United States
Environmental Protection
Agency

Municipal Environmental Research
Laboratory
Cincinnati OH 45268

EPA-600/2-80-127
August 1980

Research and Development

EPA

Maximum Utilization of Water Resources in a Planned Community

Eutrophication Potential of Surface Waters in a Developing Watershed

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into nine series. These nine broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The nine series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies
6. Scientific and Technical Assessment Reports (STAR)
7. Interagency Energy-Environment Research and Development
8. "Special" Reports
9. Miscellaneous Reports

This report has been assigned to the ENVIRONMENTAL PROTECTION TECHNOLOGY series. This series describes research performed to develop and demonstrate instrumentation, equipment, and methodology to repair or prevent environmental degradation from point and non-point sources of pollution. This work provides the new or improved technology required for the control and treatment of pollution sources to meet environmental quality standards.

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

EPA-600/2-80-127
August 1980

MAXIMUM UTILIZATION OF WATER RESOURCES IN A PLANNED COMMUNITY

Eutrophication Potential of Surface Waters in a Developing Watershed

by

C. H. Ward and J. M. King
Department of Environmental Science
and Engineering
Rice University
Houston, Texas 77001

Grant No. 802433

Project Officers

Richard Field
Anthony N. Tafuri
Storm and Combined Sewer Section
Wastewater Research Division
Municipal Environmental Research Laboratory (Cincinnati)
Edison, New Jersey 08817

MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

DISCLAIMER

This report has been reviewed by the Municipal Environmental Research Laboratory, U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research· a most vital communications link between the researcher and the user community.

This project focuses on methods of maximizing the use of water resources in a planned urban environment, while minimizing their degradation. Particular attention was directed toward determining the biological, chemical, hydrological, and physical characteristics of stormwater runoff and its corresponding role in the urban water cycle.

Francis T. Mayo, Director
Municipal Environmental Research
Laboratory

PREFACE

The overall goal of this research was to evaluate the water resource plan for The Woodlands, Texas, and to make recommendations, as necessary, to maximize its effective utilization through alterations in design and management. Any recommended alterations were to be critically evaluated as to their compatibility with the natural environment.

Collection and utilization of stormwater runoff for recreational and aesthetic purposes was a major feature of the water resources plan at The Woodlands. Control of downstream flooding was also of great importance and so storage reservoirs, in the form of recreational lakes and wet weather ponds, were created by the developers. Water quality was a concern if the impoundments were to be aesthetically appealing and/or suitable for recreation. Therefore, a major sampling and analytical program was designed to monitor water quality and quantity at different locations in the developing area. The Storm Water Management Model (SWMM) provided the focal point for combining the water quality and quantity data into a predictive tool for design and management purposes.

SWMM was originally developed for highly urbanized areas and, therefore, was calibrated for this project in an urban watershed (Hunting Bayou). Subsequently, SWMM was modified to model runoff and water quality from natural drainage areas, such as The Woodlands. Because of the lag in the construction schedule at The Woodlands, the dense urban areas were not completed during the project period. Consequently, Hunting Bayou and other urban watersheds were sampled to provide a basis for predicting pollutant loads at The Woodlands in the fully developed state.

Water analyses included many traditional physical, chemical, and biological parameters used in water quality surveys. Pathogenic bacteria were also enumerated since the role of traditional bacterial indicators in stormwater runoff was not clear. Algal bioassay tests on stormwater were conducted to assess the eutrophication potential that would exist in the stormwater impoundments. The source, transport, and fate of chlorinated hydrocarbons in stormwater runoff were also investigated.

Several of the large Woodlands impoundments will receive reclaimed wastewater as the major input during dry weather.

Besides their use as a source of irrigation water, the lakes will be used for non-contact recreation--primarily fishing and boating. Because the reclaimed wastewater must be disinfected, there was a concern about disinfectant toxicity to the aquatic life in the lakes. Consequently, comparative fish toxicity tests were conducted with ozone and chlorine, the two alternatives available at the water reclamation plant.

Porous pavement was considered by the developers as a method for reducing excessive runoff due to urbanization and an experimental parking lot was constructed. Hydraulic data were collected and used to develop a model compatible with SWMM, to predict the effects of using porous pavement in development. Water quality changes due to infiltration through the paving were also determined.

Hopefully, the results of this project will contribute in a positive way to the development of techniques to utilize our urban water resources in a manner more compatible with our cherished natural environment.

ABSTRACT

The monthly occurrence and distribution of algae in 15 aquatic habitats in The Woodlands were studied over a 33-month period. The majority of the 140 identified species were members of the Chlorophyta, while the least number of species belonged to the Pyrrophyta. Most of the algal species were not indigenous to one collection site, thus a rather diverse algal flora was found throughout The Woodlands watershed. Differences in total algal species were due, primarily, to changes in the numbers of green algal species present in the various habitats.

Seventy-nine species of algae were identified from Panther Branch. However, species composition was not uniform along this stream due to inflow of water from Bear Branch, the Conference Center Lakes, and wet weather ponds. The algal standing crops in both the headwaters and lower regions of Panther Branch were dominated by euglenoids and/or diatoms. Also, there was a significant increase in algal numbers between the headwaters and lower portions of Panther Branch. During periods of low flow, phosphorus was the single most limiting nutrient for algal growth in this stream. However, additions of nitrogen to stormwater runoff from Panther Branch stimulated algal growth to a greater extent than phosphorus additions.

Forty-nine species of algae were identified from the Conference Center Lakes. During the study period, the largest change in species composition occurred in the Chlorophyta, which resulted in a final dominance by these algae instead of euglenoids. The algal standing crops of Lake B fluctuated dramatically over a two-year period and dominance of algal numbers varied with seasonal fluctuations of species in the various algal groups. Nutrient limitation studies showed that phosphorus additions to low-flow water increased algal cell yields, while yields in stormwater samples were increased by nitrogen additions.

Species representing 52 algal genera were identified from surface soils collected from 25 disturbed and 26 undisturbed sites in The Woodlands. Undisturbed soils had more diverse algal populations, but smaller standing crops, than disturbed soils, even though concentrations of nitrogen and phosphorus were higher than in most disturbed soils. Disturbance of soil and changes in soil pH were primary factors which influenced algal distribution. Soil disturbance caused development of more

diverse blue-green algal flora, due to accompanying increases in soil pH. Decreased soil pH favored dominance by green algae. Standing crops of algae decreased with soil depth at three undisturbed collection sites and algae were not present below a depth of 30 cm. Bioassays showed that phosphorus was the nutrient most limiting for algal growth in water leachates of soils.

During the 33 months of study, rather extensive stands of aquatic vascular plants developed in the littoral zones of the Conference Center Lakes, primarily in Lake B and to a lesser extent in Lake A.

This report was submitted in fulfillment of Grant No. 802433 under the sponsorship of the U.S. Environmental Protection Agency. This report covers a period from July 1973 to December 1976.

CONTENTS

FIGURES

TABLES

ACKNOWLEDGMENTS

This project was supported by the U.S. Environmental Protection Agency, The Woodlands Development Corporation, and Rice University. The excellent technical assistance of Mrs. G. A. T. Fortenberry is greatly appreciated. Also, Dr. Frank Roe is acknowledged for providing stormwater runoff samples and chemical data.

The authors also express their sincere gratitude to the EPA Project Officers, Anthony Tafuri and Richard Field.

SECTION 1

INTRODUCTION

GENERAL STATEMENT

Eutrophication may be broadly defined as nutrient enrichment that results in high biological productivity and a decreased volume within an ecosystem. In undisturbed lakes, eutrophication is a natural "aging" process and eventually culminates in the disappearance of the lake itself. However, addition of excessive quantities of nitrogen and phosphorus to aquatic ecosystems often accelerates eutrophication and poses a serious problem in water quality management. Municipal sewage (1,2,3), agricultural drainage (4), managed forestland drainage (5), and edaphic fertilization often promote eutrophication by enhancing the growth of bacteria, algae, and aquatic vascular plants. Population densities of these organisms often reach nuisance proportions and interfere with the esthetic qualities of water resources. Scums of algae and excessive growth of aquatic macrophytes discourage boating and swimming activities. Algal "blooms" discolor and impart unsatisfactory tastes to the water (1,6,7), excrete toxins into the water (8,9,10), clog filters (11), and upon decomposition produce foul odors (1,7). Anoxic conditions, formed by rapid decomposition of algae, may also result in later summer fish kills (7). Accordingly, values of lake properties may depreciate and, as Palmer (7) has reported, there are increased burdens on municipal water systems due to additional costs incurred in the filtration and deodorization of the water.

The literature on eutrophication is voluminous and often contradictory. Several reviews are available (12,13,14,15,16) and no attempt will be made to review the entire literature in this report. Most limnological studies have been either on lakes that were or were not eutrophic at the time of study and few investigations have continued long enough to follow changes in the trophic status of lakes. Even fewer studies have been initiated on a drainage system before the construction of lakes; thus, complete developmental histories of the water resources of a particular watershed are lacking.

Sewage effluent is a prime contributor of nitrogen and phosphorus to waterways. Also, significant quantities of these elements may be transported to aquatic ecosystems from watersheds. If the watershed is used for urban purposes, the role of surface runoff becomes ecologically more critical since urbanization increases the amount of nitrogen and phosphorus discharged to surface waters (17,18,19,20). However, there seems to be conflicting opinions on the stimulatory effects of urban runoff on algal growth (21,22,23).

The Woodlands, a planned new community located north of Houston, Texas, is an ideal location for investigating the impact of urbanization on the water resources of a particular drainage system. Since two small recreational lakes in The Woodlands will receive treated and untreated stormwater and treated sewage effluent, they are being used as natural biological reactors for comparing water qualities before and after community development. Likewise, Panther Branch, which drains the major portion of The Woodlands, is being investigated to determine the eutrophication potentials of low-flow water and stormwater runoff as urbanization increases in the watershed. Data from the study of Panther Branch can also be used to assess the impact of The Woodlands on dowstream receiving waters. Chemical analyses are being utilized to ascertain quantities of nutrients which are present in these aquatic ecosystems. Controlled nutrient limitation studies are being used to obtain information on possible limiting nutrients for algal growth. Thus, accurate description of expected water quality, combined with detailed knowledge of the indigenous aquatic flora, should permit formulation of strategies for water management. These strategies may then be employed in controlling eutrophication in a larger recreational lake which is being constructed in The Woodlands.

RESEARCH OBJECTIVES

The following research objectives were assigned to this project:

1. Characterization of algal populations in The Woodlands watershed. Utilization of this baseline data in assessing the influence of urbanization on diversity, distribution, and standing crops of algae in the lentic and lotic habitats of The Woodlands.

2. Determine which physicochemical parameters significantly influence changes in natural algal populations in aquatic ecosystems of The Woodlands.

3. Determine which nutrient is most limiting for algal growth in stormwater runoff and low-flow water from various sites in The Woodlands.

4. Identification of aquatic vascular plants and their distribution in The Woodlands.

5. Determine the impact of urbanization on the edaphic algal population in The Woodlands.

PROJECT OVERVIEW

From October, 1973, to May, 1976, a concerted effort was made to evaluate the impact of urbanization on the aquatic flora in The Woodlands. Several aquatic habitats were sampled on a regular basis to identify factors which influence algal population dynamics. Nutrient limitation studies were conducted to determine which nutrient was most limiting for algal growth during conditions of low flow and stormwater runoff. Water from Hunting Bayou and Westbury Square, developed communities near Houston, Texas, were used in bioassay experiments. The impact of urbanization on edaphic algal populations was also determined.

SECTION 2

CONCLUSIONS

The physicochemical parameters in the aquatic habitats of The Woodlands were not selective for growth and dominance by only a few algae. The algal associations encountered were indicative of oligotrophic or slightly mesotrophic waters.

The algal populations in Panther Branch are not uniform in species composition and collections from one site would not be indicative of the total algal populations of the stream.

Changes in NH_4-N influenced all algal populations in the segment of Panther Branch between sites P-10 and P-30.

The development of standing crops of phytoplankton in Panther Branch is influenced to a large extent by stream flow rates.

Phosphorus is the limiting nutrient for algal growth in the Conference Center Lakes and Panther Branch during low flow, while nitrogen is more limiting than phosphorus for algal growth in stormwater samples. Thus, operation of the phosphorus precipitation system could be suspended during periods of high flow, since phosphorus is flushed from aquatic habitats in The Woodlands during this time. However, there is the potential that phosphorus transported from The Woodlands may accumulate in downstream receiving waters and cause eutrophication. A savings in water treatment costs of $500 to $1,200 per day or about $50,000 per year, depending on the number of rainy days, could be achieved by this program.

Disturbance of land in The Woodlands is accompanied by decreases in the diversity of species and increases in numbers of edaphic algae. Fertilization of the soil and increased soil pH result in larger standing crops of blue-green algae and diatoms. Thus, surface runoff from fertilized soils serves as a source of nutrients and troublesome algae.

The littoral zones of the Conference Center Lakes are developing rather extensive growths of aquatic vascular plants. If these plants are not managed properly, they will completely encompass these lakes.

SECTION 3

RECOMMENDATIONS

A water quality management program should be instituted to insure proper maintenance of the aquatic ecosystems in The Woodlands. The first flush of nutrients during storm events should be captured or diverted and treated before release into Panther Branch or the Conference Center Lakes. Homeowners and golf course managers should be encouraged to select and apply fertilizers with caution, since excessive, long-term fertilization could result in nutrient buildups in aquatic systems of The Woodlands.

The wet weather ponds and marshes in The Woodlands should be managed since they often overflow into Panther Branch. Excessive concentrations of algae and nutrients in these habitats would ultimately affect the water quality of Panther Branch and its downstream receiving waters, especially if Panther Branch water is utilized to control water levels in preexisting and future lakes.

Nutrient concentrations and detention times in the Conference Center Lakes should be controlled in order to prevent excessive concentrations of algae. Treated sewage effluent and/or well water could be used to periodically flush these lakes and dilute algal nutrients.

The aquatic vascular plants should be managed in order to prevent them from totally encompassing the Conference Center Lakes. This might be accomplished by increasing the slopes of the littoral zones and/or by harvesting and removal of the plants.

A long-term program should be established to monitor nutrient levels and algal concentrations in The Woodlands. This would allow identification of potential water management problems and formulation of corrective strategies.

SECTION 4

EXPERIMENTAL PLAN

PANTHER BRANCH

The following research program was used to assess the impact of increasing urbanization on algal population dynamics in Panther Branch:

1. Diversity and standing crops of algae were determined on a seasonal basis at several collection sites along Panther Branch. Data collected above and below the major area of construction in The Woodlands were compared in order to determine the influence of urbanization on abundance and transport of algae in this stream. Temporal and spatial changes in both algae and physicochemical parameters were compared (single and multiple regressions) to determine which factors significantly influenced algal populations in Panther Branch.

2. Algal bioassays were conducted with water collected from Panther Branch to determine whether nitrogen and/or phosphorus was the limiting nutrient for algal growth. Low-flow water and stormwater runoff were used to compare possible limiting nutrients above and below The Woodlands construction area. Bioassays with water collected on a diurnal basis at two sites in Panther Branch allowed determination of temporal and spatial changes in limiting nutrients.

3. For comparative purposes, standing crops and diversity of algae were studied at a collection site in Spring Creek. Water from this site was also used in algal bioassays similar to those conducted for Panther Branch samples.

CONFERENCE CENTER LAKES (A & B)

The following research program was followed for assessing the impact of urbanization of the Conference Center Lakes in The Woodlands:

1. Algal population dynamics were investigated on a seasonal basis in the Conference Center Lakes,

particularly Lake B. Data on algal standing crops were correlated with physicochemical parameters for identification of factors which significantly influenced the algal populations.

2. Algal bioassays with low-flow water and stormwater runoff from the lakes were conducted to determine which nutrient(s) was limiting for algal growth.

3. The aquatic vascular plants were surveyed and their distribution in the lakes noted.

WET WEATHER PONDS

For comparative purposes, three wet weather ponds in The Woodlands area were studied according to the following program:

1. Standing crops and species diversities of algae were determined on a seasonal basis.

2. Aquatic vascular plants were surveyed to determine their distribution in The Woodlands.

EDAPHIC ALGAE

The impact of urbanization on edaphic algal populations in The Woodlands was determined as follows:

1. Diversity and standing crops of algae were determined in undisturbed and disturbed soils (fertilized and unfertilized) and as a function of soil depth.

2. Concentrations of potential soil nutrients were determined from water leachates. Data were correlated with the algal data to identify factors which influenced the distribution of edaphic algae.

3. Soil leachates were used in algal bioassay studies to determine the limiting nutrient for algal growth if the soil was inundated.

SECTION 5

RESULTS AND DISCUSSION

ALGAL POPULATIONS IN THE WOODLANDS WATERSHED

Water samples for algal studies were collected from fifteen sites in The Woodlands area (Figures 1 and 2). Monthly samples were collected at the sites on Panther Branch during the first year of study and then at random time intervals for the remainder of this investigation. Monthly samples were collected for three years from Lake B and at random intervals from Lake A. A description of each collection site is provided in Table 1.

From October, 1973 to April, 1976, 140 species of algae were collected and identified from Panther Branch, Spring Branch, Lake B, and three wet weather ponds (Table 2). Seventy-seven species (55%) were present at more than one site, while 26 species (18.6%) were found at all sites. Thirty-seven species (26.4%) were collected from only one site, and 21 of these algae were found in one of the wet weather ponds (site GP). Thus, most of the algal species were not indigenous to one aquatic system and contributed to a rather diverse algal flora in The Woodlands area. Primary emphasis was placed on analyses of stream and lake phytoplankton, since preliminary studies indicated sparse populations of attached algae. Also, phytoplankton represent those algae most consistently transported in aquatic habitats and the most likely to have sustained impact on downstream receiving waters.

The algal populations at the various collection sites, especially GP, were composed of diverse assemblages of green algae. Of the total number of algae identified, 65.7% were green algae, 10.7% were blue-greens, 11.4% were chrysophytes, 11.4% were euglenoids, and 0.7% were dinoflagellates. With the exception of the Chlorophyta, the number of species in the various algal divisions did not vary significantly from one site to another (Table 2). Differences in total algal species were influenced primarily by changes in the number of green algae present at the various sites.

The algal associations encountered in The Woodlands are indicative of oligotrophic waters (24). Since the algal populations were relatively diverse, these aquatic ecosystems were not under stresses which selectively favored the presence of only a

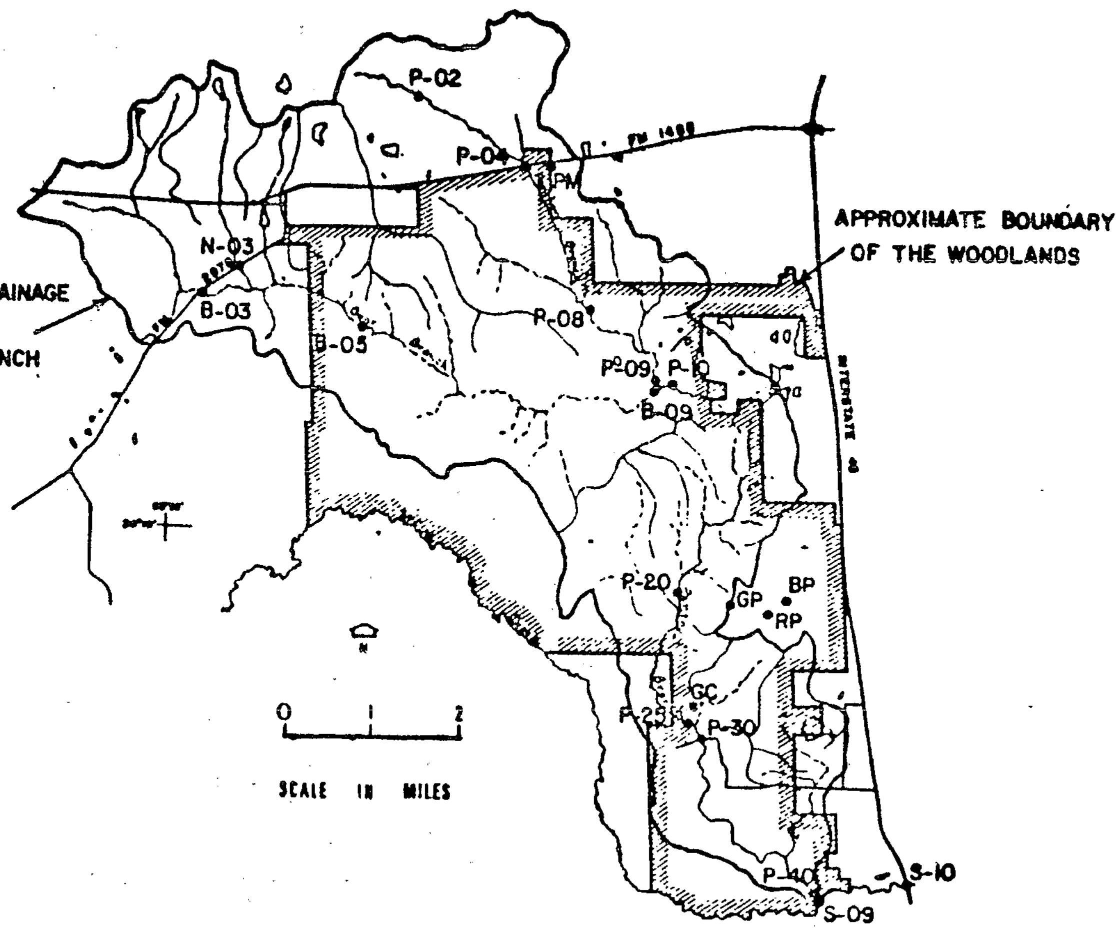

Figure 1. Location of aquatic collection sites.

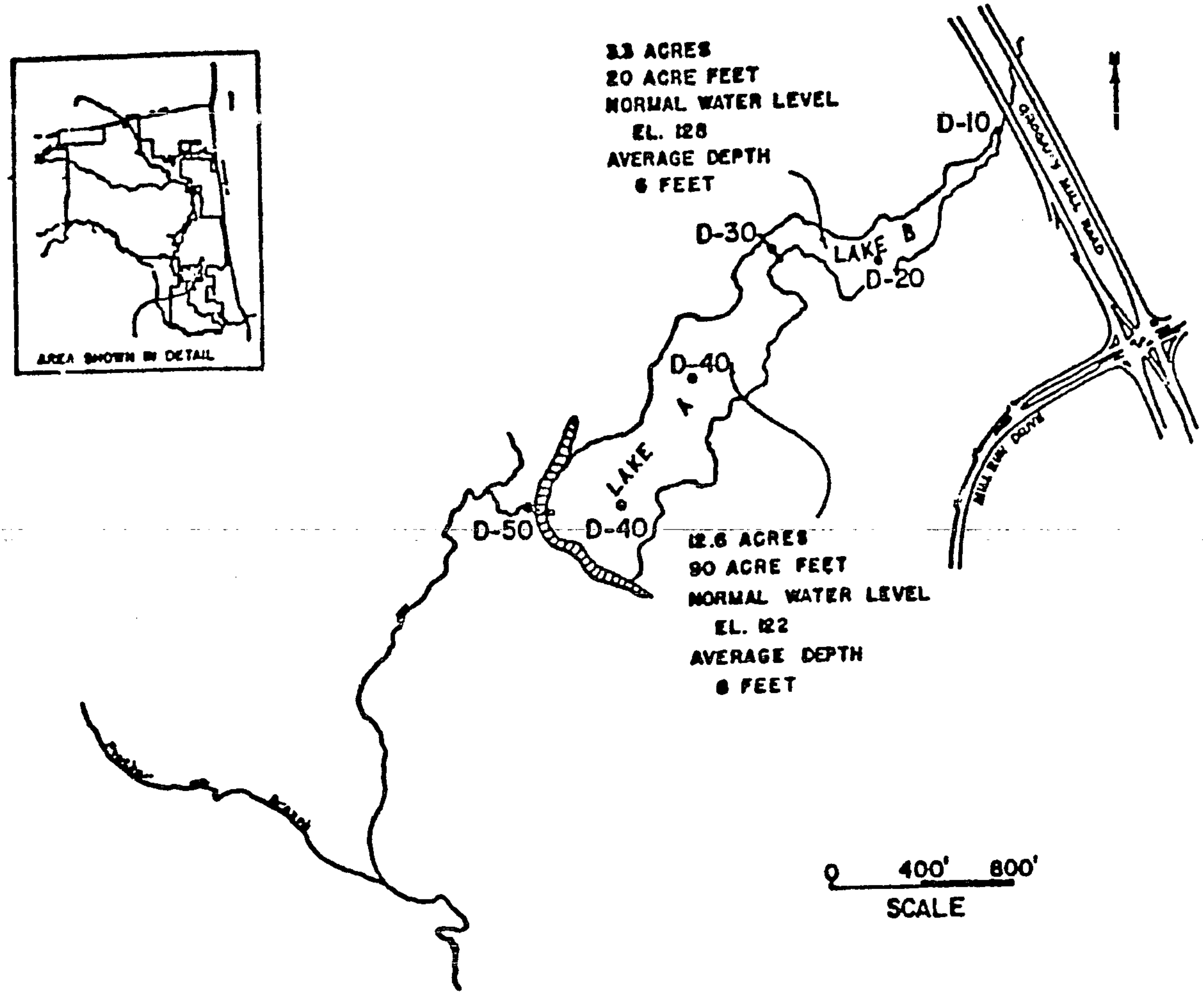

Figure 2. Location of collection sites on Conference Center Lakes.

