This report describes a biological lakes system that optimizes wastewater treatment and provides good quality water for spray irrigation and ground water recharge. Data in this report covers a period from 1972 to 1975.

Dr. Edith J. Tebo
Director
Great Lakes National Program Office

ABSTRACT

Michigan State University in cooperation with the City of East Lansing, Michigan, constructed a permanent facility for the experimental treatment, recycle and reuse of municipal sewage plant effluents on a 200 ha (500 acre) site on the main campus. The facility provides for the diversion of up to 7570 m^3/day (2 MGD) of secondary effluent from the East Lansing activated sludge treatment plant. However, storage capacity limits year round treatment to 2270 m^3/day (0.6 MGD). This waste flow is directed away from the receiving stream to an intensely managed aquatic and terrestrial nutrient recycling system. The facility consists of a portion of the East Lansing Wastewater Treatment Plant, a transmission line, four experimental lakes and a spray irrigation site. A primary objective is to strip nutrients from the waste flow as it proceeds through the system by incorporating nutrients into harvestable biomass.

The system has been in operation with tertiary effluent for about 18 months. It is scheduled to go "on-line" with secondary effluent in 1976. Biological activity in the aquatic system has a major impact on water quality as evidenced by significantly reduced water concentrations of phosphorus, nitrogen and inorganic carbon. Much of the nutrient flow is shunted into harvestable plant material, both in the aquatic and terrestrial portions of the system.

This report represents a synthesis of preliminary research results from a multidisciplinary program involving approximately 25 university faculty scientists. This report is submitted in fulfillment of Grant No. Y005065 by the Institute of Water Research for the City of East Lansing, Michigan, under the partial support of the Environmental Protection Agency. This was a Comprehensive Grant involving coordinated support of the USEPA Construction Grant, Research and Great Lakes Demonstration Programs. Work was completed as of January, 1975.

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ACKNOWLEDGMENTS

This report was prepared by the Institute of Water Research, Michigan State University, to fulfill the obligations of EPA Grant No. Y005065 awarded to the City of East Lansing, Michigan, in 1972. It represents a status report on the performance and operation of the Water Quality Management Facility since its routine start-up in the summer of 1974. It also represents a synthesis of all aspects of research being performed in conjunction with the facility, regardless of funding source. The bulk of these research results cover the period from 1974 to December, 1975, although a few pilot level studies date back to 1969. It should be clearly recognized that many findings are preliminary in nature in view of the relatively short operational history of the facility, and the fact that it has only been operated with tertiary effluent to date due to construction delays associated with the new East Lansing sewage treatment plant.

In a multidisciplinary program as broad in scope as this one, it is indeed difficult to give equivalent credit in relation to the contribution by the many members of the project.

The report is based upon the cooperation and input from the individual research project leaders. This group includes Drs. Domy C. Adriano, Donald L. Beaver, James W. Butcher, Richard A. Cole, Walter Conley, Frank M. D'Itri, P. David Fisher, James Hook, Howard E. Johnson, Walter N. Mack, Richard W. Merritt, Clarence D. McNabb, Harold D. Newson, Frank Reed, Gene R. Safir, Gerhardt Schneider, Steven N. Stephenson, Milo B. Tesar, James Tiedje, Ted S. Vinson, Donald P. White, Eugene P. Whiteside, and David C. Wiggert, plus many of their graduate students. Departmental affiliations and areas of responsibility for these project leaders is listed in Section 4 of this report. No attempt will be made to associate unpublished data and research results with a particular individual. To do so would be extremely cumbersome and would fail to give appropriate recognition to results arising from the shared efforts of many.

Dr. Robert C. Ball and Dr. Howard A. Tanner originally envisioned this project and spent several years making it a reality. We owe them special thanks. Dr. Marvin E. Stephenson contributed to the initial planning and decision for this project.

Financial support for both construction and research for this project has come from several sources. These include the U.S. Environmental Protection Agency, the State of Michigan, and the Rockefeller, Ford and Kresge Foundations. In addition, we are indebted to the City of East Lansing and Mr. Jack Patriarche, City Manager, for support and cooperation, particularly in negotiating the federal and state grants which were awarded directly to the City. Michigan State University has committed the land as well as human and material resources. Throughout the entire course of the project, we have been guided by the efforts of Dr. Milton Muelder, then Vice President for Research Development, who served as the voice of the University in all official matters, on and off campus and by Dr. John Cantlon, the present Vice President for Research and Development. We would also like to acknowledge the support of the U.S. Department of the Interior's Office of Water Research and Technology and the MSU Agricultural Experiment Station for support of individual projects and personnel. We would also like to thank Mr. Stephen Poloncik and Mr. Ralph G. Christensen of the Chicago Office of the U.S. Environmental Protection Agency for their guidance and support.

SECTION 1

INTRODUCTION

Conventional treatment of municipal wastewater in its present form was first developed in the late 1800's and early 1900's as a means of insuring public health with little regard for environmental degradation. It relied heavily on the "self purifying" properties of streams. The first concerns for the receiving water environment were related to maintenance of oxygen in lakes and streams at levels that would insure fish production. Thus, the tests of the effectiveness of treatment through the 1950's relied heavily on BOD and coliform bacteria standards. Concern for eutrophication of receiving waters in the 1960's has led to more and more emphasis on removing nutrients, especially phosphorus and nitrogen, to protect the surface waters of the U.S. The additional technology required for nutrient removal requires large economic costs for both construction and operation. This "add-on" conventional technology has also proven to be energy inefficient, has resulted in a major secondary problem of what to do with the large quantities of sludge that result, and represents a failure to recycle the valuable nutrients into useful products. Thus, alternative means of treatment that are energy efficient and result in recycling of increasingly scarce nutrients at least possible cost to the environment are needed.

One such technology that has been in use for hundreds of years is land treatment. Even though this technique has been practiced for hundreds of years, very little hard scientific data on its potential and the environmental trade-offs involved in its adoption were available prior to 1960. The Water Quality Management Project (WQMP) at Michigan State University was conceived as a combination lake (lagoon)-land treatment research and demonstration facility in the mid-60's by Dr. Robert C. Ball and Dr. Howard Tanner at Michigan State University. Its purpose was to provide a highly flexible system of lakes and land treatment areas that would allow innovative research on the ability of lakes or land or a combination of the two to treat wastewater with maximum recycle potential. The ultimate goal of this project is to provide design and operating criteria for such facilities.

Funding for the project was finally put together from several sources (see Acknowledgments) and construction began in 1972. This report represents a summary of system design, operation, and research performed on the project through December, 1975.

SECTION 2

CONCLUSIONS

The Michigan State University Water Quality Management Project (WQMP) is a research, demonstration, and management facility that was designed and built to thoroughly explore the concept that aquatic, marsh, and terrestrial ecosystems can serve as adjuncts or replacements for conventional wastewater treatment systems under selected conditions, and that these systems can be effective in wastewater treatment, resource reuse, and energy conservation.

Construction of the WQMP is now complete and all field facilities are now in operation testing its capacity to (1) renovate wastewater, (2) to recover and reutilize nutrients, and (3) recharge the groundwater aquifer.

Although the full facility is only now officially complete, many parts of it have been operational for varying lengths of time through the expedient of temporary pumps, and other equipment, and through use of poor quality, tertiary effluent from the old East Lansing sewage treatment plant. Thus, conclusions at this time are tentative and are based upon those segments of the facility that have been in operation long enough to permit a first approximation of the data base. The following conclusions must be regarded as having been derived from less than full integration of the complete facility. Conclusions to date are as follows:

(1) The four lakes (total area of 16 ha) on the WQMP significantly decreased phosphorus concentrations during 1975, the first year of operation. The lakes received poor quality tertiary effluent at a rate of 1893 m^3/d (0.5 MGD). This rate resulted in a detention time of about 30 days per lake. The significant decrease of phosphorus resulted from sorption on the native clays used to seal the bottom of the lakes and to a lesser extent from uptake and removal by harvest of aquatic macrophytes and by aquatic plant mediated physical-chemical precipitation of phosphates. Subsequent data taken after the clays were saturated indicate that the four lakes can remove

only about 1 mg P/ℓ or less of incoming phosphorus from secondary effluent through the latter two mechanisms.

(2) The four lakes are highly efficient at stripping nitrogen from wastewater primarily through out-gassing as a result of the aquatic plant mediated high pH values above the pK of ammonia gas formation and to a lesser extent through denitrification during periods of high respiration associated with aquatic plant decay.

(3) During the first year of operation, passage of wastewater through the four lakes results in significant decreases in alkalinity and in significant softening of water.

(4) Efficient management of the four lakes for most efficient wastewater treatment is a function of detention time and plant harvest to maintain selective plant populations. Thus, understanding the biology of the aquatic plants is essential and is an area of active research on the WQMP.

(5) The lakes do reduce coliform bacteria to levels below discharge standards.

(6) Major efforts on the land treatment site to date have emphasized obtaining pre-irrigation baseline data. Data on soil chemistry, soil mapping, vegetation, nitrifying and denitrifying bacteria, plant parasitic nematode populations, insect vectors of various pathogens, small mammal populations, and avian populations have been collected. Very limited data to date indicate no significant impact of irrigation on mammal and bird populations.

(7) Preliminary studies on the effects of 20 varieties of forage crops indicate that they are highly efficient at uptake of nitrogen and phosphorus from wastewater and have the potential of renovating up to 7.5 cm/week of wastewater.

(8) Older forests are not efficient at removal of nitrogen from wastewater according to preliminary data. They do efficiently remove phosphorus.

(9) Old field vegetation does respond to wastewater irrigation by increased biomass production but not by increased production of new stems. This increased biomass production has the potential for removal of most of the applied nitrogen if the fields were harvested. The litter disappearance rate was also increased by irrigation.

(10) Tree plantations were established with 10 species of trees. These trees do respond to wastewater irrigation with increased growth. Much of the

phosphorus (95%), 65% of total nitrogen, and many of the cations are removed by spray irrigation on this plantation.

(11) Winter spray irrigation is possible in Michigan. However, removal of nutrients from this wastewater was low. Data are very preliminary and more studies will be conducted.

(12) Calculation of the hydraulic capacity of the site suggests that an average infiltration of about 5 cm/week can be expected. At this infiltration rate and without winter irrigation, the storage capacity of the four lakes limits year-round operation to 2270 m^3/d (0.6 MGD).

SECTION 3

RECOMMENDATIONS

The ultimate goal of the WQMP is to establish design and operating criteria for combined lake-land irrigation wastewater treatment facilities. Not enough data have been collected to date to allow establishment of such criteria. The following tentative criteria are suggested:

(1) If the goal is to minimize phosphorus discharge, all water should be spray irrigated on the land. No discharge directly from the lake system should be allowed.

(2) The lakes should be managed to strip nitrogen from the incoming wastewater. This wastewater could then be irrigated on areas with low nitrogen removal potential, such as forests, without contamination of groundwater.

(3) Efficient management of the lakes will entail adjustment of detention time and/or selective aquatic plant harvest. The effects of such management on plant populations and nutrient dynamics needs to be studied in more detail.

(4) Spray irrigation on old fields, forage crops, or newly established tree plantations during the growing season appears to effectively renovate wastewater. High nitrogen wastewater should not be irrigated in older forests since removal efficiency is low.

(5) In order to better understand the underlying ecological mechanisms and to establish design and operating criteria for such systems, the following research is needed:

   (a) Continue ongoing mass balances through the WQMP lakes to assess the nutrient removal potential over time.

   (b) Continue studies on the rate and extent of material compartmentalization between the water, sediments, and biota within the lake system so that the actual and potential removal mechanisms are known.

(c) Expand efforts aimed at evaluating the interacting variables such as light, carbon, phosphorus, and temperature controlling aquatic plant growth kinetics and interspecific competition so that the lakes can be managed to encourage the most efficient plant populations.

(d) Further examine the rate, extent and mechanisms of nutrient concentration by various plant assemblages, including both biological factors and biologically induced physical-chemical factors so that equations can be developed for predicting plant mediated nutrient removal.

(e) Develop better methods to harvest plant biomass prior to bacterial recycle of nutrients so that reuse can be maximized and respiratory, low oxygen events in the lakes can be minimized.

(g) Continue studies on how to maximize fish production within wastewater lakes relative to the wastewater treatment objectives.

(h) Further explore the use of harvested plant biomass for livestock, poultry, and fish food as a means of recycling nutrients from the wastewater.

(i) Continue ongoing research aimed at completion of input-output mass balances on the terrestrial site for water and nutrients so that nutrient removal and recycle potential can be evaluated.

(j) Continue to monitor the rate and extent of material and water transfer within the terrestrial ecosystem so that underlying mechanisms are better understood and management potential is better clarified.

(k) Continue to evaluate the potential of wastewater irrigation during the winter so that the potential for year round operation can be evaluated.

(l) Evaluate the effect of management techniques on mammal, bird, and invertebrate populations as a means of predicting environmental impact.

(m) Develop quantitative information on the public health aspects of this and similar systems with the goal of obtaining relative risk comparisons of alternative wastewater treatment schemes.

(n) Compare relative economics and energetics of this and similar recycling projects to conventional systems.

After all the above studies are completed, design and operating criteria for the best combination of lake-land irrigation systems need to be developed. This is the ultimate goal of research on the WQMP.

SECTION 4
RESEARCH OVERVIEW

A MULTIDISCIPLINARY CHALLENGE

The Water Quality Management Project is a large systems level study embracing elements of both aquatic and terrestrial ecosystems. Central to the goal of developing design and management criteria that can be used by others, is achieving a high level of predictability on how similar systems will perform in other localities. However, the ability to interpret and predict structure, function, and response of entire ecological systems to perturbations is only in its embryonic stages. Ecosystems are dynamic and involve highly variable biological material that is changing and adapting through time in response to changing environmental conditions. Faced with the immediate need to understand and categorize the essential components of the specific water and land ecosystems that make up the operational base of the Water Quality Management Project, it was essential that a number of decisions concerning research be made early in the project.

The decisions faced included: (1) where would the decision making authority reside and who would give direction and purpose to the research and other efforts, and provide the base dollar support, (2) what would be the basis for a system of priorities of research, (3) how would the broad spectrum of expertise of a university campus be encouraged to become involved in the solution of the needed research, and (4) how would the findings be translated into a management operation, and from that into design specifications for public use.

PROJECT MANAGEMENT

The research and demonstration nature of this project places special importance on the management of the facility. To maximize research yield from the WQMP, it is necessary that project management include encouragement to research scientists on the MSU campus, coordination of research effort, and maintenance of operational and management conditions which allow attainment of research objectives. In addition, management responsibilities include meshing the various research objectives with demonstration aspects of the facility. Management of the facility became one of the prime functions of the Institute of Water Research (IWR).

Included in the responsibilities of the IWR are writing and reviewing of research proposals, developing research priorities, development of a record-keeping system, constant overview of all research on the site, personnel management, and monitoring water quality and other indices of system performance. This last task calls for maintenance of complete laboratory facilities and personnel to analyze large numbers of water samples in addition to evaluating chemical and biological quality of other samples collected for specific research projects.

Since the WQMP is located on the Michigan State University campus, continuous interface with the public is important. A great many people visit the project each year, both as individuals and in organized groups. Education of the public in the various environmental trade-offs associated with such wastewater renovation projects is an important adjunct of the project, and every effort is made to encourage the public to visit the facility.

In short, the role of the IWR with respect to the research aspects of the project are twofold: (1) to function as a service group to researchers in obtaining and distributing routine monitoring data, and (2) to function as a synthesizer, integrator and disseminator of information in those cases where normally it would not be done.

The Approach

Initially, high priority was placed on obtaining baseline data on the physical and chemical parameters of the area that the project would occupy. These baseline data included soil mapping and classification, chemical analysis of the wastewater that would reach the project, design of data handling procedures, and classification of plants and animals of the area. These are referred to further in this section. Many of these are to be discontinued when the data base is complete.

A second order of priority included those investigation areas started earlier that required continuity into the actual operation of the facility, such as water chemical data, and the inception of a broad array of research projects that could only be undertaken after wastewater became available on a routine basis. These included:

Lake Studies--

1. Mass balance studies to characterize the rate, extent, and mechanisms of nutrient concentration by primary producers. Included is also an assessment of biologically induced physical-chemical precipitation of nutrient compounds.
2. Studies to assess the natural attenuation of human pathogens.
3. Development of management strategies to selectively promote the growth of macrophytes, phytoplankton or filamentous algae. Variables include wastewater quality and detention time, time and extent of harvest, water level control, and basin morphometry.
4. Management of fish populations within the lakes in a manner consistent with achieving wastewater treatment objectives.
5. The utilization of harvested plants, zooplankton, and invertebrates for use as diet supplements for livestock, poultry, and cultured fish.
6. Economic and energy evaluation of alternative management strategies for this system and comparison with other technologies.

Terrestrial Studies--

1. Management of the soil-vegetative complex in post-agricultural old fields with emphasis on nitrogen cycling.
2. Forested ecosystem studies to parallel old field studies.
3. Row crop studies designed to assess ability of selected plants to tolerate heavy hydraulic loadings and to extract nutrients from wastewater.
4. Winter irrigation studies to assess the suitability of winter soils to extract nutrients.
5. Surface and ground water hydrologic studies.
6. Fate of waterborne pathogens in terrestrial systems.

The research and demonstration nature of this project negates establishment of a fixed set of standard operating procedures, and a prime challenge is to mesh facility operation to ongoing research and demonstration projects. Evaluation and planning for future facility needs are conducted by the IWR, but much of the future development of the site will depend upon results of current and future research. Thus, long-range planning must be updated frequently as research results become available. Specific research and monitoring projects that have been conducted to date are summarized below.

Individual Projects and Investigators

In addition to investigators in the IWR there are over 20 other faculty from the campus that have been or are now actively engaged in research on the project. Most have graduate students who are developing their investigations into theses. Others have completed detailed write-ups in report form and have submitted them to the IWR where they are kept on file. A listing of these includes the following.

Dr. Domy C. Adriano, Department of Crop and Soil Sciences -- *Nutrient dynamics in soils irrigated with wastewater.*

Work began July 1, 1974, with emphasis on characterizing soil nutrient profiles in a well defined "microwatershed" on the irrigation site. Dr. Adriano left the campus and the areas of research he started have been incorporated into the overall research project of Dr. Thomas Burton. The soil nutrient profile data are reported in the Baseline Watershed Studies subsection of Section 8. Cooperating investigators on this project included Dr. James Tiedje, Department of Crop & Soil Sciences and Dr. Frank Reed Department of Botany and Plant Pathology.

Dr. Donald L. Beaver, Department of Zoology -- *Avian-insect interactions and the influence of wastewater irrigation.*

Work began in June, 1974, to establish pre-irrigation baseline information on bird populations on the entire irrigation area. A second aspect focused on bird feeding habits in an area scheduled for irrigation. This will be a graduate thesis topic. Pre-operational studies have been completed and will later serve as benchmark information needed for post-operational comparisons. Initial findings are summarized in Section 8.

Dr. Thomas Burton, Institute of Water Research and Department of Zoology -- *Nutrient dynamics in forested and old field ecosystems irrigated with wastewater.*

Work began in 1975. Studies initiated earlier by Drs. Adriano and Stephenson were incorporated in a greatly expanded research effort. This research is currently active and is emphasizing nitrate movement in the soil under different management strategies. See detailed report in Section 8.

Dr. James W. Butcher, Department of Zoology -- *Influences of wastewater irrigation on soil and litter invertebrates.*

This project started in June, 1974, and is designed to assess the role of soil and litter fauna in nutrient retention and soil fertility as reflected in crop yield. Pre-irrigation studies were completed and represent valuable baseline data. No follow up studies are envisioned at this time since the investigators have switched to other projects. Background data are summarized in Section 8. Cooperating investigators include Drs. Delbert Mokma and Lynn Robertson of the Department of Crop and Soil Sciences and Ms. Renate Snider of the Department of Zoology.

Dr. Richard A. Cole, Department of Fisheries and Wildlife -- *Role of amphibians in nutrient cycling in wastewater ponds.*

This study was begun in January of 1975 to examine the role of amphibians in nutrient export from the lake system and their impact on primary productivity. It is currently an active study that will result in a Ph.D. thesis by Ms. Diana Weigman. Dr. Richard Wassersug of the University of Chicago has been a cooperating investigator on the project. No results are available at this time.

Dr. Walter Conley, Department of Fisheries and Wildlife -- *Ecology of small mammals in the wastewater irrigation site.*

Work began early in 1974 to characterize small mammal populations prior to wastewater irrigation. This is a companion project to the bird population studies and was primarily designed to develop baseline data for later comparison. These data are summarized in Section 8. In an earlier phase of the WQMP, Dr. Conley prepared a document describing a conceptual ecosystem model which was formulated for developing research strategy on the terrestrial portion of the project. This is available as IWR Technical Report No. 38, pp. 1-140.

Dr. Frank M. D'Itri, Institute of Water Research and Department of Fisheries and Wildlife -- *Water chemistry and monitoring for the WQMP.*

This program began in 1971 to characterize wastewater quality at the East Lansing Sewage Treatment Plant and later expanded to include water sampling at key transfer points in the WQMP. Included in this program is the operation, maintenance, and quality control of the IWR Analytical Laboratory. These data are included in this report.

Dr. P. David Fisher, Department of Systems and Electrial Engineering -- *Data management and development of on-line monitoring systems for ecosystem management.*

This project began in 1974 to develop an efficient data management system to input, store, retrieve, and manipulate the large amount of numerical information generated from all cooperating projects. Two reports are available from the IWR on this latter phase of the study: (1) A computer-based data aquisition and control system for the MSU Water Quality Management Project, pp. 1-14 and (2) dedicated Remote Data Logger for IWR Spray Irrigation Site Meterological Tower, pp. 1-56. After development, this program has faltered since most researchers prefer to analyze their own data.

Dr. James Hook, Department of Crop and Soil Sciences -- *Management of the soil-vegetation complex of old fields and forage row crops.*

This is a continuation of an earlier study begun by Dr. Adriano and has now expanded to study changes in soil water quality under cultivated forage crops and managed old fields. Work began in 1975 and cooperating investigators include Dr. Thomas Burton and Dr. Milo Tesar. Early data are included in Section 8.

Dr. Howard E. Johnson, Department of Fisheries and Wildlife -- *Utilization of wastewater for fish culture.*

The project started in July, 1975, to examine the potential for culturing fish in wastewater and for utilizing by-products of wastewater ponds (macrophytes, algae, and invertebrates) as fish food. The project also includes management studies on fish planted in Lake 4. The program is currently active and results through 1975 are summarized in Section 7.

Dr. Darrell L. King, Institute of Water Research and Department of Fisheries and Wildlife -- *Aquatic fertility in the wastewater lakes of the WQMP.*

This study began in 1974 and represents the primary synthesis and integration of data generated in the lake monitoring program for the WQMP. Results of this synthesis are included in Section 7.

Dr. Walter N. Mack, Institute of Water Research and Department of Microbiology and Public Health -- *Public health related studies on the WQMP.*

Pilot studies on viral and bacterial pathogens in the East Lansing Sewage Treatment Plant date back to about 1970. This has been a continuing project to characterize the attenuation of human pathogens in municipal wastewater as it flows through all elements of the WQMP. Data are not available on the attenuation of viruses in the system at this time. Data on bacteria are summarized in Section 7.

Dr. Clarence D. McNabb, Department of Fisheries and Wildlife -- *Productivity of macrophytes and algae in wastewater ponds.*

This study began at a pilot level about 1970 and has continued to the present time. The project is evaluating the potential of using submersed macrophytes and algae for reclamation of wastewater with emphasis on nutrient uptake. These data are incorporated in Section 7.

Dr. Richard W. Merritt, Department of Entomology -- *Ecology of aquatic insects in the WQMP lakes.*

The study began in July, 1975, to determine the nature and extent of aquatic insect productivity with emphasis on midge populations and their potential as pests. Data collected through 1975 are summarized in Section 7.

Dr. Harold D. Newson, Department of Entomology -- *Medical entomological aspects of the wastewater irrigation site.*

Research started in July, 1973, for baseline data on biting insects as potential disease vectors and population levels of plant parasitic nematodes. Continuing research is now examining population changes associated with wastewater irrigation with emphasis on the epidemiology of California encephalitis virus. Data are summarized in Section 8. Cooperating investigators include Drs. James Butcher and Richard Snider from the Department of Zoology and Drs. George Bird, Charles Laughlin, and John Knierim from the Department of Entomology.

Dr. Frank Reed, Department of Botany and Plant Pathology -- *Vegetation responses to wastewater irrigation.*

Dr. Reed began this study in 1973 cooperating with Dr. Stephen Stephenson of the same department and Dr. Domy Adriano of the Department of Crop and Soil Sciences. Primary emphasis was on the "old field" system of the WQMP. Dr. Reed left the MSU faculty in 1975 but these studies are being continued with considerable modification by Drs. Thomas Burton and James Hook. The data through 1975 are summarized in Section 8.

Dr. Gene R. Safir, Department of Botany and Plant Pathology -- *Mycorrhizal root systems and wastewater recycling efficiency.*

This study began in 1975 to examine symbiotic root-fungus interactions and their role in nutrient-water uptake by old field vegetation irrigated by wastewater. No data are yet available. This study is currently active as a graduate research thesis.

Dr. Stephen N. Stephenson, Department of Botany and Plant Pathology -- *Vegetative studies on old field ecosystems.*

Pilot studies began in about 1971 to examine productivity and diversity changes in old fields on the WQMP subjected to fertilization. Vegetative mapping for the terrestrial site was also conducted to establish preoperational benchmarks on the abundance and distribution of plant species. These data are included in Section 8. Cooperating investigators included Dr. Frank Reed from the Department of Botany and Plant Pathology and more recently Dr. Thomas Burton of the Institute of Water Research and Department of Zoology.

Dr. Milo B. Tesar, Department of Crop and Soil Sciences -- *Production of forage crops irrigated with wastewater.*

This project began in 1974 to assess the ability of selected forage crops to tolerate heavy application of wastewater. Studies of nutrient and heavy metal uptake are also part of the project. Initial findings are incorporated in Section 8. Cooperating investigators include Drs. Bernard Knezek and James Hook from the same department. This study is currently active.

Dr. James Tiedje, Department of Crop and Soil Sciences -- *Studies on microorganisms responsible for nitrogen transformations at the WQMP site.*

The project began in 1974 and was designed primarily to assess the denitrification potential for the lake system and selected portions of the irrigation site. Initial data are summarized in Section 8. Cooperating investigators included Drs. Domy Adriano, Bernard Knezek, and Frank Reed.

Dr. Ted S. Vinson, Department of Civil and Sanitary Engineering -- *Soil infiltration of wastewater under freezing conditions.*

This study began in 1974 to characterize the rate and extent of wastewater percolation under wintertime irrigation. See report MSU-CE-75-2, "A field study on the relationship of temperature and ice to infiltration at a spray irrigation facility." Data are summarized in Section 8. Cooperating investigators include Dr. David Wiggert from the same department and Dr. Thomas Burton of the Institute of Water Research and Department of Zoology.

Dr. Donald P. White and Dr. Gerhardt Schneider, Department of Forestry -- *Nutrient cycling in forest ecosystems irrigated with wastewater.*

Research began in 1971 on a small plot basis on the WQMP irrigation site. Parallel studies were also conducted at a nearby wastewater irrigation site. Current studies by these two investigators are examining responses of a tree plantation being irrigated with wastewater. Initial results of both studies are included in Section 8.

Dr. Eugene P. Whiteside, Department of Crop and Soil Sciences -- *Sampling classification, description, and mapping of soils on the Water Quality Management Project site.*

Dr. Whiteside was responsible for the overall soil mapping program for the WQMP irrigation site. The study began in 1974 by T. Zobick, a graduate student, and is now completed and included in this report in Section 8.

Dr. David C. Wiggert, Department of Civil and Sanitary Engineering -- *Ground water hydrology.*

This investigator began work on ground water hydrology for the WQMP site in 1972 and these efforts are currently active. Dispersion modeling of the Saginaw aquifer and monitoring of both surface and unsaturated subsurface flows make up the bulk of this study. Some of these results are summarized in Section 8. Cooperating investigators include Drs. Ted Vinson and David McIntosh of the same department.

SECTION 5

DESCRIPTION OF FACILITY

LOCATION

The project is located in the Red Cedar River Watershed, a tributary of the Grand River of the Great Lakes drainage (Figure 1) at an intercept of 42°43'50" north latitude and 84°28'58" west longitude. A more precise location would be T4N, R1, 2W, Sections 1, 6, 31, 36, Ingham County, Michigan. It is entirely within the boundaries of the MSU campus forming most of its southern boundary (Figure 2).

It lies above the Saginaw geological formation of sandstone and shale which is approximately 12 m below the surface of the site. Overlying this formation is a conglomerate of glacial debris of sand, clay, and gravel. The surface soil pattern is complex and is described in detail later in this report. The climate in the region of the project is influenced by the Great Lakes, and has an annual precipitation of approximately 77.2 cm. Precipitation from April through October averages 51.4 cm, with widely varying extremes from year to year. Approximately 20% of the precipitation falls as snow. About 65% of precipitation is lost by evaporation. The average growing season is about 154 days, and about 79% of the days of the year are cloudy.

PHYSICAL FEATURES

The physical facility for the Michigan State University wastewater recycling project consists of four basic elements: (1) an activated sludge sewage treatment plant designed for maximal operational flexibility so that water ranging from primary to tertiary effluent can be transported to the wastewater recycling facility; (2) a transmission line; (3) a lake system; and (4) a land irrigation system. This system is schematically shown in Figure 3. The following is a more detailed discussion of the facility.

Figure 1. Principal rivers in the state of Michigan and location of the Red Cedar River watershed, site of the Michigan State University Water Quality Management Project.

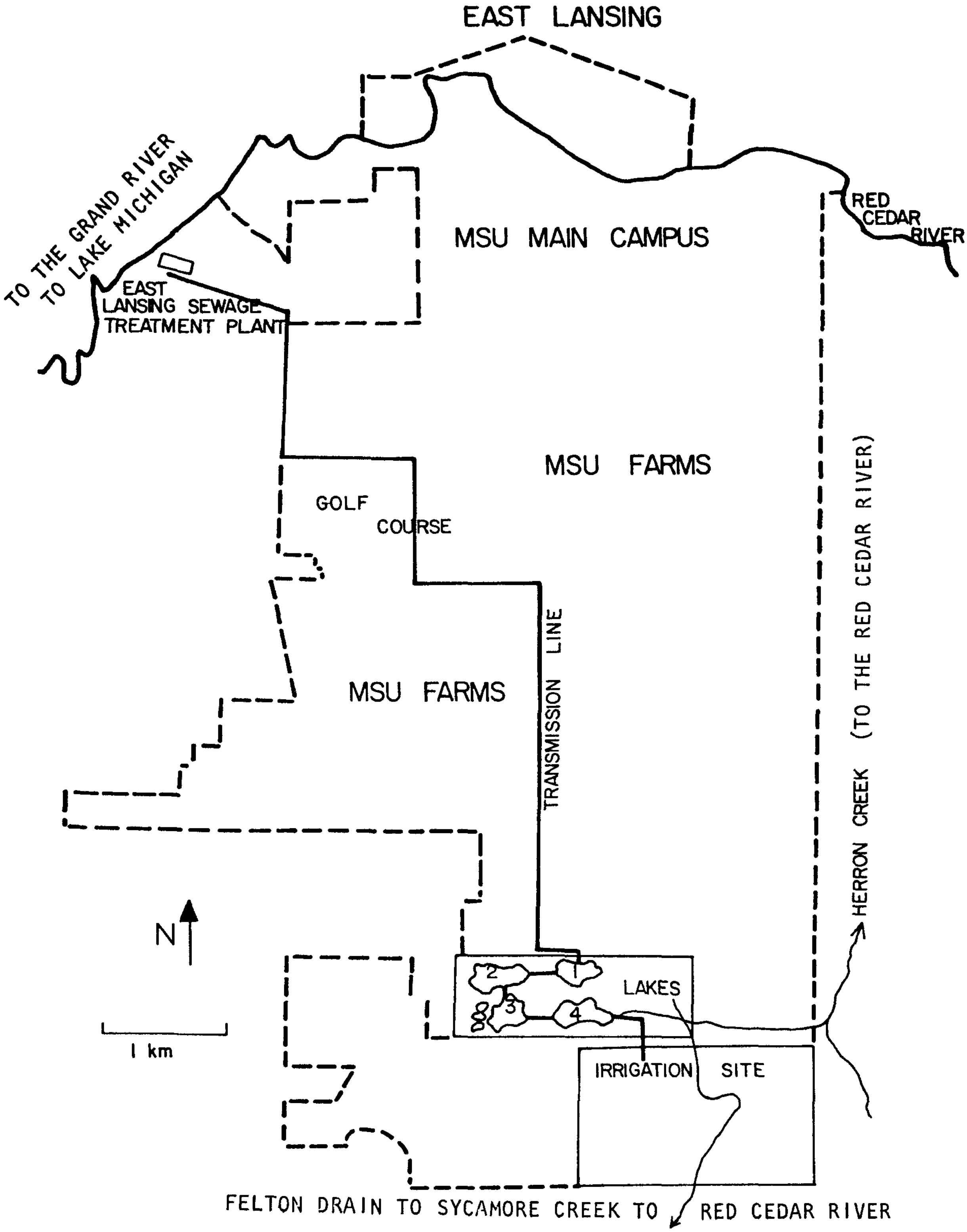


Figure 2. Location of the WQMP on the MSU campus. Figure is drawn to scale with the dashed line designating the boundary of University property.

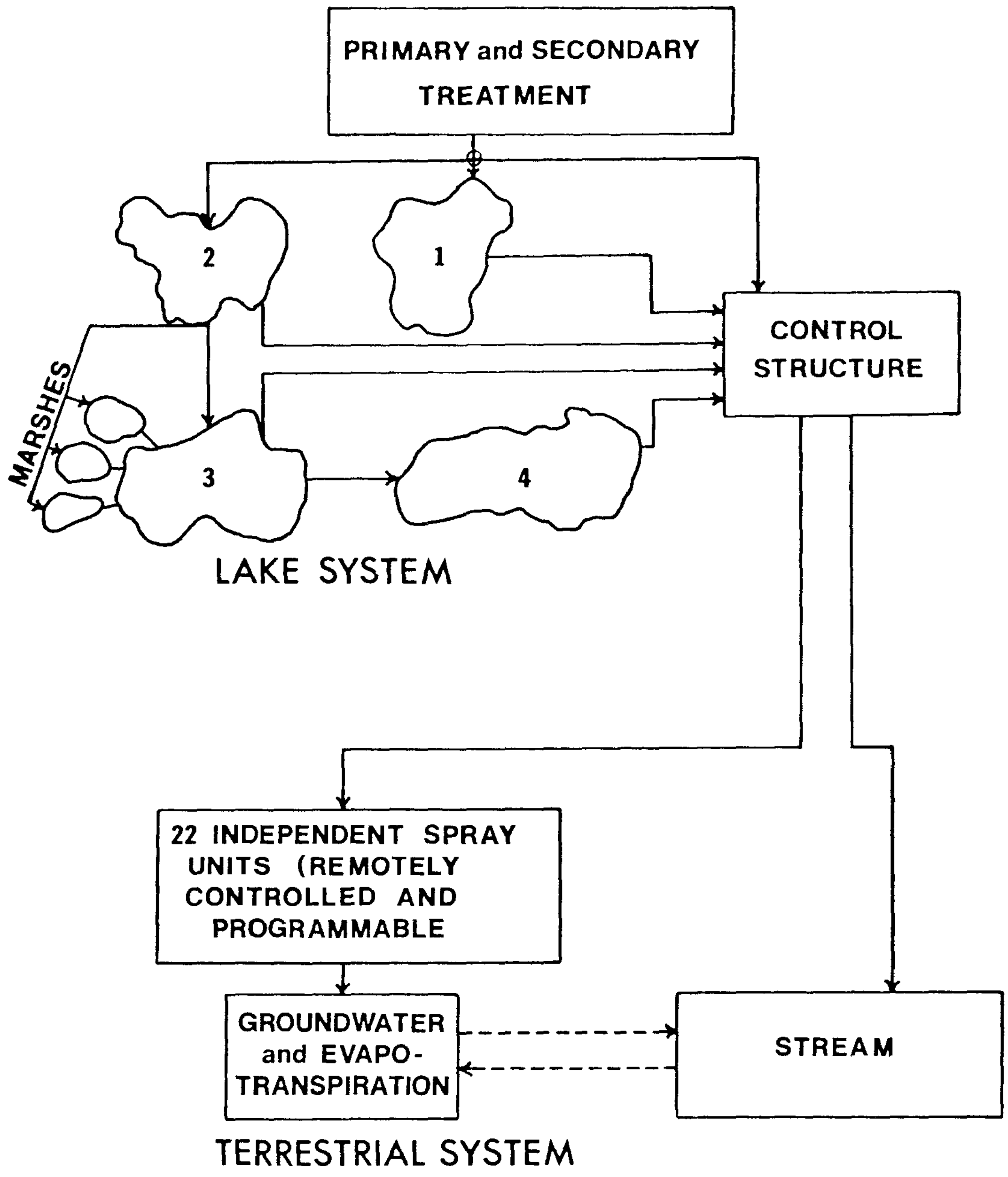


Figure 3. Flow schematic of the WQMP. (Arrows represent the water distribution network.)

Sewage Treatment Plant and Transmission Line

The East Lansing Sewage Treatment Plant services the City of East Lansing, Michigan State University with its 50,000 students and employees, and the adjoining community and represents the first element of our system.

It is a conventional extended aeration, activated sludge facility with an original capacity of 30,300 m^3/d (8 MGD). The effluent is typical of many university communities in that it is somewhat "weak." The effluent profile, giving concentrations of some key parameters, is shown in TABLE 1. Modification and enlargement to capacity of 56,770 m^3/d (15 MGD) was completed in early 1976, after the period of research covered in this report. As an integral part of this modification, the Michigan State University program has developed a parallel treatment chain within this plant that has a current capacity of 7570 m^3/d (2 MGD). The operation of this portion differs from the main plant in that the effluent receives no pretreatment for the partial chemical removal of phosphorus. The effluent (secondary or primary) from this chain is directed to a pumping station with two variable speed pumps. Flow is transmitted through the second element of the system, a 53 cm concrete asbestos pipeline. It traverses 7.25 km to the southern border of the MSU campus where it enters the 200 ha research site. Here it discharges into the first of four man-made lakes.

Lake System

The influent wastewater from the pipeline is received by the first lake and then flows by gravity through each of the other lakes (Figure 4) to a control building and pump house servicing the adjacent spray irrigation site. The lakes have a total surface area of 16 ha with the maximum depth of 2.4 m at each outlet structure and a mean depth of 1.8 m. This depth was chosen to maintain the entire bottom within the euphotic zone in order to encourage the growth of aquatic plants. The bottom was also contoured in a uniform manner to ease mechanical harvesting. Each lake has a collection basin at the outlet so that water may be lowered to implement the collection of fish or other aquatic fauna. This area is serviced by a ramp to allow access by both boats and trucks. Control of discharge and lake level is afforded by sliding gate valves and slash boards. The interlake transfer system and connection to the irrigation site is so designed that effluent can be taken

TABLE 1. AVERAGE CONCENTRATIONS (ppm) AND RANGES (WITHIN PARENTHESES) OF SELECTED CHEMICAL PARAMETERS IN WASTEWATER FROM THE EAST LANSING SEWAGE TREATMENT PLANT (VALUES WERE OBTAINED FROM DATA FROM THE PERIOD OF OCTOBER, 1973, TO MARCH, 1975)

	East Lansing Wastewater		
Chemical Parameter	Raw	Primary	Secondary*
Total Phosphorus mg/ℓ-P	7.0 (3.6-9.5)	5.0 (2.6-10.5)	2.6 (0.5-9.1)
Soluble Phosphorus mg/ℓ-P	3.0 (2.7-5.7)	1.1 (2.1-3.8)	1.1 (0.3-7.9)
Ammonia Nitrogen mg/ℓ-N	9.3 (4.1-32)	16.0 (8.6-25)	9.7 (5.2-22)
Nitrite Nitrogen mg/ℓ-N	0.005 (<0.005-0.03)	0.25 (<0.005-0.13)	0.25 (0.07-0.90)
Nitrate Nitrogen mg/ℓ-N	0.54 (0.16-3.1)	0.2 (0.09-2.33)	1.07 (0.16-7.0)
Kjeldahl Nitrogen mg/ℓ-N	25.3 (4.4-38)	26.3 (18.7-45)	12.7 (8.5-28)
Total Carbon mg/ℓ-C	183.0 (67-202)	171.0 (55-215)	120.0 (60-227)
Total Organic Carbon mg/ℓ-C	73.0 (43-105)	50.0 (38-97)	30.0 (12-111)
Boron mg/ℓ-B	0.33 (0.19-0.49)	0.31 (0.29-0.35)	0.33 (0.21-0.42)
Calcium mg/ℓ-Ca	108.0 (95-125)	110.0 (85-125)	113.0 (90-129)
Sodium mg/ℓ-Na	103.0 (58-295)	110.0 (59-295)	119.0 (63-300)
Magnesium mg/ℓ-Mg	25.0 (20-29)	26.0 (20-30)	24.0 (20-28)
Manganese mg/ℓ-Mn	0.16 (0.10-0.39)	--- ---	0.09 (0.03-0.18)
Suspended Solids	76.0 (16-232)	65.0 (6-406)	16.0 (4-305)
Total Solids	718.0 (378-1026)	704.0 (427-1072)	702.0 (358-928)

* With Fe polymers added for phosphorus control.

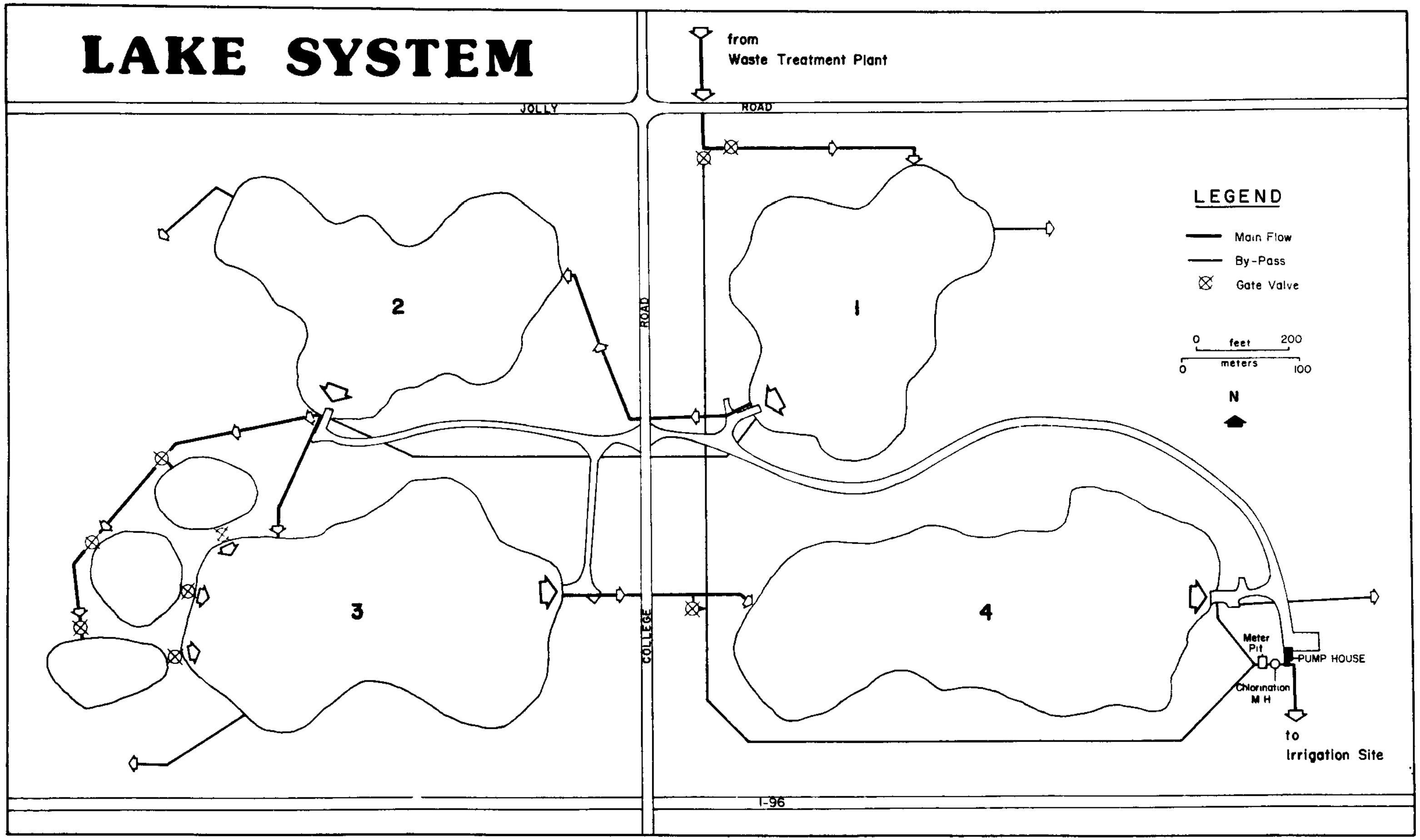


Figure 4. Flow diagram for lake system showing main flow and alternate by-pass system. Drawn to scale.

directly from the pipeline, or water can be intercepted at the discharge of any of the lakes in the system or mixed from any combination of lakes. Furthermore, water from any of the lakes can be discharged from either the surface, mid-depth, or near the bottom of the outlet structure. These features afford researchers with a wide range of water qualities to be applied and tested on the irrigation site.

Marsh System

Marsh systems with their high rates of internal nutrient cycling may prove to be an efficient system for the uptake and conversion of wastewater nutrients into usable products. To test the possibilities and feasibility of this concept, three 0.4 ha marshes were constructed adjacent to Lake 3 (Figure 5) which are fed from the discharge of Lake 2 in the system. Return water from the marshes enters Lake 3. The basins of the marshes were constructed in a terrace design that results in three zones of depths of 15, 60, and 90 cm. This design will allow development of plant and animal communities in these basins quite comparable with natural marshes of this area.

