United States
Environmental Protection
Agency

Great Lakes National
Program Office
536 South Clark Street, Room 932
Chicago, IL 60605

EPA-905/9-81-003
May, 1981

# environmental impact of land use on water quality

Final Report on the Black Creek Project
Phase II

# FOREWORD

The U.S. Environmnental Protection Agency was created because of increasing public and governmental 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 Great Lakes National Program Office(GLNPO) of the U.S. EPA was established in Region V, Chicago, to provide specific focus on the water quality concerns of the Great Lakes. The Section 108(a) Demonstration Grant Program of the Clean Water Act(PL 92-500) is specific to the Great Lakes drainage basin and thus is administered by the Great Lakes National Program Office.

Several sediment erosion-control projects within the Great Lakes drainage basin have been funded as a result of Section 108(a). This report describes one such project supported by this office to carry out our responsibility to improve water quality in the Great Lakes.

We hope the information and data contained herein will help planners and managers of pollution control agencies to make better decisions in carrying forward their pollution control responsibilities.

Madonna F. McGrath<br>
Director<br>
Great Lakes National Program Office

EPA-905/9-81-0
May, 1981

# ENVIRONMENTAL IMPACT OF LAND USE ON WATER QUALITY

Final Report
On the
Black Creek Project
Phase II

Prepared for

## U.S. ENVIRONMENTAL PROTECTION AGENCY

Great Lakes National Program Office
536 South Clark Street
Chicago, Illinois 60605

RALPH CHRISTENSEN
Section 108a Program

CARL D. WILSON
Project Officer

UNDER U.S. EPA GRANT NO. G 005335
To

## ALLEN COUNTY SOIL & WATER CONSERVATION DISTRICT

Purdue University, University of Illinois

TABLE OF CONTENTS

## *LIST OF CONTRIBUTORS*

*S. Amin, Graduate Research Assistant, Department of Agricultural Engineering, Purdue University*

*D. B. Beasley, Assistant Professor, Department of Agricultural Engineering, Purdue University*

*A. B. Bottcher, Assistant Professor, Department of Agricultural Engineering, University of Florida (formerly, Graduate Instructor, Purdue University)*

*P. K. Carter, Programmer, Department of Agricultural Engineering, Purdue University*

*R. F. Davila, formerly Graduate Research Assistant, Department of Agricultural Engineering, Purdue University*

*T. A. Dillaha, Graduate Instructor, Department of Agricultural Engineering, Purdue University*

*R. A. Dorich, Graduate Research Assistant, Department of Agronomy, Purdue University*

*D. R. Dudley, Division of Surveillance, Ohio Environmental Protection Agency*

*O. T. Gorman, Museum of Natural History, University of Kansas*

*L. F. Huggins, Professor, Department of Agricultural Engineering, Purdue University*

*J. R. Karr, Department of Ecology, Ethology, and Evolution, University of Illinois*

*R. E. Land, Field Coordinator, Department of Agricultural Engineering, Purdue University*

*S. B. Lovejoy, Assistant Professor, Department of Agricultural Economics, Purdue University*

*S. J. Mahler, Systems Analyst, Department of Agricultural Engineering, Purdue University*

*E. R. Miller, Department of Agricultural Engineering, Purdue University*

*E. J. Monke, Professor, Department of Agricultural Engineering, Purdue University*

*J. B. Morrison, Department of Agricultural Information, Purdue University*

*D. W. Nelson, Professor, Department of Agronomy, Purdue University*

*F. D. Parent, Graduate Research Assistant, Department of Agricultural Economics, Purdue University*

*M. A. Purschwitz, Staff Engineer, American Society of Agricultural Engineers (formerly Graduate Research Assistant, Purdue University)*

*L. A. Toth, Department of Ecology, Ethology, and Evolution, University of Illinois*

*R. Z. Wheaton, Associate Professor, Department of Agricultural Engineering, Purdue University*

*ACKNOWLEDGEMENT*

*The Board of Supervisors of the Allen County Soil and Water Conservation District wishes to express its thanks to the investigators represented in this report. In addition, special thanks is due to Reg Warner and James Lake who served as administrators during the project, and to Dan McCain, Soil Consevationist, in Allen County for the Soil Consevation Service.*

*Mick Lomont, Chairman*
*Board of Supervisors*
*Allen County SWCD*

# FINAL REPORT - BLACK CREEK II

by
J. B. Morrison

## INTRODUCTION

The Black Creek Watershed, located in Allen County Indiana, is the site of an intensive study of the impact of agricultural land use on water quality.

Under the direction of the Allen County Soil and Water Conservation District, a program of land treatment, complemented by water quality monitoring and supporting scientific studies, has been carried out since 1972, when participants in a conference on the Maumee River suggested that agricultural practices in the Maumee River Basin were contributing to the degradation of the river and of Lake Erie.

Work on the Black Creek watershed, during the first five years of the project was reported in detail in the four volume "Environmental Impact of Land Use on Water Quality," EPA 905/9-77-007 (A-D). The current report, which covers a period of three years from 1977 through 1980, is intended to summarize the findings of the initial effort, and to update those findings with results of water quality monitoring and supporting studies conducted during this period.

### Purpose of the Black Creek Project

Although the Black Creek Watershed is located in the headwaters of the Maumee River, the focus of the Black Creek Project, was, from its inception, directed at Lake Erie. In the early years of the last decade, it was fashionable to talk about the "death of Lake Erie." Lake Erie was easily identified as the most polluted of the Great Lakes. It's shallow depth, combined with the existance on its shores of highly urbanized areas such as the Cleveland and Detroit areas, and its role as the receiving body for drainage water from agricultural basins such as the Maumee, threatened the viability of the lake.

Particularly troublesome in the Western Basin were algal blooms which had as their eventual impact reduction of available oxygen for fish life.

In 1972, prior to the adoption by Congress that year of the Water Quality Act Amendments, much work to control pollution in the Lake Erie Basin had been accomplished. Municipal treatment plants throughout the basin had been updated and other improvements, including removal of phosphorus from effluent, were under construction or being planned. Regulations on industrial polluters had been tightened and were due to be tightened even more with the Water Quality Act Amendments.

Although municipalities and industries had from time to time pointed an accusing finger at agriculture as a co-equal polluter of the lake, the concept of nonpoint source pollution was not a generally understood term. Few studies had been done which attempted to relate fertilizer, cropping practice, pesticides and herbicides, and soil erosion to water quality. Generally, however, a relationship was being hypothesized. The elements of this relationship were as follows:

1. In bodies of water like Lake Erie, a major water quality problem is the growth of algae.

2. In most fresh water lakes, the availability of phosphorus is limiting to the growth of algae.

3. Phosphorus loading from point sources can be estimated and controlled.

4. It may be possible to eliminate all phosphorus from point sources without effecting algal growth, if phosphorus from nonpoint sources, primarily agriculture, is not also controlled.

Since the 1930's, agricultural conservation programs have been aimed at controlling soil erosion. The primary purpose of these programs has been to preserve the soil resource for the production of food for the current population and for future generations. The primary question posed by the Black Creek study is as follows:

Can traditional soil conservation practices be applied in such a way as to improve water quality?

Although the project concentrated on a relatively small watershed, a goal has been to apply the knowledge gained in the Black Creek Watershed to the larger area of the Maumee River Basin, so as to understand its impact on Lake Erie.

Simultaneously, the watershed was studied in several ways. Loadings of sediment and chemicals were monitored throughout the watershed to determine their impact on the chemical and physical properties of water entering the Maumee River. Monitored water quality parameters were also used to evaluate the success of individual Best Management Practices on the reduction of nonpoint source pollution. Additionally, the monitored data were used to verify a generalized model by which the present capabilities of other watersheds to control agricultural nonpoint source pollution can be assessed and with which best management practices can be planned to reduce further pollution in a cost-effective manner. At the same time, biological studies were directed toward measuring the impact of the practices installed in the first phase of the project on the biological integrity of the streams. Certain of these practices, those which altered the streams or the riparian lands adjacent to the streams, tended to disrupt the biological community in the aquatic system.

In addition, efforts have been made to assess the economic impact of agricultural pollution control programs and their social impact on the community of the Black Creek Watershed.

SELECTION OF THE BLACK CREEK WATERSHED

In selecting the Black Creek Watershed as a study area, care was taken to select a watershed to reflect as closely as possible the characteristics of the Maumee Basin. Comparisons of Black Creek and the Maumee are contained in detail in Volume II of the Black Creek Final Report (EPA 905/9-77-07-B). Here, it is sufficient to observe that proportions of land use, soil types, land capability classes, and population characteristics in the watershed are similar to those of the total basin.

## PURPOSE OF THE REPORT

The report is intended to consolidate and update materials collected during the eight year period, covered by the Black Creek Project. However, it concentrates primarily on the years between 1977 and 1980, and represents a major interim report in the total project. The organization of this report is a collection of research papers presented by project investigators. A final report, which synthesizes all of the work covered during these eight years and an additional two-year period, will be published in 1983.

The following sections are intended to summarize the research findings and implications as reported by the project investigators. Details which support their conclusions are set forth in the individual papers.

## FINDINGS OF THE BLACK CREEK PROJECT

The question most often asked about the Black Creek Project is "How much did you improve water quality?" The answer to that question is at once straight forward but extremely complex. Clearly, based on water quality monitoring results extending from 1975 through 1980, there was a reduction in sediment and sediment-related pollutants leaving the Black Creek Watershed, which can be attributed in part to the application of Best Management Practices throughout the project period. (For a complete report of the practices installed see EPA 905/9-77-007-B).

Specifically, sediment losses from the watershed declined after 1975. In addition, mean concentrations of sediment, adjusted to account for flow difference, also declined after 1975. At the same time, reductions in sediment-associated nutrients -- sediment phosphorus and sediment nitrogen -- also declined.

Losses of sediment-bound phosphorus were relatively high in 1975 (4.9 kg/ha) but averaged only about 1.1 kg/ha as the project continued. Sediment-bound nitrogen losses were also very high in 1975 (30 kg/ha) but declined to around 5 kg/ha thereafter. Some of these reductions have been shown by simulation to have been due to favorable weather patterns but an encouraging trend toward better water quality nevertheless exists.

In line with the discussion of the critical role phosphorus plays in a receiving body of water like Lake Erie, the reduction in sediment-bound phosphorus loss is significant, exceeding the reduction, if applied to the Maumee Basin, generally suggested as necessary to achieve from nonpoint sources. This suggests that the land treatment applied to Black Creek, if applied to the Basin, would achieve a worthwhile water quality purpose in addition to its soil conservation benefits.

This conclusion is reinforced by studies of the availability of sediment bound phosphorus to algae, also conducted in association with the project. Algae are unable to mine all of the phosphorus attached to sediment. As a result of these studies it was determined that most of the phosphorus which will become available to algae becomes available in the laboratory in two days. This represents 25 percent of the total sediment bound phosphorus. In two weeks, an additional 5 percent of total phosphorus becomes available to algae. Thus 30 percent of the phosphorus carried from areas like the Black Creek Watershed to Lake Erie are available to contribute to algal blooms, and the reduction of sediment bound phosphorus entering the lake. Such a reduction, which can be achieved by the implementation of Best Management Practices, is significant because up to 90 percent of the total phosphorus yield from agricultural lands is attached to sediment.

The amount of sediment lost is related to rainfall, while the average concentration is related to land conditions at the time rainfall occurs. February, March and June were the months of highest total sediment loss and were also the months of highest total loss of sediment bound nutrients. May and June were the months when sediment concentrations were highest in water leaving the watershed.

Although definite reductions were shown in the loss of sediment and sediment related nutrients. Comparable reductions were not shown in the loss of soluble forms of the nutrients. Losses of soluble inorganic phosphorus (SIP) from the watershed have increased each year since 1976. SIP losses were not correlated with runoff volumes. This finding suggests that the installation of BMPs had little effect on SIP. The increased yearly loss of SIP was probably due to increased septic tank flow in the watershed.

Soluble forms of nitrogen lost from the watershed were directly related to runoff volume. Concentrations of most forms of nitrogen did not change during the project. The installation of Best Management Practices apparently did not reduce the loss of soluble forms of nitrogen from the watershed.

In fact, the installation of Best Management Practices may have increased the loss of nitrogen as nitrate, largely as a result of the greater infiltration produced by the management practices, resulting in a higher proportion of the water leaving the watershed as a result of subsurface flow. Subsurface water provides a mechanism for greater leaching of nitrate.

Greatest losses of most soluble forms of nitrogen and soluble inorganic phosphorus occurred in the months of Feburary, March, April and December. Snowmelt runoff contributed significant amounts of soluble nutrients in February and March.

Thus, it must be concluded that as far as two of the more important pollutants associated with the Maumee River from the standpoint of Lake Erie -- phosphorus and sediment -- that, as demonstrated by the Black Creek project, a reduction can be achieved through the installation of Best Management Practices and that this reduction is sufficient to have an impact on the lake if applied in a basin-wide program.

These potential benefits have not been achieved without costs, however. These costs are of two fundamental kinds -- economic and environmental.

As detailed in Volume II of the Black Creek Final Report, the economic cost of installing Best Management Practices was not trivial amounting to $709,791. An analysis, performed on a subjective basis on the costs of practices which it was believed would have produced a comparable result indicated that the water quality benefit could have been achieved at a cost of $323,460. Projected to the Maumee Basin, this translates to a cost of $125,000,000 in 1979 dollars. Simulation studies have indicated that at least a significant portion of this cost could be avoided by greater reliance on conservation tillage as a management tool. Although relatively small amounts of funding can achieve worthwhile conservation purposes, programs to improve water quality most deal with a total system. On the scale of the Maumee River Basin, costs will be significant, even with a well designed and tightly administered plan.

The environmental costs of the project were largely experienced by the aquatic life in Black Creek, and derivitively, to some extent, the Maumee River. As a headwater stream, the natural environment for aquatic life in the stream system of the Black Creek Watershed is expected to be harsh. However, some of the construction activities such as channel grade stabilization or clearing of tall vegetation on or along the channel banks are man caused and clearly had detrimental effects on the aquatic community some of which may be long lasting. For example, the removal of near stream vegetation can result in increased water temperature, increased sunlight falling on the stream, and a resulting increase in microscopic plant life such as algae in the stream.

The fish population in the Black Creek Watershed was highly variable during the eight years for which data was collected in the project. During the period, 44 species of fish were identified, although it was unusual to find more than 20 species represented during a single fish collection period.

Very few fish species are resident in the Black Creek Watershed continuously throughout the year. Most species leave the rather harsh environment of the headwater stream during certain periods of the year and return when conditions have become more favorable.

Based on the sampling work conducted in the Black Creek, it is clear that some species declined during the construction period, while others seemed to thrive on the conditions made possible by the altered habitat. At any rate, the composition was altered and the stability of the population present before construction activities begun has probably not yet been achieved.

The conclusion is that practices which include significant channel work will have an impact on the aquatic life in the watershed and the duration and length of this impact will vary with individual species. Disturbances in the Black Creek Watershed were probably largely masked because of the availability of the Maumee River as a source of individuals to re-colonize the Black Creek Watershed. If all of the tributary streams in a significant stretch of the river had been simultaneously altered as was the Black Creek, the overall impact could have been greater. Moreover, these practices were shown to be only marginally effective in reducing sediments and channel pollution of the Black Creek stream system. In retrospect, these practices, desirable as they might seem to landowners, should not have been classified as Best Management Practices in the first place.

PERMANANCE OF TREATMENT PRACTICES IN THE WATERSHED

A question equally important to the success of the Black Creek Project in achieving water quality goals has been a question about whether water quality practices would be maintained after the cost-sharing money which encouraged their installation had been exhausted.

In general, the answer to this question has been different for structural practices than for management practices such as reduced tillage and crop residue management.

Structural practices -- waterways, drop structures, terraces -- have largely been maintained, while management-oriented practices are more likely to be abandoned. This is true despite the fact that management practices, where adapted to the conditions of the watershed, have been considered to be of less cost than structural practices.

It has been suggested that the structural practices have been maintained more faithfully because they furnish a visual reminder of a commitment made to the project. Cultural and other management related practices are more easily ignored since no permanent visual reminder is present.

Practices such as crop residue management were determined to be much more likely to be maintained by person identified as "opinion leaders" in sociological investigations than by others. This leads to two conclusions. First, the practices adopted by opinion leaders did not "filter down" to other residents of the watershed as easily as might have been hoped. Secondly, the tendency of the opinion leaders to continue practices may well have represented the greater involvement of these individuals in project planning and implementation, suggesting that in future projects, it should be a goal to involve as many landowners as possible in the planning of the project.

In general, there are indications that the awareness of individual landowners within the watershed have increased throughout the project, and there is a slightly greater tendency on the part of watershed landowners to consider that water quality may be a problem on which they are capable of contribution to the solution.

Willingness to participate in the project and maintain project practices has also been shown to be correlated with the perception of individuals about whose responsibility soil conservation ultimately is. Landowners who believe conservation to be the responsibility of the individual landowner were much more likely to participate in the project, suggesting that education programs can have an impact if successfully carried out in conjunction with watershed projects.

## CONDUCTING A LAND RELATED WATER QUALITY PROGRAM

Conducting the Black Creek Project was, to a large extent, an exercise in gaining new insights into the most efficient way to plan watershed management projects and to evaluate their results. These insights can be phrased in terms of how similar projects can be most efficiently planned and managed, and in terms of relationships that can be used to project results to larger and more complex areas.

A fundamental conclusion, based on work conducted during the first five years of the project, is that a voluntary program, supplemented with cost-sharing incentives, can be successful in encouraging the establishment of Best Management Practices in a watershed area. A corollary of this conclusion is that a locally based unit of government, such as a soil and water conservation district, can effectively manage a project which has as its ultimate objective results which extend beyond the local area.

### Monitoring and Modeling

A competent laboratory can accurately access the components of a water sample delivered to it. However, the interpretation of these results is less straight forward.

Losses of sediment and related nutrients in a watershed are very event oriented. Thus, if there is no runoff, there are no runoff associated losses. Since an ultimate goal of Black Creek Project research was focused on the Maumee River and Lake Erie, an estimate of annual loadings to the river was essential, thus it was critical that runoff events not be missed. Automated samplers were thus considered a necessity.

It can be observed that if the focus of the study had been only on the biology of the Black Creek itself unterminated samples would have been less important. Aquatic organisms do not "see" loadings; they "see" concentrations. If the materials entering the stream are not highly toxic to aquatic life, wide temporary variations in concentrations can be tolerated by fishes which inhabit headwater streams. For determining the suitability of the aquatic environment to fishes, a few, well chosen grab samples may very well be sufficient, since peak concentrations which pass so rapidly that they cannot be found by grab sampling are probably well within the time limits which can be tolerated by fish.

Both a grab sampling and an automated sampling program were simultaneously conducted in the Black Creek Watershed. Cost of the sampling program was not trivial, and in fact exceeded the cost of land treatment. While this can be justified in terms of an experimental - demonstration project like the Black Creek Project, it cannot be considered as a part of routine water quality improvement programs.

Black Creek investigators thus recommend that watershed projects be carried out with a combination of limited monitoring including appropriate fish assessments and computer based simulation modeling. A product of the Black Creek project is such a model -- the ANSWERS model -- which has been described in detail in previous reports.

Briefly, the ANSWERS model is a spatially distributed model which simulates surface and subsurface flow from a variety of elements within a watershed. The model is event oriented. It is written in a computer language, FORTRAN, which is available at most computing facilities. Since initial publication of the model, in 1977, several refinements and improvements have been made, increasing the scope of the model and adding to its reliability.

The model is capable of aiding in the evaluation of a water quality project. It is also useful in planning water quality programs, a utility which has been demonstrated in the planning of water quality measures in subwatersheds under a special conservation program in Allen County, Indiana.

One effort, which continues within the Black Creek effort, is the updating of the ANSWERS model by incorporation of more reliable data concerning the impact of various management practices on sediment loss and the loss of related nutrients, especially the individual BMP studies. Initial results of these studies indicate that all BMPs under evaluation can result in significant reductions in sediment loss over those associated with conventional tillage. However, quantification of results awaits the collection of more data.

## Other Studies

Other studies have resulted in a deeper understanding of some of the dynamics of sediment and nutrient movement within a watershed.

A study of tile drainage, began as a portion of the initial Black Creek study and discussed in the Final Black Creek Report, indicates that appropriately installed drainage in soils typical of the Maumee Basin can result in a reduction in sediment associated pollution, such as phorphorus.

In conjunction with further development of the ANSWERS model, investigations were begun into methods of accounting for the distribution of nitrogen within a watershed. Results which give good agreement with monitored data have been obtained.

Certain relationships have been established which should be useful in future studies. For example, as a part of the study relating to availability of phosphorus to algae, it was determined that this amount, for a given situation, could be readily estimated by two simple chemical tests. The amount of phosphorus extractable by ammonium floride is roughly equivalent to the amount extracted by algae in two-day incubation and the additional amount extracted by sodium hydroxyde approximates the additional amount extracted in two-week incubations.

## IMPLICATIONS OF THE BLACK CREEK PROJECT

For the agricultural nutrient of most concern to water quality planners, phosphorus, Best Management Practices such as were applied in the Black Creek Watershed can provide a significant reduction. Best Management Practices offer less promise of controlling soluble forms of nutrients such as SIP, and may, in fact, increase the amounts of soluble nitrogen which enter receiving bodies of water. Sediment, if it is a problem, can also be significantly reduced by the installation of Best Management Practices.

Intensive treatment of areas like the Black Creek Watershed would have to be coordinated on a large scale basis to have much impact on ultimate receiving waters such as Lake Erie. This implies careful planning both on a basin-wide and individual watershed levels. Computer models, such as the ANSWERS model can provide assistance in both planning and evaluating the results of treatment programs on small watersheds within the framework of a total land treatment program.

Educational efforts, and the involvement of as many landowners as possible in planning and implementing treatment programs can help insure the success of the initial efforts, and more importantly, help assure that project components will be maintained after the first flush of activity has been completed. Furthermore, proper location of BMPs can simultaneously obtain water quality benefits as well as soil conservation benefits by maintaining productivity levels.

The economic cost of treating an area as large as the Maumee Basin is not trivial and can be measured in terms of hundreds of millions of dollars. However, these costs are not uncompetitive with the equally large costs involved in the removal of comparable amounts of phosphorus from point sources of water pollution.

It is the concensus of the investigators in the Black Creek Project that the ultimate result of land treatment programs will be an environmental benefit. This benefit is not achieved without the risk of environmental damage. In fact, an agricultural watershed is always a disturbed watershed. Practices can be found which can minimize damage to the physical and chemical components of water quality. But these practices may in themselves not be beneficial to the aquatic life of the stream. If enough streams are disturbed along a waterway like the Maumee, the cumulative effect may be damage to fish life and other aquatic organisms. Some thought should therefore be given, when water quality improvement projects are planned, to designating certain areas for wildlife within the total project.

The most satisfactory areas for this purpose will probably be areas which are currently relatively undisturbed. Maintenance of small wooded areas, such as the Wertz Wood, discussed in detail in previous Black Creek reports, should be given a high priority. Parklands and natural areas, where they currently exist, should be maintained to help minimize the damage done by agricultural activities within the total basin. Popular support in the agricultural community for programs which do not make some improvements to agricultural drainage is unlikely, but, as has been shown in this project, subsurface drainage at least can also be important to maintaining improved water quality. However, projects should be planned with the intention of minimizing disturbances of stream channels and near stream vegetation. These modifications should only be undertaken when it is clear that the benefits will outweight the environmental risks they entail.

# WATER QUALITY: SEDIMENT AND NUTRIENT LOADINGS FROM CROPLAND

by

D.W. Nelson, D.B. Beasley, E.J. Monke, and R.A. Dorich

Public Law 92-500 passed in 1972 mandated that each state prepare a water quality management plan which encompasses nonpoint as well as point sources of pollution. In attempting to prepare strategies and/or plans for control of nonpoint pollution, most state and federal planning/regulatory officials became aware that relative little is known about the amounts of water pollutants originating from agricultural land or the effectiveness of techniques to control or minimize pollutant deliveries. Preliminary studies suggested that the most significant water pollutants originating from cropland are sediment, plant nutrients, and pesticides (1).

Although a number of small watersheds (<30 ha) at various locations in the eastern U.S. had been periodically monitored during the past 20 years, no monitoring of a medium size ( 1000 ha) agricultural watershed had been conducted. Furthermore, a long term study of the effects of agricultural activities on water quality was started in 1973 on a 5000 ha watershed in Allen County, Indiana. The project was funded under the Great Lakes Program, Region V U.S. Environmental Protection Agency and involved coordinated efforts of the Allen County Soil Conservation District, the Soil Conservation Service, Purdue University, and the University of Illinois. The objective of the project was to determine if water quality in the watershed and in the Maumee River could be improved by implementation of a wide range of soil conservation practices in the drainage area. For details of the project consult Lake and Morrison (2).

## MATERIALS AND METHODS

### Study Area

The 5000 ha Black Creek watershed (Figure 1) was selected for study because it was representative of the soils and land uses prevailing in the Maumee River drainage basin. Table 1 provides information on the soils and land use in the watershed. About two-thirds of the area consists of nearly level lake plain and beach ridge soils, whereas one-third of the area is gently sloping (3-6%) glacial till soils. Land use in the watershed is about 60% row crops, 30% small grain and pasture, and 10% woods, roads, and developed areas. The drainage pattern in the area consists of one natural stream (Black Creek) running from west to east and discharging into the Maumee River (Figure 1). A number of constructed drainage ditches intersecting with Black Creek are used as outlets for surface and tile drains. Most of the lake plain soils in the watershed are tile drained.

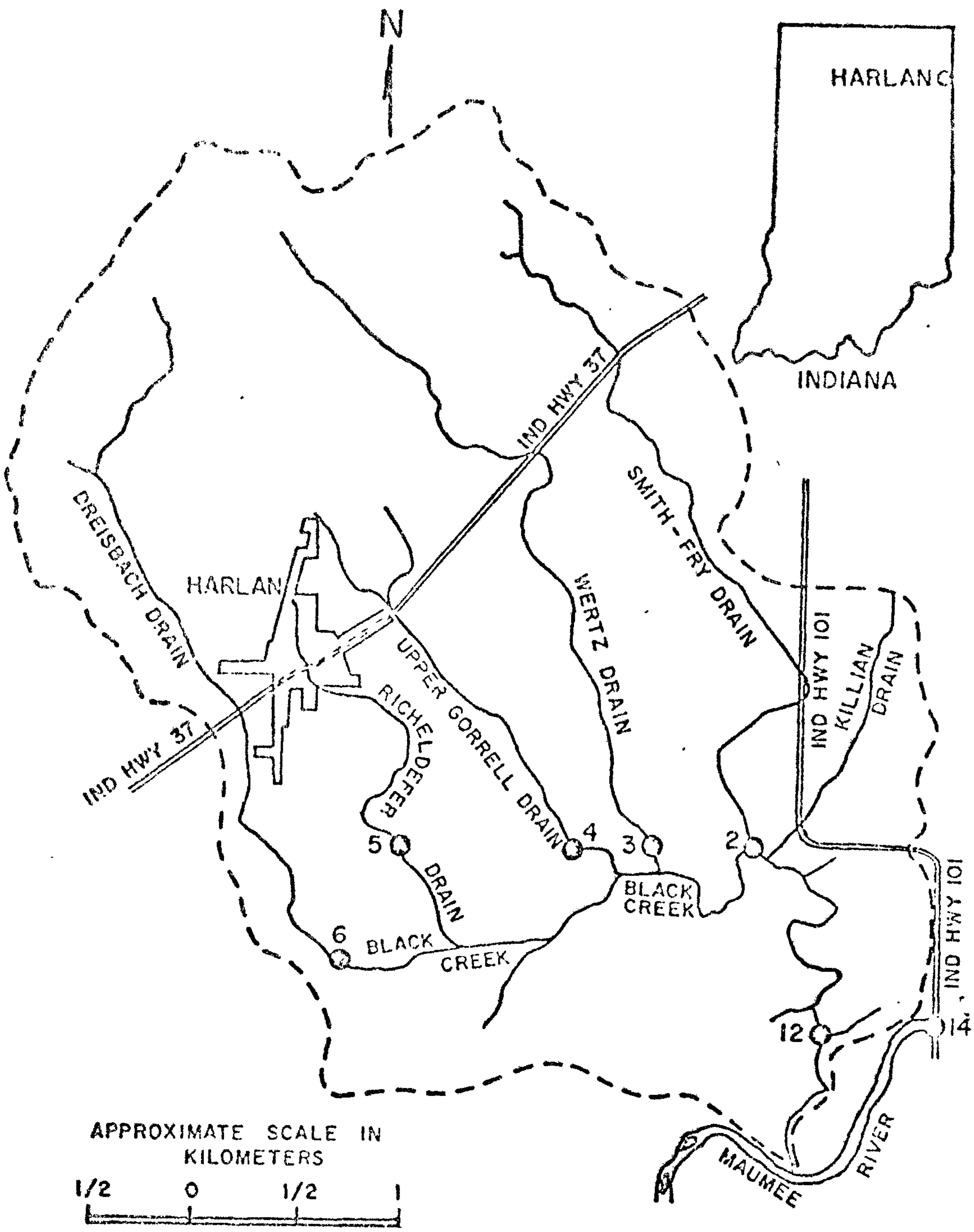



Figure 1. Map of the Black Creek study area.