TABLE 1. LOCATION DESCRIPTIONS OF AQUATIC COLLECTION SITES

Sites	Location
P-01	Panther Branch, vicinity FM 1488.
P-09	Panther Branch, 100 feet upstream of confluence with Bear Branch.
P-10	Panther Branch, 500 feet downstream of confluence with Bear Branch.
P-20	Panther Branch, 1 mile upstream from Station P-30.
P-25	Panther Branch, 1/4 mile upstream from Station P-30.
P-30	Panther Branch, U.S.G.S. Gauging Station at Sawdust Road.
P-40	Panther Branch, 100 feet upstream of confluence with Spring Creek.
S-09	Spring Creek, 100 feet upstream of confluence with Panther Branch.
S-10	Spring Creek, vicinity Interstate 45 at U.S.G.S. Gauging Station.
PM	Wet Weather Pond, vicinity FM 1488.
RP	Wet Weather Pond, entrance to Woodlands on old Robinson Road.
GP	Wet Weather Pond, vicinity of old Robinson Road entrance.
LB	Lake B, Conference Center.
BP	Small pond, Robinson Road entrance.
GC	Watertrap, golf course near P-25.

TABLE 2. SUMMARY OF ALGAE DISTRIBUTION IN THE WOODLANDS

	Collection Site[d]					
Division	PB	SB	GP	RP	PM	LB
Chlorophyta (92)[a]	43[b] (54.4)[c]	19 (35.8)	67 (67)	30 (53.6)	52 (59.8)	21 (42.9)
Cyanophyta (15)	8 (10.1)	7 (13.2)	10 (1.0)	5 (8.9)	10 (11.5)	6 (12.2)
Chrysophyta (16)	12 (15.2)	12 (22.6)	9 (9)	10 (17.9)	10 (11.5)	10 (20.4)
Euglenophyta (16)	15 (19.0)	14 (26.4)	13 (13)	11 (19.6)	14 (16.1)	12 (24.5)
Pyrrophyta (1)	1 (1.3)	1 (2.0)	1 (1)	-	1 (1.1)	-
Total (140)	79	53	100	56	87	49

[a] Total species/division; [b] Number species/site; [c] % of total species/site;
[d] Refer to Figure 1 for site location

few species. However, major perturbations of the systems would probably result in species composition changes and seasonal dominance would be assumed by blue-green algae, dinoflagellates, or certain species of diatoms (24). Studies also indicate the presence of most algal species throughout the year, even though numbers fluctuate on a seasonal basis.

PANTHER BRANCH--WATER QUALITY

Monthly water quality parameters for sites P-10 and P-30 are presented in Figures 3 and 4, respectively. All of the water quality data collected in The Woodlands project are presented in Stormwater Runoff Quality: Data Collection, Reduction and Analysis (25). The pH at both sites was usually in the acidic range, except in the second year when the pH at P-30 steadily increased toward the alkaline range. This was due, in part, to inflow of treated sewage effluent and golf course drainage into Panther Branch above site P-30. Variation in temperature and dissolved oxygen followed a seasonal pattern with higher dissolved oxygen concentrations and lower temperatures prevailing in winter. Fluctuations in discharge were relatively similar for both sites but the magnitude of discharge was higher at P-30. The relatively high concentrations of suspended solids at P-10 in May and June of the first year were due to construction of a U.S.G.S. gauging station at this site. During construction, a relatively stagnant pool of water formed above P-10 and developed a dense growth of *Oedogonium*. Concentrations of suspended solids were higher at P-30 than at P-10, especially during the first year when construction activities and watershed disturbance were at their maximum.

Levels of NH_4-N, O-PO_4, and NO_3-N fluctuated significantly at both sites. Concentrations of NH_4-N and O-PO_4 were higher at P-30, while significant long-term differences in NO_3-N or NO_2-N levels were not noted at either site. Levels of O-PO_4 were high during the first year, but diminished in the second year of study. Concentrations of NH_4-N and NO_3-N, especially at P-10, fluctuated throughout both years and remained relatively high at both sites. Nitrogen and phosphorus concentrations at P-10 were influenced by inflow of water from marshes located above this site, while P-30 water quality was influenced by drainage from the golf course and construction areas in The Woodlands and inflow of treated sewage effluent.

Table 3 represents the average yearly values for various physicochemical parameters at various sites along Panther Branch. With few exceptions, concentrations of O-PO_4, NH_4-N, NO_2-N, and suspended solids at each site were either similar for both years or decreased during the second year of study. However, with the exception of NO_2-N, there were increased concentrations of these elements at P-30 during both years. Concentrations of NO_3-N increased along the course of Panther Branch

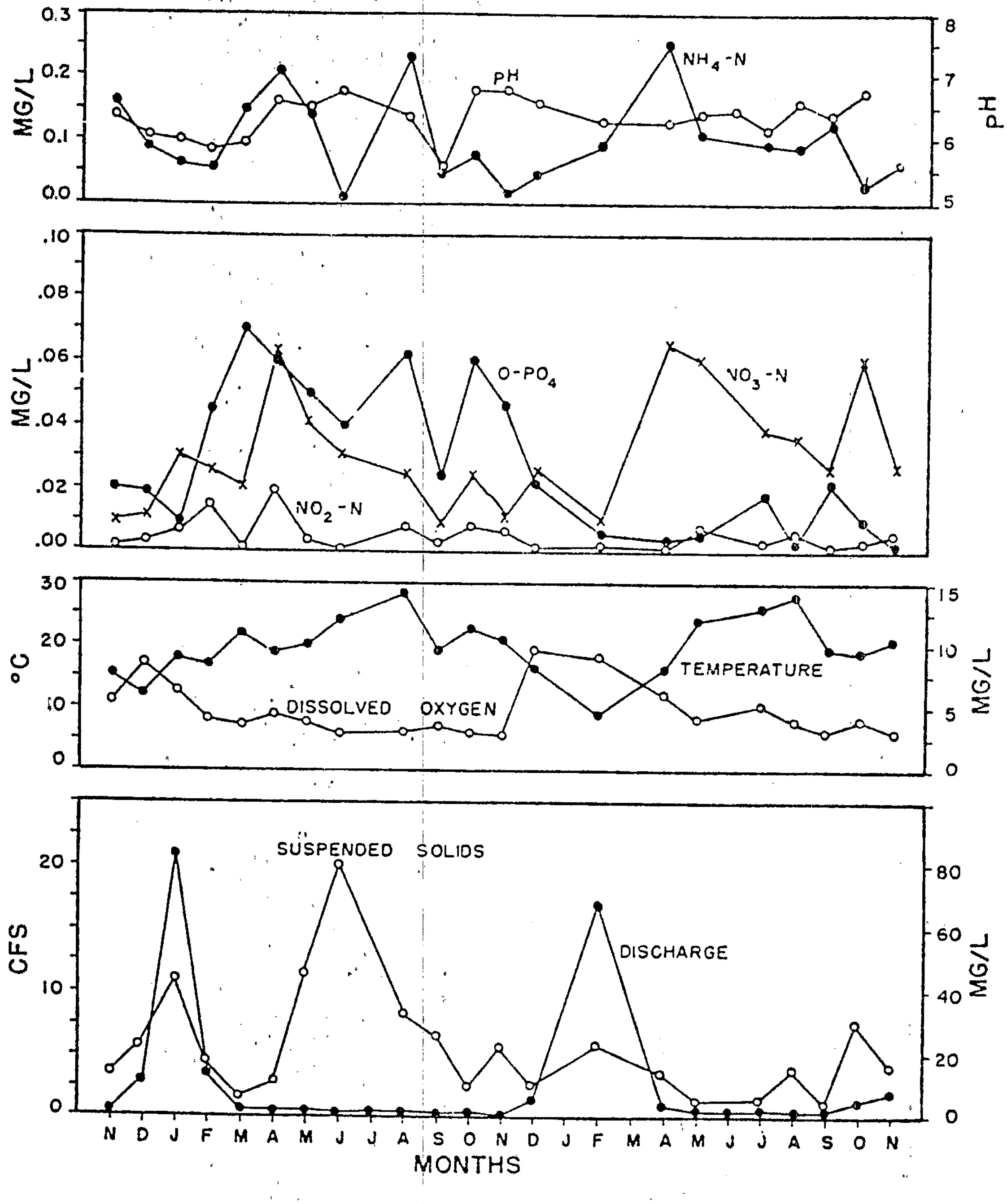

Figure 3. Seasonal changes in physicochemical parameters at P-10 in Panther Branch.

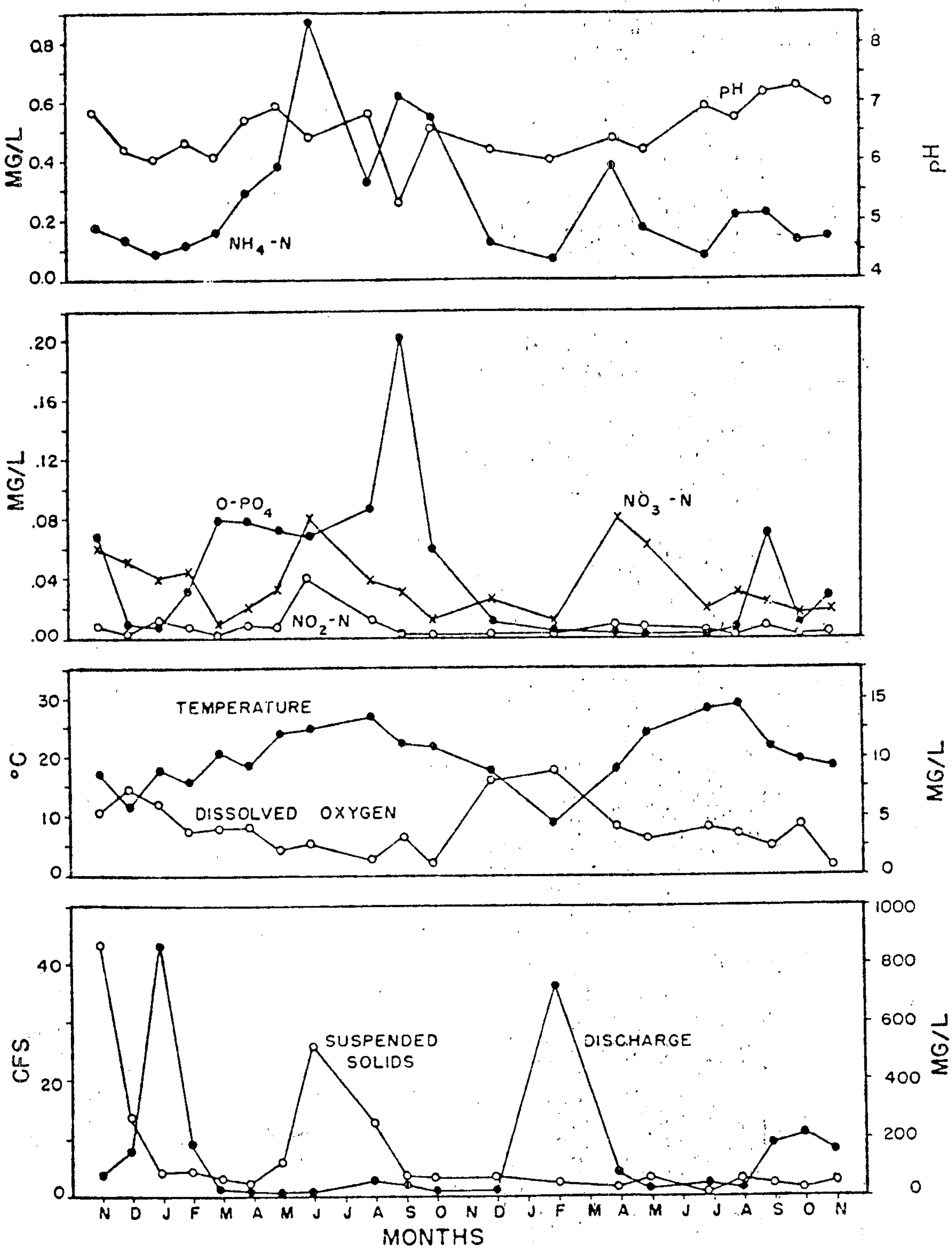

Figure 4. Seasonal changes in physicochemical parameters at P-30 in Panther Branch.

TABLE 3. AVERAGE YEARLY VALUES FOR PHYSICOCHEMICAL PARAMETERS AT VARIOUS SITES ALONG PANTHER BRANCH

SITE Year	PHYSICOCHEMICAL PARAMETERS							
	O-PO_4 (mg/l)	NH_4-N (mg/l)	NO_2-N (mg/l)	NO_3-N (mg/l)	Suspended Solids (mg/l)	pH	DO (mg/l)	Temp. (°C)
P-10								
74	0.045	0.096	0.007	0.027	27.9	6.4	4.1	20.9
75	0.008	0.104	0.003	0.039	13.5	6.5	4.9	20.4
P-20								
74	0.058	0.192	0.006	0.015	81.5	6.6	2.9	23.0
75	0.110	0.106	0.006	0.030	22.7	6.4	5.7	20.5
P-25								
74	0.159	0.259	0.010	0.027	120.3	6.7	3.3	22.0
75	0.005	0.117	0.005	0.035	46.2	6.5	6.6	22.5
P-30								
74	0.072	0.322	0.010	0.036	107.1	6.3	3.9	20.6
75	0.017	0.168	0.006	0.076	45.8	6.6	4.1	21.2
P-30 - P-10								
74	0.027	0.226	0.003	0.009	79.2	-0.1	-0.2	-0.3
75	0.009	0.064	0.003	0.037	32.3	+0.1	-0.8	+0.9

during both years, with the largest increase occurring in the second year. Dissolved oxygen concentrations were relatively uniform, but were generally higher in the second year. There was, however, a lower average dissolved oxygen concentration at P-30 than at P-10. Temperature and pH were relatively uniform at both sites during both years. Aberrations in average concentrations of physicochemical parameters at P-20 were probably due to inflow of water from the Conference Center Lakes. This, combined with inflow of water from marshes and drainage from the golf course, probably resulted in the increased concentrations of nutrients along the course of Panther Branch. Also, massive land disturbance in the watershed in the first year of study probably accounted for the higher concentrations of various nutrients and suspended solids than those noted in the second year.

PANTHER BRANCH--ALGAL POPULATIONS

Seventy-nine species of algae were identified from Panther Branch. Twenty-six species (32.9%) were identified from all sites along Panther Branch, 18 species (22.8%) were present at two collection sites, and 35 species (44.3%) were found at only one site. Thus, the algal populations along Panther Branch are not uniform in species composition and collections from only one site would not be indicative of the total algal populations of the stream.

Site P-01 is located in the headwaters of Panther Branch and often receives overflow water from surrounding marshes and wet weather ponds. Site P-10 is below the confluence of Panther and Bear Branches, while site P-30 is located below the outfall from the Conference Center Lakes. Thus, changes in the number and composition of algae (Table 4) along Panther Branch are probably influenced by entry of water from these sources. Preexisting algal populations may be diluted and new algal species may be added at points of confluence. This latter fact was exemplified by the presence of only two algae (Cocconeis sp., Cosmarium hammeri) in Panther Branch which were not identified from other collection sites in The Woodlands.

Standing crops of algae at sites P-10 and P-30 are presented in Figures 5 and 6, respectively. On a seasonal basis, algal cell numbers fluctuated more at site P-30 than at P-10. The algal standing crops at both sites were dominated primarily by members of the Euglenophyta and green algae were minor components of the total algal populations. Numbers of blue-green algae were comparatively low at both sites, even though they were more numerous at site P-30. A survey of various collection sites along Panther Branch (May, 1974) also indicated that standing crops in this stream were dominated by euglenoids and/or diatoms, while numbers of green algae and blue-green algae were comparatively low (Figure 7). Dominance of this type is indicative of slightly acid streams with high organic carbon content.

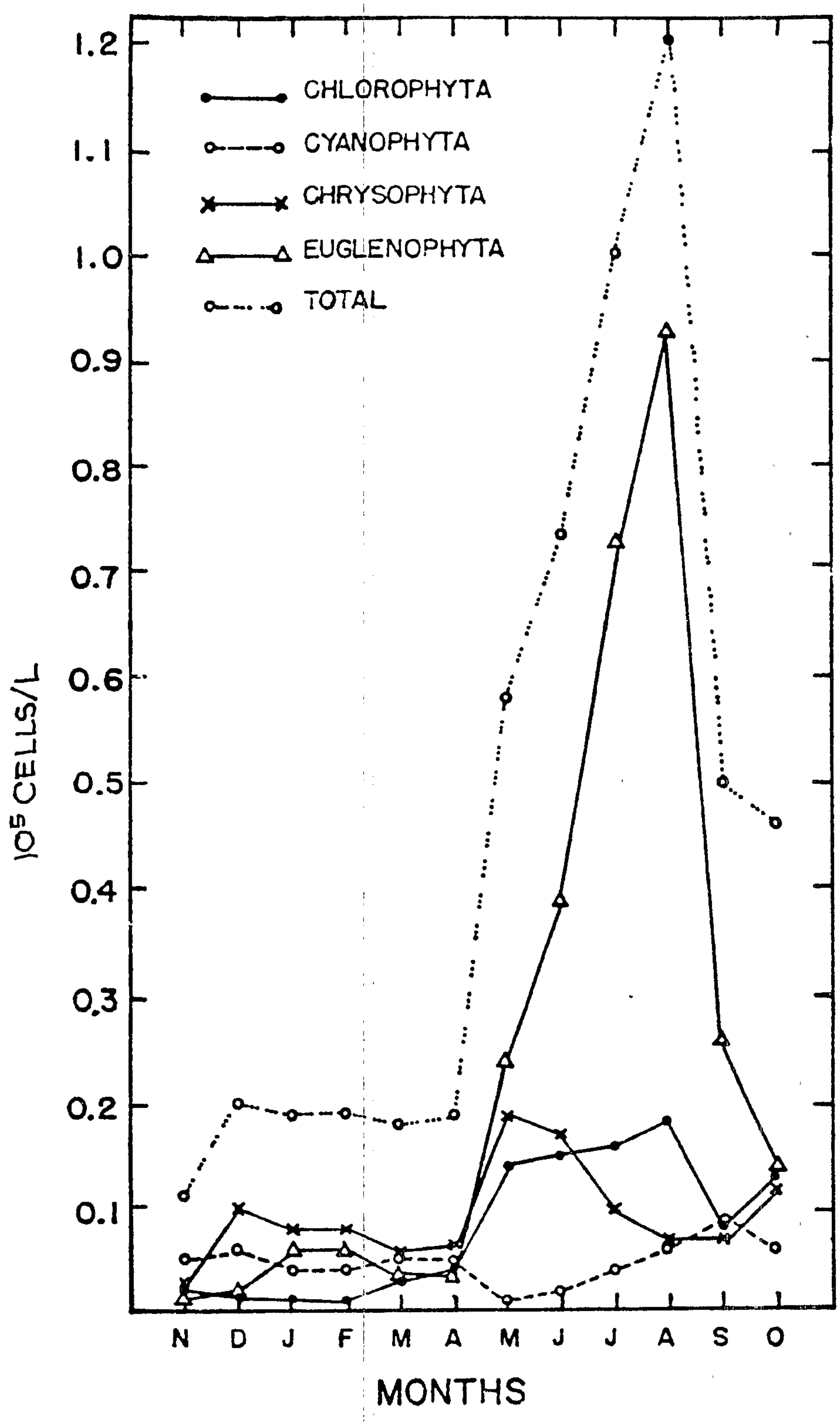

Figure 5. Seasonal algal standing crops at P-10 in Panther Branch.

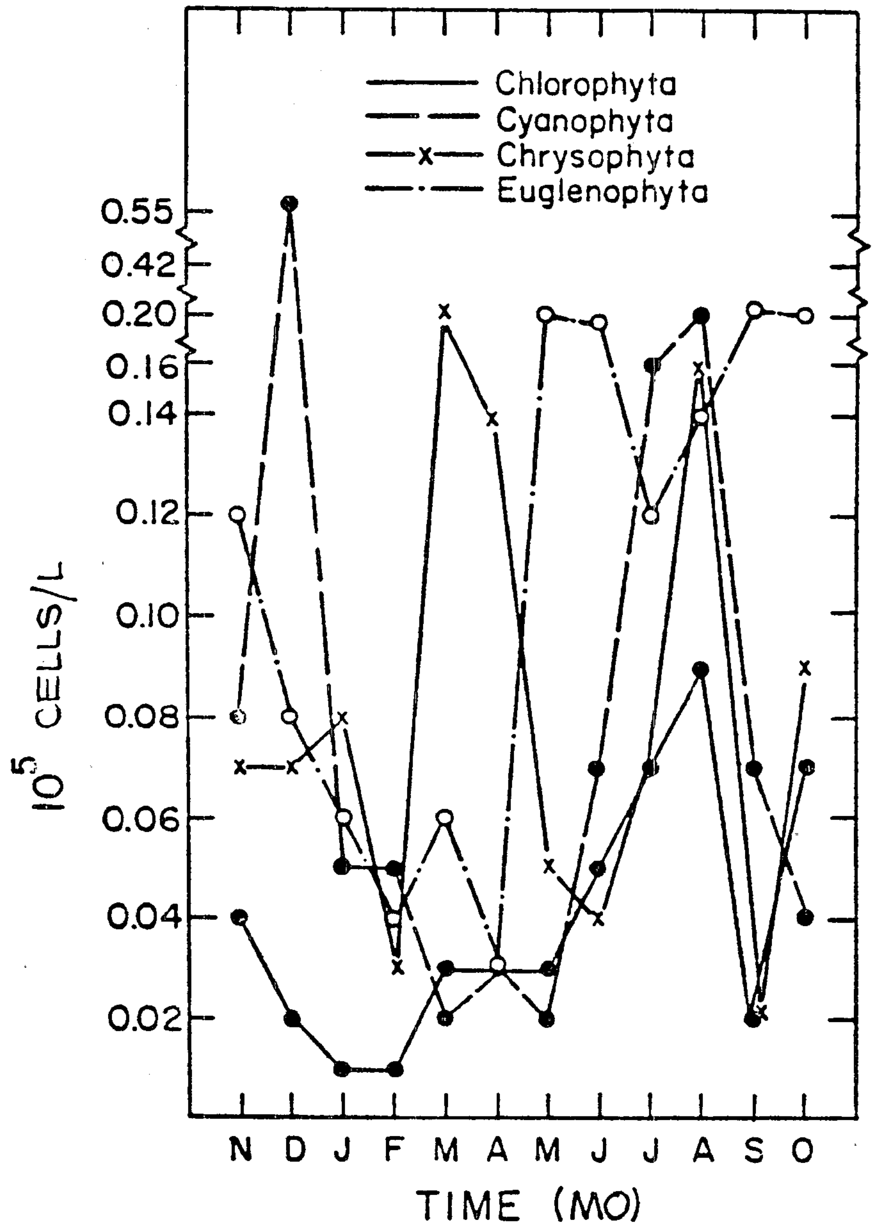

Figure 6. Seasonal algal standing crops at P-30 in Panther Branch.