In the construction of the lakes and marshes, particular attention was given to the sealing of the basins to prevent loss of water through the bottom soils. Native clay was used and percolation tests indicated a very low permeability of 0.18 cm/d.

Pump Station

The manifold system of pipes that serve as collectors for each of the four lakes and for the transmission line discharges into a meter pit and wet well at a pump station (Figure 6). From this point, water can be sent to the spray irrigation sites under 5.1 atm (75 psi) of pressure by two pumps, one a 152 hp (metric) and the other a 76 hp (metric) pump.

The pump station serves as the nerve center for the entire project and contains all of the control units necessary for the operation of the pumps and the spray units at the land irrigation site. In the design of the pump station, provision was made for monitoring the operation of the entire plant including the programming of spray schedules. Time and duration of spray application as well as the selection of water quality is directed from a single control panel. The pump station site also serves as storage and work

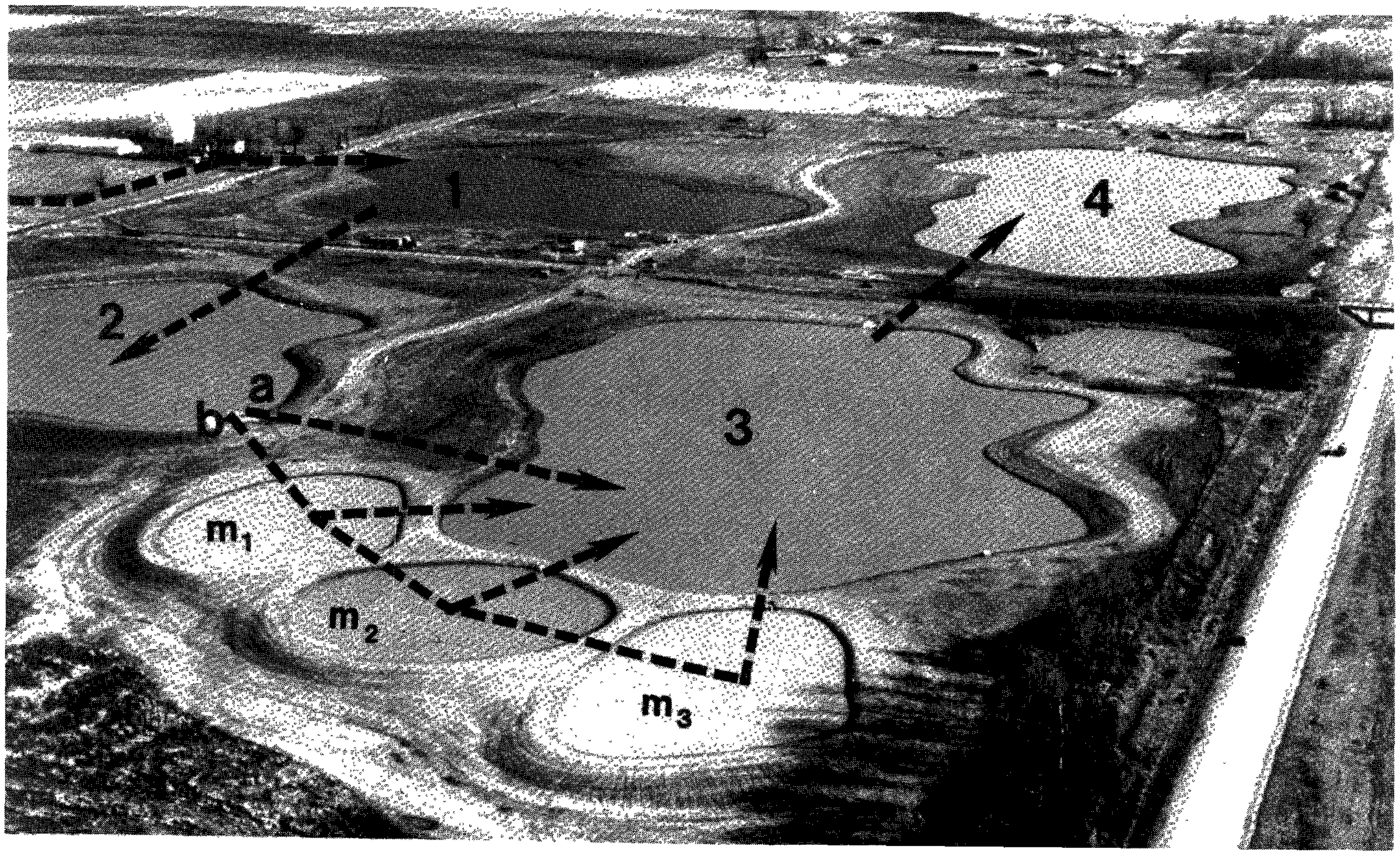


Figure 5. Photograph, looking east, of the lake system with arrows indicating flow. Water can be discharged from Lake 2 directly into Lake 3 by route a, or into the marshes (m_1, m_2, m_3) by route b. Marshes appear large due to a wide angle camera lens.

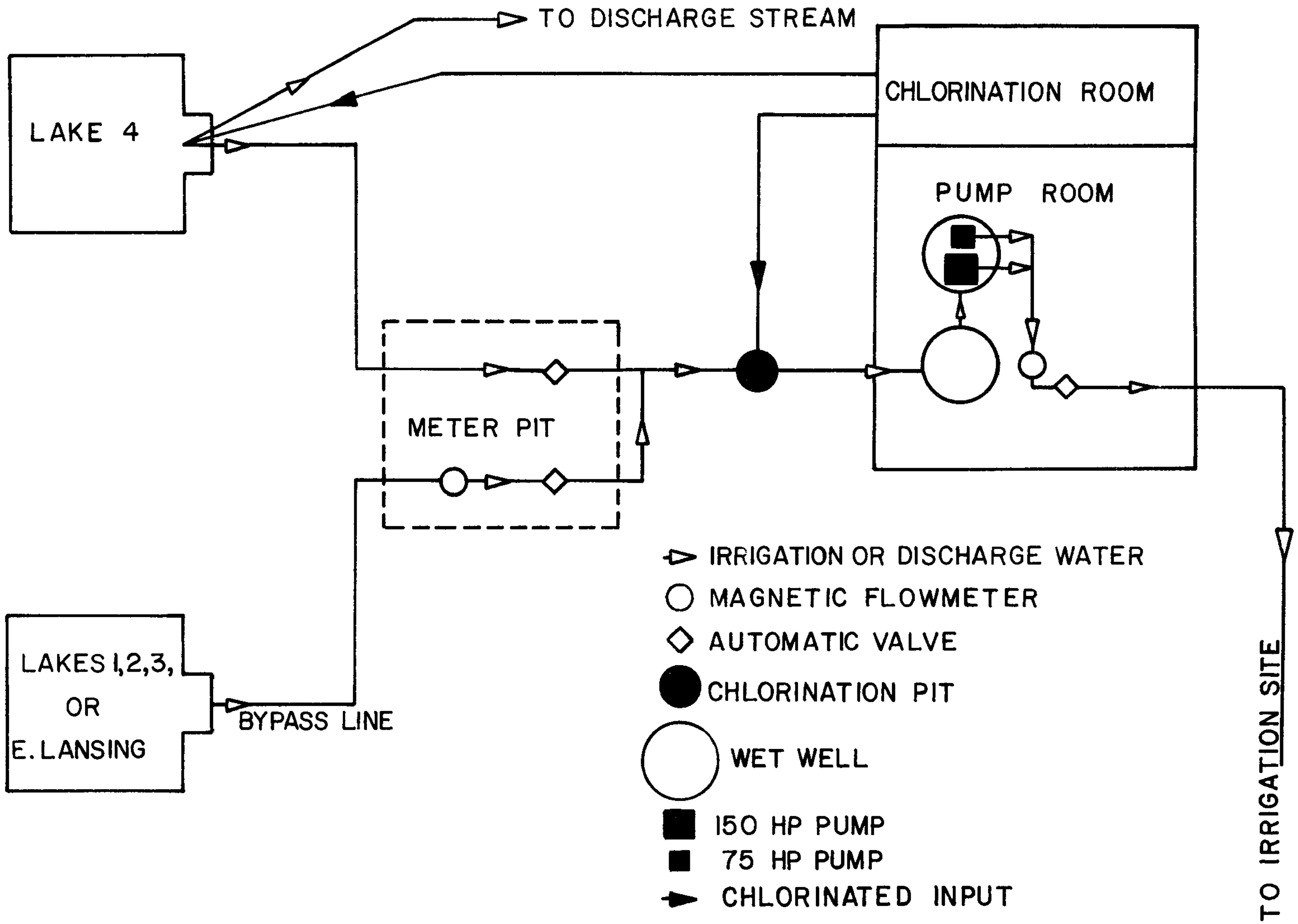


Figure 6. Flow schematic for pump station.

area for housing equipment used on the project and for the necessary shop work.

As indicated in Figure 3 and shown in Figure 7, water can be discharged from any of the lakes, by gravity, directly to the surface stream. This was accomplished by constructing an artificial channel from near Lake 4 east to the confluence of Herron Creek, a tributary of the Red Cedar River. Chlorination of irrigation water or water discharged directly to the surface stream is accomplished at the pump station. Chlorination of effluent leaving the WQMP portion of the East Lansing Sewage Treatment Plant is also possible, but it has not been chlorinated to date.

Spray Irrigation Site

The irrigation site (Figures 7 and 8) is a 130 ha tract of land that was once farmed but has been lying idle for approximately 15 years. The contour of the land is gently rolling and is bisected by a drain (Felton Drain) that was formerly a natural water course but has since been dredged. This drain enters a stream (Sycamore Creek) that flows into the Red Cedar River then on to Lake Michigan via the Grand River. The land is an admixture of many soil types and is characterized by old field volunteer vegetation with the exception of a sugar maple-beech woodlot (Figure 7) comprising about one-fifth of the total area. The tract is bordered on the north by Interstate Highway 96 and on the east and south by county roads (Figure 9). The west border adjoins Michigan State University farm property. The entire area is fenced. The portion designed for spray irrigation constitutes 58 ha lying approximately in the center of the tract with a 240 m buffer zone adjoining the two county roads and the neighboring home sites (Figure 8).

Irrigation water from the pump station passes through an underground 53 cm pipeline to the center of the irrigation site and joins another running laterally through the east and west axis of the property. The main east-west supply pipe is about 1100 m in length. At approximately 100 m intervals, a pair of electrically activated control valves are located. One set supplies the area north of the pipeline and the other supplies the area south of the pipeline. These valves are controlled and programmed from the pump station. Attached to each of the valves are four surface distribution pipes which subdivide the irrigation area into 24 independent irrigation zones. A typical

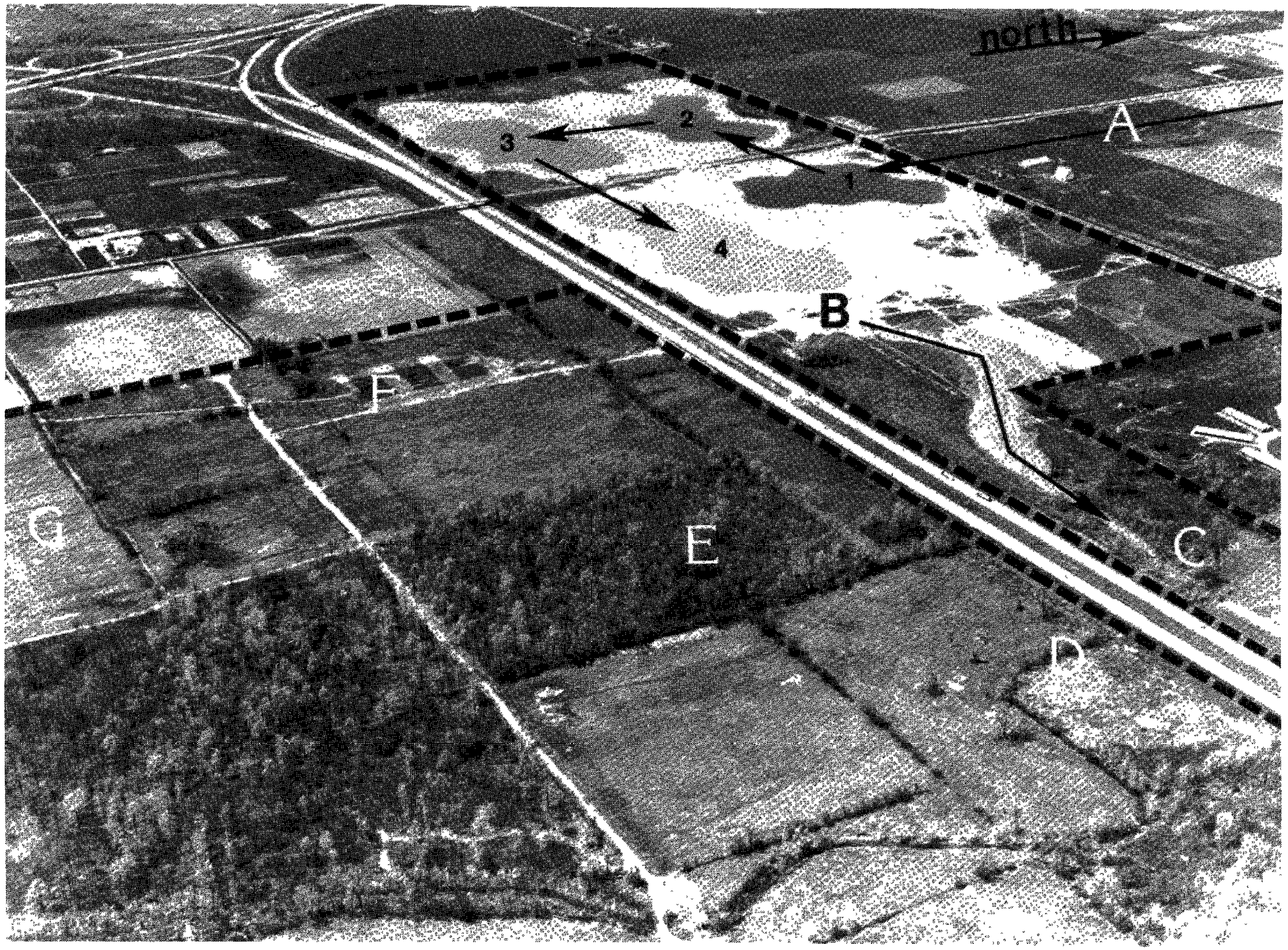


Figure 7. Photograph of lakes and a portion of the irrigation site. Dashed line denotes boundary of project site: (A) transmission line from East Lansing, (B) pump station, (C) artificial channel to Herron Creek, (D) Felton Drain, (E) woodlot, (F) forage crop plots, and (G) tree plantation.

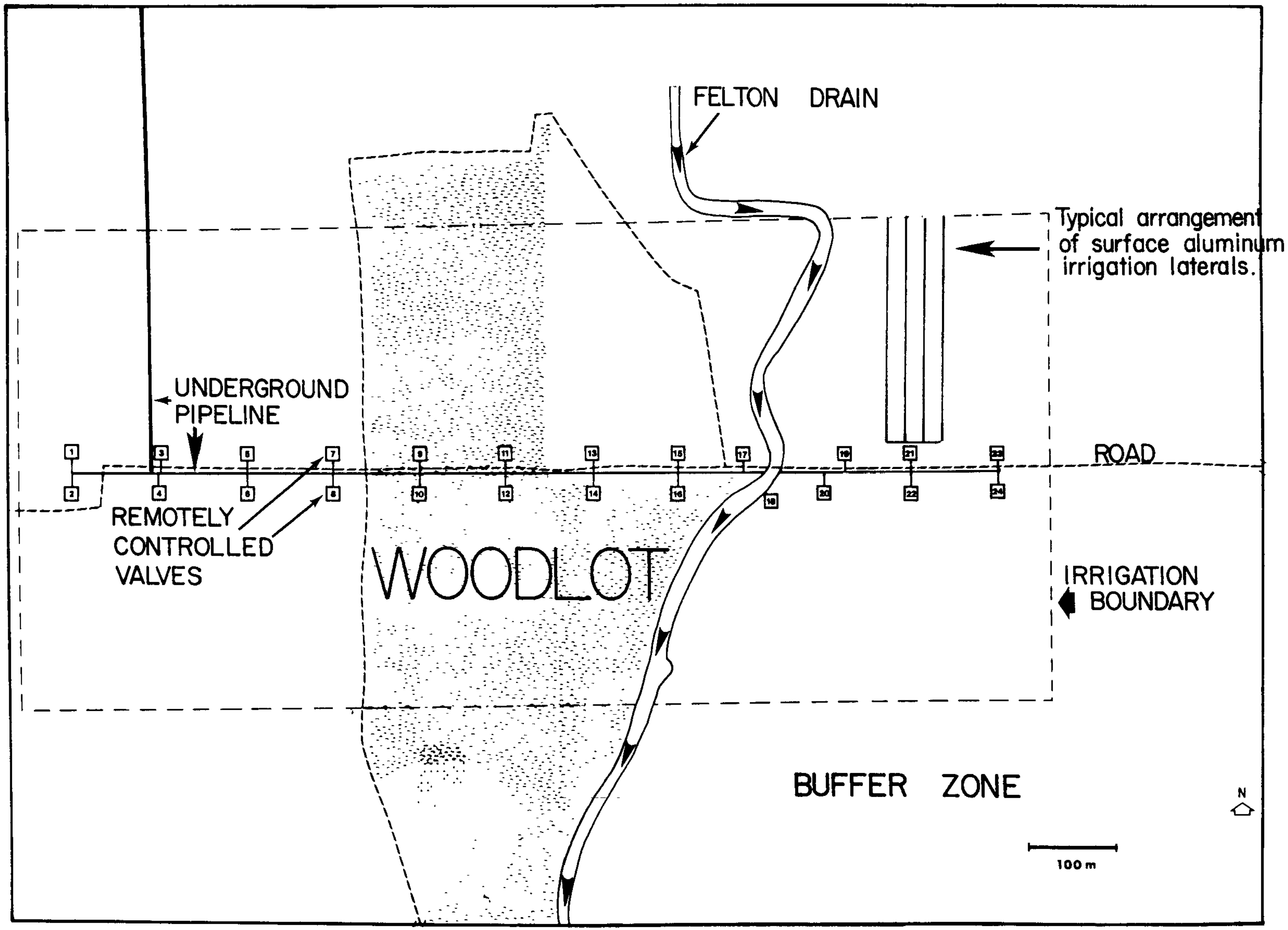


Figure 8. Physical features of the WQMP irrigation site.

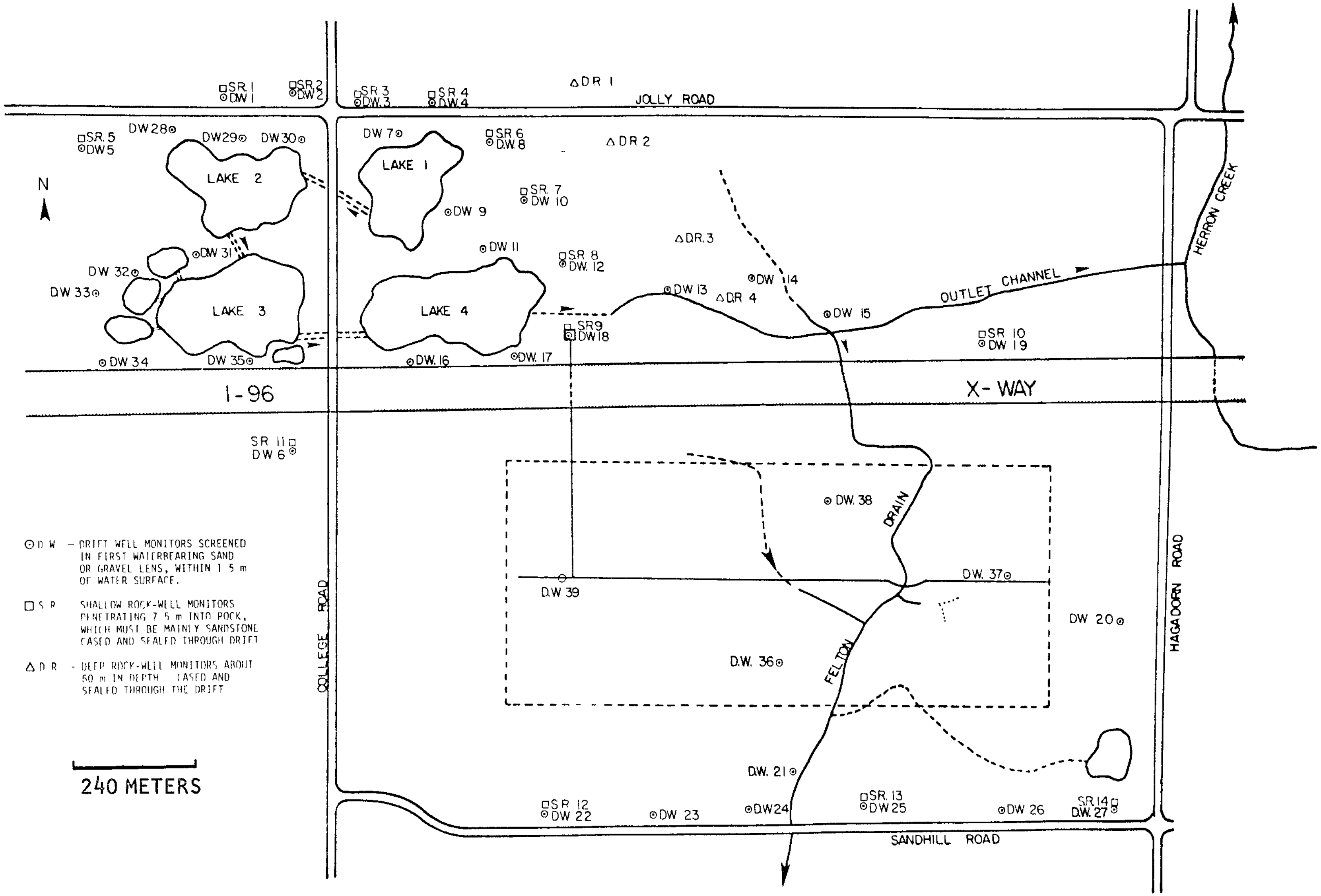


Figure 9. Location of monitoring wells.

zone is shown in Figure 8 extending north of control valve number 21. The pipes in each zone are aluminum and extend about 240 m north or south from the individual valves. Risers with sprayheads are staggered in alternate lines at 27 m intervals. Sprayheads are conventional Buckner 8600 units which at operating pressures of 5 atm create a spray radius of 18 m resulting in an overlap of approximately 50%.

Dimensional data for the entire facility is summarized in TABLE 2.

Monitoring Wells

Within and surrounding both the lake and land sites, we have drilled approximately 60 wells to monitor the level and quality of subsurface water. Included are 41 drift wells, 14 shallow rock and four deep rock wells as shown in Figure 9. All wells are 10 cm in diameter, with a 91 cm copper screen point and sanitary seals to prevent bacteriological contamination. The drift wells, the shallowest of the three, are positioned in the glacial drift between 12 and 18 m. Samples are obtained by pressurizing the drift wells and forcing the water through a plastic pipe which extends to the bottom of the well. Both shallow and deep rock wells extend into the aquifer which provides the water supply for the university. The shallow rock wells are approximately 25 m deep on the average, and the deep rock wells average about 55 m. All the shallow and deep rock wells are equipped with submersible pumps for sampling.

Gauging Stations

Surface water flow for the entire watershed study is measured by means of a network of recording gauging stations. Both V-notch weirs and Parshall Flumes have been installed at key points to enable us to monitor surface flows from identifiable subbasins in the irrigation area. The location of these structures is shown in Figure 10.

CONSTRUCTION COSTS

Construction costs for this project are summarized in TABLE 3. These costs do not include land acquisition costs for the 200 ha site, since the land had been purchased by Michigan State University several years previously. Funding came from a variety of sources including the Ford Foundation, the

TABLE 2. DIMENSIONAL DATA FOR THE WATER QUALITY MANAGEMENT FACILITY

Sewage Treatment Plant - East Lansing	56,775 m^3/day (15 MGD)
MSU Subunit	7,570 m^3/day (2 MGD)
MSU Potential	22,710 m^3/day (6 MGD)
Transmission Line (Asbestos-Concrete)	
Diameter	53 cm (21 inches)
Length	7.25 km (4.5 miles)
Lakes (four)	
No. 1 Surface Area	3.28 ha (8.1 acres)
No. 1 Water Elevation	271.9 m (892.0 feet)
No. 2 Surface Area	3.32 ha (8.2 acres)
No. 2 Water Elevation	270.0 m (886.0 feet)
No. 3 Surface Area	4.37 ha (10.8 acres)
No. 3 Water Elevation	269.1 m (883.0 feet)
No. 4 Surface Area	4.98 ha (12.3 acres)
No. 4 Water Elevation	268.2 m (880.0 feet)
Maximum Depth (all)	2.44 m (8 feet)
Mean Depth (all)	1.83 m (6 feet)
Marshes (three)	
Surface Area (all)	0.40 ha (1 acre)
Maximum Depth (all)	0.91 m (3 feet)
Mean Depth (all)	0.61 m (2 feet)
Irrigation Site	
Total Land Area	127 ha (314 acres)
Spray Zone Area	57.9 ha (143 acres)
Buffer Zone Width (East and South)	244 m (800 feet)
Buffer Zone Width (West)	0 (0)
Buffer Zone Width (North)	61 m (200 feet)
Main Irrigation Valves (24)	
Aluminum Surface Laterals (4 per valve)	
Length (alternating)	231 : 244 m (760 : 800 feet)
Diameter	15 : 10 : 5 cm (6 : 4 : 2 inches)
Distance Apart	24.4 m (80 feet)
Sprinkler Heads (Buckner)	
Spacing Along Pipe	27.4 m (90 feet)
Operating Pressure	5.1 atm (75 psi)
Spray Radius	18 m (60 feet)
Overlap	50% (50%)

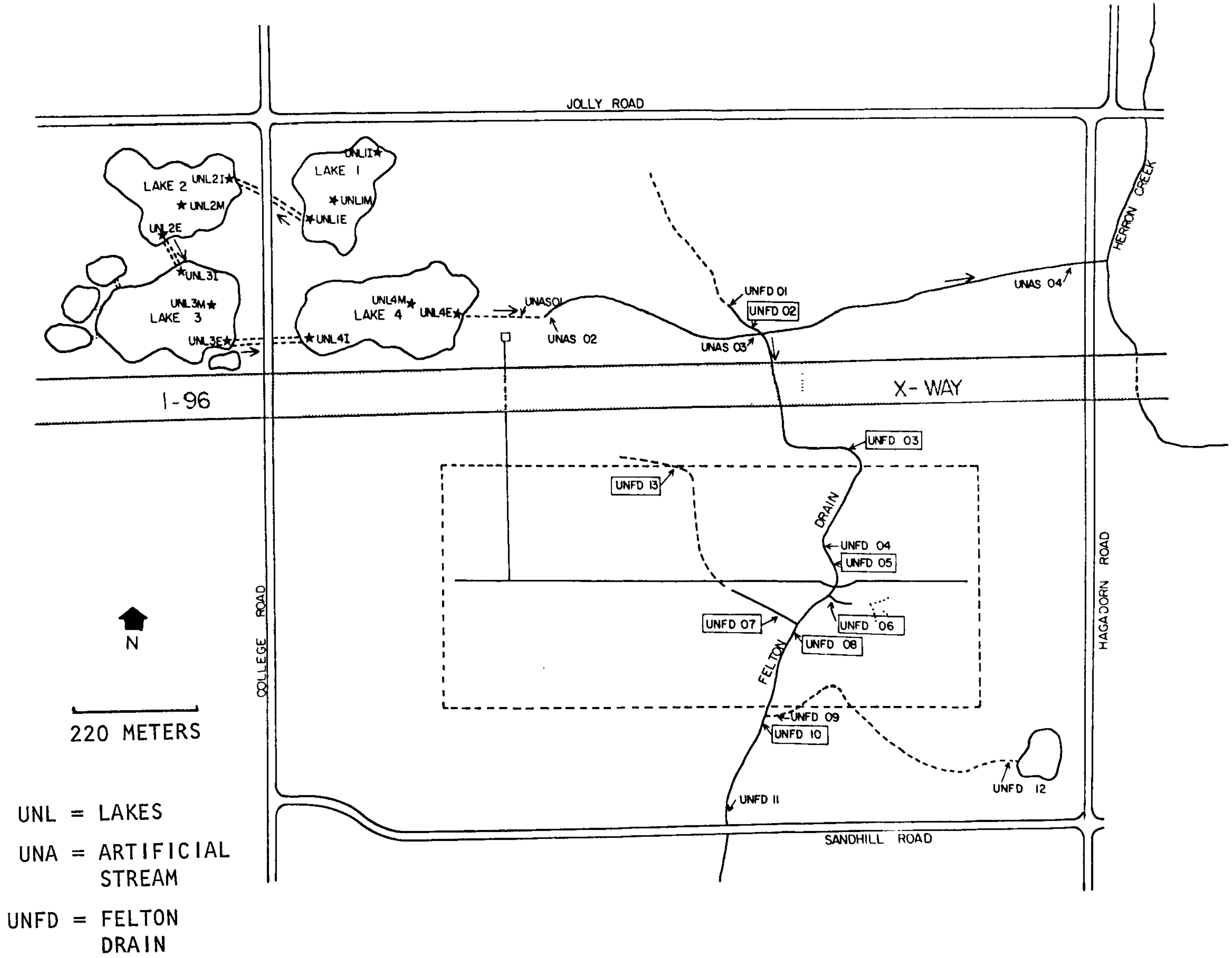


Figure 10. Location and station designation of water quality monitoring points. Sampling stations enclosed by a rectangle denote location of recording stream gauging stations.

TABLE 3. CONSTRUCTION COST BREAKDOWN FOR THE MSU WATER QUALITY MANAGEMENT FACILITY

Item	Cost
Modifications and Additions at the East Lansing Sewage Treatment Plant	$ 391,918
Installation of the Transmission Line	378,335
Lake Development	1,178,146
Irrigation Development	187,886
Engineering Fees and Preliminary Expenses	262,694
TOTAL PROJECT COST	$2,398,979

Kresge Foundation, the Rockefeller Foundation, and the State of Michigan as well as the U.S. Environmental Protection Agency, Comprehensive Grant Y005065.

MONITORING

As both a service and as a basic research effort, there is a need for continuous monitoring of a large array of chemical and physical parameters connected with both the operation of the wastewater treatment plant and with the lake and land facets of the recycling system. As a service to all investigators working on the total project, data are collected on about 33 chemical parameters (TABLE 4) representing collections starting with the raw sewage entering the sewage treatment plant, the attenuation and removal of materials as they move through primary and secondary treatment and as they enter the pipeline leading to the lake system. The chemical parameters of interest are checked as they move through the lake system from one lake to the next and into the pump station. Similar and further tests are made through the stream outfall system and to the several areas of the spray irrigation site. A similar series of analyses are made from the test well system. These are to identify movement of chemical materials into the soil mantle and down into the subsoil and groundwater aquifer if such movement does take place. Location of the sampling stations for the monitoring program, exclusive of the East Lansing Sewage Treatment Plant component were

TABLE 4. THE MICHIGAN STATE UNIVERSITY WATER QUALITY MANAGEMENT PROJECT CORE CHEMICAL PARAMETER LIST FOR THE MONITORING PROGRAM.

Parameter		Analytical Method
1.	Alkalinity	Auto Analyzer - Buffered Indicator
2.	BOD	Standard Methods
3.	Calcium	Atomic Absorption
4.	Carbon-Total	Beckman Carbon Analyzer
5.	Carbon-Total Dissolved	Beckman Carbon Analyzer
6.	Carbon-Dissolved Organic	Beckman Carbon Analyzer
7.	Carbon-Total Organic	Beckman Carbon Analyzer
8.	Chloride	Auto Analyzer - Mercuric Thiocyanate
9.	Cadmium	Atomic Absorption
10.	Chromium	Atomic Absorption
11.	Conductance	Electrode Measurement
12.	Copper	Atomic Absorption
13.	Dissolved Oxygen	Electrode Measurement
14.	Fecal Coliform	Standard Methods
15.	Fluoride	Auto Analyzer - Lanthanum alizarin complex
16.	Hardness	Auto Analyzer - Mg EDTA indicator
17.	Iron	Atomic Absorption
18.	Lead	Atomic Absorption
19.	Magnesium	Atomic Absorption
20.	Manganese	Atomic Absorption
21.	Nickel	Atomic Absorption
22.	Nitrogen-Ammonia	Auto Analyzer - Phenate method
23.	Nitrogen-Nitrate	Auto Analyzer - Cu-Cd reduction, Diazo coupling
24.	Nitrogen-Nitrite	Auto Analyzer - Diazo coupling
25.	Nitrogen-Total Kjeldahl	Auto Analyzer - Digestion then Phenate
26.	pH	Electrode Measurement
27.	Phosphorus-Total	Auto Analyzer - Digestion, Molybdenum Blue
28.	Phosphorus-Soluble	Auto Analyzer - Molybdenum Blue
29.	Potassium	Emission Spectroscopy
30.	Sodium	Emission Spectroscopy
31.	Sulfate	Auto Analyzer - Turbidimetric
32.	Suspended Solids	Gravimetric
33.	Zinc	Atomic Absorption

shown in Figures 9 and 10. Samples from the East Lansing Sewage Treatment Plant and the lakes are 24 hour composites while all sampling of surface water leaving the irrigation site is done on an event basis using automatic samplers. When surface flow is encountered the sampling interval is every one to six hours depending on rate of change of discharge. Our "Shallow Rock" wells and "Drift" wells are sampled once per month and the "Deep Rock" wells every three months.

Most chemical parameters are analyzed by the Institute of Water Research's chemical laboratory under the direction of an analytical chemist and his staff using EPA approved automated techniques whenever possible (TABLE 4). Quality control is checked through the splitting of samples with outside laboratories, duplication of analyses within the laboratory, and through use of EPA provided standard test solutions. This program is cooperating with and is a part of the quality control system of the International Joint Commission's Reference Group on Pollution from Land Use Activities.

Paralleling the chemical monitoring program, microbiological samples for bacteria are taken at every major transfer point within the system. This includes identification from the raw sewage through the treatment plant, through the pipeline to the lake system, and to all aspects of the spray irrigation site.

Even though the facility is designed as a research and demonstration facility, it still must be operated under the "Discharge Permit" system. The NPDES limitations for effluent from this system are shown in TABLE 5.

TABLE 5. COMPARISON OF THE NPDES EFFLUENT STANDARDS AT SELECTED POINTS IN THE WATER QUALITY MANAGEMENT PROJECT TREATMENT SCHEME DURING SEPTEMBER, 1975

Effluent Characteristic	Discharge Limitations (mg/ℓ except where noted) Summer	 Winter	 ELSTP-2°	Average Concentrations (mg/ℓ except where noted) in Effluents (ranges in parenthesis) Lake 1	 Lake 2	 Lake 3	 Lake 4†
Biochemical Oxygen Demand (BOD)	10	15	13.0 (1.-100.)	4.36 (2.15-6.60)	2.43 (1.30-4.53)	9.68 (3.55-16.10)	1.44 (0.10-4.20)
Suspended Solids	10	10	2.3 (<1-6)	3.6 (<1-13)	2.9 (<1-19)	9.5 (<1-21)	2.4 (<1-9)
Ammonia-Nitrogen (as N)	2	--	0.39 (0.10-1.0)	0.27 (0.10-0.70)	0.20 (0.10-0.40)	0.53 (0.17-1.20)	0.37 (0.06-0.30)
Dissolved Oxygen Minimum	5	5	7.53 (2.6-14.4)	13.1 (9.45-18.8)	12.3 (9.10-16.0)	11.7 (3.20-16.2)	11.7 (9.60-14.6)
Fecal Coliform Bacteria (MF)	200/100 ml	200/100 ml	65	3731.36 (0-21,000)	0 (0-0)	1.45 (0-12)	0.36 (0-4)
pH	6.5-9.0	6.5-9.0	8.40 (6.70-9.00)	9.20 (8.80-9.65)	9.55 (8.90-9.90)	8.90 (8.15-10.1)	9.49 (8.40-10.3)
Phosphorus	*	*	1.29 (0.64-2.4)	0.94 (0.58-1.37)	0.42 (0.23-0.67)	0.30 (0.15-0.46)	0.05 (0.03-0.10)

* The effluent shall contain a maximum of not more than 20% of the total phosphorus contained in the sewage prior to treatment; and insofar as optimum operations of the facility will attain such a level, shall contain not more than 1 mg/ℓ of total phosphorus.

† Lake 4 values are values representative of water at the outfall or discharge from the facility.

SECTION 6

OPERATION SINCE CONSTRUCTION

THE OPERATIONAL CHALLENGE

In any wastewater treatment scheme the prime challenge is to concentrate materials from a dilute solution. Raw domestic wastewater is at least 99% water and treatment methods to concentrate dilute wastes are expensive in terms of energy and materials. Total removal is, in most cases, not possible and where possible usually not practicable. But, to date emphasis has been placed on removal for disposal rather than on recycle.

While many examples of waste removal and associated tradeoffs exist, wastewater borne phosphorus has received considerable attention and can be used as an example of the problem of dilution. Raw domestic wastewater contains about 10 mg phosphorus per liter which equates to a concentration of 0.001%. This is extremely dilute but considerably more concentrated than the 0.000001% phosphorus level which causes excess plant production in natural waterways. Chemically induced phosphorus removal within mechanical wastewater treatment facilities provides effluent with about one mg phosphorus per liter or 0.0001% phosphorus. While 90% phosphorus removal represents a significant degree of concentration, the effluent still exceeds by two orders of magnitude the phosphorus content which leads to deleterious alterations in natural surface waters.

Obviously, the significant expenditure of energy and material associated with physical-chemical removal of phosphorus ameliorates the situation but does not totally solve the problem and does not supply much return of a useable product. Similar considerations apply to other nutrient materials as well as to heavy metals and other contaminants found at extremely dilute concentrations in domestic wastewaters.

Evaluating the potential of natural ecosystems to concentrate materials from dilute water-carried wastes while producing a product of value is the objective of the Water Quality Management Project. The operational challenge for the WQMP is to develop methods of managing both aquatic and terrestrial ecosystems to maximize concentration of materials from an extremely dilute solution in a potentially reusable form; thereby cleansing wastewater to minimize impact on both groundwater and surface water resources.

WASTEWATER FLOW HISTORY

The lakes of the WQMP were first filled during the fall of 1973 with a poor quality, tertiary effluent from the old, overloaded East Lansing wastewater treatment facility (see TABLE 1 for water quality). Inflow was stopped and this water remained in the lakes until the summer of 1974 because water drawdowns were required to repair a variety of hydraulic conduits. These corrections included a number of leaks in the 7.25 km pipeline between East Lansing Sewage Treatment Plant and Lake 1, repairs to the slide gates on Lake 2 and repairs to the wet well. All repairs and modifications were made by the contractors under the terms of the contract. After repairs were completed, pumping was resumed and the poor quality, tertiary effluent was admitted at a rate of 1893 m^3/d (0.5 MGD) for a short period during the autumn of 1974 to evaluate delivery capacity. Additional water was delivered to the first lake in late 1974 and early 1975 to make up for that water taken from the bottom of Lake 1 for winter spray irrigation.

Beginning in April, 1975, the WQMP began to routinely receive poor quality tertiary effluent from the old East Lansing Sewage Treatment Plant at a rate of 1893 m^3/d (0.5 MGD). This effluent was pumped to the WQMP and flowed by gravity in a series fashion through the four lakes (Figure 4). Additional water from East Lansing was pumped to the WQMP to meet terrestrial irrigation needs as required. All water irrigated was directly from the pipeline from East Lansing or from the bottom of Lake 1.

From April to mid-July effluent was withdrawn from the final clarifier of the existing portion of the East Lansing wastewater treatment facility. In mid-July the new wastewater treatment facility was placed in operation. During the week required to move the WQMP pump intake from the old to the new clarifier, no water was pumped to the WQMP. After the new intake was operational, pumping of good quality tertiary effluent resumed and continued until October. No water was received after October, 1975, since the pumps were being moved to allow completion of the special secondary wastewater treatment facility associated with the WQMP. This special part of the East Lansing Sewage Treatment Plant will supply the WQMP with secondary effluent not subjected to phosphate removal starting in April, 1976.

All effluent admitted to the WQMP prior to December, 1975, was secondary wastewater effluent to which iron salts and organic polymers had been added to remove phosphorus. Thus, the data reported in this report reflect the ability of the WQMP to process wastewater from which some of the phosphorus had been removed by chemical means.

The WQMP received a total of 4.05×10^5 m^3 (107.06 million gallons) of wastewater from April to October, 1975 (Figure 11). Of this total, 24.6% or 9.99×10^4 m^3 (26.4 million gallons) was spray-irrigated on the terrestrial portion of the WQMP. The remainder or 3.05×10^5 m^3 (80.66 million gallons) was allowed to flow by gravity through the four lakes and out the Herron Creek diversion to the Red Cedar River.

Of the water irrigation, 16.4% was applied to row crops at rates varying from 2.5 to 7.5 cm/week, 61.3% was applied to old fields at rates varying from 3.5 to 7.1 cm/week, 19.9% was delivered to a tree plantation at the rate of 5.2 cm/week, 1.9% was sprayed in a forest zone during October at rates of 5 cm/week, and 0.5% was sprayed on a flow diversion zone to irrigated trees planted as a buffer around the terrestrial irrigation area. The period of irrigation on the row crop area was from May 14 to September 8. The old fields were sprayed from May 12 to October 23 and the forest spraying commenced on October 2. The diversion zone was sprayed when necessary to equalize pressures during repairs to the various spray lines.

Irrigation water came either directly from the conduit from East Lansing or from the bottom gate of Lake 1, depending on the needs of individual investigators. All wastewater sprayed directly from the East Lansing conduit was chlorinated at the pump house immediately prior to irrigation while that from Lake 1 was not. The row crop area and the forest spray zone received chlorinated effluent directly from the East Lansing conduit while the old fields and the tree plantation received water from the bottom of Lake 1. The diversion zone received water from both sources.

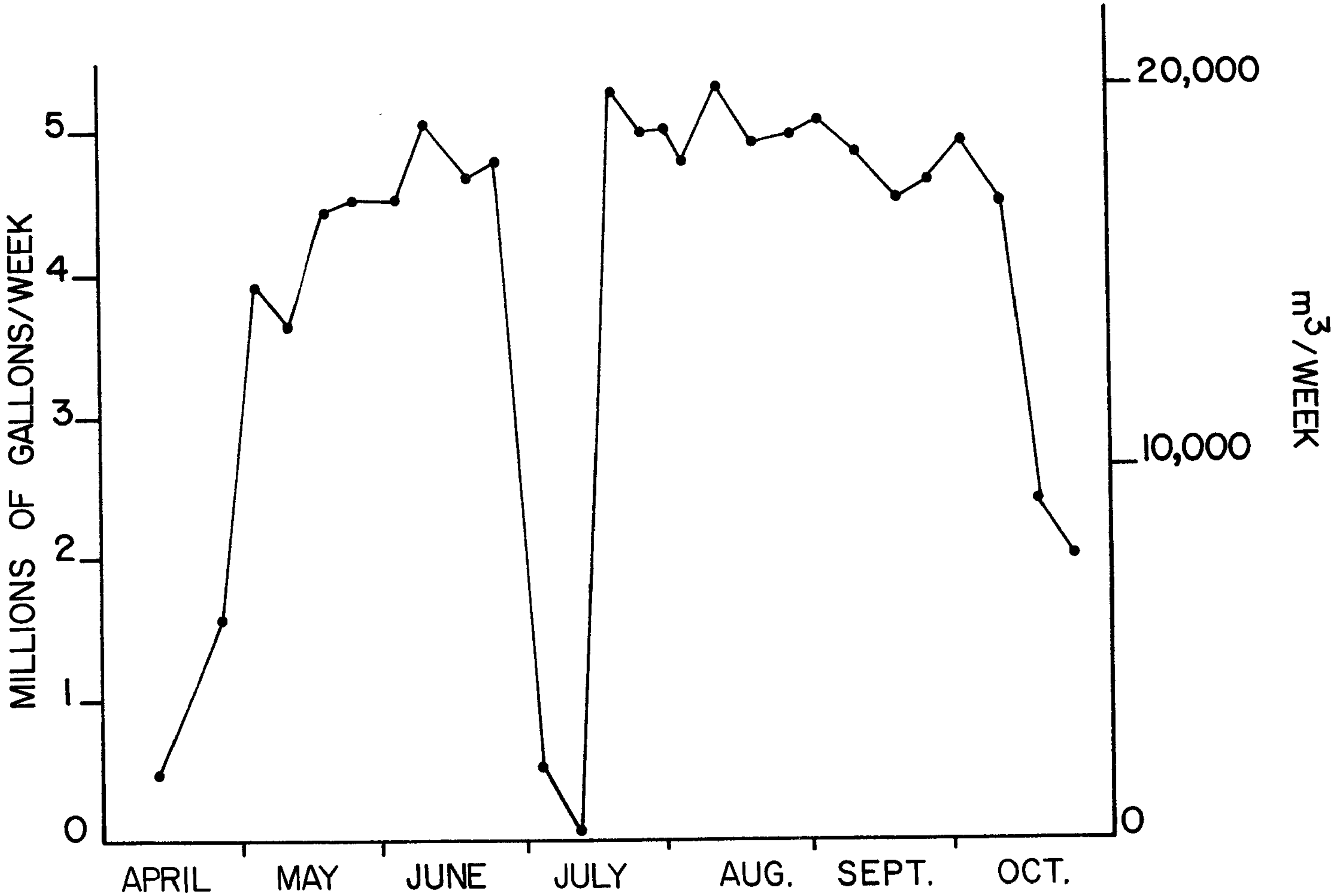


Figure 11. Rate of wastewater delivery from the East Lansing wastewater treatment facility to the WQMP from April to October, 1975.