Table 1. Characteristics of the Black Creek Watershed and two intensively studied drainage areas within the watershed.

| Characteristics | Black Creek Watershed | Smith-Fry Drain (Site 2) | Driesback Drain (Site 6) |
|---|---|---|---|
| Drainage area, ha | 4950 | 942 | 714 |
| Soils: | | | |
| Lake plain & beach ridge | 64% | 71% | 26% |
| Glacial till | 36% | 29% | 74% |
| Land use: | | | |
| Row crops | 58% | 63% | 40% |
| Small grain & pasture | 31% | 26% | 44% |
| Woods | 6% | 8% | 4% |
| Urban, roads, etc. | 5% | 3% | 12% |
| Number of homes: | --- | 28 | 143 |

Monitoring Systems

Grab sampling stations were established at 14 sites within the watershed and on the Maumee River to provide weekly data on the quality of water originating from soils and land uses in the drainage area above the site. Automated samplers (PS 69) and flow measuring devices were installed at three locations (Sites 2, 6, and 12) in the watershed (Figure 1) to provide continuous flow data and to permit calculation of loadings on a storm or time period basis. Meteorological conditions in the watershed were continuously monitored. A complete hydrometeorological station with automatic data acquisition and remote transmission capabilities was established at Site 6. The amount of rainfall was measured at seven other locations in the watershed and rainwater samples were collected for chemical analysis at two locations.

Temperature and dissolved oxygen concentration of water were measured *in situ* and shortly after collection pH, turbidity, and alkalinity were measured in grab samples. Water samples taken by grab or automated methods were frozen soon after collection, transported to the Water Quality Laboratory at Purdue University and analyzed for suspended solids, $NH_4^+$-N, soluble organic N, sediment-bound N, soluble inorganic P (filtered reactive P), soluble organic P, and sediment-bound P. Pesticides, alkaline earth cations, and heavy metals were measured in selected samples. Methods used for analysis of all samples were those prescribed by the American Public Health Association (3) or the U.S. Environmental Protection Agency (4).

Data Processing

Loadings of sediment and nutrients were calculated by integration of flow and concentration data on a storm, monthly, quarterly, or yearly basis. Flow weighted mean concentrations (monthly basis) were calculated by dividing the monthly load of sediment or nutrient by the monthly volume of runoff. The average total N and P concentrations in suspended sediment were calculated by dividing the monthly sediment-bound N and P loads by the monthly sediment load. The enrichment ratios for total N and P were calculated by dividing the total N and P concentrations in sediment by the average total N and P concentrations in soils present in the drainage area. Linear regression and correlation techniques (5) were used to determine the relationships between monthly or quarterly runoff volume, sediment losses, nutrient losses, and nutrient concentrations in sediment.

## RESULTS AND DISCUSSION

Reconnaissance sampling within the watershed revealed that no significant amounts of hexane-soluble pesticides were present in water, sediment, or fish tissue. Specific pesticides evaluated included aldrin, dieldrin, DDT and metabolites, atrazine, trifluralin, and 2,4,5-T (2). Analysis of weekly grab samples established that the dissolved oxygen, temperature, pH, alkalinity, and alkaline earth cations levels exhibited trends which were typical for medium size agricultural watersheds (6). Heavy metals were present in only trace concentrations (6).

### Sediment and Nutrient Loads

Table 2 provides information on rainfall, runoff, and sediment lost from the two major drainage areas in the Black Creek Watershed during the period 1975 to 1978. Precipitation was above normal in 1975, below normal in 1976, and near normal in 1977 and 1978. Runoff volumes tended to be highest during years with greatest rainfall, however, the percentage of precipitation appearing as runoff varied over the years (26% in 1975, 17% in 1976, 20% in 1977, 26% in 1978, 27% in 1979, 26% during the first half of 1980, and an average of 23% over 5 years). During the period of 1975 through 1979, sediment discharges averaged 844 and 1100 hg/ha for Sites 2 and 6, respectively. However, sediment losses in 1975 were 4 to 8 times higher than the yearly average of the other 4 years. Sediment losses during 1977 and 1978 were low (range of 380 to 544 hg/ha including both Sites 2 and 6 during 1977 and 1978) even though rainfall during these years was normal. This finding suggests that the best management practices implemented in the watershed during 1975 and 1976 resulted in reduced sediment losses in subsequent years.

Data on amounts of sediment-bound N and P discharged from the two drainage areas during 1975 to 1980 is also given in Table 2. The quantities of sediment-bound nutrients lost from the drainage areas decreased markedly after 1975, generally in proportion to reductions in sediment loss. Application of best management practices in the watershed was, at least in part, responsible for reductions in amounts of sediment-bound nutrients observed during the course of the study.

Table 2. Rainfall, runoff, and sediment and nutrient loss occurring in two drainage areas of the Black Creek watershed during the period 1975 to 1980.

| Parameter | Site no | Year | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 1975 | 1976 | 1977 | 1978 | 1979 | 1980[a] | Ave.[b] |
| Rainfall, cm | 2 & 6 | 108 | 66 | 96 | 77 | 79 | 39 | 85 |
| Runoff, cm | 2 | 29.1 | 12.4 | 18.5 | 18.5 | 23 | 12 | 20 |
| | 6 | 26.0 | 10.1 | 19.4 | 21.3 | 20 | 8 | 19 |
| Sediment loss, kg/ha | 2 | 2126 | 637 | 435 | 380 | 640 | 392 | 844 |
| | 6 | 3735 | 384 | 452 | 544 | 437 | 263 | 1110 |
| Sediment P loss, kg/ha | 2 | 5.24 | 0.98 | 1.67 | 0.65 | 0.94 | 1.19 | 1.90 |
| | 6 | 4.51 | 0.73 | 1.78 | 0.79 | 1.07 | 1.41 | 1.78 |
| Sediment N loss, kg/ha | 2 | 31.25 | 4.82 | 4.55 | 6.10 | 6.08 | 3.70 | 10.56 |
| | 6 | 28.98 | 2.86 | 4.71 | 6.91 | 5.00 | 4.78 | 9.69 |
| Sol. inorg. P loss, kg/ha | 2 | 0.14 | 0.06 | 0.14 | 0.21 | 0.22 | 0.15 | 0.15 |
| | 6 | 0.34 | 0.18 | 0.47 | 0.68 | 0.59 | 0.16 | 0.48 |
| Sol. org. P loss, kg/ha | 2 | 0.11 | 0.04 | 0.06 | 0.08 | 0.07 | 0.02 | 0.07 |
| | 6 | 0.13 | 0.04 | 0.10 | 0.35 | 0.08 | 0.05 | 0.15 |
| $NH_4^+$-N loss, kg/ha | 2 | 1.51 | 0.60 | 0.58 | 0.75 | 0.69 | 0.57 | 0.83 |
| | 6 | 1.82 | 0.85 | 1.30 | 1.06 | 1.32 | 0.56 | 1.67 |
| $NO_3^-$-N loss, kg/ha | 2 | 19.01 | 5.55 | 15.42 | 8.27 | 20.92 | 13.68 | 13.83 |
| | 6 | 11.63 | 2.39 | 12.73 | 5.96 | 9.36 | 5.41 | 8.41 |
| Sol. org. N loss, kg/ha | 2 | 2.33 | 0.93 | 1.10 | 1.66 | 1.82 | 1.05 | 1.57 |
| | 6 | 2.51 | 0.74 | 1.78 | 2.89 | 1.98 | 0.77 | 2.13 |

a 1980 averages include data only from first 6 months of 1980
b Average excludes 1980 data

Table 2 also provides data on the amounts of soluble nutrients discharged from the two drainage areas during a five and one half year period. Although the amounts of soluble inorganic P annually discharged from the drainage areas were low (<0.7 kg/ha/year), there is no indication that the amounts lost decreased with the time during the study. In fact, there was a marked increase in soluble inorganic P during 1978 and 1979. One explanation for the increase in soluble P loss at Site 6 during 1978 and 1979 is that large volumes of untreated household wastewater was discharged into the drainage ditches near Harlan during the time an interceptor sewer was being constructed. Previous studies have shown that septic tank effluents were a major source of soluble P measured at Site 6 (7). The amounts of $NH_4^+$-N, $NO_3^-$-N, soluble organic N, and soluble organic P discharged from the drainage areas each year were directly related to the volume of runoff. Losses of soluble organic P were very low (<0.13 kg/ha/year) except at Site 6 in 1978 where septic tank effluent likely contributed to the load. Soluble organic N losses were significant (0.74 to 2.78 kg/ha/year) during all years at each site and the higher losses measured at Site 6 probably reflect septic tank inputs. Losses of $NH_4^+$-N were relatively low (0.58-1.82 kg N/ha/yr) throughout the period of study except for Site 6 during 1978. Septic tank effluents were likely responsible for the higher $NH_4^+$-N losses observed at Site 6 in 1978. The amounts of $NO_3^-$-N in drainage water appeared to be related to amounts of rainfall in the watershed; i.e., loss of $NO_3^-$-N were highest in 1975, 1977, and 1979, the three years with highest rainfall. Losses of $NO_3^-$-N were relatively large (average of 13 and 8 kg N/ha/year for Sites 2 and 6, respectively) and likely reflect the fact that the watershed is tile drained and that the soils are maintained in a high state of fertility by applications of manure and inorganic N fertilizers. Although the amounts of $NO_3^-$-N discharged from the watershed were substantial, the annual flow weighted mean $NO_3^-$-N concentration never exceeded the U.S. Environmental Protection Agency drinking water standard (10 mg/liter).

The data in Table 2 suggest that adoption of best management practices to control soil erosion has not resulted in a reduction in the discharge of soluble forms of N and P from the watershed. In fact, there is an indication that losses of soluble N and P increased slightly as soil conservation practices were implemented during the study. In future projects some attention should be given to implementation of best management practices which minimize the transport in drainage water of soluble nutrients originating from cropland.

The annual discharges of sediment, sediment-bound nutrients, and soluble N from Site 2 (nearly all cropland) and Site 6 (affected by sewage) were similar to those from large river basins and some small watersheds (Table 3). However, the annual sediment losses measured at Sites 2 and 6 tended to be lower than sediment losses reported for several small (<33 ha) watersheds planted to row crops. There is little sediment deposition in small watersheds, but considerable deposition in the Black Creek area. The soluble inorganic P loadings measured at Sites 2 and 6 were similar to those reported from both river basins and for small watersheds. Soluble N ($NH_4^+$-N plus $NO_3^-$-N) loadings at Sites 2 and 6 were higher than those reported for many small watersheds. This finding likely results from $NO_3^-$-N in tile drainage water present in the Black Creek Watershed, but absent in most of the small watersheds previously studied. The higher soluble N levels also reflects the influence of septic inputs upon $NH_4^+$-N levels in samples from Site 6.

Table 3. Annual sediment and nutrient loading from selected agricultural watersheds in the United States.

| Watershed | | Land | Pollutants transported | | | | | |
|---|---|---|---|---|---|---|---|---|
| Location | Size | Use | Sediment | Sed. P | Sol. P[a] | Sed. N | Sol. N. | References |
| | ha | | -----------------kg/ha/year----------------- | | | | | |
| Ohio (Maumee River Basin)[d] | $1.639 \times 10^6$ | Mixed | 950 | 1.53 | 0.29 | -- | 13.4 | 9 |
| Ohio (Portage River Basin)[d] | $111 \times 10^3$ | Mixed | 658 | 0.84 | 0.30 | -- | 13.1 | 9 |
| Ohio (Plot 111)[d] | 3.2 | Soybeans | -- | 1.09 | 0.13 | -- | 12.3 | 9 |
| Mich. (Ave. of Plots)[e] | 0.8 | Row Crops | 12940 | -- | 0.71 | 25.8 | 2.8 | 10 |
| Georgia (Watershed P2[f] | 1.3 | Corn | 6022 | -- | -- | 10.3 | 3.7 | 11 |
| Iowa (Watershed 2)[g] | 3.3 | Corn | 9980 | -- | 0.09 | 14.8 | 1.4 | 12 |
| Oklahoma (Watershed C3)[h] | 17.9 | Cotton | 3900 | 5.6 | 1.1 | 9.7 | 1.9 | 13 |
| (Watershed 2)[i] | 1.5 | Corn Wheat Pasture | -- | -- | 0.27 | -- | 12.08 | 14 |
| Ohio (Maumee)[j] | - | Cropland | 80-5100 | 0.7-4.3 | 0.05-0.3 | | | 1 |
| Michigan (Mill Creek)[j] | - | Cropland | 20-70 | 0.1-0.3 | 0.1-0.3 | 4.3-10°C | | 1 |
| Ag Watersheds[j] | - | Cropland | 400-800 | 0.6-0.9 | 0.3-0.4 | 16-31°c | | 1 |

(a) Sol. P is soluble inorganic P (filtered reactive phosphate); (b) Sol. N is ($NH_4^+$-N + $NO_3^-$)-N; (c) Sediment-bound and soluble N combined; (d) Average of data from 1975-1976; (e) Average of data from 1974-1975; (f) Average of data from 1973-1975; (g) Average of data from 1969-1975; (h) Average of data from 1966-1976; (i) Average of data from 1968-1972; (j) Average of two years data from 1975-1977.

Sediment and Nutrient Concentrations

Rainfall, runoff, and flow-weighted mean concentrations of sediment and nutrients measured at Sites 2 and 6 during the period of 1975 through 1980 are presented in Table 4. Suspended sediment concentrations measured at Sites 2 and 6 over the 5 year period averaged 392 and 504 mg/l, respectively, and were maximal in 1975 at sites 2 and 6 (732 and 1435 mg/l, respectively). However, suspended sediment concentrations measured at Site 2 and 6 remained relatively constant throughout the rest of the study (206 to 515 and 216 to 380 mg/l, respectively). The average concentrations of sediment-bound nutrients measured at Sites 2 and 6 remained relatively constant over the period from 1976 through 1980, but were very high during 1975 (Table 4). The average sediment P concentrations measured at Sites 2 and 6 over 5 years were 0.85 and 0.65 mg/l, respectively, while sediment N concentrations averaged 4.6 and 4.42, respectively. Although peak concentrations of sediment and sediment-bound N and P were measured during 1975, soluble inorganic and organic forms of N and P did not follow the same trend. Measured soluble constituents (soluble inorganic P, organic P, $NH_4^+$-N, and soluble organic N) remained relatively constant for each constituent, measured at each site (Table 4). The exception to this is the relatively high concentrations of soluble inorganic P, organic P, $NH_4^+$-N, and organic N occurring at Site 6, during 1978, even though runoff was about average during the year. When concentrations of soluble inorganic P, organic P, $NH_4^+$-N, and organic N measured at Sites 2 and 6 are compared for each of the six years (Table 4), the concentrations measured at Site 6 always exceeded that measured at Site 2 except in one case (soluble organic P in 1976). The trend is evidenced by each of the five and one-half year averages (Table 4). Just the opposite is true for $NO_3^-$-N measurements at the two sites over the 6 year period. In very year the average $NO_3^-$-N concentrations measured at Site 2 exceeded that at Site 6. As indicated by this data, septic effluents which enter the Site 6 subwatershed had a larger effect upon the average concentrations of soluble inorganic P, organic P, $NH_4^+$-N and organic N measured in the watershed streams than did agricultural input as measured in Site 2. On the other hand, the system (Site 2 subwatershed) which was comprised primarily of agricultural drainage contained higher average concentrations of $NO_3^-$-N than was measured in a subwatershed influenced by septic effluents. This higher $NO_3^-$-N concentration measured in the largely agricultural watershed is possible evidence for the influence of tile drainage water on stream water quality.

Table 4. Rainfall, runoff, and flow weighted mean concentrations, sediment and nutrient loss occurring in two drainage areas of the Black Creek Watershed during the period 1975 to 1978.

| Parameter | Site no. | Year 1975 | 1976 | 1977 | 1978 | 1979 | 1980[a] | Ave[b] |
|---|---|---|---|---|---|---|---|---|
| Rainfall, cm | 2 & 6 | 108 | 66 | 96 | 77 | 79 | 39 | 85 |
| Runoff, cm | 2 | 29.1 | 12.4 | 18.5 | 18.5 | 23 | 12 | 20 |
| | 6 | 26.0 | 10.1 | 19.4 | 21.3 | 20 | 8 | 19 |
| Sediment, mg/l | 2 | 732 | 515 | 236 | 206 | 273 | 328 | 392 |
| | 6 | 1435 | 380 | 232 | 256 | 216 | 325 | 504 |
| Sediment P, mg/l | 2 | 1.80 | 0.79 | 0.90 | 0.35 | 0.40 | 1.97 | 0.85 |
| | 6 | 1.73 | 0.72 | 0.92 | 0.37 | 0.53 | 1.74 | 0.65 |
| Sediment N, mg/l | 2 | 10.75 | 3.89 | 2.47 | 3.30 | 2.59 | 3.10 | 4.60 |
| | 6 | 11.13 | 2.82 | 2.42 | 3.24 | 2.47 | 5.90 | 4.42 |
| Sol. inorg. P, mg/l | 2 | 0.05 | 0.05 | 0.07 | 0.12 | 0.10 | 0.13 | 0.08 |
| | 6 | 0.13 | 0.18 | 0.24 | 0.32 | 0.29 | 0.20 | 0.23 |
| Sol. org. P, mg/l | 2 | 0.04 | 0.03 | 0.03 | 0.04 | 0.03 | 0.02 | 0.03 |
| | 6 | 0.05 | 0.04 | 0.05 | 0.17 | 0.04 | 0.07 | 0.08 |
| $NH_4^+$-N, mg/l | 2 | 0.52 | 0.48 | 0.31 | 0.40 | 0.29 | 0.48 | 0.40 |
| | 6 | 0.70 | 0.84 | 0.67 | 1.44 | 0.65 | 0.69 | 0.86 |
| $NH_3^-$-N, mg/l | 2 | 6.54 | 4.49 | 8.35 | 4.48 | 8.91 | 11.45 | 6.55 |
| | 6 | 4.47 | 2.36 | 6.55 | 2.80 | 4.62 | 6.69 | 4.16 |
| Sol. org. N, mg/l | 2 | 0.80 | 0.75 | 0.60 | 0.90 | 0.78 | 0.88 | 0.77 |
| | 6 | 0.96 | 0.73 | 0.91 | 1.35 | 0.98 | 0.95 | 0.99 |

a 1980 averages include data only from first 6 months of 1980

b Average excludes 1980 data

## Average Monthly Loads

Average monthly rainfall, runoff, sediment loss and nutrient loss values measured at Sites 2 and 6 are given in Table 5 and plotted in Figures 2 through 6. Rainfall was reasonably well spread throughout the year with April, June and August having the highest monthly averages. However, as would be expected due to soil and plant cover conditions, runoff volumes were largest during the winter and early spring months (December through April) (Figure 2). Sediment losses measured at Site 2 were maximal in February, March, May and June, (Figure 2), while at Site 6 greatest sediment loss was measured in March, April, May and June (Figure 5). Highest sediment N and P losses measured at Sites 2 and 6 (Figure 3) generally occurred during the same time of year as high sediment losses. The highest monthly losses of $NH_4^+$-N, soluble organic N, inorganic P, and soluble organic P were observed in the period February through April (Figures 4 and 5). This finding suggests that snowmelt runoff and early spring rains were responsible for significant transport of soluble N and P. Some of the soluble N and P transported likely was leached from residues from the previous crop present on the soil surface at the time of snowmelt. Nitrate-N losses closely paralleled runoff measured at Sites 2 and 6 (Figure 6) indicating the importance of surface runoff, subsurface flow, and tile drainage in the export of $NO_3^-$-N from subwatersheds within the Black Creek Watershed.

Table 5. Average monthly rainfall, runoff, and sediment and nutrient losses from the drainage area during 1975-1980.[a]

| Month | Site | Rain-fall | Total runoff | Sediment lost | $NH_4^+$-N lost | $NO_3^-$-N lost | Sediment N lost | Sol. inorg. P lost | Sediment P lost |
|---|---|---|---|---|---|---|---|---|---|
| | | ----cm---- | | -------------------------- | ---------- | kg/ha | ---------- | ---------- | ---------- |
| Jan. | 2 | 3.2 | 1.01 | 23 | 0.04 | 0.83 | 0.25 | 0.004 | 0.038 |
| | 6 | | 1.00 | 46 | 0.13 | 0.54 | 0.47 | 0.017 | 0.080 |
| Feb. | 2 | 4.0 | 2.21 | 121 | 0.14 | 1.27 | 0.86 | 0.020 | 0.231 |
| | 6 | | 2.79 | 101 | 0.27 | 1.19 | 0.68 | 0.079 | 0.193 |
| Mar. | 2 | 7.6 | 5.67 | 140 | 0.26 | 3.52 | 1.63 | 0.065 | 0.344 |
| | | | 5.41 | 139 | 0.61 | 2.02 | 1.48 | 0.169 | 0.344 |
| Apr. | 2 | 8.9 | 3.15 | 93 | 0.11 | 2.55 | 0.94 | 0.017 | 0.171 |
| | 6 | | 1.32 | 181 | 0.07 | 0.58 | 1.11 | 0.010 | 0.236 |
| May | 2 | 7.3 | 1.41 | 166 | 0.08 | 0.91 | 2.38 | 0.007 | 0.356 |
| | 6 | | 1.32 | 181 | 0.07 | 0.58 | 1.11 | 0.010 | 0.236 |
| June | 2 | 10.6 | 1.61 | 121 | 0.06 | 1.68 | 2.01 | 0.010 | 0.299 |
| | 6 | | 1.24 | 312 | 0.05 | 0.67 | 2.61 | 0.012 | 0.229 |
| July | 2 | 5.6 | 0.16 | 7 | 0.01 | 0.12 | 0.06 | 0.002 | 0.013 |
| | 6 | | 0.12 | 7 | 0.01 | 0.07 | 0.07 | 0.002 | 0.015 |
| Aug. | 2 | 11.5 | 0.17 | 2 | <0.01 | 0.02 | 0.01 | 0.001 | 0.004 |
| | 6 | | 0.29 | 8 | 0.01 | 0.05 | 0.08 | 0.006 | 0.023 |
| Sept. | 2 | 6.0 | 0.34 | 10 | 0.01 | 0.13 | 0.08 | 0.003 | 0.026 |
| | 6 | | 0.31 | 10 | 0.01 | 0.09 | 0.12 | 0.010 | 0.038 |
| Oct. | 2 | 5.0 | 0.13 | 1 | <0.01 | 0.02 | 0.01 | <0.001 | 0.002 |
| | 6 | | 0.01 | 1 | 0.01 | 0.02 | 0.01 | 0.002 | 0.003 |
| Nov. | 2 | 6.4 | 0.59 | 11 | 0.02 | 0.34 | 0.14 | 0.003 | 0.039 |
| | 6 | | 0.52 | 13 | 0.08 | 0.17 | 0.15 | 0.011 | 0.048 |
| Dec. | 2 | 5.8 | 3.30 | 93 | 0.09 | 3.04 | 0.99 | 0.032 | 0.325 |
| | 6 | | 2.40 | 65 | 0.14 | 1.51 | 0.82 | 0.057 | 0.355 |
| TOTAL | 2 | 8.19 | 19.8 | 788 | 0.82 | 14.43 | 9.36 | 0.164 | 1.848 |
| | 6 | | 18.2 | 985 | 1.52 | 8.25 | 9.09 | 0.419 | 1.784 |

a First 6 months averages include 6 years of data while last 6 months include 5 years.

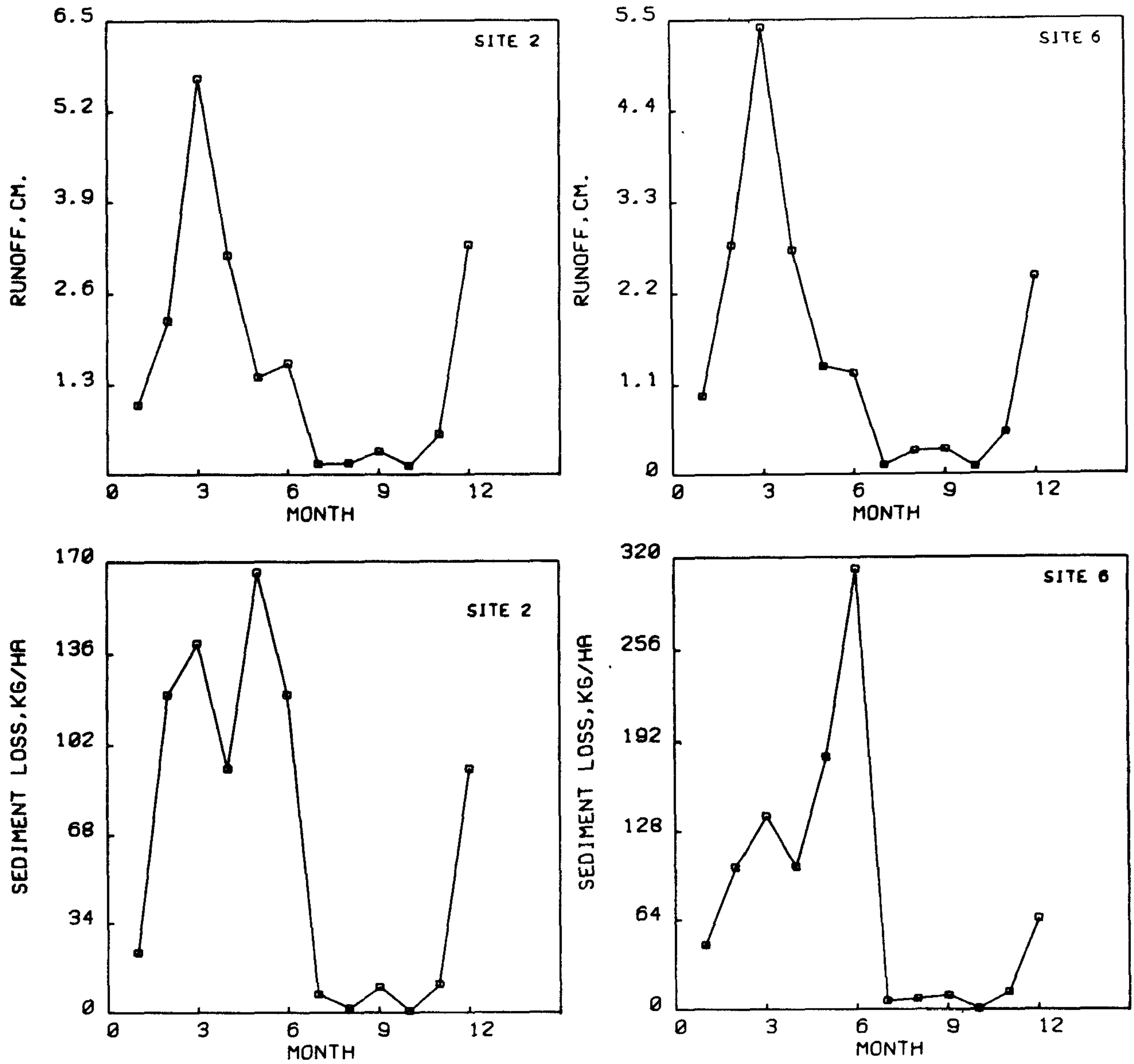



Figure 2. Average monthly runoff and sediment losses measured at Sites 2 and 6 in the watershed during the period 1975-1980.