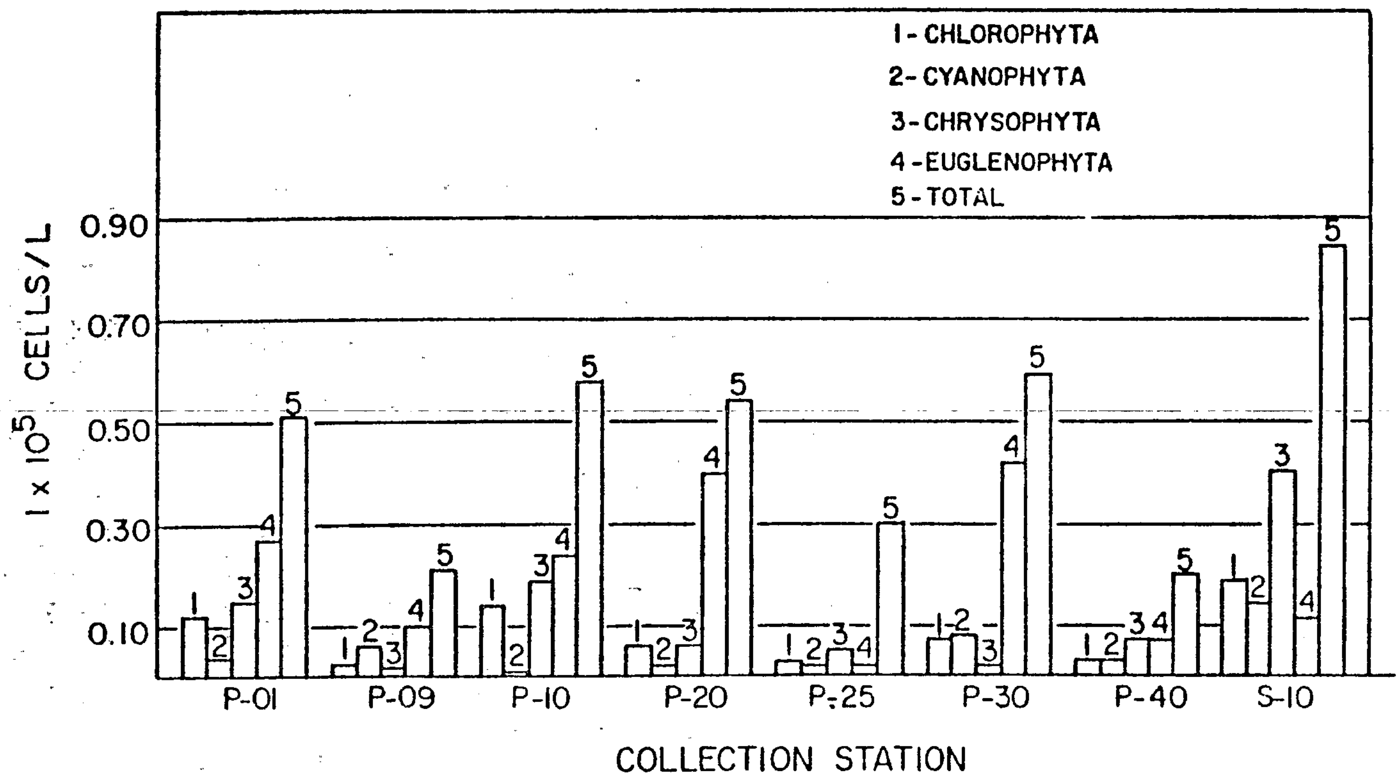

Figure 7. Standing crops of algae at various sites in Panther Branch and Spring Creek.

TABLE 4. DISTRIBUTION OF ALGAL SPECIES AT THREE SITES IN PANTHER BRANCH

Division	Collection Site		
	P-01	P-10	P-30
Chlorophyta	32[a] (54.2)[b]	17 (38.6)	19 (41.3)
Cyanophyta	6 (10.2)	5 (11.4)	6 (13.0)
Chrysophyta	10 (17.0)	8 (18.2)	10 (21.7)
Euglenophyta	10 (17.0)	13 (29.5)	11 (24.0)
Pyrrophyta	1 (1.6)	1 (2.3)	-
Total	59	44	46

[a]number species/site; [b]% of total species/site

The algal standing crops were somewhat higher at P-10 than at P-30. However, data in Figures 5 and 6 represent cells/liter and do not indicate the numbers of algae transported by the stream. Thus, the seasonal mass transport of algae at sites P-10 and P-30 are presented in Table 5. These data showed significant increases in algal cell numbers between P-10 and P-30. Entry of water along this stretch of Panther Branch could have influenced algal standing crops at P-30. Also, increased standing crops were probably due, in part, to cell divisions by the various algal species. The data in Table 5 were converted to mass transport of the total algal population on a dry weight basis by use of a formula derived from data in the literature (26) and from observations in our laboratory. On this basis, 18.3 kg algae/yr were transported by P-10, while 121.0 kg algae/yr were transported by P-30. This represents a change of 103.0 kg algae/yr between the two sites. Assuming that algae are composed of 50% carbon (24), there was a gain of approximately 51.5 kg carbon/yr due to algae.

Multiple regressional analyses showed that the physicochemical parameters in Table 6 were responsible for major variations in algal populations at sites P-10 and P-30. Single regressions indicated no apparent uniformity in factors which influenced algal standing crops at these sites. However, changes

TABLE 5. MASS TRANSPORT (CELLS/YR) OF ALGAE IN PANTHER BRANCH

Division	Collection Site		
	P-10	P-30	P-30 - P-10
Chlorophyta	3.02×10^{12}	6.54×10^{12}	3.52×10^{12}
Cyanophyta	9.08×10^{12}	2.16×10^{14}	2.07×10^{14}
Chrysophyta	1.78×10^{13}	3.53×10^{13}	1.75×10^{13}
Euglenophyta	1.42×10^{13}	3.42×10^{13}	2.00×10^{13}
Total	4.41×10^{13}	2.92×10^{14}	2.48×10^{14}

in NH_4-N influenced changes in all algal populations in the segment of Panther Branch between P-10 and P-30 (Table 7).

The diversity and standing crops of species within a particular algal population are governed by complex interactions between various physicochemical parameters. For example, a change in the concentration of a particular nutrient might result in a dramatic change in the standing crop of only one species. However, regression analyses would indicate variation in the total algal population, when, in fact, the variation was due to only one species. This might account for the relatively low correlations between the physicochemical parameters and algal populations in Tables 6 and 7. It is also possible that some unmeasured parameter was a major factor which controlled changes in algal populations.

PANTHER BRANCH--NUTRIENT LIMITATIONS

The development of standing crops of phytoplankton in Panther Branch is influenced to a large extent by stream flow rates. High-flow rates do not provide adequate detention times for development of large standing crops at any given point along the stream. However, reductions in flow rates and/or pooling in the stream allow detention times suitable for development of large standing crops, provided nutrients are not limiting for algal growth. Development of algal populations in this stream, as in other aquatic ecosystems, is influenced by concentrations and availability of various algal nutrients. This point is not

TABLE 6. SUMMARY FROM REGRESSION ANALYSES OF PHYSICOCHEMICAL PARAMETERS AND ALGAL CELL NUMBERS AT TWO SITES IN PANTHER BRANCH

Physicochemical **Parameters**	**Chlorophyta**		**Cyanophyta**		**Chrysophyta**		**Euglenophyta**	
	P-10	**P-30**	**P-10**	**P-30**	**P-10**	**P-30**	**P-10**	**P-30**
Discharge	.182[a]	.282	.032	.010	.011	.005	.058	.142
NH_4-N	.026	.554	.028	.003	.171	.022	.133	.267
NO_3-N	.022	.001	.206	.583	.074	.427	.001	.052
Suspended Solids	.249	.065	.263	.502	.433	.067	.183	.026
O-PO_4	.013	.000	.007	.179	.009	.048	.004	.234
pH	.266	.209	.276	.043	.141	.006	.035	.001
Temperature	.666	.153	.011	.044	.038	.006	.631	.401
Regression Coefficient R^2 minus O-PO_4	.781	.923	.596	.842	.642	.623	.922	.522
Regression Coefficient R^2 plus O-PO_4	.788	.930	.610	.849	.684	.645	.922	.729

[a] Based on Monthly Averages

TABLE 7. SUMMARY OF REGRESSION ANALYSES OF CHANGES IN PHYSICOCHEMICAL PARAMETERS AND ALGAL CELL NUMBERS BETWEEN SITES P-10 AND P-30 IN PANTHER BRANCH

Physicochemical Parameters	Algal Division			
	Chlorophyta	Cyanophyta	Chrysophyta	Euglenophyta
NH_4-N	.497 [a]	.271	.291	.468
O-PO_4	.445	.016	.219	.042
NO_3-N	.000	.572	.149	.021
Suspended Solids	.034	.523	.000	.018
pH	.166	.001	.013	.270
Discharge	.187	.008	.008	.025
Regression Coefficient (R^2)	.982	.915	.846	.614

[a] Based on Monthly Averages

only pertinent to development of phytoplankton in Panther Branch, but also to aquatic systems which might receive water from this stream. Thus, it is imperative to have some knowledge of which nutrients stimulate algal growth in Panther Branch water. Therefore, algal bioassays were conducted to determine whether nitrogen and/or phosphorus were limiting for algal growth.

During early stages of urbanization in The Woodlands, low-flow water samples from various points along Panther Branch exhibited no significant variations in their ability to support algal growth (Figure 8). Cell yields were increased by additions of both nitrogen and phosphorus to water samples and phosphorus was the most important single limiting nutrient along Panther Branch. The introduction of treated sewage effluent and agricultural runoff into Spring Creek, above sites S-09 and S-10, was probably responsible for the comparatively larger algal yields in water from this stream. A similar study conducted at a later date (September, 1975) indicated that water from site P-25 supported more algal growth than water from other sites along Panther Branch (Figure 9). Cell yields at P-25 were comparable to those obtained with water from S-10 in Spring Creek. This was probably due to the introduction of nutrients into Panther Branch from the surrounding golf course. Reduced algal yields in water for P-30 were probably due to dilution of nutrients by inflow of water from the Conference Center Lakes and a golf course pond. However, it is possible that some toxic material was present in the water or that some nutrient, other than nitrogen or phosphorus, was limiting algal growth. Additions of both nitrogen and phosphorus to water samples increased cell yields, while nitrogen was the single nutrient which most stimulated algal growth at all sites except P-30 and S-10. Additional studies indicated that phosphorus was the limiting nutrient at P-30. Algal growth was also stimulated in water from Panther Branch by removal of turbidity.

Variations in yields of the test alga were also noted in low-flow water collected on a diurnal basis at P-10 (Figure 10). Additions of both nitrogen and phosphorus to the test samples produced the greatest stimulation of algal growth, while enrichment with either nitrogen or phosphorus indicated variable growth stimulation. In a similar study with P-30, water collected during the same diurnal time period produced results similar to those at P-10 (Figure 11). However, phosphorus appeared to be the nutrient most limiting for algal growth in low-flow water from P-30.

Algal bioassays were also conducted with water collected from Panther Branch at various time intervals during the course of storm events. The stormwater runoff collected below the major area of construction in The Woodlands (site P-30) seemed to fluctuate in its ability to support the growth of algae

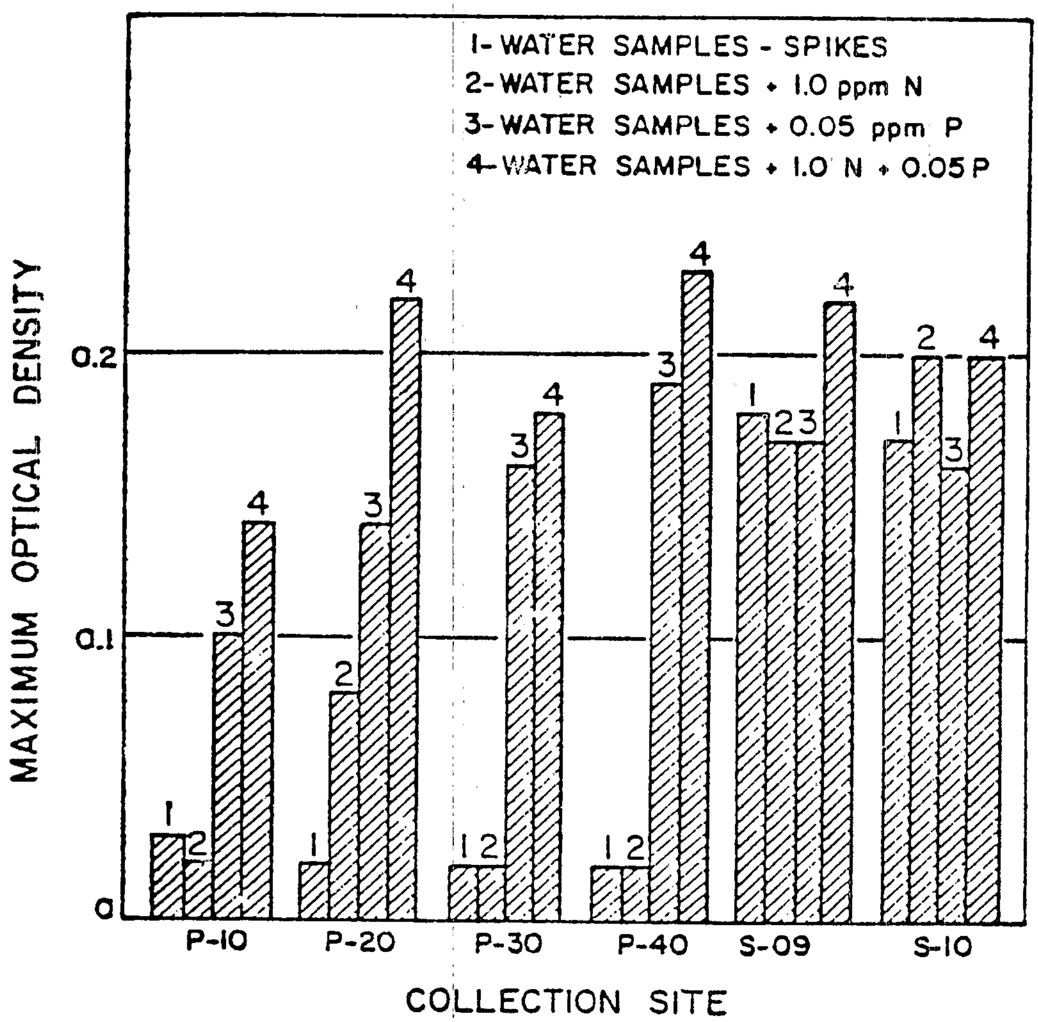

Figure 8. Optical densities of Selenastrum capricornutum after incubation in water from Panther Branch and Spring Creek (May, 1974).

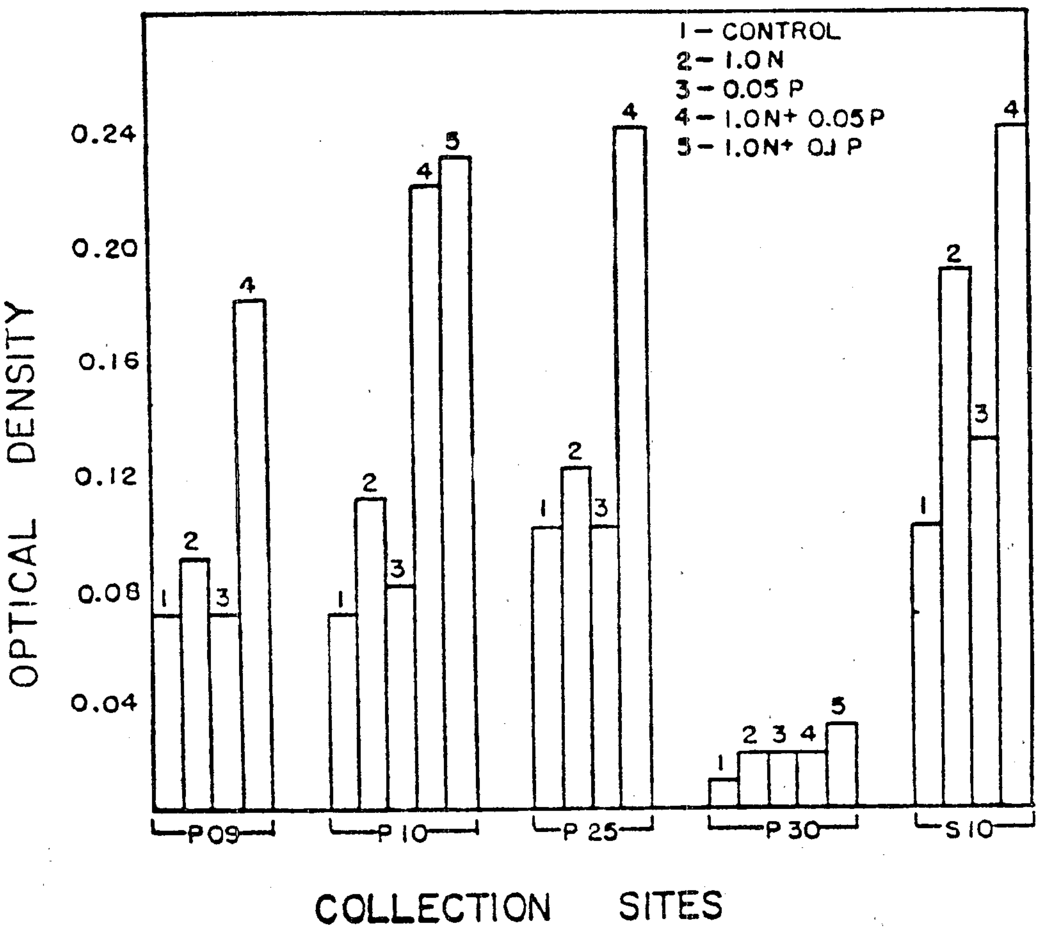

Figure 9. Growth of *Selenastrum capricornutum* in water from Panther Branch and Spring Creek (September, 1975).

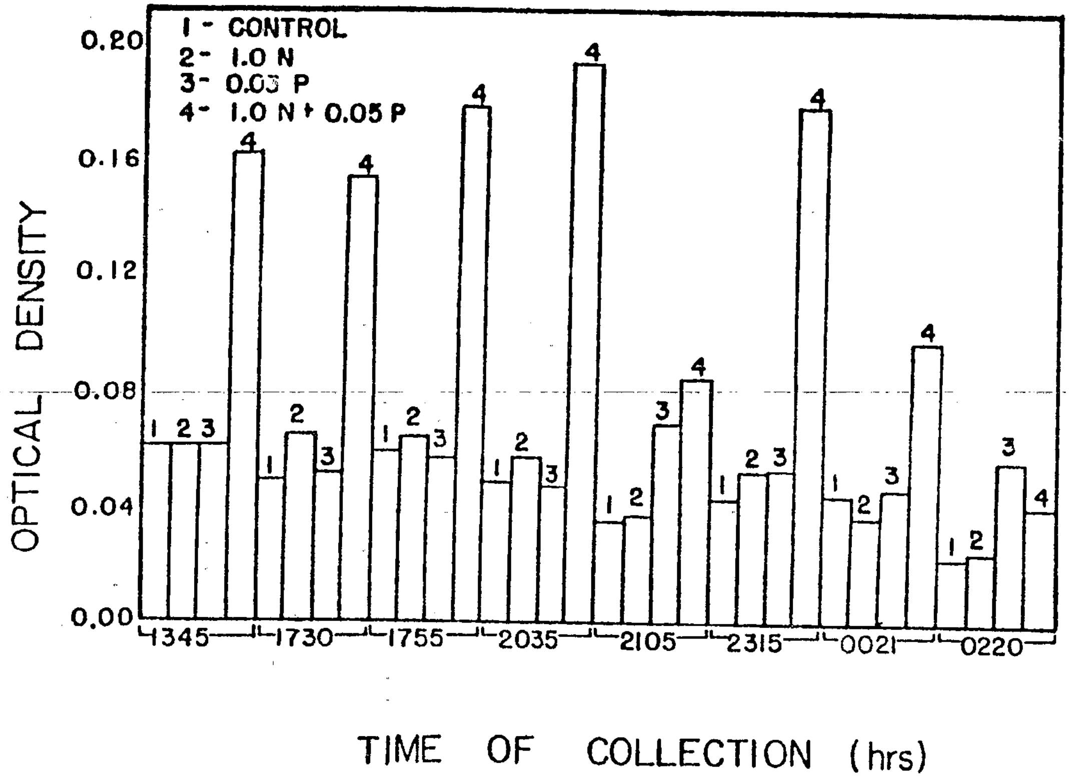

Figure 10. Growth of Selenastrum in diurnal low-flow samples from P-10 (September 21-22, 1974).

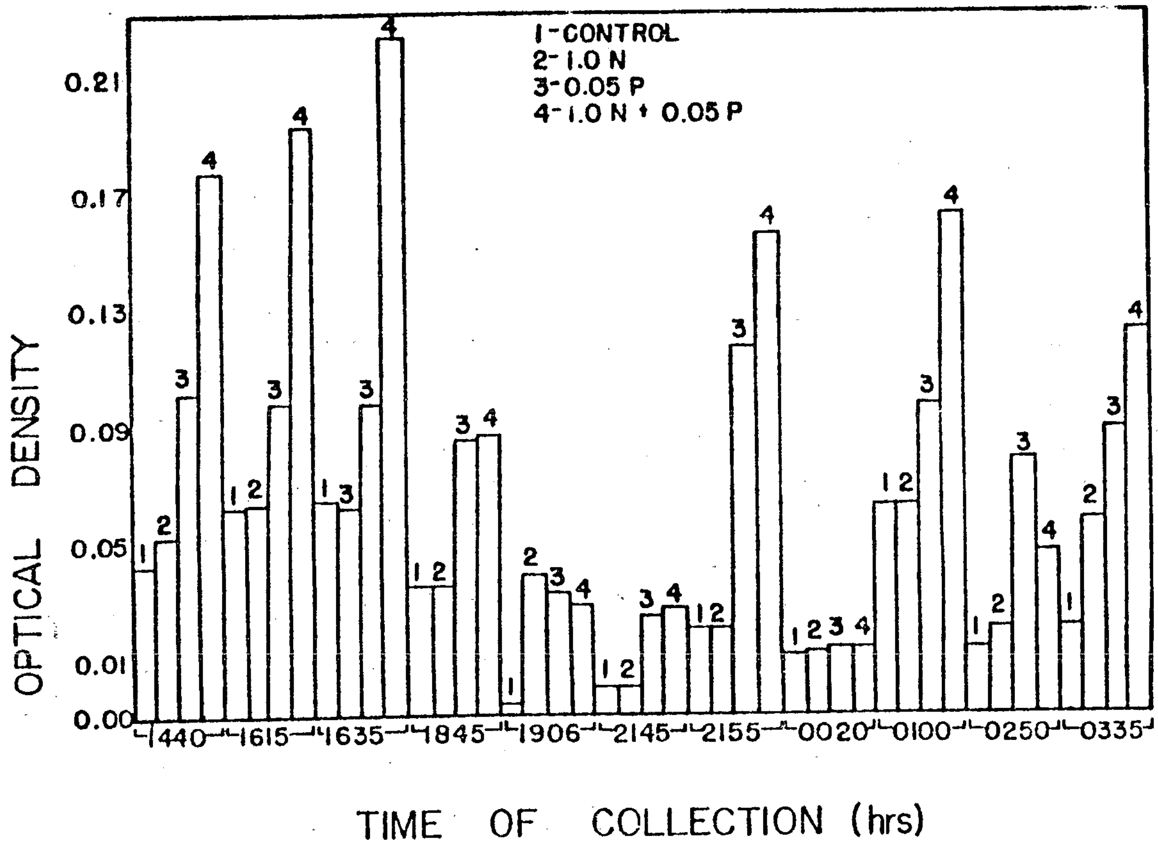

Figure 11. Growth of Selenastrum in diurnal low-flow samples from P-30 (September 21-22, 1974).