Since 81% of the irrigation water was withdrawn from the first lake, the loading on the first lake exceeded that on the three downstream lakes. In effect, in addition to operating as a lake, the first lake was also used as a surge basin for irrigation water. This was particularly apparent during mid-July when flow from East Lansing was stopped. During this period all irrigation water was withdrawn from the bottom of Lake 1 and the lake level fell considerably.

Including periods when flow was not possible, the average daily input to the WQMP for the entire period from April to October was 2.23×10^3 m^3/d (0.59 MGD)(Figure 11). Of this, 5.68×10^2 m^3/d (0.15 MGD) was sprayed on the terrestrial site and 1.67×10^3 m^3/d (0.44 MGD) was processed through the four lakes.

Although operation of the WQMP with secondary effluent not subjected to phosphate removal was not possible prior to December, 1975, the opportunity to operate this sytem with a "tertiary" effluent was of real value to the long-term research conducted on this facility. Although the data collected reflected the tertiary nature of the effluent (about 2.6 mg P/ℓ), real knowledge of the effects of ecological perturbations associated with such effluent on lake-land systems was gained. In effect, one point on a curve has been established for an effluent of "low" phosphorus concentration. Starting in 1976, evaluation of the system with a secondary effluent not subject to phosphorus reduction (about 5-7 mg P/ℓ) will be possible.

SECTION 7

RESULT OF LAKE STUDIES

IMBALANCE OF NUTRIENT RATIOS

Successful operation of the aquatic portion of the WQMP requires that materials borne in the wastewater at dilute concentrations be removed as the water flows by gravity through the four lakes. The efficiency of removal is dependent upon uptake of these materials by aquatic biota and upon biologically accelerated physical-chemical removal mechanisms. The system is powered by the sun through plant photosynthesis, and operational direction is dictated by climatic conditions including the amount of solar input and by the chemical quality of the inflowing water.

Since the primary step involves photosynthesis by algae and aquatic vascular plants, the nutrient supply relative to photosynthetic demand is of prime import to such systems. It is here that the nature of the wastewater exerts a primary effect.

As shown in Figure 12, food enters a population with a Carbon:Nitrogen: Phosphorus ratio characteristic of living material. The use of the food and the carbon loss prior to elimination of the wastes to a water carried system initiates an imbalance in the Carbon:Nitrogen:Phosphorus ratio which is exacerbated by phosphate detergents and further altered during conventional biological wastewater treatment. The result is an effluent extremely rich in phosphorus, rich in nitrogen, and impoverished in carbon relative to the needs of plants which, through photosynthesis, initiate nutrient recycle.

This shortage of carbon is of little consequence to terrestrial plants because of the abundance of carbon in the air. However, aquatic plants in ponds and lakes do not have ready access to atmospheric carbon, and it is this shortage of carbon which triggers the many biotic and abiotic alterations in aquatic wastewater treatment systems.

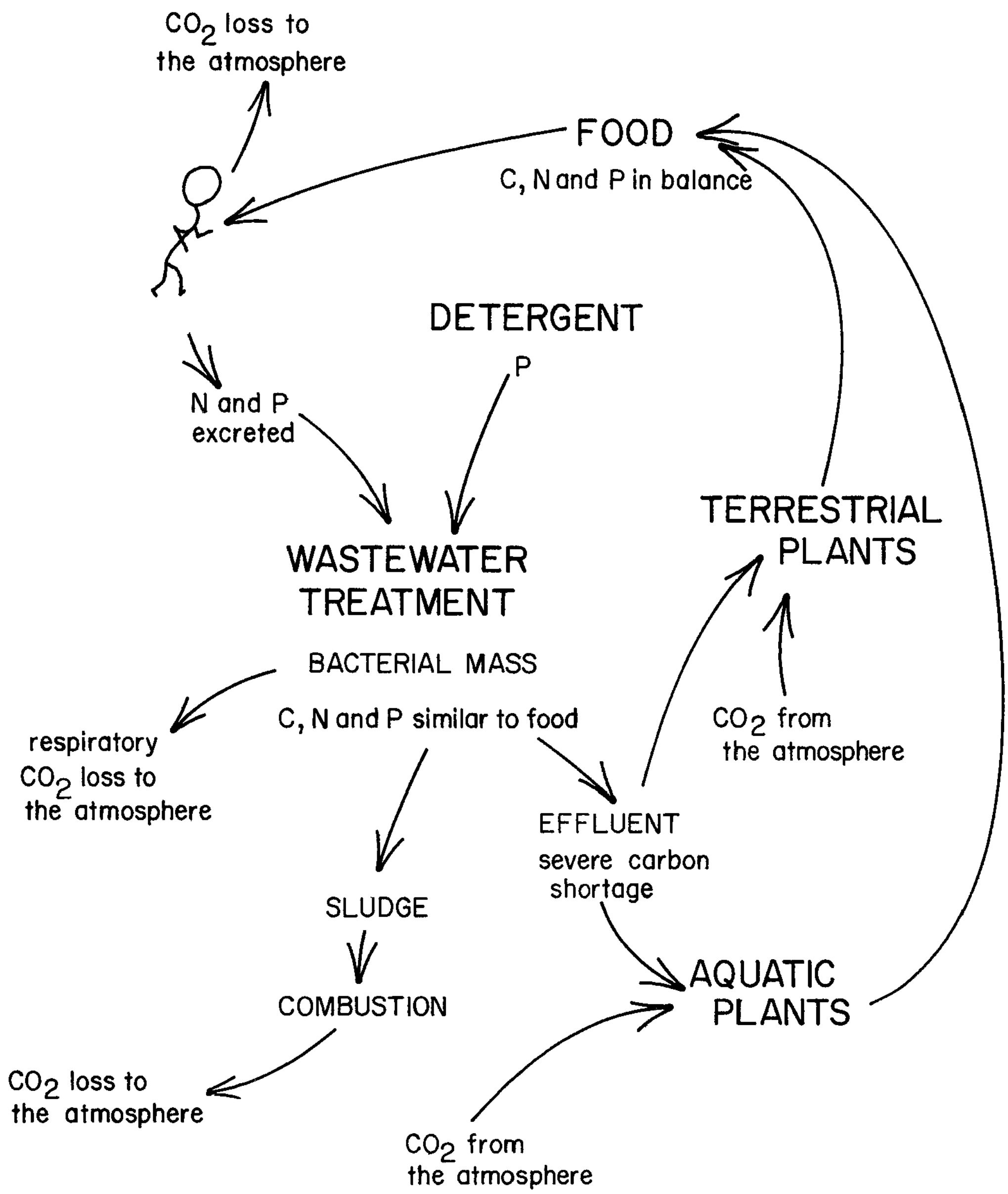


Figure 12. Causes of plant nutrient imbalances in wastewater.

The three sources of inorganic carbon available to photosynthetic aquatic organisms are respiratory carbon dioxide from heterotrophic aquatic organisms, atmospheric recarbonation, and the carbonate-bicarbonate alkalinity system. Of these three sources, the only significant reserve of inorganic carbon is contained within the alkalinity system.

Atmospheric recarbonation may supply as much as 40 mg C/m^2/hour (Schindler, 1975), but 20 mg C/m^2/hour is a more probable value for the WQMP if photosynthetic withdrawal has markedly depleted the free carbon dioxide content of the water. Even after a 24 hour day this would amount to less than 0.5 mg C/ℓ in a system with an effective photic depth of just one meter. Algal populations in sewage lagoons fix between 12 and 24 mg $CO_2/\ell/d$ during summer months (King, 1972).

Respiratory carbon dioxide supply is dependent upon the amount of organic matter available to the bacterial populations. Within the WQMP, such organic substrate is limited because of the nature of the wastewater input and the young age of the lakes. There were, however, periods of marked respiratory activity in the WQMP lakes during the summer of 1975.

The alkalinity system then serves as a significant reserve source of carbon dioxide for plant photosynthesis in the WQMP lakes. However, withdrawal of carbon dioxide from the alkalinity system by plants causes a variety of changes within the chemical system. Most of these changes tend to favor physical-chemical removal of phosphorus, metals and, depending on the form present, nitrogen.

The carbonate-bicarbonate equilibrium is fixed by the first and second dissociations of carbonic acid given in Equations 1 and 2.

$$H^+ + HCO_3^- \rightleftharpoons HOH + CO_2 \qquad (1)$$

$$HCO_3^- \rightleftharpoons H^+ + CO_3^= \qquad (2)$$

As plants withdraw the free carbon dioxide, these reactions both move to the right yielding Equation 3.

$$2\ HCO_3^- \rightleftharpoons CO_2 + CO_3^= + HOH \qquad (3)$$

Since this action is accompanied by an increase in carbonate and a decrease in bicarbonate, the hydrogen ion concentration decreases and the pH rises as shown in Equation 4.

$$[H^+] = \frac{K_2[HCO_3^-]}{[CO_3^=]} \tag{4}$$

These changes in chemical equilibrium initiate a variety of physical-chemical concentration and removal mechanisms.

Of particular import is the precipitation of calcium carbonate which can be accelerated by photosynthetic uptake of carbon dioxide as shown in Equation 5.

$$Ca^{++} + 2HCO_3^- \rightleftharpoons CO_2 + CaCO_{3(s)} + HOH \tag{5}$$

This process results in a decline in alkalinity and softening of the water while simultaneously increasing direct precipitation as well as co-precipitation of phosphorus and metals. The resulting elevation of pH favors the loss of ammonia to the air by accelerating dissociation of the ammonium ion to free ammonia gas as shown in Equation 6 for which the pK value is about 9.2.

$$NH_4^+ \rightleftharpoons NH_{3(g)} + H^+ \tag{6}$$

Thus, in addition to direct uptake by the biota, the plant photosynthetic activity does much to accelerate abiotic concentration and removal of waste materials. As such, development of an understanding of the mechanisms controlling these ecological perturbations offers significant promise for optimizing waste removal and nutrient recycle in these solar powered aquatic systems.

THE BIOTA

Plants

Shortly after the lakes were filled in the autumn of 1973, vascular macrophytes were collected from nearby natural lakes and planted into Lakes 2, 3, and 4. Species introduced included *Potamogeton foliosus*, *Elodea canadensis*, *Najas flexilis*, *Elodea nuttallii*, and *Myriophyllum spicatum*.

Biomass of macrophytes were determined at intervals after planting using a random quadrat technique.

During the summer of 1974 when there was little water movement through the lakes and when water level was drawn down for structural repairs, only Elodea candensis and Potamogeton foliosus became well established with the latter showing mass increases of about 100 times the mass planted. Elodea canadensis was present at about 10 times the plant mass.

The pattern of plant activity was significantly altered during the summer of 1975 when the WQMP was operated with throughput of 1893 m^3/d (0.5 MGD) of wastewater effluent. Phytoplankton densities were determined for each lake by taking 35 water samples at randomly chosen sites, by pooling these samples, and then analyzing the pooled sample using a standard 0.45 μ membrane filter technique. Phytoplankton densities were highly variable as shown in Figure 13 but were generally in the neighborhood of 10^4 cells per ml; a value considerably lower than that commonly found in wastewater systems. Forty-seven different taxa of algae were encountered during the summer of 1975 with phytoplankton dominance largely being shared by green algae and diatoms except for one period of bluegreen algal dominance in Lake 4.

The most obvious plant invader during 1975 was the periphytic algae Cladophora fracta. As shown in Figure 14, this plant dominated Lake 2 throughout the 1975 season and became dominant in Lake 3 by mid-summer. Lake 1 supported little plant activity other than the phytoplankton until after the period in July when the lake level was drawn down. At that point Potamogeton foliosus, Ceratophyllum demersum, and Cladophora fracta all began growth in Lake 1. Lake 4 was dominated by Elodea canadensis throughout the spring and summer of 1975 with Cladophora fracta being present in the spring and Potamogeton foliosus representing significant growth at times during the summer.

Zooplankton

Zooplankton are common inhabitants of all four lakes with their numbers in each lake varying widely from scarce to extreme abundance. When abundant, these organisms concentrate in large amorphous groups to the point where tens of kilograms can be collected in a short while with a dip-net. However, the non-dispersed nature of these zooplankton populations make difficult accurate

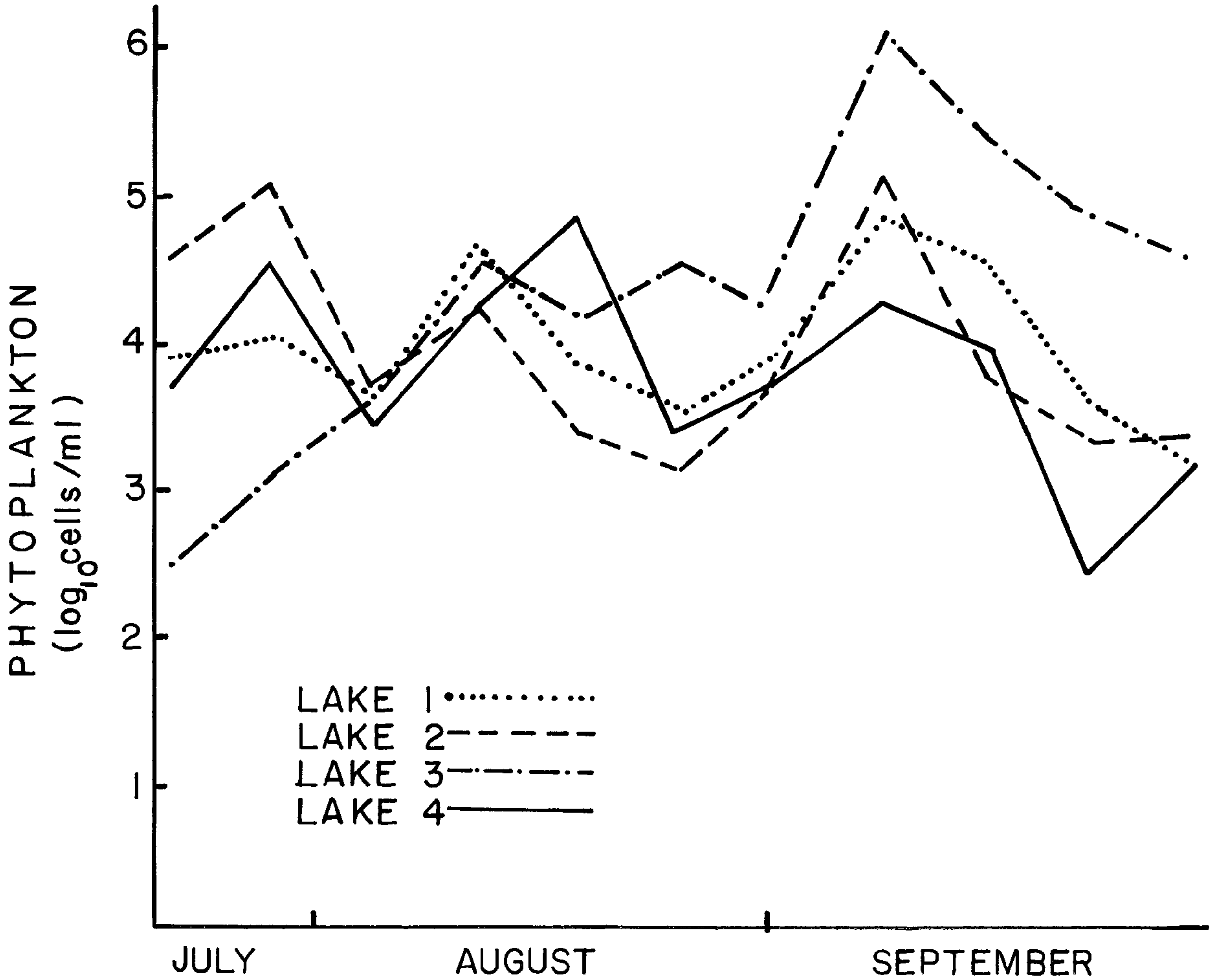


Figure 13. Phytoplankton abundance within the four WQMP lakes during the summer of 1975.

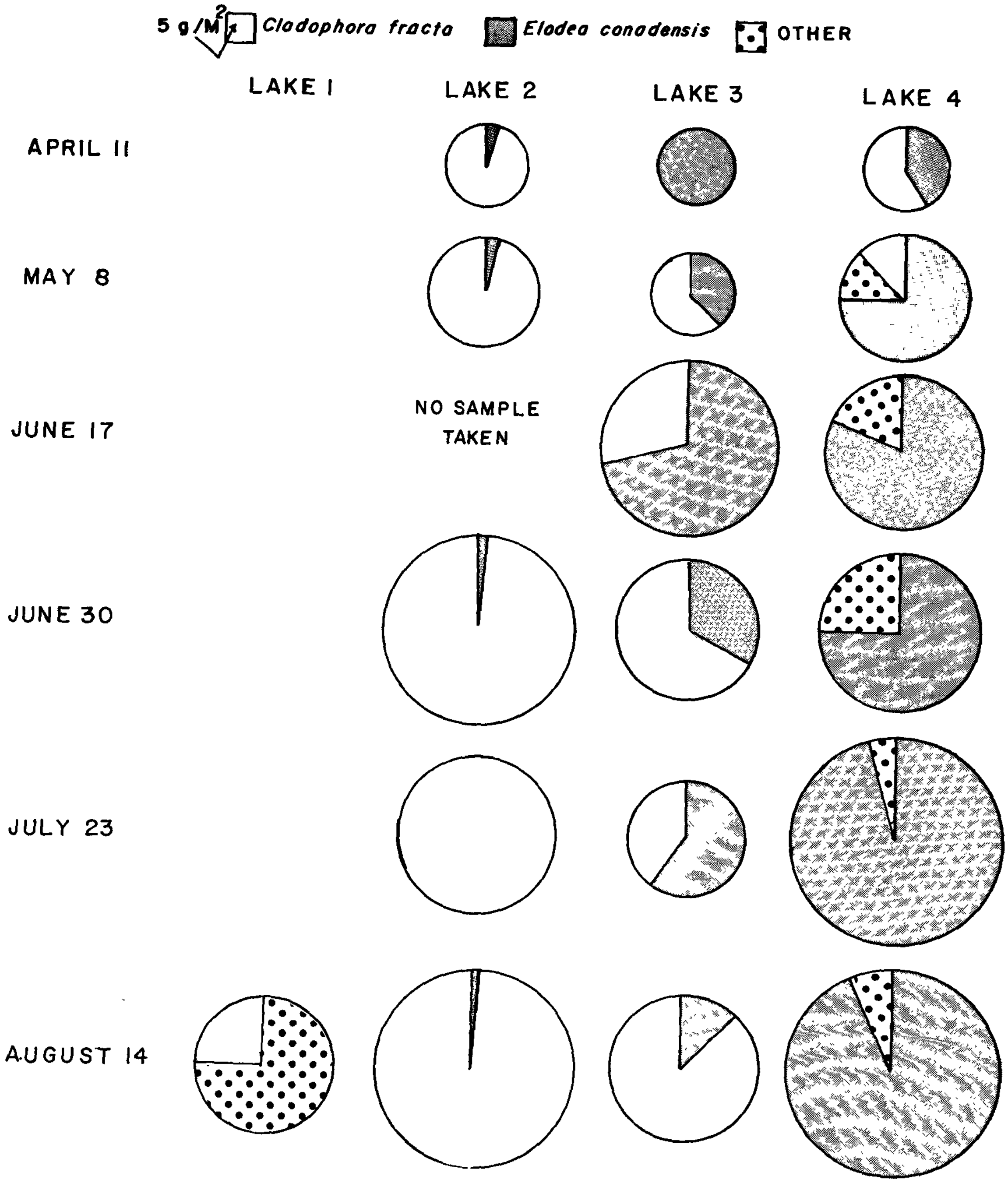


Figure 14. Relative abundance of macrophytes and filamentous algae in the four WQMP lakes during 1975.

estimate of total zooplankton numbers and activity. Qualitative data on zooplankton were collected by making several plankton tows in each lake using a Wisconsin plankton net. No quantitative data were available as of December, 1975.

To date seven different species of Cladocera, five Rotifera and one Copepoda have been encountered in the lake system.

Aquatic Insects

Aquatic insect populations include large numbers of midges (Chironomidae) and apparent significant populations of damselflies and dragonflies (Odonata), a wide variety of true bugs (Hemiptera) and lesser populations of mayflies (Ephemeroptera). An example of the magnitude of the insect populations in the various lakes is given for the Chironomidae in TABLE 6. Emergent traps were also used to estimate the populations of adult aquatic insects. Quantitative data were not available on other species as of December, 1975.

TABLE 6. MEAN NUMBER OF CHIRONOMID LARVAE COLLECTED AT EACH OF FOUR DEPTHS FROM THE FOUR WQMP LAKES DURING AUGUST AND SEPTEMBER, 1975

Depth (cm)	Lake 1	Lake 2	Lake 3	Lake 4
		Number/m^2		
50	1294	3022	1478	4121
100	758	2210	672	2400
180	3156	1326	789	1500
240	2896	2639	1399	1052

Fish

Sticklebacks (Eucalia inconstans) were unavoidably introduced when the aquatic macrophytes were planted into the lakes. By 1975 these small fish had developed significant populations in Lakes 3 and 4.

On June 17, 1975, approximately 750 largemouth bass fingerlings (Micropterus salmoides) and 2000 fathead minnows (Pimephales promelas) were stocked in Lake 4 to determine if water quality conditions in the lakes impose limits on either fish production or fish quality. The fish populations were sampled during July, August, and September with a 30 m beach seine and during September and November with variable mesh experimental gill nets. Sticklebacks were the only species taken with the seine and largemouth bass were taken with the gill nets in September and November.

Sticklebacks were the predominant food item in the bass stomachs in September but only insects and crustaceans were found in stomachs from the November sample. Sticklebacks fed primarily on cladoceran and small insect larvae.

The largemouth bass grew very rapidly during the period from June to September (TABLE 7) reflecting the abundance of food for these fish. The average increment of growth was 15.1 cm and 132.8 g for the three month period. The 19.5 cm average length of these bass after one growth season is greater than growth values reported for other northern regions of the United States and is comparable to that reported for bass in southern states where the growth season is approximately six months.

TABLE 7. LENGTH AND WEIGHT OF LARGEMOUTH BASS FROM WATER QUALITY MANAGEMENT PROJECT (LAKE 4)

		Total Length (cm)		Weight (g)	
Sample Date	No. Fish	Average	Range	Average	Range
6-17-75	22	4.4	4.0- 4.9	1.2	0.9-2.2
9-18-75	14	19.5	18.0-20.5	133	113-153
11-4-75	3	19.8	19.0-21.0	117	95-142

This rapid growth is indicative of excellent water quality, an abundant food source, and a low population density. Although dissolved oxygen was temporarily depressed in July, it was not reflected in the growth of the bass.

Suitable oxygen conditions were probably found near the inflow from Lake 3 or in the shallow nearshore waters.

No survival studies or population density studies were made, so growth cannot be converted to total biomass production. If survival were 100%, largemouth bass production would equal 99.6 kg dry weight and would represent a sink for about 4 kg of P (assuming 4% P) and about 10 kg of N. These estimates represent maximum values since survival was certainly less than 100% but do indicate that the fish population does not represent a major sink for nutrients.

During 1976, additional bass fingerlings and hybrid sunfish will be stocked in Lake 4. Undoubtedly the growth rates of bass and the other species will be reduced as the population density increases but optimum growth rates should be maintained with careful management of the population density.

Fish, insects, and plants collected from the WQMP lakes were subjected to analyses for chlorinated hydrocarbons and the fish were examined for heavy metals. The chlorinated hydrocarbon results were presented in TABLE 8, and TABLE 9 contains the results of the heavy metal analysis.

Chromatograms of all plant and animal samples revealed only low concentrations of chlorinated hydrocarbon residues and, while the identity of specific residues has not been confirmed, traces of p,p'-DDT and methoxyclor were indicated in samples of fish, insects, and plants. Some peaks corresponding to Aroclor 1254 were evident, especially in the aquatic insects, but in general concentrations were too low to clearly indicate PCB residues. In most samples, residue concentrations were below the limits of detectability (0.001 ppm); but residues tentatively identified as DDT and methoxyclor occurred at concentrations up to 0.1 ppm. From these preliminary data, there was no indication of concentrations accumulating in the higher trophic levels or in specific lakes.

Concentrations in the water mass were below detectable levels, and since all of the chlorinated hydrocarbons are lipophyllic and showed such low levels (TABLE 8), it was not deemed worthwhile to analyze for their presence in the bottom sediments. Thus, no such tests were carried out.

Additional sampling and analysis is necessary to determine positive identification and distribution of residues in the lake system, but these

TABLE 8. CONCENTRATIONS OF CHLORINATED HYDROCARBON INSECTICIDES AND PCB (AROCLOR 1254) IN BIOTA FROM THE WATER QUALITY MANAGEMENT SITE (PPM WET WEIGHT)*

Species-Date	Lake	p,p'-DDT	p,p'-DDD	p,p'-DDE	Meth-oxychlor	Other Pesticides†	Aroclor 1254‡
Largemouth Bass - 9/18/75§	4	0.3	<0.01	0.06	0.66	<0.01	<0.01
Stickleback - 7/1/75#	2	<0.01	0.27	<0.01	0.64	<0.01	<0.01
Stickleback - 7/1/75#	3	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Stickleback - 7/1/75#	4	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Insects - 7/10/75	1	0.25	<0.01	0.18	<0.01	<0.01	<0.5
Insects - 7/1/75	2	<0.01	<0.01	0.21	<0.01	<0.01	<0.5
Insects - 7/1/75	4	0.39	<0.01	0.20	<0.01	<0.01	<0.5
Plants - 7/1/75	1	0.19	<0.01	<0.01	0.24	<0.01	<0.01
Plants - 7/1/75	2	0.82	<0.01	<0.01	0.35	<0.01	<0.5
Plants - 7/1/75	3	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Plants - 7/1/75	4	<0.01	<0.01	<0.01	0.33	<0.01	<0.01

* Residue identification is tentative and is regarded as preliminary data.
† Other pesticides - hexachlorobenzene, lindane, aldrin, kelthane, heptachlorepoxide, dieldrin, and endrin.
‡ Aroclor 1254 quantification based on the average value of 4 peaks.
§ Muscle only.
# Entire fish.

TABLE 9. CONCENTRATIONS OF HEAVY METALS IN FISH FROM WATER QUALITY MANAGEMENT PROJECT LAKES (PPM WET WEIGHT)

	Largemouth Bass* 9/18/75	Largemouth Bass* 11/4/75	Stickleback† 9/19/75	Stickleback† 9/19/75	Stickleback† 10/30/75	Stickleback† 10/30/75
Lake	4	4	3	4	3	4
No. Fish	9	3	5	5	5	8
Mn - Ave	1.1	1.6	8.4	9.8	8.7	9.6
Range	(0.9-1.5)	(1.4-1.9)	---	---	---	---
Fe - Ave	5	16	20	26	26	34
Range	(1.0-16)	(8.0-17)	---	---	---	---
Zn - Ave	12	14	42	44	46	40
Range	(8-16)	(11-17)	---	---	---	---
Cu - Ave	<0.1	<0.1	1.9	1.6	2.0	1.6
Range	(<0.1-1.3)	(<0.1-1.0)	---	---	---	---
Cr - Ave	0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Range	(<0.1-0.5)	---	---	---	---	---
Ni - Ave	0.2	<0.1	<0.1	<0.1	<0.1	<0.1
Range	(<0.1-0.6)	---	---	---	---	---

* Largemouth bass were analyzed as muscle tissue only.

† Sticklebacks were analyzed as a composite of whole fish.

preliminary data do indicate that the lake system has not received significant contamination by either chlorinated hydrocarbons or polychlorinated biphenyls.

The concentrations of heavy metals in the bass samples taken in September and November do not indicate a significant contamination problem (TABLE 9). Slightly higher levels of heavy metals were found in sticklebacks than in bass, but this may reflect the fact that the entire fish was analyzed for the stickleback while only muscle tissue of the largemouth bass was analyzed. There are plans to continue monitoring for heavy metals in the fish during the next year to evaluate potential for accumulation within the lakes and plans to extend the analysis to include lead, cadmium, and mercury.

In addition to evaluations of fish within the WQMP lakes, a study has been initiated to evaluate the potential of using products harvested from the lakes to prepare diets for the culture of fish in other waters. A diet incorporating *Daphnia sp.* and *Cladophora fracta* was prepared using data generated from a least cost computer program designed to meet nutritional requirements of salmonids. A feeding trial using 16 rainbow trout fingerlings in each of the six 0.19 m^3 (50 gallon) tanks was conducted to compare growth rates of fish fed the experimental diet with control groups fed a commercial trout diet. Preliminary data indicate that the fish on the test diet grew at a slower rate than the control fish fed on a commercial diet. Acceptance of food by hatchery fish is a function of pellet size and consistency and diet composition, and it is believed that a change will result in improved palatability. Feeding trials using rainbow trout fingerlings will be conducted in the future to test changes aimed at improving palatability.

In addition, a diet is now being prepared that will utilize *Elodea canadensis* ensilaged with poultry wastes as a non-protein nitrogen source. This new diet will be fed to carp in laboratory feeding trials.

WATER CHEMISTRY AND ECOLOGICAL INTERACTIONS

Introduction

Most of the beneficial attributes of ponds or lakes in the improvement of wastewater quality are linked to a three way interaction between the aquatic plants, the bacteria, and the water chemistry. Removal of nutrients and metals is closely tied to the photosynthetic activity of aquatic plants and the associated alterations in water chemistry due to plant withdrawal of carbon dioxide from the alkalinity system. Bacterial utilization of both allochthonous and autochthonous organics recharges the alkalinity and, if dominant, tends to redissolve some of the chemical precipitates. As such, attempts to optimize waste removal in such systems must include consideration and manipulation of the factors which control these two major categories of biotic activity. Figure 15, a schematic presentation of this process, shows the need to export material to minimize bacterial recycle.

Factors of potential importance to plants in wastewater lakes include solar energy input, water temperature, and the nutrient content of the wastewater. Nutrients of prime importance to plants are nitrogen, phosphorus, and carbon with the required trace nutrients usually being present in abundance in wastewater. In most cases wastewater also contains nitrogen and phosphorus at concentrations in excess of that required by plants.

As shown in Figure 16, the nutrient content decreases as the wastewater flows through the WQMP lakes but the phosphorus concentration remains at a level sufficient to support aquatic plants within all four lakes. Nitrogen availability would appear to meet the need of aquatic plants in all lakes except perhaps Lake 4.

The data in Figure 16 are average values for the indicated parameter within each lake for the entire month of August, 1975, given with one standard deviation either side of the mean. Obviously, the nutrient concentrations decrease from lake to lake but the decreased variability in nutrient levels within each lake in a downstream direction also indicates a marked degree of stabilization by the aquatic ecosystem.

Data collected since the completion of this study indicate that the apparent phosphorus removal was accomplished by sorption of P on bottom sediments. After this sorption capacity was exceeded in 1977, phosphorus concentrations in Lake 4 exceeded the State of Michigan discharge standards of 1 mg P/ℓ. Thus, lakes are not efficient at phosphorus removal and water out of the lakes should be sprayed on the land site instead of being discharged directly to surface streams.

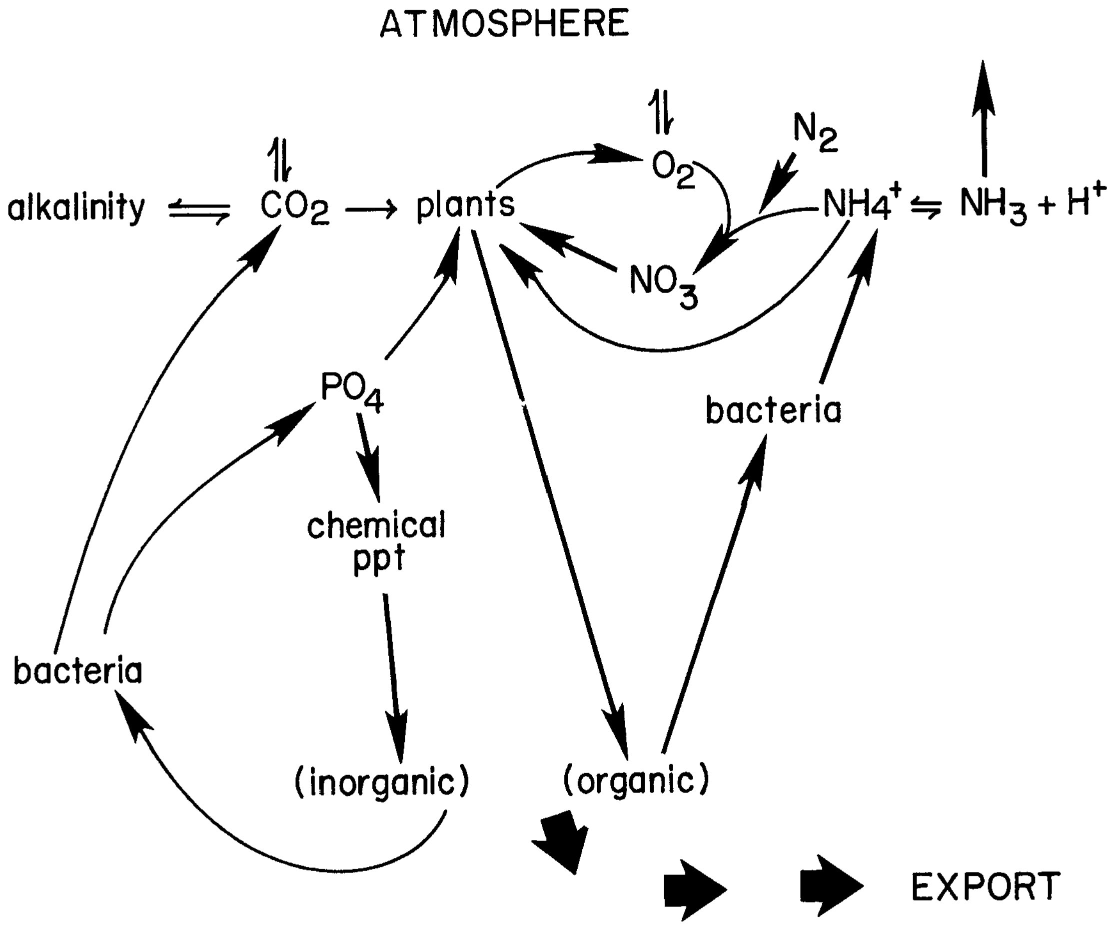


Figure 15. Nutrient pathways within an enriched aquatic ecosystem.

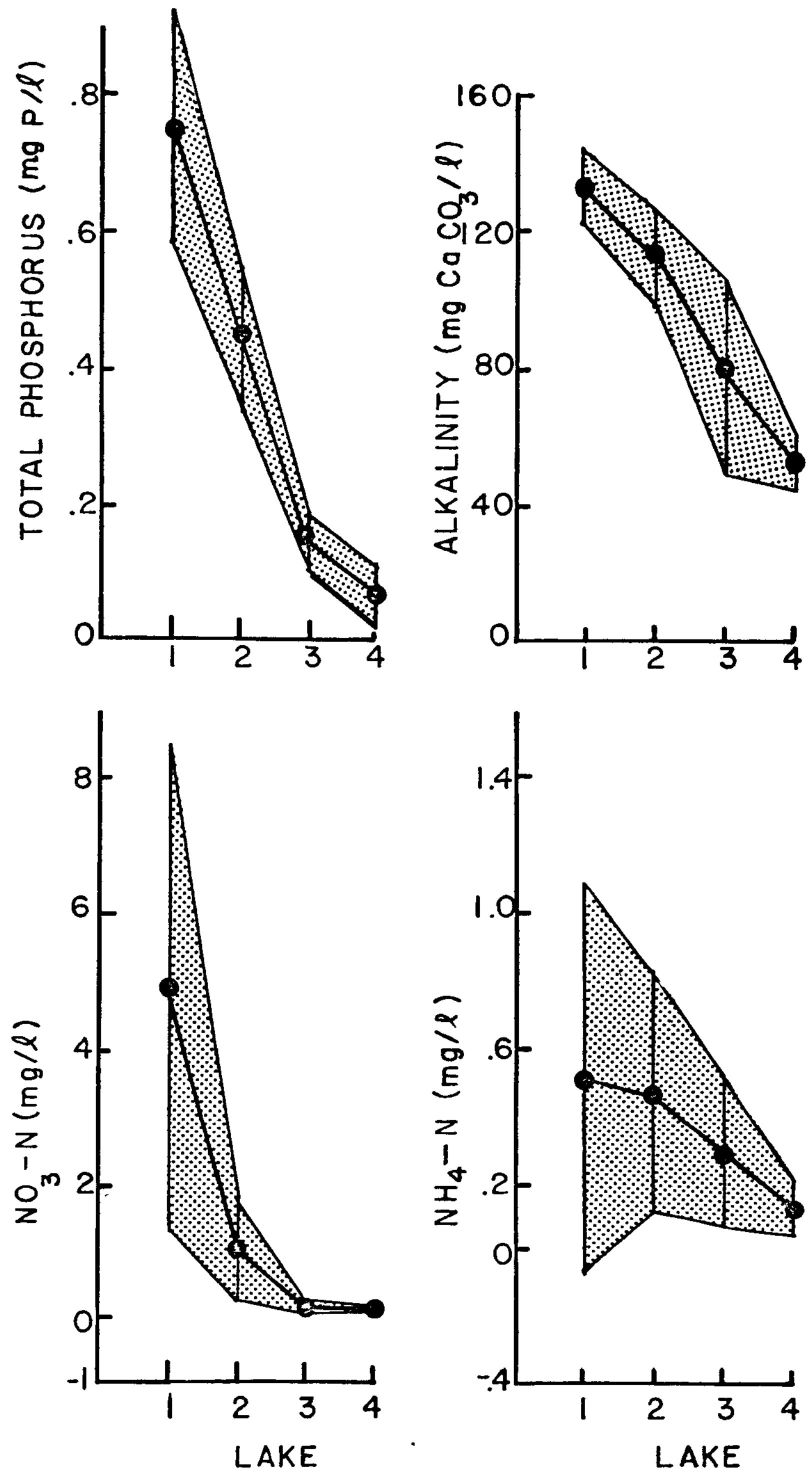


Figure 16. Nutrient levels in the four WQMP lakes during August, 1975. Values given are means ± one standard deviation.

LIGHT-CARBON INTERACTIONS

Since phosphorus and nitrogen were present throughout the lake system, attention was focused on carbon and light as parameters controlling plant activity. For this purpose, diurnal oxygen and pH data were obtained from each of the lakes at weekly intervals during August and early September, 1975. The maximum gain in dissolved oxygen (DO) extracted from these data was used as a measure of photosynthetic activity. The minimum pH each day was used with alkalinity determinations to calculate the maximum concentration of free carbon dioxide in the water on that day. Measures of solar input were obtained from a pyroheliometer located less than a mile from the lakes.

Total photosynthetic activity, represented by gain of DO over a single day, is plotted as a function of light intensity and as a function of free carbon dioxide concentration in Figure 17. In both cases, there is an apparent relationship between these parameters and photosynthetic activity but, in both cases, the correlation coefficient (r) does not suggest a tight relationship. Inspection of these data suggested that light appeared to be a more important factor in Lake 1 while carbon appeared to have a greater import in Lake 4. Biotic activity in Lakes 2 and 3 appeared to be affected by both light and carbon.

Based on this analysis, the gain of DO within the lakes was plotted as a function of the log of the cross-product of existing light and carbon levels. As shown in Figure 18, this relationship yielded a correlation coefficient of 0.8, a marked improvement over that obtained from consideration of either of these parameters as single limits. As such, it appears that during this period total photosynthesis within the four WQMP lakes was controlled to a considerable extent by an interaction between light and free carbon dioxide availability.

Application of the equation resulting from the linear regression of the data presented in Figure 18 yields Figure 19. This latter figure suggests that if carbon dioxide is abundant, light availability is the prime factor controlling plant activity and that increases from 30 to 100 langleys is of greater import than is an equal increase at higher light levels. At free carbon dioxide concentrations at and below atmospheric equilibrium (about 16 μmoles/ℓ), the availability of free carbon dioxide appears to be of

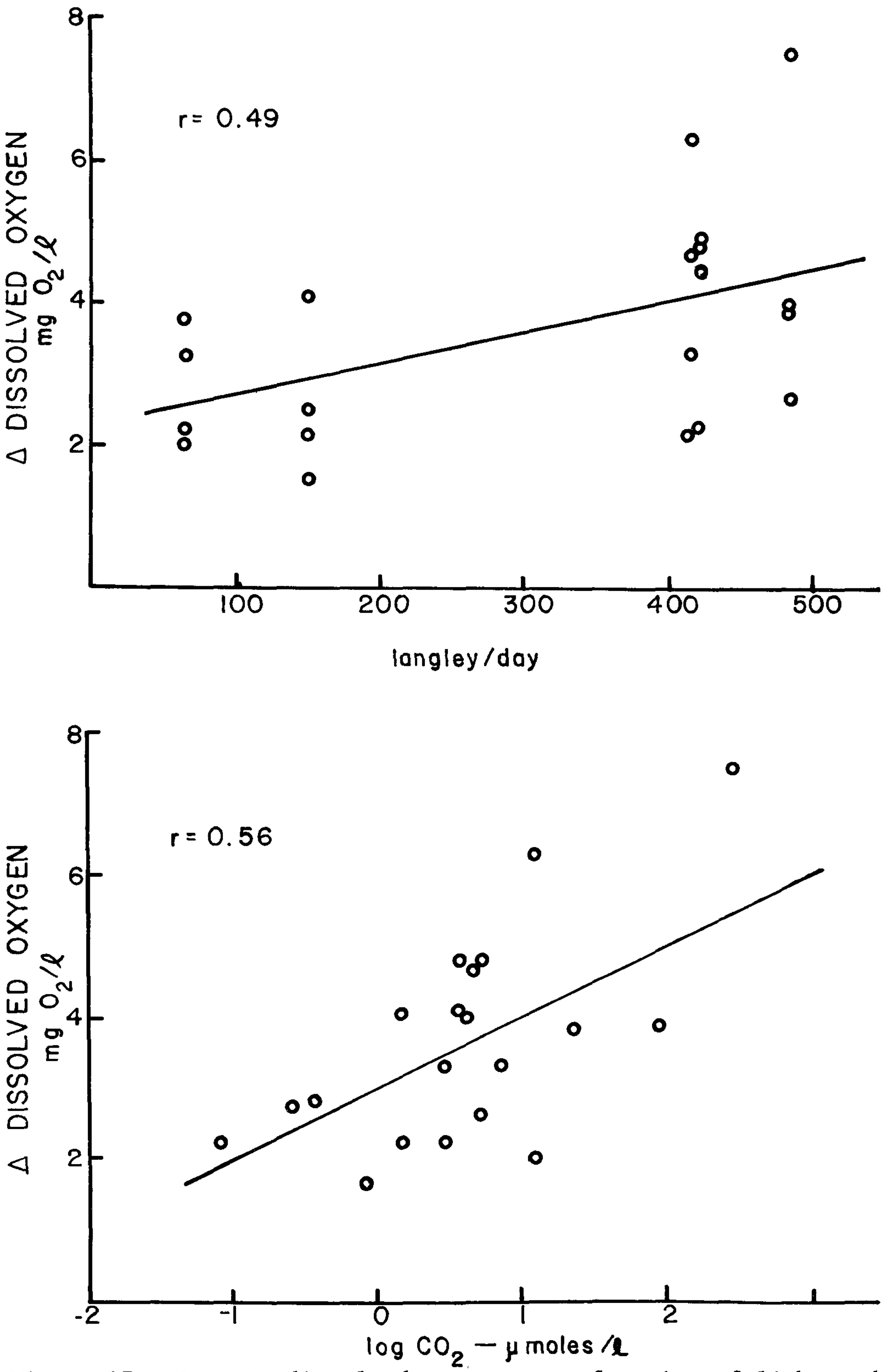


Figure 17. Gain in dissolved oxygen as a function of light and and carbon dioxide availability in the four WQMP lakes during August, 1975.