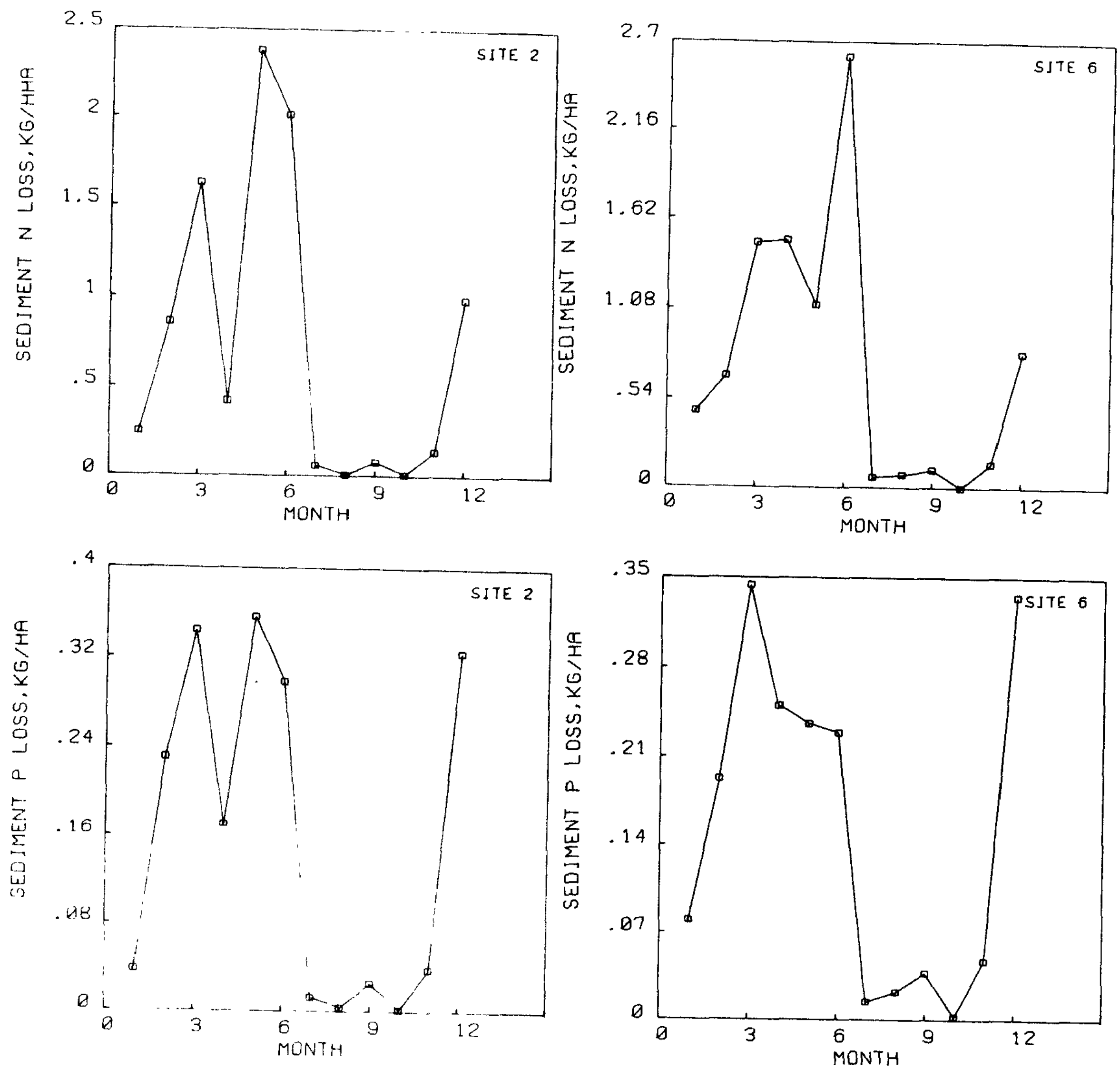



Figure 3. Average monthly sediment-bound N and P losses measured at Sites 2 and 6 in the Watershed during the period 1975-1980.

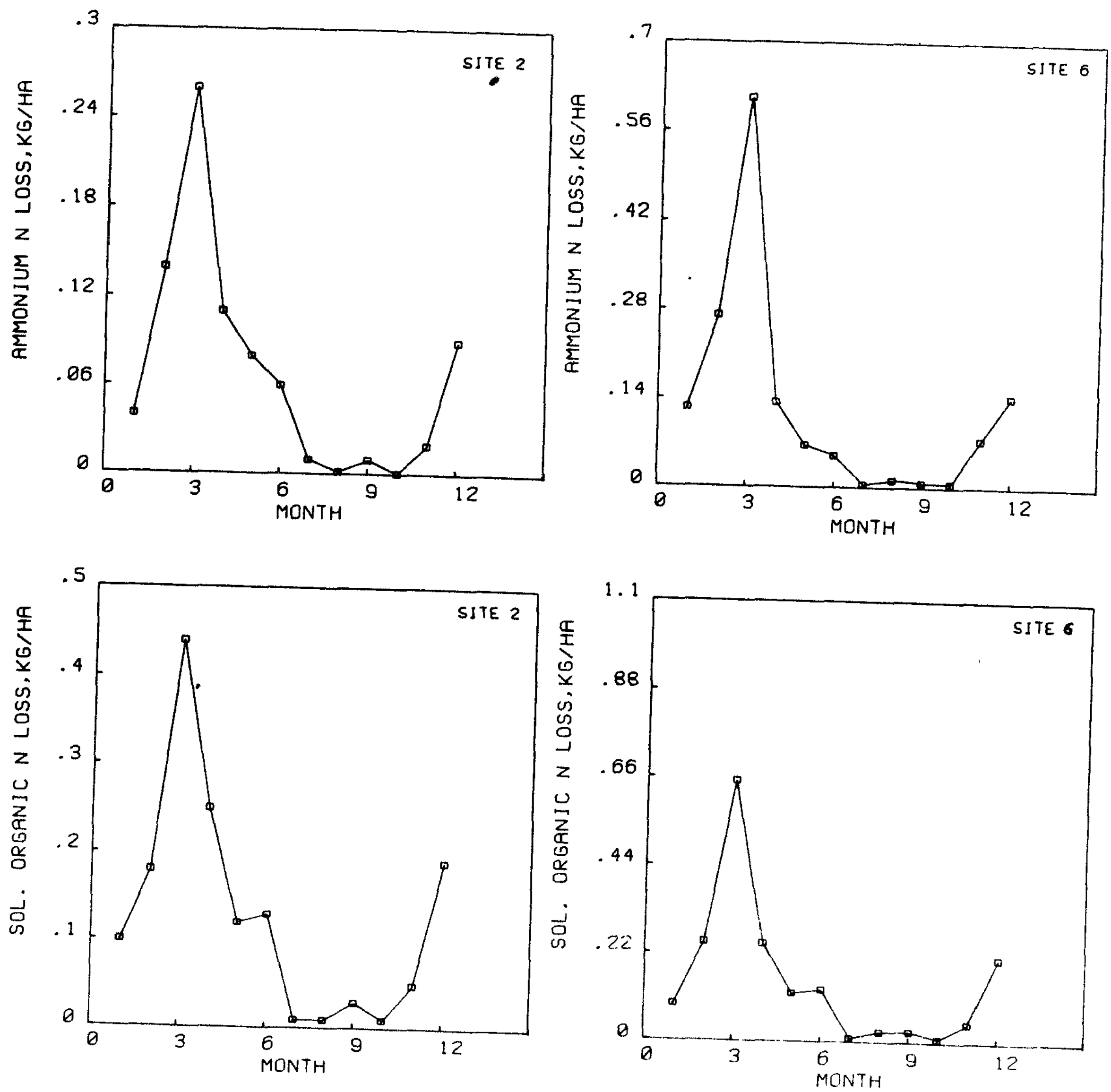



Figure 4. Average monthly ammonium N and soluble organic N losses measured at Sites 2 and 6 in the Watershed during the period 1975-1980.

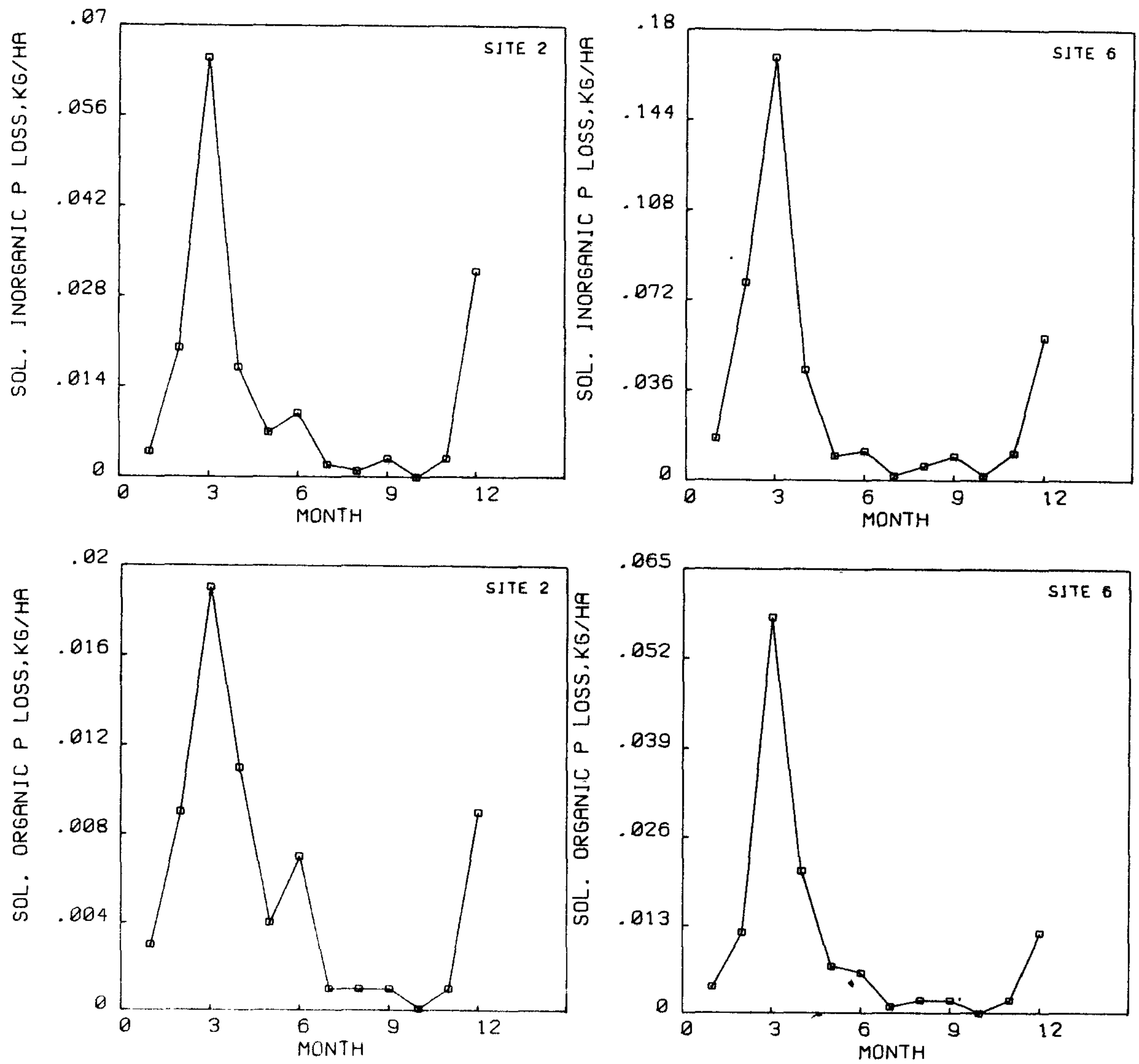



Figure 5. Average monthly soluble inorganic P and soluble organic P losses measured at Sites 2 and 6 in the Watershed during the period 1975-1980.

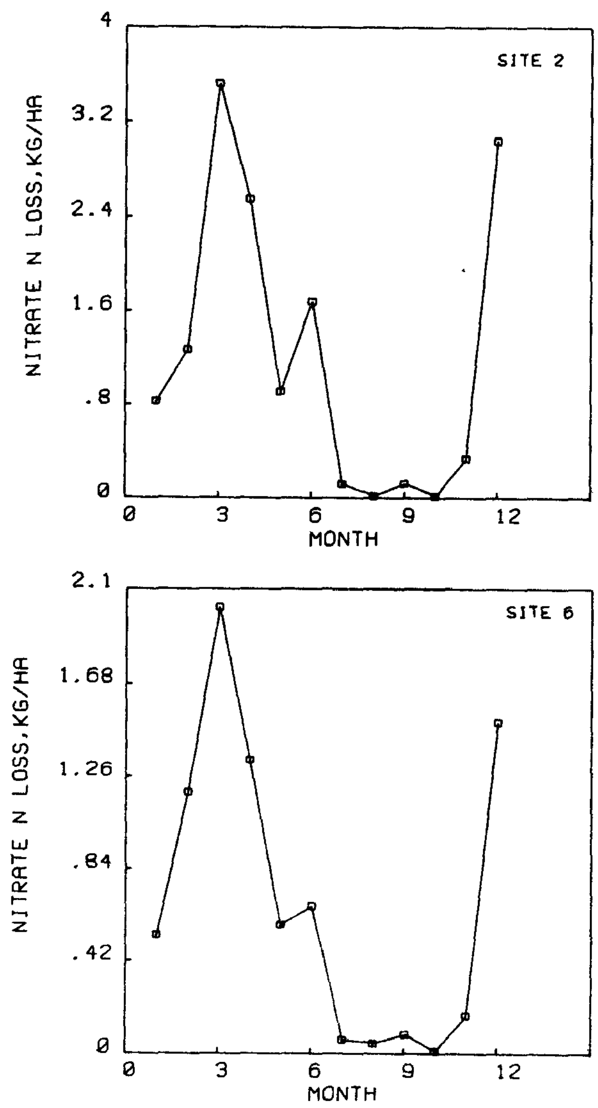



Figure 6. Average monthly nitrate N losses measured at Sites 2 and 6 in the Watershed during the period 1975-1980.

Average Monthly Flow Weighted Mean Concentrations

Average monthly flow weighted mean suspended solids and nutrient concentrations measured in drainage water at Sites 2 and 6 are given in Table 6 and Figure 7-10. Suspended solids and sediment-bound nutrients concentrations measured at Sites 2 were highest in February, April and May (Figures 7 and 8), while losses at Site 6 were highest in May, June and July (Figures 7 and 8). Fortunately, the poorest water quality from the standpoint of suspended sediment and insoluble nutrients occurred during the annual periods of highest stream flows. Soluble organic N concentrations remained relatively constant throughout the year with ranges of 0.58 to 0.99 mg/l and 0.89 to 1.21 mg/l for Sites 2 and 6, respectively. For Site 2 the highest soluble organic N concentrations occurred in January and September, Figure 8, while the highest concentrations measured at Site 6 occurred in March and June (Figure 8).

Ammonium N concentrations measured at Site 2 were highest in February and May and lowest in August and October (Figure 9). At Site 6, $NH_4^+$-N concentrations tended to be relatively low between April and September, and higher from October to March (Figure 9). Low $NH_4^+$-N concentrations in late summer reflects assimilation by algae and aquatic weed growth in the ditches throughout this period. The monthly average $NH_4^+$-N concentrations at Site 6 was usually higher than that in Site 2 demonstrating the effect of the input of sewage (Table 6). Nitrate N concentrations measured at Site 2 were highest (>8 mg/l) in January, April, June and December. Relatively low $NO_3^-$-N concentrations (<2 mg/l) were observed in Site 2 during August and October when tile drains were not running and little water was present in the ditches (Figure 9). While $NO_3^-$-N concentrations measured at Site 2 ranged widely between 1.18 and 10.44 mg/l, those at Site 6 remained relatively constant ranging between 1.63 and 6.29 mg/l (Figure 7).

Despite the algae and weed growth in the streams, soluble inorganic P concentrations at Site 2 fell below 0.04 mg/l only in October, and reached as high as 0.125 mg/l in July (Figure 10). Soluble inorganic P concentrations at Site 6 averaged below 0.163 mg/l during only 2 months and never averaged below 0.070 mg/l (Figure 10). The ability of the stream at Site 2 to maintain both relatively high concentrations of soluble inorganic P and growth of algae and aquatic weeds may be due to supply of soluble inorganic P to the water through equilibrium processes by stream sediment enriched with P. High soluble inorganic P concentrations measured at Site 6 are probably due to septic system effluents. Soluble organic P concentrations ranged from 0.001 to 0.0063 mg/l, and 0.0021 to 0.117 mg/l for Sites 2 and 6, respectively. The highest soluble organic P concentrations occurred in July and March for Sites 2 and 6, respectively.

Table 6. Average flow weighted mean concentrations of sediment and nutrients measured in two drainage areas of the Black Creek Watershed during the period from 1975 - 1980.[a]

| Month | Site | Suspended Solids | $NH_4^+$-N | $NO_3^-$-N | Sol. org. N | Sed. N | Sol. inorg. P | Sol. org P | Sed. P |
|---|---|---|---|---|---|---|---|---|---|
| | | ---------- | ---------- | ---------- | ---------- | mg/l | ---------- | ---------- | ---------- |
| Jan. | 2 | 227 | 2.40 | 8.22 | 0.99 | 2.48 | 0.040 | 0.030 | 0.376 |
| | 6 | 479 | 1.29 | 5.54 | 0.97 | 4.81 | 0.17 | 0.043 | 0.829 |
| Feb. | 2 | 548 | 0.63 | 5.74 | 0.81 | 3.89 | 0.090 | 0.041 | 1.045 |
| | 6 | 366 | 0.98 | 4.27 | 0.89 | 2.44 | 0.283 | 0.043 | 0.692 |
| Mar. | 2 | 247 | 0.46 | 6.21 | 0.78 | 2.88 | 0.5 | 0.034 | 0.607 |
| | 6 | 257 | 1.13 | 3.74 | 1.21 | 2.73 | 0.313 | 0.117 | 0.636 |
| Apr. | 2 | 295 | 0.35 | 8.10 | 0.79 | 2.98 | 0.054 | 0.035 | 0.543 |
| | 6 | 376 | 0.49 | 4.92 | 0.90 | 5.49 | 0.163 | 0.077 | 0.918 |
| May | 2 | 1177 | 0.57 | 6.45 | 0.85 | 16.88 | 0.050 | 0.028 | 2.525 |
| | 6 | 1375 | 0.51 | 4.43 | 0.93 | 8.41 | 0.072 | 0.054 | 1.791 |
| June | 2 | 752 | 0.37 | 10.44 | 0.81 | 12.48 | 0.062 | 0.043 | 1.857 |
| | 6 | 2518 | 0.41 | 5.39 | 1.07 | 21.05 | 0.098 | 0.051 | 1.847 |
| July | 2 | 438 | 0.63 | 7.50 | 0.63 | 3.75 | 0.125 | 0.063 | 0.813 |
| | 6 | 550 | 0.48 | 5.43 | 0.93 | 5.73 | 0.200 | 0.050 | 1.217 |
| Aug. | 2 | 118 | 0.12 | 0.18 | 0.59 | 0.59 | 0.059 | 0.059 | 0.235 |
| | 6 | 282 | 0.44 | 1.66 | 0.94 | 2.86 | 0.190 | 0.054 | 0.776 |
| Sept. | 2 | 294 | 0.29 | 38.2 | 0.88 | 2.35 | 0.088 | 0.029 | 0.765 |
| | 6 | 333 | 0.30 | 2.87 | 0.90 | 3.72 | 0.315 | 0.058 | 1.212 |
| Oct. | 2 | 77 | 0.08 | 1.53 | 0.77 | 0.77 | 0.001 | 0.001 | 0.154 |
| | 6 | 124 | 0.67 | 1.63 | 1.00 | 0.51 | 0.164 | 0.021 | 0.306 |
| Nov. | 2 | 186 | 0.34 | 5.76 | 0.85 | 2.37 | 0.050 | 0.017 | 0.661 |
| | 6 | 242 | 1.45 | 3.30 | 0.94 | 2.94 | 0.219 | 0.038 | 0.919 |
| Dec. | 2 | 282 | 0.27 | 9.21 | 0.58 | 3.00 | 0.097 | 0.027 | 0.985 |
| | 6 | 271 | 0.60 | 6.29 | 0.89 | 3.44 | 0.240 | 0.050 | 1.397 |
| Total | 2 | 399 | 0.42 | 7.31 | 0.77 | 4.74 | 0.083 | 0.030 | 0.936 |
| | 6 | 551 | 0.84 | 4.53 | 1.01 | 4.99 | 0.230 | 0.070 | 0.980 |

a) First 6 months averages 6 years of data, while last 6 months include only 5 years of data.

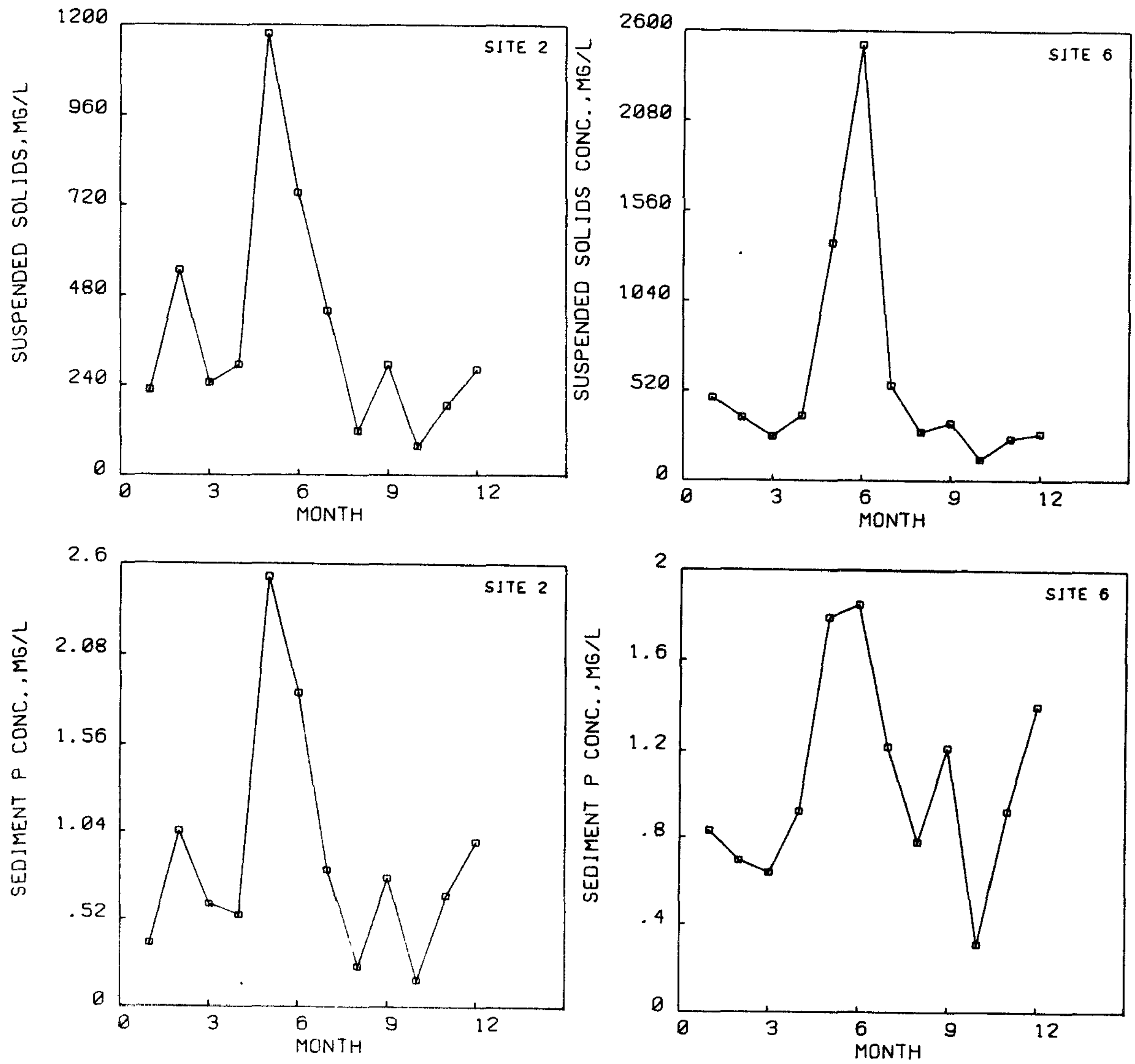



Figure 7. Average monthly flow weighted mean suspended solids and sediment P concentrations measured in drainage water at Sites 2 and 6 during the period 1975-1980.

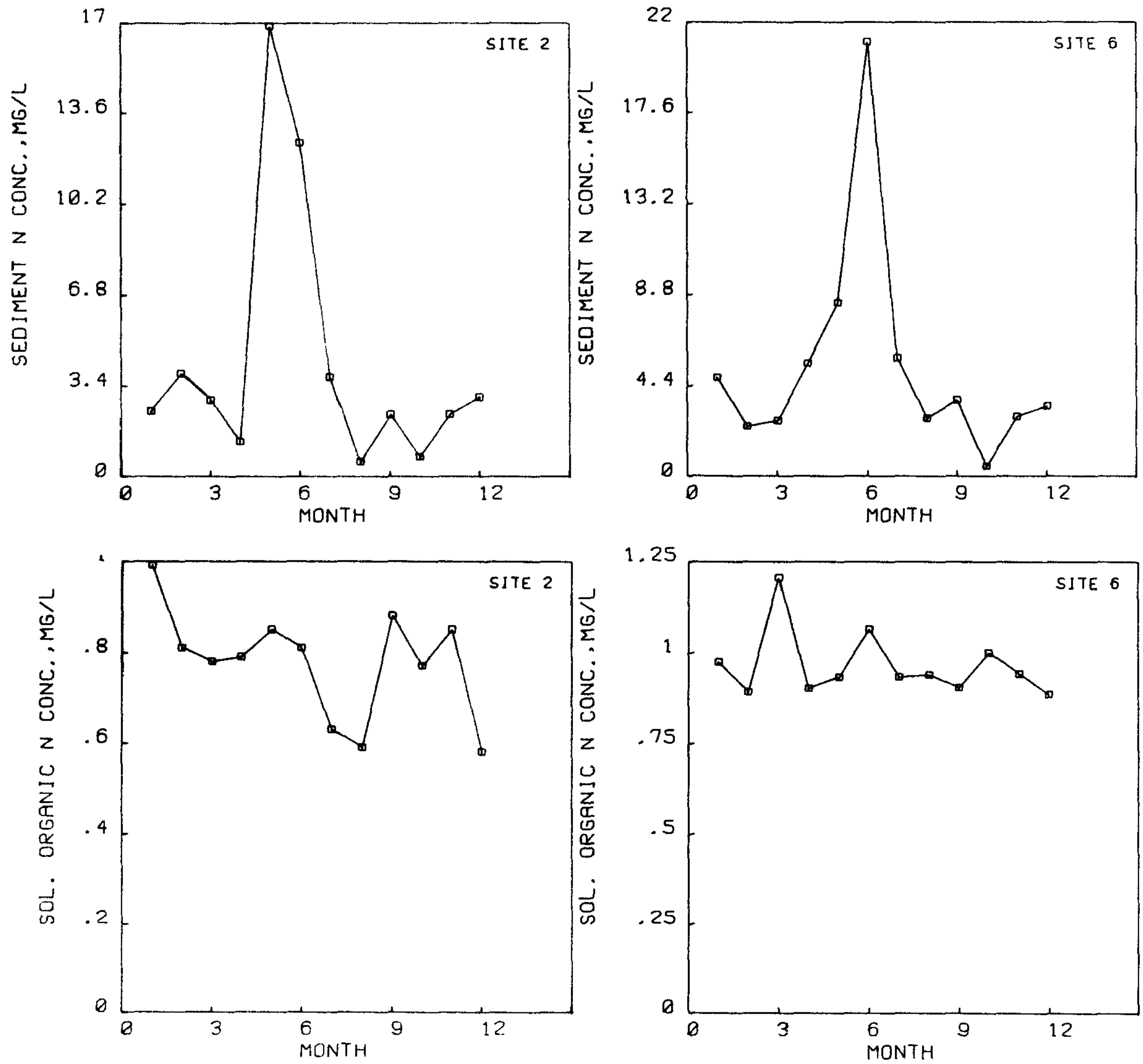



Figure 8. Average monthly flow weighed mean sediment N and soluble organic N concentrations measured in drainage water at Sites 2 and 6 during the period 1975-1980.