(Figures 12 and 13). The first flush of nutrients into Panther Branch was reflected by increased cell yields in corresponding water samples. However, as the storm progressed there was a decrease in algal cell yields in test waters. Subsequent increases in discharge were also accompanied by increased yields in the test water (Figure 14). Algal cells were increased dramatically by enrichment of stormwater samples with both nitrogen and phosphorus. However, nitrogen was most limiting for algal growth in stormwater runoff collected from P-10 and P-30 during a single storm event (Figure 15). Larger algal yields were noted in P-30 water during initial phases of the storm due to increased concentrations of algal nutrients.

Miller _et al_. (27) stated that 1 μg P/l yields 0.43 mg dry weight of algae, while 1 μg total soluble inorganic nitrogen (TSIN) per liter (NH_3-N + NO_3-N + NO_2-N) yields 0.038 mg dry weight of algae. These values were used to calculate theoretical algal yields from measured concentrations of TSIN and O-PO_4 at sites P-10 (Table 8) and P-30 (Table 9). These data indicate that theoretical yields for both TSIN and O-PO_4 varied on a monthly basis at both sites and tended to decrease during the second year of study. However, potential yields were greater in water from P-30 than from P-10. Table 10 presents a similar treatment of the average yearly values of TSIN and O-PO_4. These data indicate an increase in the potential of water to support algal growth as it moves downstream in Panther Branch. The increase in TSIN and O-PO_4 were sufficient to increase theoretical yields at P-30 in amounts indicated in Table 10. However, potential yields generally decreased during the second year of study.

Bioassays were also used to determine the stimulatory effects of discrete stormwater samples collected from Hunting Bayou and Westbury Square on algal growth. At Hunting Bayou (March 20-21, 1975), algal growth was stimulated by the addition of nitrogen and phosphorus to the first water sample and by nitrogen or phosphorus additions to the second water sample (Figure 16). However, algal growth was not enhanced by the addition of nutrients during the latter portions of the storm. Reduction in growth capacity could have been caused by nutrient limitations or by some toxic substance(s) which was washed into the stream. Unfortunately, combined nitrogen and phosphorus spikes were not added to these samples. If a toxic substance was present, it inhibited _Selenastrum_ in small quantities or was present in sufficiently high concentrations to prevent dilution to a non-inhibitory concentration. Reduced growth may also have been due to a deficiency in some trace element which was essential for algal growth. Even so, the data indicated a definite variation in the capacity of the stormwater runoff to support algal growth.

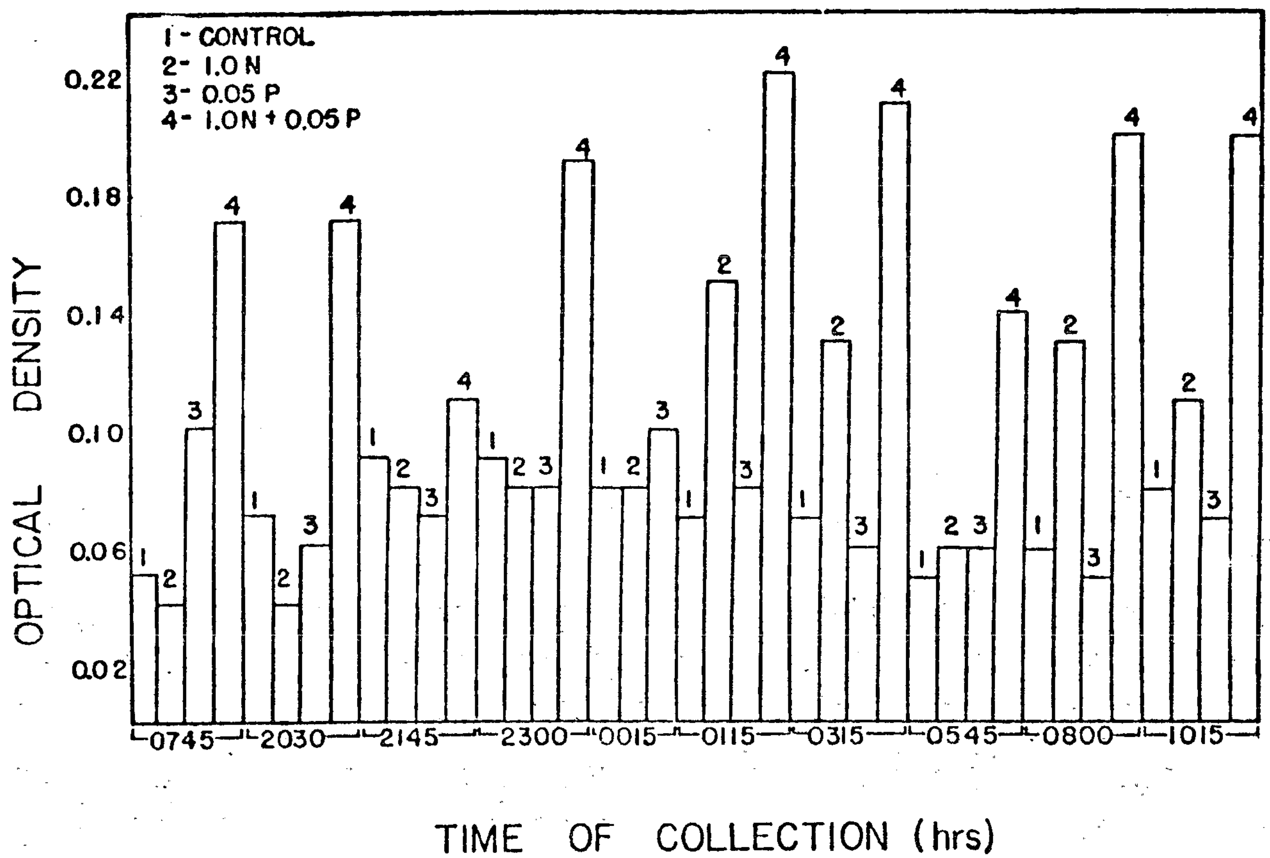

Figure 12. Growth of Selenastrum in stormwater runoff from P-30 (January 18, 1974).

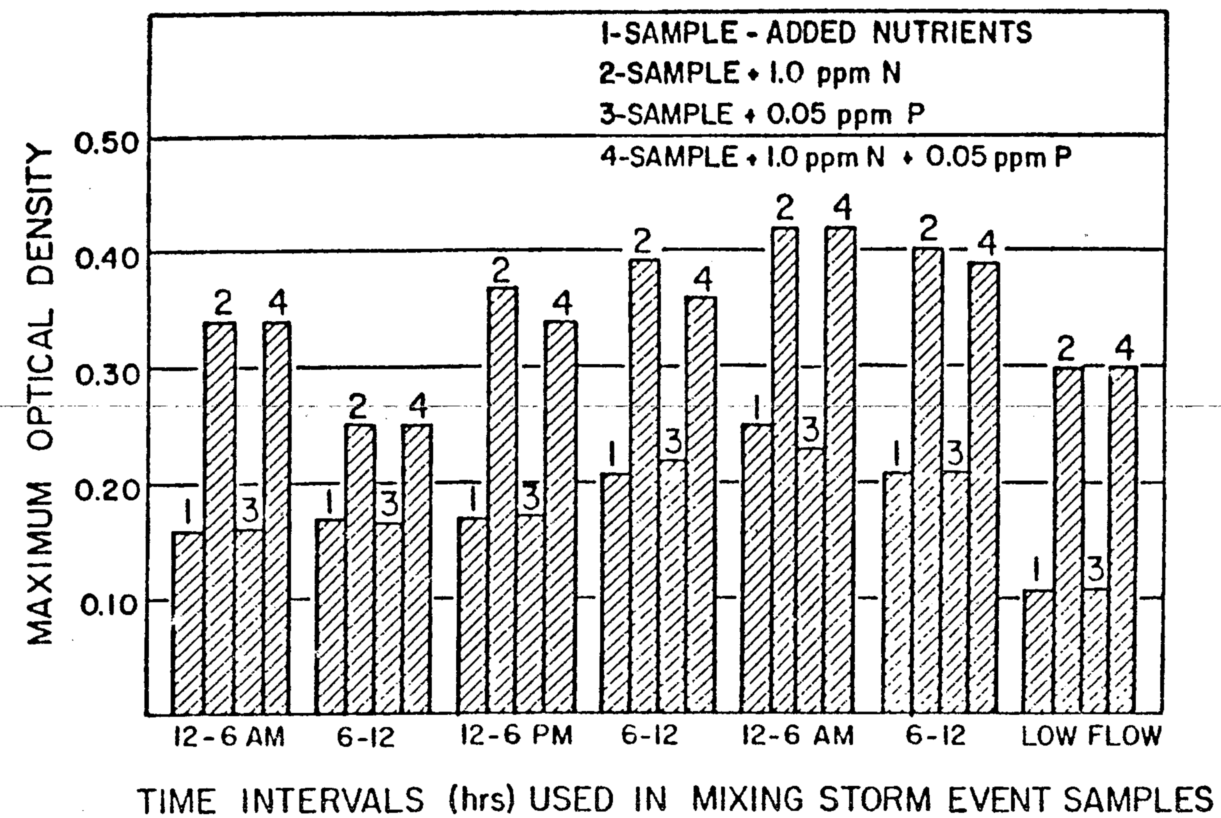

Figure 13. Growth of Selenastrum in six-hour mixture of stormwater runoff from P-30 (October 28, 1974).

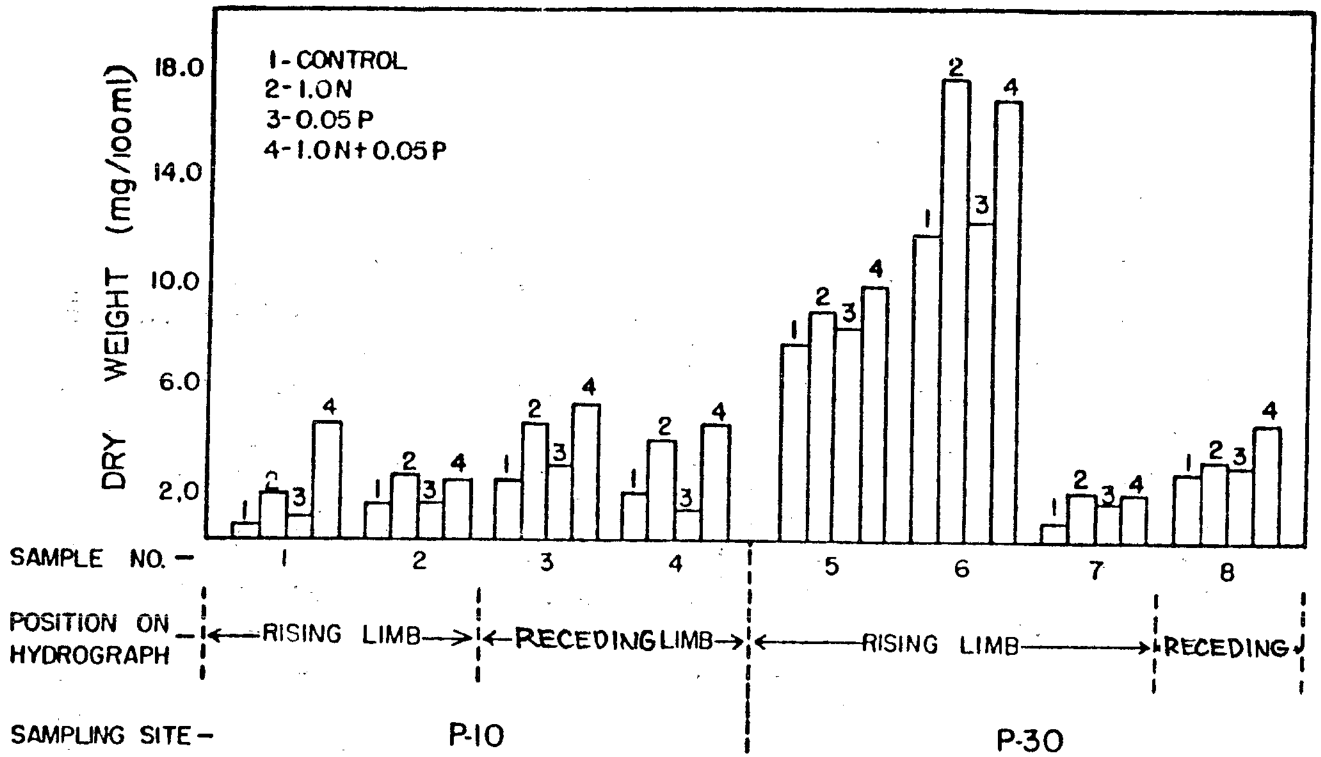

Figure 14. Growth of Selenastrum in stormwater runoff in relation to hydrograph position at P-30 (April, 1975).

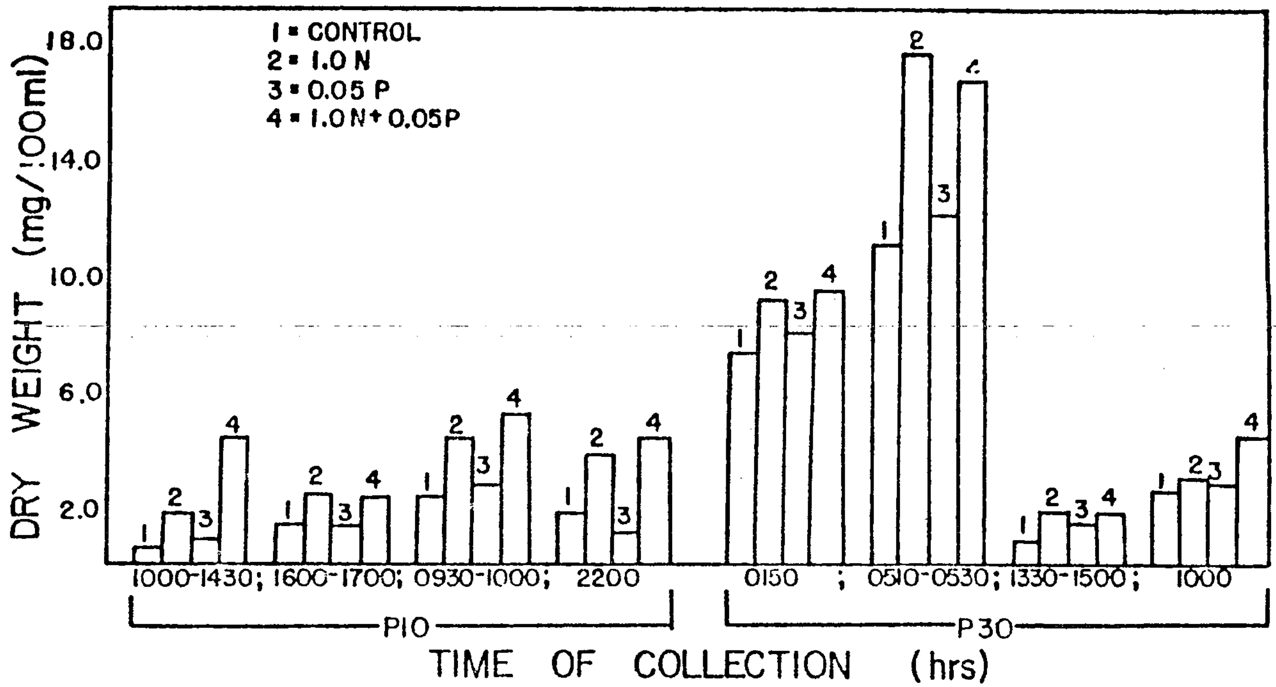

Figure 15. Growth of Selenastrum in stormwater runoff from P-10 and P-30 (April, 1975).

TABLE 8. THEORETICAL YIELDS OF ALGAE BASED ON NITROGEN AND PHOSPHORUS CONCENTRATIONS AT P-10

MONTH	TSIN[a] (mg/l)	PO_4-P (mg/l)	TSIN Yield (mg/l)	PO_4-P Yield (mg/l)
Nov.	0.170	0.020	6.5	8.6
Dec.	0.105	0.018	4.0	7.7
Jan.	0.100	0.010	3.8	4.3
Feb.	0.096	0.045	3.6	19.4
Mar.	0.170	0.070	6.5	30.1
Apr.	0.292	0.060	11.1	25.8
May	0.233	0.050	8.9	21.5
Jun.	0.040	0.040	1.5	17.2
Jul.	-	-	-	-
Aug.	0.263	0.064	10.0	27.5
Sept.	0.063	0.024	2.4	10.3
Oct.	0.103	0.060	3.9	25.8
Nov.	0.037	0.046	1.4	19.8
Dec.	0.075	0.021	2.9	9.0
Jan.	-	-	-	-
Feb.	0.101	0.006	3.8	2.6
Mar.	-	-	-	-
Apr.	0.087	0.004	3.3	1.7
May	0.167	0.004	6.3	1.7
Jun.	-	-	-	-
Jul.	0.131	0.016	5.0	6.9
Aug.	0.128	0.004	4.9	1.7
Sept.	0.157	0.022	6.0	9.5
Oct.	0.093	0.010	3.5	4.3
Nov.	0.490	0.003	18.6	1.3

[a]TSIN: Total Soluble Inorganic Nitrogen (NH_3-N + NO_3-N + NO_2-N)

TABLE 9. THEORETICAL YIELDS OF ALGAE BASED ON NITROGEN AND PHOSPHORUS CONCENTRATIONS AT P-30

MONTH	TSIN[a] (mg/l)	PO_4-P (mg/l)	TSIN Yield (mg/l)	PO_4-P Yield (mg/l)
Nov.	0.250	0.070	9.5	30.1
Dec.	0.190	0.010	7.2	4.3
Jan.	0.150	0.008	5.7	3.4
Feb.	0.175	0.030	6.7	12.9
Mar.	0.170	0.080	6.5	34.4
Apr.	0.320	0.080	12.2	34.4
May	0.425	0.075	16.2	32.3
Jun.	1.000	0.070	38.0	30.1
Jul.	-	-	-	-
Aug.	0.368	0.085	14.0	36.6
Sept.	0.662	0.250	25.2	107.5
Oct.	0.576	0.060	21.9	25.8
Nov.	-	-	-	-
Dec.	0.161	0.015	6.1	6.4
Jan.	-	-	-	-
Feb.	0.084	0.008	3.2	3.4
Mar.	-	-	-	-
Apr.	0.472	0.005	17.9	2.2
May	0.251	0.005	9.5	2.2
Jun.	-	-	-	-
Jul.	0.103	0.005	3.9	2.2
Aug.	0.257	0.010	9.8	4.3
Sept.	0.279	0.070	10.6	30.1
Oct.	0.146	0.015	5.5	6.5
Nov.	0.173	0.030	6.6	12.9

[a]TSIN: Total Soluble Inorganic Nitrogen (NH_3-N + NO_3-N + NO_2-N)

TABLE 10. THEORETICAL YIELDS OF ALGAE BASED ON AVERAGE YEARLY CONCENTRATIONS OF NITROGEN AND PHOSPHORUS AT P-10 AND P-30

SITE Year	TSIN[a] (mg/l)	PO_4-P (mg/l)	TSIN Yield (mg/l)	PO_4-P Yield (mg/l)
P-10				
74	0.130	0.045	4.9	19.4
75	0.146	0.008	5.5	3.4
P-20				
74	0.213	0.058	8.1	24.9
75	0.142	0.110	5.4	47.3
P-25				
74	0.296	0.159	11.2	68.4
75	0.157	0.005	6.0	2.2
P-30				
74	0.368	0.072	14.0	40.0
75	0.250	0.017	9.5	7.3
P-30 - P-10				
74	0.238	0.027	9.0	11.6
75	0.104	0.009	4.0	3.9

[a]TSIN: Total Soluble Inorganic Nitrogen
(NH_3-N + NO_3-N + NO_2-N)

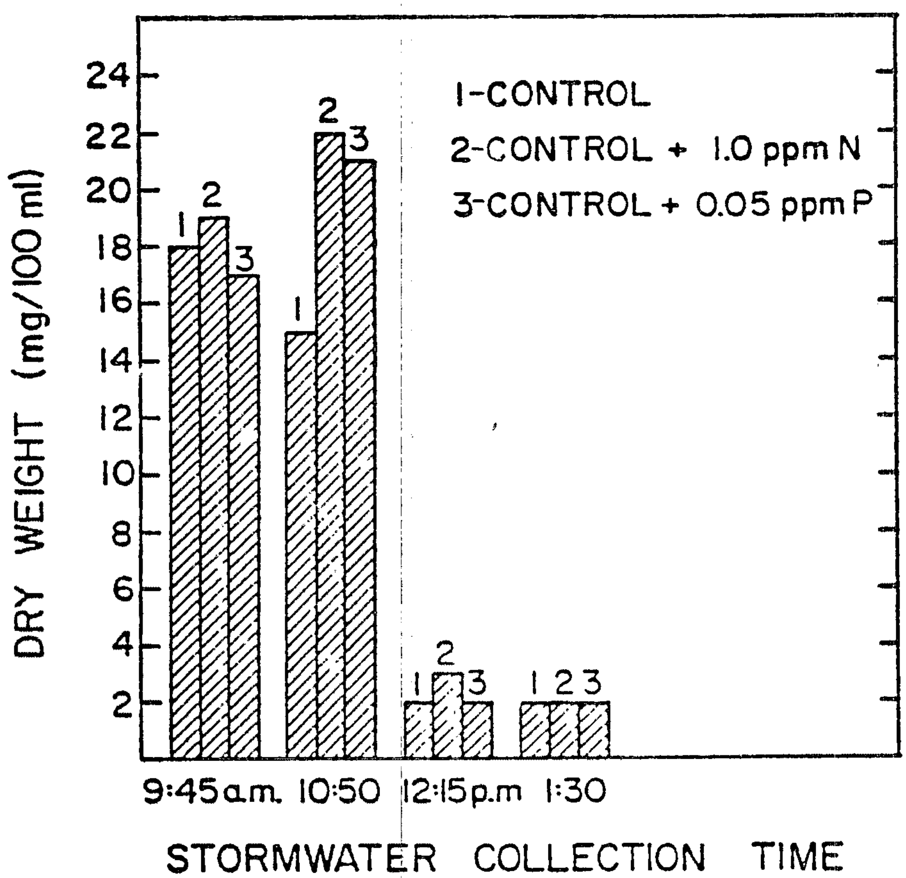

Figure 16. Growth of *Selenastrum* in stormwater runoff from Hunting Bayou (March 20, 1974).

Data from a second storm event at Hunting Bayou (April 11-12, 1975) were similar to those described above. With the exception of the 4:30 p.m. sample, there was a definite stimulation of algal growth with additions of nitrogen or both nitrogen and phosphorus to the water samples, and slight or no stimulation with only phosphorus spikes (Figures 17 and 18). The marked reduction in algal growth, even with combined nitrogen and phosphorus, in this sample could again have been due to the presence of some toxic agent or the absence of some essential trace element. Additional data obtained from bioassys of stormwater from Westbury Square (Figure 19) also indicated that nitrogen was the limiting nutrient for algal growth in stormwater runoff.

In urban areas the first rains and runoff usually contain significant quantities of dissolved solids, including troublesome amounts of nitrogen and phosphorus. Thus, it might be advantageous to collect the first stormwater runoff and treat it with the sewage. After the first flush, stormwater could then be directed through recreational lakes to achieve mixing and washout of accumulated bottom sediments. In The Woodlands, this procedure could be most useful in mitigating the effects of surface runoff from the golf course and lawns on algal growth in receiving waters.

LAKE B--WATER QUALITY

Investigations of the Lake Harrison system were confined primarily to the smaller, upstream lake (Lake B). Suspended solids and turbidity in Lake B were high throughout most of the study period due to large concentrations of particulate materials transported to the lake by surface drainage from construction sites (Table 11). Water piped into Lake B from Panther Branch also contained high concentrations of suspended solids. Consequently, light penetration into the water column was greatly reduced and the euphotic zone was restriced to the upper few centimeters of the lake.