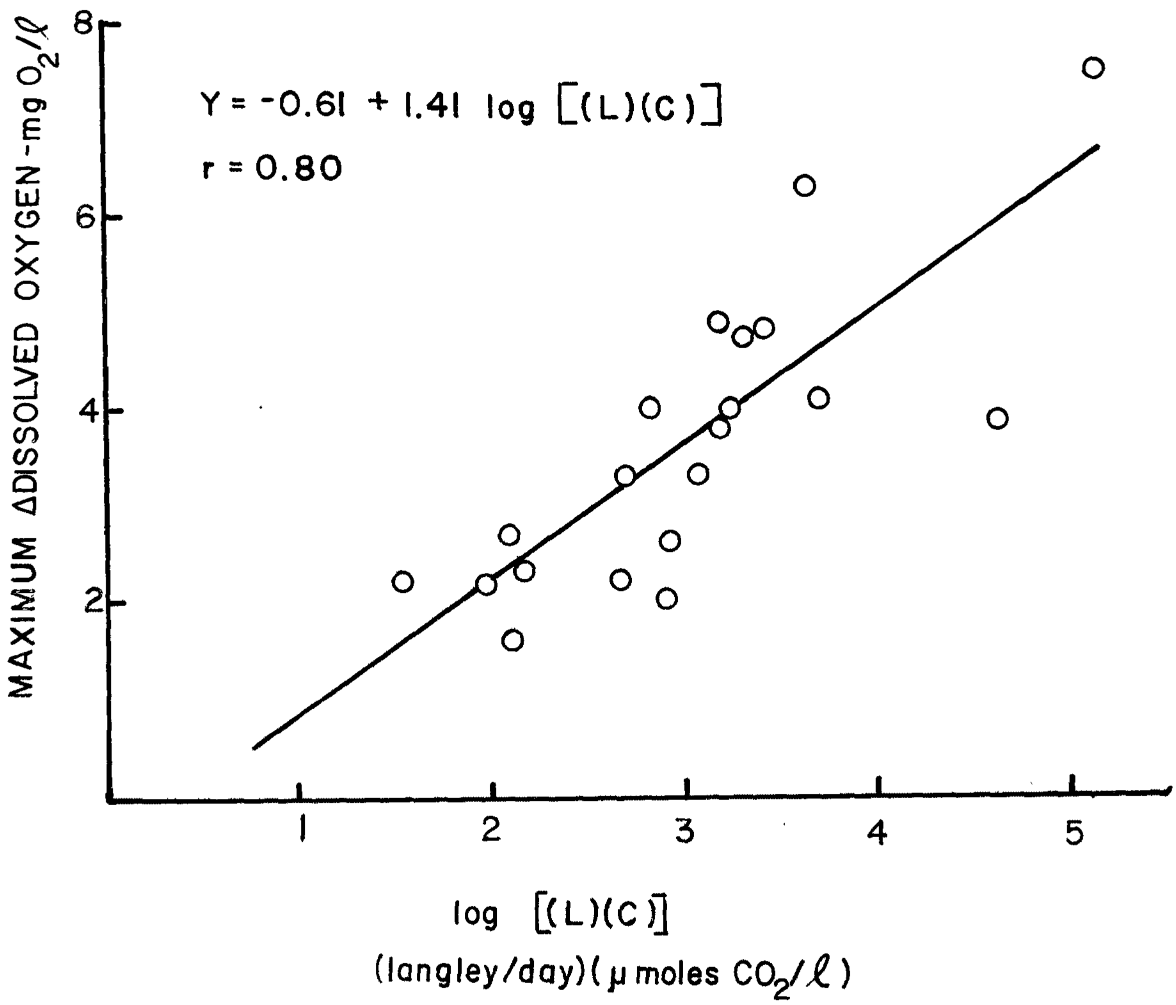


Figure 18. Gain in dissolved oxygen as a function of the cross-product of available light and carbon dioxide.

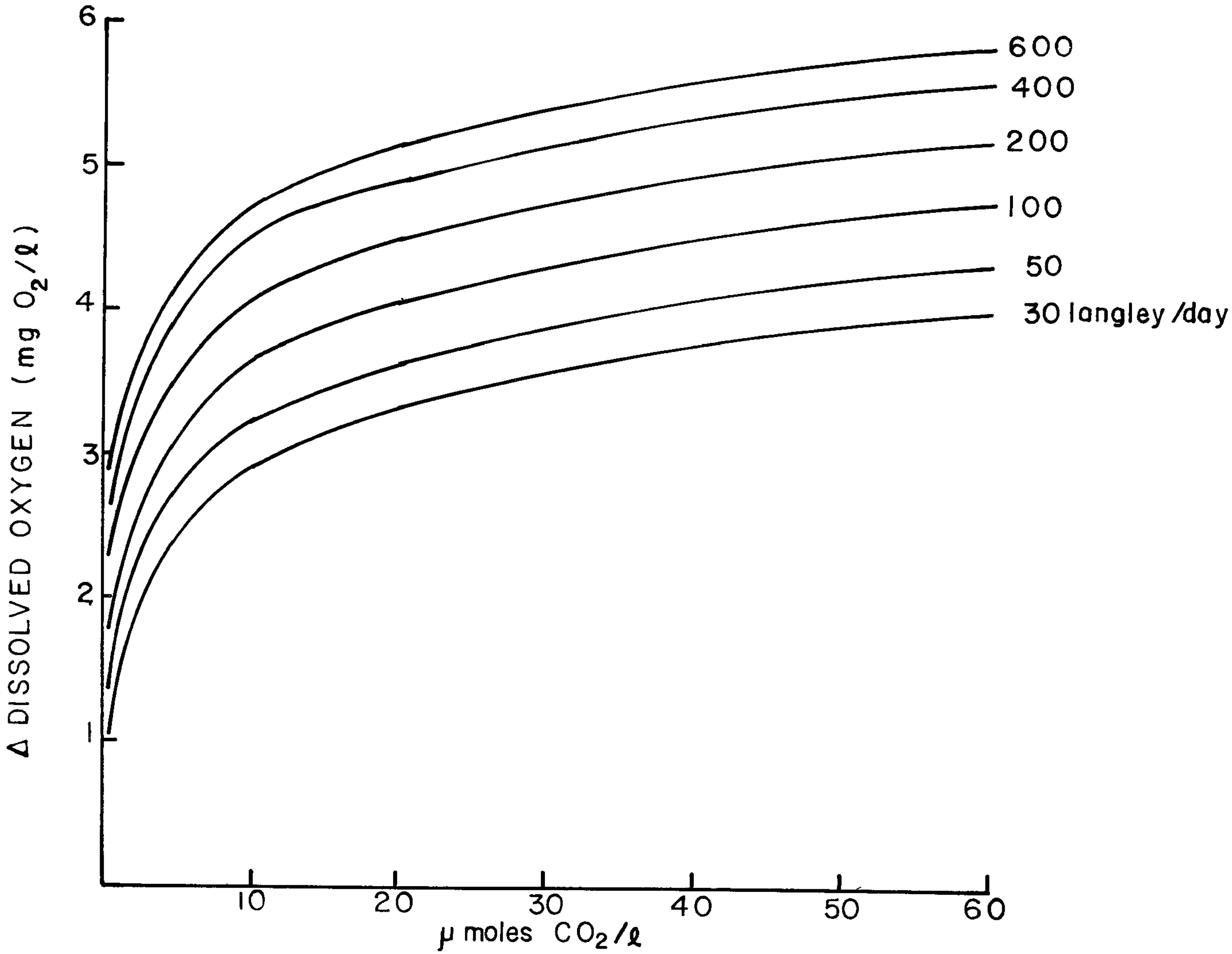


Figure 19. Calculated relationship between photosynthetic oxygen production and light and carbon dioxide availability within the WQMP lakes in late August, 1975.

significant import in controlling aquatic plant photosynthesis. Thus, increasing detention time to allow greater recarbonation would result in increased productivity while decreased detention time would have the opposite effect.

The average free carbon dioxide concentration during the month of August, 1975, decreased from 28 μmoles/ℓ in Lake 1 to 16 μmoles/ℓ in Lake 2 to 6 μmoles/ℓ in Lake 3 to 3 μmoles/ℓ in Lake 4. Comparison of these data with Figure 19 indicates the increasing role of free carbon dioxide in controlling plant activity as the wastewater moves through the WQMP lakes.

While the free carbon dioxide content of the lakes varied significantly from day to day, light availability also varied significantly over the month of August as is shown in Figure 20. However, to some extent the free carbon dioxide content is also a function of solar powered biotic activity over both time and space within the lake system. Solar insolation triggers photosynthesis by the aquatic plants which withdraw carbon dioxide from the alkalinity system resulting in lower free carbon dioxide concentrations. Continued photosynthetic uptake of carbon dioxide results in lowered carbon dioxide levels within a given lake as a function of time while also yielding a spatial change in the free carbon dioxide level in the water as it moves downstream through the lakes. Thus, it appears that plant activity in the WQMP lakes during the summer months is directly related to solar intensity, the alkalinity of the incoming wastewater, and to the rate of water movement through the four lakes. The latter factor is the only factor that is readily controlled. Thus, detention time is the major management procedure for controlling plant activity in such lakes.

SEASONAL CHANGES

While the above considerations suggest the importance of light and carbon in controlling photosynthetic activity of the entire aquatic plant community during mid-summer, it says little about other seasons of the year. Examination of the growth pattern of the aquatic macrophyte Elodea canadensis within Lake 4 during 1975 suggests a close relationship between the growth rate of this plant and the free carbon dioxide content of the water over the entire growing season as shown in the following discussion.

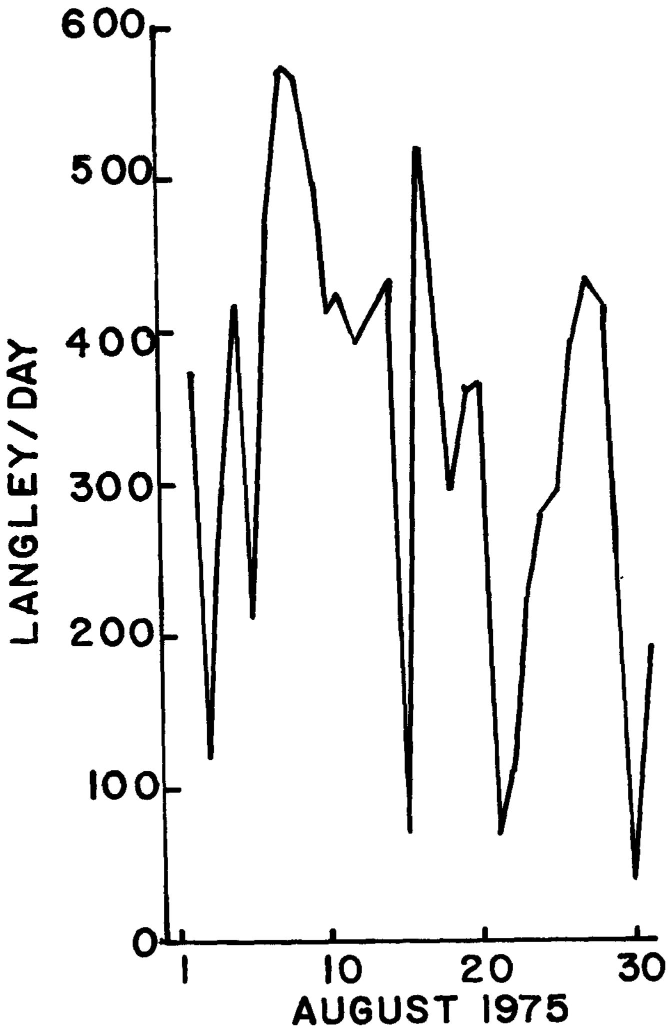


Figure 20. Variation in sunlight availability to the WQMP lakes during August, 1975.

Standing crop biomass of macrophytes within the WQMP lakes was determined six times during the spring and summer of 1975 at intervals ranging from 13 to 40 days. The resulting estimates of Elodea canadensis biomass within Lake 4 are presented in Figure 21 with the associated specific growth rates. Specific growth rate was determined from the relationship shown in Equation 7 where M_1 and M_2 refer to standing crop biomass at time T_1 and T_2, $\bar{M}$ is the average standing crop biomass over the time interval, and specific growth rate, μ, carries the unit of $time^{-1}$.

$$\frac{\frac{M_2 - M_1}{T_2 - T_1}}{\bar{M}} = \mu \qquad (7)$$

Examination of Figure 21 suggests that growth rate of Elodea canadensis was markedly accelerated in early July. Inspection of Figure 22 indicates that during this period respiratory activity exceeded photosynthetic reoxygenation and that the marked decline in DO was accompanied by significant recarbonation of the water. In fact, this respiration was sufficient to recarbonate the lake to the level found in early May. The resurgence of growth of Elodea canadensis at the same time the lake was recarbonated suggests some degree of interaction between these two phenomona.

The degree of interrelationship is illustrated in Figure 23, a plot of the specific growth rate of Elodea canadensis against the average free carbon dioxide concentration over the periods for which specific growth rates were calculated. The equation given on Figure 23 for the line drawn through the data is the familiar Monod application to entire organisms of the Michaelis-Menten equation used for enzyme kinetics as shown in Equation 8.

$$\mu = \mu max \frac{S}{K_s + S} \qquad (8)$$

where: μ = the specific growth rate ($Time^{-1}$)

μmax = the maximum specific growth rate ($Time^{-1}$)

S = the substrate concentration (in this case μmoles free CO_2/ℓ)

K_s = the half saturating substrate level (in this case μmoles free CO_2/ℓ)

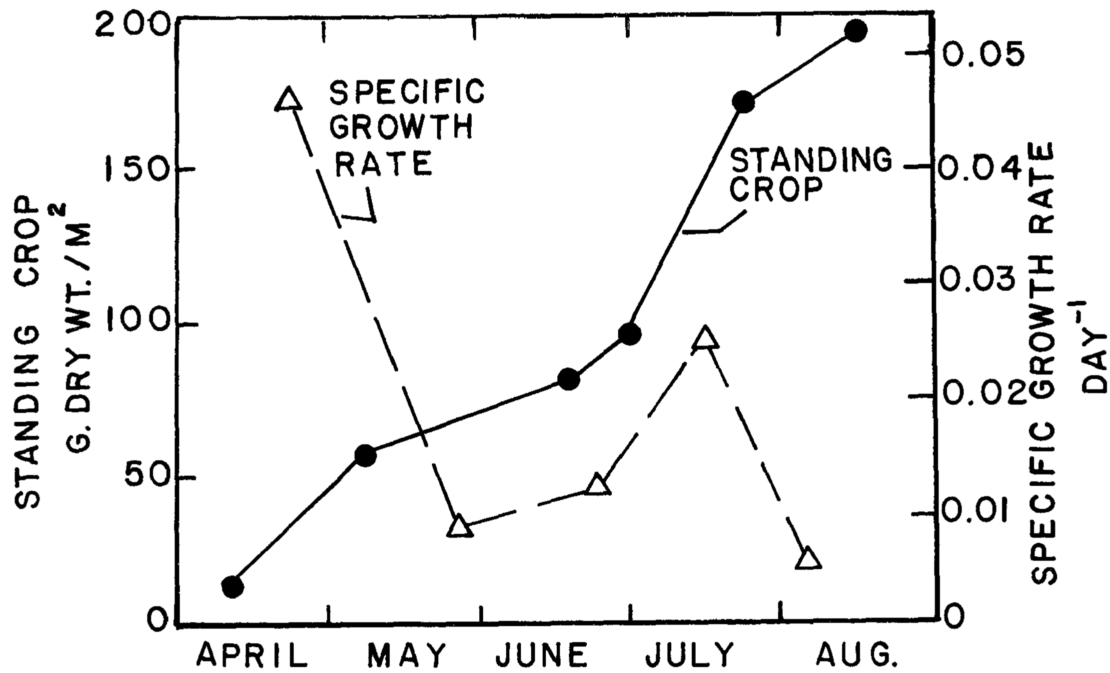


Figure 21. Standing crop biomass and specific growth rate of Elodea canadensis in WQMP Lake 4 during 1975.

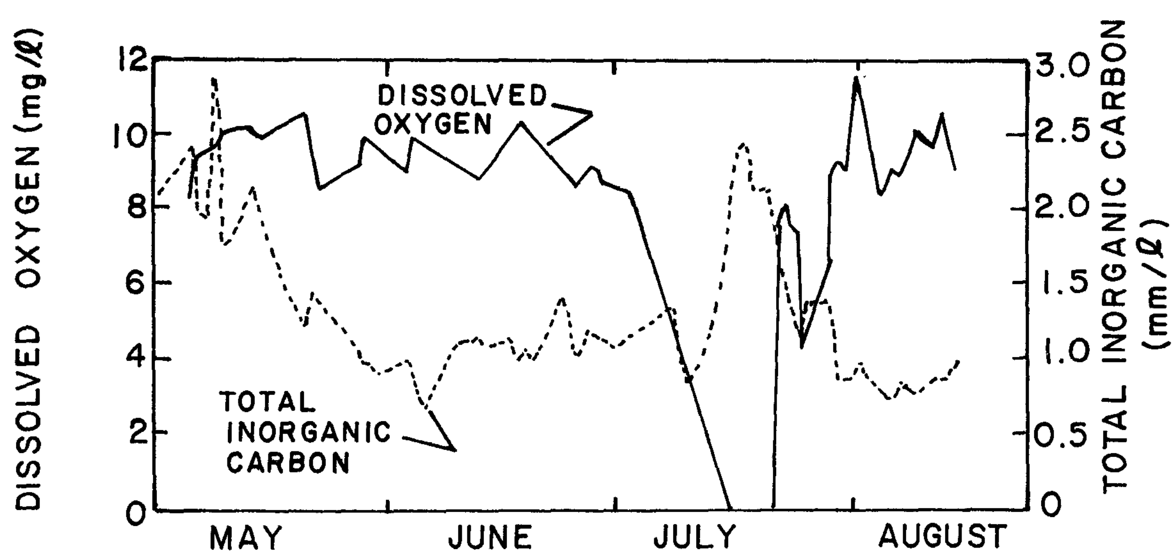


Figure 22. Dissolved oxygen and total inorganic carbon concentrations in WQMP Lake 4 during 1975.

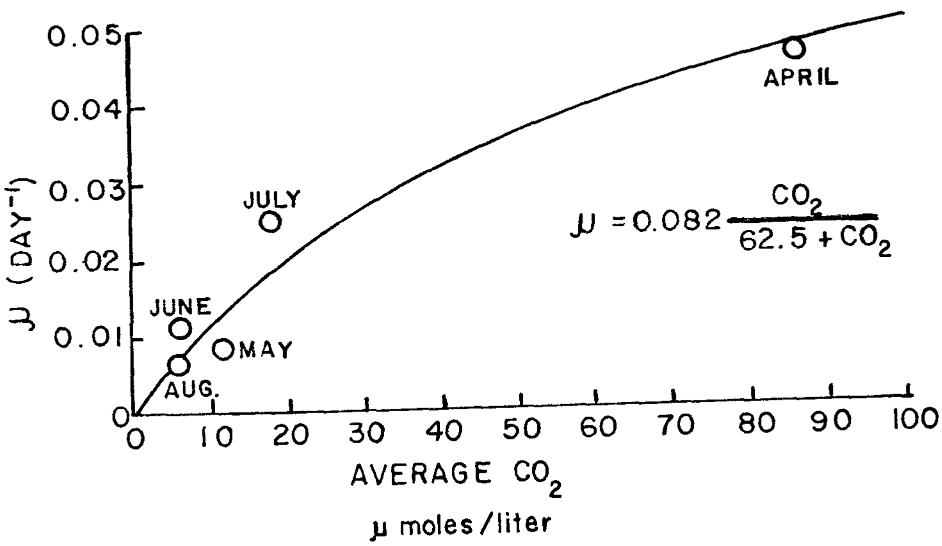


Figure 23. Relationship between specific growth rate of Elodea canadensis and the free carbon dioxide content of Lake 4 during 1975. The line drawn through these data was calculated with the indicated equation.

Despite the limited number of data points available, the data given in Figure 23 yield a good preliminary indication that the growth rate of Elodea canadensis within the WQMP lakes is directly related to the availability of free carbon dioxide. Light is of obvious importance to these plants also but over the long and variable intervals between the times of macrophyte sampling, light intensity averages to reasonably uniform values while the free carbon dioxide level decreases throughout the growing season.

As was shown in Figure 14, the pattern of macrophyte dominance varied a good deal within the four lakes. Lakes 2, 3, and 4 were stocked with a mixture of several species of aquatic plants in 1973 including Potamogeton foliosus, Elodea canadensis, Najas flexilis, Elodea nuttallii, and Myriophyllum spicatum. Lake 1 was not stocked except for incidental introduction and remained a phytoplankton dominated lake until after the drawdown in July after which the new East Lansing wastewater treatment facility was placed in operation. At that point Potamogeton foliosus, Ceratophyllum demersum, and Cladophora fracta began to grow. The factor limiting macrophyte activity in this lake appears to have been the more limited light penetration due to the turbidity generated by particulate carry-over from the old, overloaded East

Lansing wastewater treatment facility. However, the lack of stocked plants in Lake 1 may have had some effect.

Lake 2 was dominated by the periphytic alga Cladophora fracta throughout the spring and summer of 1975 (Figure 14). This plant grows as a benthic mat but as it ages it detaches, rises, and floats in amorphous masses at the water surface. This growth form offers significant promise for the removal of material from the lakes in that one ton dry weight of this alga was removed from Lake 2 with reasonably modest effort on a trial basis.

Lake 3 supported a good growth of Elodea canadensis until late June when it was overgrown by Cladophora fracta (Figure 14). With a nominal detention time of one month per lake at a throughput of 1665 m^3/d (0.44 MGD), the wastewater added to initiate the continuous throughput in mid-April should begin to enter Lake 3 by mid-June. This suggests that some component in the wastewater may have favored Cladophora over Elodea.

Lake 4 was dominated by Elodea canadensis throughout the growing season of 1975 (Figure 14). Cladophora fracta, while present, never overgrew the Elodea.

From the data collected to date, it appears that the availability of an inorganic nitrogen source may be important as a factor determining the competitive edge between Cladophora and Elodea. The inorganic nitrogen content of a single mean water mass decreases significantly as it passes through the four lakes as is shown in Figure 24. From this figure, it can be seen that for this water mass the mean total inorganic nitrogen concentration fell from 7.58 to 2.70 mgN/ℓ through Lake 2 where Cladophora was abundant and from 2.70 to 0.30 mgN/ℓ in Lake 3 where it eventually out-competed Elodea. Little inorganic nitrogen entered Lake 4, little was removed, and this last lake maintained an Elodea dominance throughout the 1975 growing season.

The total content of Elodea canadensis harvested from the lake system was about 2.1% on an organic weight basis while Cladophora fracta averaged 5.4% nitrogen on an organic weight basis. The apparent greater demand for nitrogen by Cladophora plus the generally low level of inorganic nitrogen in Lake 4 (as low as 0.01 mg N/ℓ) suggest that a nitrogen shortage may have limited the Cladophora in this lake and that this nitrogen limitation was between 0.01 and 0.30 mg N/ℓ.

Thus, total photosynthesis in the WQMP lakes during summer months is apparently controlled by the availability of light and carbon dioxide, while

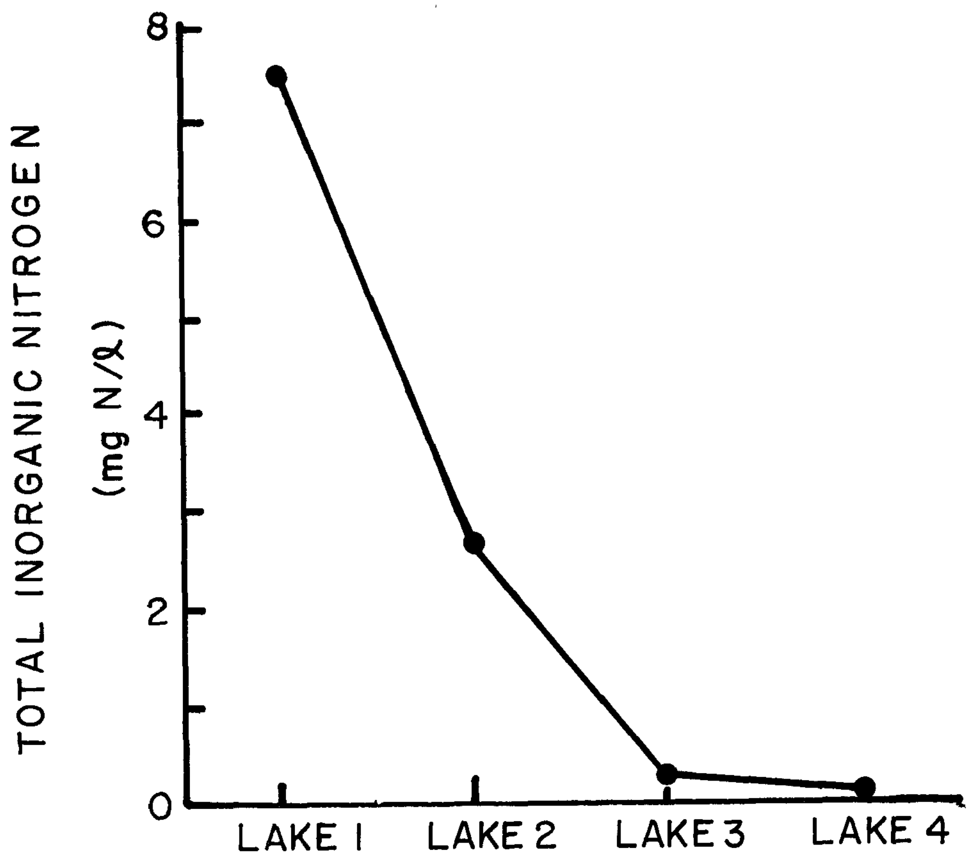


Figure 24. Total inorganic nitrogen content of a single water mass moving through the WQMP lakes during the summer of 1975.

the makeup of the plant community is determined, at least in part, by other interacting factors including nitrogen availability.

PLANT GENERATED NUTRIENT REMOVAL

Extraction of carbon dioxide from the alkalinity system by the plants as the water flows through the four lakes results in marked alterations in the water chemistry. Perhaps the best single indicator of change in the chemical equilibrium of the wastewater as it flows through the WQMP lakes is seen in the alteration of alkalinity shown in Figure 25. Plant uptake of carbon dioxide from the alkalinity alters the equilibrium, resulting in increased pH and increased carbonate ion concentration to the point where the solubility is exceeded and carbonate precipitates as calcium carbonate. This activity

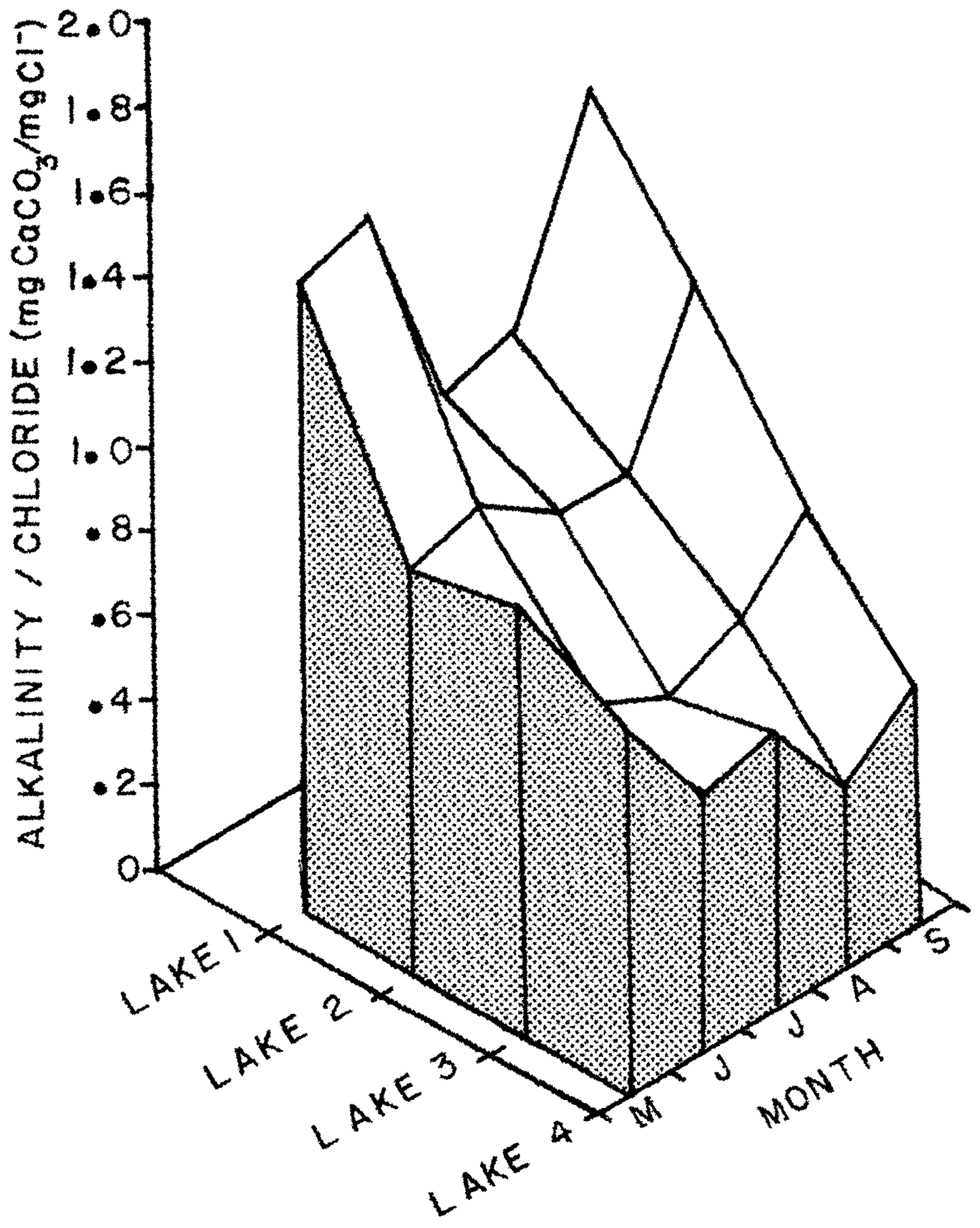


Figure 25. Variation of alkalinity as a function of chloride to correct for evaporation within the four WQMP lakes during 1975.

accelerates the chemical formation and precipitation of a variety of metal salts and phosphates, both directly and as co-precipitates with the carbonate.

As the wastewater moves through the four lakes, pH rises and alkalinity decreases as is shown for a single nominal water mass (calculated by assuming an average detention time of 30 days per lake, e.g. the mass of water in Lake 1 at day one would be in Lake 2 at day 31, etc.) in Figure 26. Relative alterations in the more common cations and anions are given in Figure 27. Generally, then, plant extraction of carbon from the alkalinity initiates a variety of chemical interactions which markedly increase the waste concentration and removal potentials of a lake.

When the wastewater enters the WQMP lakes, it is supersaturated with free carbon dioxide, reflecting the intense bacterial respiration which occurs within the activated sludge process. This supersaturation of carbon dioxide relative to atmospheric equilibrium allows the incoming wastewater to carry amounts of total inorganic carbon exceeding the atmospheric equilibrium determined solubility of calcium carbonate. However, given adequate sunlight, plant photosynthesis is stimulated by the elevated nitrogen and phosphorus content of wastewater and will rapidly reduce the free carbon dioxide far below atmospheric equilibrium. As a result, the carbonate content increases rapidly as the wastewater moves through the WQMP lakes as shown in Figure 28.

This figure represents the carbonate content of the wastewater in the WQMP lakes during the summer of 1975 as calculated from measured pH and alkalinity values plotted against the measured pH. Calcium determined solubility of carbonate is given for the inlet water and for Lake 4. Obviously the other cations are of importance but the high levels of carbonate and the general dynamic nature of these lakes suggest a rapidly changing system of fluctuating stability.

The rapidity of change within the lakes was illustrated by the significant respiration induced recarbonation of Lake 4 during the short period in July shown in Figure 22. The phosphorus level within this lake did not increase much during this respiratory event, but this may reflect the very low phosphorus level present within Lake 4 during the summer months. However, a similar respiratory event within Lake 3 during late August and early September resulted in significant phosphorus release as is shown in Figure 29. The general decline in pH and DO and the concomitant increase in free carbon

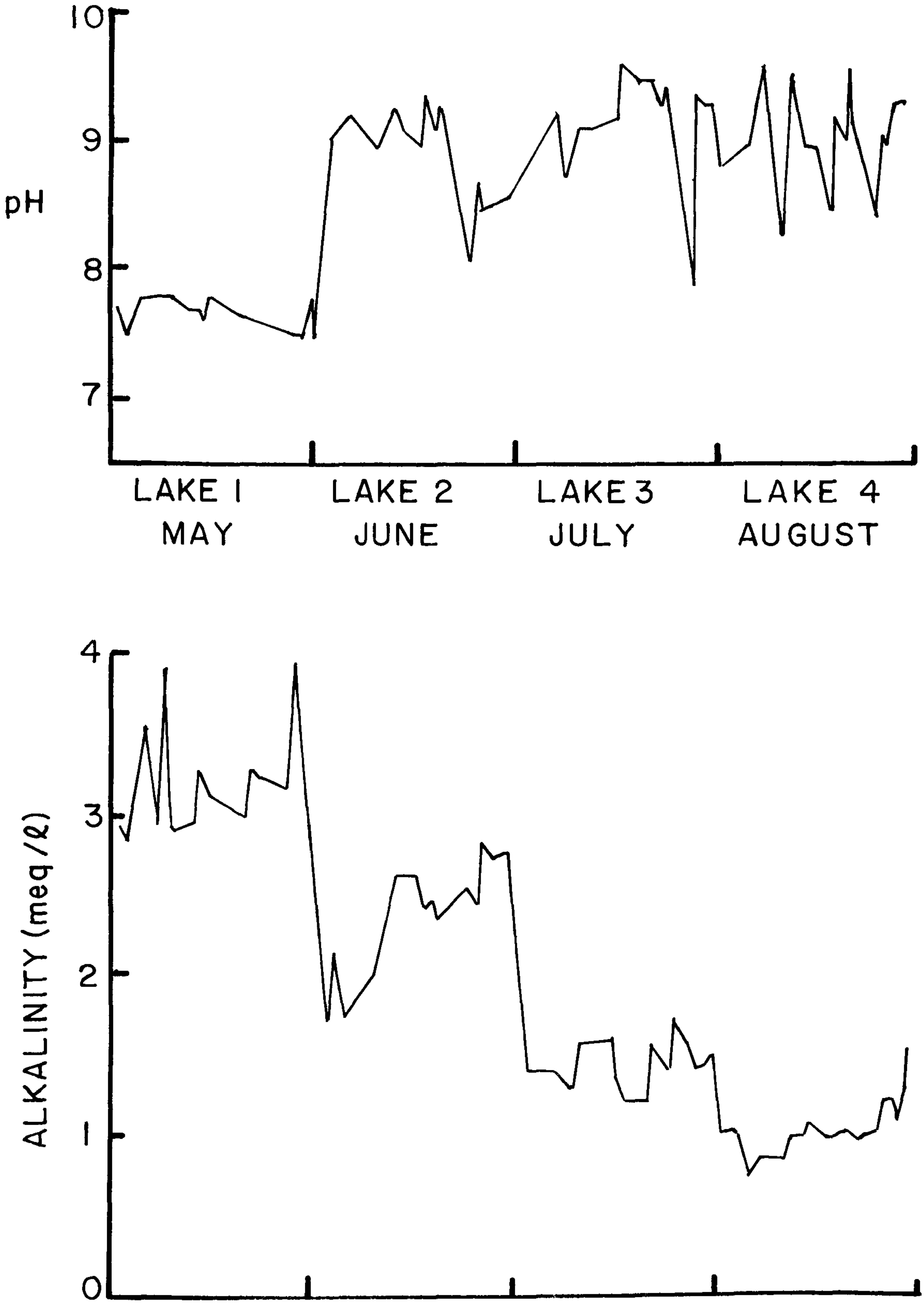


Figure 26. Variation in alkalinity and pH within a single water mass moving through the WQMP lakes during 1975.

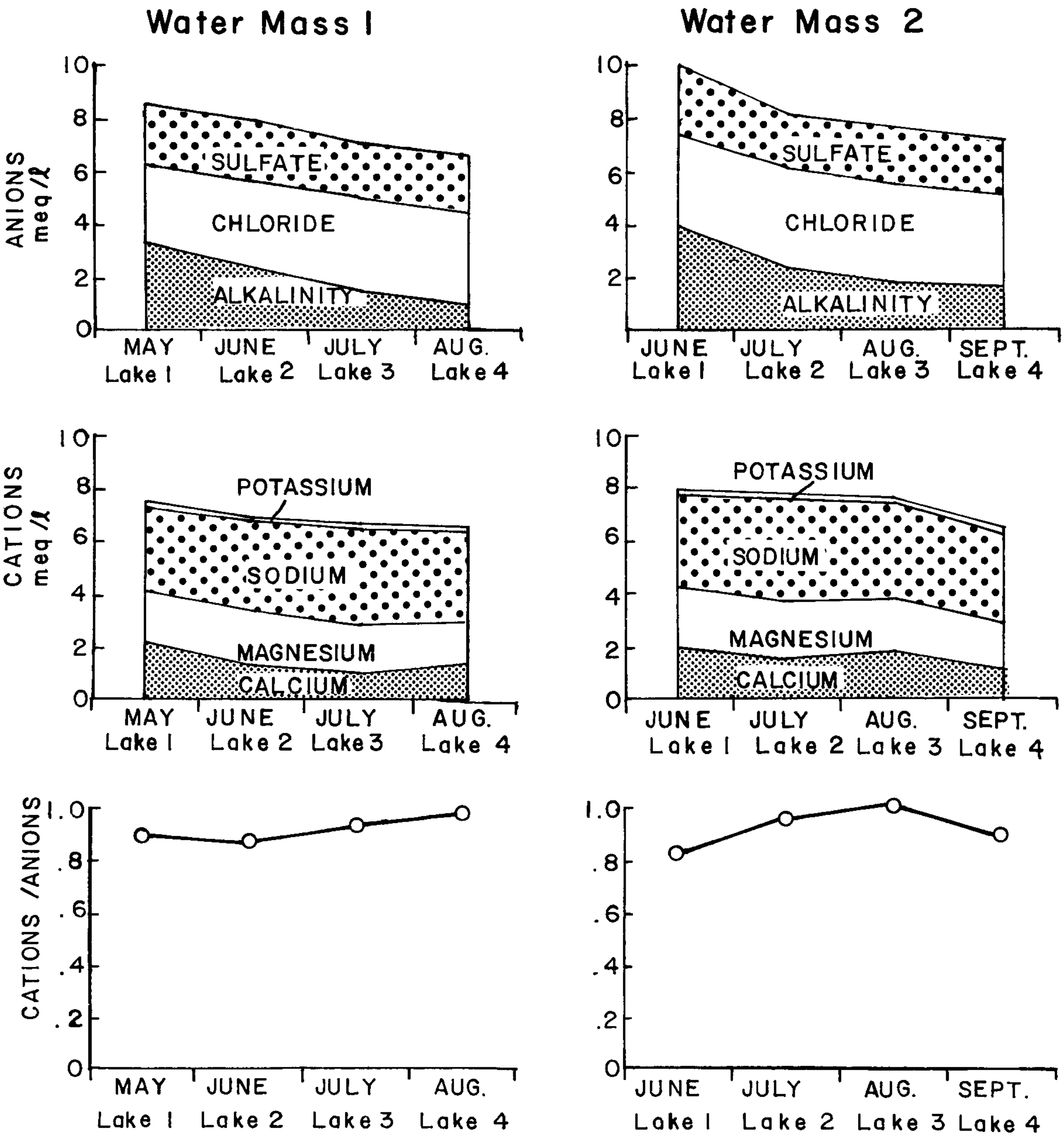


Figure 27. Relative variation in the more common cations and anions through the WQMP lakes during 1975. Water mass 1 is mass of water as it moves through each lake with a 30 day detention time; e.g., mass in Lake 1 on day 1 is in Lake 2 on day 31, etc.

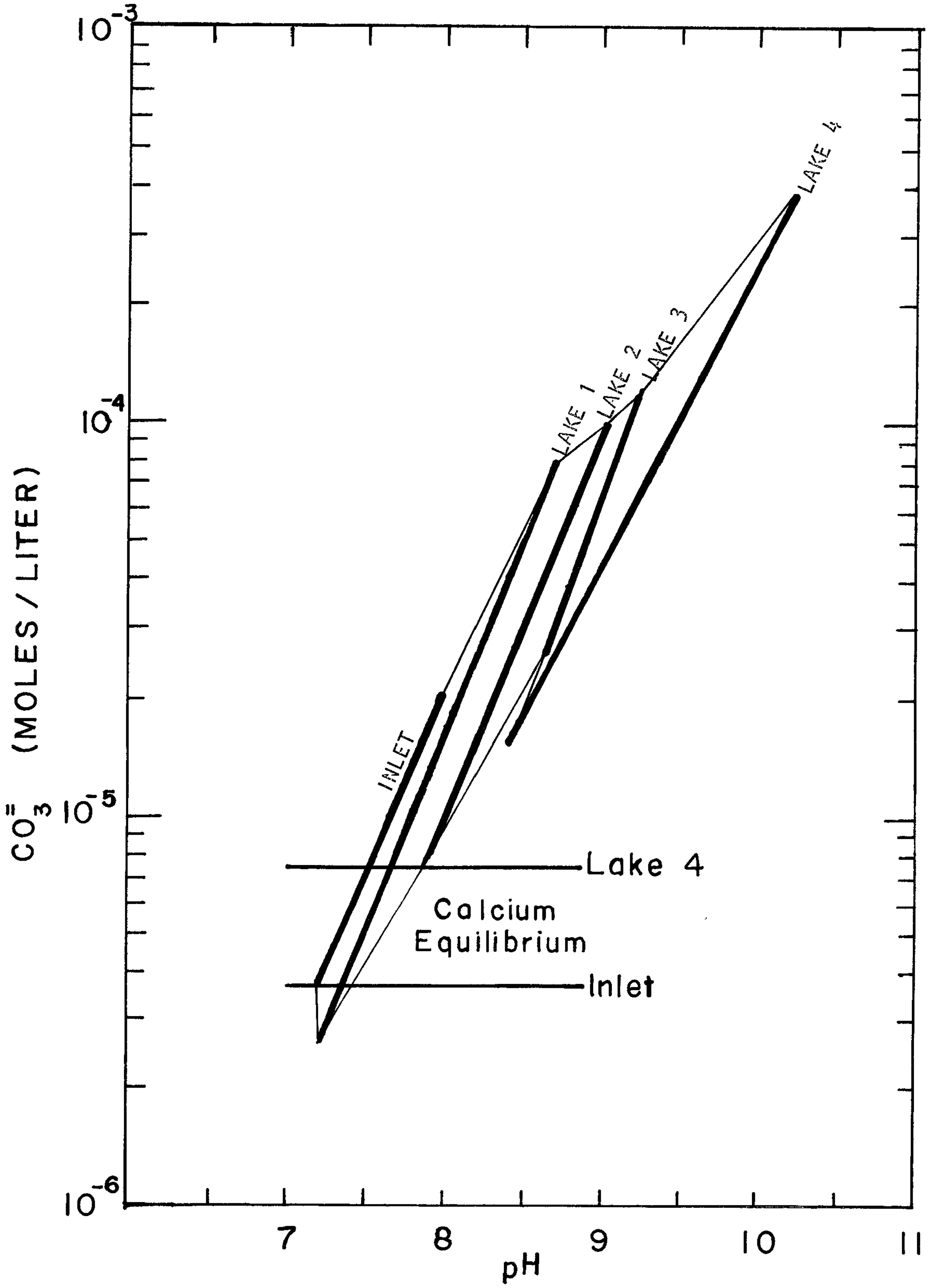


Figure 28. pH determined solubility of carbonate ion within the WQMP lakes given with calcium determined values for Lake 1 and Lake 4.

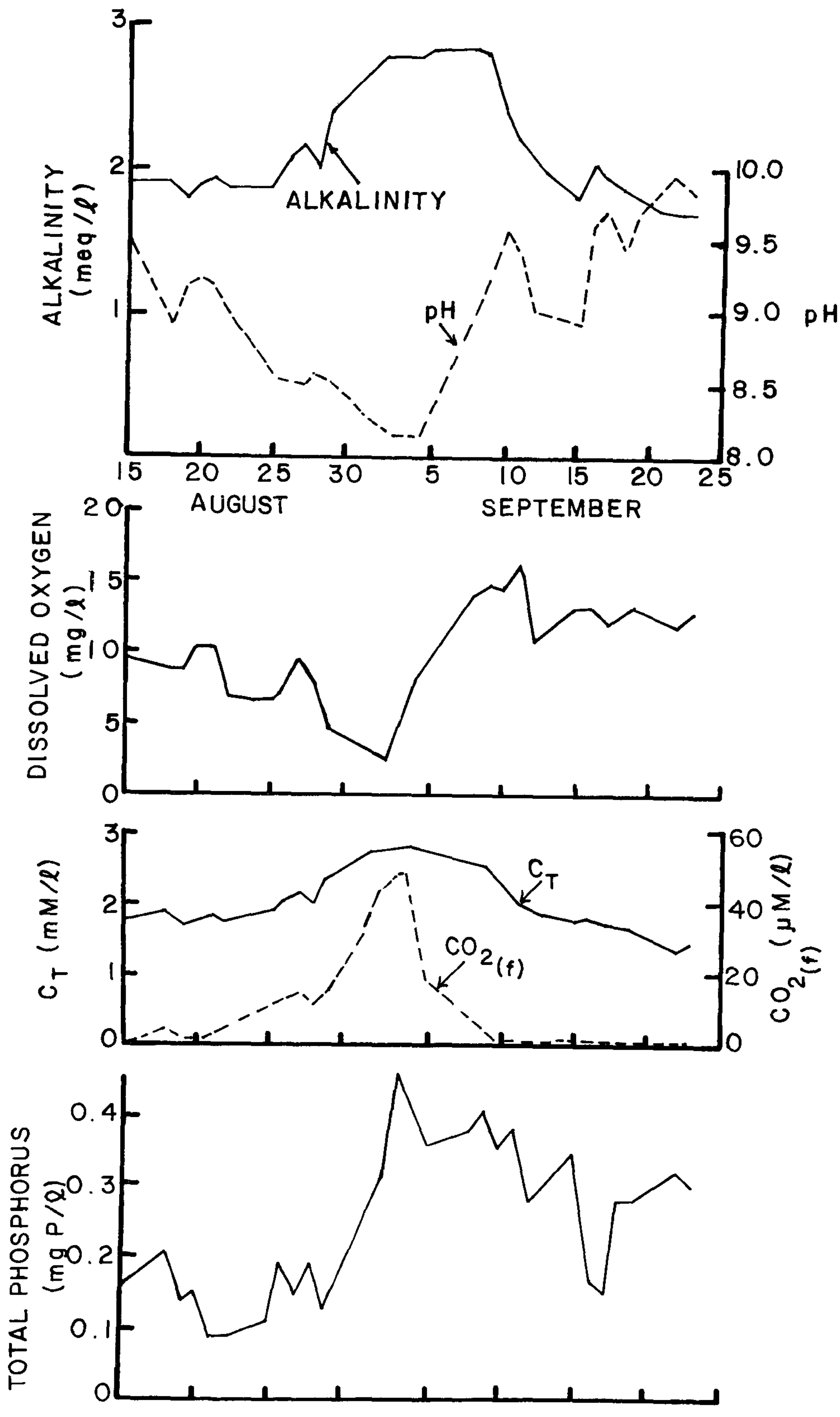


Figure 29. Variation in water chemistry associated with a respiratory event in WQMP Lake 3 in 1975.

dioxide indicate significant respiratory activity, suggesting that bacteria mineralized the organic plant biomass previously manufactured within the lake. This initial respiratory activity was not accompanied by release of phosphorus. Rather, the phosphorus release appears to have been initiated as the alkalinity began to increase at about the time when the free carbon dioxide concentration began to exceed the atmospheric equilibrium level. This suggests that bacterial respiration of accumulated plant biomass recarbonated the lake water to the point where the solubilities of phosphate precipitates and phosphate-bearing carbonates were exceeded and that this material was in fact redissolved. Thus, long term loss by physical-chemical precipitation does not appear to represent a significant sink for phosphorus in these lakes.