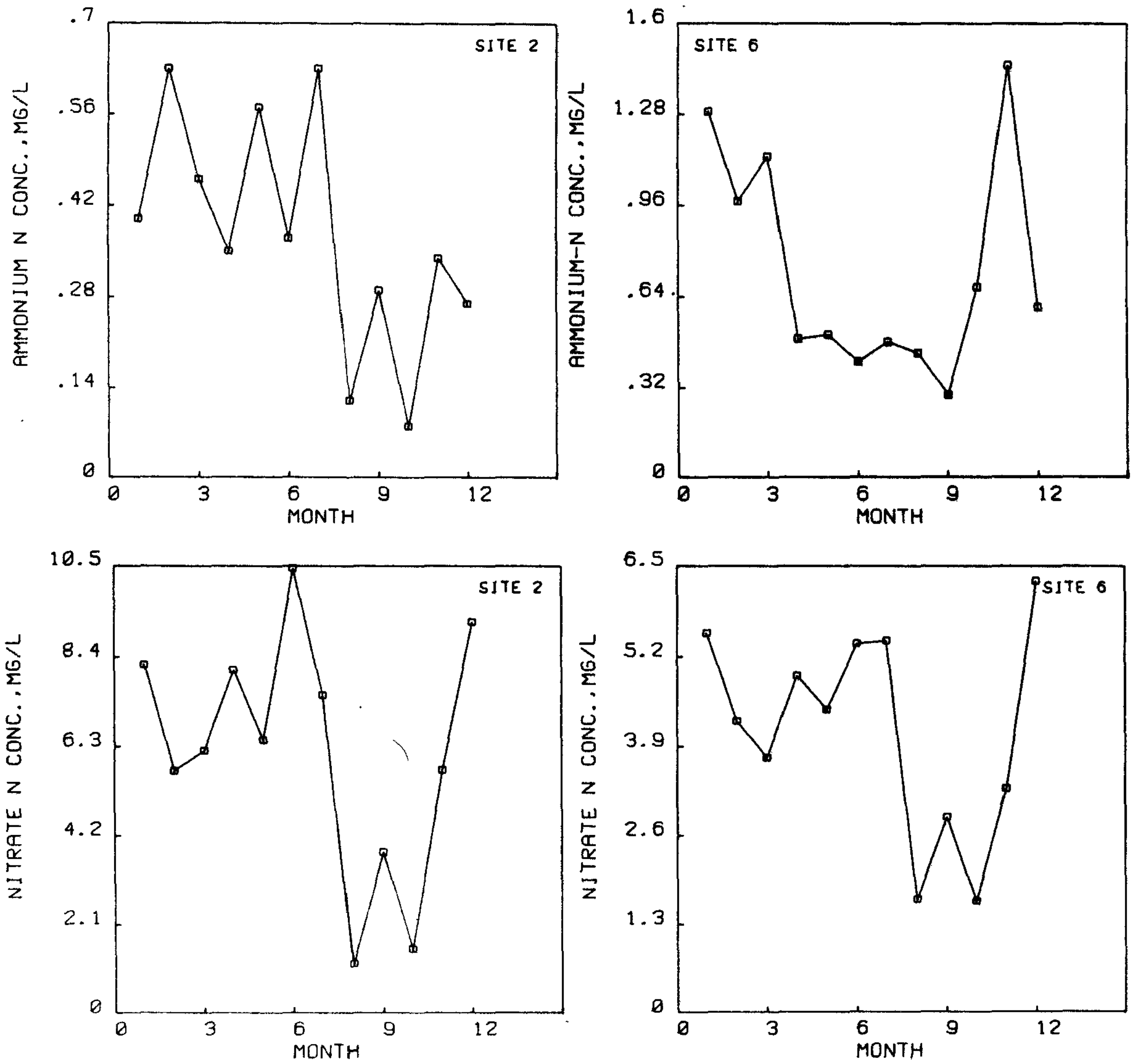



Figure 9. Average monthly flow weighted mean ammonium N and nitrate N concentrations measured in drainage water at Sites 2 and 6 during the period 1975-1980.

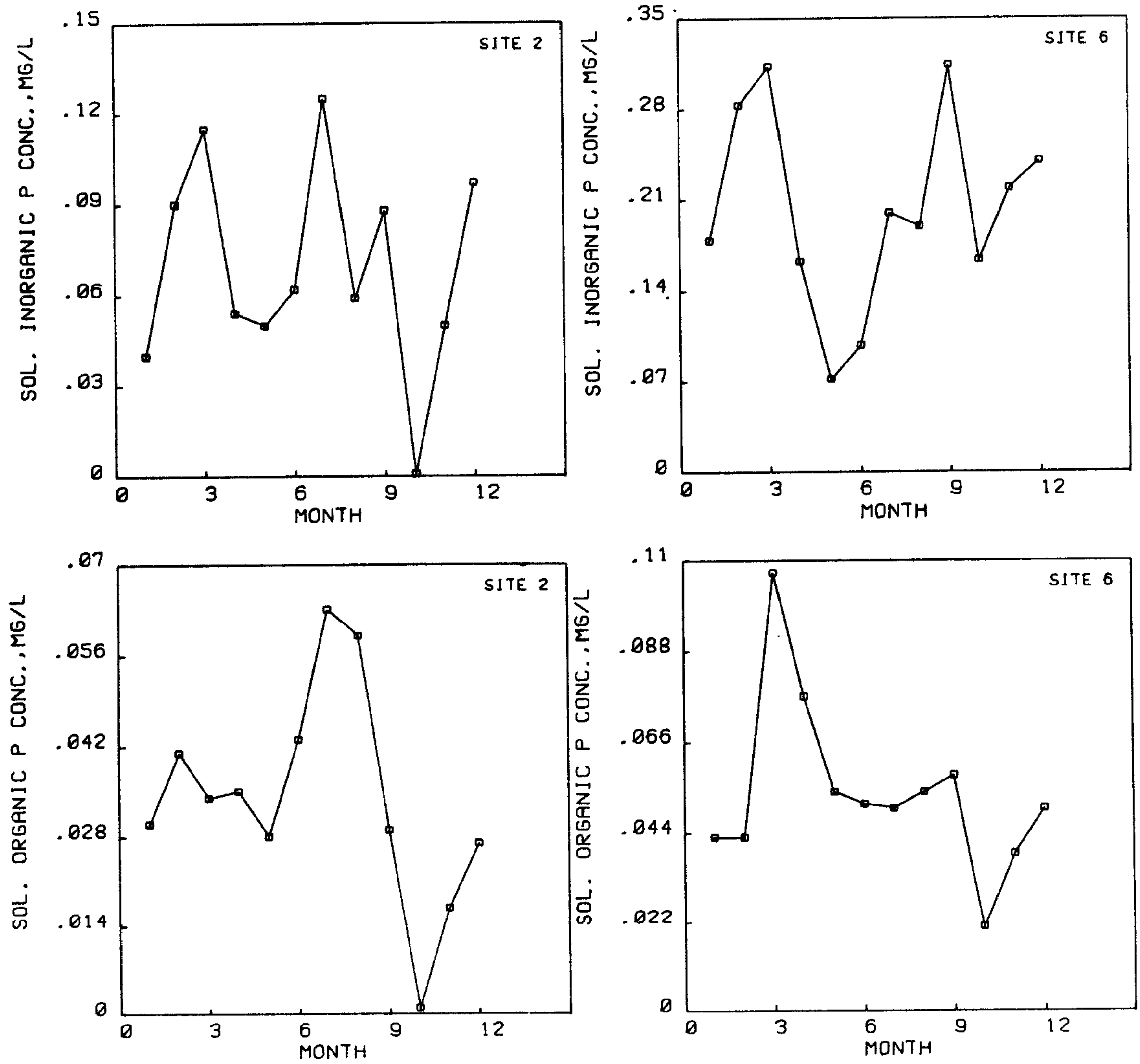



Figure 10. Average monthly flow weighted mean soluble inorganic P and soluble organic P concentrations measured in drainage water at Sites 2 and 6 during the period 1975-1980.

Nutrient Concentrations in Sediment

The average monthly total N and total P concentrations in suspended stream sediments and N and P enrichment ratios for the Site 2 and 6 subwatersheds are presented in Table 7 and Figures 11 and 12. The 6 year average total N concentrations in suspended sediments from Sites 2 and 6 were 1.190 and 0.894% respectively. Monthly averages for sediment total N concentrations at Sites 2 and 6 ranged from 0.500 to 1.660% and 0.101 to 1.460%, respectively, with the highest monthly averages occurring June and April, respectively (Figure 11). The 6 year average total P concentrations in suspended sediments at Sites 2 and 6 were 0.235 and 0.175% respectively. The monthly average sediment P concentration remained relatively constant for Site 2 (ranging from 0.166 to 0.355%), (Figure 11), but varied more widely at Site 6 (ranging from 0.073 to .516%)(Figure 11). The two highest monthly average P concentration for both sites occurred during November and December.

The 6 year average total N enrichment ratios for the Sites 2 and 6 drainage areas were 7.2 and 5.8, respectively. The highest monthly average N enrichments ratio for Sites 2 and 6 occurred in June and April, respectively, (Figure 12) and, as might be predicted, corresponds to the highest monthly average N concentration. The 6 year average total P enrichment ratios for Sites 2 and 6 were 3.5 and 3.8, respectively (Figure 12).

Relationships Between Monthly Runoff, Sediment Loss and Nutrient Loss

Table 8 and Figures 13 through 19 provides data on the degree of relationship between runoff, sediment loss, and nutrient losses from the Sites 2 and 6 areas over the period 1975 to 1980. Statistical significance is demonstrated for monthly and quarterly regressions when $r^2$ values are greater than 0.098 and 0.388, respectively. Data from both monthly and quarterly periods were used in the correlation studies.

Losses of $NH_4^+$-N, $NO_3^-$-N, soluble organic N and soluble inorganic P were highly correlated ($r^2 > 0.60$) with the total volume of runoff measured at both Sites 2 and 6 when both quarterly and monthly data was examined (Table 8). Regression plots of the above monthly parameters measured at Sites 2 and 6 are given in Figures 13-15. Average monthly soluble organic P losses measured at Sites 2 and 6 were highly correlated with monthly runoff ($r^2$ = 0.89 and 0.65, respectively) as presented in Figure 15. Average quarterly soluble organic P loss at Site 2 were also highly correlated with runoff ($r^2$ = 0.85). Monthly and quarterly sediment P losses measured at Site 2 were only weakly correlated with runoff ($r^2$ = 0.33 and 0.43, respectively), as was monthly sediment P loss measured at Site 6 (Figure 15).

Table 7. Average[a] monthly enrichment ratios and total N and P concentrations in suspended sediments in drainage water collected at Sites 2 and 6 in the Black Creek Watershed (all data calculated from average monthly loadings).

| Month | Site | Nutrients in sediment Total N | Total P | Nutrient enrichment ratio Total N[b] | Total P[c] |
|---|---|---|---|---|---|
| | | ---------mg/l--------- | | | |
| Jan. | 2 | 1.093 | 0.166 | 6.5 | 2.4 |
| | 6 | 1.004 | 0.173 | 6.0 | 2.5 |
| Feb. | 2 | 0.710 | 0.191 | 4.2 | 2.8 |
| | 6 | 0.668 | 0.189 | 4.0 | 2.8 |
| Mar. | 2 | 1.166 | 0.246 | 6.9 | 3.6 |
| | 6 | 1.063 | 0.247 | 6.4 | 3.6 |
| Apr. | 2 | 1.010 | 0.184 | 2.7 | 2.7 |
| | 6 | 1.460 | 0.244 | 8.7 | 3.6 |
| May | 2 | 1.434 | 0.215 | 8.5 | 3.1 |
| | 6 | 0.612 | 0.130 | 5.0 | 1.1 |
| June | 2 | 1.660 | 0.247 | 9.9 | 3.6 |
| | 6 | 0.836 | 0.073 | 5.0 | 1.1 |
| July | 2 | 0.856 | 0.186 | 5.1 | 2.7 |
| | 6 | 1.042 | 0.22 | 6.2 | 3.3 |
| Aug. | 2 | 0.500 | 0.199 | 3.0 | 2.9 |
| | 6 | 0.101 | 0.276 | 6.1 | 4.0 |
| Sept. | 2 | 0.799 | 0.260 | 4.8 | 3.8 |
| | 6 | 1.117 | 0.364 | 6.7 | 5.3 |
| Oct. | 2 | 1.000 | 0.200 | 6.0 | 2.9 |
| | 6 | 0.410 | 0.246 | 2.4 | 3.6 |
| Nov. | 2 | 1.274 | 0.355 | 7.6 | 5.2 |
| | 6 | 1.211 | 0.379 | 7.2 | 5.6 |
| Dec. | 2 | 10.64 | 0.349 | 6.4 | 5.1 |
| | 6 | 1.270 | 0.516 | 7.6 | 7.6 |
| Overall | 2 | 1.190 | 0.235 | 7.2 | 3.5 |
| | 6 | 0.894 | 0.175 | 5.8 | 3.8 |

a) First 6 months averages include 6 years of data, while the last 6 months include 5 years of data

b) Average total N concentrations in Sites 2 and 6 drainage area soils was 1670 and 1674 µg/g, respectively.

c) Average total P concentrations in sites 2 and 6 drainage area soils was 680 µg/g.

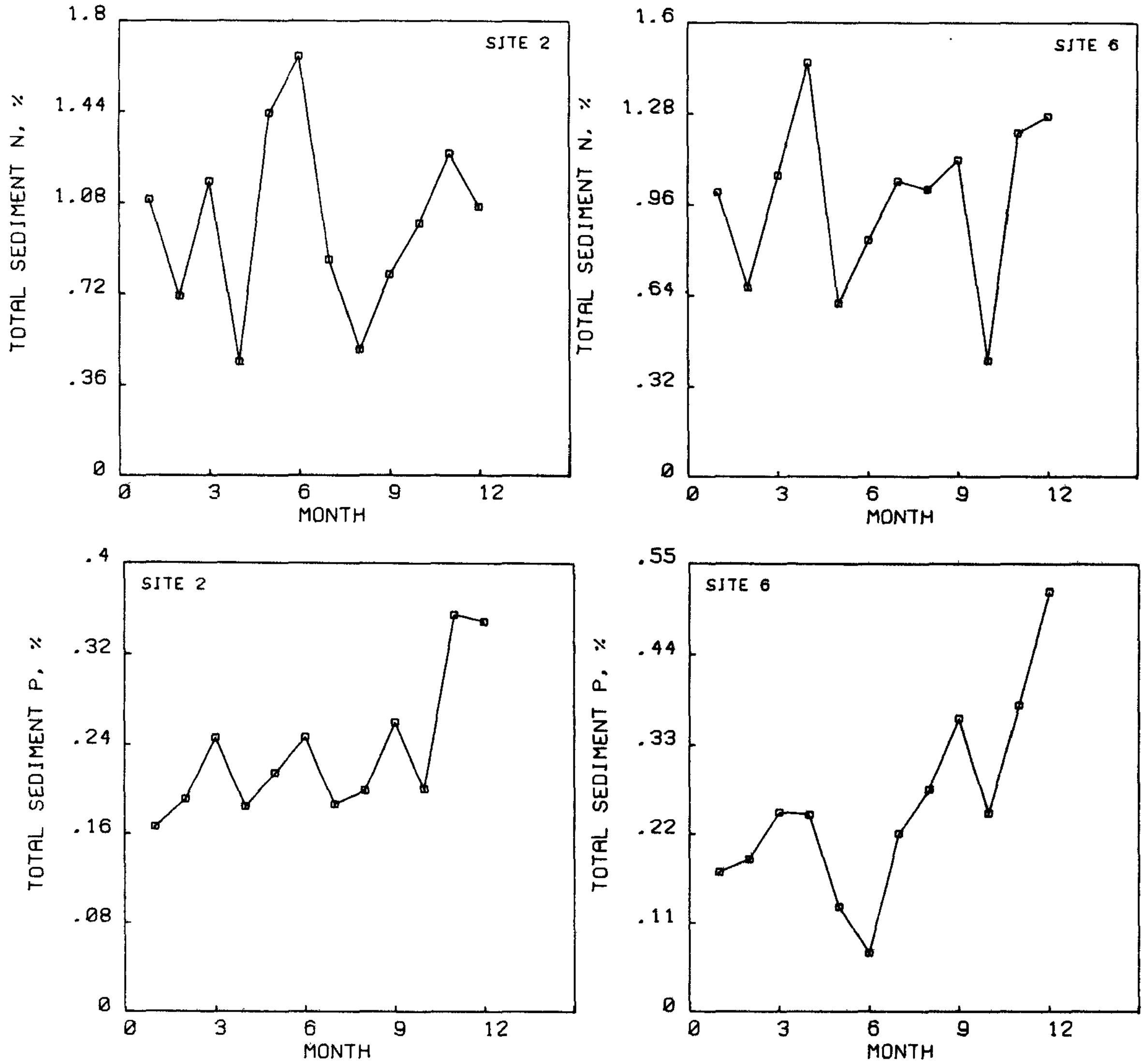



Figure 11. Average monthly weighted mean concentrations of total N and total P in sediment transported past Sites 2 and 6 during the period 1975-1980.

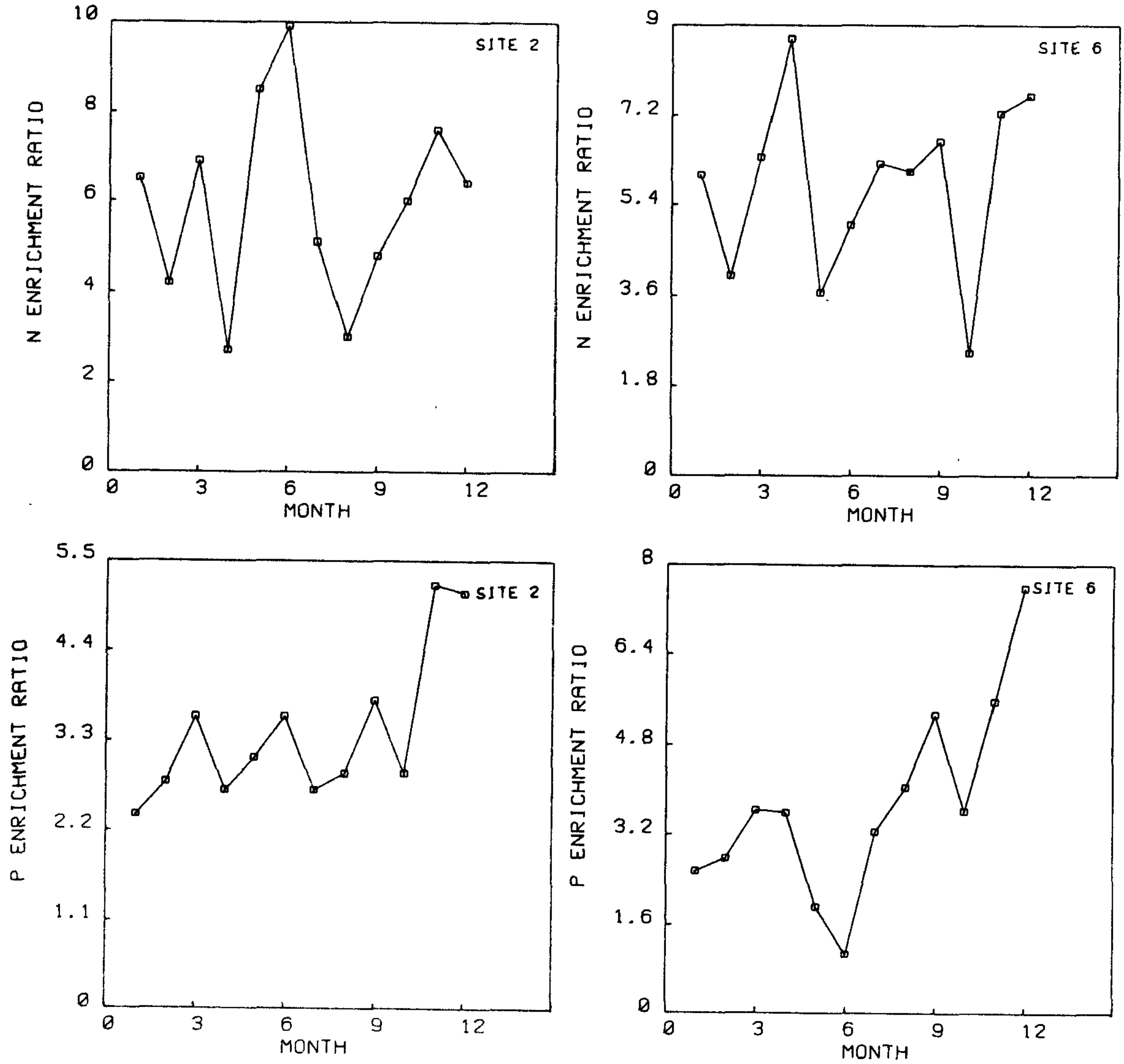



Figure 12. Average monthly weighted mean N and P enrichment ratios for sediment transported past Sites 2 and 6 during the period 1975-1980.

Quarterly and monthly sediment-bound nutrient (N and P) losses were well correlated ($r^2 > 0.65$) with sediment loss measured at Sites 2 and 6 (Table 8). Figure 6 presents average monthly sediment N and P losses measured at Sites 2 and 6 plotted against monthly sediment loss. Monthly soluble $NH_4^+$, soluble organic N and soluble organic P losses measured at Site 2 were weakly correlated with sediment loss (Table 8, Figure 17), as were quarterly averages of the same parameters measured at Site 2. Monthly (Figure 18) sediment N loss and sediment P loss measured at Sites 2 and 6 were strongly correlated ($r^2 >$ 0.67). While soluble inorganic P and sediment P losses were not significantly correlated, soluble organic P and $NH_4^+$-N losses were highly correlated with soluble organic N loss when quarterly and monthly averages measured at Sites 2 and 6, (Figure 19) were examined ($r^2 > 0.74$).

Monthly $NH_4^+$-N losses were weakly correlated with sediment losses measured at Site 2 (Figure 18) but not at Site 6, indicating the influence of septic effluents upon $NH_4^+$-N levels at Site 6. The $NH_4^+$-N losses measured at Site 2, on the other hand, appeared to somewhat dependent on sediment N losses measured at Site 2. The relationship between monthly soluble organic P and $NH_4^+$-N losses measured at Sites 2 and 6 to soluble organic N losses are presented in Figure 19.

These findings suggest that monthly or annual loadings of $NH_4^+$-N, $NO_3^-$-N, soluble organic N, soluble inorganic P, and soluble organic P leaving a watershed can be approximated by multiplying the annual flow weighted mean concentrations by the volume of runoff during the period. This procedure predicted the five-year average monthly loadings with reasonable accuracy. However, when applied to individual year monthly data significant deviations from observed values were obtained. This approach may prove useful in models of soluble nutrient transport from watersheds.

The above findings also indicate that monthly or annual loadings of sediment-bound N and P leaving a watershed can be estimated by multiplying the mean total N and P concentrations, respectively, in sediment by the amount of sediment discharged. This procedure predicted the average monthly sediment-bound nutrient discharges with reasonable accuracy. However, when used to calculate monthly losses of sediment-bound nutrients for individual years significant differences from measured values were obtained. It is apparent that this approach will be valid for use in models which predict transport of sediment-bound nutrients.