The pH of Lake B was usually alkaline, but fluctuations into the acidic range were observed (Table 11). Stabilization of pH at 8.3 (September to November, 1975) was due primarily to inflow of alkaline, treated sewage effluent into the lake. The overall alkaline pH probably reflects impact of watershed alteration and manipulation of influent water on lake water quality, since small, undisturbed lakes in The Woodlands vicinity generally have acid or near neutral pH values.

Concentrations of nitrogen and phosphorus varied considerably in Lake B (Table 11). In early phases of development (November, 1973 to May, 1974), waterfall construction was in progress and the lake experienced extreme fluctuations in water volume. During this period, surface runoff was the only source of water and nutrients for the lake. On completion of the spill-

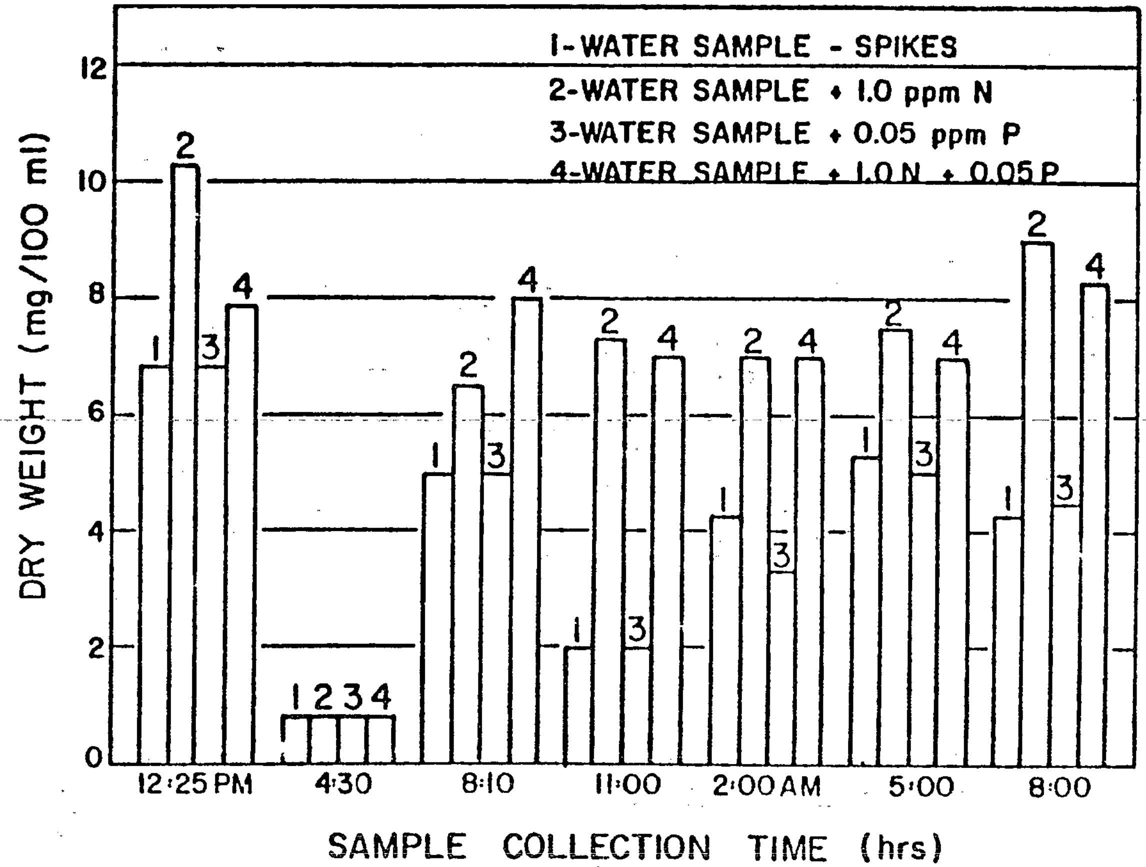

Figure 17. Growth of Selenastrum in stormwater runoff from Hunting Bayou (March 26, 1974).

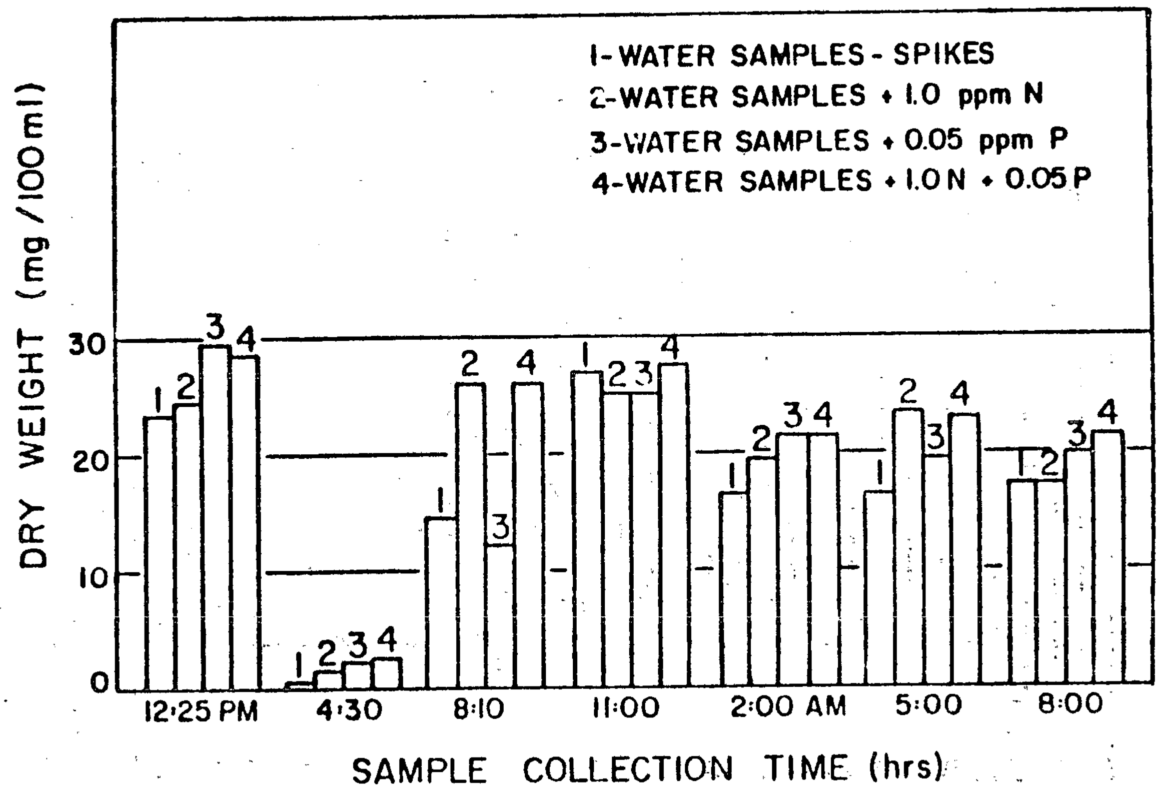

Figure 18. Growth of *Anabaena flos-aquae* in stormwater runoff from Hunting Bayou (May 8, 1975).

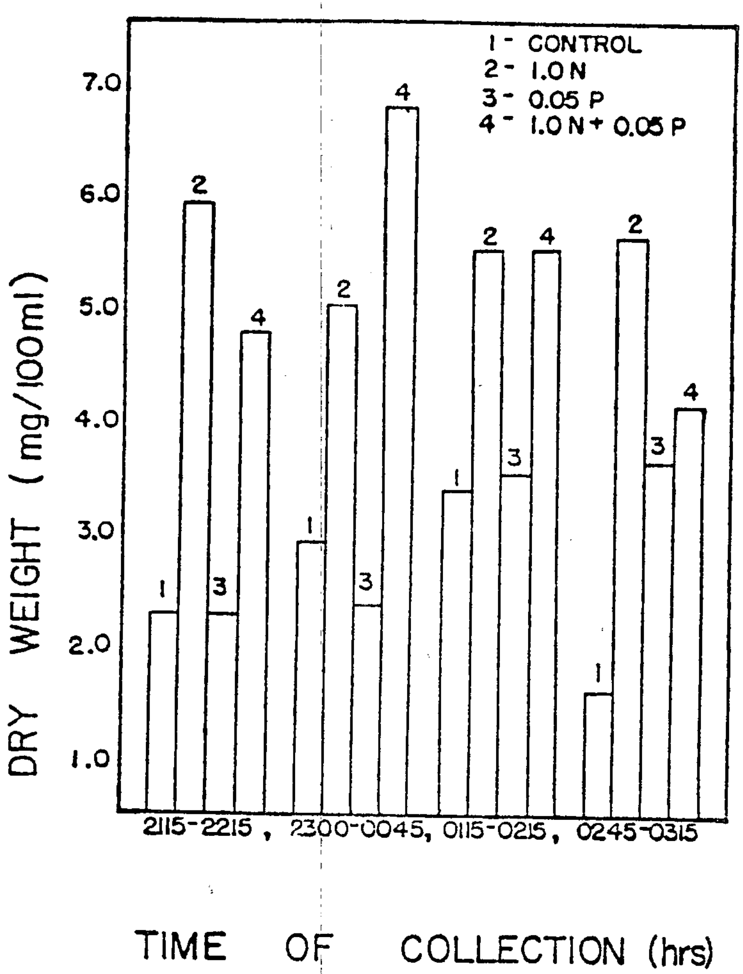

Figure 19. Growth of Selenastrum in stormwater runoff from Westbury Square (May 8, 1975).

TABLE 11. WATER QUALITY OF LAKE B DURING MONTHS BETWEEN NOVEMBER, 1973 AND NOVEMBER, 1975

Month	Suspended Solids	Turbidity (JTU)	pH	Temp. (C)	NH_3-N (mg/l)	NO_3-N (mg/l)	NO_2-N (mg/l)	PO_4-P (mg/l)
Nov.	650	-	8.5	16.0	0.13	0.06	0.04	0.22
Dec.	507	-	7.8	15.9	0.08	0.06	0.04	0.08
Jan.	400	-	7.4	19.5	0.21	0.10	0.02	0.01
Feb.	406	135	7.9	18.7	0.11	0.09	0.02	0.05
Mar.	704	381	7.9	23.2	0.07	0.09	0.01	0.07
Jun.	642	380	8.0	31.0	0.09	0.11	0.01	0.05
Jul.	-	-	7.8	28.0	0.10	0.10	0.02	0.01
Aug.	1068	440	7.5	29.0	0.05	0.29	0.04	0.10
Sept.	1050	500	6.4	25.0	0.07	0.27	0.01	0.06
Oct.	1140	560	8.0	24.0	0.02	0.11	0.01	0.05
Jan.	313	25	7.8	13.0	0.08	0.11	0.01	0.01
Feb.	131	78	6.1	10.4	0.06	0.03	0.01	0.01
Jul.	10	38	7.9	27.4	0.02	0.03	0.01	0.09
Aug.	14	27	8.1	28.3	0.05	0.03	0.03	0.03
Sept.	1250	690	8.3	24.0	0.14	0.39	0.21	0.05
Oct.	1278	580	8.3	19.5	0.09	0.21	0.04	0.04
Nov.	78	42	8.3	22.5	0.09	0.02	0.04	0.02

- indicates that data was not available

way, the lake basin filled rapidly and extreme fluctuations in water level ceased. Increased concentrations of nitrogen (August, 1974 and September, 1975) resulted from surface drainage from heavily fertilized lawns and inflow of water from Panther Branch, which received irrigation drainage from the golf course. Phosphorus concentrations were also higher during periods of high nitrogen concentrations.

Stormwater runoff was a significant source of dissolved and particulate solids for Lake B (Table 12). Concentrations of suspended solids remained in the lake system. Turbidity increased with surface runoff due to the influx of solids into the lake. Average concentrations of NH_3-N, NO_3-N, and especially PO_4-P were also higher in stormwater runoff than in low-flow water.

TABLE 12. COMPARISON OF AVERAGE AND MAXIMUM WATER QUALITY PARAMETERS FOR LOW FLOW AND STORMWATER RUNOFF IN LAKE B

Parameter	Low Flow		Stormwater Runoff	
	Avg.	Max.	Avg.	Max.
Suspended Solids (mg/l)	603	1278	1273	2660
Turbidity (JTU)	298	690	375	900
NH_4-N (mg/l)	0.09	0.21	0.11	0.15
NO_3-N (mg/l)	0.12	0.39	0.15	2.1
NO_2-N (mg/l)	0.03	0.21	0.01	0.05
PO_4-P (mg/l)	0.06	0.22	0.11	0.36

LAKE B--ALGAL POPULATIONS

From December, 1973 to May, 1976, forty-nine species of algae were identified from Lake B of the Conference Center Lakes. During the study period, dominance of the species composition changed from euglenoids to green algae (Table 13). The largest change in species composition occurred in the Chlorophyta and induced subsequent changes in ratios of other species to total species composition (Figure 20).

TABLE 13. OCCURRENCE OF ALGAL SPECIES IN LAKE B

	Number Species Identified		
Algal Division	1974	1975	1976
Chlorophyta(21)[a]	5[b](22.7)[c]	16(38.1)	21(42.9)
Cyanophyta(6)	2(9.1)	6(14.3)	6(12.2)
Chrysophyta(10)	5(22.7)	8(19.0)	10(20.4)
Euglenophyta(12)	10(45.5)	12(28.6)	12(24.5)
Total (49)	22	42	49

[a] total species/division

[b] number species

[c] % of total species/site

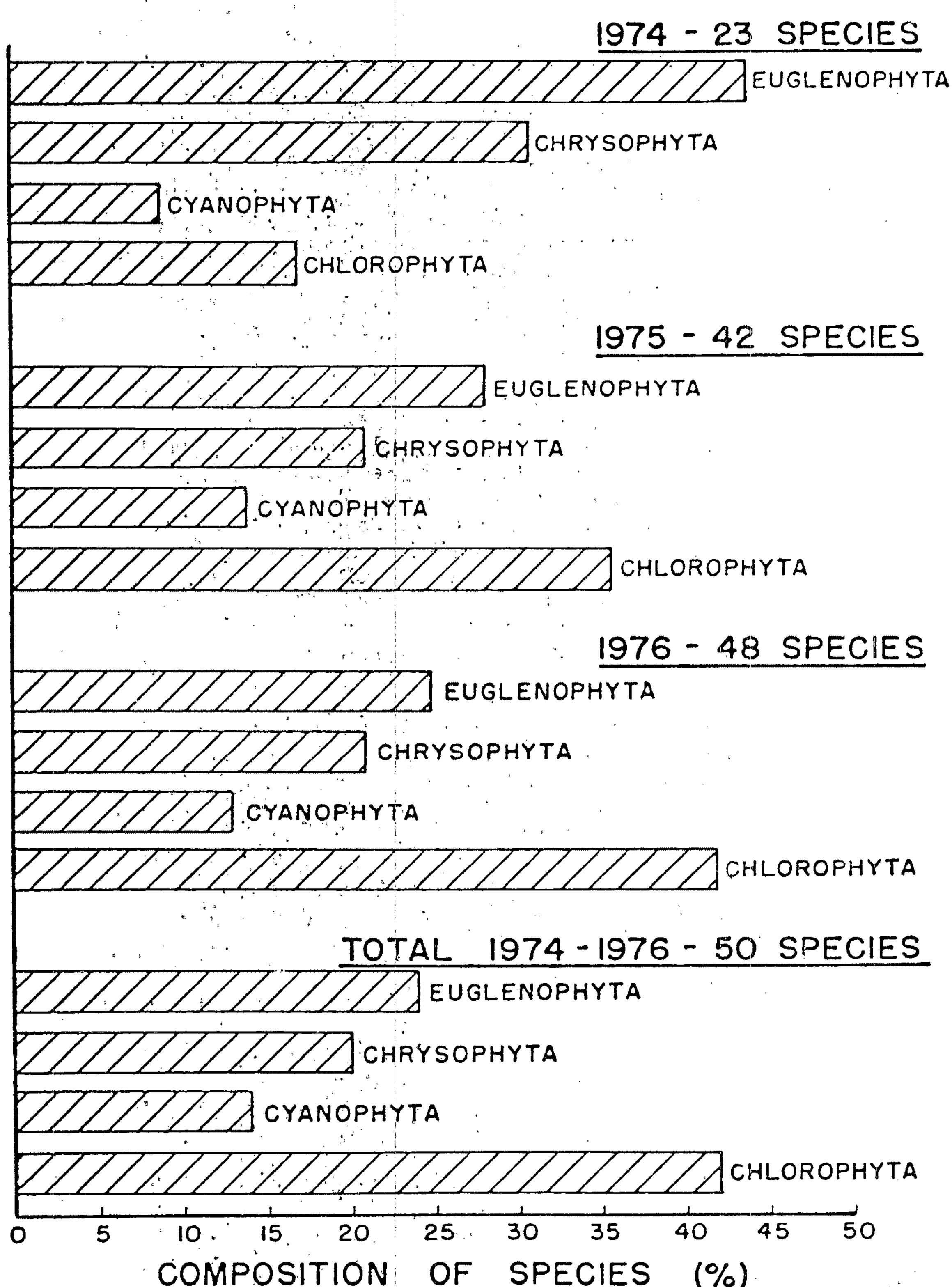

Figure 20. Percent species composition, by division, for Lake B over a three-year period.

Algal standing crops in Lake B (Figure 21) fluctuated dramatically over a two-year period. The Cyanophyta reached maximum peaks during the summer, while maximum standing crops of Chrysophyta occurred in winter months. The green algae obtained maximum cell numbers in September, but euglenoids dominated the algal standing crop during this month. Algal numbers in Lake B increased during the second year of study due primarily to larger standing crops of blue-green algae. Subsequent studies indicated no significant increases in phytoplankton from November, 1975 to May, 1976. However, a dense phytoplankton community composed of <u>Oedogonium</u> and <u>Spirogyra</u> developed in the littoral zone of this lake.

Since algal species differ in size, cell numbers do not always reflect actual biomass. Therefore, total cell numbers were converted to dry weight and cell volume estimates by use of tables available in the literature (24,26,28) and calculations performed in our laboratory. Figure 22 presents estimates of algal biomass by division on the basis of percent of total dry weight. Euglenoids dominated algal biomass, except in February of 1975 when diatoms were dominant. Chrysophycean algae were major codominants during winter months, while cyanophycean algae were major codominants in summer months. Chlorophycean algae were minor contributors to algal solids in the lake.

Algal populations in Lake B were relatively low when compared to other aquatic ecosystems. For example, cell numbers exceeding 10^4 cells/ml have been reported for Lake Michigan (29) and in highly nutrified water in southeastern Texas (30). Algal cell numbers and biomass in Lake B were well below the 10^6 cells/l (31) or 8 mg/l (32) values reported as being sufficient to classify algal growth as a water bloom. Algal cell volume in Lake B was also well below the bloom proportion reported by Kramer <u>et al</u>. (31). Average total algal biomass in Lake B was 38.88 μg/l, while average suspended solids was 603 mg/l (Table 14). Thus, algae were a minor part of the particulate material in Lake B, and suspended solids were definitely not of algal origin.

According to Vollenweider (33), algae are composed of 40-60% carbon by weight. On the basis of a 50% carbon content, total dry weight values per month were converted to carbon estimates (Table 14). These conversions indicated that algae contributed little to organic loads of Lake B, since the average concentration of total organic carbon was 16.85 mg/l. The average rate of change in algal carbon, based on gains and losses in algal biomass at 30-day intervals, was 0.14 mg C/m^2/day. Even though this figure is not a daily rate of carbon production, it can be used to make general comparisons between algal carbon in Lake B and other aquatic ecosystems. For example, Rodhe (34) reported algal production values of 7-25 g C/m^2/yr for oligotrophic lakes, 75-250 g C/m^2/yr for naturally

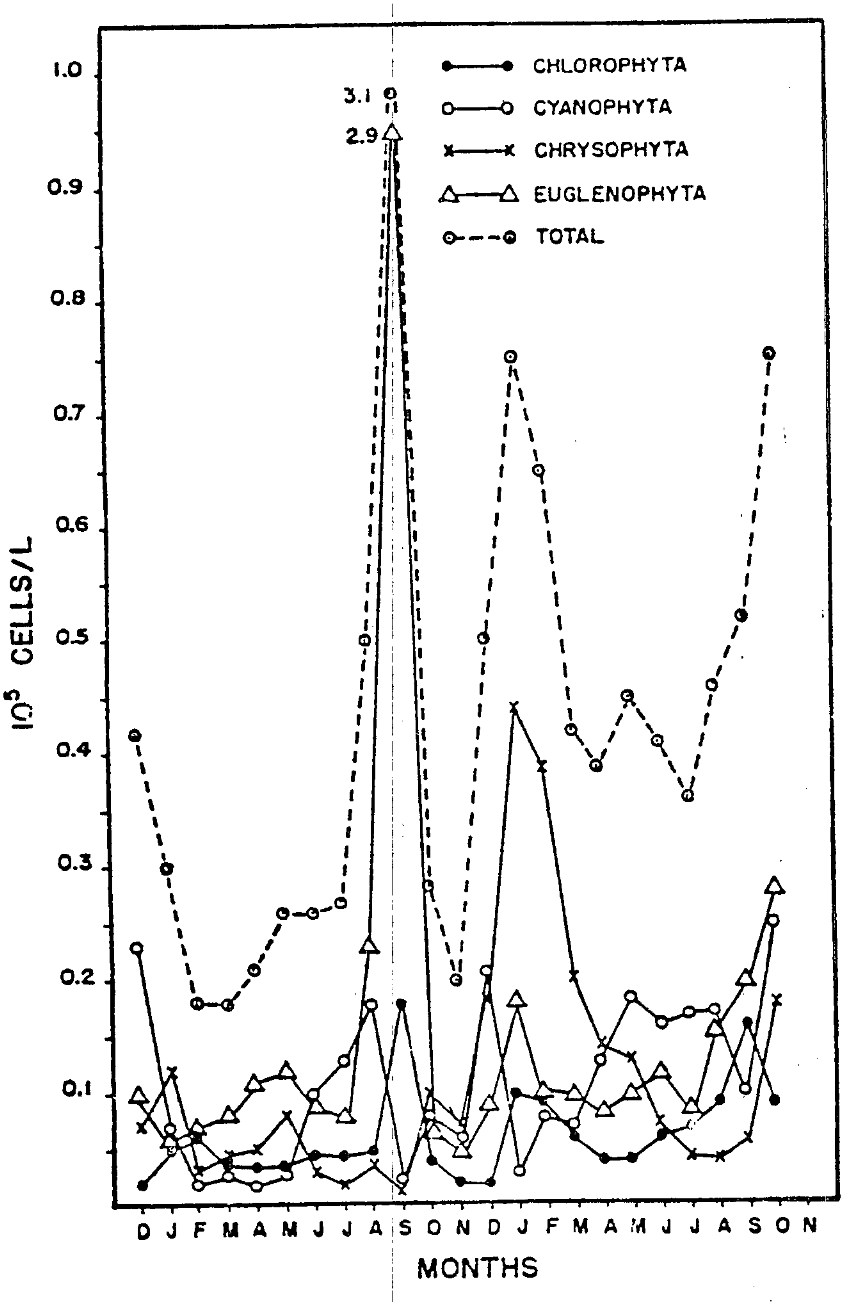

Figure 21. Seasonal algal standing crops in Lake B.