The bloom of a coccoid green alga which followed this respiratory period led to a rapid rise in both pH and DO, a sharp decrease in free carbon dioxide, and a decline in alkalinity back to the level present prior to the respiratory period. While the phosphorus concentration declined as the alkalinity decreased, it did not decline with the alkalinity proportionate to the gain noted during the period of respiratory induced resolubilization. This gives some indication that coprecipitation and secondary substitution may be important in the abiotic removal of phosphorus. However, such abiotic removal represents a small amount, and the net effect is that such physical-chemical precipitation of phosphorus cannot be counted on to remove enough phosphorus to meet discharge standards.

The origin of the organic substrate which supported the respiratory excess in Lake 4 is unknown, but available data suggest that some combination of settled phytoplankton, early summer Cladophora growths, and Potamogeton, which declined during this period, represented the energy source for the bacteria. The significant growths of Elodea which were overgrown by Cladophora, as well as the Cladophora, were the most probable bacterial food substrates during the respiratory period within Lake 3.

Under the operating conditions to date, the efficiency of the WQMP lakes in the removal of wastewater constituents depends directly on the type of waste material. Nitrogen removal was excellent as was shown in Figure 24. Phosphorus removal was impressive as shown in Figure 30, although data collected in 1976 and 1977 indicate that this phosphorus loss was primarily to sorption on bottom clays. This removal declined to low levels after

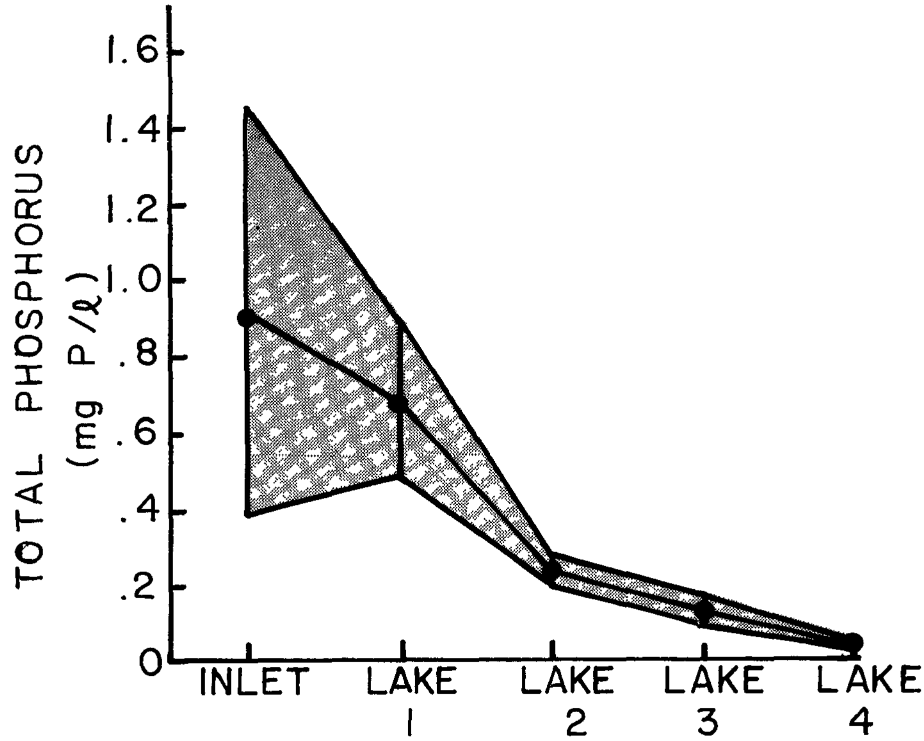


Figure 30. Decline in total phosphorus as wastewater passed through the WQMP lakes in 1975. Values given are means ± one standard deviation.

saturation of bottom clays with phosphorus. There was little removal of boron, chloride, and a variety of the more common cations. The pattern for boron, shown in Figure 31, is reasonably typical for those materials not removed by the lake ecosystem and for which the concentration in the lakes reflects the concentration in the wastewater entering the lakes. Concentration of such materials in the influent appears to reflect stormwater dilution and associated infiltration into domestic sewers as well as the variable population load associated with academic vacations at Michigan State University.

Nitrogen was removed by biotic uptake and by out-gassing of ammonia associated with biologically elevated pH values in the lakes at and above the pK value for ammonium ion dissociation and by denitrification during respiratory events. Results from preliminary studies indicate insignificant nitrogen fixation in both the water and the sediment and low populations of

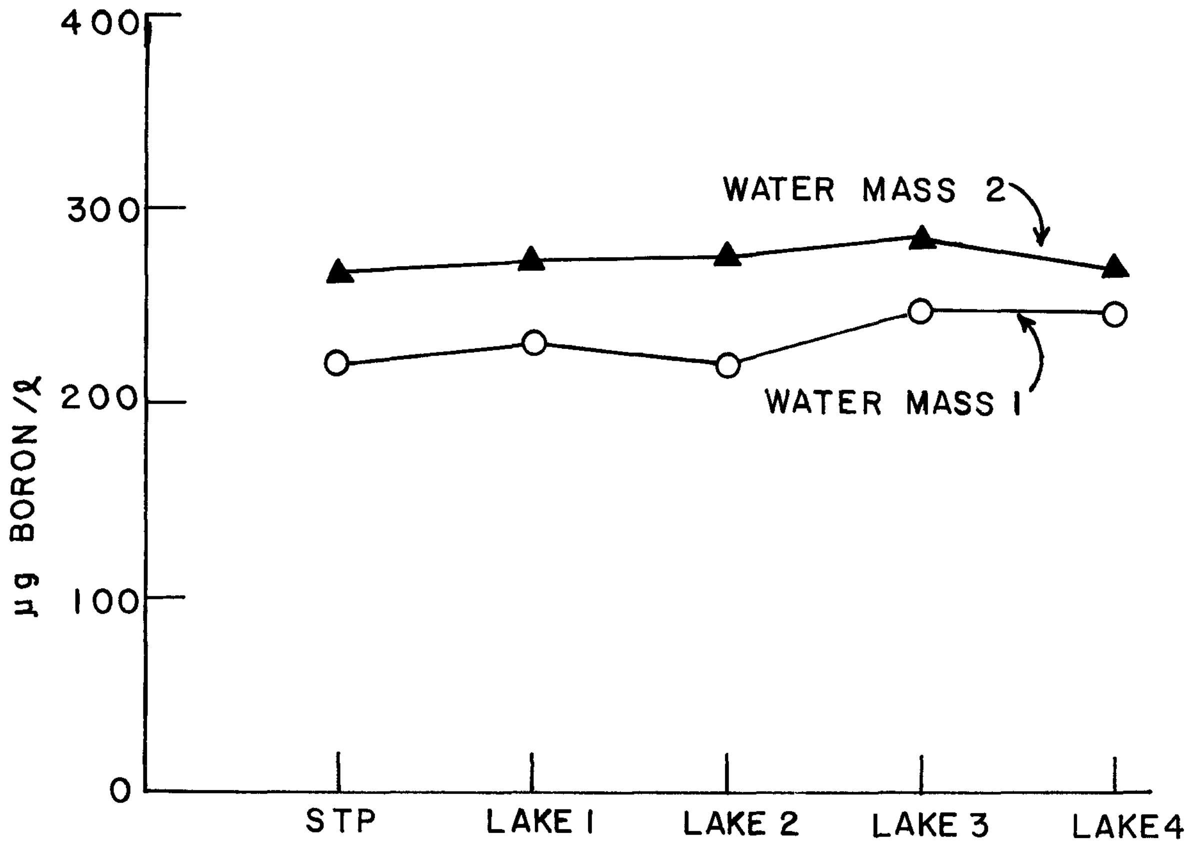


Figure 31. Boron concentration of wastewater as it passed through the WQMP lakes.

nitrifying bacteria within the lakes. Lakes appear to operate as very efficient strippers of nitrogen and offer great flexibility for design of lake-land irrigation systems.

Decreases in phosphorus were associated with both biotic uptake and biotic induced physical-chemical precipitation. Data collected since 1975 suggests that over 90% of phosphorus removal was a function of sorption on the clay bottom and that this removal ceases once bottom clays are saturated.

Generally, then, the nutrient removal which occurred was associated directly with the photosynthetic activity of various aquatic plants or with sorption on bottom clays. Release of phosphorus, both biotic and abiotic, apparently associated with bacterial use of aquatic plants indicates the need to harvest the plants prior to their serving as a bacterial energy source. However, such plant harvest must be optimized to allow maintenance of sufficient plant activity with the lakes to maintain the chemical equilibrium in a range favoring physical-chemical precipitation of phosphorus and metals. It appeared in 1975 that maintenance of this balance would become especially critical with the increased phosphorus load applied when completion of construction in 1976 allowed introduction of secondary effluent not subject to chemical additions for phosphorus removal. Data collected since that time indicate that no mechanisms other than biotic uptake exist in such wastewater lakes which will allow long term phosphorus removal. Biotic uptake and harvest can only remove 10% or less of incoming phosphorus.

Since the maintenance of optimum nutrient removal capacity of these dynamic lake systems appears to be related directly to a controlled harvest of plants and to plant mediated pH changes, the growth rate and form of growth of the plants are key considerations in the development of a successful management scheme. To date the lakes have been dominated by the periphytic alga, Cladophora fracta, the vascular macrophyte, Elodea canadensis, and by relatively rare blooms of planktonic algae. The absence of efficient low cost removal schemes for phytoplankton suggest that attempts at efficient removal of plant biomass from the lakes must be focused upon the periphyton and the macrophytes.

Of those plants which have grown well within the WQMP lakes, Cladophora fracta appears to offer significant advantages. It grows as a periphyton and then rises and floats at the surface where it is relatively easy to harvest. The harvested biomass is roughly 50% organic and 50% inorganic on a dry weight basis. This suggests that significant amounts of the inorganic precipitates are captured by the benthic Cladophora mat and are then brought to the surface where they can be removed. The exact growth rates and growth kinetics of this plant are unknown, but visual observation during the initial year of operation suggests that this plant grows quite rapidly.

Obviously, it would be desirable to maximize the growth of those plants which allow the greatest biomass removal in the shortest time while minimizing competing plant species. Considerations in meeting this goal include the development of a good working understanding of the kinetic growth response of the various plants to the changing multiparameter environmental equilibrium as the wastewater flows through the lakes in addition to the ease of harvest of the plants. From the data available to date, it appears that the primary variables interacting to control plant activity in wastewater are light, carbon, and temperature. Since none of these parameters are particularly amenable to direct manipulation on a field scale, it appears that the control technique to optimize plant type will be to vary the detention time relative to the chemical nature of the wastewater and ambient light and temperature conditions. Selective plant harvest to encourage selected species offers a second management possibility, but data are too sparse at this time to offer any conclusions.

PUBLIC HEALTH CONSIDERATIONS

From the data collected to date, the WQMP lakes appear to be extremely efficient in removing those bacteria commonly used as indicators of the pathogenic quality of water. As is shown in Figure 32, coliform bacteria numbers were reduced several orders of magnitude as the wastewater moved through the lakes. Fecal streptococci were reduced 42% with some indication of increases in the downstream lakes, perhaps contributed by the ducks which used these lakes.

Another indication of the improvement in water quality is seen in the difference in the dominant populations of denitrifying bacteria. In excess of 80% of the denitrifying bacteria in Lake 1 were Alcaligenes faecalis which, though they may be found in nature, are common residents of the intestinal tract of vertebrates. In Lake 4, 80% of the denitrifying bacteria were Pseudomonas sp., the most common natural denitrifier found in lake sediments.

Examination of the experimental wells throughout the project for bacterial contamination yielded the following results. Twenty-four of the 41 drift wells were dry while the 14 shallow rock and deep rock wells contained water. One of the shallow rock wells contained 108 coliform bacteria per 100 ml. A companion well drilled close by contained bacteria but no coliforms. A repeat sampling after chlorination and 45 minutes of pumping indicated no coliform bacteria in either of these wells. Apparently, the well was not properly chlorinated after it was drilled. No coliform bacteria were found in any of the other wells.

Viral pathogens and other pathogenic bacteria represent other areas of concern. No data are available from the WQMP on this subject at this time.

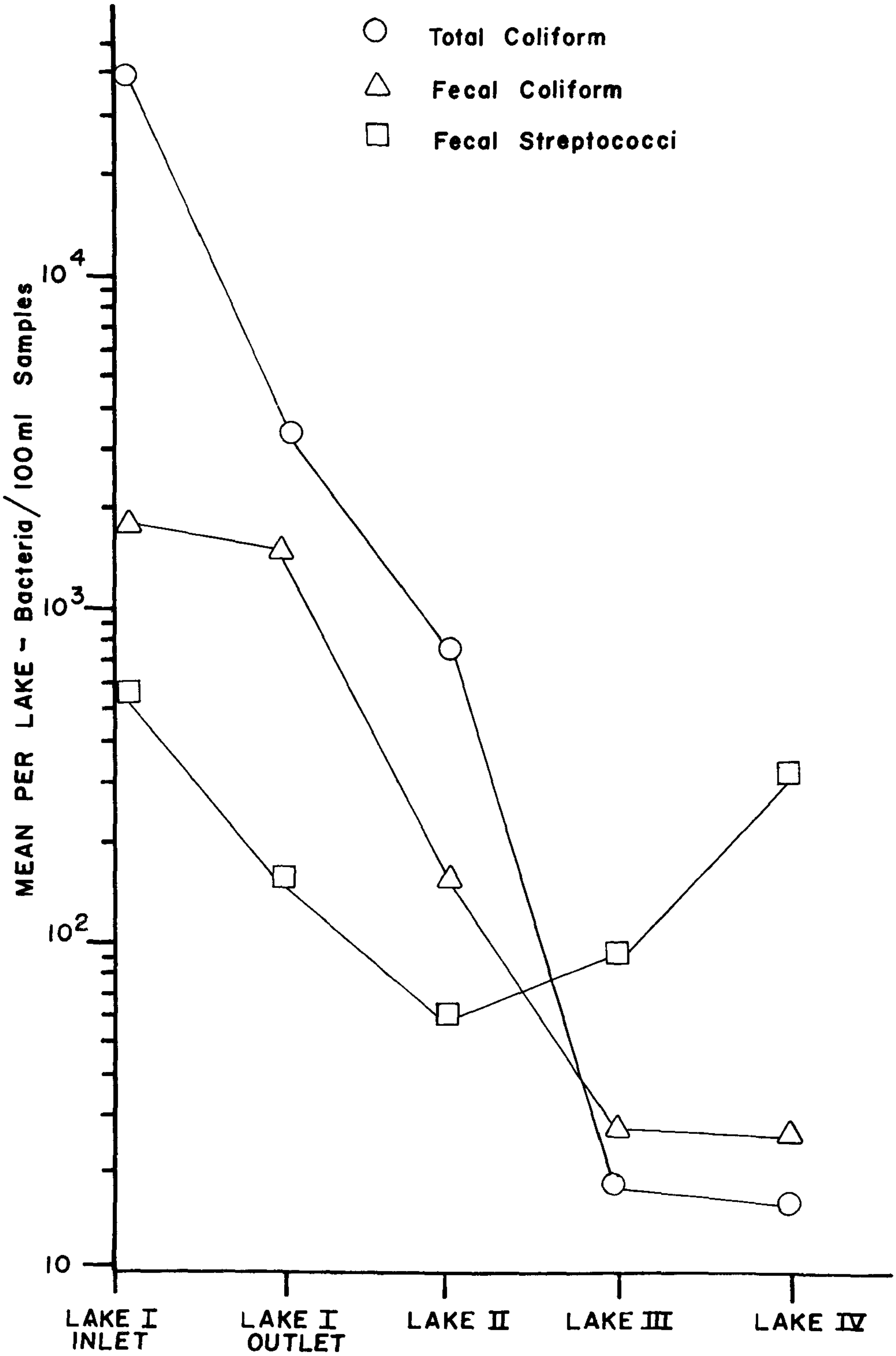


Figure 32. Variation of bacteria commonly used as indicators of the pathogenic quality of water within the WQMP lakes.

SECTION 8

LAND APPLICATION STUDIES

INTRODUCTION

Numerous terrestrial sites in the United States and elsewhere are being utilized for reclamation and recycle of treated and untreated municipal wastewater. A variety of application techniques are used. These fall into three major catagories including: (1) rapid infiltration, (2) overland flow, and (3) spray irrigation. Emphasis on the WQMP has been on spray irrigation as this technique seems to offer the most promise as a means of application for large cropping systems.

While many spray irrigation systems are presently operating, the information on which this technology is based is somewhat limited. Some data have been collected at several sites with the most complete and best known data being that collected at Pennsylvania State University (Sopper and Kardos, 1973). Much additional data are needed before adoption of land application on a large scale. Some of the major data needs include: (1) The sorption capacity of soils in a given region for nutrients such as phosphorus, nitrogen, and cations and for toxins such as heavy metals and borate (i.e., what is the life expectancy of such systems). (2) Data are needed on movement of nutrients and toxins through the soil water to groundwater, and mass balances need to be constructed on a regional basis for each major constituent of wastewater. (3) Data are needed on environmental and economic trade-offs involved in conversion from conventional sewage treatment facilities to land treatment facilities. For example, data presently available indicate that wastewater renovation in terms of phosphorus and heavy metals removal is highly efficient on spray irrigation systems for many soil types. However, most studies indicate that nitrate is readily leached from such systems. Thus, is the increased removal of phosphorus and heavy metals (leading to an expected improvement in surface water quality) worth the increased nitrate contamination of groundwater? (4) Data are needed on a mass balance basis for movement of nutrients and heavy metals through a variety of vegetative types operated under a variety of harvest regimes in order to ascertain what system is best able to recycle nutrients in wastewater into usable by-products. (5) Data are needed on the public health aspects of wastewater application, particularly on possible viral contamination problems in both spray-generated aerosols and in groundwater leachates.

Such a list of data needs could be expanded much further, but the above list indicates the magnitude of the problem. The terrestrial studies of the WQMP have as their goal the collection of data on land application adequate to determine the feasibility of such application and, if feasible, to establish design criteria for constructing and operating such a system. It also has as its goal the identification of environmental trade-offs involved in utilizing such systems.

In the initial stages of the WQMP, emphasis has been on collection of baseline data for the terrestrial site. Some data have also been collected on vegetational and animal responses to wastewater irrigation.

In 1975, a total of 100,000 m^3 of wastewater were applied to the spray irrigation site (Figure 33). As stated earlier, most of this water (82.4%) was pumped from the bottom of Lake 1; the row crop area (A in Figure 33) received effluent directly from the East Lansing Sewage Treatment Plant. The sugar maple-beech forest (D in Figure 33) did not start receiving wastewater until October, 1975. It was planned to irrigate this forest with secondary effluent direct from the East Lansing conduit, but shutdown of the pumping facility from East Lansing forced a temporary change over to the bottom of Lake 1.

Most irrigation occurred during the growing season (May to October), but one of the abandoned fields (K in Figure 33) received wastewater during the winter, 1974-1975. TABLE 10 summarizes the irrigation schedule and a general description of other areas in Figure 33. The general description of the spray irrigation site was included in Section 5.

Specific baseline data and research findings are summarized in the following sections.

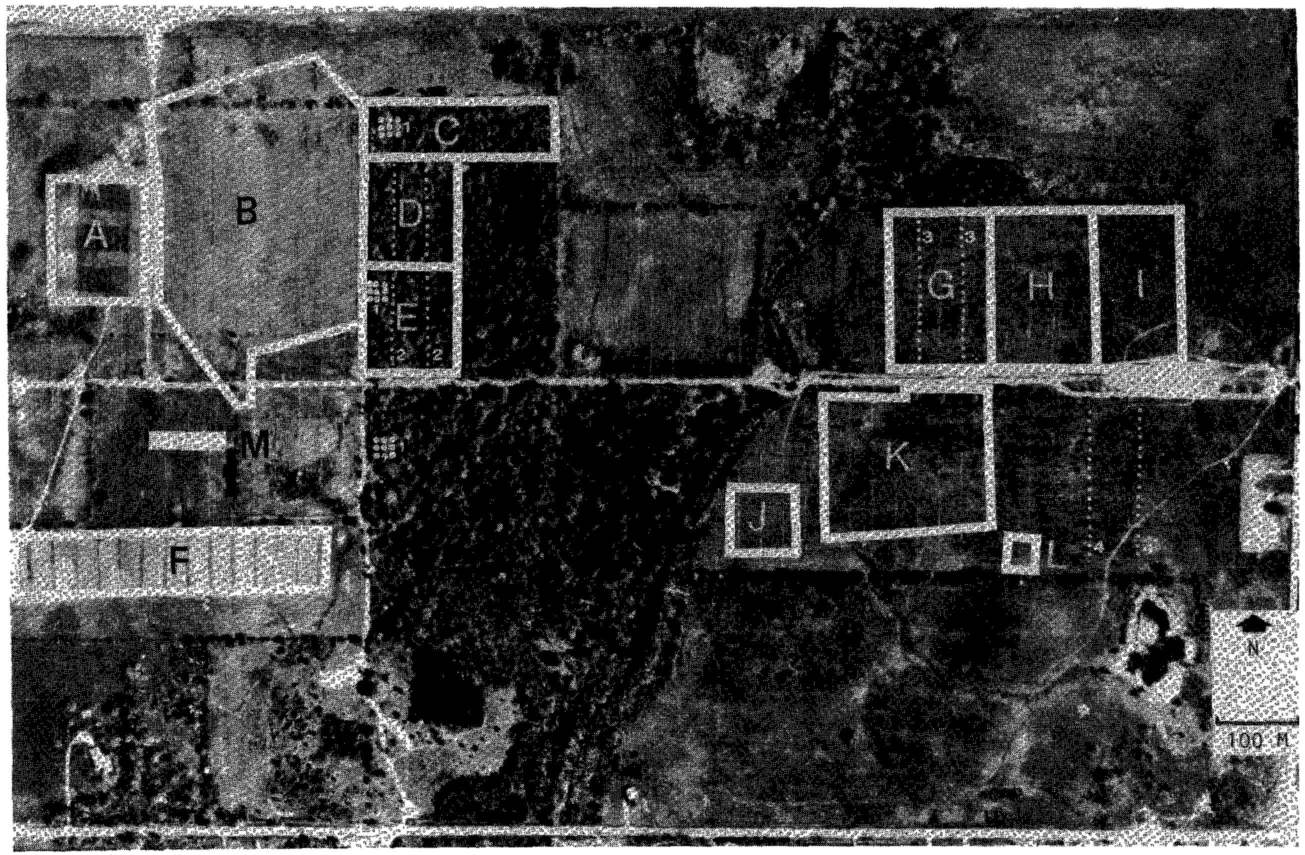


Figure 33. Photograph of the spray irrigation area showing major research areas.

TABLE 10. SUMMARY OF SPRAY IRRIGATION FOR TERRESTRIAL SITE FOR 1975 (THROUGH OCTOBER 22)

Land Use	Amount Applied (m^3)	% of Total	Source of Water	Designation (Figure 33)
Row Crops (20 grain and forage crop varieties)	16,435	16.4	Secondary Effluent	A
Micro Watershed - Baseline Study	0	---	---	B
Sugar Maple - Beech Forest	0	---	---	C
Sugar Maple - Beech Forest	1,206 697	1.2 0.7	Secondary Effluent Bottom of Lake 1	D D
Sugar Maple-Beech Forest	0	---	---	E
Forest Plantation (10 species, 5600 trees)	20,053	20.0	Bottom of Lake 1	F
Old field	24,664	24.6	Bottom of Lake 1	G
Old field	12,335	12.3	Bottom of Lake 1	H
Old field	0	---	---	I
Soil Microorganisms	0	---	---	J
Abandoned Fields (Winter Spray Site)	24,508	24.4	Bottom of Lake 1	K
Large Infiltrometer	0	---	---	L
Diversion Zone	492	0.5	As needed	-
Soil Test Trench	0	---	---	M
TOTAL	100,390	100.0	---	-

DESCRIPTIVE DATA

Soils

The soils of the WQMP were mapped intensively in 1974 and 1975 by T. Zobeck, a graduate student under the supervision of Dr. E.P. Whiteside in the Crop and Soil Sciences Department at Michigan State University. This mapping has been completed and two intensity maps have been prepared. The first (Figure 34), a medium intensity map, approximates maps prepared at the county level by the Soil Conservation Service. County level maps are constructed on the basis of samples taken every 201 m (40 rods), and at least

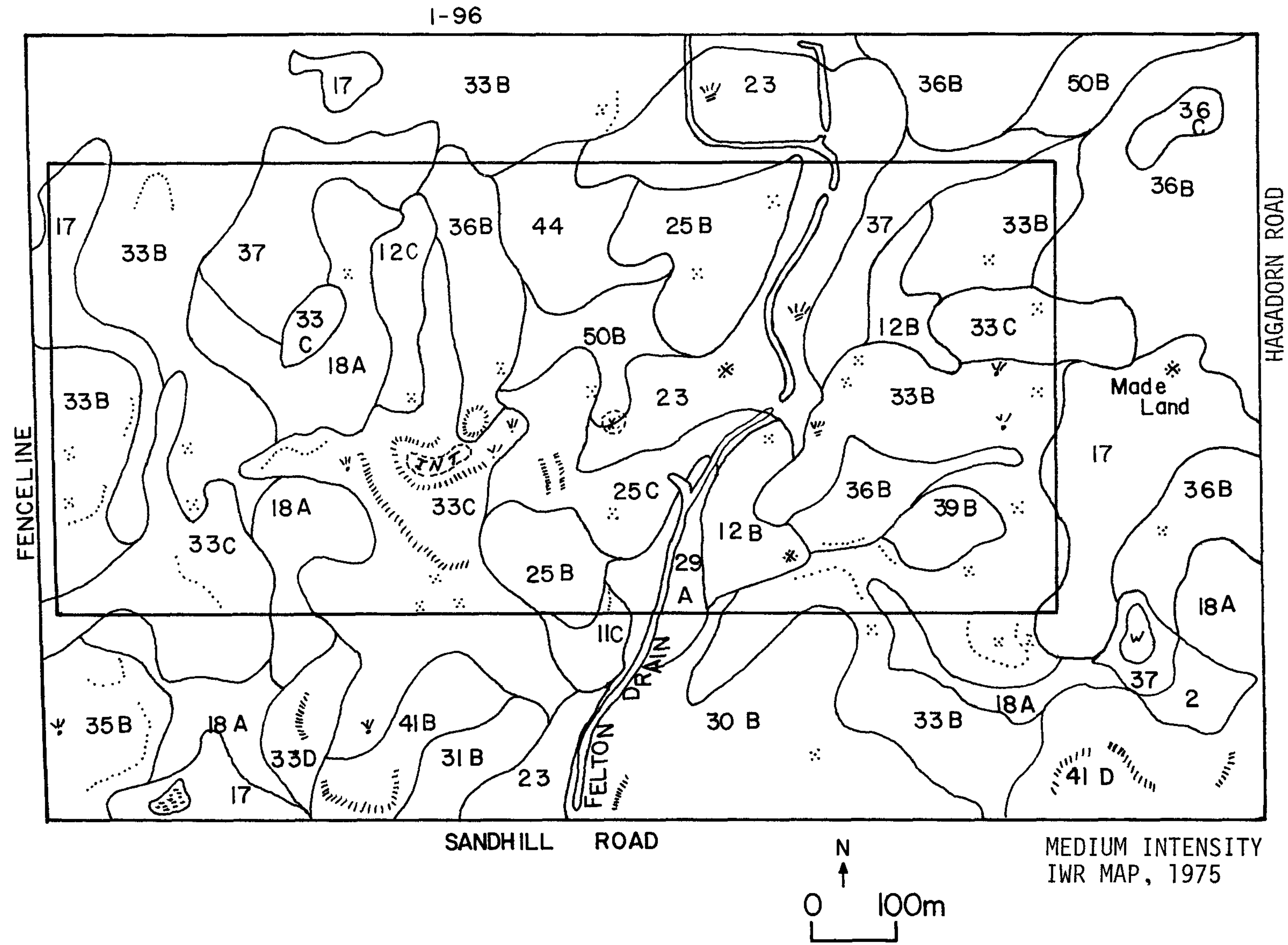


Figure 34. Medium intensity soil map of the spray irrigation site and buffer zone areas. (Legend follows.)

Series

2	Houghton	31	Metea
11	Boyer-Spinks	33	Marlette
12	Boyer	35	Oshtemo
17	Colwood complex	36	Owosso-Marlette
18	Capac	37	Sebewa
23	Gilford	39	Sisson
25	Riddles-Hillsdale	41	Spinks
29	Matherton	44	Lamson-Colwood
30	Metamora-Capac	50	Teasdale

A	Slopes 0 - 2%	C	Slopes 6 - 12%
B	Slopes 2 - 6%	D	Slopes 12 - 18%

∴	Sand Spot		Wet Spot
⁂	Clay Spot		Organic Soil Area
(I) or (INT)	Intermittent Pond		
(W)	Pond		Marsh
	Slopes <18%		Slopes >18%
2 33/12	Soil Boundaries		Drain

Figure 34 (continued). Legend of medium intensity soil map of the spray irrigation site and buffer zone areas.

81 ha of a soil must be present in the county before it will be recognized. Studies on the WQMP indicate that on the average only 23% of the soils in a named series (mapping unit) were actually composed of that soil on the medium intensity map. General soil descriptions for this map are summarized in TABLE 11.

The high degree of heterogeneity in soils of the WQMP made more intensive sampling a necessity. Thus, a map was constructed on the basis of samples taken 55 m apart. This high intensity map includes only the terrestrial irrigation site (Figure 35). It does not include the buffer zone as did the medium intensity map. Studies on the WQMP indicate that on the average 49% of the soils in a series (mapping unit) are actually composed of that soil (a more than two-fold increase in accuracy over the medium intensity map). The medium intensity map includes 15 different mapping units, while the high intensity map includes 19 such units. This new map enables those scientists carrying out research on the land distribution area to develop a more accurate model of their research plan and make use of the specific soil types of concern to them.

The medium intensity map (Figure 34) uses the legend currently used by the Soil Conservation Service and the Michigan Agricultural Experiment Station. The high intensity map (Figure 35) makes use of different soil mapping units. Thus, the two maps are not directly comparable.

General descriptions of the soil types from the high intensity map (Figure 35) are given in TABLE 12. Nevertheless, at least 58 different soil types have been collected one or more times on the WQMP, so the high intensity map still omits some information. All soil mapping units that occupy at least 0.5 ha are included on the high intensity map.

A further study of the heterogeneity of the soils on the WQMP was conducted by excavating a 184 m T-shaped trench (an E-W 121 m trench and a N-S 63 m right angle trench) on an abandoned field site (area M, Figure 33). In this T-shaped trench, 17 different units were identified (TABLE 13). Only 27% of the soils in the E-W trench were close to soils found in that name on the high intensity map, while the N-S transect contained 62% of soils close to that found in the same (average of 39% compared to 23 and 49% for the medium and high intensity maps, respectively).

TABLE 11. GENERAL SOIL DESCRIPTION -- MEDIUM INTENSITY MAP

		General Soil Description		
Map Symbol	Soil Name	Surface Soil	Subsoil	Underlying Materials
2	Houghton Muck	Muck	Mucky peat	Peat
11	Boyer-Spinks Loamy Sand	Loamy sand	Loamy sand to sandy loam	Sand and gravel
12	Boyer Sandy Loam	Loamy sand	Sandy loam	Sand and gravel
17	Colwood Complex	Loam	Silt loam to silty clay loam	Very fine sands and silts
18	Capac Loam	Loam	Clay loam	Loam
23	Gilford	Sandy loam to loamy sand	Sandy loam	Sand and gravel
25	Riddles-Hillsdale Sandy Loams	Sandy loam	Sandy clay loam to sandy loam	Sandy loam to loamy sand
29	Matherton Sandy Loam	Loam	Gravelly loam to sandy clay loam	Sand and gravel
30	Matamora-Capac Sandy Loam	Sandy loam to loam	Sandy loam to clay loam	Loam to clay loam
31	Metea Loamy Sand	Loamy sand	Loamy sand to sand	Loam to clay loam
33	Miami-Marlette Loams	Loam	Clay loam	Loam to silt loam
35	Oshtemo Sandy Loam	Loamy sand	Sandy loam to loamy sand	Sand and gravel
36	Owosso-Marlette Sandy Loam	Sandy loam to loam	Sandy loam to sandy clay loam	Loam to clay loam
37	Sebewa Loam	Loam to sandy loam	Gravelly sandy clay loam to clay loam	Sand and gravel
39	Sisson Loam	Fine sandy loam	Silt loam to silty clay loam	Very fine sand and silts
41	Spinks Loamy Sand	Loamy sand	Loamy sand to sandy loam	Sand
44	Lamson-Colwood Complex	Loam to fine sandy loam	Fine sandy loam to silty clay loam	Fine sand to loamy very fine sand and silts
50	Teasdale Sandy Loam	Sandy loam	Sandy clay loam to sandy loam	Sandy loam to loamy sand

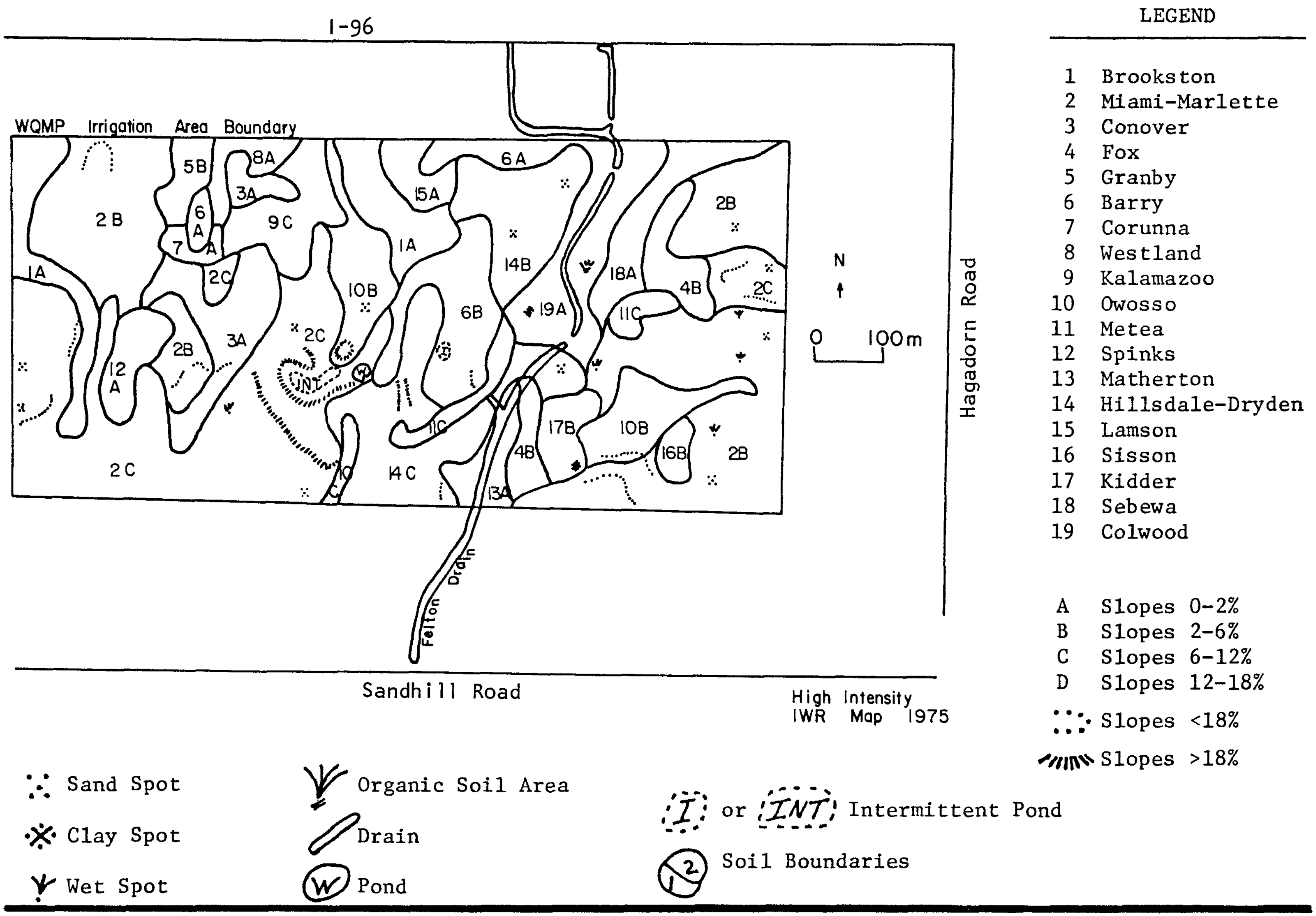


Figure 35. High intensity soil map of the spray irrigation area.

TABLE 12. GENERAL SOIL DESCRIPTION -- HIGH INTENSITY MAP

Map Symbol	Soil Name	General Soil Description: Surface Soil	Subsoil	Underlying Material
1	Brookston	Loam	Clay loam	Loam to silt loam
2	Miami and Marlette	Loam	Clay loam	Loam to silt loam
3	Conover	Loam	Clay loam	Loam to silt loam
4	Fox	Loam	Gravelly clay loam to sandy clay loam	Sand and gravel
5	Granby	Loamy sand	Fine sand	Sand to fine sand
6	Barry	Sandy loam	Sandy clay loam	Sandy loam
7	Corunna	Sandy loam	Sandy loam	Loam to clay loam
8	Westland	Silty clay loam	Clay loam to gravelly clay loam	Gravel and sand
9	Kalamazoo	Loam	Gravelly clay loam to sandy clay loam	Sand and gravel
10	Owosso	Sandy loam	Sandy loam to sandy clay loam	Loam to clay loam
11	Metea	Loamy sand	Loamy sand to sand	Loam to clay loam
12	Spinks	Loamy sand	Loamy sand to sandy loam	Sand
13	Matherton	Loam	Gravelly loam to sandy clay loam	Sand and gravel
14	Hillsdale	Sandy loam	Sandy clay loam to sandy loam	Sandy loam to loamy sand
15	Lamson	Fine sandy loam	Fine sandy loam to silt loam	Fine sand to loamy very fine sand
16	Sisson	Fine sandy loam	Silt loam to silty clay loam	Very fine sands and silts
17	Kidder	Clay loam	Sandy clay loam	Gravelly sandy loam
18	Sebewa	Loam to sandy loam	Gravelly sandy clay loam to clay loam	Sand and gravel
19	Colwood	Loam	Silt loam to silty clay loam	Very fine sands and silts

TABLE 13. LENGTH OF EXPOSURE BY SOIL SERIES IN TRENCHES (AREA M, FIGURE 33) ON THE WATER QUALITY MANAGEMENT PROJECT

Series	Length of Series (m)	% of Excavation
Capac	7.9	4.31
Metamora	1.8	1.00
Celina	1.1	0.58
Teasdale	1.4	0.75
Owosso	14.6	7.96
Owosso, Sandy Substrate	3.5	1.82
Miami-Marlette	5.5	2.99
Miami	4.3	2.32
Wawaka	25.3	13.76
Spinks	3.4	1.82
Oshtemo-Spinks	4.6	2.49
Oshtemo	2.7	1.49
Riddles	30.8	16.75
Riddles, Sandy Substrate	9.9	5.39
Riddles, Fine Variant	14.8	8.04
Hillsdale	17.5	9.54
Saylesville	34.9	18.99
TOTAL	184.0	100.00

The soil heterogeneity on the WQMP is typical of soils in glacial areas. Such variation in soil composition makes land use and management decisions difficult. Placement of lysimeters to adequately sample soil water also becomes difficult, and large numbers of lysimeters are needed to approximate an average value. Predictive modeling or measurement of water flow through such complex soil systems becomes tenuous. Extrapolation to large areas is risky. Therefore, construction of mass balances for these systems will always have high built-in error terms. Thus, large numbers of lysimeters were placed in each experimental area so that average leachate values "typical" of the whole site could be determined.

Mapping at closer intervals than 55 m is much too time consuming and expensive for the whole project. Thus, maps already prepared will be used except for special areas where more comprehensive mapping is required.

Vegetation

The vegetation of the terrestrial site was mapped in the summer of 1974 (Figure 36). This general vegetation map will serve as a baseline

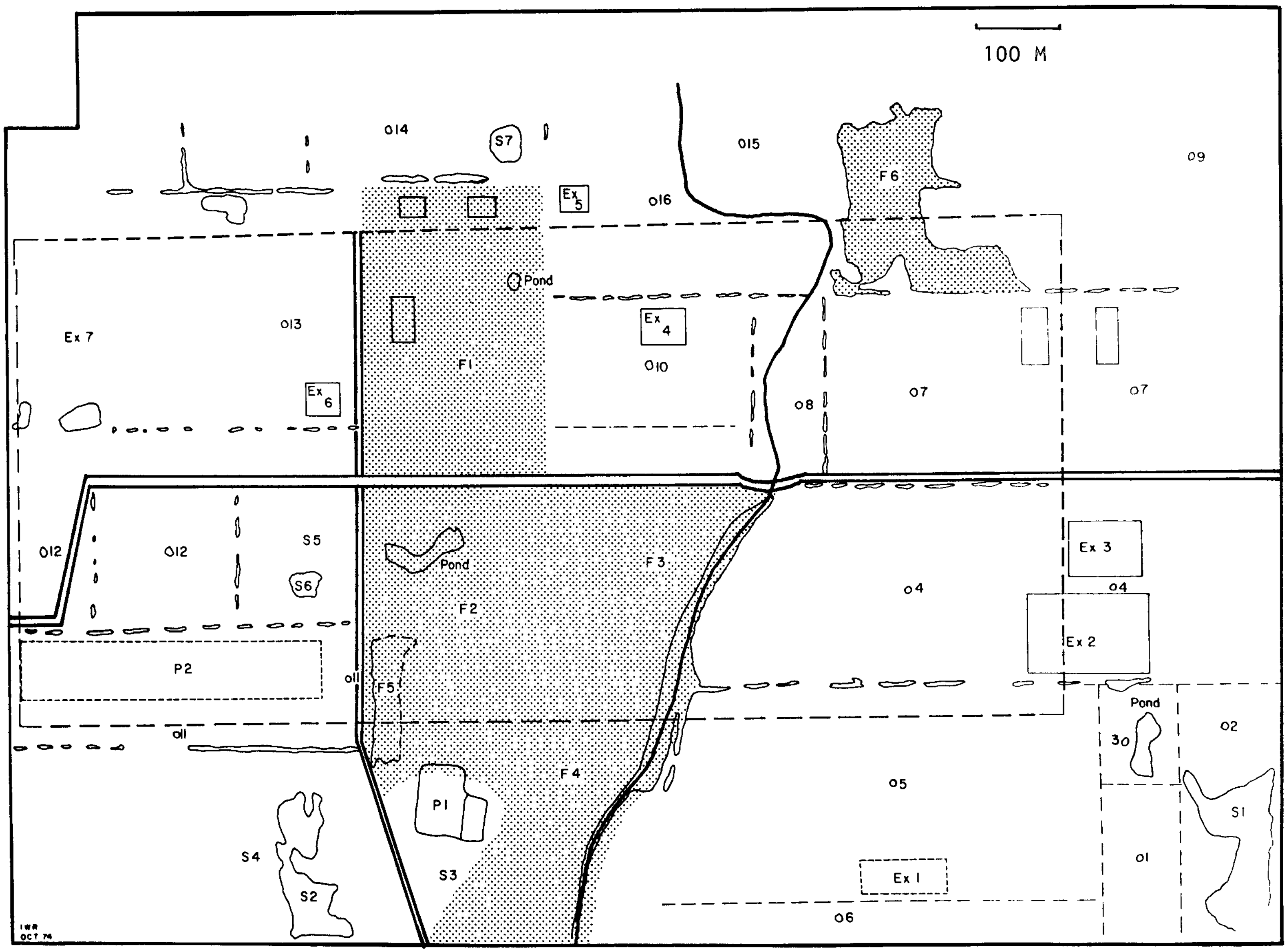


Figure 36. General vegetation map of the spray irrigation site. (Legend follows.)

Map Symbols	General Description
I. O_1 - O_{16}	Oldfields dominated by *Agropyron repens* (quackgrass), *Solidago sp.* (goldenrod), *Bromus inermis* (smooth bromegrass), and *Aster sp.* over much of the area. Some woody invasion occurs at some sites.
II. S_1 - S_7	Second growth shrubland - tree growth-includes mixtures of tall shrubs and small trees with herbaceous understory. Shrubs include patches of black locust (*Robinia*), willow (*Salix*), dogwood (*Cornus*), hawthorns (*Crataegus*), elm (*Ulmus*), sumac (*Rhus*), cherry (*Prunus*).
III. P_1 - P_2	Plantations; P_1 = plantation of large *Pinus sylvestris* and *P. nigra*; P_2 = new plantation of 10 mixed species-see section on forests for explanation.
IV. F_1 - F_6	Forest; F_1 = sugar maple, beech, elm, red maple and basswood; F_2 = sugar maple, beech, white ash, elm, and hickory; F_3 = sugar maple, beech, red maple, red oak, and black maple; F_4 = highly variable open forest along Felton Drain with clones of quaking aspen; F_5 = disturbed site with sumac and apple trees present; F_6 = open woodland similar in composition to F_1. Shrubs and herbaceous layers indicate that most areas have not been cultivated. F_1 - F_3 was sampled with point-centered quadrats (points centered on spray heads) and importance values, density, and basal area data are available in WQMP files.
V. Ex_1 - Ex_6	Experimental areas. Ex_1 = teasel population study area; Ex_2 - Ex_6 = fertilization experiments (experiments completed - areas no longer in use).