Table 8. Relationship between total runoff, sediment loss, and nutrient losses from the Sites 2 and 6 drainage area during 1975-1980

| Variable 1 | Variable 2 | Site 2 Quarterly[a] | Site 2 Monthly[b] | Site 6 Quarterly | Site 6 Monthly |
|---|---|---|---|---|---|
| | | $r^2$ | | | |
| Total runoff | Sediment loss | 0.51 | 0.39 | 0.25 | 0.21 |
| Total runoff | $NH_4^+$-N loss | 0.81 | 0.75 | 0.66 | 0.72 |
| Total runoff | $NO_3^-$-N loss | 0.70 | 0.75 | 0.76 | 0.75 |
| Total runoff | Sol. org. N loss | 0.94 | 0.95 | 0.88 | 0.90 |
| Total runoff | Sediment N loss | 0.399 | 0.31 | 0.29 | 0.27 |
| Total runoff | Sol. inorg. P loss | 0.60 | 0.78 | 0.72 | 0.83 |
| Total runoff | Sol. org. P loss | 0.85 | 0.89 | 0.49 | 0.65 |
| Total runoff | Sediment P loss | 0.43 | 0.33 | 0.39 | 0.43 |
| Sediment loss | $NH_4^+$-N loss | 0.57 | 0.45 | 0.02 | 0.03 |
| Sediment loss | $NO_3^-$-N loss | 0.28 | 0.23 | 0.19 | 0.14 |
| Sediment loss | Sol. org. N loss | 0.46 | 0.33 | 0.17 | 0.14 |
| Sediment loss | Sediment N loss | 0.94 | 0.91 | 0.98 | 0.95 |
| Sediment loss | Sol. inorg. P loss | 0.09 | 0.16 | 0.01 | 0.03 |
| Sediment loss | Sol. org. P loss | 0.61 | 0.39 | 0.03 | 0.04 |
| Sediment loss | Sediment P loss | 0.92 | 0.90 | 0.83 | 0.65 |
| Sediment loss | Total N in sediment | 0.06 | 0.01 | 0.02 | 0.00 |
| Sediment loss | Total P in sediment | 0.00 | 0.00 | 0.09 | 0.02 |
| Sediment loss | $NH_4^+$-N loss | 0.48 | 0.36 | 0.23 | 0.18 |
| Sediment loss | $NH_3^-$-N loss | 0.20 | 0.16 | 0.23 | 0.18 |
| Sediment P loss | Sol. inorg. P loss | 0.08 | 0.15 | 0.04 | 0.14 |
| Sol. org. N loss | Sol. org. P loss | 0.85 | 0.98 | 0.76 | 0.87 |
| Sol. org. N loss | $NH_4^+$-N loss | 0.81 | 0.74 | 0.84 | 0.89 |

a) Statistical significance for monthly data at the 1% confidence level is indicated by $r^2 > 0.099$ (66 replicates)

b) Statistical significance for quarterly data at the 1% level of confidence is indicated by $r^2 > 0.388$

## Quarterly Trends in Sediment and Nutrient Losses

Quarterly runoff losses of sediment and nutrients measured at Sites 2 and 6 are presented in Figures 20-24. As seen in Figure 20, annual peaks in runoff volumes measured at Site 2 seem to have been on a slight decline over the 22 quarter sampling period, possibly as a result of runoff and erosion control practices implemented in the Site 2 subwatershed. However, there are no trends in runoff volume measured at Site 6 (Figure 20). Quarterly losses of sediment and sediment N and P measured at Sites 2 and 6 generally followed similar patterns (Figures 20-21). The massive storm event which occurred during the second quarter of 1975 produced the maximum runoff over the five and one-half year period and also yield the maximum sediment and sediment-bound nutrient losses. However, unlike runoff, the sediment and sediment-bound nutrient losses occurring in the second quarter of 1975 were extraordinarily

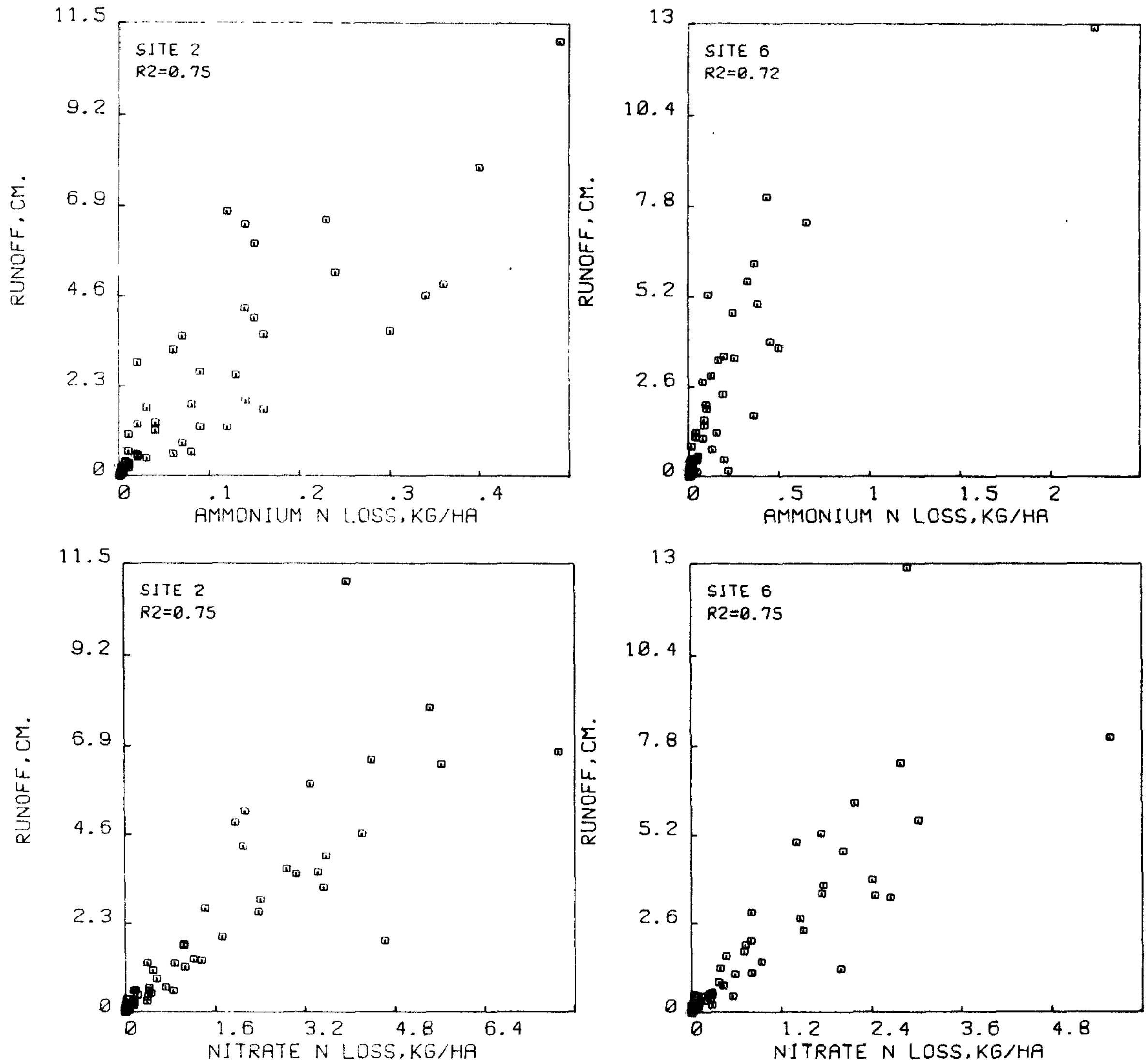



Figure 13. Relationships between monthly runoff volumes and monthly losses of ammonium N and nitrate N at Sites 2 and 6 during the period 1975-1980.

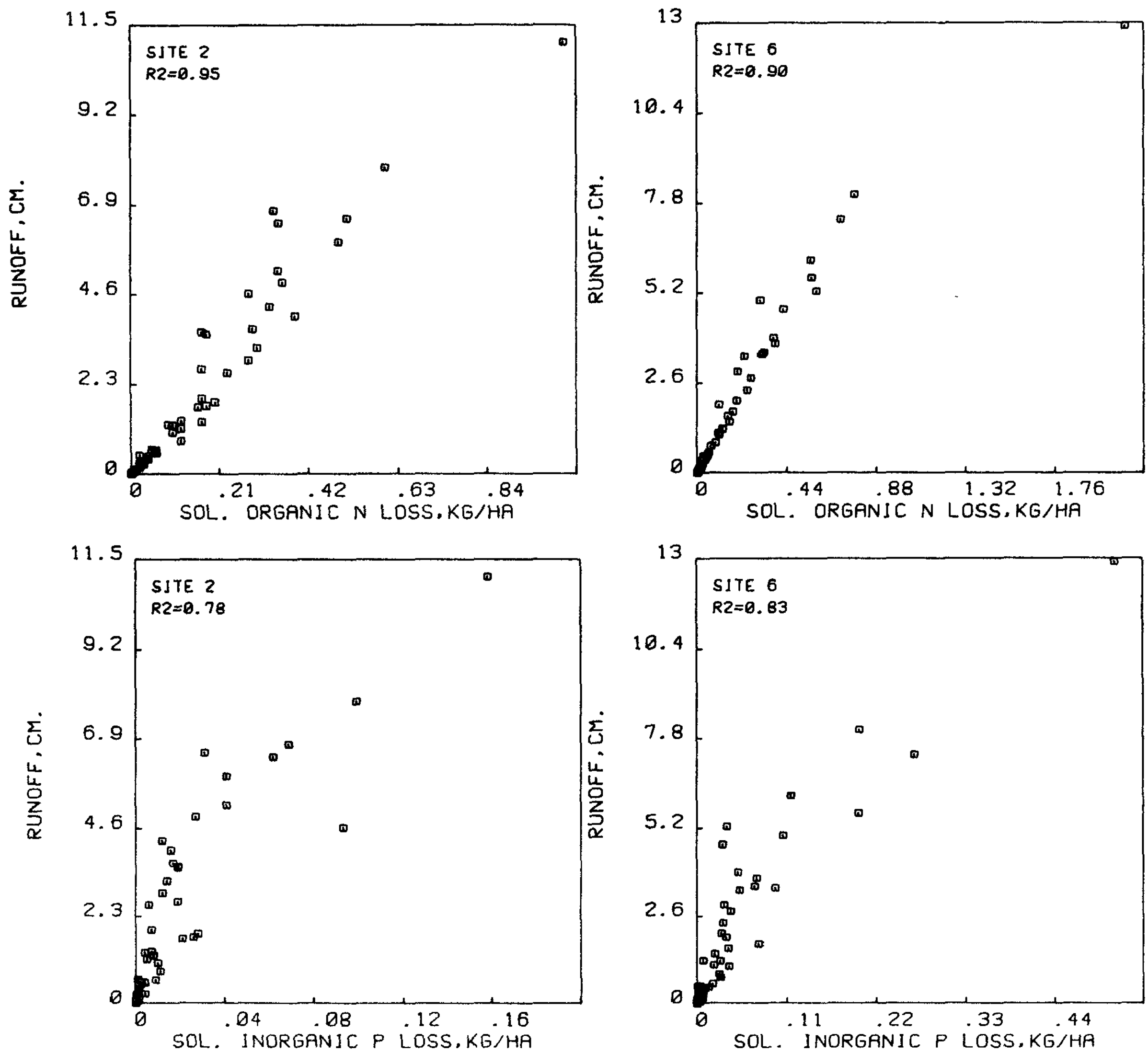



Figure 14. Relationships between monthly runoff volumes and monthly losses of soluble organic N and soluble inorganic P at Sites 2 and 6 during the period 1975-1980.

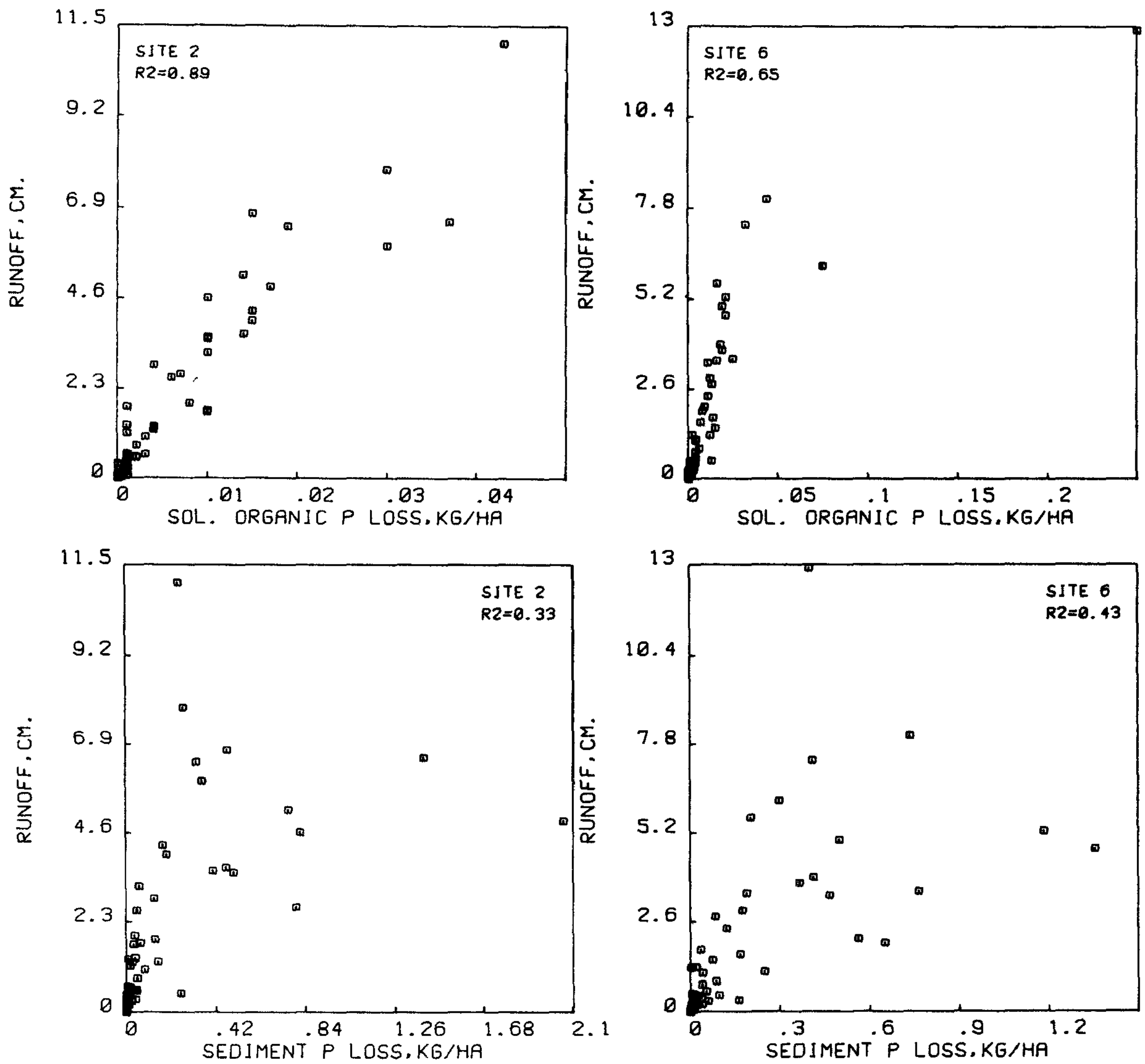



Figure 15. Relationships between monthly runoff volume and monthly losses of soluble organic P and sediment P at Sites 2 and 6 during the period 1975-1980.

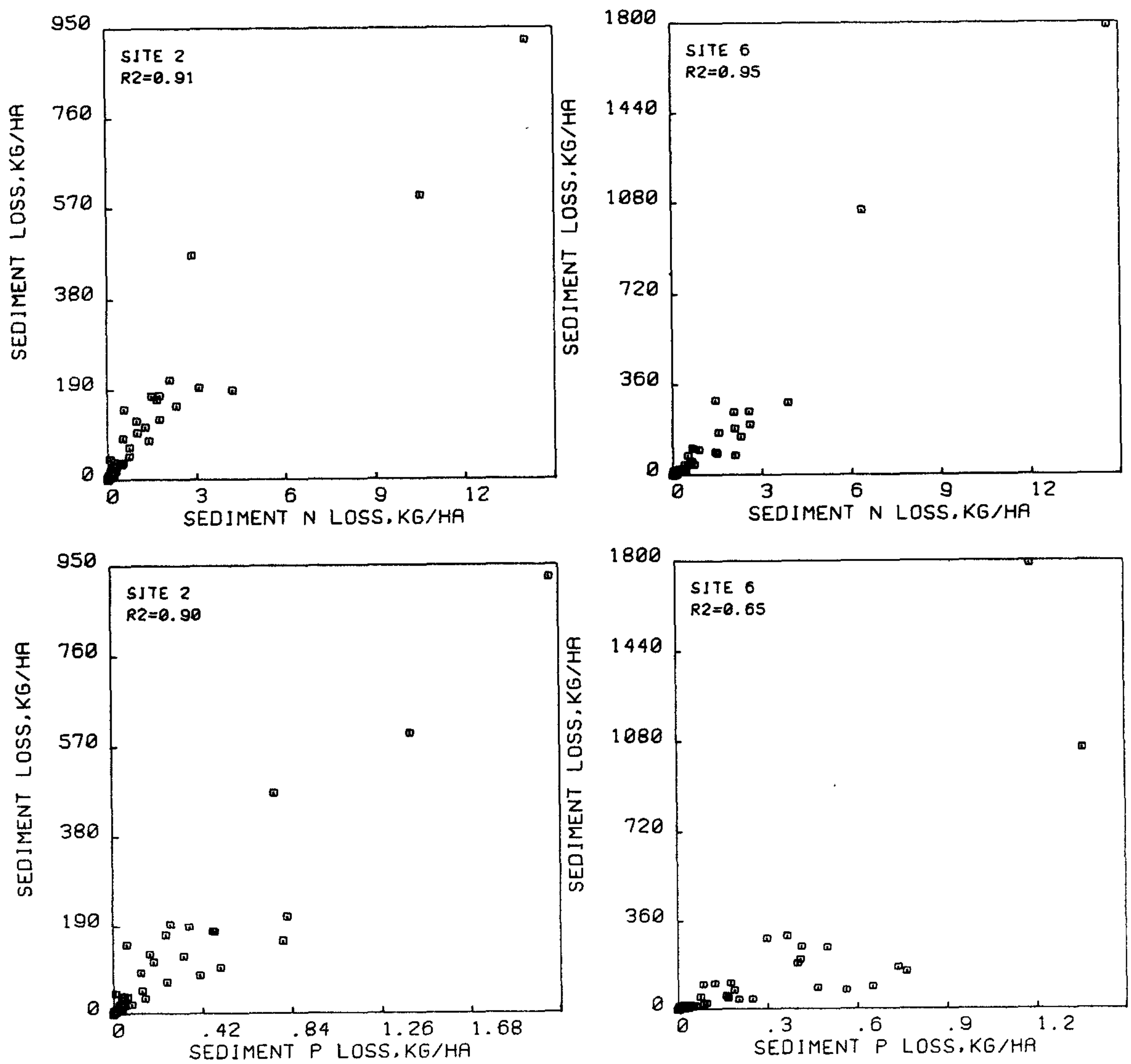



Figure 16. Relationships between monthly sediment losses and monthly losses of sediment N and sediment P at Sites 2 and 6 during the period 1975-1980.

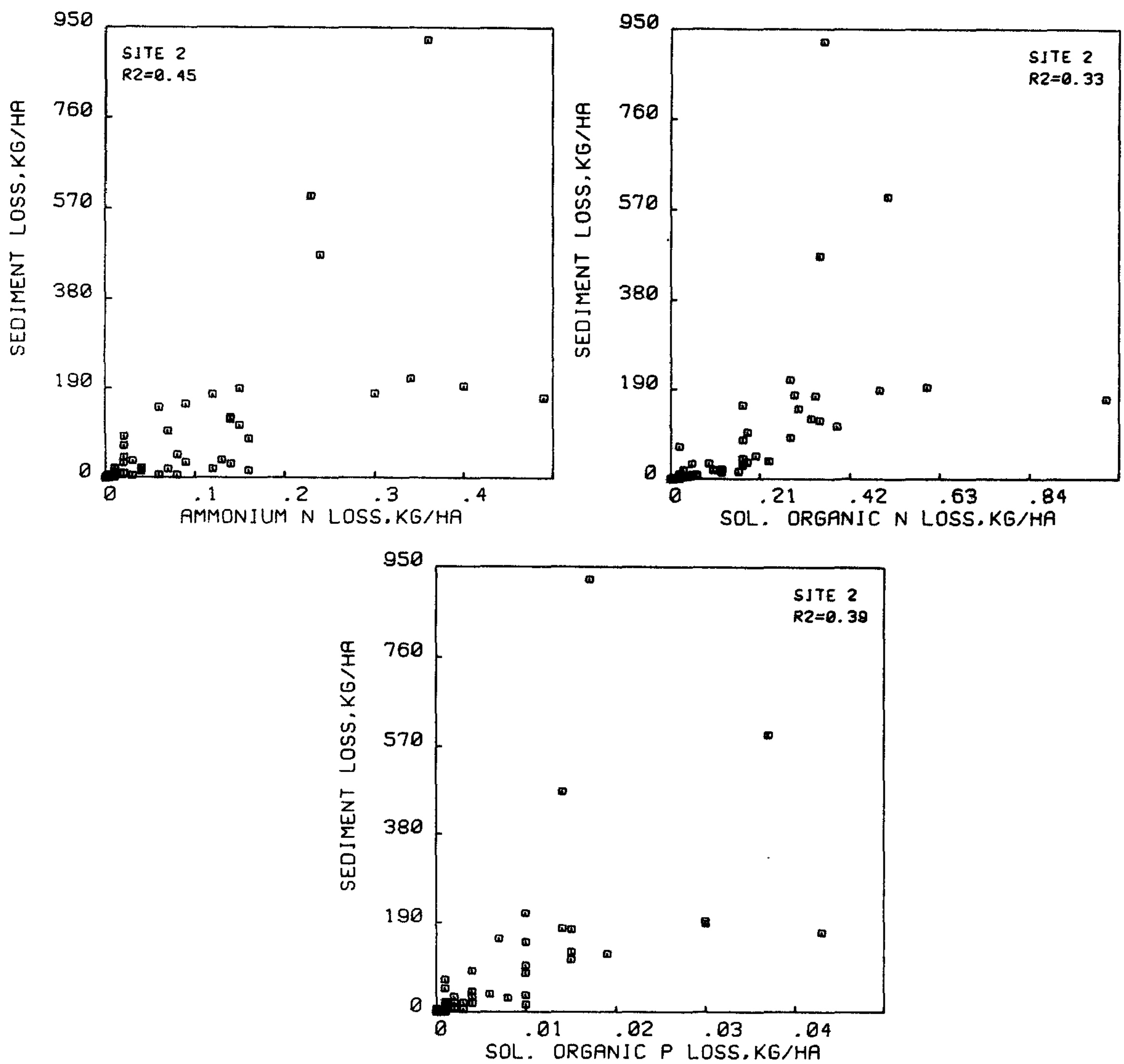



Figure 17. Relationships between monthly sediment losses and monthly losses of ammonium N, soluble organic N, and soluble organic P at Site 2 during the period 1975-1980.

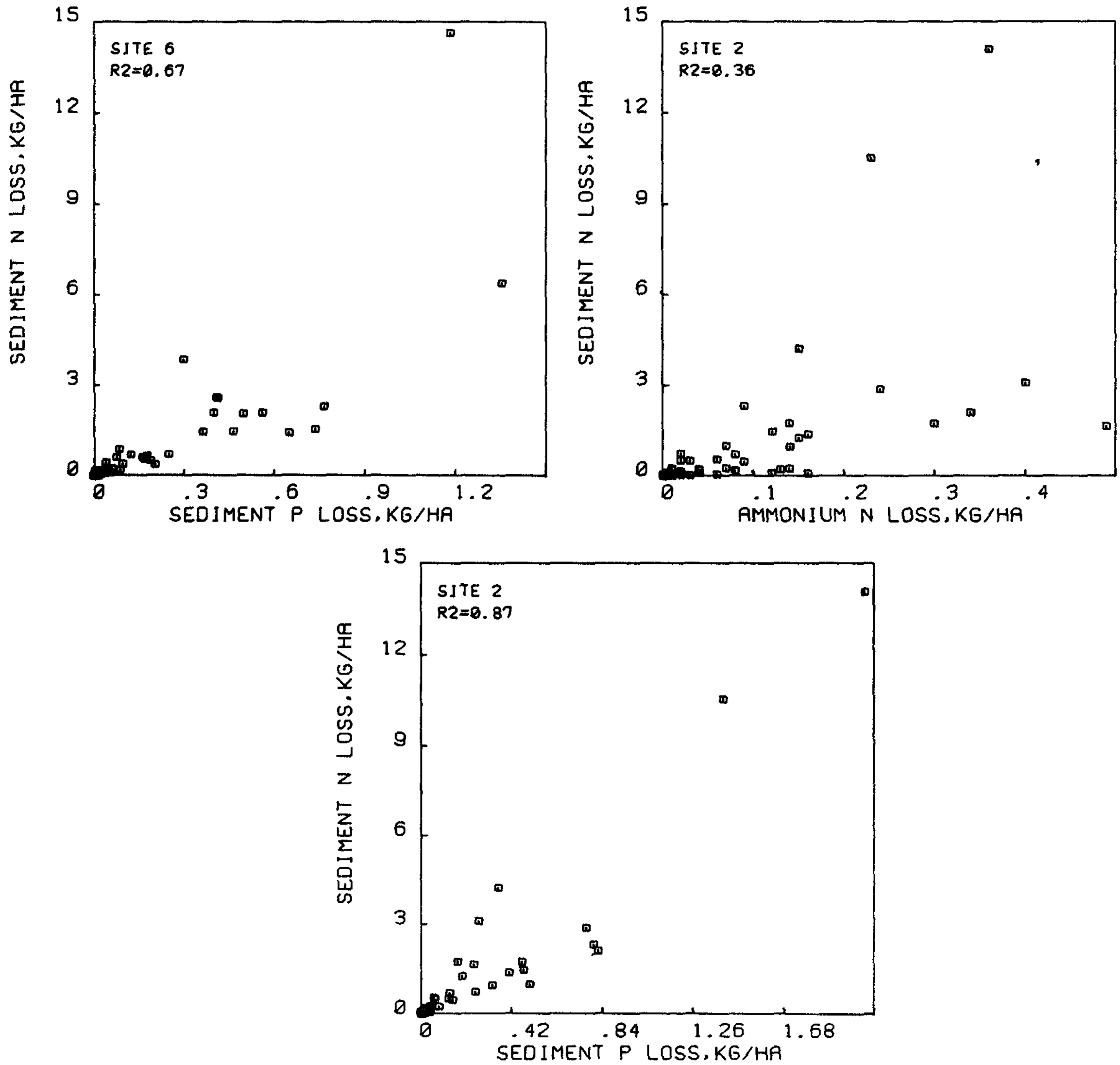



Figure 18. Relationship between monthly sediment N losses and monthly losses of sediment P and ammonium N, at Sites 2 and 6 during the period 1975-1980.

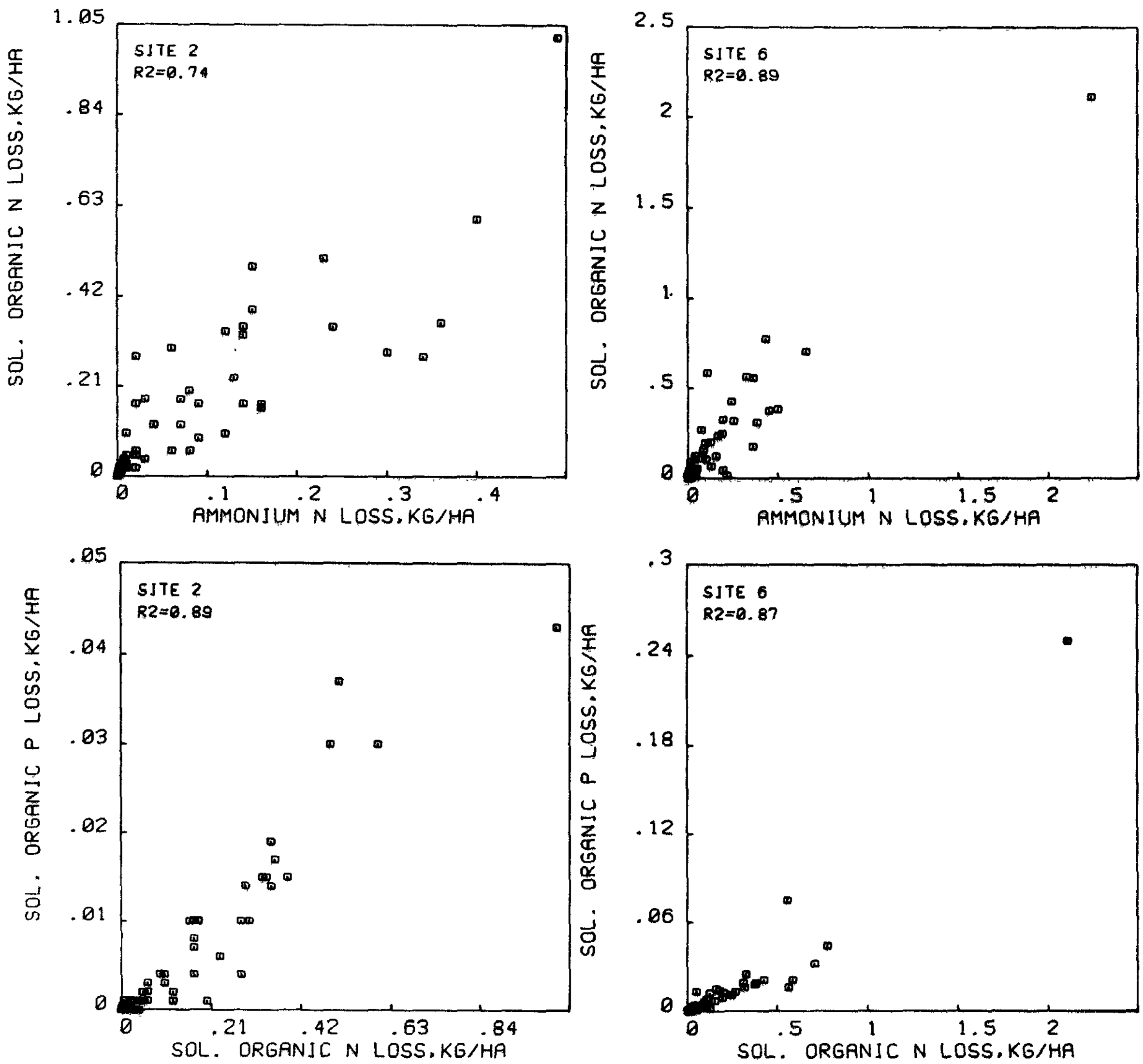



Figure 19. Relationships between monthly soluble organic N losses and losses of ammonium N and soluble organic P at Sites 2 and 6 during the period 1975-1980.