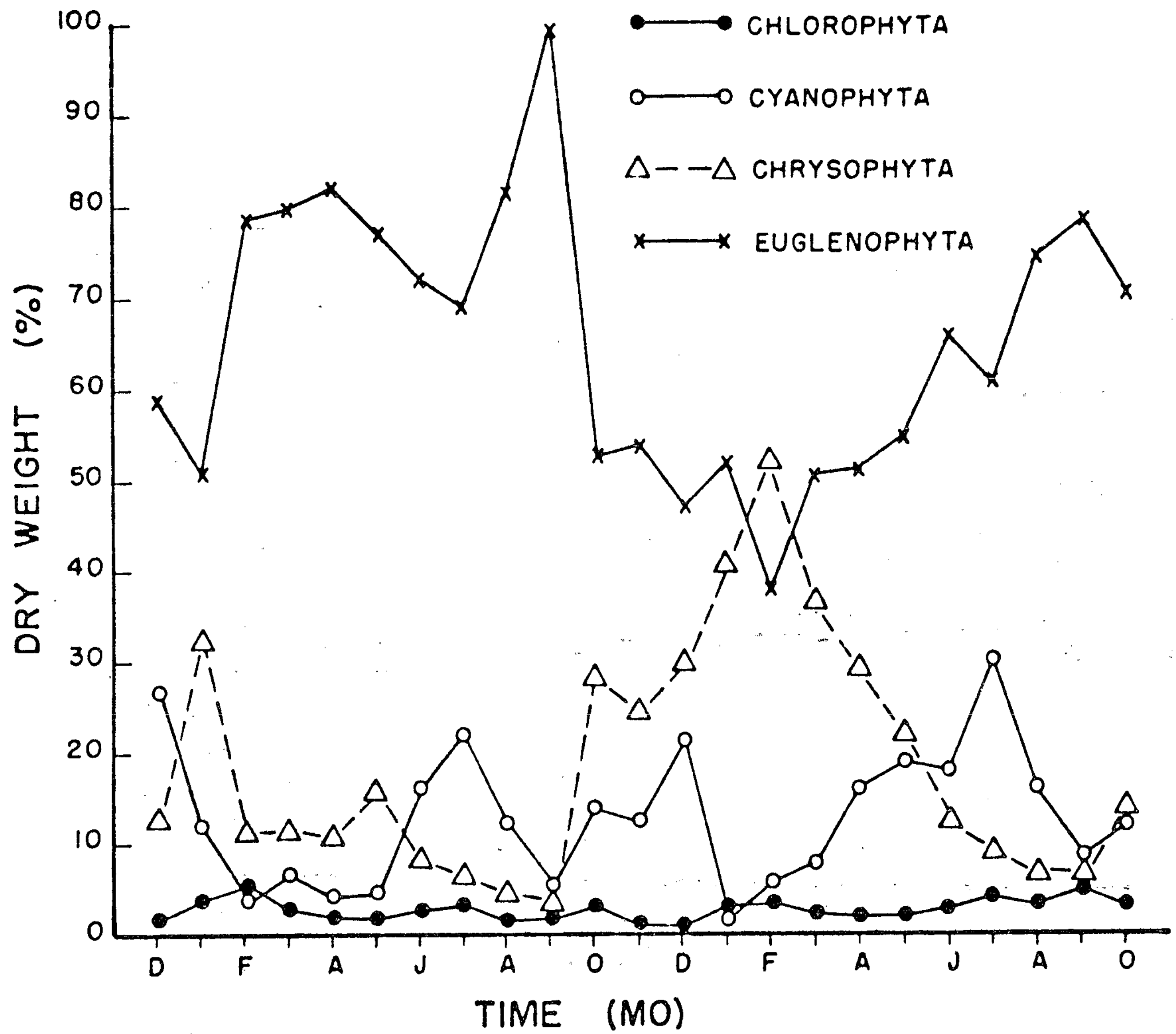

Figure 22. Percent dry weight of algae, by division, in Lake B (December, 1973 to October, 1975).

TABLE 14. COMPARISON OF ALGAL BIOMASS AND CARBON CONTENT CONTRIBUTED BY EACH ALGAL DIVISION

Algal Division	Weight Range (µg/l)	Average Weight (µg/l)	Average Carbon Content (µg/l)
Chlorophyta	0.24 - 2.16	0.74	0.37
Cyanophyta	0.52 - 6.50	2.80	1.40
Chrysophyta	0.42 - 18.48	4.62	2.31
Euglenophyta	6.5 - 377.00	30.63	15.32
Total	11.6 - 380.10	38.88	19.44

eutrophic lakes, and 350-700 g $C/m^2/yr$ for culturally eutrophic lakes. Even though these data are subject to interpretation, they provide a general picture of primary productivity in lakes with various trophic classifications. More specifically, Wetzel (24) reported annual productivity values (g $C/m^2/yr$) of 36 for Castle Lake, California (oligotrophic), 160 for Clear Lake, California (mesotrophic), and 369 for Lake Wintergreen, Michigan (eutrophic). Lake B probably had productivity rates resembling those of oligotrophic waters. Even considering loss of algal cells by grazing or sedimentation, it is unlikely that Lake B had productivity rates approaching those of mesotrophic or eutrophic lakes.

Multiple regression indicated that the measured physicochemical parameters in Table 15 influenced algal numbers in Lake B. The relatively low regression values indicate that measured physicochemical parameters were not responsible for total changes in algal numbers in this lake. Other factors or interactions of various factors may have exerted more impact on changes. The composition and standing crops of algae were probably significantly influenced by the recirculation of water in the lake and by the use of Panther Branch water to maintain the constant volume lake.

CONFERENCE CENTER LAKES--NUTRIENT LIMITATIONS

Nutrient limitation studies with low-flow water collected from Lake B revealed that algal growth was not stimulated by addition of nitrogen to the water (Figures 23 and 24). However, phosphorus spikes did stimulate algal growth, thus indicating that phosphorus was the limiting nutrient for algal growth in Lake B and Lake A (Figure 24). The relatively high levels of growth with combined spikes also indicated that algal numbers could be increased substantially by additions of both nitrogen and phosphorus to the water and that other nutrients were not

TABLE 15. SUMMARY OF REGRESSION ANALYSES WITH PHYSICOCHEMICAL PARAMETERS AND ALGAL NUMBERS IN LAKE B

Physicochemical Parameters	Algal Division			
	Chlorophyta	Cyanophyta	Chrysophyta	Euglenophyta
NO_3-N	.341[a]	.009	.056	.501
Suspended Solids	.159	.031	.007	.014
O-PO_4	.102	.127	.057	.029
NH_4-N	.057	.031	.038	.025
pH	.033	.103	.003	.001
Dissolved Oxygen	.005	.112	.106	.003
Temperature	.000	.002	.606	.012
Regression Coefficient R^2	.696	.415	.872	.585

a Based on Monthly Averages

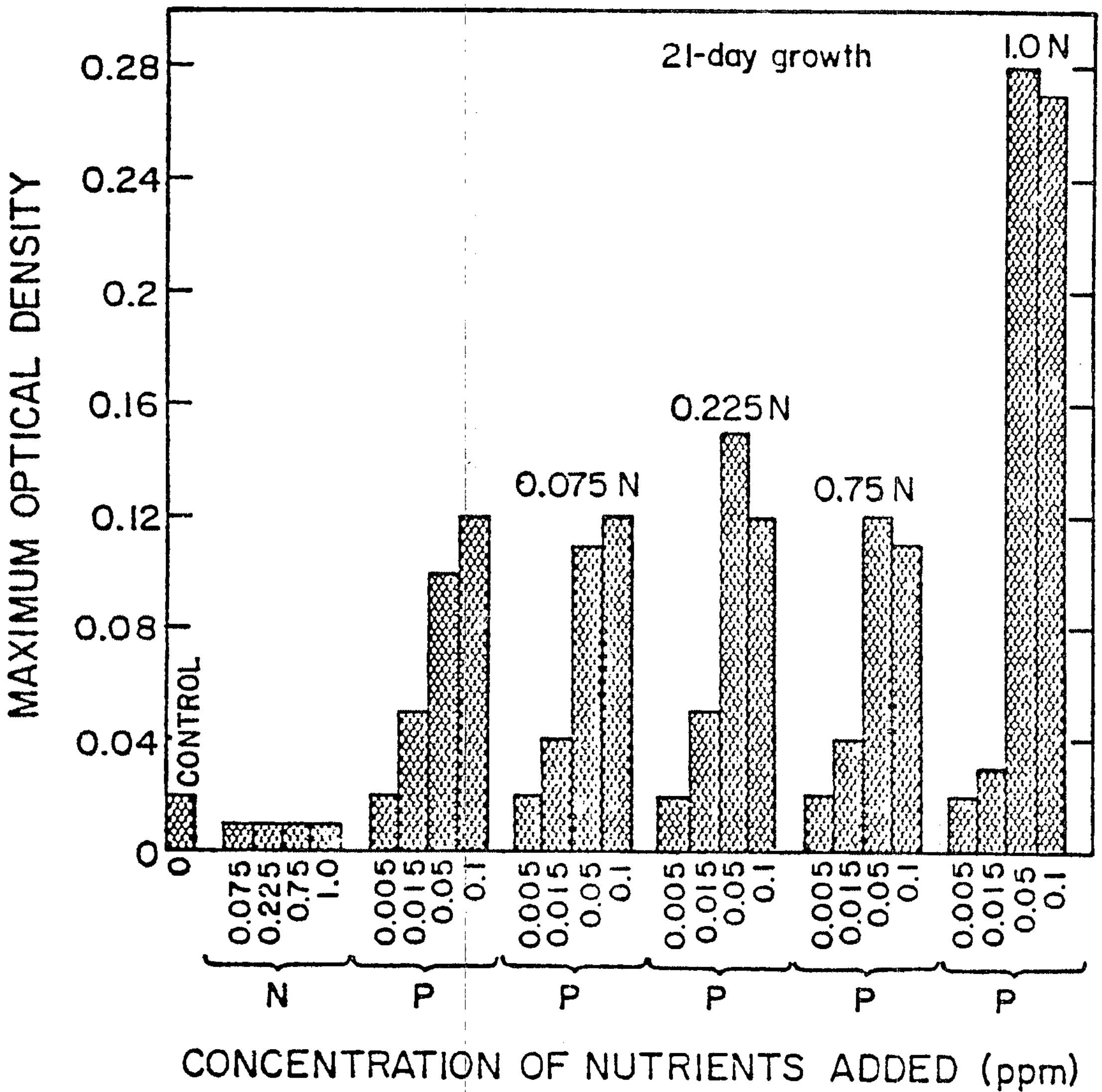

Figure 23. Growth of <u>Selenastrum</u> in low-flow water from Lake B (May, 1974).

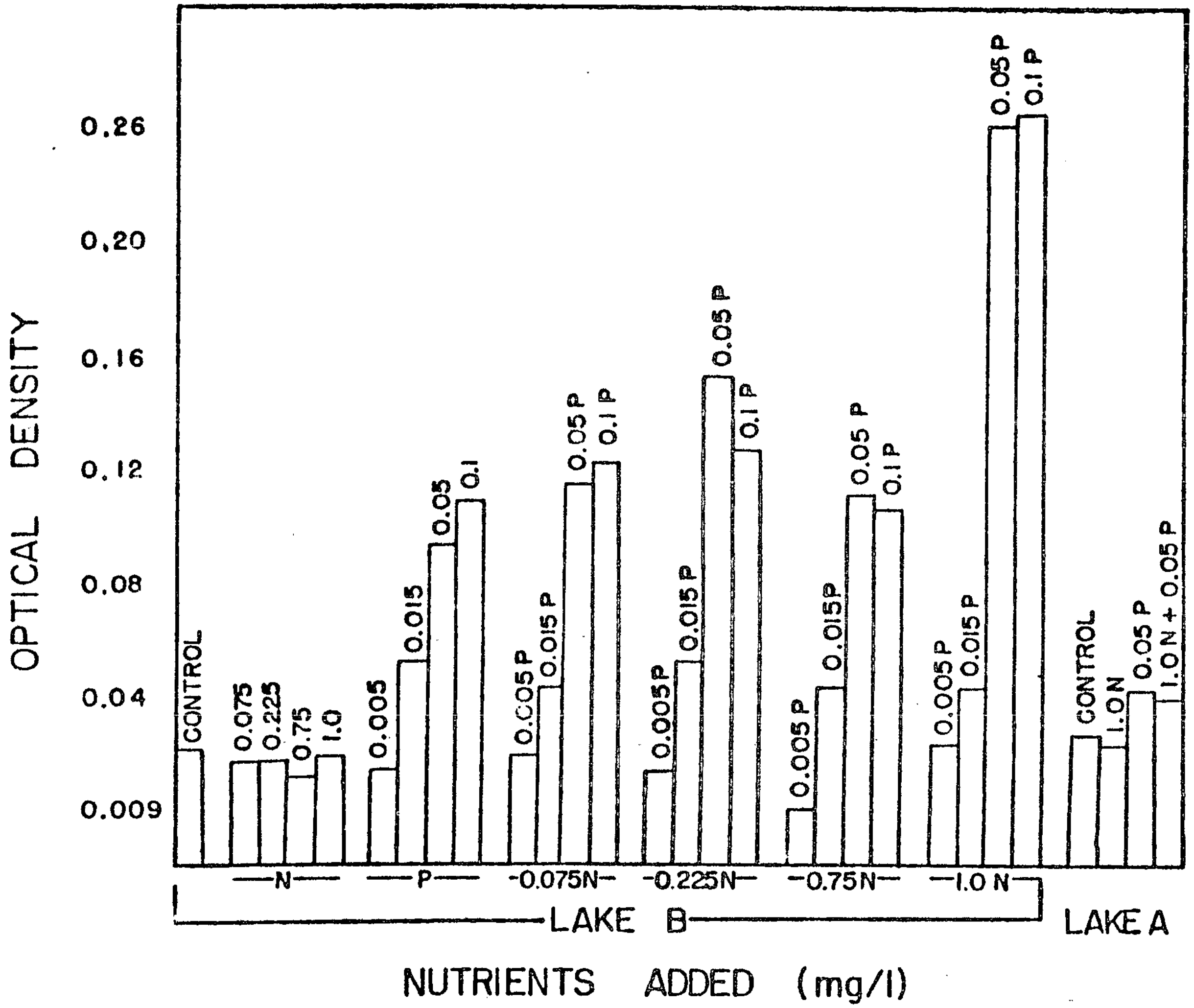

Figure 24. Growth of Selenastrum in low-flow water from Lakes A and B (May, 1975).

particularly limiting for algal growth. However, bioassays with stormwater runoff collected from Lakes A and B (Figure 25) indicated that nitrogen was more limiting than phosphorus for algal growth.

The data of Miller et al. (27), previously discussed, were used to calculate theoretical algal yields from measured concentrations of TSIN and PO_4-P in Lake B (Table 16). These data indicate that theoretical yields were substantially higher than observed algal biomass provided that some factor, other than nitrogen or phosphorus, was not limiting for algal growth. Ratios of nitrogen and phosphorus may be used to estimate which of these nutrients is potentially limiting for production of algal biomass. Miller et al. (27) and Chiaudani and Vighi (35) reported optimum N:P ratios of 11.3 and 10, respectively, for growth of Selenastrum capricornutum. A ratio of 15:1 was reported as optimum for algal growth by Fitzgerald (36), while Vollenweider (33) reported a range of 10-15 as optimum. On the basis of a 10:1 ratio, phosphorus is a potential limiting nutrient for algal growth during some months, while nitrogen is potentially limiting in other months (Table 16). However, algal biomass in Lake B never exceeded theoretical yields; thus, these nutrients were probably not the primary limiting factor in the lake.

Bioassays indicated that low-flow water from Lake B could support a biomass of S. capricornutum which exceeded recorded algal biomass. A filtered and autoclaved sample produced 27 mg/l dry weight of S. capricornutum, while a portion of the same sample autoclaved before filtration suppored a yield of 50 mg/l. Autoclaving of lake water seemed to solubilize nutrients which could be utilized for growth by the test alga. Bioassays with unautoclaved, filter sterilized water probably provided low estimates of growth supporting capabilities of Lake B water. Yields of S. capricornutum were also increased by removal of turbidity (suspended solids) from Lake B water by use of various size filters. A 97% reduction in turbidity resulted in a 94% increase in algal yield, while a 56% turbidity reduction increased algal yield by 84%. Nutrient spikes also indicated that phosphorus additions stimulated algal growth in the majority of Lake B water samples. However, nitrogen was, on occasion, the limiting nutrient for algal growth in low-flow water and was always the limiting nutrient in surface runoff collected during storm events. Correlations between theoretical yields, observed biomass, cell volume, and bioassay yields are not possible since water samples for chemical analyses and algal bioassays were not collected simultaneously. The stimulation of algal growth by nitrogen and phosphorus spikes does indicate that other nutrients were present in quantities sufficient to support added growth of the test alga. Thus, nitrogen and phosphorus were primary limiting nutrients, but were not necessarily the limiting growth factors in Lake B.

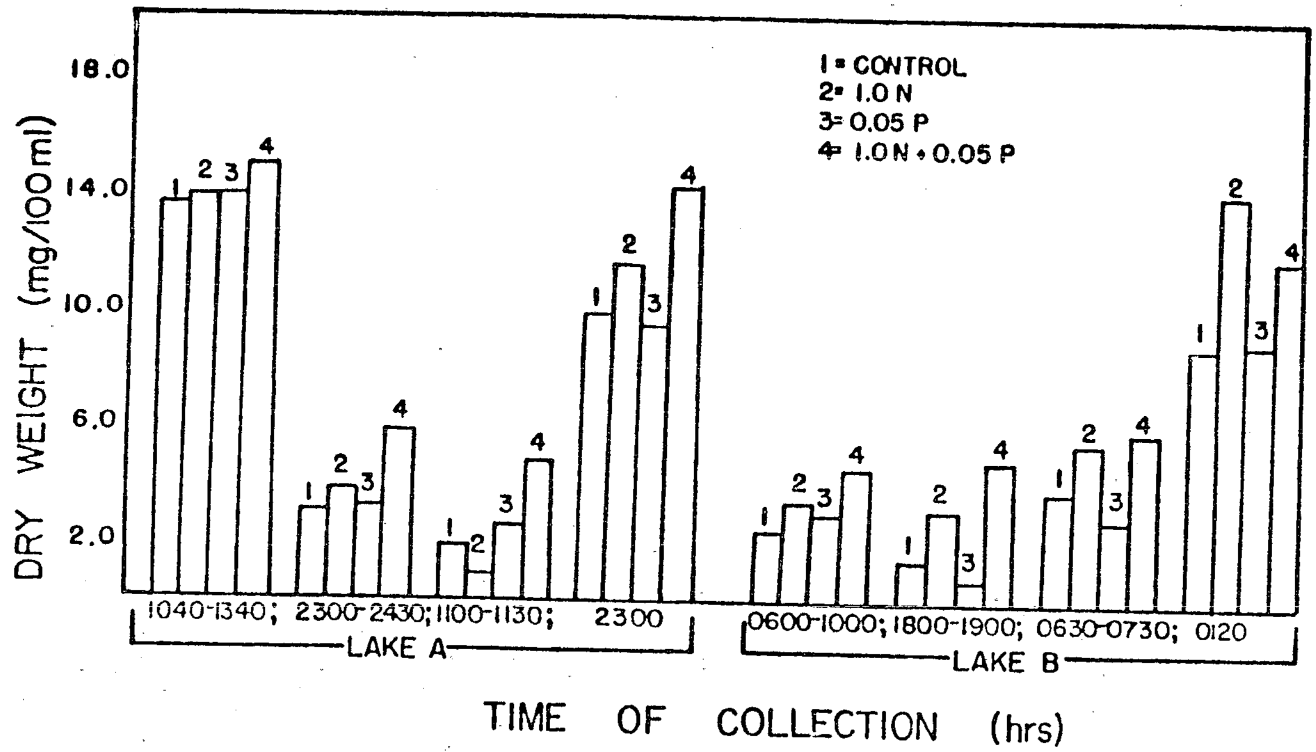

Figure 25. Growth of Selenastrum in stormwater runoff from Lakes A and B (March, 1975).

TABLE 16. THEORETICAL YIELDS* OF ALGAE AND N:P RATIOS BASED ON NITROGEN AND PHOSPHORUS CONCENTRATIONS OF LAKE B

Month	TSIN+ (mg/l)	PO_4-P (mg/l)	N:P	TSIN Yield (mg/l)	PO_4-P Yield (mg/l)	Recorded Algal Weight (μg/l)
Dec.	0.18	0.08	2.3:1	6.8	34.4	0.022
Jan.	0.33	0.01	33:1	12.5	4.3	0.015
Feb.	0.22	0.05	4.4:1	8.4	21.5	0.012
Mar.	0.17	0.07	2.4:1	6.5	30.1	0.013
Jun.	0.21	0.05	4.2:1	8.0	21.5	0.016
Jul.	0.22	0.01	22:1	8.4	4.3	0.015
Aug.	0.18	0.10	1.8:1	6.8	43.0	0.036
Sept.	0.35	0.06	5.8:1	13.3	25.8	0.380
Oct.	0.14	0.05	2.8:1	5.3	21.5	0.014
Jan.	0.20	0.01	20:1	7.6	4.3	0.044
Feb.	0.10	0.01	10:1	3.8	4.3	0.031
Jul.	0.06	0.09	1:1.5	2.3	38.7	0.017
Aug.	0.11	0.03	3.7:1	4.2	12.9	0.028
Sept.	0.74	0.05	14.8:1	28.1	21.5	0.033
Oct.	0.34	0.04	8.5:1	12.9	17.2	0.052

*Theoretical yields based on conversion factors of Miller _et al_. (27)

+TSIN: total soluble inorganic nitrogen (NH_3-N + NO_3-N + NO_2-N)

Lake B parameters were compared to those of lakes with various trophic levels (24). Total organic carbon and phosphorus concentrations in Lake B resemble those of eutrophic lakes, while total nitrogen falls within the range of oligo-mesotrophic lakes. However, phytoplankton biomass and algal carbon indicated that Lake B was ultra-oligotrophic. Nutrient supplies seemed sufficient to support algal standing crops and biomass in excess of those actually observed in Lake B.

The high initial turbidity of Lake B probably limited algal diversity to those species physiologically or morphologically adapted for existence at low-light intensities. Reductions in turbidity seemed to allow a more diverse assemblage of algae, composed primarily of chlorophycean species, to develop in the lake. However, even with reduced turbidity, algal biomass was dominated by euglenoids and chrysophytes or blue-green algae. Growth of green algae may have been limited by the high pH, high turbidity, or a combination of these two factors. The relatively low algal biomass indicates that some factor, possibly turbidity, was limiting algal growth. However, dense floating mats of Spirogyra sp. and Oedogonium sp. developed in the littoral zones of Lake B. Reduced turbidity would probably be accompanied by comparatively higher yields of algae in Lake B, and, at this time, algal growth would probably be limited by nitrogen and phosphorus concentrations in the lake. Future reductions in lake turbidity might necessitate some management strategy, such as regulations of detention time or use of well water to dilute nutrients entering the lake via treated sewage effluent or Panther Branch water.

Since nitrate-nitrogen and orthophosphate-phosphorus contribute heavily to algal blooms, it may be desirable to limit or prohibit homeowner and golf course use of nitrate-nitrogen and to substitute ammonia or urea fertilizers for use in increasing lawn fertility. Another source of both nitrogen and phosphorus could be eliminated by reducing the amount of lawn clippings and tree litter which could be transported to the lakes by urban runoff.

In urban areas, the first rains and runoff usually contain significant quantities of dissolved solids, including troublesome amounts of nitrogen and phosphorus. Thus, it might be advantageous from the standpoint of eutrophication to collect the first stormwater runoff and treat it with the sewage. After the first flush, stormwater could then be directed through the lakes to achieve mixing and washout of accumulated bottom sediments.

During periods of low rainfall, when phosphorus would be expected to accumulate in lakes and concentrations of phosphorus approach those known to cause blooms under laboratory conditions, it might become desirable to use phosphorus precipitating chemicals to lower the phosphorus level below the critical value.

Soil renovation of wastewater is also practical under some circumstances. It may be that the recreational lakes should be designed so that groundwater serves as the primary source of recharge. Stormwater and sewage effluent could be percolated through and renovated by a spreading basin before going to the lakes as groundwater.

The above possible strategies represent only a few that could be utilized in maintaining a desired water quality in The Woodlands lakes. These strategies may be neither necessary nor financially justifiable unless there is high expectation that one or more will help control eutrophication. The design of a lake management program which will maintain the aesthetic and recreational values of the lakes can only be achieved through a detailed study of the biological and chemical components of that habitat.