Figure 36 (continued). Legend of general vegetation map of the spray irrigation site. Complete breakdown of map symbols are available from the files of the Institute of Water Research, MSU, WQMP, upon request.

characterization of vegetation and will form the basis for planning research/ irrigation on the project. More detailed analyses (site specific) will be required for each specific study and will be collected as subsequent studies are undertaken.

Hydrologic Limitation of Soils

Regardless of the vegetation, the long term usefulness of the terrestrial site demands that the soil resource not be degraded. The dynamic nature of the soil must be recognized, including the myriad interactions between physical, chemical, and biological factors. Any physical compaction or swelling will affect water percolation while chemical alteration of the ion exchange capacity of a soil can also change both the chemical and physical nature of a soil. Physical and chemical changes can alter the ability of a soil to receive water and can also lead to alterations in soil aeration, pH, and other chemical equilibria which in turn affect the large and diverse soil biota. Changes in soil biota can affect both vegetative yield and the number of types of plants which can be used. Thus, when wastewater is applied to the land, the soil must be treated as an ecological system, and alterations in all of the controlling equilibria should be considered.

The high intensity soil map (Figure 35) of the spray irrigation site was used to calculate the hydraulic limits and phosphorus adsorption for the site (Figures 37 and 38). Values for hydrologic limit and phosphorus adsorption capacity were taken from Schneider and Erickson (1972) and are summarized in TABLE 14 along with corresponding areas of each soil type.

Combining soil types with similar hydrologic limits and phosphorus adsorption capacities yield Figures 37 and 38. The weighted average hydrologic limit on the entire 58.3 ha spray site is 4.77 cm of water per ha per week. The average minimum estimate for phosphorus adsorption capacity is 1586 kg/ha of phosphorus in the first 0.9 m of soil; maximum estimates are 1994 kg/ha phosphorus. These estimates are conservative since no consideration was given to vegetative uptake of phosphorus followed by harvest and removal of the vegetation. In addition, the estimates were based on short-term column breakthrough studies which do not reflect long-term crystallization and resultant release of some binding sites. Despite potential problems associated with generalization and lumping of the diverse soils and slopes in

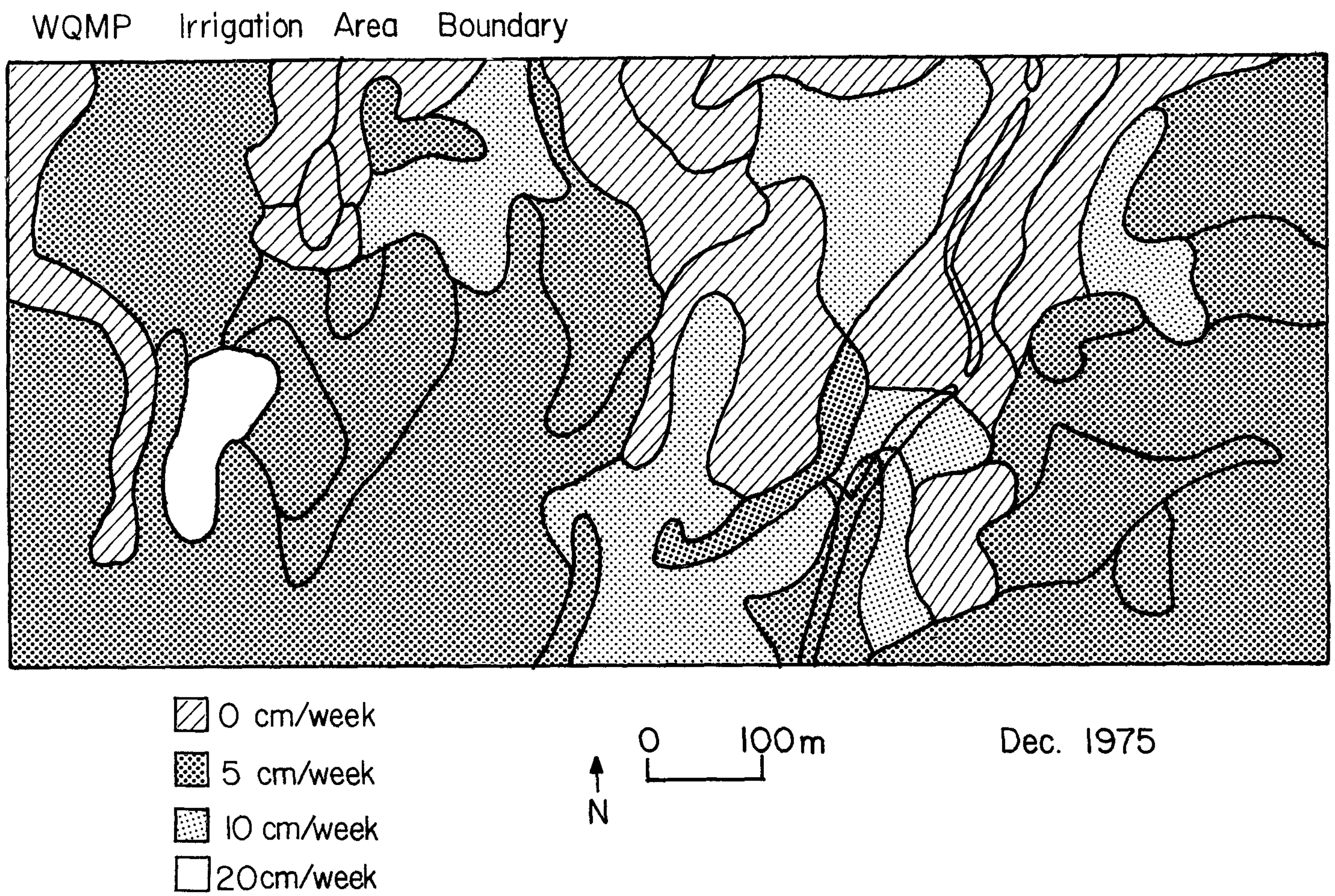


Figure 37. Hydraulic limitations for the spray irrigation site.

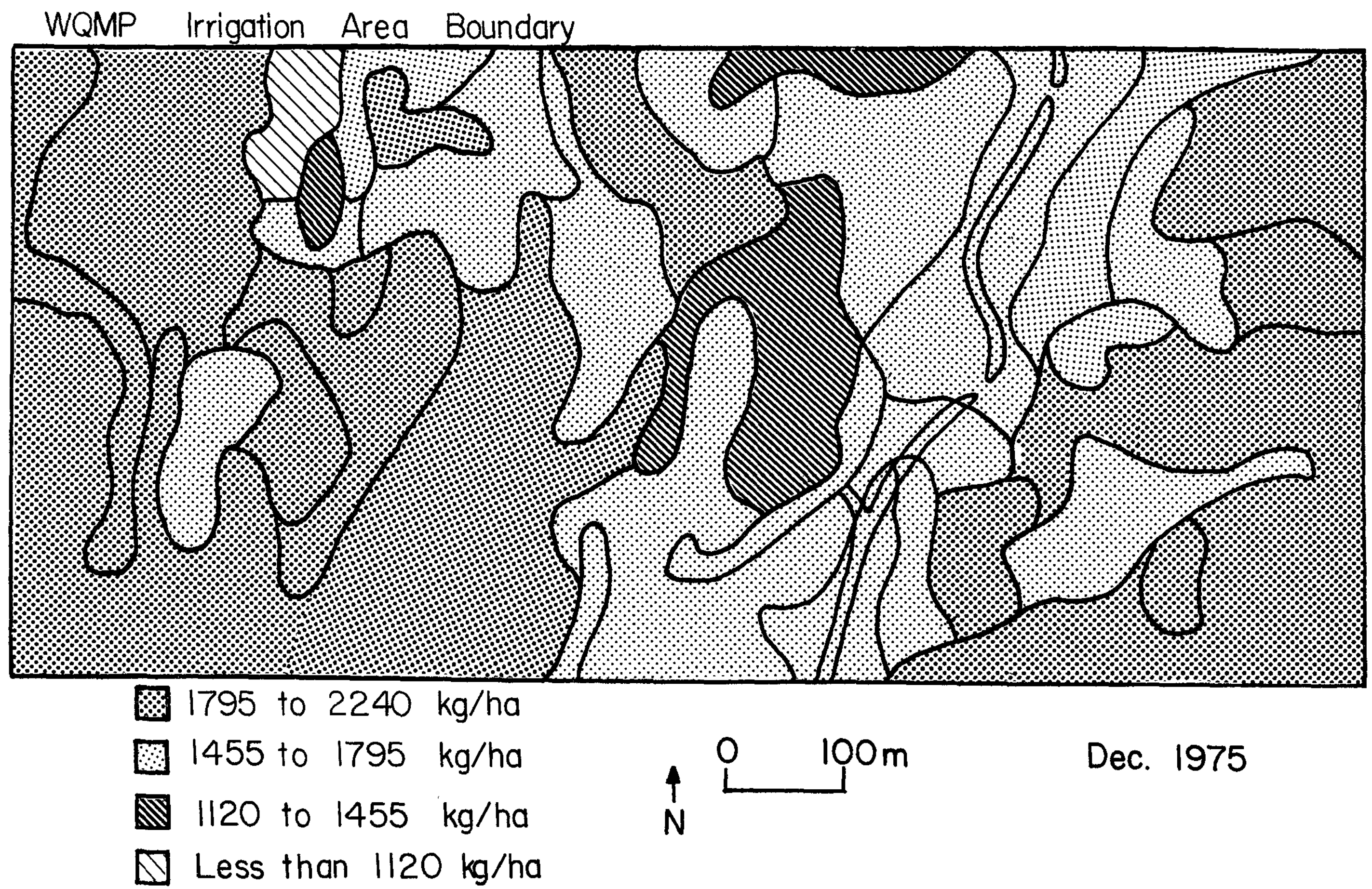


Figure 38. Phosphorus adsorption capacity of soils of the spray irrigation site.

TABLE 14. HYDROLOGIC LIMITATION AND PHOSPHORUS ADSORPTION CAPACITY OF SOILS OF THE IRRIGATION SITE

Map Symbol*	Soil Name	Hydrologic Limitation†	Phosphorus Adsorption Capacity‡	Hectares in Irrigation Site
2	Miami and Marlette	Severe	High	24.56
14	Hillsdale	Moderate	Medium	6.68
6	Barry	Very Severe	Low	3.66
10	Owosso	Severe	Medium	3.24
1	Brookston	Very Severe	High	3.05
19	Colwood	Very Severe	High	2.95
3	Conover	Severe	High	2.71
4	Fox	Moderate	Medium to Low	1.50
9	Kalamazoo	Moderate	Medium to Low	1.71
18	Sebewa	Very Severe	Medium	1.56
12	Spinks	Slight	Medium	1.04
11	Metea	Severe	Medium	1.00
13	Matherton	Severe	Medium to Low	0.98
15	Lamson	Very Severe	Medium	0.81
17	Kidder	Very Severe	High to Medium	0.78
8	Westland	Very Severe	Medium	0.68
5	Granby	Very Severe	Very Low	0.61
16	Sisson	Severe	High	0.41
7	Corunna	Very Severe	Medium	0.34

* See Figure 35 (High Intensity Soil Map).

† Hydrologic Limitation: Slight = 20 cm/week maximum application.
Moderate = 10 cm/week maximum application.
Severe = 5 cm/week maximum application.
Very Severe = 0 cm/week maximum application.

‡ Phosphorus Adsorption Capacity: Very High = >2240 (kg/ha in top 0.9 m)
High = 1795-2240 (kg/ha in top 0.9 m)
Medium = 1455-1795 (kg/ha in top 0.9 m)
Low = 1120-1455 (kg/ha in top 0.9 m)
Very Low = <1120 (kg/ha in top 0.9 m)

the irrigation area, these estimates represent first approximations for both water application rate and phosphorus adsorption capacity.

The feasibility of spray irrigation in the winter in Michigan is unknown at present (see subsequent portion of this section for preliminary data). The following annual loading calculations are based on the assumption that irrigation may not be possible for periods ranging from 0 to 16 weeks each year.

The average hydrologic limitation of 4.77 cm of water per ha per week over the 58.3 ha spray site would allow a weekly application of 27,810 m^3 of water (7.35 million gallons) per week or 3972 m^3/d (1.05 MGD) if irrigation were possible 52 weeks per year. However, if the annual irrigation period was reduced by climatic constraints to 36 weeks, the hydraulic load applied would total approximately 1,000,000 m^3 (264.5 million gallons) per year or an average of 2745 m^3/d (0.72 MGD). Similarly determined values for a 40 week irrigation period would be 3048 m^3/d (0.81 MGD).

The length of time that the top 0.9 m of these soils could continue to sorb phosphorus at a loading of 2745 m^3/d of wastewater (0.72 MGD) would be 18.5 years if the incoming wastewater had an average concentration of 5 mg P/ℓ or 85.9 kg/ha/yr. Crops in the experimental plots in 1974 removed from 18 to 27 kg/ha/yr (see Crops portion of this section). Assuming a removal of 25 kg/ha/yr in vegetation, the effective soil loading would be 60.9 kg/ha/yr resulting in phosphorus saturation in about 26 years. If the next 0.9 m of soil were also available for adsorption before reaching the water table (as is likely), then the life expectancy of the soil system for P removal would be well over 50 years at a spray irrigation schedule of 4.77 cm/ha/week for 36 weeks per year (the hydraulic limit of the site).

Obviously if no water is irrigated during the 16 week period associated with a 36 week irrigation period, sufficient water storage capacity must be available to hold all inflowing wastewater during the 16 week period. Thus, the storage capacity demand associated with a 36 week irrigation period would be 307,440 m^3 (81 million gallons). It is also apparent that the storage reservoir would have to be empty at the end of the 36 week irrigation period and would be full at the end of the 16 week storage period. Thus, to irrigate at a rate of 4.77 cm/week on 58.3 ha for a 36 week irrigation period, a storage volume of 307,440 m^3 (248.5 acre-feet) would be required and the average daily input of wastewater would be limited to 2745 m^3/d (0.72 MGD) if the facility was operated on a 365 day year basis.

The total storage capacity of the four WQMP lakes at normal operating level is 259,000 m^3 (210 acre-feet) of water. Thus, if these lakes were drained by December 1 and allowed to fill during a 16 week storage period, the daily input of wastewater on a 365 day basis would be limited to 2312 m^3 (0.61 MGD). This would yield a maximum irrigation of 2.8 cm of water per ha per week during the 36 week irrigation period and would mean that the lakes would have to be drained each year. Obviously this would reduce the evaluation of the potential that aquatic systems have for recycle of wastewaters.

The WQMP is a flexible system and the 4.77 cm/week during the 36 week spray season can be irrigated on the land, and subsequently shunted through the East Lansing Sewage Treatment Plant during the 16 week non-irrigation period. However, design of a self-contained land treatment system would require a larger storage capacity than was built into the WQMP. The irrigation area of the WQMP can accept 47 m^3 of wastewater per day per ha (0.0123 MGD/ha). Thus, 81 ha of land would be required for the application of 3785 m^3/d of wastewater (1 MGD) without winter spraying on similar soil types in this area with a required winter storage capacity of 424,000 m^3 (344 acre-feet).

BASELINE WATERSHED STUDIES

Surface runoff at this site will occur, in general, only under loading rates in excess of 5 cm/week either from natural precipitation or wastewater irrigation. Wastewater application is being controlled so that runoff occurs only as a result of natural precipitation inputs. Therefore, infiltration and percolation of water through the soils become the dominant transport mechanism for losses of materials from the site. Nevertheless, runoff caused by natural precipitation can transport some of the nutrients and possibly toxins added by wastewater irrigation and these losses have to be quantified.

Runoff losses of nutrients and other materials are most easily quantified using a watershed input-output approach. Due to the lack of significant slopes, there are few readily definable watersheds on the project. One small 7.3 ha old field watershed does exist (B in Figure 33), and it has been reserved for baseline studies of nutrient cycling prior to wastewater irrigation. Inputs and outputs are being monitored in order to construct mass balances for the watershed. Intrasystem nutrient cycling will also be monitored with particular emphasis on buildup or transformation of materials within the soil. After these baseline data are collected, the watershed can then be experimentally manipulated under various wastewater irrigation regimes.

Two major types of studies have presently been completed on this watershed. These include baseline studies of nitrifying and denitrifying microbial populations and studies of soil chemistry. Data from these two studies are summarized below.

Population Analyses of Microorganisms Responsible for Nitrification and Denitrification

Soil samples were taken in August and December, 1974, from a variety of soil types on the baseline watershed. Population estimates were made using the most probable number technique. Results are summarized in TABLE 15.

Soil Chemistry

Paired soil samples (3 m apart) were taken at 24 sampling sites in the 7.3 ha baseline watershed (B in Figure 33). Sampling sites were located along a "star" shaped group of criss-crossing transects. A north-south transect (9 sampling sites) was centrally located with an east-west transect (7 sites) located at right angles to it. A northeast-southwest transect (4 sites) and a northwest-southeast transect (4 sites) complete the sampling layout. Thus, the entire watershed has been systematically sampled; this sampling scheme tends to bias the results towards the center of the watershed with fewer sampling sites located peripherally.

Analytical procedures followed standard methods for soil analyses. Preanalysis treatment of samples is summarized below.

Total Kjeldahl N--

Soils were ground to pass through a 10 mm sieve. Analyses were done on both air dry and wet samples. Wet samples were stored in a freezer at 26°C until analysis. Results are reported on a dry weight basis, but wet weight determinations are available. Analyses followed semi-micro Kjeldahl techniques.

NO_3-N and Cl--

Anions were extracted from wet soil (stored at 26°C until analysis) with $CaSO_4$. Results are reported as μg N or Cl/g dry soil (air dry basis). Results are also available on a wet weight basis.

TABLE 15. MEAN POPULATIONS OF NITRIFYING AND DENITRIFYING MICROORGANISMS FOUND IN THE BASELINE WATERSHED PRIOR TO EFFLUENT IRRIGATION

Date	Sample	Characteristics of Soil	Population (MPN per g/dry wt of soil) Denitrifiers	Nitrifiers
December, 1974	1	well drained; fine sandy loam	$5.1x10^6$	$3.3x10^3$
	2	somewhat poorly drained; sandy loam	$1.4x10^5$	$6.3x10^2$
	3	poorly drained-somewhat poorly drained; fine sandy loam	$1.0x10^5$	$2.8x10^2$
	4	poorly drained; loam	$6.9x10^5$	$2.0x10^4$
	5	moderately well drained; loam → fine sandy loam	$2.0x10^5$	$7.3x10^2$
August, 1974	1	lowland	$9.8x10^4$	
	2	midland	$2.5x10^5$	
	3	upland	$4.8x10^4$	

Available PO_4-P--

Phosphate was extracted from air dried soil using Bray's dilute acid-dilute fluoride solution and analyzed for PO_4-P content following standard procedures. This phosphorus is readily available to plants.

Total P--

Total P was determined on an aliquot of digested soil using a nitric-perchloric acid digestion followed by dissolution in hydrochloric acid. Results are reported on a dry weight basis (μg P/g dry soil).

Moisture Content--

Moisture content was determined by dividing the weight of water at time of field sampling by the dry weight of the soil.

Other Parameters--

Other parameters measured include extractable (in 1 N ammonium acetate) Na, K, Ca, and Mg; total (digested as in Total P above) Na, K, Ca, Mg, Zn, Mn, and Fe; pH (measured in a 1:1 soil:water paste after one hour of water contact) and boron (hot water extract). Pb and Cu were below levels of detection with presently available equipment (without a graphite furnace). The parameters listed above are not included in the present summary as initial research emphasis will be on P and N cycling utilizing Cl as a conservative "tracer" element for wastewater movement. However, all the above analyses are complete and these baseline data are available as part of our central data bank.

Results and Discussion

Data on N, P, Cl, and moisture content are summarized in TABLE 16. Certain trends are apparent. Available P and NO_3-N are very low in these soils and decrease rapidly with depth in the soil column (TABLE 16). Therefore, vegetation on these fields is likely to be limited by one or both of these nutrients. Total Kjeldahl nitrogen reflects the nitrogen bound in root biomass with levels being high in the surface soils but decreasing exponentially with depth (from 1095 μg/g at the surface to 34 μg/g at 300 cm). Total P is more variable but is generally higher at the surface and decreases with depth down to 125 cm. Beyond that, total P levels are relatively constant. Chloride is also higher at the surface and decreases rapidly down to

TABLE 16. SUMMARY OF CHEMICAL ANALYSIS OF SOILS TAKEN FROM THE BASELINE OLD FIELD WATERSHED IN THE WQMP (ALL VALUES ARE μg/g DRY SOIL ± ONE STANDARD DEVIATION)

Depth (cm)	% Water	Chloride	NO_3-N	Kjeldahl N	Available P	Total P
0- 5	13.76±9.64	12.91±6.74	3.84±4.24	1095±382	6.48±6.94	342±204
5- 10	11.21±5.66	7.50±3.37	3.94±4.85	1008±329	4.36±4.29	341±222
10- 15	9.51±4.11	5.73±2.48	3.65±3.58	762±320	3.10±2.31	324±212
15- 31	9.47±10.69	4.44±2.24	3.00±2.87	599±297	2.50±2.16	283±183
31- 46	7.30±5.47	4.21±3.54	2.02±1.39	379±249	2.93±4.33	254±221
46- 61	7.77±5.28	3.83±1.34	1.78±1.14	247±117	2.39±5.42	245±202
61- 76	8.43±6.00	3.95±1.56	1.77±1.04	222±121	2.60±4.97	252±155
76- 91	9.75±5.42	4.28±2.54	1.81±1.25	178±116	2.34±3.29	282±171
91-107	10.57±4.99	4.17±1.35	1.77±1.08	134±91	2.61±3.43	277±162
107-122	11.76±7.86	4.08±1.53	1.75±1.14	102±75	2.19±3.02	283±232
122-137	11.69±5.20	4.03±1.20	1.60±1.00	81±61	1.91±2.92	236±118
137-152	11.30±3.86	4.07±1.57	1.61±1.04	68±58	1.30±2.15	231±89
152-183	11.12±3.07	4.55±1.85	1.64±0.99	59±42	0.80±1.41	238±79
183-213	10.61±4.57	3.90±1.15	1.25±0.81	52±37	0.92±1.86	250±80
213-244	9.80±3.40	3.62±0.75	1.19±0.87	42±52	0.64±0.93	235±82
244-274	9.61±1.66	3.74±1.15	0.94±0.87	45±20	0.65±0.80	230±80
274-305	11.17±3.26	3.84±0.75	0.58±0.29	34±12	0.68±1.28	256±91

25 cm where it becomes relatively constant throughout the soil column (TABLE 16). Chloride is expected to be relatively constant with depth; high surface values may reflect the extraction technique rather than real differences. Anion exchange capacity would certainly be affected by the organic acids in the surface soils and could affect the $CaSO_4$ extraction. These soil data reflect the very low fertility of this abandoned field site. Addition of the nutrients in wastewater to this field will likely result in increased vegetative growth and vigor. This will be tested in the future.

These soil data will form the basis for comparison with soils after wastewater irrigation is initiated. Samples are stored for additional analyses, should such analyses be needed. Soil Samples collected systematically over the entire irrigation site are also stored for analysis should they be needed in future studies.

VEGETATIONAL RESPONSES OF ABANDONED FIELDS TO WASTEWATER IRRIGATION

Fields on marginal soils have been abandoned over much of the United States. This land is relatively inexpensive and represents an under-utilized resource. Use of such land for wastewater renovation is desirable as it would return these fields to useful productivity and, at the same time, would alleviate the wastewater disposal problem. Also, these fields may be able to renovate wastewater with a minimum investment of effort by operators of such systems, an attractive attribute for small communities where manpower is limited. A study of vegetation responses on old fields to wastewater irrigation was initiated in 1975.

Materials and Methods

Initial studies were begun in May, 1975, on vegetational responses of an abandoned field (areas G, H, I, K in Figure 33) on the WQMP to application of treated municipal effluent sprayed from the bottom of Lake 1.

Irrigation from the bottom of Lake 1 was initiated on May 21, 1975, and continued through October, 1975. Therefore, irrigation encompassed the entire growing season. Application was at the rate of 7.1 cm/week on spray zone 21 (1.8 ha, G in Figure 33); 4.3 cm/week on spray zone 22 (this 2.5 ha zone had received 19.4 cm of wastewater the previous winter -- K in Figure 33); and

3.5 cm/week on spray zone 23 (1.8 ha, H in Figure 33). Wastewater was applied in two applications per week.

Inputs of total P, NO_3-N, and total Kjeldahl N were monitored in samples from spray zones 21 and 23. Ten glass collectors were randomly located in each zone; two composite samples from each zone were analyzed for each spray application.

Vegetation was sampled at two week intervals starting prior to spraying in April, 1975. Initially, eight random 0.5 m quadrat clip samples (0.25 m^2) were taken every two weeks in each of the three irrigated areas in two nearby control areas (area I and adjacent to K in Figure 33). The number of quadrats were increased to 12 after the first four sampling dates. Ten random 10 cm soil cores were also taken for soil moisture determinations. Vegetation and litter samples were sorted to species, counted, dried, and weighed. Dried samples were analyzed for N and P content.

Results and Discussion

Mean living biomass increases on each of the zones are illustrated in Figure 39. Production of new biomass was accelerated in the area receiving 7.1 cm of wastewater over production in the unsprayed areas. There are possible increases in the other irrigated areas as well, but they are not as evident as in zone 21. Much of this increase in production may be related to a more constant soil moisture regime (Figure 40), with all three of the irrigated areas remaining constantly moist. The unsprayed areas underwent rather dry conditions on a periodic basis. Specific growth rates for the unsprayed areas reflect the severity of these drought periods (Figure 39) with the dry conditions between May 28 and June 11 having particularly devastating effects. This dry period occurred at the time when goldenrod, Solidago sp., was beginning its period of rapid biomass accumulation (Figure 41). Quackgrass, Agropyron repens, had already achieved most of its biomass accumulation (Figure 41). Thus, the early June dry period appears to have resulted in a delayed onset of rapid biomass accumulation for Solidago sp. on the unsprayed areas resulting in lower biomass accumulation on these areas in June compared to the irrigated areas. Growth did resume as soil moisture increased on the control areas; but total biomass accumulation never caught up with the sprayed areas, particularly the area receiving 7.1 cm of wastewater.

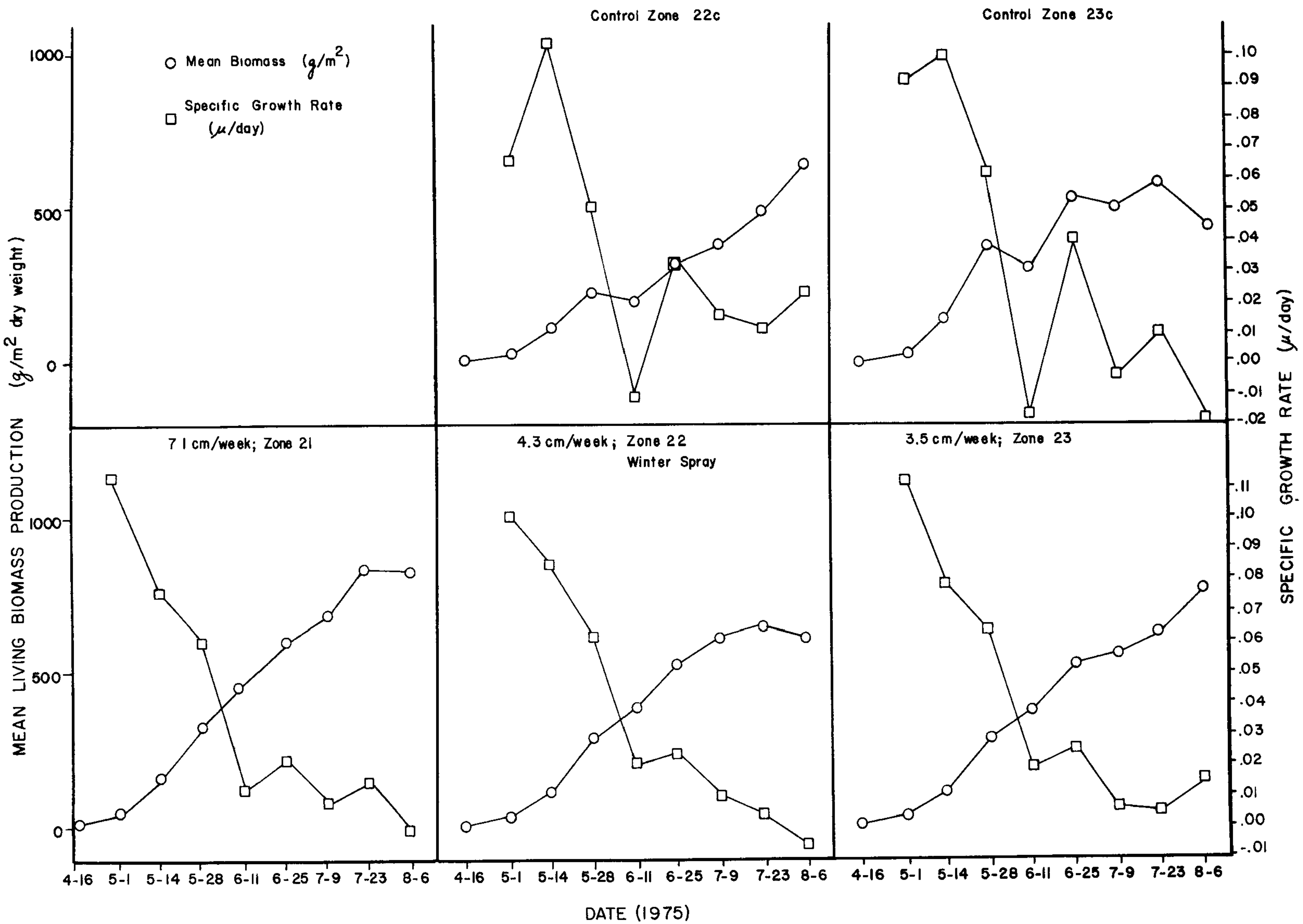


Figure 39. Mean total biomass and specific growth rate of plants on the old fields.

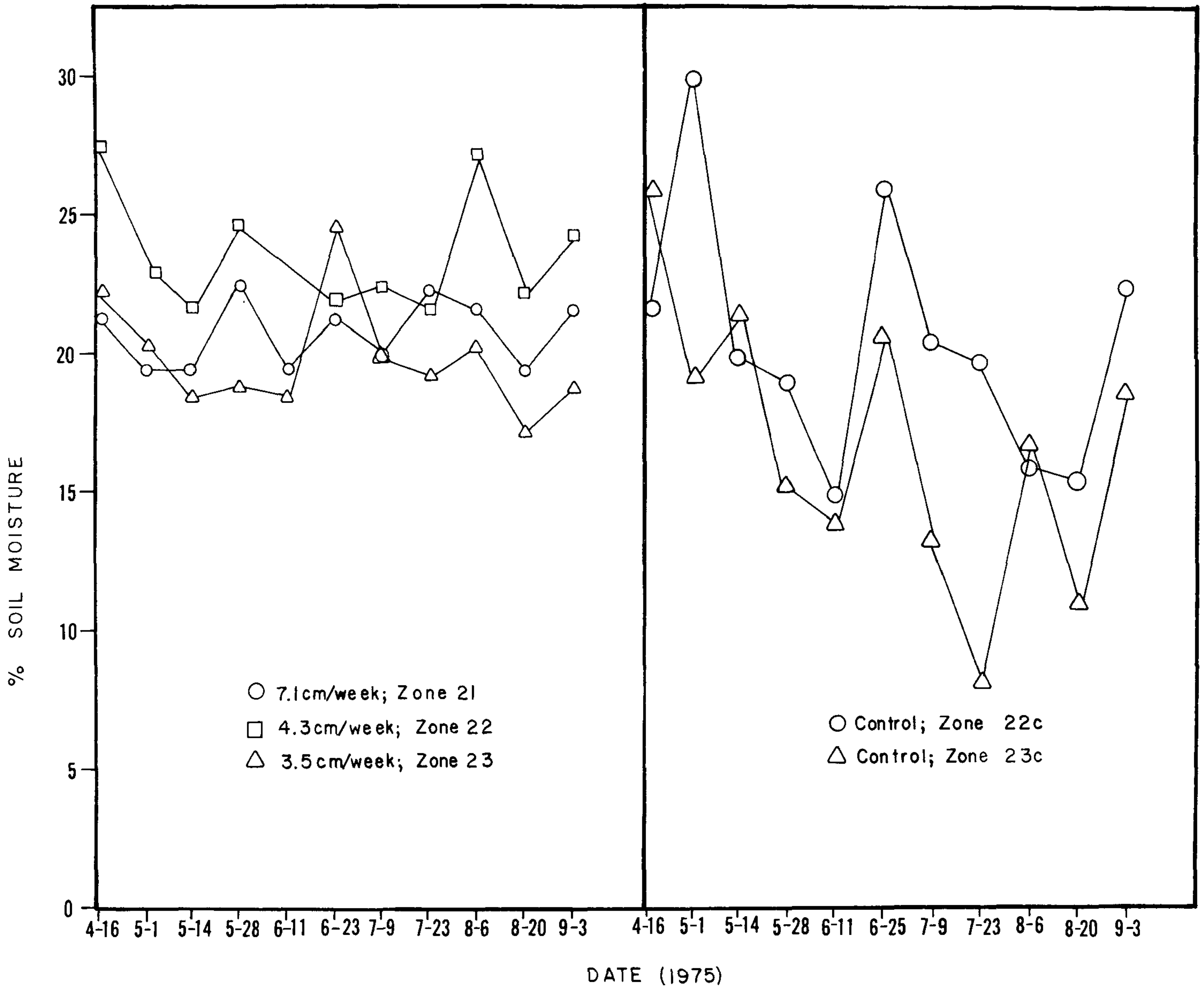


Figure 40. Changes in soil moisture in the old fields during irrigation.

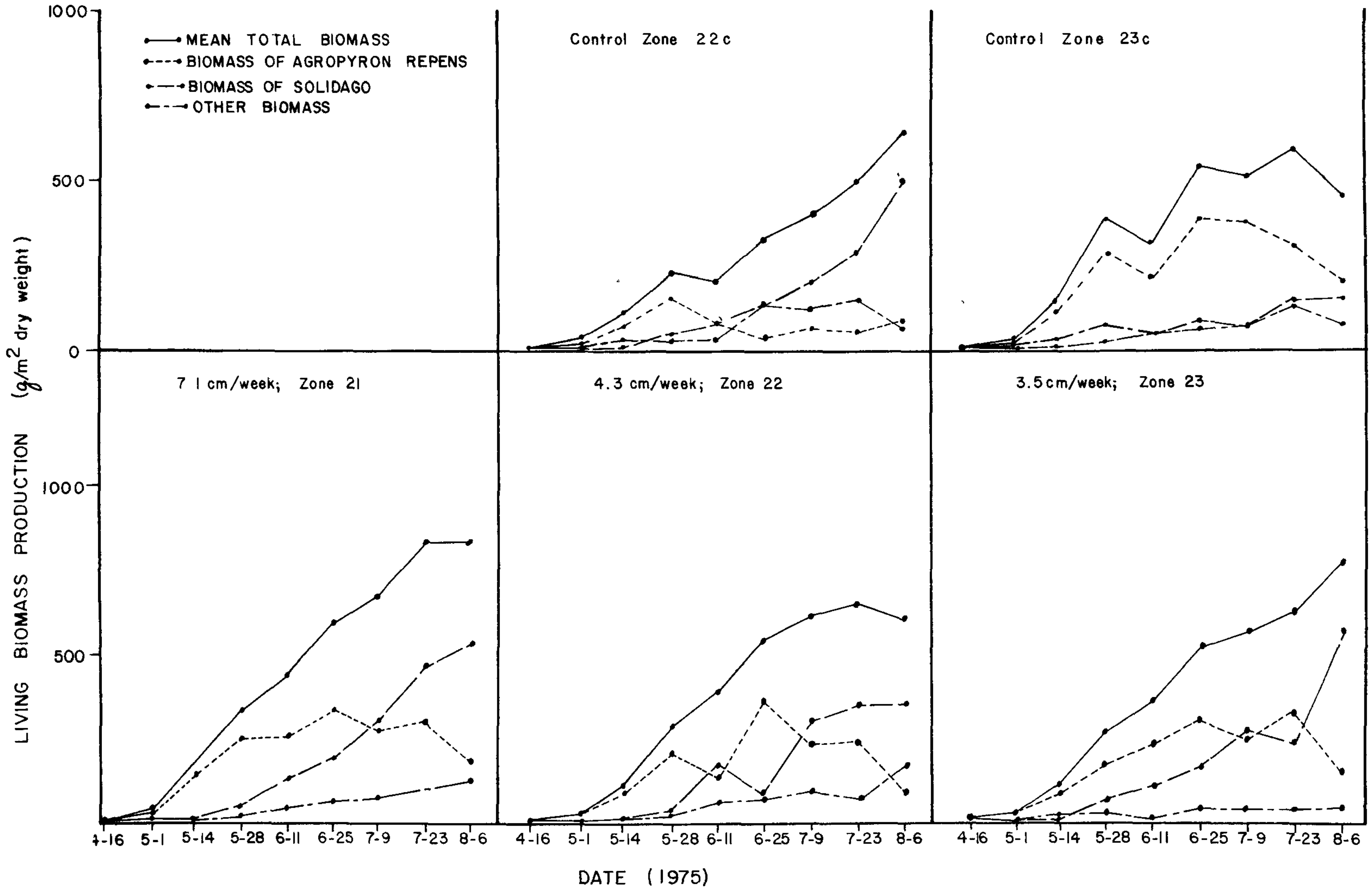


Figure 41. Mean living biomass production for the major species on the old fields.

Data indicate that the plant biomass had taken up from 43 to 89 kg/ha of N on the five areas (79 to 89 kg/ha on the irrigated areas, 43 kg/ha on control zone 22c, and 74 kg/ha on control zone 23c) by June 25, 1975. Only 65 kg/ha of N had been applied on the plot receiving maximum wastewater input. Thus, harvesting of the accumulated plant biomass would have removed more total N than was applied in wastewater at the rate of 7.1 cm/week through June 25, 1975.

For the entire growing season, vegetation uptake was not as effective. By August 6, 1975, biomass accumulation had reached its maximum. At that point, vegetation on the 7.1 cm/week site had taken up 140 kg N/ha, the 4.3 cm/week site had taken up 90 kg N/ha, and the 3.5 cm/week site had taken up 112 kg N/ha. Little additional biomass increase or nitrogen uptake occurred. Thus, harvest of plant biomass after this date would have removed 45% of applied N on the 7.1 cm/week site, 48% of applied N on the 4.3 cm/week site, and 73% of applied N on the 3.5 cm/week site. If harvest had occurred in June as discussed above, regrowth of vegetation should have occurred resulting in substantially increased uptake and better renovation than would have occurred with a mid-August only harvest. Thus, timing of harvest for removal of nutrients is of critical importance. Harvesting should be initiated immediately after the period when the specific growth rate for the plant community begins to decrease exponentially and prior to the time when biomass accumulation reaches a plateau. Plots of specific growth rate versus biomass accumulation (Figure 39) indicate that harvesting between May 28 and June 25 would have been most efficient in 1975. Further, quackgrass, Agropyron repens, accounted for the majority of biomass accumulation prior to May 28 on all plots; whereas goldenrod, Solidago sp., became important on subsequent dates (Figure 41). Quackgrass is a much more desirable forage for livestock than is goldenrod. Thus, harvesting around June 10 would remove the majority of nutrients accumulated to that point in time as a desirable, predominately grass forage. It is possible that quackgrass would respond to cutting with a renewed period of rapid growth and biomass accumulation resulting in substantial additional removal (in a second harvest) of nutrients. Therefore, harvesting around June 10 is recommended with the exact date determined by sampling biomass accumulation and specific growth rate on a routine basis. A second harvest should also be considered.

The increased biomass accumulation discussed above was accomplished by the functional response of more rapid growth of plants already present and not by the numerical response of production of more stems per unit area (Figure 42). There were no important shifts in diversity between irrigated and non-irrigated areas. Diversity changes in these predominantly perennial communities would be expected to occur in subsequent years rather than in the initial year of irrigation. Monitoring of future shifts in diversity should be interesting.

Litter decomposition rates were markedly enhanced by application of wastewater in all three experimental areas compared to the two control areas (Figure 43). Therefore, nutrients bound in dead vegetation were recycled much more rapidly due to irrigation and were more available for production of new biomass. These nutrients were also more available for leaching from the system. Mass balance studies of nutrient movement in these systems will be initiated during the next growing season.

Conclusions

Results to date are for the 1975 growing season only. Analyses are continuing and the following conclusions should be viewed as preliminary. Thus far, analyses indicate that:

(1) Production of new biomass in old field communities increases substantially as a result of wastewater irrigation.

(2) This increased production is a result of more rapid growth and cannot be attributed to an increase in numbers of stems per unit area.

(3) Wastewater irrigation has not resulted in diversity shifts during the first season. However, the perennial plants may respond in the following season resulting in delayed diversity changes.

(4) Rate of decomposition of litter has been increased substantially by wastewater irrigation.

(5) Monitoring of biomass accumulation and specific growth rate for the whole community is a valid way of determining the most efficient harvest schedule; harvesting should have been conducted about June 10, 1975, with a second harvest later in the year.

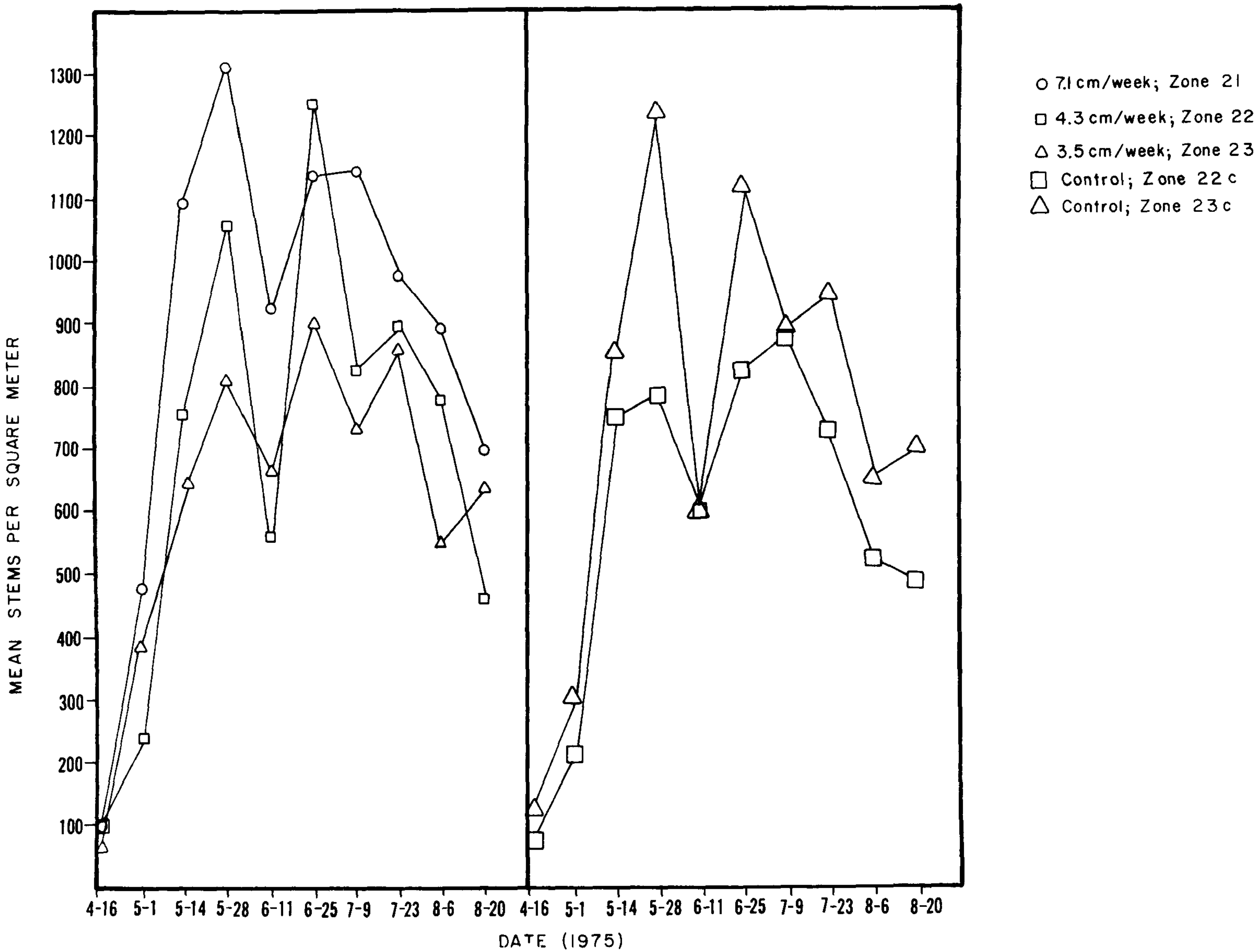


Figure 42. Mean stem production on wastewater irrigated and non-irrigated old fields.