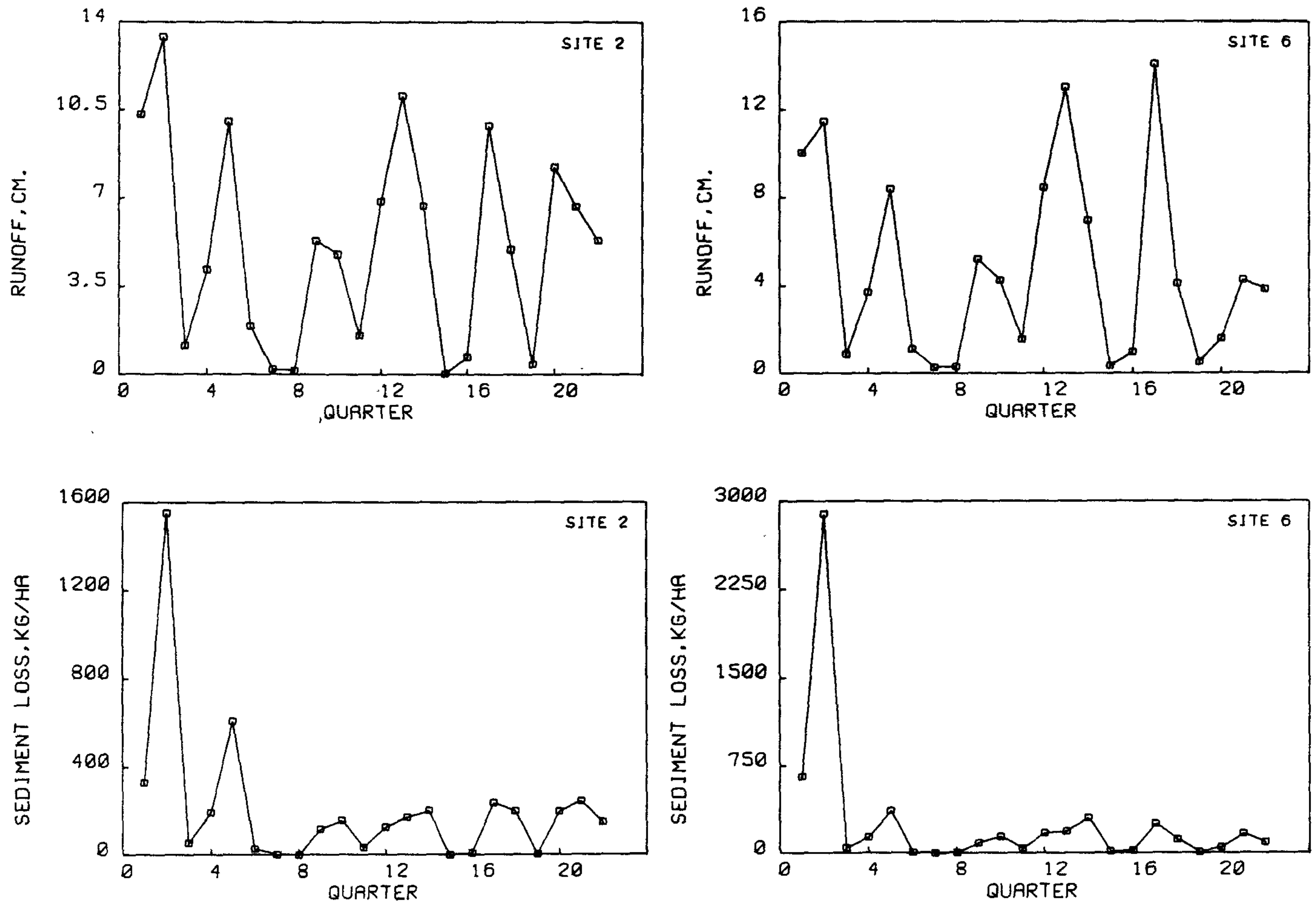



Figure 20. Quarterly runoff volumes and sediment losses at Sites 2 and 6 beginning with the first calendar quarter of 1975.

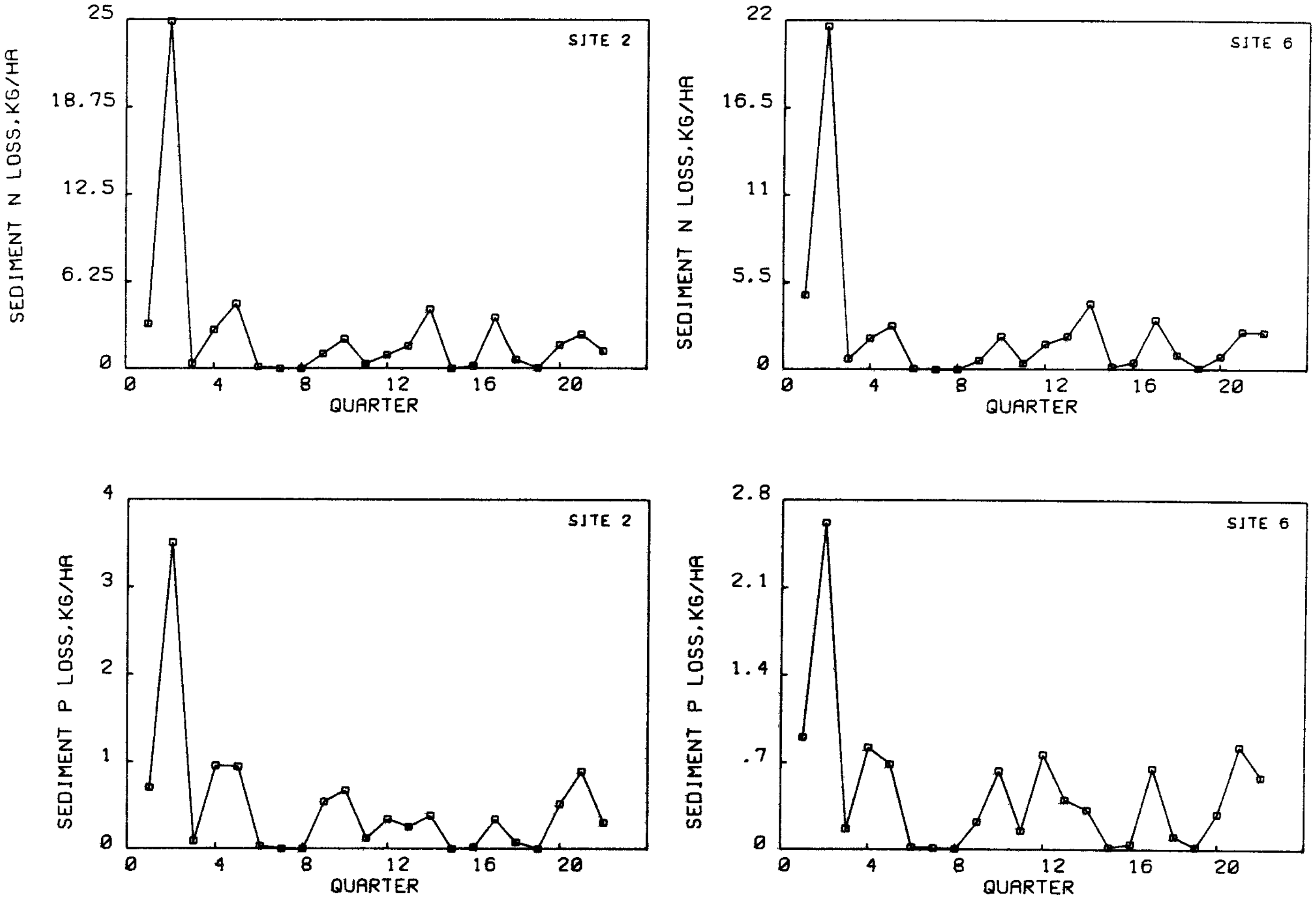



Figure 21. Quarterly sediment N and sediment P losses at Sites 2 and 6 beginning with the first calendar quarter of 1975.

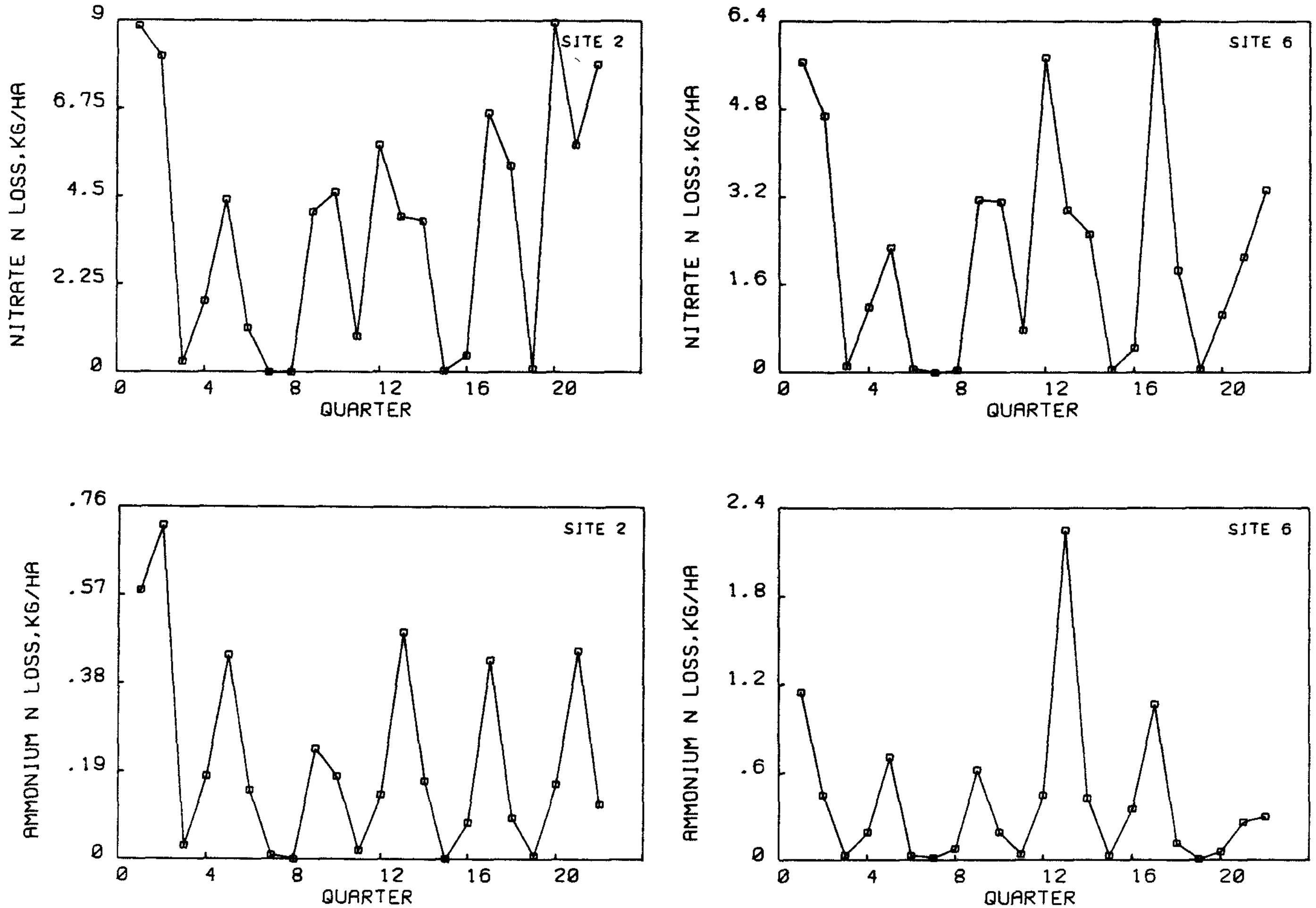



Figure 22. Quarterly nitrate N and ammonium N losses at Sites 2 and 6 beginning with the first calendar quarter of 1975.

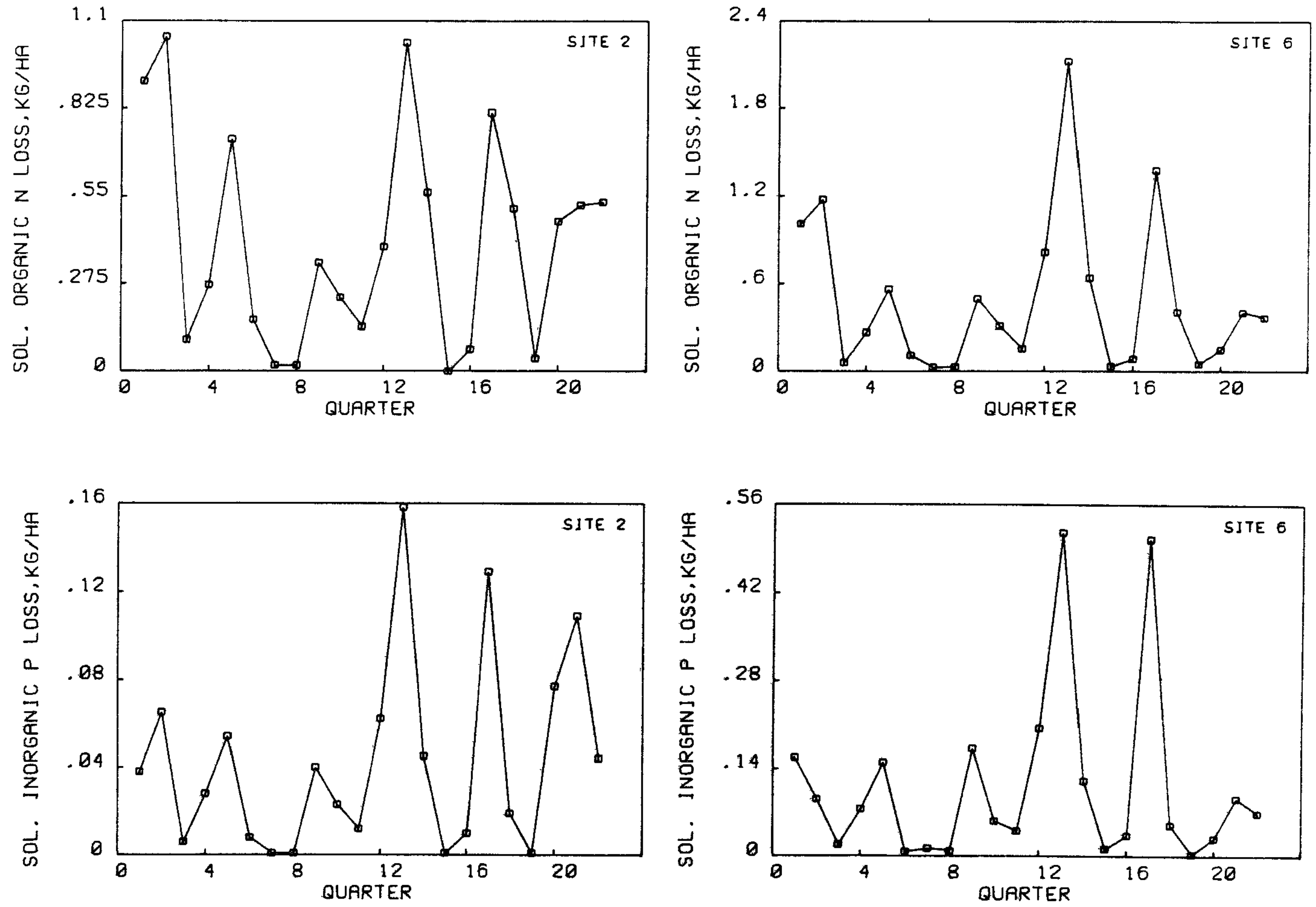



Figure 23. Quarterly losses of soluble organic N and soluble inorganic P at Sites 2 and 6 beginning with the first calendar quarter of 1975.

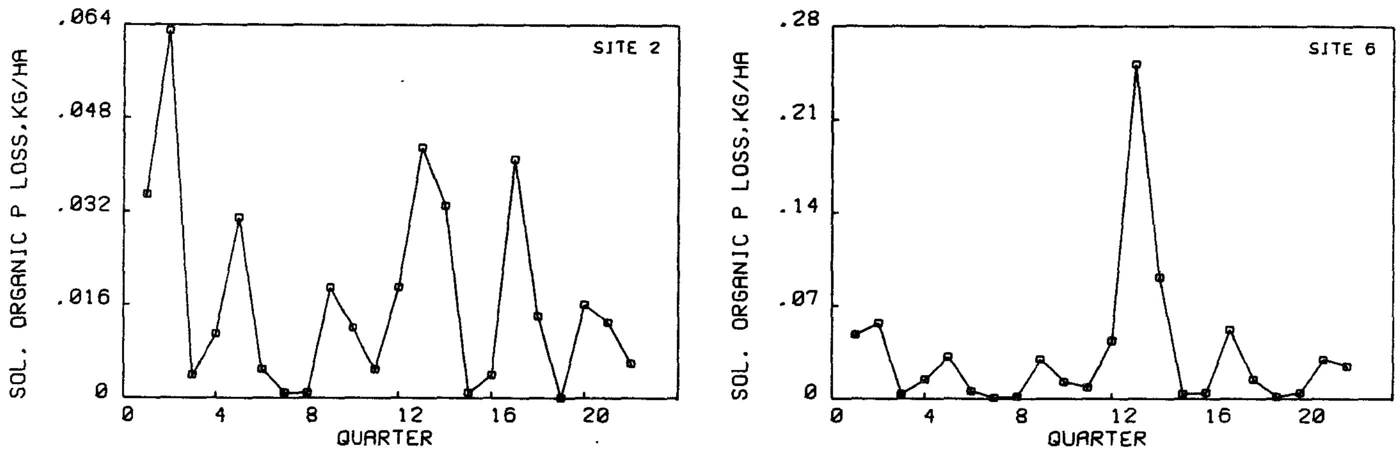



Figure 24. Quarterly losses of soluble organic P at Sites 2 and 6 beginning with the first calendar quarter of 1975.

high (usually > 6 fold) when compared to peak losses occurring in later years. There is a suggestion that quarterly losses of sediment and sediment-bound nutrients have declined during the course of the study in response to implementation of BMPs. Even though runoff has declined slightly over the 22 quarter sampling period, $NO_3^-$-N losses measured at Sites 2 and 6 appear to be increasing (Figure 22). The increasing $NO_3^-$-N losses over the sampling period may be an indication of increases in N fertilization in the subwatershed and/or increase in $NO_3^-$-N leaching from soils and loss via tile lines. The increased in $NO_3^-$-N leaching may be a symptom of runoff and erosion control measures taken within the watershed which allow increased infiltration of rainwater.

Quarterly losses of other soluble constituents ($NH_4^+$-N, soluble organic N, soluble inorganic P, and soluble organic P) measured at Sites 2 and 6 generally followed similar trends. That is, most soluble constituents showed peaks during the 2nd, 5th, 9th, 13th, 17th, and 21st quarters with maximums measured during the 2nd, 13th and 17th quarters (Figures 23-24). The maximum losses of the soluble constituents corresponded to the periods of maximum runoff.

Trends in Quarterly Sediment and Nutrient Concentrations in Drainage Water

Quarterly flow weighted mean concentrations of suspended solids and sediment-bound and soluble nutrients measured in drainage water at Sites 2 and 6 over the 22 quarter sampling period are given in Figures 25-28. Concentrations of solids, sediment N, and sediment P were normally highest during the first and second quarters of each year; however, in some cases the fourth quarter also had high concentrations of sediment and sediment-bound nutrients (Figures 25 and 26). Highest concentrations of sediment and sediment-bound nutrients in drainage water were measured during the second quarter of 1975 where the large rainfall event transported large amounts of soil material. Interestingly, a large runoff event which occurred during the 22nd quarter did not result in high quarterly suspended solids and sediment-bound nutrient concentrations. During the period 1978 to 1980 the quarterly sediment P concentrations tended to be considerably higher at Site 6 as compared to Site 2 likely as a result of septic tank effluents.

The quarterly nitrate N concentrations tended to increase with time at both monitoring sites (Figure 26). This increase in nitrate concentration in drainage water may reflect increasing rates of fertilizer or manure applications in the watershed or may result from increased nitrate in tile drainage water. The implementation of best management practices in the watershed may have increased the proportion of rainwater which reaches streams by subsurface flow at the expense of surface runoff. Tile drainage water normally has a two or three-fold higher nitrate N concentration than does surface runoff.

The quarterly ammonium N and soluble organic N concentrations in drainage water remained relatively constant throughout the period of measurement (Figure 27). Highest concentrations were normally observed during the first and fourth quarters of each calendar year. Drainage water flowing past Site 6 always had higher ammonium N concentrations than did Site 2 drainage water. The concentrations of soluble organic N were similar at Sites 2 and 6.

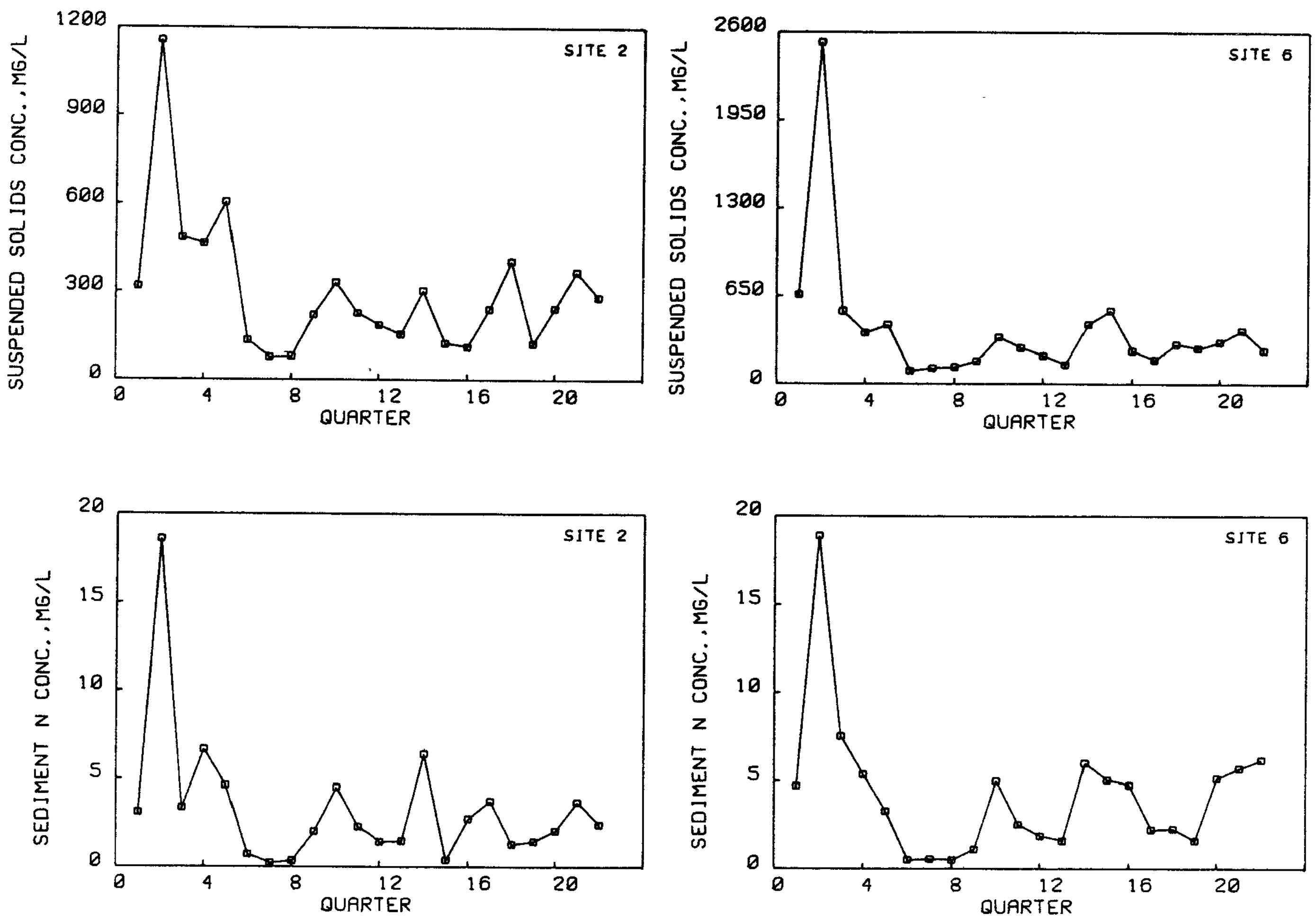



Figure 25. Quarterly flow weighted mean concentrations of suspended solids and sediment N measured in drainage waters at Sites 2 and 6 beginning with the first calendar quarter of 1975.

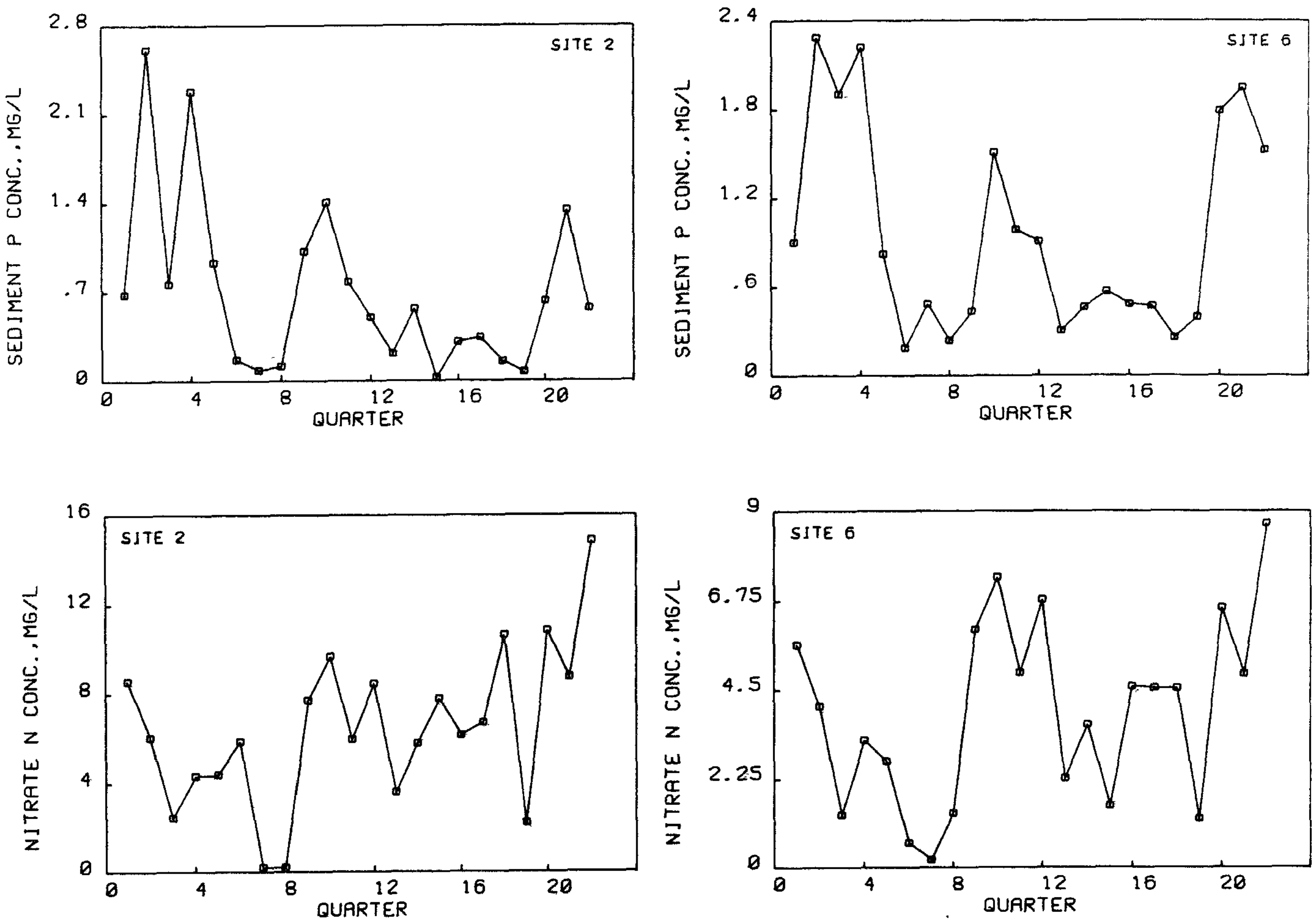



Figure 26. Quarterly flow weighted mean concentrations of sediment P and nitrate N measured in drainage water at Sites 2 and 6 beginning with the first calendar quarter of 1975.