EDAPHIC ALGAE

As members of the terrestrial microbiota, algae may function in the formation and stabilization of soils (37,38). Some blue-green algae, notably species of Nostoc and Anabaena, contribute to soil fertility through nitrogen fixation (39,40,41), and metabolites excreted by algae may be utilized by other microorganisms (38,42). Even though edaphic algae occupy such important positions in the ecology of terrestrial habitats, they have received relatively little attention from phycologists. Relationships between edaphic algae, soil pH, soil type, and macrovegetation have been determined for various surface soils in the United States (43,44,45,46,47,48,49). Few publications (41,50,51,52) deal with standing crops of edaphic algae, and there is a paucity of information on the distribution of algae with depth in soils of the United States (52,53,54,55). Previous work on the relationships between the distribution of soil algae and the chemistry of soils is unknown to the authors.

Thus, an investigation was conducted to determine the effects of various types of land usage on distribution of edaphic algae. Qualitative and quantitative determinations of soil algal populations, as related to soil chemistry and soil depth, were made for several disturbed and undisturbed soils. The ability of water leachates from various soils to support algal growth was also evaluated.

Fifty-one sites were selected for collection of surface soil samples (Figure 26). Twenty-five sites were located in disturbed and 26 in undisturbed portions of the study area. Since some of the sites were situated in and around the Conference Center Lakes, a more detailed map of their distribution is presented in Figure 27. Samples were taken from the lake basins before inundation. A description of each site is presented in Table 17.

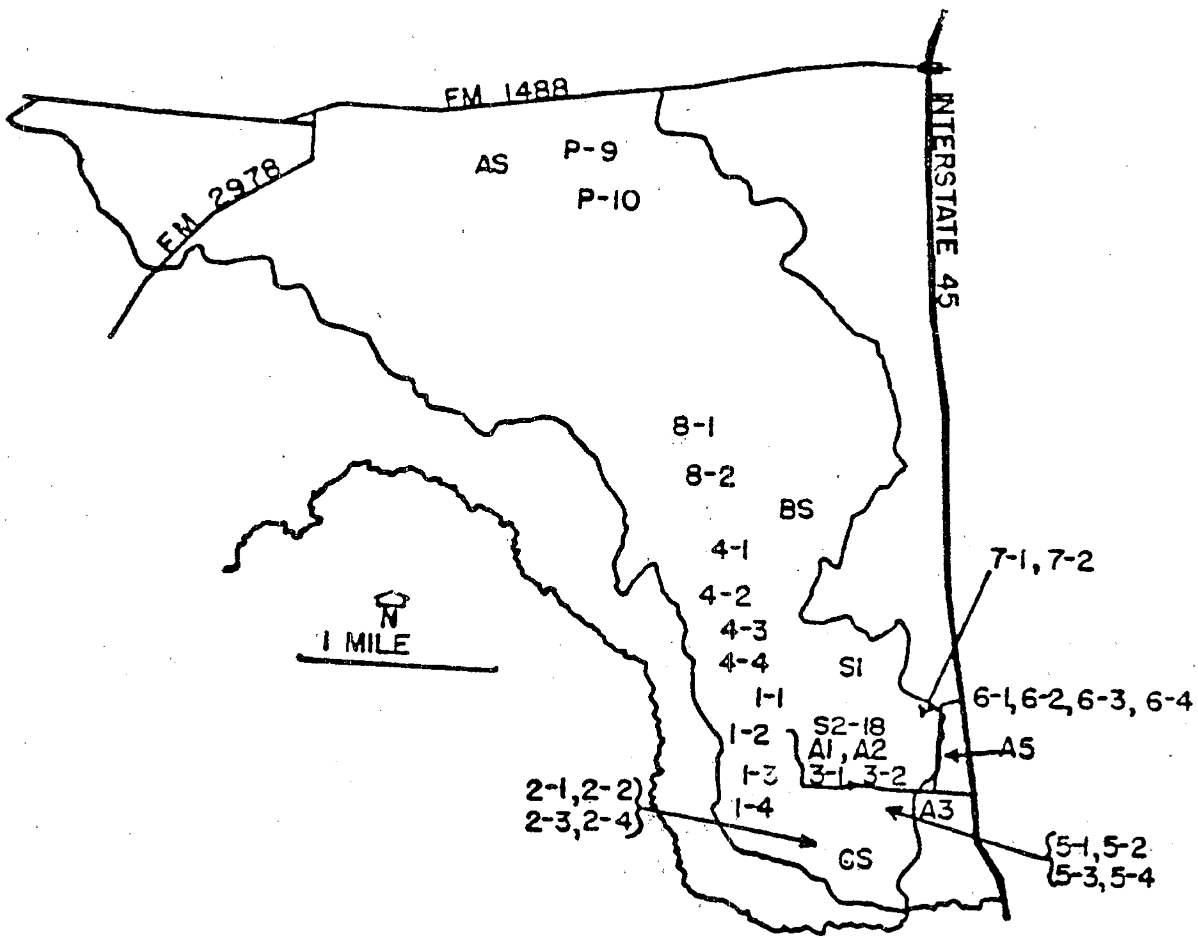

Figure 26. Location of soil collection sites.

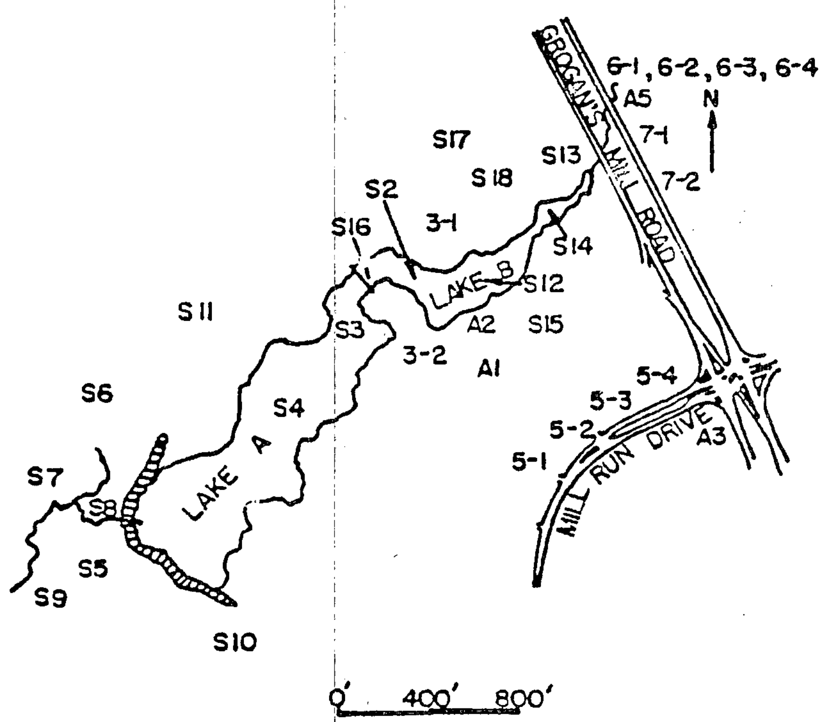

Figure 27. Location of soil collection sites in Conference Center Lakes area.

TABLE 17. DESCRIPTION OF SOIL COLLECTION SITES

Site No.	Description	Disturbed	Fertilized	pH
S1	Woods	-	-	6.9
S2	Lake Basin	+	-	6.7
S3	Lake Basin	+	-	6.7
S4	Lake Basin	+	-	6.9
S5	Woods	-	-	6.3
S6	Woods	-	-	6.2
S7	Woods	-	-	6.0
S8	Woods	-	-	5.8
S9	Lake Basin	+	-	6.7
S10	Woods	-	-	5.9
S11	Woods	-	-	5.6
S12	Lake Basin	+	-	7.1
S13	Woods	-	-	5.9
S14	Lake Basin	+	-	6.8
S15	Woods	-	-	6.2
S16	Lake Basin	+	-	7.4
S17	Woods	-	-	5.3
S18	Woods	-	-	6.4
A1	Woods	-	-	6.2
A2	Lake Shoreline	+	-	6.6
A3	Woods	-	-	6.0

(continued)

TABLE 17 (continued)

Site No.	Description	Disturbed	Fertilized	pH
A4	Roadside	+	+	6.7
A5	Swale	+	+	7.7
P-9	Woods	-	-	6.0
P-10	Woods	-	-	5.9
1-1, 1-2, 1-3, 1-4	Golf Course	+	+	7.2, 7.0*, 7.1, 6.4
2-1, 2-2, 2-3, 2-4	Woods	-	-	6.0, 5.3, 5.7, 6.2
3-1, 3-2	Lawn	+	+	8.1, 7.7
4-1, 4-2, 4-3, 4-4	Woods	-	-	6.8, 6.9, 6.9, 6.8
5-1, 5-2, 5-3, 5-4	Roadside	+	+	6.4, 6.7, 6.5, 7.8
6-1, 6-2 6-3, 6-4	Swale	+	+	8.8, 8.5 8.7, 7.2
7-1, 7-2	Roadside	+	+	8.5, 8.5
8-1, 8-2	Woods	-	-	7.0, 7.0
AS	Woods	-	-	5.7
BS	Woods	-	-	6.3
CS	Woods	-	-	6.1

- indicates no

+ indicates yes

* pH values respective to Site No.

Representatives of 52 genera of algae were identified from 153 surface samples of soils collected from the 51 sites in the study area (Table 18). The majority of genera, in both disturbed and undisturbed soils, were members of the Chlorophyta, while only three genera belonged to the Euglenophyta. Chlamydomonas, Chlorococcum, Oscillatoria, and Phormidium were ubiquitous, while several algae (Anabaena, Gloeotrichia, Pyrobotrys, and Scytonema) were found only in disturbed soils which had received applications of commercial fertilizer. Thirteen genera of algae (10 greens, 1 diatom, 2 euglenoids) were present only in undisturbed soils. There was no uniformity in the distribution of algae, even in soils which had been collected from similar sites. Actually, there is little reason to believe that exact uniformity of algal populations would occur in a particular soil. Thus, the possible combinations of edaphic algal communities which may develop in a particular area seem to be astronomical. All algal cells which reach a particular soil do not survive, due to their inabilities to adapt to changing physicochemical conditions or to form resistant cells. Archibald (43), on the basis of surveys of edaphic algae in closely spaced samples collected along transections, stated that there is no predictability in the distribution of soil microalgae. On the other hand, Arvik (50) reported that it is probable that an association may be found between edaphic algae and a given soil type. Exact correlations between edaphic algae and specific soil parameters will probably become

TABLE 18. SUMMARY OF EDAPHIC ALGAL DISTRIBUTION IN THE WOODLANDS

			Disturbed-fertilized			
Division	Woods	Disturbed-unfertilized	Golf Course	Swale	Road-side	Lawn
Chlorophyta	27	15	7	3	5	4
Cyanophyta	5	5	4	7	5	4
Chrysophyta	11	7	4	4	4	3
Euglenophyta	3	1	1	1	1	-
Total genera/ site	46	28	16	15	15	11

Total genera identified--52

evident only when the microalgae are identified to the species level. Unfortunately, specific identifications of algae are often laborious and time-consuming; thus, they are not feasible when large numbers of soils are being analyzed. Even so, identifications of edaphic algae to the generic level provide information for determining overall effects of land usage on algal populations.

Undisturbed soils in the study area had a greater diversity of algae, particularly green algae, than the disturbed soils. Disturbance of soils favored the development of a more diverse blue-green algal flora, probably due to increases in soil pH which accompanied soil disturbance. As shown in Table 18, soil disturbance affects the ratio of green to blue-green algae, with the number of genera of blue-green algae exceeding the number of green algae in the soils which had the highest pH values. With decreasing pH, there was a tendency toward a dominance of green algae. Floristic surveys in other regions of the United States (17,48,56) have also shown that alkaline soils favor the development of a more luxuriant blue-green algal flora than do acid soils.

The largest standing crops of edaphic algae were found in soils collected from the golf course (Table 19). Green algae were more numerous in soils with a pH of 7.3 or less, while members of the Chrysophyta outnumbered blue-green algae regardless of soil pH. Jurgensen and Davey (41) have stated that an inverse relationship exists between soil pH and algal numbers. This relationship seems to apply to disturbed soils in the study area, with the exception of soils from the roadside. Roadside collection sites were located on steep inclines, and washout of algae by surface runoff may have been responsible for reduced standing crops at these sites. However, undisturbed soils had the lowest pH and the smallest standing crop of algae. Thus, the above relationship, if it is valid, might apply only to soils collected from similar sites where pH is the major variable.

Standing crops of algae decreased with soil depth in the study area (Table 20). This inverse relationship between algal numbers and soil depth has also been noted for other soils in the United States (53,54), and surveys of vertical cores of soil (52,55) indicate that algae are not usually encountered below soil depths of 15 cm. This was the case for two sites in the study area, but at one site Chlamydomonas was found at depths of 30 cm. Soils from the latter site were water-logged for extended periods, thus providing ample moisture which perhaps facilitated active movement of algae to greater depths. Some algae may actively migrate when soil moisture is abundant, particularly if they are facultative heterotrophs. However, light availability limits most algae to surface soils, and their presence in lower strata is probably due to resistant cells which are moved by

TABLE 19. ALGAL NUMBERS (CELLS/G) IN VARIOUS SOILS IN THE WOODLANDS

Collection Site	Chlorophyta	Cyanophyta	Chrysophyta	Total
Golf course	39,629*	1,446	13,084	54,159
Lawn	17,400	7,195	12,790	37,385
Swale	8,298	4,533	22,238	35,069
Roadside	6,628	1,788	6,264	14,680
Woods	3,853	586	1,297	5,736

*figures represent average values

TABLE 20. ALGAL NUMBERS (CELLS/G) AT VARIOUS DEPTH INTERVALS IN CORE SAMPLES FROM THE WOODLANDS

Soil Depth (cm)	Collection Site*		
	AS	BS	CS
0 - 5	1,200+	4,000	1,900
5 - 10	1,600	1,500	400
10 - 15	100	2,300	100
15 - 20	0	500	0
20 - 25	0	100	0
25 - 30	0	100	0
30-35	0	0	0
35 - 40	0	0	0

*refer to Figure 26

+average of triplicate samples

percolation of water. Bold (personal communication) has found algae at depths of 244 cm in soils near Austin, Texas.

Leachates from golf course soils had the highest concentrations of nitrogen and phosphorus (Table 21), due to regular additions of commercial fertilizer (Scott's Proturf). The lawn and roadside collection sites were also fertilized, but not as heavily as the golf course. Fertilizers reached the swale soils only by way of surface runoff from fertilized areas, and decomposition of plant litter was probably the major source of nitrogen and phosphorus for the swales. Likewise, decomposition of plant debris was the primary source of nitrogen and phosphorus for soils in the undisturbed areas of the study area. In fact, the wooded areas had a thick ground cover of plant debris, and in many locations thick layers of humus were present. However, it seems that standing crops and diversity of edaphic algae are not dependent solely upon concentrations of nitrogen and phosphorus in the soils. Disturbance of soil and changes in pH, as previously discussed, are probably primary factors which influence algal distribution. For example, the undisturbed soils had a more diverse algal population but a smaller standing crop of algae than the disturbed soils, even though concentrations of nitrogen and phosphorus were higher than in most disturbed soils. Admittedly, soil leachates do not measure total nitrogen and phosphorus in the soils, but rather quantities of nitrogen and phosphorus which are readily released from soils.

TABLE 21. CHEMICAL ANALYSES OF LEACHATES FROM VARIOUS SOILS IN THE WOODLANDS

Collection Site	pH	NO_3-N (mg/l)	NO_2-N (mg/l)	O-PO_4 (mg/l)	T-P (mg/l)
Golf course	6.7*	2.84	0.260	3.42	5.41
Lawn	6.9	0.68	0.008	0.30	0.53
Swale	7.8	0.46	0.015	0.87	1.00
Roadside	7.3	1.26	0.016	0.33	0.53
Woods	6.1	1.15	0.300	0.99	2.11

*average values

In order to assess the role of undisturbed soils in providing nutrients for algal growth, bioassays were conducted with leachates from three undisturbed sites. Nitrogen and phosphorus concentrations of leachates are presented in Table 22 and the results of the bioassays are shown in Figure 28. The leachates exhibited varying abilities to support growth of the test alga. Growth was enhanced significantly by additions of phosphorus to leachates from all sites, while addition of nitrogen did not significantly influence the yield of the test alga. Thus, if undisturbed areas are inundated, phosphorus could possibly be the nutrient most limiting for algal growth. Bioassays with water from the man-made lakes in the study area indicate that phosphorus is the nutrient most limiting for algal growth. However, during periods of rainfall, significant quantities of nutrients are washed into the lakes from surrounding lawns and golf course greens. Bioassays with water collected from the lakes during periods of surface runoff indicate that nitrogen is the limiting nutrient.

TABLE 22. CHEMICAL ANALYSES OF LEACHATES FROM SURFACE SOILS UTILIZED IN ALGAL BIOASSAYS

Collection Site*	pH	NO_3-N (mg/l)	NO_2-N (mg/l)	O-PO_4 (mg/l)
AS	6.4	3.90	0.50	0.22
BS	6.9	1.54	0.96	0.30
CS	6.6	2.88	0.56	0.40

*refer to Figure 26

Since terrestrial and aquatic ecosystems are connected hydrologically, they cannot be considered as totally separate units. Surface drainage serves as a major component in this hydrologic linkage and is thus an important ecological parameter. Land usage in a watershed will determine the quality, as well as the quantity, of surface runoff; thus, influencing aquatic habitats in the watershed. In addition to providing potential nutrients for algal growth, surface drainage probably transports algal cells to aquatic habitats from surrounding soils. Since land use affects edaphic algal populations, it must also influence the diversity of algae which could be transported by surface runoff. For example, a more diverse assemblage of blue-green algae could potentially enter lakes in the study area by surface drainage from disturbed rather than undisturbed soils.

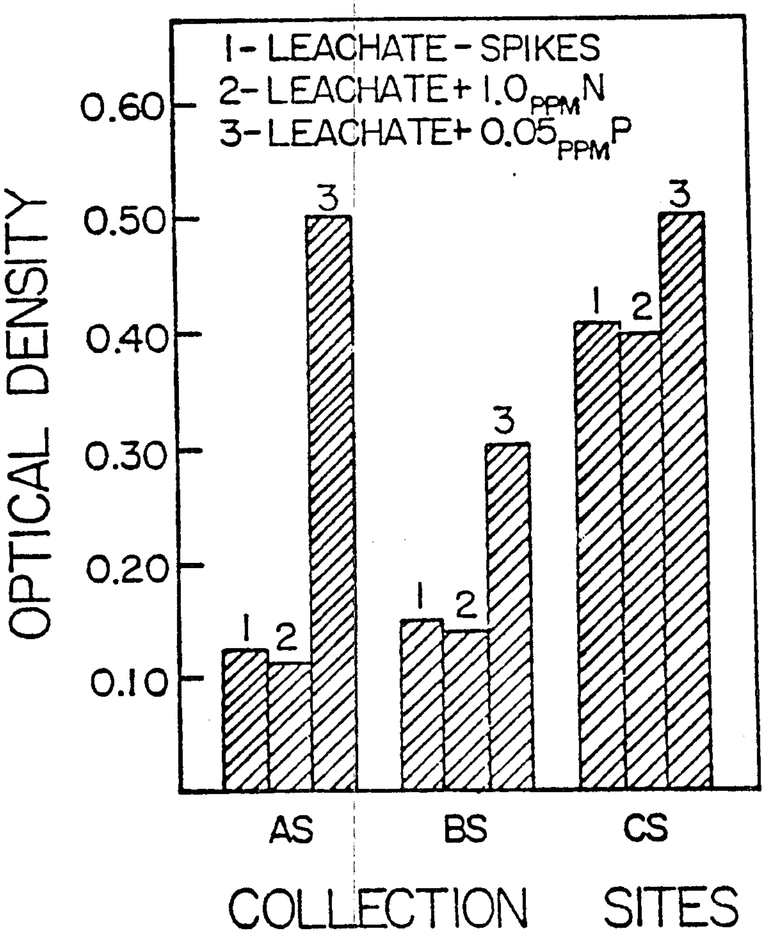

Figure 28. Growth of <u>Selenastrum</u> in leachates of various soils from The Woodlands.

AQUATIC VASCULAR PLANTS

The aquatic vascular plants of The Woodlands were not extensively investigated due to their limited distribution in the watershed. Only 15 species of aquatic macrophytes were identified and these were found in only four of the established collection sites. Of these species, only three were found in the Conference Center Lakes.

During the first year of study, the Conference Center Lakes did not develop a population of aquatic vascular plants, but during the second year, Juncus repens and Sagittaria graminea invaded the southwestern side of Lake B. However, in the third year of study, the major portion of the littoral zone of Lake B and portions of Lake A (Figure 29) developed rather extensive stands of Typha latifola, in addition to the two species mentioned above. Thus, in a three-year period, the aquatic vascular plants have invaded and spread through the littoral zone of these lakes. Unless some management strategy is instituted, there is a strong probability that these plants will totally encompass the lakes and gradually develop to nuisance levels.

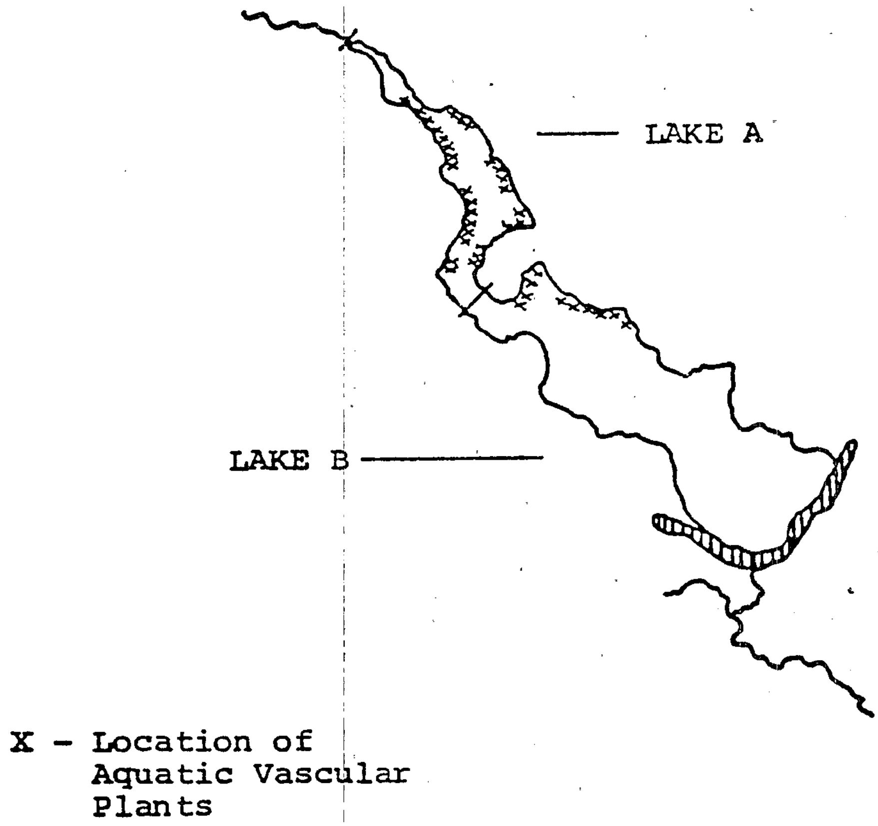

Figure 29. Distribution of aquatic vascular plants in the Conference Center Lakes.

REFERENCES

1. Edmondson, W. T. Eutrophication in North America. In: Eutrophication: Causes, Consequences, Correctives, Anon., ed. Proc. NAS-NRC Symposium, Washington, D.C., 1969.

2. Sylvester, R. O. An Engineering and Ecological Study for the Rehabilitation of Green Lake. University of Washington, Seattle, 1960.

3. Hasler, A. O. Eutrophication of Lakes by Domestic Drainage. Ecology, 28:383-395, 1947.

4. Biggar, J. W., and R. B. Corey. Agricultural Drainage and Eutrophication. In: Eutrophication: Causes, Consequences, Correctives, Anon., ed. Proc. NAS-NRC Symposium, Washington, D.C., 1969.

5. Cooper, C. F. Nutrient Output from Managed Forests. In: Eutrophication: Causes, Consequences, Correctives, Anon., ed. Proc. NAS-NRC Symposium, Washington, D.C., 1969.