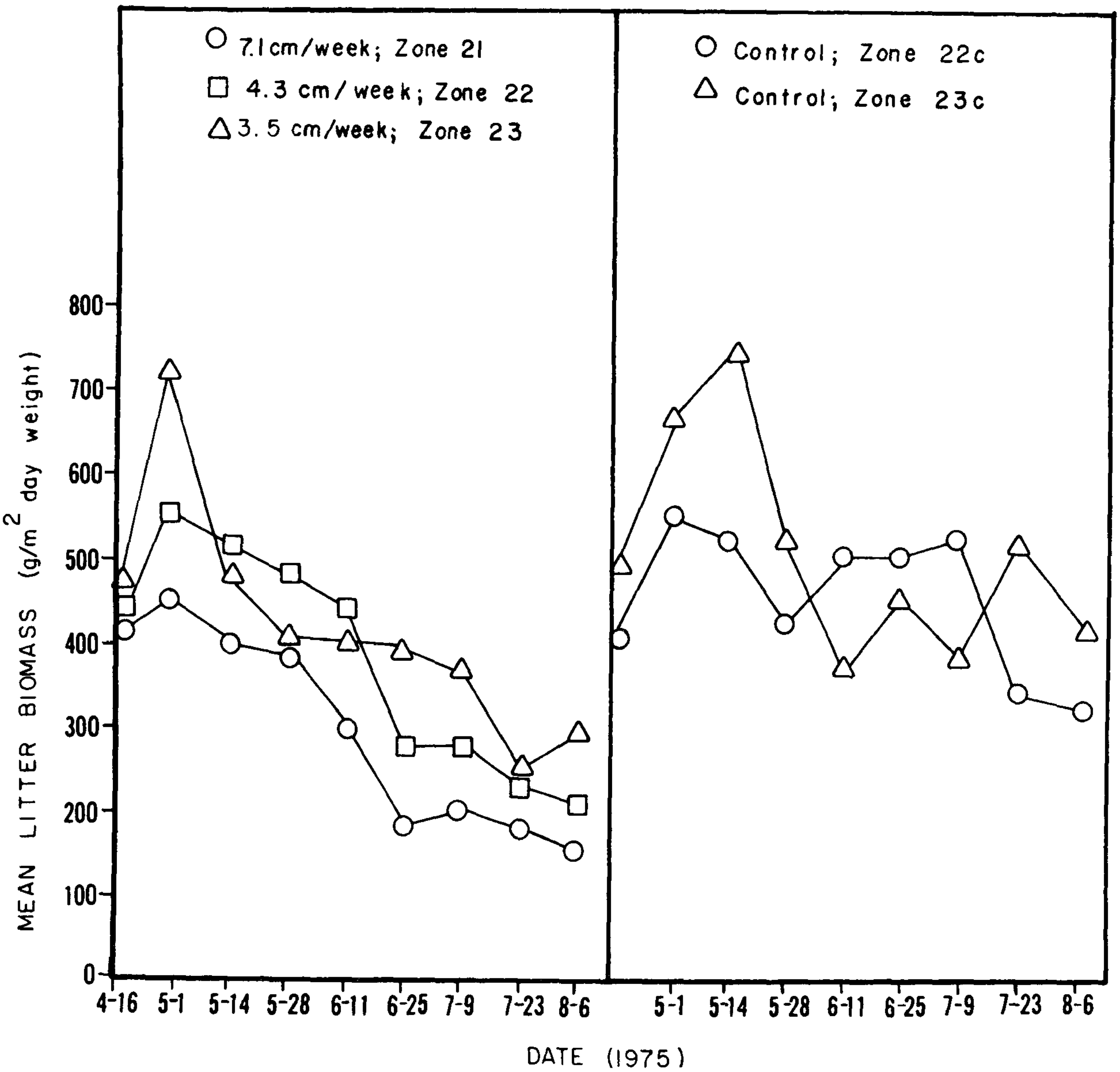


Figure 43. Mean litter disappearance rate in wastewater irrigated and non-irrigated old field areas.

(6) Biomass accumulation of nitrogen by the plant community is sufficient for complete removal of all nitrogen applied in wastewater at an application rate of 7.1 cm/week during the first six weeks of growth. Harvesting leads to renewed growth of plants resulting in even more nutrient removal. Without harvesting, biomass (and nutrient) accumulation peaks in early August, and little nutrient removal occurs later in the season. A single harvest in mid-August would remove only 45 to 73% of applied N for the 3.5 to 7.1 cm/week application rates. Thus, two harvests per year are recommended.

Future Research

Vegetational responses to wastewater application on these old field plots (areas G, H, I in Figure 33) will be continued during the upcoming year. Application rates will be at rates of 5 and 10 cm/week. The irrigated plots will be subdivided into subplots. Some subplots will not be harvested, some will be harvested once, and others will be harvested twice. Time of harvest will be determined by monitoring specific growth rate and biomass accumulation. Control (unsprayed) plots will also be monitored as will the winter spray plot (it will receive 5 cm/week during the summer). All studies conducted during 1975 will be continued in 1976. Lysimeter and runoff studies will be initiated in 1976 allowing construction of mass balances for nutrients.

RESPONSE OF FORESTED ECOSYSTEMS TO WASTEWATER IRRIGATION

Introduction

Research on wastewater application to forested ecosystems on the WQMP falls into three categories. These include (1) a preliminary study on the feasibility of wastewater irrigation using a series of small 4 m^2 plots irrigated by trickle-irrigation, (2) a study on spray irrigation using large 1.2 ha plots, and (3) a study of the impact of wastewater irrigation on a newly established mixed hardwood-conifer plantation. The first study has been completed while the other two studies are just getting underway. Each study will be discussed separately below.

Small Plot Study

A study on wastewater application to forests was conducted in 1972 and 1973 on the WQMP prior to complete installation of the spray irrigation system. As a result, secondary sewage effluent from the city of East Lansing was trucked to the site and applied to 4 m^2 plots (sites labeled in Figure 33) using gravity-feed trickle-irrigation techniques. The experimental design consisted of three replicated blocks of five random plots located on Miami sandy loam soil along the western edge of a second-growth sugar maple-beech forest (Figure 33). Each of the three blocks consisted of five plots with the following treatments: a non-irrigated control plot, a 5 cm/week well-water irrigated control plot, and three plots which recieved 2.5, 5.0 and 7.5 cm of chlorinated secondary wastewater effluent per week. Irrigation was at the rate of 2.5 to 5.0 cm per hour, one day per week from August 1 to October 10, 1972, and from June 8 to October 19, 1973. Losses of nutrients in soil water under each plot were monitored at depths of 30 and 60 cm with porous cup suction lysimeters.

Average nutrient concentrations and loading rates are presented in TABLE 17. Two facts are worth noting. First, total P concentrations in sewage were only 1.0 mg/ℓ in 1972 and 0.7 mg/ℓ in 1973. Thus, loadings approximate tertiary effluent loadings. Second, nitrogen loading was about equally divided between NH_4-N and NO_3-N in 1972 while 81% (97.5 kg/ha) of the nitrogen applied in 1973 was in the NH_4-N form.

The dominant trend in the small forest plot data was the high flushing rate of NO_3-N. Often NO_3-N concentrations in the 60 cm lysimeters were higher than concentrations in application of wastewater due to flushing of existing NO_3-N from the system and/or to conversion of organic and NH_4-N to NO_3-N. Concentration of NO_3-N, at times, exceeded 20 mg/ℓ. A perfect example of the overall flushing process can be seen in the data of the 7.5 cm/week application rate of wastewater in 1973 at the 60 cm lysimeter depth. About 120 kg/ha of nitrogen was applied by irrigation with 81% (97.5 kg/ha) of this nitrogen being in the NH_4-N form. However, 87% (77 kg/ha) of the total N reaching the lysimeters was in the form of NO_3-N. Since total NO_3-N loading for that rate was only 12 kg/ha, 65 kg/ha had to come from NH_4-N and organic N transformation and/or from flushing of N from the system.

TABLE 17. WASTEWATER IRRIGATION AND NUTRIENT LOADING RATES FOR THE SMALL PLOT STUDY, 1972 AND 1973

(A) Average concentrations (mg/ℓ) of sewage effluent and well water.

Year	NH_4-N	NO_3-N	Organic N	Total N	Total P
(A) Sewage Effluent					
1972	4.8	5.2	1.5	11.5	1.0
1973	6.5	0.8	0.7	8.0	0.7
(B) Well Water					
1972	0.04	0.04	0.02	0.10	<0.01
1973	0.04	0.04	0.02	0.10	<0.01

(B) Average nutrient loading rate (kg/ha) with different levels (mm) of well water (w) and wastewater irrigations(s).

	1972				1973			
Nutrient	25 s	50 s	75 s	50 w	25 s	50 s	75 s	50 w
NH_4-N	12.0	24.0	36.0	0.2	32.5	65.0	97.5	0.4
NO_3-N	16.0	32.0	48.0	0.2	4.0	8.0	12.0	0.4
Organic N	3.8	7.6	11.4	0.1	3.5	7.0	10.5	0.2
Total N	31.8	63.6	95.4	0.5	40.0	80.0	120.0	0.5
Total P	2.5	5.0	7.5	<0.1	3.5	7.0	10.5	<0.1

Calculation of groundwater recharge according to Thornthwaite's and Mather's Water Budget Method (Thornthwaite and Mather, 1967) permitted calculation of mass balance nutrient budgets for the forest (TABLE 18). These data indicate that phosphorus is about 98% retained in soils for all three levels of irrigation while only 12 to 45% of nitrogen is retained. Irrigation with well water resulted in flushing of 26.8 kg/ha of nitrogen from the system. Most nitrogen losses were in the form of NO_3-N. These relatively

TABLE 18. ESTIMATION OF TOTAL NITROGEN AND TOTAL PHOSPHORUS BUDGET FOR THE SMALL PLOT STUDIES, 1972 AND 1973

		Irrigation Rate (mm/week)			
		Well Water	Wastewater		
Budget Item	Budget Relationship	50	25	50	75
Nitrogen:		kg/ha			
Wastewater Loading	Input	1.6	68.8	137.6	206.2
Loss to Water Table	Output	26.8	50.0	76.0	180.7
Phosphorus:					
Wastewater Loading	Input	0.1	6.2	12.0	18.1
Loss to Water Table	Output	0.3	0.1	0.2	0.4

high NO_3-N losses could have resulted from the high hourly application (2.5 to 5.0 cm/hour). However, other studies including those at Pennsylvania State University (Sopper and Kardos, 1973) have shown high NO_3-N losses as well. Renovation of phosphorus in wastewater was obtained at a "cost" of groundwater NO_3-N contamination. Therefore, irrigation of wastewater in hardwood forests in Michigan is feasible only if the groundwater recharge from uncontaminated areas is large enough to facilitate dilution of the high NO_3-N levels or if low N wastewater is available from lagoons. If groundwater dilution is counted on, the problem has simply been shifted from surface water to the groundwater resources. However, phosphorus (and probably heavy metals) are almost completely removed. This benefit may outweigh the cost of NO_3-N groundwater contamination, especially in areas where the groundwater dilution pool is large or where the groundwater is already high in nitrates.

Large Plot Spray Irrigation Study

One spray irrigation zone (2.4 ha) in the northwest portion of the sugar maple-beech forest on the WQMP was subdivided into two (1.2 ha) plots (areas D and E in Figure 33) in order to see if the initial findings from the small plot trickle-irrigation study were applicable to larger scale spray irrigation of wastewater. Litter fall, litter decomposition, production of new plant tissue, and herbaceous species diversity data have been collected for one year as baseline data in areas C, D and E in Figure 33. These data will also be collected during spray irrigation.

One of the two 1.2 ha plots on the spray irrigation zone (area D in Figure 33) started receiving 5.0 cm (two 2.5 cm applications per week at a rate of 0.5 cm/hour) of chlorinated secondary municipal effluent concomitant with litter fall in early October, 1975. Spray irrigation continued through November 20, 1975, when freezing conditions became common. Spray irrigation will resume with the spring thaw. Twenty-six porous cup suction lysimeters were placed at depths ranging from 15 to 150 cm under the spray zone, six of which were placed under the unsprayed 1.2 ha control (area E, Figure 33). As soon as lysimeters presently on order arrive, the lysimeter monitoring network will be completed and will include 40 lysimeters on the irrigated plot and 40 on the control plot. Mass balances of nutrients (inputs from rain and wastewater irrigation and outputs to groundwater and runoff) will be constructed for various forms of phosphorus and nitrogen and for Cl.

Preliminary data indicate that phosphorus is readily retained by the soil while NO_3-N is flushed out of the system; concentrations of NO_3-N at 150 cm depths are often higher than input values by a factor of two indicating both flushing of "old" NO_3-N as well as high leaching rates for newly applied NO_3-N. Initial levels in excess of 30 mg/ℓ have been recorded. These initial data are very preliminary but indicate that results from the small trickle-irrigated plots can generally be extrapolated to the whole forest system.

The application of wastewater to the hardwoods forest ecosystem will be continued over the next two years in order to quantify effects of such irrigation on nutrient budgets and groundwater contamination. Vegetational dynamics will also be monitored.

Tree Plantation Study

The feasibility of utilizing secondary municipal effluent in production of forest products is under investigation. The research area is located in the southwest corner of the WQMP spray irrigation site (F in Figure 33). A 2.1 ha old field was planted with nine tree species on April 1, 1974. The species were Norway spruce (Picea abies), white spruce (Picea glauca), Scotch pine (Pinus sylvestris), black walnut (Juglans nigra), black cherry (Prunus serotina), tulip poplar (Liriodendron tulipifera), white ash (Fraxinus americana), northern red oak (Quercus rubra), and eastern cottonwood (Populus deltoides). American sycamore (Platanus occidentalis) was added in April, 1975.

The experimental design consists of 14 replications in a randomized complete block design with each replication containing 40 trees of one species per 61 m row in 10 rows. Spacing is 1.5 m in the row and 2.1 m between rows. There are a total of 400 trees per replicate or 5600 trees.

Wastewater irrigation from the bottom of Lake 1 was at the rate of 0.4 cm/hr or 2.6 cm applied two days per week over the 3 month growing season in 1975; 26 cm were applied in 1974. Replication #1 received no irrigation and served as a control. Wastewater samples were collected weekly from the spray irrigation heads; soil water was sampled from 15 porous cup suction lysimeters placed 61 cm into the soil. Analysis of vegetational response was by harvesting the largest specimen of each species in each row of the first 10 replications. Soil samples were collected from four depths (0-15, 15-30, 45-60, 105-120 cm) in July, 1974, and May and September, 1975.

Nutrient removal for the whole site appeared to be reasonably effective. Removal was 95% for P, 64% for total N, 68% for K, 46% for Ca, 54% for Mg, and 71% for Na. Some of this apparent uptake was likely due not only to the fast growing tree seedlings but also to the grasses which voluntarily grew between tree rows.

Data on plant biomass and nutrient levels are still being analyzed. Problems with installation and operation of the spray irrigation system in 1974 led to death of many trees. With consistent irrigation in 1975, seedling biomass and nutrient content samples indicated a significant growth increase as compared to 1974. Whether wastewater can effectively be used in management of forest plantations or not remains an open question; this research project is aimed at providing such information.

RESPONSE OF CROPS TO WASTEWATER IRRIGATION

The terrestrial spray site operation has a finite life expectancy based on the ability of soils on the site to retain nutrients and toxins. Uptake of nutrients by plants with subsequent removal of nutrients from the site in plant biomass is an advantageous way of prolonging the life of the system, especially if plant biomass removal is in the form of useful by-products. Thus, agricultural production would be an ideal mechanism for nutrient removal if it resulted in production of useful products uncontaminated with high levels of heavy metals or other toxins.

A program to assess the response of various crops to wastewater irrigation with secondary municipal effluent was initiated on the WQMP in 1974 (area A, Figure 33). Crops included 8 varieties of grasses, 6 varieties of alfalfa, 2 varieties of birdsfoot trefoil, 2 varieties of corn, and 2 varieties of sorghum (TABLE 19). The experimental design consisted of a split-plot block design with three replications. Annuals and perennials were whole plots and species were subplots within effluent levels. Effluent levels were not replicated. The three effluent levels used were 2.5 cm, 5.1 cm, and 7.6 cm. Plots were established on a 0.9 ha old field site on a uniform Miami loam soil. There were a total of 180 plots (1.8 m wide and 9.1 m long for perennials; 3.1 m wide and 9.1 m long for annuals with 4 rows per plot, and 0.76 m spacing between rows).

Data on yields of crops, application of wastewater, nutrients applied, and nutrient removal by crop harvest are presented in TABLES 20 and 21. Data for the two years are not entirely comparable since irrigation did not start until July 17 in 1974 and since heavy raccoon damage to the corn crop in 1975 made estimates for this crop impossible. These data do demonstrate that crops can potentially remove more N and P than was added in wastewater at the 2.5 cm/week irrigation level. Almost all applied N was removed in harvest for all crops at even the 7.6 cm/week level but phosphorus removal

TABLE 19. VARIETIES OF CROPS GROWN ON THE WATER QUALITY MANAGEMENT PROJECT

I. Grasses: Planted August, 1973; harvested in 1974.

1. Smooth bromegrass (*Bromus inermis* Leyss) cultivar Sac (southern)
2. Smooth bromegrass (*Bromus inermis* Leyss) Canadian source (northern)
3. Orchardgrass (*Dactylis glomerata* L.) cultivar Nordstern
4. Tall fescue (*Festuca arundinacea* Schreb.) cultivar Ky. 31
5. Timothy (*Phleum pratense* Leyss) cultivar Verdant
6. Kentucky bluegrass (*Poa pratensis* Leyss) cultivar Park
7. Creeping foxtail (*Alopecurus arundinaceus* Poir) cultivar Garrison
8. Reed canarygrass (*Phalaris arundinacea* L.) commercial

II. Legumes: Planted August, 1973; harvested in 1974.

9. Alfalfa (*Medicago sativa* L.) cultivar Saranac
10. Alfalfa (*Medicago sativa* L.) cultivar Agate (*Phytophthora* resistant)
11. Alfalfa (*Medicago sativa* L.) cultivar Vernal
12. Alfalfa (*Medicago sativa* L.) cultivar 520
13. Alfalfa (*Medicago sativa* L.) cultivar Iroquois
14. Alfalfa (*Medicago sativa* L.) cultivar Ramsey
15. Birdsfoot trefoil (*Lotus corniculatus* L.) cultivar Viking
16. Birdsfoot trefoil (*Lotus corniculatus* L.) cultivar Carrol

III. Annuals: Planted and harvested in 1974.

17. Corn (*Zea mays* L.) cultivar Funk G-4444
18. Corn (*Zea mays* L.) cultivar Mich. 560-3X
19. Sorghum-sudangrass hydrid (*Sorghum bicolor* L. Moench x *S. sudanense* P. Stapf) cultivar Pioneer 908
20. Forage sorghum (*Sorghum bicolor* L. Moench) cultivar Pioneer 931

efficiency dropped to less than 40% in most cases. Alfalfa appeared to be the best plant for nutrient removal. It removed more nitrogen at all levels of application than any of the other three. However, alfalfa is a nitrogen-fixer and may have fixed much of the nitrogen removed in its biomass. Orchardgrass was best of the non-nitrogen fixing plants for nitrogen removal except at 2.5 cm/week application rates where corn removed more N. There is little difference for removal among the 4 crops examined; all removed 18 to 36 kg/ha regardless of application rate (TABLE 21).

A significant unanswered question for this project is data on leaching of nutrients in soil water and runoff. This information has not been collected as yet. The experiment will be repeated in 1976 to obtain further

TABLE 20. YIELDS (12% MOISTURE; mt/ha) OF PERENNIALS (CUT 3X) AND ANNUALS* (CUT ONCE) IN 1974 and 1975.

Species, Variety	Effluent Per Week (Started July 17, 1974 and May 20, 1975							
	2.5 cm 1974	2.5 cm 1975	5.1 cm 1974	5.1 cm 1975	7.6 cm 1974	7.6 cm 1975	Average 1974	Average 1975
Legumes								
Alfalfa (6)	10.98	13.55	11.76	13.88	11.51	13.04	11.42	13.50
Birdsfoot Trefoil (2)	9.16	11.16	11.22	12.66	10.00	12.34	10.13	12.05
Grasses								
Brome, Sac (Southern)	7.15	7.31	10.39	7.59	9.63	9.03	9.06	7.70
Brome, Canadian	7.44	5.48	10.17	8.91	9.88	9.74	9.16	7.75
Reed, Canary, Commercial	7.37	8.91	9.25	9.94	7.75	12.81	8.12	10.57
Tall Fescue, Ky. 31	8.15	8.71	9.48	10.55	9.39	13.04	9.01	10.77
Orchard, Nordstern	7.73	8.04	8.47	9.74	8.74	10.86	8.31	9.56
Ky. Bluegrass, Park	4.53	5.01	8.24	9.78	5.53	10.55	6.10	8.24
Timothy, Verdant	6.65	6.85	6.56	8.56	6.59	10.59	6.60	8.66
Reed Foxtail, Garrison	4.53	5.17	6.47	10.10	5.67	10.06	5.56	8.31
Average	6.69	6.83	8.63	9.21	7.90	10.84	7.74	8.98
Corn								
Funk G-4444	16.85		14.78		13.64		15.09	
(bu/acre)	99		76		68		81	
Mich. 575-2X	15.41		14.47		12.72		14.20	
(bu/acre)	66		59		45		57	
Sorghum								
Forage, Pioneer 931	12.79	19.71	11.89	21.20	14.65	19.19	13.11	20.05
Sudangrass, Pioneer 988	9.72	14.42	10.75	12.35	10.55	12.36	10.34	13.05

*Corn was not harvested in 1975 because of severe damage from raccoons.

TABLE 21. APPLICATION OF NITROGEN AND PHOSPHORUS IN WASTEWATER AND FERTILIZER AND REMOVAL OF NITROGEN AND PHOSPHORUS BY HARVESTING IN 1974 AND 1975 (AMOUNT APPLIED IS BASED ON A 10-WEEK IRRIGATION PERIOD IN 1974 AND AN 18-WEEK PERIOD IN 1975)

	2.5 cm/wk				5.1 cm/wk				7.6 cm/wk			
	Nitrogen		Phosphorus		Nitrogen		Phosphorus		Nitrogen		Phosphorus	
Crop	1974	1975	1974	1975	1974	1975	1974	1975	1974	1975	1974	1975
Amount Applied in Wastewater (kg/ha)	46	92	6	6	91	138	12	12	137	186	18	18
Amount Applied in Fertilizer (kg/ha)*	30	45	39	58	30	45	39	58	30	45	39	58
Total	76	137	45	64	121	183	51	70	167	231	57	76
Alfalfa - Removal (kg/ha)	248	430	18	23	328	396	24	28	314	412	21	24
Orchardgrass - Removal (kg/ha)	165	192	23	23	195	247	22	26	225	294	22	28
Forage Sorghum - Removal (kg/ha)	114	175	21	33	93	166	20	36	144	190	26	34
Corn, Mich - Removal (kg/ha)	202	†	23	†	150	†	20	†	137	†	27	†

*Fertilizer added as starter fertilizer in spring.

†No estimate for corn for 1975 because of raccoon damage.

data on crop yields and nutrient removal. Each plot will also be monitored for soil losses of nutrients using porous cup suction lysimeters.

ANIMAL STUDIES

Introduction

The impact of wastewater irrigation on animal populations is an important consideration in feasibility studies of wastewater irrigation. Many soil and litter organisms clearly are greatly affected by changes in the moisture regime. In turn, these organisms may be responsible for litter decomposition either directly during microbial degradation or indirectly as processors of large organic matter into small organic matter. Changes in moisture content of litter and soil and enhanced turnover of litter and the nutrients it contains also may affect larger invertebrate and vertebrate populations by temporal changes in food supply brought about by increased litter decomposition rates, and by changes in habitat brought about by vegetational responses to increased moisture and nutrients in wastewater inputs. Any investigation of wastewater usage for terrestrial irrigation must consider these impacts. Only a few studies have been conducted elsewhere on these problems, and more complete data are necessary for a complete assessment of wastewater irrigation systems.

Data on response of animal populations to wastewater irrigation will be collected as part of the ongoing studies on the terrestrial site at the WQMP. The early efforts in this direction have dealt with establishing baseline data on species presently on the site and with design and establishment of experiments or monitoring networks designed to monitor responses of animal populations to irrigation. Baseline data and future research plans are summarized below for the soil and litter fauna, plant parasitic nematodes, insect vectors for human pathogens, and for avian and mammalian populations.

Soil and Litter Fauna

A survey of soil and litter fauna on the project site was conducted in 1973. Twenty different sampling sites were established representing abandoned field and forested ecosystems on three major soil types (sandy loam, loamy sand, loam). Core samples (5.1 cm diameter, 15.2 cm deep) were taken at monthly intervals from July to October, 1973; soil fauna were heat-extracted in Tullgren funnels. A series of pit traps containing ethylene glycol were also sampled at 5 to 7 day intervals from July to November; pit traps were located in four old field areas and in a forested area.

Soil type played only a minor role in distribution of species; cover type and concurrent moisture and temperature levels were the key determinants of species distribution. Since each of these latter parameters will be changed by irrigation, significant changes in the soil, and litter fauna are to be expected as a consequence of irrigation.

The soil-dwelling fauna was characterized by large numbers of nematodes, collembola, and oribatid and predatory mites. Collembola were the only group studied in detail (TABLE 22). They showed significant habitat differences (TABLE 22). Pit trap data on Collembola distribution are also summarized in TABLE 22. Smaller numbers of Hemiptera, Diplura, Thysanoptera, Pauropoda, and Protura were collected. Millipedes were more common than centipedes but both occurred in all soil and cover types. Surface fauna, as assessed with pit trap collects, differed markedly from soil fauna and included large numbers of Hymenoptera, Hemiptera, Diptera, Coleoptera, Gastropoda, Arachnida, and Isopoda. Predatory mites were more common than oribatids. Data on other components of the soil and litter fauna are still being analyzed.

Studies of Disease Related Invertebrate Populations

The second major group of invertebrate studies presently underway on the terrestrial site of the WQMP deal with pathogenic invertebrates or with invertebrate vectors of human related diseases. These studies fall into two major categories: (1) the plant pathogenic nematodes and (2) the insect vectors of human diseases. Activities in these two categories have dealt with establishing pre-irrigation baseline data. These data are summarized below.

Plant Parasitic Nematodes--

During October and November, 1973, the spray irrigation portion of the WQMP was divided into 116 plots. On December 4 and 5, 1973, the plots were sampled by taking twenty-five 2.5 by 20 cm cores of soil from each plot. The samples were immediately placed in plastic bags and stored at 12.5 C. In January and February the soil-borne nematodes were extracted from 100 cc

TABLE 22. COLLEMBOLA COLLECTED ON THE TERRESTRIAL SITE OF THE WQMP JULY TO OCTOBER, 1973.

I. Core Soil Samples

Species Common in All Samples	Species Found Only in Wooded Areas	Rare Species
Mesaphorura granulata	*Neanura muscorum*	*Isotomiella minor*
M. krausbaueri	*Paranura caeca*	*Folsomides parvus*
Protaphorua armatus	*Lepidocyrtus unifasciatus*	*Isotomodes productus*
Onychiurus sp.	*L. pallidus*	*I. klostermani*
Isotoma notabilis	*L. lignorum*	*Proisotoma americana*
Folsomia fimetaria	*Pseudachorufes aureofasciatus*	*Hypogastrura montana*
Willemia intermedia		*Pseudosinella alba*
Hypogastrura armatus		
H. macgillivrayi		
Proisotoma sepulcaralis		
Xenylla welchi		
Orchesella ainsliei		
Tomocerus sp.		
Lepidocyrtus paradoxus		
L. violaceous		
L. cyaneus		
Pseudosinella violenta		
P. rolfsi		
Entomobrya sp.		
Entomobryoides sp.		
Architomocerura crassicauda		

II. Pit Trap Collection

Species Common in All Samples	Species Found Only in Wood Areas
Tomocerus flavescens	*Ptenothrix marmorata*
Tomocerus sp.	*Isotomurus palustris balteatus*
Lepidocyrtus paradoxus	*Entomobryoides purpurascens*

(continued)

TABLE 22 (continued).

Species Common in All Samples	Species Found *Only* in Wooded Areas
Lepidocyrtus violaceous	*Lepidocyrtus unifasciatus*
L. cyaneus	*L. lanuginosus*
Orchesella albosa	*L. helenae*
O. villosa	*Orchesella hexfasciata*
O. ainsliei	*Neanura muscorum*
Entomobrya griseoolivata	*Hypogastrura packardi dentatus*
Entomobrya sp.	
Entomobryoides guthriei	
Isotoma notabilis	
I. violacea	
Pseudosinella violenta	
P. rolfsi	
Paranura sp.	
Hypogastrura brevispina	
Sminthuridae	

aliquots of the sample from each plot, using a modified centrifugation-flotation technique.

Stylet-bearing nematodes occurred on all plots. These nematodes were identified and quantitative population estimates made (TABLE 23). A total of 44,560 specimens of plant parasitic nematodes, belonging to 24 genera and 59 species, were isolated and identified. Dagger, ring, and spiral nematodes (*Xiphinema americanum*, *Criconemoides* sp., and *Helicotylenchus* sp., respectively) accounted for 59% of the entire population and were widely distributed throughout the experimental site. Root-lesion, root-knot, and cyst nematodes (*Pratylenchus* sp., *Meloidogyne* sp., and *Heterodera* sp., respectively) accounted for only 3% of the total population.

Root-lesion, root-knot, and cyst nematodes are generally considered to be the most economically significant phytopathogenic nematodes associated with agricultural crops grown in Michigan (Bird, 1973). Specimens of these three nematodes had relatively low population densities and frequencies of occurrence on the irrigation site. It is highly probable that the use of this site for the production of various agricultural crops grown under sewage effluent irrigation will favor increases in the distribution and population density of phytopathogenic nematode species with some subsequent losses in production.

Insect Vector Studies--

Eight species of mosquitoes and one species of deer fly were collected on the WQMP terrestrial site. Landing counts (from 10 forested stations collected for three two-hour periods, 2 days per week) in 1973 and 1974 indicated that three species of mosquitoes were abundant enough (greater than 40 per hour) to present possible public health problems but were not common enough to warrant initiation of control measures (TABLE 24). Light trap collections indicated that all three species migrate distances of 200 meters or more.

Serum samples from 162 mammals (182 samples) collected from the WQMP irrigation site prior to wastewater irrigation revealed the presence of a La Crosse subtype of California encephalitis (5 positive tests included 3 fox squirrels, 1 red squirrel, and 1 chipmunk) and that an enzootic transmission cycle of the California encephalitis virus was present on the project site *prior* to wastewater irrigation. Studies elsewhere have shown that the

TABLE 23. TAXA, FREQUENCY OF OCCURRENCE, AND POPULATION DENSITY OF STYLET-BEARING NEMATODES INHABITING SOIL OF THE WATER QUALITY MANAGEMENT PROJECT

CLASS	ORDER	SUBORDER	SUPERFAMILY	FAMILY	SUBFAMILY	GENUS	SPECIES	RECOVERY[1] (%)	SPECIMENS[2] RECOVERED	POPULATION (MEAN & RANGE)
Nematoda								100	44,560	384(3-2,710)
	Dorylaimida							93	8,561	79(10-180)
		Dorylaimina						93	8,561	79(10-180)
			Dorylaimoidea					91	8,036	76(10-180)
				Longidoridae				91	8,036	76(10-180)
					Longidorinae			91	8,036	76(10-180)
						1. *Xiphinema*		91	8,036	76(10-180)
							1. *X. americanum*	91	8,036	76(10-180)
			Diphtherophoroidea					15	525	29(10-60)
				Diphtherophoridae				6	155	22(10-35)
					Diphtherophorinae			6	155	22(10-35)
						2. *Diphtherophora*		6	155	22(10-35)
							2. *D. obesus*	6	155	22(10-35)
				Trichodoridae				9	370	34(10-60)
					Trichodorinae			9	370	34(10-60)
						3. *Trichodorus*		9	370	34(10-60)
							3. *T. proximus*	9	370	34(10-60)
	Tylenchida							91	35,945	339 (8-2,710)
		Aphelenchina						3	130	33(20-50)
			Aphelenchoidea					3	130	33(20-50)
				Aphelenchoididae				3	130	33(20-50)
					Aphelenchoidinae			3	130	33(20-50)
						4. *Aphelenchoides*		3	130	33(20-50)
							4. *A. parietinus*	1	50	50(50)
							5. *A. ritzema-bosi*	1	20	20(20)
							6. *A. saprophilus*	2	60	30(20-40)
		Tylenchina						91	35,815	337 (8-2,710)
			Atylenchoidea					0	0	0(0)
			Neotylenchoidea					10	740	95(30-150)
				Neotylenchidae				10	740	95(30-150)
					Neotylenchinae			10	740	95(30-150)
						5. *Nothotylenchus*		1	30	[illegible]0(30)
							7. *N. acris*	1	30	30(30)
						6. *Boleodorus*		9	710	65(30-150)
							8. *B. thylactus*	9	710	65(30-150)
			Criconematoidea					81	19,010	231(9-2,710)
				Criconematidae				52	14,858	248(9-2,710)
					Criconematinae			52	14,858	248(9-2,710)
						7. *Criconema*		17	1,568	78(10-500)
							9. *C. octangulare*	17	1,568	78(10-500)
						8. *Crossonema*		16	1,094	58(10-450)
							10. *C. cobbi*	3	40	10(40)
							11. *C. menzeli*	13	1,054	70(10-450)
						9. *Criconemoides*		39	9,542	104(10-1,720)
							12. *C. curvata*	12	1,545	110(20-320)
							13. *C. denoudeni*	1	10	10(10)
							14. *C. rustica*	15	3,464	204(10-1,720)
							15. *C. zenoplax*	7	653	82(20-198)
							16. *C. permistum*	6	1,165	165(45-400)
							17. *C. petasum*	2	50	25(10-40)
							18. *C. mutabile*	1	10	10(10)
							19. *C. ornata*	3	150	50(40-70)
							20. *C. princeps*	2	50	50(50)
							21. *C. macrodora*	3	220	73(20-100)
							22. *Criconemo*. n. sp.	31	1,835	51(9-250)
							23. *Criconemoides* spp.	9	390	35(10-100)

(continued)

TABLE 23 (continued).

CLASS	ORDER	SUBORDER	SUPERFAMILY	FAMILY	SUBFAMILY	GENUS	SPECIES	RECOVERY[1] (%)	SPECIMENS[2] RECOVERED	POPULATION[3] (MEAN & RANGE)
					Hemicycliophorinae			44	2,654	51(3-180)
						10. *Hemicycliophora*		44	2,654	51(3-180)
							24. *H. similis*	1	3	3(3)
							25. *H. uniformis*	36	2,338	56(10-180)
							26. *H. vidua*	8	313	35(3-100)
				Paratylenchidae				37	4,152	90(9-2,710)
					Paratylenchinae			37	4,152	90(9-2,710)
						11. *Paratylenchus*		30	3,881	129(9-2,710)
							27. *P. projectus*	4	2,954	591(20-2,710)
							28. *Paratylenchus* spp.	26	929	31(9-150)
						12. *Gracilacus*		9	269	24(9-60)
							29. *G. aciculus*	1	40	40(40)
							30. *G. aculentus*	3	79	26(9-60)
							31. *G. audriellus*	3	100	33(10-50)
							32. *Gracilacus* spp.	3	50	13(10-20)
			Tylenchoidea					83	10,828	113(9-850)
				Tylenchidae				65	3,784	31(9-180)
					Tylenchinae			62	3,644	31(9-180)
						13. *Aglenchus*		43	1,111	22(9-50)
							33. *A. costatus*	43	1,111	22(9-50)
						14. *Cephalenchus*		11	330	25(10-70)
							34. *C. leptus*	11	330	25(10-70)
						15. *Tylenchus*		41	2,203	45(9-180)
							35. *T. davainei*	5	249	42(9-80)
							36. *T. vesiculosus*	1	10	10(10)
							37. *Tylenchus* spp.	35	1,944	47(9-180)
					Psilenchinae			7	130	16(10-20)
						16. *Psilenchus*		7	130	16(10-20)
							38. *P. hilarulus*	4	60	15(10-20)
							39. *Psilenchus* spp.	3	70	18(10-20)
					Ditylenchinae			1	10	10(10)
						17. *Ditylenchus*		1	10	10(10)
							40. *Ditylenchus* spp.	1	10	10(10)
				Pratylenchidae				35	938	23(9-60)
					Pratylenchinae			35	938	23(9-60)
						18. *Pratylenchus*		35	938	23(9-60)
							41. *P. crenatus*	4	117	23(9-58)
							42. *P. neglectus*	3	80	27(10-60)
							43. *P. penetrans*	3	50	17(10-30)
							44. *Pratylenchus* spp.	28	691	22(9-60)
				Tylenchorhynchidae				25	1,985	44(10-200)
					Tylenchorhynchinae			25	1,985	44(10-200)
						19. *Tylenchorhynchus*		23	1,925	46(10-200)
							45. *T. maximus*	19	1,110	50(10-200)
							46. *T. nudus*	13	566	38(10-170)
							47. *T. davainei*	5	249	42(9-80)
						20. *Tetylenchus*		1	10	10(10)
							48. *T. joctus*	1	10	10(10)
						21. *Merlinius*		2	50	25(10-40)
							49. *M. brevidens*	2	50	25(10-40)
				Hoplolaimidae				54	8,843	140(10-850)
					Rotylenchinae			54	8,843	140(10-850)
						22. *Helicotylenchus*		54	8,843	140(10-850)
							50. *H. crenacauda*	2	35	18(10-25)
							51. *H. digonicus*	3	420	105(10-320)
							52. *H. lobus*	1	25	25(25)
							53. *H. paxilli*	1	50	50(50)
							54. *H. platyurus*	38	7,383	168(10-850)
							55. *H. pseudorobustus*	2	139	70(9-130)
							56. *H. varicaudatus*	1	15	15(15)
							57. *Helicotylen.* spp.	14	776	49(8-450)
			Heteroderoidea					21	315	13(8-50)
				Heteroderidae				21	315	13(8-50)
					Heteroderinae			21	315	13(8-50)
						23. *Heterodera*		2	20	10(10)
							58. Heterodera spp.	2	20	10(10)
						24. *Meloidogyne*		20	295	13(8-50)
							59. *Meloidogyne* spp.	20	295	13(8-50)

[1] Percent of 116 soil samples (250 cc).

[2] Total number of specimens recovered from the 116 soil samples (based on 250 cc of soil per sample).

[3] Mean and range population densities of samples containing specific taxa (based on 250 cc of soil per sample).

TABLE 24. RANGE OF LANDING COUNTS PER TWO HOUR PERIOD FOR FEMALE MOSQUITOES IN THE FOREST ON THE WQMP TERRESTRIAL SITE

Time	Aedes stimulans		Aedes vexans		Aedes triseriatus	
	1973	1974	1973	1974	1973	1974
May 29 - June 15	139-188	54-197	47-134	76-190	16-48	18-28
June 15 - June 28	92-144	40- 49	10-228	30- 46	17-25	9-16
July 2 - July 15	115-146	34- 48	3- 13	4- 16	12-24	2- 8
July 16 - July 26	108-159	20- 39	2- 69	0	11-26	0
July 27 - August 15	6- 87	2- 15	3- 37	0	1-12	0
August 16 - August 30	0- 6	0- 3	2- 52	0	1- 4	0

encephalitis cycle is maintained in nature by an Aedes triseriatus - small mammal transmission cycle; this appears to be true on the WQMP. The other two species of Aedes are also possible encephalitis vectors.

Wastewater irrigation may enhance the breeding potential of these three species and perhaps may cause an increase in diversity and numbers of other species; this will increase changes of human exposure to the encephalitis virus. Mosquitoes are also potential, but unproven vectors, for dog heartworm. The incidence of dog heartworm has been continuously rising in Michigan in recent years. If spraying leads to an overabundance of mosquitoes, control measures may have to be implemented to reduce discomfort and chances of disease transmission to the neighboring communities.

Avian Populations

Data on bird populations were taken by census techniques on the WQMP terrestrial site in 1974 and 1975. Ninety species were observed in 1975 (TABLE 25) including 10 observed for the first time; 23 species observed in 1974 were not seen in 1975 (TABLE 26). These 23 species were mostly migrants and no significance is attached to their absence.

Breeding bird populations were increased 164% in 1975 over 1974 population estimates (TABLE 27 and 28). Most of this increase occurred in abandoned fields (TABLE 28) but some increase also occurred in the woods (TABLE 27). There were no significant differences between areas receiving wastewater irrigation and areas not receiving irrigation (TABLE 28).

TABLE 25. LIST OF SPECIES OBSERVED ON THE CENSUS FROM MAY 2 TO SEPTEMBER 16, 1975 (52 MAN HOURS)

Great Blue Heron	Swainson's Thrush
Green Heron	Veery
Mallard	Ruby-Crowned Kinglet
Blue-Winged Teal	Cedar Waxwing
Wood Duck	Starling
Red-Tailed Hawk	Solitary Vireo
American Kestrel	Red-Eyed Vireo
Bobwhite	Philadelphia Vireo*
Ring-Necked Pheasant	Warbling Vireo
Killdeer	Black & White Warbler
American Woodcock*	Golden-Winged Warbler
Solitary Sandpiper	Blue-Winged Warbler
Greater Yellowlegs*	Tennessee Warbler
Rock Dove	Nashville Warbler
Mourning Dove	Yellow Warbler
Yellow-Billed Cuckoo	Magnolia Warbler
Black-Billed Cuckoo	Black-Throated Warbler
Great Horned Owl	Yellow-Rumped Warbler
Ruby-Throated Hummingbird	Chestnut-Sided Warbler
Common Flicker	Bay-Breasted Warbler
Red-Bellied Woodpecker	Blackpoll Warbler
Red-Headed Woodpecker	Ovenbird
Hairy Woodpecker	Northern Waterthrush*
Downy Woodpecker	Yellowthroat
Eastern Kingbird	American Redstart
Great Crested Flycatcher	Bobolink
Least Flycatcher	Eastern Meadowlark
Eastern Wood Pewee	Red-Winged Blackbird
Horned Lark	Northern Oriole
Tree Swallow*	Common Grackle
Rough Winged Swallow*	Brown-Headed Cowbird
Barn Swallow	Scarlet Tanager
Blue Jay	Cardinal
Common Crow	Rose-Breasted Grosbeak
Black-Capped Chickadee	Indigo Bunting
Tufted Titmouse	Purple Finch*
White-Breasted Nuthatch	American Goldfinch
Red-Breasted Nuthatch	Rufous-Sided Towhee
Short-Billed Marsh Wren	Savannah Sparrow
Long-Billed Marsh Wren[a]	Vesper Sparrow*
House Wren	Field Sparrow
Grey Catbird	White-Crowned Sparrow*
Brown Thrasher	White-Throated Sparrow
American Robin	Song Sparrow
Wood Thrush	Henslow's Sparrow

*New Species

TABLE 26. BIRDS SEEN IN CENSUS AREA IN 1974 BUT NOT IN 1975

Canada Goose	Grey-Cheeked Thrush
Sharp-Shinned Hawk	Golden-Crowned Kinglet
Rough Grouse	Blackburnian Warbler
Herring Gull	Pine Warbler
Whippoorwill	Palm Warbler
Chimney Swift	Wilson's Warbler
Yellow-Bellied Sapsucker	Canada Warbler
Eastern Phoebe	Grasshopper Sparrow
Acadian Flycatcher	Tree Sparrow
Willow Flycatcher	Lincoln Sparrow
Olive-Sided Flycatcher	Swamp Sparrow
Purple Martin	

TABLE 27. BREEDING BIRD SPECIES IN FORESTS ON THE WQMP AND THEIR NUMBERS FOR 10 ACRES (4 ha)

Species	No. in 1974	No./10 Acres 1974	No. in 1975	No./10 Acres 1975
Tufted Titmouse	1	0.28	5	1.41
Cardinal	4	1.13	4	1.13
Red-Eyed Vireo	2	0.56	4	1.13
Eastern Wood Pewee	3	0.85	3	0.85
Black-Capped Chickadee	3	0.85	3	0.85
Indigo Bunting	3	0.85	3	0.85
Blue Jay	2	0.56	3	0.85
Rose-Breasted Grosbeck	0	0.00	3	0.85
Downy Woodpecker	2	0.56	2	0.56
American Robin	2	0.56	2	0.56
Great-Crested Flycatcher	1	0.28	2	0.56
Northern Oriole	1	0.28	2	0.56
Common Flicker	2	0.56	1	0.28
Great Horned Owl	0	0.00	1	0.28
Wood Thrush	0	0.00	1	0.28
Ovenbird	0	0.00	1	0.28
White-Breasted Nuthatch	2	0.56	0	0.00
Acadian Flycatcher	1	0.28	0	0.00
Total	29		40	

TABLE 28. BREEDING BIRD SPECIES IN OLD FIELDS ON THE WQMP AND THEIR NUMBERS PER 10 ACRES (4 ha)

Species	Untreated - No Irrigation				Treated - Wastewater Irrigated			
	No.'74	No./10a	No.'75	No./10a	No.'74	No./10a	No.'75	No./10a
Red-winged Blackbird	6	0.98	15	2.45	6	1.26	15	3.14
Song Sparrow	11	1.80	17	2.78	10	2.09	9	1.88
Field Sparrow	9	1.47	12	1.96	5	1.05	4	0.84
Yellow Throat	2	0.33	3	0.49	5	1.05	8	1.67
Eastern Meadowlark	4	0.65	4	0.65	2	0.42	7	1.46
Bobolink	3	0.49	5	0.82	2	0.42	5	1.05
Common Flicker	0	0.00	4	0.65	1	0.21	3	0.63
Common Goldfinch	3	0.49	3	0.49	3	0.63	3	0.63
Cardinal	0	0.00	2	0.33	1	0.21	4	0.84
Savannah Sparrow	2	0.33	4	0.65	0	0.00	1	0.21
Catbird	1	0.16	2	0.33	1	0.21	2	0.42
American Robin	0	0.00	0	0.00	2	0.42	4	0.84
Northern Oriole	0	0.00	3	0.49	1	0.21	1	0.21
Blue Jay	0	0.00	1	0.16	0	0.00	3	0.63
Brown Thrasher	0	0.00	1	0.16	1	0.21	2	0.42
House Wren	2	0.33	1	0.16	3	0.63	1	0.21
Black Capped Chickadee	0	0.00	1	0.16	1	0.21	1	0.21
Warbling Vireo	1	0.16	1	0.16	0	0.00	0	0.00
Mourning Dove	0	0.00	0	0.00	0	0.00	1	0.21
Henslow's Sparrow	0	0.00	1	0.16	0	0.00	0	0.00
Yellow Warbler	0	0.00	0	0.00	0	0.00	2	0.42
Black Billed Cuckoo	0	0.00	0	0.00	0	0.00	1	0.21
Willow Flycatcher	0	0.00	0	0.00	1	0.21	0	0.00
	44		80		43		77	

Red-winged blackbirds were selected for intensive study as they are more likely to increase in irrigated areas than any other species because of their preference for wet habitats. Twenty-six nests were located on 4 (4 ha) plots (2 receiving wastewater irrigation, 2 controls). Survival of eggs and nestlings were followed in these plots (TABLE 29); there were no significant differences in numbers of fledged offspring per nest between the treatment and controls (TABLE 29). There was some indication of more abundant food on the irrigated site (less time spent foraging off the territory by the female) but data were not conclusive.