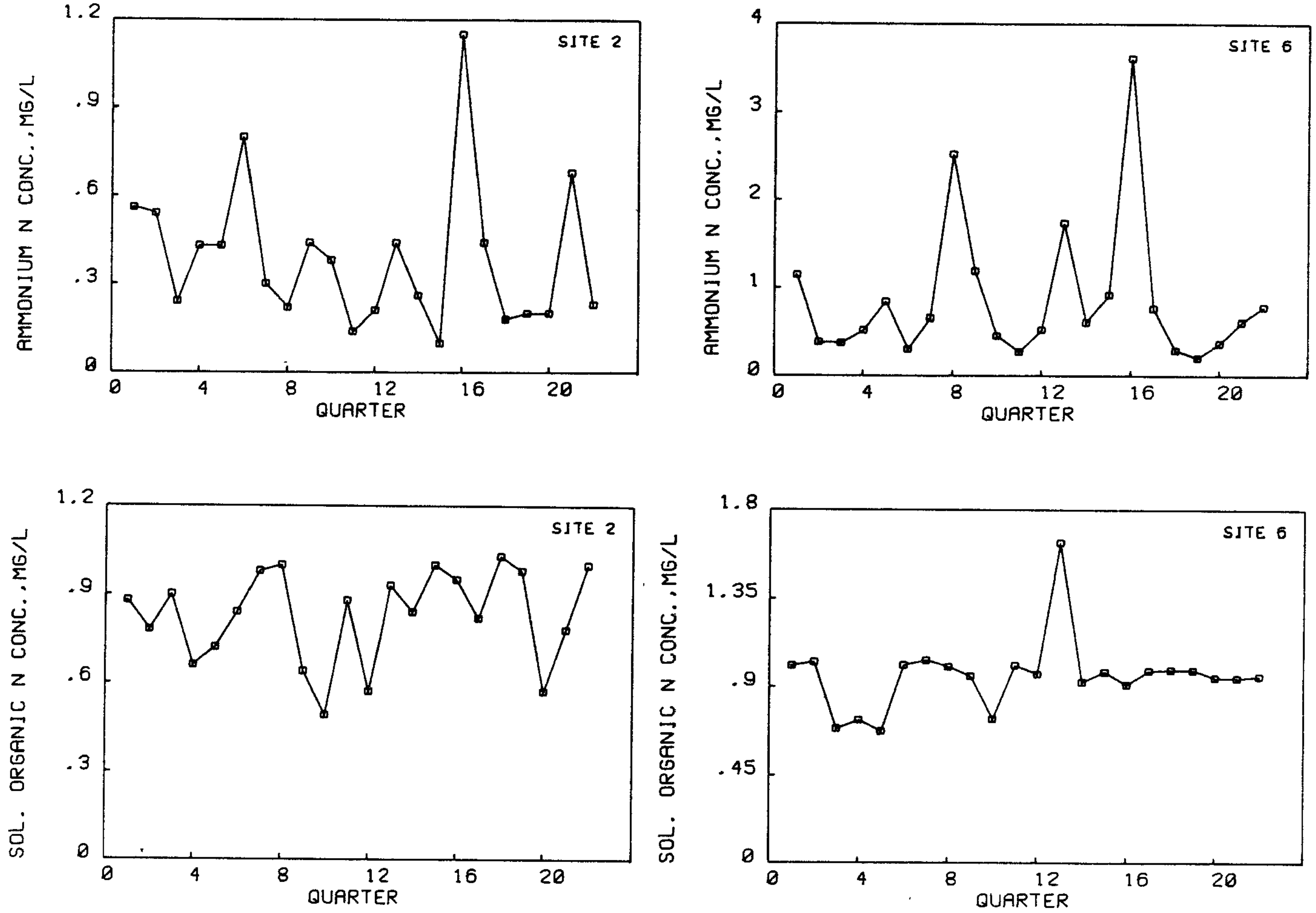



Figure 27. Quarterly flow weighted mean concentrations of ammonium N and soluble organic N measured in drainage water at Sites 2 and 6 beginning with the first calendar quarter of 1975.

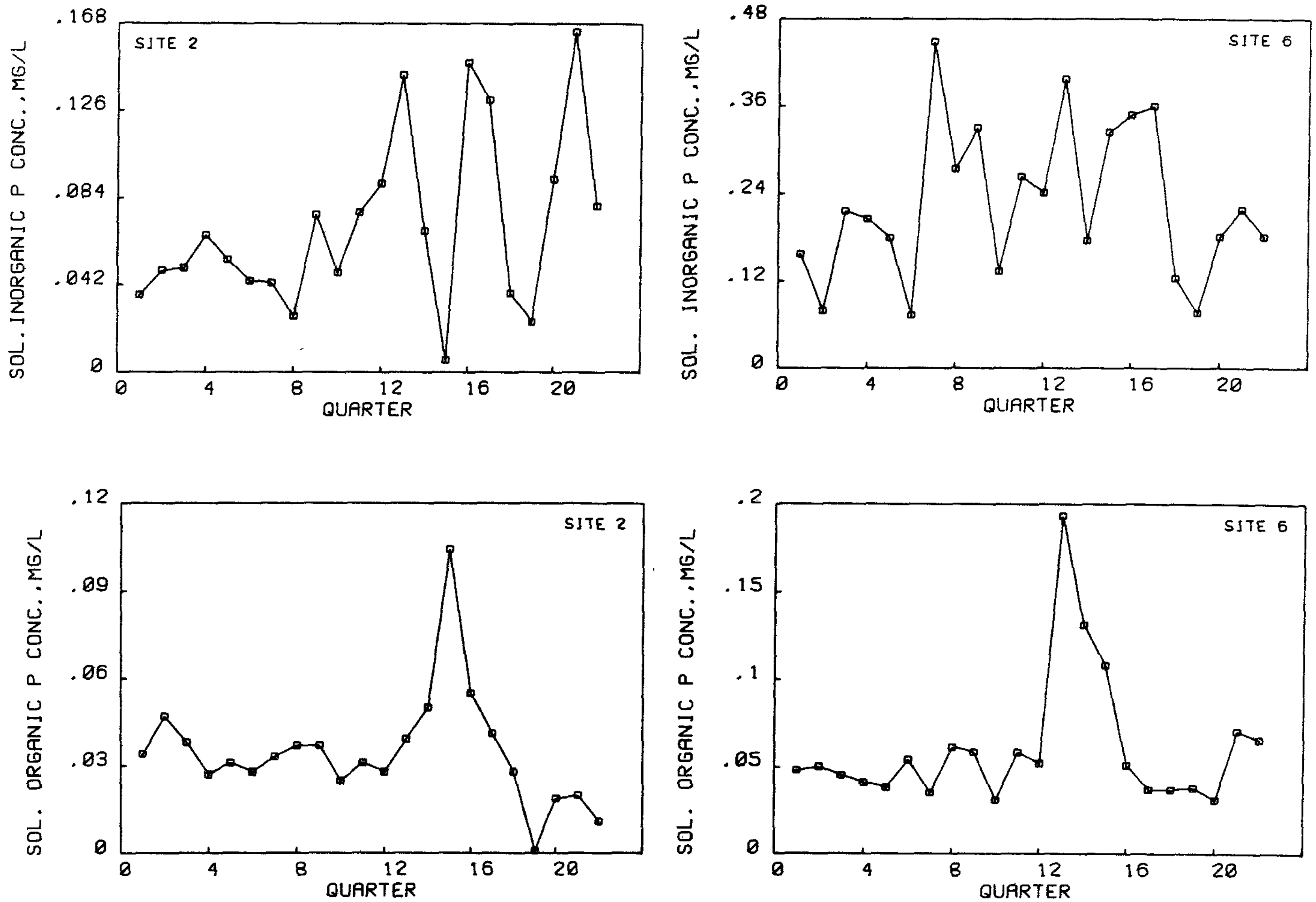



Figure 28. Quarterly flow weighted mean concentrations of soluble inorganic P and soluble organic P measured in drainage water at Sites 2 and 6 beginning with the first calendar quarter of 1975.

There was a tendency for quarterly flow weighted mean soluble inorganic P concentrations to increase with time at Site 2 (Figure 28). However, the soluble inorganic P concentrations measured at Site 6 exhibited no apparent trend except that quarterly data for 1979 and 1978 appeared to be somewhat lower than that for 1976 and 1977 (Figure 28). The new interceptor sewer installed in Harlan may be somewhat responsible for lowering soluble inorganic P concentrations measured at Site 6 during 1978 and 1979. Quarterly soluble inorganic P concentrations at Site 6 were always at least two fold higher than those at Site 2. The concentrations of soluble organic P were remarkably constant at both sampling sites except for a sharp increase in concentration measured during the first three quarters of 1978. There is no apparent explanation for the more than two fold increase in soluble organic P concentrations measured during 1978.

## REFERENCES

1. International Reference Group on Great Lakes Pollution from Land Use Activities. 1978. Environmental management strategy for the Great Lakes system. International Joint Commission, Windsor, Ontario.

2. Lake, J. and J. Morrison. 1977. Environmental impact of land use on water quality. Final report on the Black Creek Project (summary). U.S. Environmental Protection Agency, Chicago, IL. EPA-905/9-78-001. p. 3-9.

3. American Public Health Association. 1971. Standard Methods for Examination of Water and Wastewater. 13th ed. Am. Public Health Assoc., Washington, DC.

4. U.S. Environmental Protection Agency. 1971. Methods for Chemical Analysis of Water and Wastes. U.S. Environmental Protection Agency, Cincinnati, Ohio. 16020--07/71.

5. Steel, R.G.D. and J.H. Torrie. 1960. Principles and Procedures of Statistics. McGraw-Hill Book Co., Inc., New York. 482 p.

6. Nelson, D.W. and D.B. Beasley. 1978. Quality of Black Creek drainage water: Additional parameters. In Environmental impact of land use on water quality-supplemental comments. U.S. Environmental Protection Agency, Chicago, IL. EPA-905/9-77-007-D. p. 36-83.

7. Nelson, D.W., E.J. Monke, A.D. Bottcher, and L.E. Sommers. 1979. Sediment and nutrient contributions to the Maumee River from an agricultural watershed. In R. C. Loehr (ed.). Best Management Practices for Agriculture and Silviculture. Ann Arbor Science, Ann Arbor, MI. p. 491-505.

8. Logan, T.J. and R.C. Stiefel. 1979. Maumee River pilot watershed study. Watershed characteristics and pollutant loadings, Defiance Area, Ohio. U.S. Environmental Protection Agency, Chicago, IL. EPA-905/9-79-005-A. 135 p.

9. Ellis, B.G., A.E. Erickson, and A.R. Wolcott. 1978. Nitrate and phosphorus runoff losses from small watersheds in Great lakes Basin. U.S. Environmental Protection Agency, Athens, GA. EPA-600/3-78-028. 84 p.

10. Langdale, G.W., R.A. Leonard, W.G. Fleming, and W.A. Jackson. 1979. Nitrogen and chloride movement in small upland Piedmont watersheds. II. Nitrogen and chloride transport in runoff. J. Environ. Qual. 8:57-63.

11. Alberts, E.E., G.E. Schuman, and R.E. Burnnell. 1978. Seasonal runoff losses of nitrogen and phosphorus from Missouri Valley losses watersheds. J. Environ. Qual. 7:203-208.

12. Menzel, R.G., E.D. Rhoades, A.E. Olness, and S.J. Smith. 1978. Variability of annual nutrient and sediment discharges in runoff from Oklahoma cropland and rangeland. J. Environ. Qual. 7:401-406.

13. Kilmer, V.J., J.W. Gilliam, J.F. Lutz, R.T. Joyce and C.D. Eklund. 1974. Nutrient losses from fertilized grassed waterways in North Carolina. J. Environ. Qual. 3:214-219.

# MAINTENANCE OF BMPs

R.Z. Wheaton

At the start of the project over 30 land treatment practices were included in the planning process. The intent was to give each practice a fair trial. With experience it was found that only a limited number were suited to the soil type, topographic conditions, and production operations of the Black Creek Watershed and were also important in making water quality improvements. Many of the remaining practices were improvements to land mostly unrelated to water quality. In general, structure practices were preferred over cultural ones even if the structure measure had a somewhat higher initial cost.

Some of the most acceptable measures were field borders, animal waste holding tanks, sediment basins, grass waterways, tile outlet terraces, critical area planting, livestock exclusion (fencing), and pasture renovation. Also important were erosion control structures, tile outlet pipes, rock chutes, stream bank sloping and seedling, and riprap for channel stabilization. Conservation tillage (no-till or low-till) and other cultural practices were encouraged where applicable.

Because drainage is an essential production practice for much of the watershed, landowners were amenable to practices which reduced erosion in the streams since they also hoped these same practices would improve the drainage outlets. On the other hand it was necessary to demonstrate that, when properly selected, many cultural practices could be used without significant loss in crop production.

Even with the higher initial cost, structural measures were often preferred because of their low maintenance and low annual costs. A structural BMP program is easier to administer than one containing cultural BMPs. When properly designed and installed, structural measures provide the protection for which they were planned. Cultural measures are more influenced by soil properties and varying climatic and economic conditions. It is also more difficult for both the landowner and planner to assure compliance with water quality goals.

The land treatment measures have performed well. Their acceptance by landowners, their maintenance and the continued acceptability after the end of the project will be discussed later. Stream channel stabilization measures were well accepted and performed satisfactorily even though there was some early reluctance by landowners to give up the land necessary for ditches with 2:1 or flatter sideslopes. Planners and researchers were especially pleased with the rock drop structures and the channel containment accomplished by lining the toe of the channel banks in critical areas with rock. Both of these measures were somewhat experimental when initially used.

The in-channel destilling basin was essentially filled after the first few years. It would now be very expensive to be cleaned out. There is also a problem of where the soil (sediment material) could be spread. However, the need for a basin has largely disappeared now that upstream construction has

---

Acknowledgment: Data and assistance were provided by the SCS District Conservationist, Mr. T.D. McCain.

been completed. On the other hand, the sediment pond is still very functional. No measurable sediment accumulation in the sediment pond occurred between 1977 and 1979 because (1) land treatment measures above the pond were completed and (2) major runoff events such as the occurrence of a 50 year storm soon after the sediment pond was constructed have not occurred. This pond should continue to serve its function for many years. The present rate of sediment accumulation would suggest that its life would be at least 50-100 years.

Planned land treatment in the Black Creek Watershed (1973-1977) can be evaluated simply by observing what is "on the land" for the permanent (structural) practices. These "landmarks" serve as reminders to farmers and have been generally regarded as necessary and worth keeping. Unfortunately, management-type (cultural) practices such as rotations, conservation tillage or waste disposal, lacking any "landmarks," have lost their "reminder" status. Cultural practices are easily overlooked and adherance to contractual agreements as during the project years is now not necessary. SCS and SWCD efforts did make inroads in changing the attitudes of the farmers toward making water quality improvements, but cultural practices are difficult to implement year-after-year when weather, crop prices, machinery changes, etc. require ongoing changes in management decisions.

Failure to implement cultural practices to control erosion can also shorten the life of terraces, waterways, sediment basins, and other structural practices. Then when reconstruction is needed it may be more costly than for the original construction and excessive soil erosion also may have resulted in reduced productivity.

Cultural practices are usually maintained by their continued utilization. However, structural measures such as pipe inlets, dropped spillways and chutes need to be observed for signs of erosion or shifting. Noted problems should be corrected immediately. Grassed waterways and field borders need to be maintained by fertilizing and clipping. Small wet spots, scouring or other problems in the waterways or borders should be corrected and any silt bars removed. Terraces will required periodic rebuilding of ridges and removal of sediment from the channels. All practices should be maintained as nearly as possible to their original condition. Recognizing the need for maintenance is just the first step. Accomplishment may be more difficult and some type of incentive program may be needed.

Plans for land treatment systems should include maintenance schedules. Plans could even hint that failure to maintain structural practices may result in the return of some of the original cost-share money. Agreements between landowners and local districts should include provisions from maintenance beyond the life of a particular project. Economic benefits need to be better developed and described to the operator.

As already mentioned, incentives for maintenance are probably needed. They can range from financial aid to just recognition of jobs well done. Periodic contact of landowners by district personnel and yearly questionnaires about their practices have proven beneficial. A strong educational program including printed materials about maintenance should be carried out. Finally, there is a need to develop new "ideas" for encouraging landowners to maintain their land treatment practices.

# FIELD EXPERIENCES AND PROBLEMS

R. E. Land

There has been an expression of interest in an essay type report outlining some of the field experiences and particularly the problems involved in setting up, maintaining, and servicing monitoring sites and equipment on the Black Creek Project. In writing this report, it is assumed that the reader is familiar with the Black Creek Project--its location and purpose.

When I became a part of this project as Field Coordinator on April 1, 1973, most of the plans, organizational structure, area to be investigated, etc. for the project had been established. It became one of my primary functions to take some leadership in locating and establishing monitoring sites, and then servicing and maintaining those sites.

It wasn't planned or the project area was not selected for this reason, but the watershed was of such shape and topography so as to have excellent and convenient monitoring locations. There are five main tributaries to Black Creek. Entrance of these drains into Black Creek lie along the same county road--mostly in a straight east-west line. So it became no task at all to select easily accessible and strategically located sites for monitoring these subwatersheds. Easily accessible sites were also avaiable in the upland areas for monitoring special BMP's, however, in spite of this fact, and over my objections, some monitoring stations were selected in the upland area that were remote, not easily accessible, thereby making servicing and maintaining of those sites a most difficult task--especially during wet periods when intense monitoring was important--needless to say, some data was lost due to this very fact. Other sites, more accessible, were available for monitoring the same selected BMP's. We were never equipped to monitor remote stations. Mention of this problem is made for the benefit of those who may at some time work with a field monitoring program, and is not intended as a reflection on the decisions already made at "Black Creek."

At the start of the project--using Agricultural Handbook No. 224[1] as a guide--six weighing type rain gauges were established to cover the 12,000 acre watershed. Those stations were located so as to give, in our opinion, the best rainfall readings for specific areas being monitored for water quality. The rain gauges have worked well over the project period; maintenance was simple--consisting mainly of periodical recalibration, keeping oil in the receiving bucket to prevent evaporation, changing charts every six days, and other small maintenance chores. Originally, some of the rain gauges were equipped with box type recording pens which I found did not work well where dust was a factor. These pens were exchanged for trough type recording pens which did the job with few problems. We found that it was necessary to mount these instruments on a solid base to prevent vibration by the wind and etc. We have collected good, reliable precipitation records throughout the project.

Early in the program, flow measuring stations were set up at the exit of each of the five tributaries flowing into Black Creek plus three others--one on lower Black Creek, one on a reference drain outside the study area, and one on a tile drain study. It was requested that I consider methods of constructing "control sections" across the streams at each of the sites. Having had construction experience, I felt that sheet piling was the best material for this particular job. Bid documents were drawn up, and the contract was let to a local contractor who did an excellent job in driving and cutting the piling to form V-shaped weirs. We found that for this type "control section," it was necessary to place rip-rap immediately down stream from the weirs to dissipate flow energy to prevent deep "wash-outs" of the stream bed. Foxboro continuous air-type stage recorders were placed at each of the flow measuring sections. To prevent flooding of the instruments, it was necessary to place the recorders farther from the stream than recommended. The length of air hose required to reach the stream caused an excessive pressure drop in the line when an air bubble was emitted which in turn caused the recording pen to deflect in a wide tracing--thereby causing some undesirable results, such as, difficulty in chart reading, ink runs on the charts, etc. A bubble emitter pipe was connected to the air hose and placed in the middle of the streams above the weirs--this method did not work since the pipe was continuously catching debris. The bubble pipe was eventually placed in a sump. The recorders required considerable service in order for us to obtain acceptable readings.

With one of the biological investigator, we set up fourteen grab sample stations which covered water sampling over the entire watershed plus the previously mentioned reference station outside the watershed. Grab samples were taken during each runoff event and an effort was made to sample the streams on the rising side of the runoff hydrographs. The grab samples (500 ml.) were simply taken with a line attached to a bucket which was dropped into the stream. Two separate samples were taken at each stop. In most cases, the stream's flow at the sampling sites was in a rolling motion during events and mixing appeared good--so it is believed that we have taken representaive samples. Weekly "low flow" samples were also taken at these sites. Stage was recorded at the time of sampling, as well as recording water temperature, dissolved oxygen, turbidity, pH, plus other pertinent data. In addition to the grab sampling stations, twenty-one tile sampling stations were established with samples taken on a weekly basis. During the project, many "sets" of special grab samples were taken at various stations. Rain and snow samples were also taken.

A year or so after the start of the program, three automatic samplers (PS-69 samplers purchased from the U.S. Interagency Sedimentation Project) were placed on the main streams of the watershed. These samplers held seventy-two 500 ml sample bottles, however, if serviced, they were capable of continuous sampling and on occasion have operated eighty hours straight. The machines were originally timed to take samples every 15 minutes. A float switch, placed in the stream, was set to activate the samplers at approximately one foot of stage. For us, these samplers were a high maintenance machine requiring careful attention to all mechanical and electronical details. However, many of the problems were not directly attributed to the machines, such as frozen intake lines, debris over the intake lines, float switch failure, and on and on. Twice the samplers were modified in an attempt to make the machine do extra work, but the net result was a compounding of the problems.

In addition to the three large samplers, eight smaller automatic samplers were placed at select BMP sites, plus one sampler at a special drain tile study. These machines held forty-nine 500 ml. sample bottles and were also capable of continuous sampling if serviced during an event. But it should be pointed out that these samples were placed on small watersheds for which the time of the event is usually short--so forty-nine samples, in most cases, is more than adequate for the purpose. These samplers were also set originally to take samples every 15 minutes. You are saying, this is a lot of sampling, and you are right. I would estimate that we are approaching 100,000 water samples taken during the life of this project.

It is most difficult to imagine the problems that occur when servicing these monitoring stations during runoff events. "Murphy's Law" definitely takes over. It seems as though most events occur at night and especially on week-ends and holidays. Long hours are involved and extra help is needed. My wife has assisted me on many occasions, for which she is deserving of much credit. Also in thinking back on my experiences, I would have to say that I could not recommend servicing field equipment at night alone--chances for accidents are too great.

The project proposal called for a sediment basin study for the improvement of water quality--a site was selected. With help from SCS personnel, a survey was made (I wish to say that I always received the best cooperation from SCS personnel throughout the project). After the survey I designed, drew up the plans, wrote the specifications, advertized for bids, selected a contractor, and supervised construction of the sediment basin. Due to the topography of the area, the basin had a very attactive, long, slender, 7 acre surface area. Its watershed consisted of approximately 450 acres of nearly level farm land. For a period, I collected grab samples at the entrance and exit of the basin at each storm event and also on a weekly basis. Flow volume was also recorded. Two separate sediment deposit measurements were made in the basin, the results of which were discussed in a Black Creek report[2].

A desilting basin (an in stream basin) was also constructed. The same procedures were followed in setting up the contract as with the sediment basin. The contractor did excellent work in constructing the basin--holding the finished elevations to a very tight tolerance (we were fortunate in all our construction projects to have had contractors who did the job in a professional manner at very reasonalbe prices). The basin was designed[3,4,5] with two primary objectives: (1) to trap particles of high specific gravity and (2) to gain knowledge of bed load movement. Some water samples were taken during runoff events at the inlet and exit of the basin. The basin was periodically surveyed for sediment deposit. A report on this investigation has been published in a Black Creek report.[6]

It also became my assignment to construct, evaluate, and report on two mulch study areas located on the Black Creek drains. Each of the areas was constructed on ditch banks having 2:1, 3:1, and 4:1 slopes and each slope contained five treated plots. The mulch or treatment used was #4 crushed stone, straw, wood chips, Aquatain treatment, and a section with no mulch. Previously, data regarding these studies was also published in another Black Creek Report[7].

Each fall I recorded on an aerial photograph the existing ground cover for the complete watershed. Plus, an attempt was made to report any events that might affect water quality.

I have just skimmed the surface on reporting the experiences and problems involved with the Black Creek Project. A more detailed report covering these past seven and one half years would be voluminous; however, it is hoped some useful information may be gained from what is written.

REFERENCES

1. Field Mannual for Research in Agricultural Hydrology Ag. Handbook No. 224, Agricultural Research Services, U.S. Department of Agriculture.

2. Sediment Reduction by Stream Bank Modification and Sediment Traps. Best Management Practices for Non-Point Source Pollution Control Seminar, R.Z. Wheaton and R.E. Land. November 1976, pp. 155-163.

3. Textbook of Water Supply, Twort.

4. Water Quality and Treatment, Am. Water Work Association.

5. Settling Velocities of Gravel, Sand, and Silt Particles. Paper by William W. Rubey, Published with the permission of the Director of the U.S. Geological Survey.

6. Sediment Trap for Measuring Sediment Load, Non-Point Source Pollution Seminar. Pp. 93-98, R.E. Land and R.Z. Wheaton. November 20, 1975, Chicago, Illinois.

7. Streambank Stabilization, Non-Point Source Pollution Seminar. R.Z. Wheaton, pp. 86-92. November 20, 1975, Chicago, Illinois.

# EVALUATION OF SELECT BMPs

E.J. Monke, L.F. Huggins, D.B. Beasley, D.W. Nelson, T.A. Dillaha, S. Amin, M.A. Purschwitz, R.E. Land

## INTRODUCTION

Previous work in the Black Creek Watershed has involved continuous monitoring of runoff, sediment, nutrient losses, and other water quality parameters at the outlet of the watershed and several subwatershed outlets. The primary emphasis was directed toward evaluating landowner acceptance of a variety of pollution control practices and their overall influence on the quality of water being discharged from Black Creek into the Maumee River. The influence of single practices was evaluated only on plot-sized areas using a rainfall simulator.

The extensive collection of environmental data on the Black Creek Watershed was useful as a direct measure of the effectiveness of composite management practices which were applied to the land to reduce nonpoint source pollution. In so far as the Black Creek Watershed is representative of the Maumee Basin, the results are useful for assessing the contribution of agricultural nonpoint source pollutants from the basin into Lake Erie. The results were also useful for developing a simulation model called ANSWERS by which other dissimilar land areas and storm events can be investigated. This model was carefully designed to utilize fundamental relationships which are applicable to widely differing locations.

The amount of usable field data on agricultural nonpoint source pollution is quite limited. Data concerning water quality particularly at the outlets to areas with selected best management practices (BMPs) are essential to assessing the accuracy with which a watershed model can characterize the complex interactions of various ground cover, soils and farming practices prevalent in a region. Furthermore, it is important that data be made available concerning the response of small areas with uniform cover and treatment practices so that a rational selectivity between BMPs is possible. Taken together, the monitored behavior of small sub-catchments subject to uniform land treatments will provide a basis for building and refining models and, at the same time, will provide useful benchmark data by which planners can rank the relative effectiveness of different BMPs.