6. Jackson, D. F., and H. F. A. Meier. Variations in Summer Phytoplankton Populations of Skaneateles Lakes, New York. Inst. Assoc. Theor. Appl. Limnol., Proc., 16:173-183, 1966.

7. Palmer, M. C. Algae in Water Supplies of the United States. In: Algae and Man, D. F. Jackson, ed. Plenum Press, New York, 1964.

8. Schwimmer, D., and M. Schwimmer. Algae and Medicine. In: Algae and Man, D. F. Jackson, ed. Plenum Press, New York, 1964.

9. Rose, E. T. Toxic Algae in Iowa Lakes. Proc. Iowa Acad. Sci., 60:738-745, 1953.

10. Olson, T. A. Water Poisoning - A Study of Poisonous Algae Blooms in Minnesota. Am. J. Health, 50:883-884, 1960.

11. Moore, G. T., and K. F. Kellerman. A Method of Destroying or Preventing the Growth of Algae and Certain Pathogenic Bacteria in Water Supplies. U.S.D.A. Bureau Plant Industries Bull. 64, 1904.

12. Anon. Eutrophication: Causes, Consequences, Correctives. Proc. NAS-NRC Symposium, Washington, D.C., 1969.

13. Keer, P. C., et al. The Interrelation of Carbon and Phosphorus in Regulating Hetertropic and Autotrophic Populations in Aquatic Ecosystems. Proc. 25th Purdue Industrial Waste Conference, 1970.

14. Keuntzel, L. E. Bacteria, Carbon Dioxide, and Algal Blooms. J. Wat. Poll. Control Fed., 41:1737, 1969.

15. Lee, F. An Approach to the Assessment of the Role of Phosphorus in Eutrophication. Presented to the American Chemical Society, Los Angeles, California, 1970.

16. Shapiro, J. A Statement on Phosphorus. J. Wat. Poll. Control Fed., 42:772, 1970.

17. Keup, L. E. Phosphorus in Flowing Waters. Water Research, 2:373-386, 1968.

18. Stewart, W. D. P. Nitrogen Input into Aquatic Ecosystems. In: Algae, Man and the Environment, D. F. Jackson, ed. Syracuse University Press, New York, 1968. pp. 53-72.

19. Sylvester, R. O. Nutrient Content of Drainage Water from Forested, Urban, and Agricultural Areas. In: Algae and Metropolitan Wastes. Taft Sanit. Engr. Center Publ. No. SECTR W61-3, U.S. Public Health Service, Cincinnati, Ohio, 1961. pp. 80-87.

20. Wiebel, S. R., R. J. Anderson, and R. L. Woodward. Urban Land Runoff as a Factor in Stream Pollution. J. Wat. Poll. Control Fed., 36:914-924, 1964.

21. Goldman, C. R., and R. Armstrong. Primary Productivity Studies in Lake Tahoe, California. Verh. Int. Verein. Limnol., 17:49-71, 1969.

22. Shannon, E. E., and P. L. Brezonik. Eutrophication Analysis: A Multivariate Approach. J. Sanit. Eng. Div., Am. Soc. Civ. Engrs., 98:37-57, 1972.

23. Emery, R. M., C. E. Moon, and E. G. Welch. Enriching Effects of Urban Runoff on the Productivity of a Mesotrophic Lake. Water Research, 7:1505-1516, 1973.

24. Wetzel, R. G. Limnology, 1st ed. W. B. Saunders Co., Philadelphia, 1975. 734 pp.

25. Characklis, W. G., F. J. Gaudet, F. L. Roe, and P. B. Bedient. Final Report. Maximum Utilization of Water Resources in a Planned Community; Stormwater Runoff Quality: Data Collection, Reduction, and Analysis, EPA #802433. U.S. Environmental Protection Agency, Cincinnati, Ohio, October, 1976. 99 pp.

26. Nalewajko, C. Dry Weight, Ash, and Volume Data for Some Freshwater Planktonic Algae. J. Fish. Res. Bd. Canada, 23:1285-1288, 1966.

27. Miller, W. E., J. C. Greene, and T. Shiroyama. Application of Algal Assays to Define the Effects of Wastewater Effluents upon Algal Growth in Multiple Use River Systems. In: Biostimulation and Nutrient Assessment, E. J. Middlebrooks, D. H. Falkenborg, and T. E. Maloney, eds. Ann Arbor Science, Ann Arbor, Michigan, 1976. pp. 77-92.

28. Bellinger, E. G. A Note on the Use of Algal Sizes in Estimates of Population Standing Crops. Br. Phycol. J., 9:157-161, 1974.

29. Schelske, C. L., and E. P. Stoermer. Phosphorus, Silica, and Eutrophication in Lake Michigan. In: Nutrients and Eutrophication: The Limiting-Nutrient Controversy, G. E. Liken, ed. Special Symposium, Amer. Soc. Limnol. Oceanogr., 1:157-171, 1972.

30. Olsen, R. J., C. H. Ward, J. M. King, and S. Novak. Biological Waste Stabilization Ponds at Exxon's Baytown Refinery and Chemical Plant: System Performance and Algal Activity. Proc. 31st Ann. Purdue Industrial Waste Conference, May 4-6, 1976.

31. Kramer, J. R., S. E. Herbes, and H. E. Allen. Phosphorus: Analysis of Water, Biomass, and Sediment. In: Nutrients in Natural Waters, J. R. Kramer, ed. John Wiley and Sons, New York, 1972. pp. 51-101.

32. Morton, S. D., R. Serndu, and P. H. Derse. Natural Carbon Sources, Rates of Replenishment, and Algal Growth. In: Nutrients and Eutrophication: The Limiting-Nutrient Controversey, G. E. Likens, ed. Special Symp., Amer. Soc. Limnol. Oceanogr., 1:197-205, 1972.

33. Vollenweider, R. A. Sampling Techniques and Methods for Estimating Quantity and Quality of Biomass. In: A Manual on Methods for Measuring Primary Production in Aquatic Environments, R. A. Vollenweider, ed. Int. Biol. Program Handbook, 12:4-40, 1969.

34. Rodhe, W. Crystallization of Eutrophication Concepts in Nothern Europe. In: Eutrophication: Causes, Consequences, Corrections. Natl. Acad. Sci./Natl. Res. Council, Publ. 1700, Washington, D.C., 1969. pp. 50-64.

35. Chiaudani, G., and M. Vighi. The N:P Ratio and Tests with Selenastrum to Predict Eutrophication in Lakes. Water Research, 8:1063-1069, 1974.

36. Fitzgerald, G. P. Bioassay Analysis of Nutrient Availability. In: Nutrients in Natural Waters, H. E. Allen and J. R. Kramer, eds. John Wiley and Sons, New York, 1972. pp. 147-169.

37. Booth, W. E. Algae as Pioneers in Plant Succession and Their Importance in Erosion Control. Ecol., 22:38-46, 1941.

38. Gray, T. R. G., and S. T. Williams. Soil Microorganisms. Hafner Publishing Co., New York, 1971. 240 pp.

39. P. K. De, and L. N. Mandal. Fixation of Nitrogen by Algae in Rice Soils. Soil Sci., 81:453-458, 1956.

40. Fogg, G. E. Nitrogen-fixation by Blue-green Algae. Endeavor, 6:72-175, 1947.

41. Jurgensen, M. F., and C. B. Davey. Nitrogen-fixing Blue-green Algae in Acid Forest and Nursery Soils. Can. J. Microbiol., 14:1179-1183, 1968.

42. Lund, J. W. G. Soil Algae. In: Physiology and Biochemistry of Algae, R. Lewin, ed. Academic Press, New York, 1962. pp. 759-765.

43. Archibald, P. A. A Study of the Algal Flora of Bogs with Special Reference to the Genus Chlorococcum. Ph.D. Dissertation, University of Texas, Austin, 1969.

44. Bischoff, H. W., and H. C. Bold. Phycological Studies. IV. Some Soil Algae from Enchanged Rock and Related Algal Species. University of Texas Publ. No. 6318, Austin, Texas, 1963.

45. Cameron, R. E. Communities of Soil Algae Occurring in the Sonoran Desert in Arizona. Jour. Ariz. Acad. Sci., 1:85-88, 1960.

46. Cameron, R. E. Terrestrial Algae of Southern Arizona. Trans. Amer. Microscopical Soc., 133:212-218, 1964.

47. Dykstra, R. F., F. J. MacEntee, and H. C. Bold. Some Edaphic Algae of the Texas Coast. Texas Jour. Sci., 26:171-177, 1975.

48. Hofstetter, A. M. A Preliminary Report of the Algal Flora from Selected Areas of Shelby County. Jour. Tenn. Acad. Sci., 43:20-21, 1968.

49. King, J. M. Some Edaphic Algae from Western Wisconsin. Trans. Wis. Acad. Sci., 25:200-206, 1975.

50. Arvik, J. H. Soil Algae of Northwest Florida. Quart. Jour. Florida Acad. Sci., 33:247-252, 1970.

51. Cameron, R. E., F. A. Morelli, and G. B. Blank. Soil Studies - Desert Microflora VI. Abundance of Microflora in an Area of Soil at White Mountain Range, California. Space Programs Summary, 4:212-212, Jet Propulsion Lab., California Institute of Technology, 1965.

52. Nordin, R. N., and D. W. Blinn. Analysis of a Saline Tall-grass Prairie Ecosystem. IV. Preliminary Investigations of Soil Algae. Proc. North Dakota Acad. Sci., 25:8-17, 1972.

53. Moore, G. T., and N. Carter. Further Studies on the Subterranean Algal Flora of the Missouri Botanical Garden. Ann. Mo. Bot. Gard., 13:101-117, 1926.

54. Smith, F. B. Occurrence and Distribution of Algae in Soils. Proc. Florida Acad. Sci., 7:44-49, 1944.

55. Wilson, D., and H. S. Forest. An Exploratory Study on Soil Algae. Ecol., 38:309-313, 1957.

56. MacEntee, F. J., G. Schreckenberg, and H. C. Bold. Some Observations on the Distribution of Edaphic Algae. Soil Sci., 114:717-719, 1972.

APPENDIX

METHODS AND PROCEDURES

ROUTINE PROCEDURES

Standard research techniques were utilized in most phases of this investigation. However, detailed descriptions for routine laboratory procedures, such as cleaning and sterilization of material, filtering procedures, and organism transfer techniques, will not be discussed due to universality of their use.

LIST OF BIOLOGICAL METHODS AND MEDIA

Method	Reference
Quantitative Algal Samples	1
Sample Concentration	1
Algal Enumeration	1
Sample Preservation	1
Algal Identifications	1-12
Aquatic Macrophyte Identification	15, 16
Bold's Basal Medium	18
Edaphic Algal Isolation	17
Knop's Medium	17
Aspiration Procedure	19
Bioassay Procedure	13
Growth Measurements	13, 14
Standard Test Medium	13
Standard Test Algae	13

ALGAL PROCEDURES

Water samples for algal studies were collected from 15 sites in The Woodlands area. The samples were collected in accordance with procedures in Standard Methods (1) and were processed immediately upon return to the laboratory. Water samples for algal enumeration were collected in pre-cleaned, 3.7 liter glass bottles. Algal samples were concentrated in a Sedgwick-Rafter column (1) and algal enumeration was facilitated by use of a Whipple disc and Sedgwick-Rafter counting cell (1). When possible, at least one liter of water was concentrated to a final volume of 5 ml. Concentrated samples were preserved with Lugol's iodine (1) and each individual alga was counted as one unit.

Samples for phytoplankton identification were collected by making several horizontal hauls at each station with a plankton net (#25 mesh). Preservatives were not added to these samples. Algal species were identified by microscopic examinations of wet mounts of material and each sample was examined until no additional algae were observed. A variety of taxonomic references (1-12) were consulted for species identification.

ALGAL BIOASSAYS

Water samples for use in bioassays were also collected in pre-cleaned, 3.7 liter glass bottles. Bioassays were conducted according to the procedures in the EPA "Algal Assay Procedure Bottle Test" (13). Cotton plugged, 125 ml Erlenmeyer flasks were used as culture containers and all experiments were run under standard culture conditions. In all cases, 40 ml of treated water sample were used and every effort was expended to maintain sterile conditions in test preparation. Optical densities (650 nm) and/or dry weight determinations (14) were made at appropriate intervals during the incubation period.

The storm event samples were filtered through 0.45 μ filters and were spiked with various concentrations of nitrate-nitrogen ($NaNO_3$) and orthophosphate-phosphorus (K_2HPO_4). Sample pH was adjusted to 7 and the flasks were inoculated with _Selenastrum capricornutum_. Samples were incubated and growth measurements were made at appropriate time intervals. Additional samples from a Hunting Bayou storm event were similarly prepared and inoculated with _Anabaena flos-aquae_.

The majority of the stream low-flow samples were treated as described above. However, on one occasion, aliquots of a sample were autoclaved and inoculated with _S. capricornutum_. Other aliquots of the same sample were filtered through glass, 1.2 μ and 0.45 μ filters. The glass and 1.2 μ filtered samples were autoclaved before inoculation, while the 0.45 μ filtered aliquots were inoculated directly. The pH of some of the 0.45 μ filtered samples was adjusted before inoculation.

The standard EPA test medium (13) was used to maintain the inocula for these bioassays. Variations of this medium were also used as a test medium in conjunction with the collected water samples.

AQUATIC VASCULAR PLANTS

Aquatic vascular plants were collected by hand from the Conference Center Lakes and wet weather ponds in The Woodlands area. Collections were transported to the laboratory for sorting and identification. Species identifications were made by use of standard taxonomic references (15,16).

EDAPHIC ALGAL POPULATIONS

Fifty-one sites were selected for collection of surface soil samples. The samples were taken from the lake basins before inundation, and triplicate samples were collected at each site. Soil samples were collected by use of a small garden trowel and were placed in sterile plastic bags for transport to the laboratory. To minimize carry-over from sample to sample, the trowel was wiped clean, immersed in alcohol and flamed after each sampling. In the laboratory, each sample was divided aseptically into four 20 g portions. Two of the portions were placed in separate 125 ml Erlenmeyer flasks containing 100 ml of sterile Knop's Medium (17), while the remaining two were placed in similar flasks of sterile Bold's Basal Medium (BBM) (18). The prepared flasks were placed in a controlled environment culture chamber at a temperature of 23 ± 1°C. An incident light of 400 ft-c was provided by 40 w cool-white fluorescent light bulbs set on a 12-hr light, 12-hr dark cycle. These conditions will hereinafter be referred to as standard culture conditions. After two weeks, the contents of each flask were examined microscopically and the algal genera were tabulated. The observations were repeated every week for a period of six weeks. Samples of algae were also removed from each flask and suspended in separate tubes of liquid BBM. The contents of each tube were aspirated (19) over duplicate petri dishes containing sterile BBM solidified with 15 g agar. The seeded dishes were then incubated under standard culture conditions. Upon examining the agar surfaces at two weeks, dissimilarities in colonial morphology were noticed. Portions of the various colonies were removed from the agar surface by means of sterile Pasteur pipettes, drawn to fine bores in a microflame, and placed in culture tubes containing sterile liquid BBM. When growth appeared in these tubes, the algae were studied and identified to the generic level.

Algal numbers were determined by placing 2 g of soil in 100 ml of sterile liquid BBM. The contents of the flasks were mixed thoroughly and 1 ml was pipetted aseptically onto the surface of sterile BBM agar. The inoculum was spread with a sterile transfer loop and the plates were incubated under standard culture conditions. After ten days, the number of colonies belonging to the Chlorophyta, Cyanophyta, and Chrysophyta were determined with the aid of a dissecting microscope. Triplicate plates were used for each soil tested.

Soil leachates, for use in chemical analyses and algal bioassays, were obtained by placing 250 g of oven-dried soil in vertical, plexiglass columns (length, 75 cm; internal diameter, 4.5 cm) which had their lower ends plugged with rubber stoppers. Each stopper was equipped with a glass tube to allow for passage of effluent water. Sterile glass wool was placed between the stopper and soil to permit movement of water without loss of soil from the column. Once the column had been prepared, 100 ml of deionized water were placed over the soil. The first 100 ml of effluent water were discarded and the next 500 ml were collected in pre-cleaned glass bottles. The effluent was filtered through prewashed, 0.45 μ Gelman filters, and portions of the filtrates were analyzed for NO_3-N, NO_2-N, O-PO_4, and total phosphorus with a Technicon Autoanalyzer.

Soil samples were collected from various depths by use of a metal core sampler (length, 70 cm; internal diameter, 4.5 cm). Two-inch sections were removed from the collected soil column and each was wrapped in a sterile plastic bag. The bore of the core sampler was swabbed between collections to prevent carryover of organisms from sample to sample. In the laboratory, the outer layers of each sample were removed and discarded. The remaining soil was mixed thoroughly and algal numbers were determined by the procedures outlined above. Triplicate core samples were collected at each of three collection sites.

Methods used in the batch culture bioassays with filtrates of soil leachates were similar to those described in "Algal Assay Procedure Bottle Test" (13). Forty-milliliter portions of each filtrate were transferred to sterile 125 ml Erlenmeyer flasks. Three flasks were used as controls (no added nutrients), while other sets of three flasks were spiked with nitrogen (1 mg/l N as $NaNO_3$), and/or phosphorus (0.05 mg/l P as KH_2PO_4). The prepared flasks were seeded with Selenastrum capricornutum (EPA culture), and initial cell concentrations were adjusted so that each flask contained 1×10^3 cells/ml. Cotton plugs were used as closures for the flasks and each flask was shaken daily for mixing. Algal growth was determined with a Beckman Spectrophotometer (650 nm) after 21 days incubation.

WATER CHEMISTRY

All chemical parameters were measured in the Water Chemistry Laboratory, Rice University, under the direction of Dr. F. L. Roe.

APPENDIX

REFERENCES

1. Standard Methods for the Examination of Water and Wastewater, 13th ed. A.P.H.A., W.P.C.F., A.W.W.A., 1971.

2. Huber-Pestalozzi, G. Das Phytoplankton des Susswassers. In: Die Binnengewasser, A. Thienemann, ed. Schweizerbart'sche Verlazsbuchhandlunz, Stuttgart, 1938-1961.

3. Patrick, R., and C. W. Reimer. The Diatoms of the United States, Exclusive of Alaska and Hawaii, Vol. 1, Monograph No. 13. Acad. Nat. Sci., Philadelphia, Pennsylvania, 1966. 688 pp.

4. Prescott, G. W. Algae of the Western Great Lakes Area, revised ed. William C. Brown Co., Publishers, Dubuque, 1962. 977 pp.

5. Smith, G. M. Phytoplankton of the Inland Lakes of Wisconsin, Part I. Wisconsin Geol. Nat. Hist. Surv. Bull. No. 57. Madison, 1920. 243 pp.

6. Smith, G. M. Phytoplankton of the Inland Lakes of Wisconsin, Part II. Wisconsin Geol. Nat. Hist. Surv. Bull. No. 57. Madison, 1924. 227 pp.

7. Smith, G. M. The Freshwater Algae of the United States, 2nd ed. McGraw-Hill Book Co., Inc., New York, 1950. 719 pp.

8. West, G. S., and W. West. A Monograph of the British Desmidiaceae, Vols. 1-4. The Roy. Soc., London, 1904-1912.

9. West, G. S., W. West, and N. Carter. A Monograph of the British Desmidiaceae, Vol. 5. The Roy. Soc., London, 1923.

10. West, G. S., and F. E. Fritsch. A Treatise on the British Freshwater Algae. Bibliotheca Phycologica, Ban 3, 1968. 534 pp.

11. Tiffany, L. H., and M. E. Britton. The Algae of Illinois. University of Chicago Press, Chicago, 1952. 407 pp.

12. Gomont, M. Monographic Des Oscillariees. Annales des Sciences Naturelles, VII, 15:256-263, 1892.

13. Algal Assay Procedure Bottle Test. National Eutrophication Research Program, U.S. Environmental Protection Agency, August, 1971. 82 pp.

14. Sorokin, C. Dry Weight, Packed Cell Volume and Optical Density. In: Handbook of Phycological Methods, J. R. Stein, ed. Cambridge University Press, Oxford, 1973. 448 pp.

15. Correll, D. S., and H. B. Correll. Aquatic and Wetland Plants of Southwestern United States. Water Pollution Control Research Series, No. 1630 DNL 01/72, U.S. Environmental Protection Agency, 1972. 1777 pp.

16. Hotchkiss, N. Underwater and Floating-Leaved Plants of the United States and Canada. Resource Publication 44. U.S. Department of Interior, Bureau of Sport Fisheries and Wildlife, Washington, D.C., 1967.

17. MacEntee, F. J. A Preliminary Investigation of the Soil Algae of Northeastern Pennsylvania. Soil Science, 110: 313-317, 1970.

18. Nichols, H. W. Growth Media - Freshwater. In: Handbook of Phycological Methods, J. R. Stein, ed. Cambridge University Press, Oxford, 1973. 448 pp.

19. Hoshaw, R. W., and J. R. Rosowski. Methods for Microscopic Algae. In: Handbook of Phycological Methods, J. R. Stein, ed. Cambridge University Press, Oxford, 1973. 448 pp.

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

1. REPORT NO. EPA-600/2-80-127	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE MAXIMUM UTILIZATION OF WATER RESOURCES IN A PLANNED COMMUNITY; Eutrophication Potential of Surface Waters in a Developing Watershed		5. REPORT DATE August 1980 (Issuing Date) 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) C. H. Ward and J. M. King		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Department of Environmental Science & Engineering Rice University P.O. Box 1892 Houston, Texas 77001		10. PROGRAM ELEMENT NO. 35B1C,DU No.B-124,Task 404202 11. ~~CONTRACT~~/GRANT NO. 802433
12. SPONSORING AGENCY NAME AND ADDRESS Municipal Environmental Research Laboratory--Cin.,OH Office of Research and Development U.S. Environmental Protection Agency Cincinnati, Ohio		13. TYPE OF REPORT AND PERIOD COVERED Final 7/73 - 12/76 14. SPONSORING AGENCY CODE EPA/600/14

15. SUPPLEMENTARY NOTES See also EPA-600/2-79-050a,b,c,d,e,f and EPA-600/2-80-113
Project Officers: Richard Field (201) 321-6674 - FTS 3-340-6674
Anthony N. Tafuri (201) 321-6676 - FTS 8-340-6676

16. ABSTRACT The purpose of this research was to characterize the algal populations in a developing area (The Woodlands) to evaluate the impact of urbanization on the aquatic flora in The Woodlands. Several aquatic habitats were sampled on a regular basis to identify factors which influence algal population dynamics. Nutrient limitation studies were conducted to determine which nutrient was most limiting for algal growth during conditions of low flow and stormwater runoff. Water from Hunting Bayou and Westbury Square, developed communities near Houston, Texas, were used in bioassay experiments. The impact of urbanization on edaphic algal populations was also determined. Nutrient limitation studies in Panther Branch and the Conference Center Lakes showed that phosphorus additions to low-flow water increased algal cell yields, while yields in stormwater samples were increased by nitrogen additions.

Undisturbed soils had more diverse algal populations, but smaller standing crops, than disturbed soils, even though concentrations of nitrogen and phosphorus were higher than in most disturbed soils. Soil disturbance caused development of a more diverse blue-green algal flora, probably due to accompanying increases in soil pH. Bioassays showed that phosphorus was the nutrient most limiting for algal growth in water leachates of soils.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Water resources, Urbanization	Aquatic flora, Nutrient limitation data, Algal growth, Nutrient loadings, Water leachates, Edaphic algae, Phytoplankton dynamics, Algal bioassays, Eutrophication	13B

18. DISTRIBUTION STATEMENT Release to public	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 97
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

EPA Form 2220-1 (Rev. 4-77)

☆ U.S. GOVERNMENT PRINTING OFFICE: 1980--657-165/0147

Environmental Protection
Agency

Information
Cincinnati OH 45268

Fees Paid
Environmental
Protection
Agency
EPA-335

Official Business
Penalty for Private Use, $300

Special Fourth-Class Rate
Book

Please make all necessary changes on the above label, detach or copy, and return to the address in the upper left-hand corner.

If you do not wish to receive these reports CHECK HERE ☐; detach, or copy this cover, and return to the address in the upper left-hand corner.

EPA-600/2-80-127