TABLE 29. SURVIVAL OF RED-WINGED BLACKBIRD EGGS AND NESTLINGS ON SPRAYED AND CONTROL PLOTS

Item	Spray	%	Control	%	% Diff.
No. nests	11(9)*		15(12)*		
Total eggs laid	33		38		
$\bar{X}$ clutch size	3.7		3.2		
No. hatching	26	79	24	63	16
No. fledging	21	64	18	47	17
$\bar{X}$ fledged/nest	2.3†		1.5†		

*Some nests were not followed because they appeared late in the season when full time was being devoted to foraging studies. The number in parentheses is the number of nests for which data were taken.

†These values are statistically the same ($P<.3$; t-test).

Evidence, to date, indicates that wastewater irrigation on the terrestrial site of the WQMP has had no significant effect on bird populations. Bird populations will be monitored in areas receiving wastewater irrigation as irrigation increases.

Mammal Studies

Baseline data on small mammal populations in forested and old field ecosystems have been collected for the WQMP wastewater irrigation site. Preliminary data on effects of wastewater irrigation on small mammal populations from old fields have also been collected.

Two parallel trap lines 30 m apart and 152 m long were established in each study area (lines 2, 3, 4 - Figure 33). Paired, parallel trap lines were established in an irrigation area of the forest and in a non-irrigated area. Neither had been irrigated at the time of this study, so these data were pooled and represent baseline data for the forest. A pair of parallel trap lines was established in a non-irrigated area of the old field ecosystem and another pair was established in the old field ecosystem receiving 7.1 cm/week of wastewater effluent (zone 21).

Each trap line consisted of 20 stations located at 8 m intervals. Two Museum Special snap traps and one Victor rat trap were placed within a 1.5 m radius at each station; all traps were baited with a rolled oats-peanut butter mixture. All lines were run at 12 week intervals from September, 1974, to July, 1975; each trapping period consisted of trapping of 3 successive nights (Friday, Saturday, and Sunday). Old field trap lines (treated and untreated areas) were run on the same weekend; trap lines in the forest were run on the following weekend.

A total of 122 specimens representing 7 species of small mammals were collected in the old field study area while 95 animals representing 4 species were trapped in the forest. Density estimates (number of animals captured per 100 trap-nights) for the forest (TABLE 30) and old field (TABLE 31) ecosystems varied considerably between sampling dates. The white-footed mouse, *Peromyscus leucopus*, dominated the catch in the forest; its density increased during the study (TABLE 30). No apparent trend is evident between irrigated and non-irrigated old field sites; overall, there was a general decline in density in the old field ecosystems during the course of this study (TABLE 31).

Reproductive and morphological data on weight, length, lactation, placental scars, corpora lutea, etc., were monitored in detail. Variability in the data for these parameters obscured differences in irrigated versus non-irrigated areas of the old field ecosystems. These data are available in our central data file for future comparative studies.

Conclusions

Baseline data for soil and litter fauna, pathogenic nematodes, disease carrying insects, birds, and mammals are available for the wastewater irrigation site. Data on the effect of wastewater irrigation on animal populations

TABLE 30. ANIMAL POPULATION DENSITY ESTIMATES (NUMBER OF ANIMALS PER 100 TRAP-NIGHTS) FOR FORESTED STUDY AREAS OF THE WQMP

Sample Period	Species			
	Peromyscus* leucopus	Blarina* brevicauda	Sorex* cinereus	Tamias* striatus
October, 1974	1.67	0.14	0.14	0.00
January, 1975	1.95	1.25	1.25	0.00
April, 1975	0.83	0.00	0.56	0.00
July, 1975	4.87	0.00	0.42	0.14

*Peromyscus leucopus, White-footed Mouse; Blarina brevicauda, Shorttail Shrew; Sorex cinereus, Masked Shrew; Tamias striatus, Eastern Chipmunk.

TABLE 31. ANIMAL POPULATION DENSITY ESTIMATES (NUMBER OF ANIMALS PER 100 TRAP-NIGHTS) FOR OLD FIELD STUDY AREAS OF THE WQMP

Sample Period	Treatment†	Species*						
		P.l.	P.m.	M.p.	Z.h.	B.b.	S.c.	D.v.
September, 1974	Treated	0.00	0.00	1.11	2.22	1.39	1.11	0.00
September, 1974	Untreated	0.00	0.00	3.89	0.00	3.89	2.78	0.28
December, 1974	Treated	0.00	0.00	0.28	0.00	0.83	1.39	0.00
December, 1974	Untreated	0.28	0.28	1.11	0.00	1.67	2.22	0.00
March, 1975	Treated	0.00	0.00	0.28	0.00	0.00	3.34	0.00
March, 1975	Untreated	0.00	0.00	0.28	0.00	0.00	2.22	0.00
June, 1975	Treated	0.00	0.56	1.11	0.56	0.00	0.28	0.00
June, 1975	Untreated	0.00	0.83	0.56	0.56	0.00	0.00	0.00

*P.l. - Peromyscus leucopus (the White-Footed Mouse)
P.m. - Peromyscus maniculatus (the Deer Mouse)
M.p. - Microtus pennsylvanicus (the Meadow Vole)
Z.h. - Zapus hudsonius (the Meadow Jumping Mouse)
B.b. - Blarina brevicauda (the Shorttail Shrew)
S.c. - Sorex cinereus (the Masked Shrew)
D.v. - Didelphis virginianus (the Virginia Oposum)

†Treated = wastewater irrigation at 7.1 cm/week; untreated = non-irrigated control areas.

is being taken at present; these data are not yet available for invertebrate populations. Limited amounts of wastewater irrigation on the site have not significantly affected bird populations. Mammal population data are highly variable, and mammals have had only limited exposure to irrigation. Based on these limited data, no significant differences have been demonstrated for irrigated versus non-irrigated old field areas. All data on animal populations are preliminary; data collection during more intensive years of wastewater irrigation may yield different and more statistically significant results.

WINTER SPRAY IRRIGATION

The possibility of winter spray irrigation with frozen ground conditions was investigated on a 3 ha abandoned field site from January to March, 1975 (area K, Figure 33). A total of 6 spray applications was made ranging from 2.57 to 5.51 cm at ambient temperatures ranging from -6.1 C to +0.3 C. A total of 24.6 cm was pumped to the site during this period with 19.4 cm being received at the soil surface. Thus, about 21% of the wastewater pumped was lost via evaporative processes to the atmosphere and wind transport of mist from the site, or measurements of incoming wastewater were in error.

Precipitation and spray were monitored at 47 sites with open can precipitation collectors (Figure 44). Infiltration and percolation were measured at the same 47 sites using infiltrometers (Figures 44 and 45). Mean infiltration was 4 ± 5 cm for the sprayed area and 1 ± 0.6 cm for the unsprayed area. Thus, a mean infiltration of 3.0 cm of spray was measured or 16% of the total amount sprayed on the site. Due to the high variability between samplers and the limited number of irrigation events, these data are only approximate.

In addition to the wastewater inputs, precipitation added 12.3 cm of input during the course of this study for a total input of 31.7 cm. Of this 32 cm, 12% (4 cm) evaporated, 32% (10 cm) ran off as overland flow, and 13% (4 cm) infiltrated leaving 44% (14 cm) unaccounted for. The large amount of unaccounted for water indicated significant error in field measurements of runoff and infiltration and/or a large storage as ice with unmeasured losses in Spring runoff. Some possible sources of error were: (1) unreliable infiltrometer estimates (buried glass funnels which may not have been in

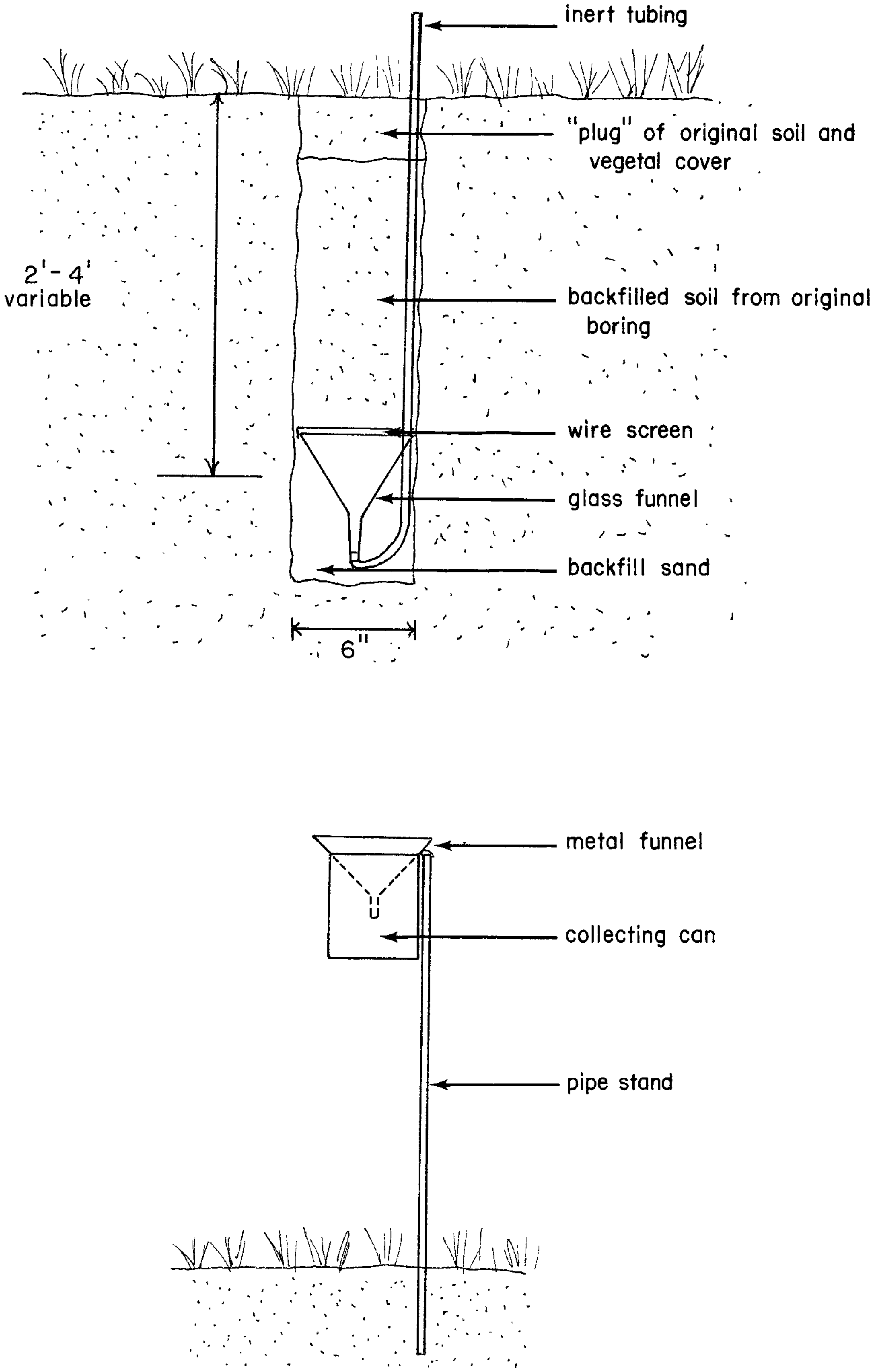


Figure 44. Design of infiltrometers (upper) and precipitation collectors used in the winter spray study.

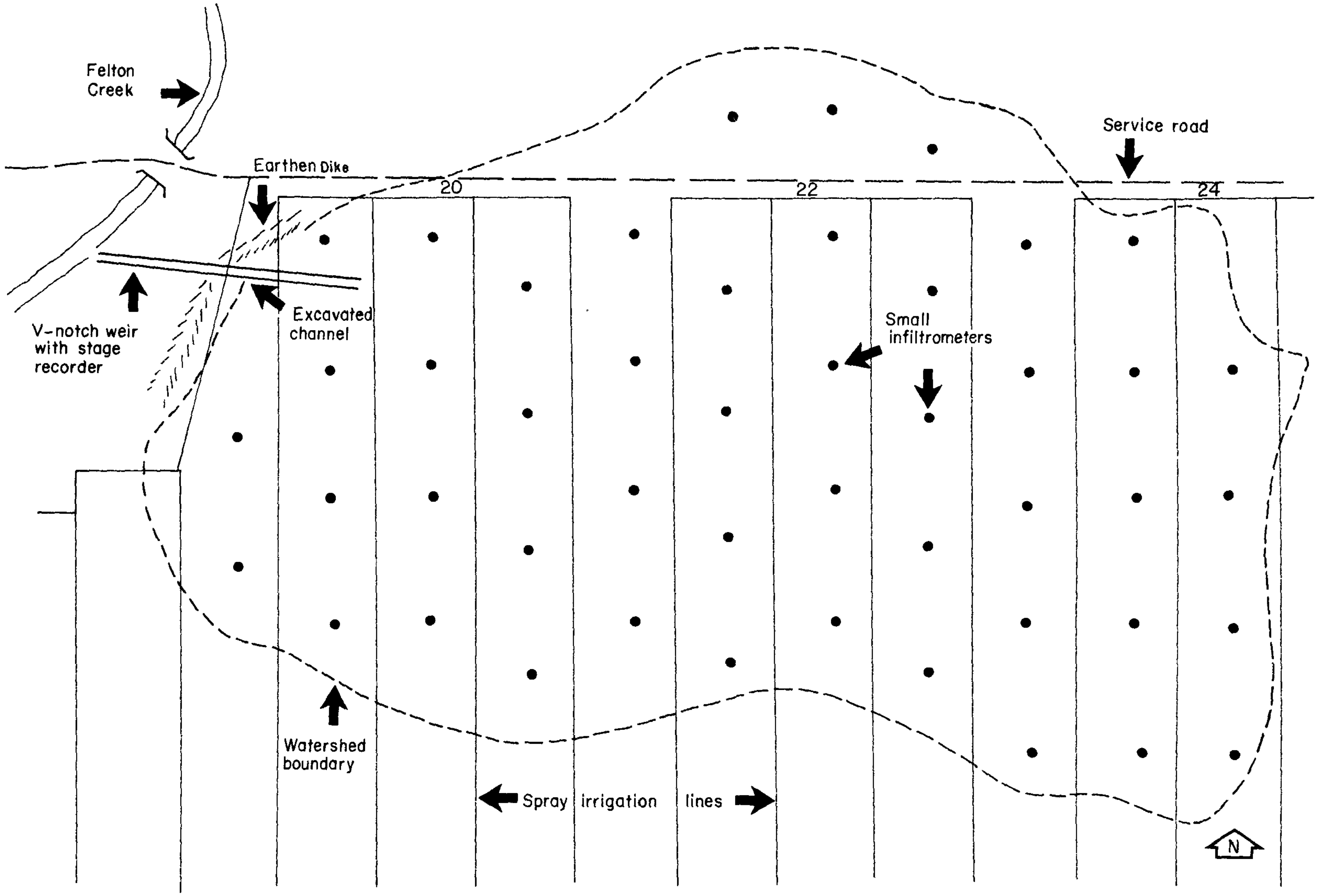


Figure 45. Design of winter spray study showing infiltrometer and precipitation collector locations.

place long enough for the soil above them to set), (2) unmeasured runoff losses (there were indications of seepage under the weir in the unlined channel, Figure 45), and (3) non-uniform distribution of spray inputs as the spray nozzles tended to freeze in position.

Incoming spray, precipitation, infiltrometer, and runoff samples were analyzed for total P, NO_3-N, NH_4-N, and B. All unaccounted for water was assumed to have infiltrated and mass balances were constructed for each of the above. Renovation efficiencies were then calculated based on apparent retention within the watershed. These efficiencies were 45% for total-P, 20% for NO_3-N, 70% for NH_4-N, and 35% for boron. These efficiencies are based on limited data and should be viewed only as preliminary estimates. If runoff were underestimated as seems likely, these efficiencies would be even lower. If infiltrated water only were considered, sprayed versus unsprayed sites would differ significantly only in NH_4-N concentrations with an apparent renovation efficiency of 35%. Renovation appears to be significant, therefore, for infiltrated water for total P, NH_4-N, and boron. Ammonia-nitrogen may have been lost as NO_3-N after warming of the soil to the point where nitrification could occur; this would have been missed in this study as infiltration studies were not continued into the summer.

Measurements of infiltration at the 47 infiltrometers permitted construction of infiltration contours. Large amounts of ponding at some sites resulted in significantly greater infiltration and percolation.

Specific studies of frost penetration were conducted at an adjacent site (area L, Figure 33) to the winter spray watershed. Results of these studies are summarized in Figure 46.

Results of this study have led to the following tentative conclusions:

(1) It is physically possible to spray wastewater on the land during the winter in Michigan, but the high NO_3-N losses and lowered renovation efficiencies for other constituents suggest that winter spraying in cold climates be investigated further.

(2) A significant percentage (32%, range = 0 - 155%) of the winter irrigated wastewater is likely to runoff as overland flow with little renovation.

(3) Some infiltration does occur (average of 13%), but this is highly variable. Infiltration is significantly increased by ponding.

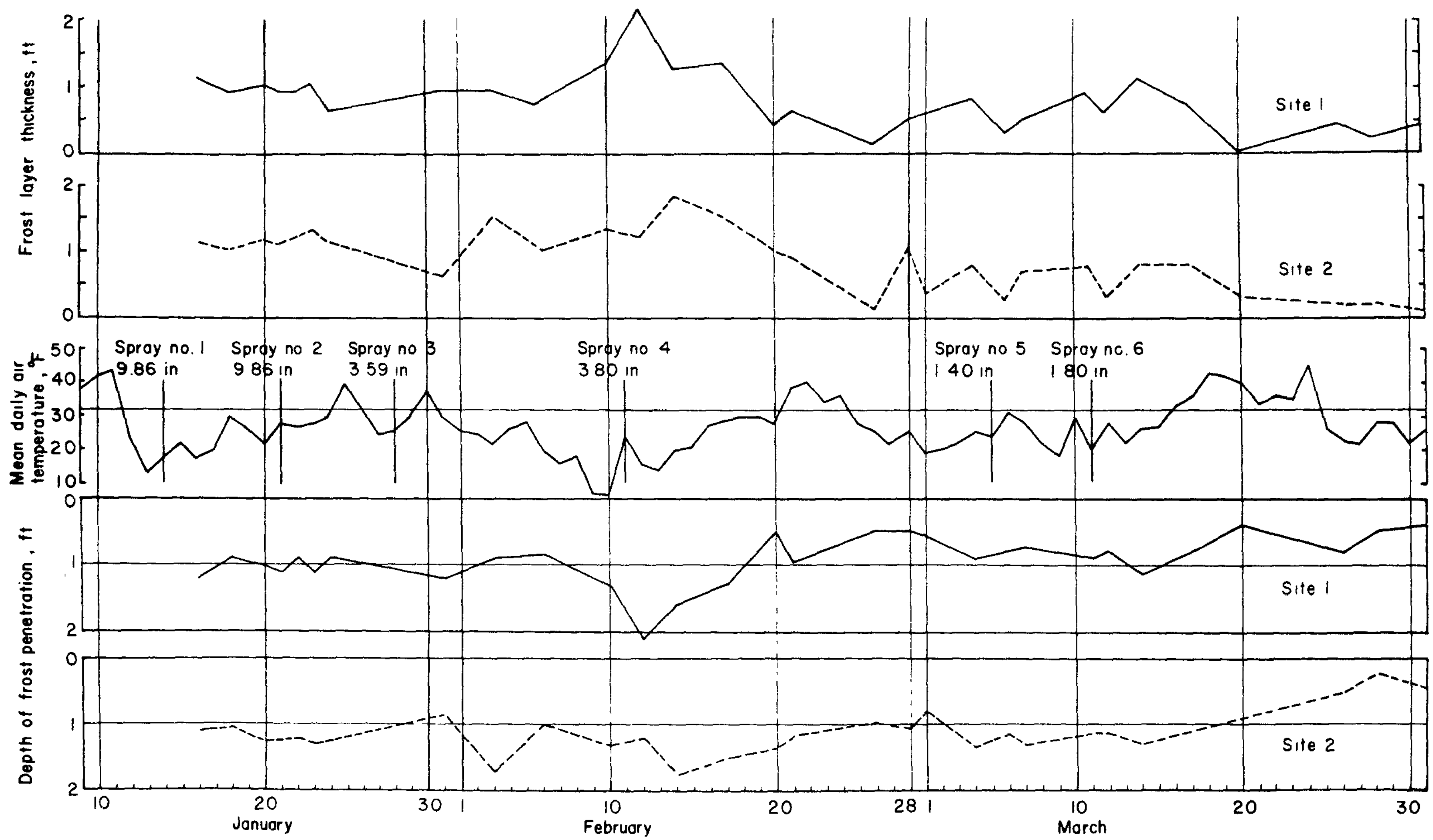


Figure 46. Depth of frost penetration, frost layer thickness, mean daily air temperature and spray application for Sites 1 and 2 during winter irrigation.

(4) Significant amounts (10-20%) of wastewater are lost by evaporative and wind transport processes during winter spray operations.

(5) More precise measurements are needed to support these tentative conclusions. Thus, research will be continued on this practice for the next two winters.

GROUNDWATER HYDROLOGY

One of the prime advantages of wastewater irrigation is recharge of the local aquifer. Such recharge is especially critical in areas of rapidly declining water tables as is true of the Lansing area. The WQMP spray irrigation program should lead to some recharge of the aquifer. The extent of this recharge and the effect of percolating wastewater on groundwater quality has to be assessed. Thus, data on subsurface geology and groundwater flow prior to and during spray irrigation is essential.

Over 60 wells have been drilled in the vicinity of the WQMP for the purpose of monitoring piezometric surfaces and groundwater quality. Boring logs from these wells provide information on the local subsurface geology; a representative cross-sectional schematic is shown in Figure 47. Water quality analyses are routinely made, and baseline data for several years have been accumulated. Changes in groundwater quality due to the WQMP have not been detected. Analyses include nitrate, chloride, coliform bacteria, and several other parameters; monitoring will continue.

Models have been developed to predict groundwater movement in the region of the WQMP with emphasis on movement of the groundwater to nearby deep wells which are the water supply for the University. One of these models, a Galerkin-based finite elements regional aquifer model, was used to predict the piezometric surface and flow field after six years of simulated pumping from major producing wells in the vicinity of the site (Figure 48 and 49). The numbered nodes are wells, node A is the lakes, and the dashed line outlines the spray site. The predicted drawdowns near some of the wells are not very accurate (due to the approximate nature of the numerical solution and to coarseness of the finite-element grid chosen for the regional area) but indicate that most groundwater moving beneath the irrigation site will migrate to the well at node 114 (Figure 48) provided pumping from the well field continues in a manner similar to present practices.

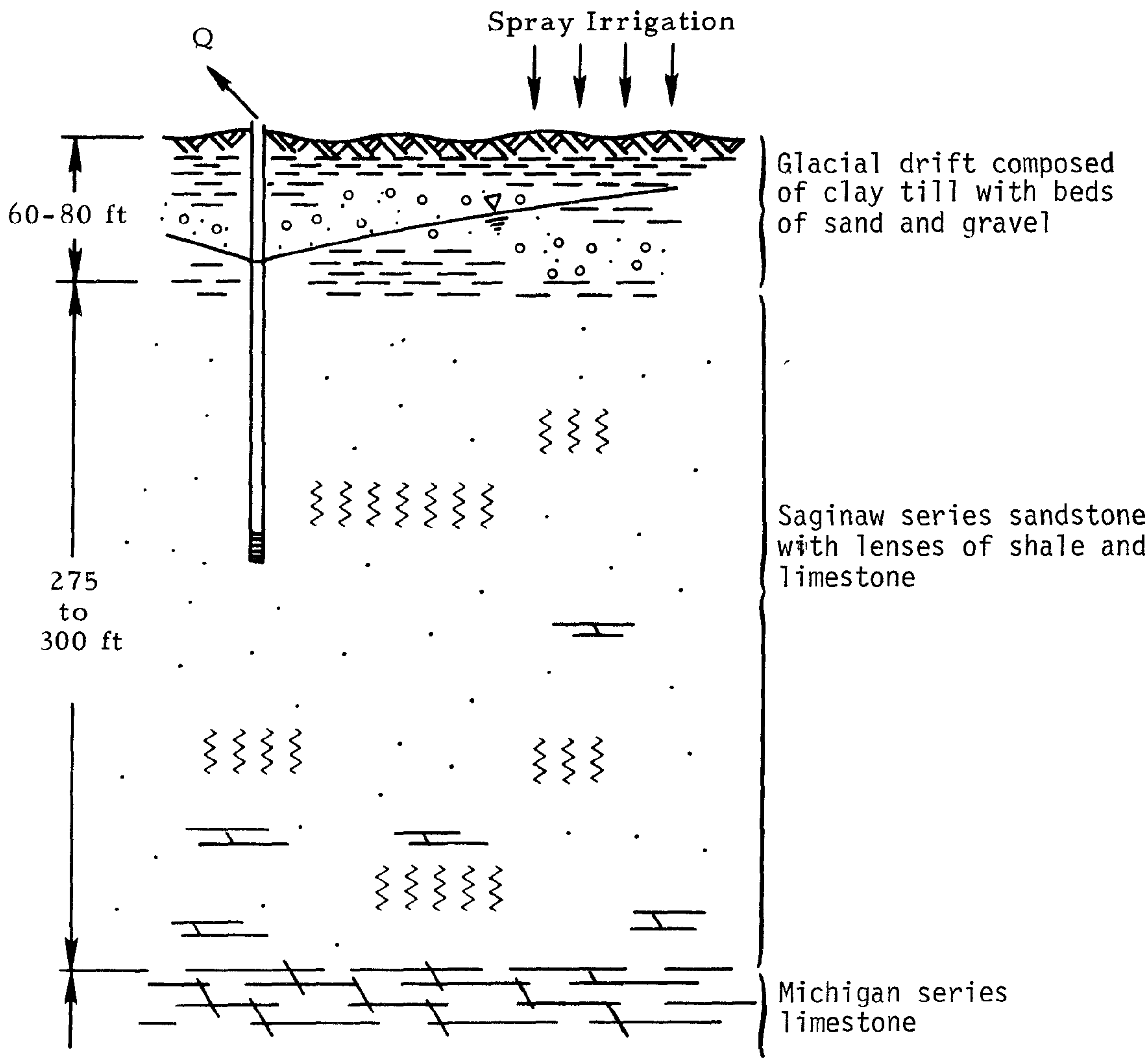
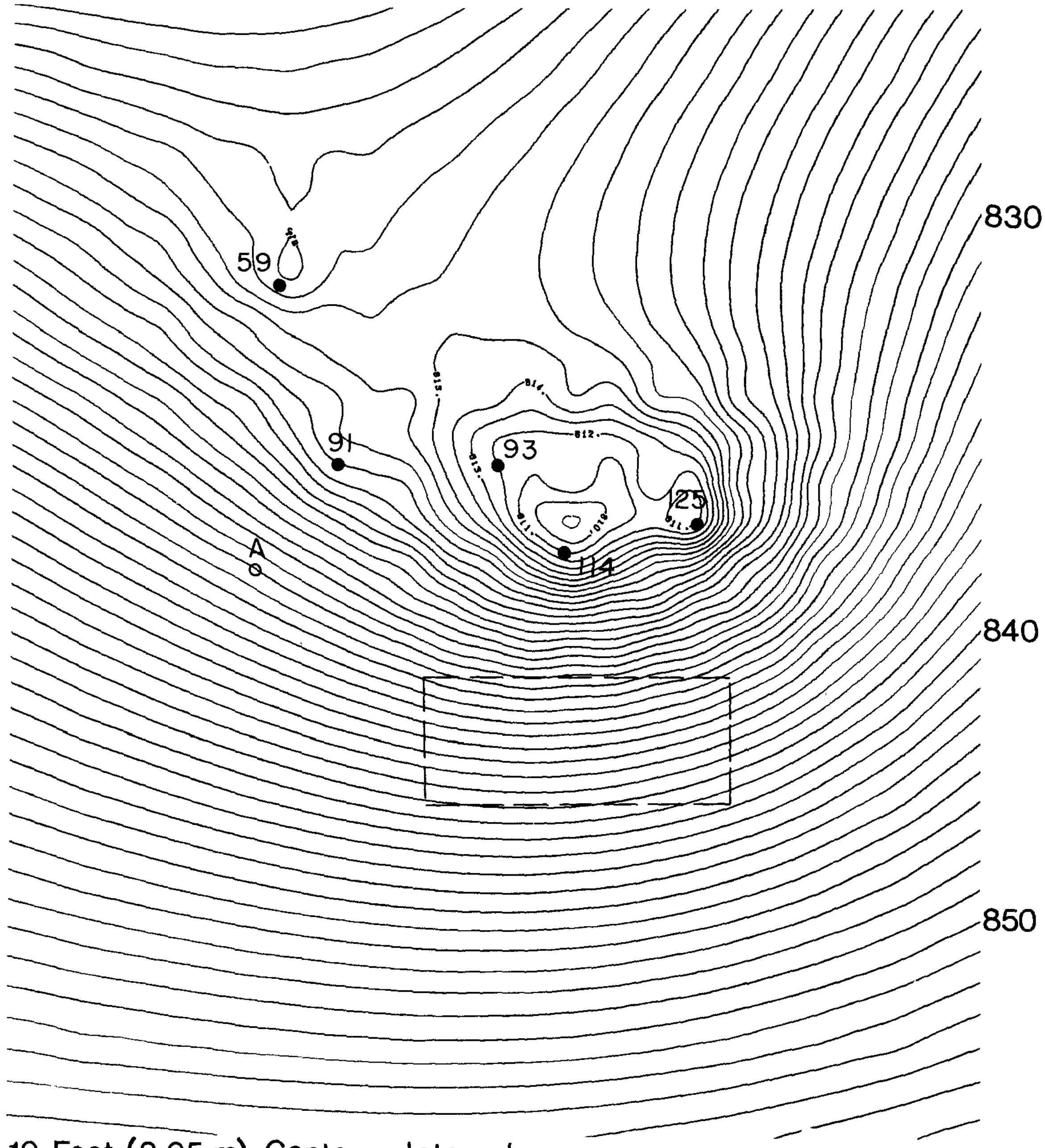


Figure 47. Representative cross section of the subsurface geology of the WQMP.



10 Foot (3.05 m) Contour Intervals

Figure 48. Predicated piezometric surfaces in the vicinity of the WQMP after six years of simulated pumping of major producing wells (numbered nodes) in the area. A = lake area; dashed line outlines spray irrigation site.

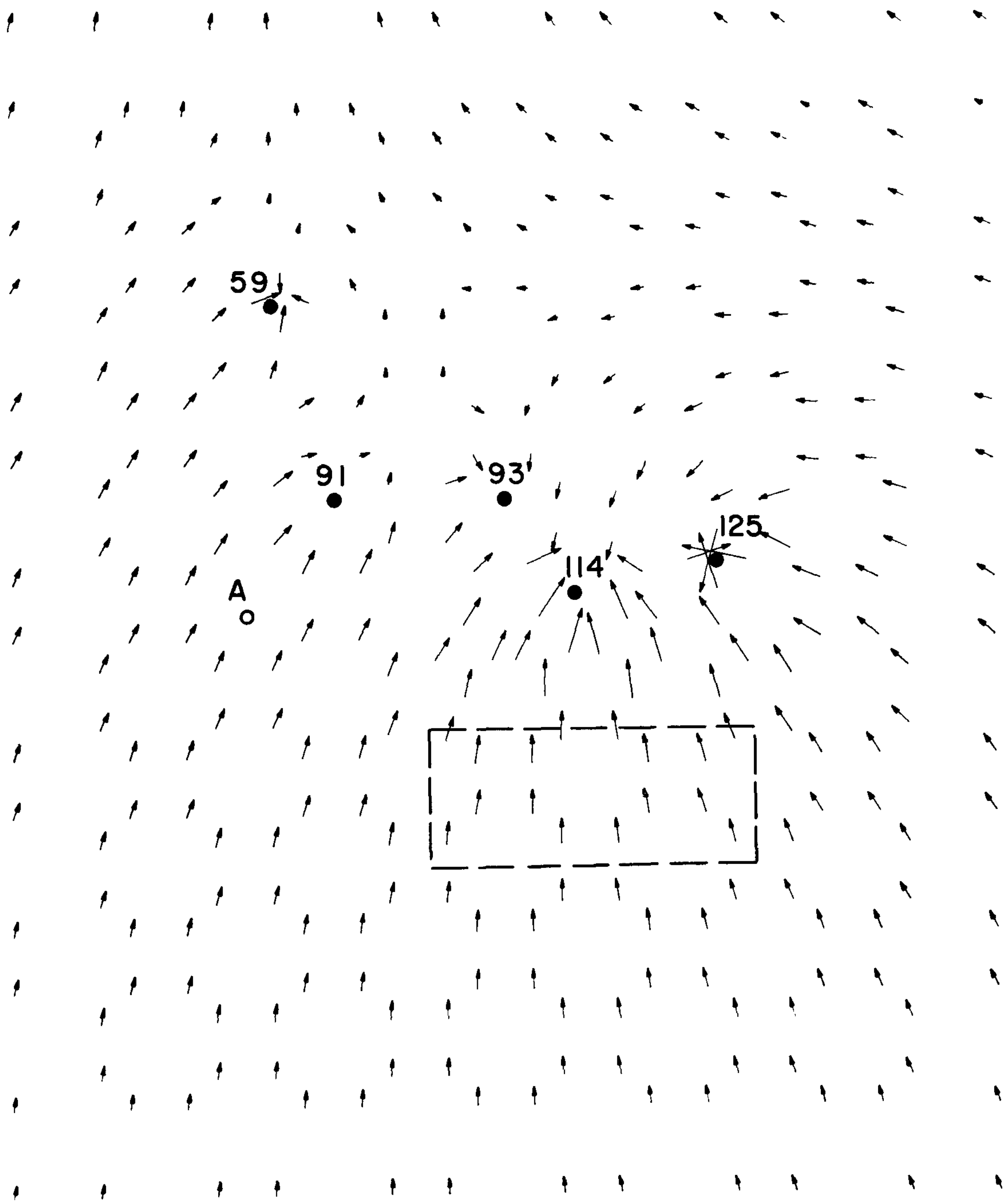


Figure 49. Predicted flow vectors after six years of simulated pumping from producing wells (numbered nodes) in the vicinity of the WQMP. A = lake area; dashed line outlines spray irrigation site.

With the objective in mind of predicting the transient movement of groundwater in localized regions beneath the spray irrigation site, a Galerkin-based finite element model has been developed. Employing the properties of an isoparametric finite element, the movement of the free surface is accomplished within the grid system without repositioning the nodal coordinates of the elements. During each time interval, a new Dirichlet boundary condition is assigned to nodal points above the free surface and piezometric heads in the aquifer are calculated. In order to provide flow continuity at nodes, the Galerkin formulation of the Darcy law is constructed, and the velocity vectors are calculated simultaneously throughout the domain. These velocities are subsequently used to shift the phreatic surface. The validity of the technique is demonstrated in Figure 50 in which a groundwater mound grows due to recharge at the surface. In the near future this model will be coupled to one for convection-dispersion of a tracer and used to simulate wastewater recharge flow conditions at the site.

With the solution of the flow equation established for either a regional aquifer or a local one, the movement of a tracer introduced by the spray irrigation process can be predicted by inserting the calculated velocity vectors into the convection-dispersion equation, which is solved again by a finite element technique. Here higher order approximations in the time domain are used to solve the generated set of first order differential equations. Initial results from the model indicate that reasonably accurate estimates of actual tracer concentration in two-dimensional flow domains can be obtained.

Future groundwater research will deal with unsteady, unsaturated flow and three-dimensional transient groundwater flow using two different models developed for this study; one based on the finite elements method and the other based on the method of characteristics.

SURFACE RUNOFF STUDIES

The effects of wastewater irrigation on stream chemistry is being assessed on the spray irrigation site. Much of the effort, to date, has been concentrated on instrumenting the streams with weirs and hydrographs so that reliable data on water movements can be documented. Automatic (ISCO) samplers

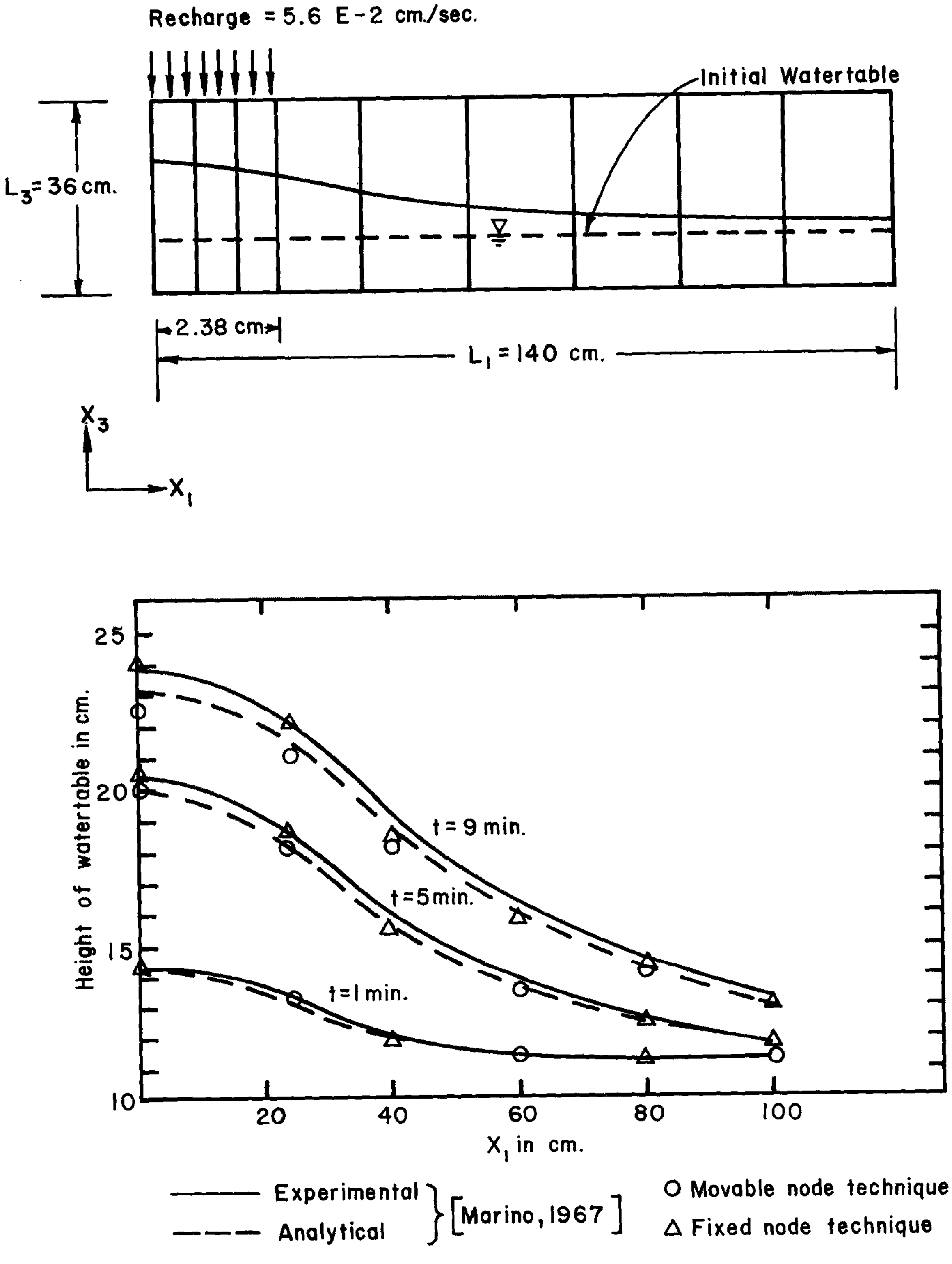


Figure 50. Simulated growth of a groundwater mound due to recharge at the surface.

have also been installed and modified to start sampling as water level rises in the stream insuring collection of stormwater data over complete hydrographs.

The major stream on the spray irrigation site is Felton Drain (D in Figure 7). This stream drains an area of farm land southeast of the lake system of the WQMP and flows under the lake system via a tile which empties into a surface channel just north of Interstate 96, the northern boundary of the spray irrigation site. A poultry research facility is located on this stream just north of the site. Some manure from this facility is spread on the surrounding grass. Runoff from the poultry facility and upland farm areas represents potential large sources of nutrients, bacteria, and viruses. The highway (I-96) also represents a significant source of chloride from winter salting operations and other nutrients as well. The sampling network on the stream system of the WQMP includes an upstream sampling station for measurement of incoming materials so that mass balances for just the spray irrigation portion of the stream can be calculated.

There are now 8 weirs installed on the site. Initial installation was completed in 1974, but most of the weirs suffered considerable damage from Spring runoff floods in 1975 due to insufficient rip-rapping around the concrete weir walls. This problem was corrected, and continuous hydrologic data on both rainfall and stream discharge are available from early summer 1975 to present.

Automatic samplers were installed at 5 locations on the streams of the WQMP in September, 1975. They have been winterized in insulated, heated houses and are presently collecting data from each major runoff event. Some runoff events have been sampled but analyses of these data are not yet complete.

Prior to installation of automatic samplers, grab samples were collected on a few dates in 1973 and 1974, and weekly samples were collected in 1975 (daily samples were collected during periods of high runoff). These data are not very conclusive but do indicate considerable loading from the upstream poultry facility with incoming NO_3-N as high as 20 mg/ℓ and chlorides as high as 20 mg/ℓ in the spring but dropping to low levels over the summer. Such large and highly variable loading from upstream sources complicates studies of movement from the spray irrigation site. Thus, emphasis will be placed on runoff studies from discrete irrigated areas rather than on the whole stream system. The entire stream system will be monitored, however, and mass balances for the stream and its tributaries will be calculated.

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TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-905/3-79-003	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE UTILIZATION OF NATURAL ECOSYSTEMS FOR WASTEWATER RENOVATION		5. REPORT DATE March, 1976
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Burton, T.M., King, D.L., Ball, R.C., and Bahr, T.G.		8. PERFORMING ORGANIZATION REPORT
9. PERFORMING ORGANIZATION NAME AND ADDRESS Institute of Water Research, Michigan State University, East Lansing, MI 48824		10. PROGRAM ELEMENT NO. 2BA 645
		11. CONTRACT/GRANT NO. YOO5065
12. SPONSORING AGENCY NAME AND ADDRESS U.S. Environmental Protection Agency, Region V Office, Chicago, IL 60604		13. TYPE OF REPORT AND PERIOD COVERE Grant - 1972-1975
		14. SPONSORING AGENCY CODE EPA-GLNP

15. SUPPLEMENTARY NOTES
This was a Comprehensive Grant involving both construction and research.
Published through the Great Lakes National Program Office

16. ABSTRACT
Michigan State University constructed on 200 ha (500 acres) of the main campus, a permanent facility for the experimental treatment, recycle and reuse of municipal sewa plant effluents. The facility provides for the diversion of up to 7570 m^3/d (2 MGD) o secondary effluent from an activated sludge treatment plant. This waste flow is direc ed away from the receiving stream to an intensely managed aquatic and terrestrial nutri ent recycling system. The facility consists of a portion of the East Lansing Wastewater Treatment Plant, a transmission line, four experimental lakes and a spray irrigation site. A primary objective is to strip nutrients from the waste flow as it proceeds through the system by incorporating nutrients into harvestable biomass.

The system has been in operation with tertiary effluent for about 18 months. It will go on line with secondary effluent in 1976. Biological activity in the aquatic system has a major impact on water quality as evidenced by significantly reduced water concentrations of phosphorus, nitrogen and inorganic carbon. Much of the nutrient flow is shunted into harvestable plant material both in the aquatic and terrestrial portions of the system.

This report represents a synthesis of preliminary research results from a multidis ciplinary program involving approximately 25 university faculty scientists. This repo is submitted in fulfillment of Grant No. Y005065, Environmental Protection Agency.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Sewage effluent, Land disposal, Lagoons, Wastewater recycling, Phosphorus removal, Euthrophication, Nutrient cycling, Groundwater hydrology, Surface hydrology, Human pathogens, Photosynthesis, Solar energy, Water quality Management	Algae, Aquatic plants, Old field ecosystems, Fish, Michigan State University, Forage, Forest ecosystems	

18. DISTRIBUTION STATEMENT Release Unlimited, Chicago, Region V, U.S. EPA NTIS-Springfield, Virginia 22161	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 154
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

☆ U.S. GOVERNMENT PRINTING OFFICE 1979-652-3