## BMP SITES

Eight BMP sites ranging in size from 2 to 28 ha were established at various locations in the Black Creek Watershed area as shown in Figure 1. In addition, the previously established tile drainage site could also be considered in a best management practice category. The selected sites including the drainage site were:

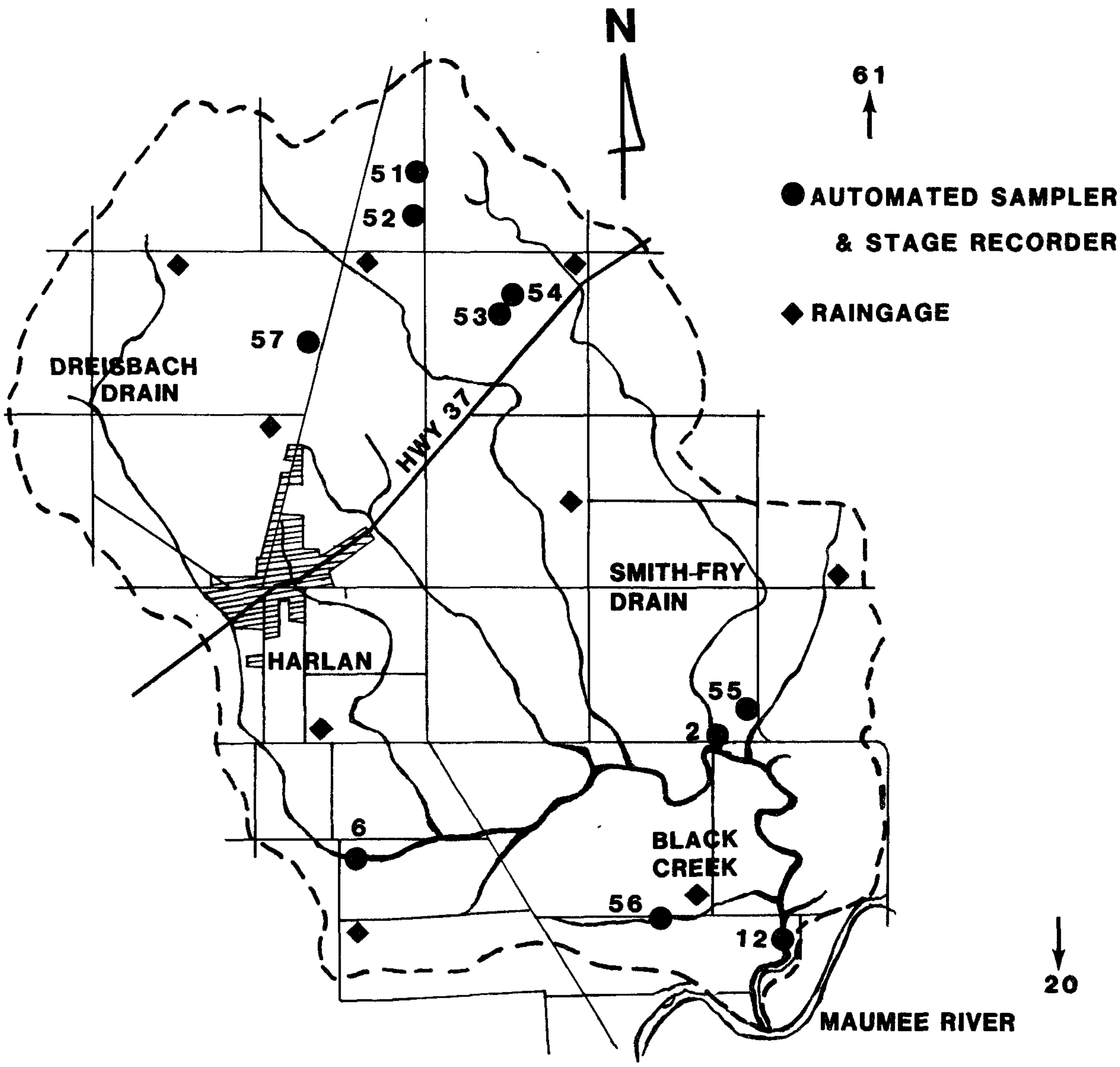



Figure 1. Monitoring locations on the Black Creek Watershed. Stations 2, 6 and 12 are for the Smith-Fry Drain, the Dreisbach Drain and Black Creek, respectively. Seven BMP sites are located on the watershed as shown and two are located a short distance away on similar soil types.

| Site No. | Farm Location | BMP |
|---|---|---|
| 20 | Becker | Subsurface drainage system |
| 51 | Bennett | Conservation tillage using a no-till planter; grassed waterway outlet |
| 52 | Schmucker | Pasture |
| 53 | Gorrell | Parallel, tile-outlet (PTO) terraces |
| 54 | Schaeffer | Conventional tillage; pipe spillway outlet |
| 55 | Dean | Parallel, tile-outlet (PTO) terraces |
| 56 | Armbruster | Conventional tillage with fall turn-plowing except for wheat; grassed waterway outlet |
| 57 | Wolfe | Conventional tillage with mostly spring turn-plowing; grassed waterway outlet |
| 61 | Hoeppner | Conservation tillage with special tillage tool; grassed waterway outlet |

An automatic sampler capable of collecting 48 discrete water samples was located at the outlet to each of the BMP sites. This sampler using some of the best features of the PS-69 sampler was designed and built in the Department of Agricultural Engineering at Purdue. Except for the subsurface drainage site, all are powered using a 12-volt heavy duty battery. A simple D.C. electrical motor driven pump was used to both collect samples and, by reversing polarity, to purge the intake line. The water stage over control sections was also recorded using H-flumes, weirs cut into sheet piling, or existing overfall structures except for the PTO terrace and pipe spillway outlets (53,54,55). At these latter sites, an elbow extension was attached to the outlet pipe so that the pipe would always flow full. The velocity of flow was then to be measured using a magnetic flow meter. However, some reliability problems are still being experienced with this particular instrument.

## RESULTS

The results to date are still relatively incomplete or inconclusive. Approximately 1200 samples are still to be analyzed from 1980. However, the primary difficulty is that during the spring and early summer months of both 1979 and 1980 few runoff-producing rainfall events occurred. Those which did occur were also small events and somewhat erratic over the experimental area. Also since the events were small they were then subject to minor perturbations which would become masked with larger events. However, on the basis of sediment concentrations, one PTO terrace site (No. 55) produced as clean or cleaner runoff then the subsurface drainage system (No. 20). The field containing the PTO terrace system was also chisel plowed and at the particular time samples were being collected was planted to a legume cover crop. Both systems delivered an almost inconsequential sediment yield (on the order of 100 ppm). The field containing the other PTO terrace site (No. 53) was conventionally tilled and planted to corn. As a consequence of this and other factors not readily apparent, sediment yields were considerably higher (on the order of 5 to 10 times depending on crop stage) than the terrace system with the additional BMPs. One conservation tillage system (No. 51) appeared to produce sediment concentrations about equal to the worst PTO terrace site. However, this catchment was rather long and, in addition to the conservation tillage treatment, contained a long, moderately sloping grassed waterway. The other conservation tillage system (No. 61), this one for a rather small, sloping catchment, gave around twice the sediment concentrations as for the conservation tillage system on the more moderately sloping and longer catchment. The one conventional tillage system which was analyzed most completely (No. 56) produced sediment concentrations much higher (on the order of three times) than the concentrations for the worst-performing conservation tillage system. This latter site was also located on a soil combination of Hoytville silty clay and Nappannee silt loam both of which contain slopes only between 0 and 1 percent. The lower part of the catchment was planted to soybeans in 1980. During the spring months in 1980, this particular catchment also produced a peak sediment concentration of 10,000 ppm. On the other hand, the highest sediment concentration measured in the principal outlet drains (No. 2 and No. 6) was only around 1,500 ppm for the same time period.

## SUMMARY

The results from the BMP sites allow a relative ranking of the various practices. In comparison to conventional tillage all BMPs give considerable benefits as far as sediment reduction is concerned. From prior analyses, we can expect sediments in the Black Creek Watershed to account for approximately 90 percent of the total phosphorus loadings and 50 percent of the total nitrogen loadings. The BMP sites are not replicate sites (replicate sites can only be approached with plots) and differences in soils, soil configuration, slopes, cropping sequence, size, etc. are readily apparent. Ultimately a normalizing process through watershed simulation will have to be accomplished in order to separate out the above variables from what is really wanted--an evaluation of BMPs themselves.

# The ANSWERS Model

D.B. Beasley, L.F. Huggins, E.J. Monke, T.A. Dillaha, III and S. Amin

During the second year of the project reported herein, several substantial changes were made to the ANSWERS (Areal Nonpoint Source Watershed Environment Response Simulation) program, originally developed as part of the Black Creek Project (Lake and Morrison, 1977). Changes included the ability to describe and simulate certain structural BMP's and their impact on water and sediment yield.

It must be noted that developmental work on improving the utility of ANSWERS is still on-going. In particular, developmental work is nearing completion on a version which includes direct simulation of nutrient losses (phosphorus) in addition to the sediment yield discussed herein. Also, improved sediment detachment and transport routines should give the user the ability to model changes in particle size distributions with changes in space and time.

## Acknowledgments

The ANSWERS simulation model development was financed with Federal funds from the U.S. Environmental Protection Agency under Sections 108a and 208 of PL 92-500 and by the Purdue Agricultural Experiment Station. The EPA grants were administered by the Soil and Water Conservation District of Allen County, Indiana and by the Indiana Heartland Coordinating Commission in Indianapolis. Special recognition is due the U.S. Dept. of Agriculture--Science and Education Administration, Agricultural Research, for technical assistance with field rainulator experiments conducted in cooperation with the Department of Agronomy, Purdue University. These field tests, together with other plot data and professional consultation made available by AR personnel, provided the basic information for development of the erosion and sediment transport components of the ANSWERS model. Earlier research supported in part by the Dept. of Interior, Office of Water Resources Research provide a foundation for the hydrologic portion of the model.

Numerous graduate students of the Department of Agricultural Engineering and professional colleagues have contributed greatly to various components and programming algorithms. Individuals deserving special mention include: J.R. Burney, G.R. Foster, H.M. Galloway, J.V. Mannering, T.D. McCain, and D.W. Nelson.

## ANSWERS Improvements

The specific component relationships used in the ANSWERS model are detailed in Beasley, et al. (1980) and Beasley and Huggins (1980). However, since certain improvements have been made to the model during and as a part of this project, they will be detailed below.

Land use changes, tillage techniques and management procedures which qualify as Best Management Practices (BMPs) for controlling non-point source pollution are simulated with ANSWERS by using appropriate parameter values for the component relationships discussed above. For example, conservation tillage generally results in a rougher surface, reduced C-factor and increased infiltration. Gully stabilization structures such a drop spillways or chutes may be simulated by reducing the slope steepness of the associated channel segments. Certain structural BMPs cannot be adequately accommodated with these component relationships. Currently, four specific BMPs which require special computational provision have been included: ponds, parallel tile-outlet terraces, grass waterways and field borders.

Both ponds and PTOs are handled in a similar manner using a trap efficiency concept. Sediment trapped from the water flowing into a pond or PTO is diverted into a special psuedo element which provides a means of tabulating the combined effectiveness of all such BMPs. Water is also assumed to be diverted, in the same ratio as sediment is trapped, into the tile drainage system. In this manner, effects of both reduced sediment loads and downstream overland flow rates are simulated.

Grass waterways and field border strips are also treated similarly to one another. It is assumed that the vegetated area within the affected element is no longer subject to any sediment detachment. Computationally, this is accomplished by adjusting the specified slope steepness by an amount which produces the desired change in sediment detachment rate for the element. Deposition within the vegetation of a grass waterway is deliberately prohibited, since any waterway that effectively traps sediment would soon fill and become ineffective. Specifying that an element has a grassed waterway forces the presence of a shadow channel element if none was already present.

## Using the ANSWERS Model

The following information is presented in an effort to acquaint the potential user with input requirements and output capabilities of ANSWERS. More detailed information is in the ANSWERS User's Manual (Beasley and Huggins, 1980).

The data file used by the ANSWERS model provides a detailed description of the watershed topography, drainage networks, soils, land uses, and BMPs. Most of the information can be readily gleaned from USDA-SCS Soil Surveys and land use and cropping surveys or summaries. Also, aerial photographs of the area, USGS topographic maps, and BMP construction or implementation data are quite useful in developing descriptions of actual watershed areas.

Input information for the ANSWERS model contains six general types of data:

1) Simulation requirements (measurement units and output control),

2) Rainfall information (times and intensities),

3) Soils information (antecedent moisture, infiltration, drainage response and potential erodibility),

4) Land use and surface information (crop type, surface roughness and storage characteristics),

5) Channel descriptions (width and roughness),

6) Individual element information (location, topography, drainage, soils, land use and BMPs).

The individual element information is the largest body of data and the most time consuming to collect. However, once the topography, soils, land use and drainage patterns have been determined for all of the elements, changes in watershed management or BMPs can be added very easily without having to totally reconstruct the input file.

Figure 1 shows the configuration of a typical ANSWERS data file. Each of the six data areas listed above are noted and will be covered individually in succeeding sections. The ANSWERS data file was designed to be self explanatory. The information contained in the soils, land use, and individual element information sections are physically measurable and can be checked for validity without having to go through a complicated process of differentiating one or more lumped parameters.

By using a very descriptive data file and the distributed parameter concept, the ANSWERS model is capable of producing a detailed accounting of the erosion and hydrologic response of a watershed subjected to a precipitation event. The output listing consists of five basic sections:

1) An "echo" of the input data (can be suppressed by removing "PRINT" parameter in line 2 of input data),

2) Watershed characteristics (calculated from elemental data),

3) Flow and sediment information at the watershed outlet and effectiveness of structural BMPs,

4) Net transported sediment yield or deposition for each element,

5) Channel deposition.

Several plotting programs have been constructed to use the input to and the output from the ANSWERS model to provide visual enhancement and better understanding of the information provided by this program. The QCKPLT program, mentioned in a previous section, uses the elemental data portion of the input file to produce the map shown in Figure 2. The arrows indicate the flow direction for each element. The shaded areas indicate "dual" elements or overland elements with companion channel elements. This map can be produced so that it will fit any scale. This feature allows one to check input data on maps with different scales by producing overlays at the specific scale needed. The grid is also very useful in physically locating the predicted "hot spot" areas.

**1**
```
STANDARD PREDATA FILE FOR  ALLEN CO., INDIANA--800823
ENGLISH UNITS ARE USED ON INPUT/OUTPUT                      PRINT
```

**2**
```
RAINFALL DATA FOR 2 GAUGE(S) FOR EVENT OF:      TEST
 GAGE NUMBER       R1
0         0.      0.00
0         9.       .52
0        15.      1.55
0        20.      2.40
0        30.      1.59
0        35.       .85
0        45.       .50
1       300.      0.00
 GAGE NUMBER       R2
0         0.      0.00
0         7.       .45
0        14.      1.25
0        18.      2.66
0        25.      1.65
0        33.       .60
0        42.       .35
1       300.      0.00
```

**3**
```
SOIL INFILTRATION, DRAINAGE AND GROUNDWATER CONSTANTS FOLLOW
NUMBER OF SOILS =    8
S 1, TP =.46, FP =.75, FC =  .40, A =  .80, P =.65, DF =  4.0, ASM =.70, K =.35
S 2, TP =.46, FP =.65, FC =  .40, A =  .80, P =.65, DF =  3.0, ASM =.70, K =.32
S 3, TP =.46, FP =.70, FC =  .40, A =  .80, P =.75, DF =  3.0, ASM =.70, K =.17
S 4, TP =.42, FP =.70, FC =  .60, A =  1.0, P =.65, DF =  4.0, ASM =.70, K =.36
S 5, TP =.44, FP =.80, FC =  .60, A =  1.0, P =.65, DF =  5.0, ASM =.70, K =.32
S 6, TP =.46, FP =.75, FC =  .60, A =  1.0, P =.65, DF =  5.0, ASM =.70, K =.36
S 7, TP =.46, FP =.75, FC =  .40, A =  .80, P =.65, DF =  3.0, ASM =.70, K =.38
S 8, TP =.35, FP =.65, FC =  .90, A =  1.6, P =.60, DF =  6.0, ASM =.70, K =.35
DRAINAGE COEFFICIENT FOR TILE DRAINS = 0.25 IN/24HR
GROUNDWATER RELEASE FRACTION =    .005
```

**4**
```
SURFACE ROUGHNESS AND CROP CONSTANTS FOLLOW
NUMBER OF CROPS AND SURFACES =   6
C 1, CROP= S1 CORN, PIT=.01, PER=0.0, RC=.47, HU= 2.0, N=.075, C=.50
C 2, CROP= CORN-NT, PIT=.06, PER=.75, RC=.55, HU= 2.5, N=.120, C=.30
C 3, CROP=BEANS TP, PIT=.01, PER=.45, RC=.47, HU= 1.5, N=.060, C=.60
C 4, CROP=S.GRAINS, PIT=.04, PER=.90, RC=.55, HU= 2.0, N=.120, C=.15
C 5, CROP= PASTURE, PIT=.03, PER=1.0, RC=.40, HU= 1.5, N=.150, C=.04
C 6, CROP=  WOODS , PIT=.10, PER=.90, RC=.55, HU= 3.5, N=.200, C=.15
```

**5**
```
CHANNEL SPECIFICATIONS FOLLOW
NUMBER OF TYPES OF CHANNELS =   4,
CHANNEL 1 WIDTH =15.0  FT, ROUGHNESS COEFF.(N) = .035
CHANNEL 2 WIDTH =10.0  FT, ROUGHNESS COEFF.(N) = .040
CHANNEL 3 WIDTH = 7.0  FT, ROUGHNESS COEFF.(N) = .045
CHANNEL 4 WIDTH = 4.0  FT, ROUGHNESS COEFF.(N) = .050
```

**6**
```
ELEMENT SPECIFICATIONS FOR MIDDLETOWN WATERSHED
EACH ELEMENT IS 528.0FT   SQUARE
OUTFLOW FROM ROW  21 COLUMN    3
 1 15     4 270   1   1   R1         0                                     827.8
 1 16     5 259   3   1   R1         0                                     828.8
 .  .     .  .    .   .   .     .    .                                         .
 .  .     .  .    .   .   .     .    .                                         .
 7 20     9 186   2   1   R1         0  2                                  822.8
 7 22     2 135   1   2   R1         0                                     835.3
 7 23     3 180   3   5   R1 TILE    0                                     835.3
 8 11    20 270 201   2   R2 TILE    5  4  32                              799.7
 8 12    17 180 302   2   R2 TILE    5  4  20                              799.3
 8 13    16 180 303   1   R2 TILE    5  4  20                              802.2
 8 14    12 148   1   1   R2 TILE    0  1                                  809.2
 .  .     .  .    .   .   .     .    .                                         .
 .  .     .  .    .   .   .     .    .                                         .
20 19     8 180   1   2   R2 TILE    0  3  20                              802.0
20 20     8 180   1   2   R2 TILE    0                                     803.0
21  3     9 270 102   1   R2 TILE    3  4  40                              766.5
21  4    28 180 108   1   R2 TILE    3  4  40                              762.0
 .  .     .  .    .   .   .     .    .                                         .
 .  .     .  .    .   .   .     .    .                                         .
22 13     2   0   3   4   R2         0                                     799.5
22 14 9   5  90   1   4   R2         0                                     798.0
```

Figure 1.  Typical ANSWERS input data file

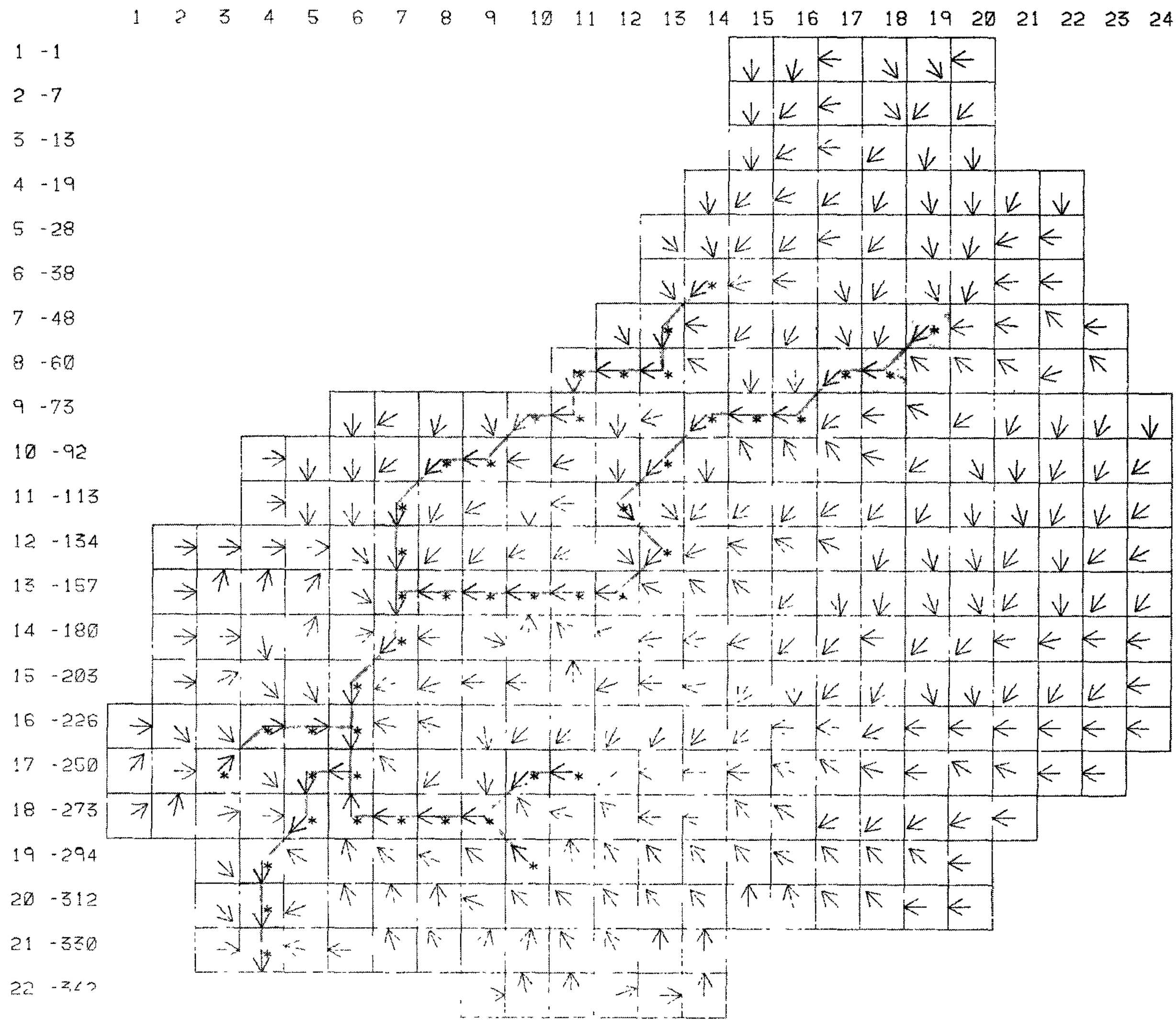



Figure 2. Example elemental map produced by QCKPLT program

Figure 3 shows the graphic output from the HYPLT program. HYPLT uses standard CALCOMP-compatible calls and plots the rainfall hyetograph, the runoff hydrograph and the sediment concentration curve. The program directly uses the hydrograph portion of the output listing.

The information presented in Figure 4 comes directly from the net transported sediment yield or deposition section of the ANSWERS output. Several programming steps are required to "reconstruct" an elemental data format (row and column coordinates) and input the individual element information to a program called CONTUR. CONTUR allows the user to set the levels of sediment yield or deposition at which contours are desired. The program produces a map at any desired scale (up to the maximum size the plotter allows). The shading in Figure 4 is for additional visual effect. The portions of the watershed with closely spaced contours show areas with excessive transported soil loss

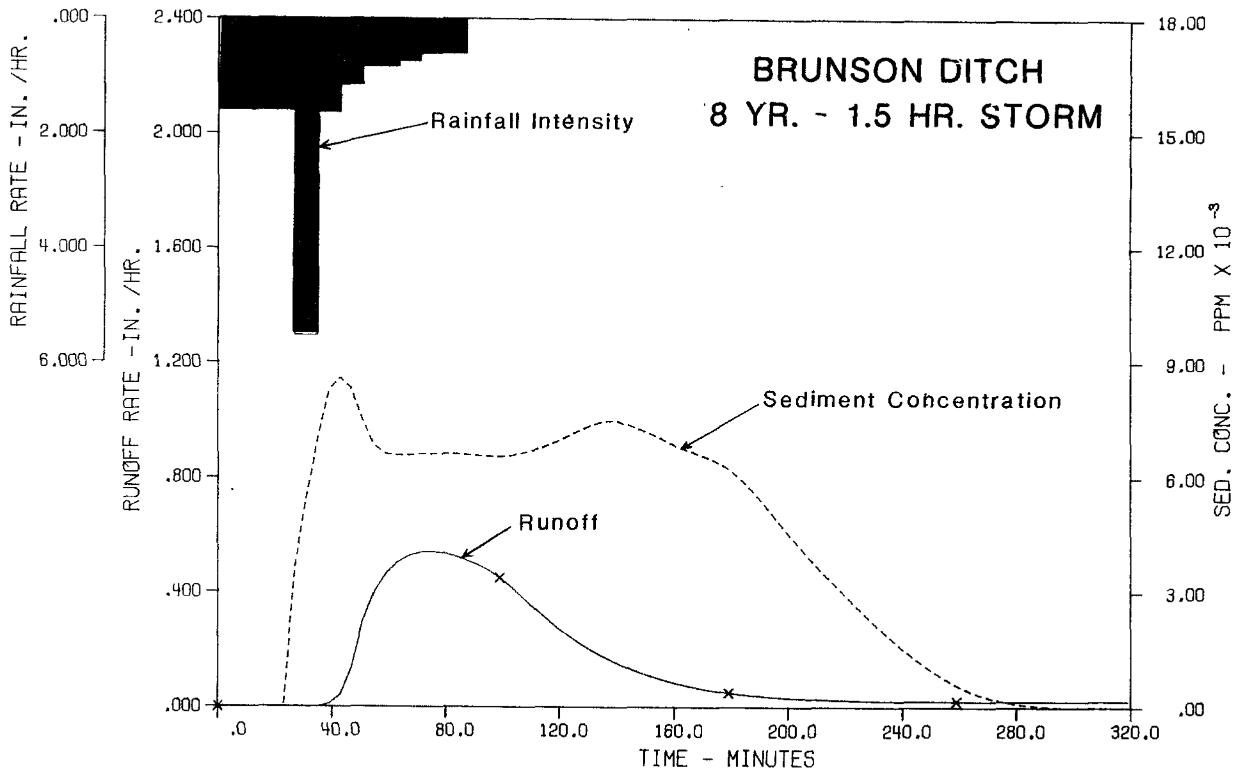



Figure 3. Example output of HYPLT plotting program

or deposition. In general, high transported soil loss areas will be found near high deposition areas. This is due to the fact that steep slopes blend into flat slopes near the channels.

## Planning and Evaluation Case Studies

The following case studies are examples of the application of ANSWERS in two different areas - planning and evaluation. Continuing development of the model should allow even more descriptive and useful outputs in the future.

The relationship between monitored information and simulation results is very important. In earlier sections, it has been pointed out that monitoring studies cannot provide the detailed information necessary to determine cause-effect relationships. Also, the use of unvalidated models or models with too many simplifying assumptions or undescriptive relationships leads to the same result -- a lack of complete understanding of the causes and effects. This section will detail the use of the ANSWERS model coupled with data gathered from an extensive monitoring system for use in both the planning and evaluation roles.

The planning example utilizes the model on an ungaged watershed in Allen County, Indiana. The topography, soils, land uses, management systems and precipitation inputs are very similar to monitored information from the Black

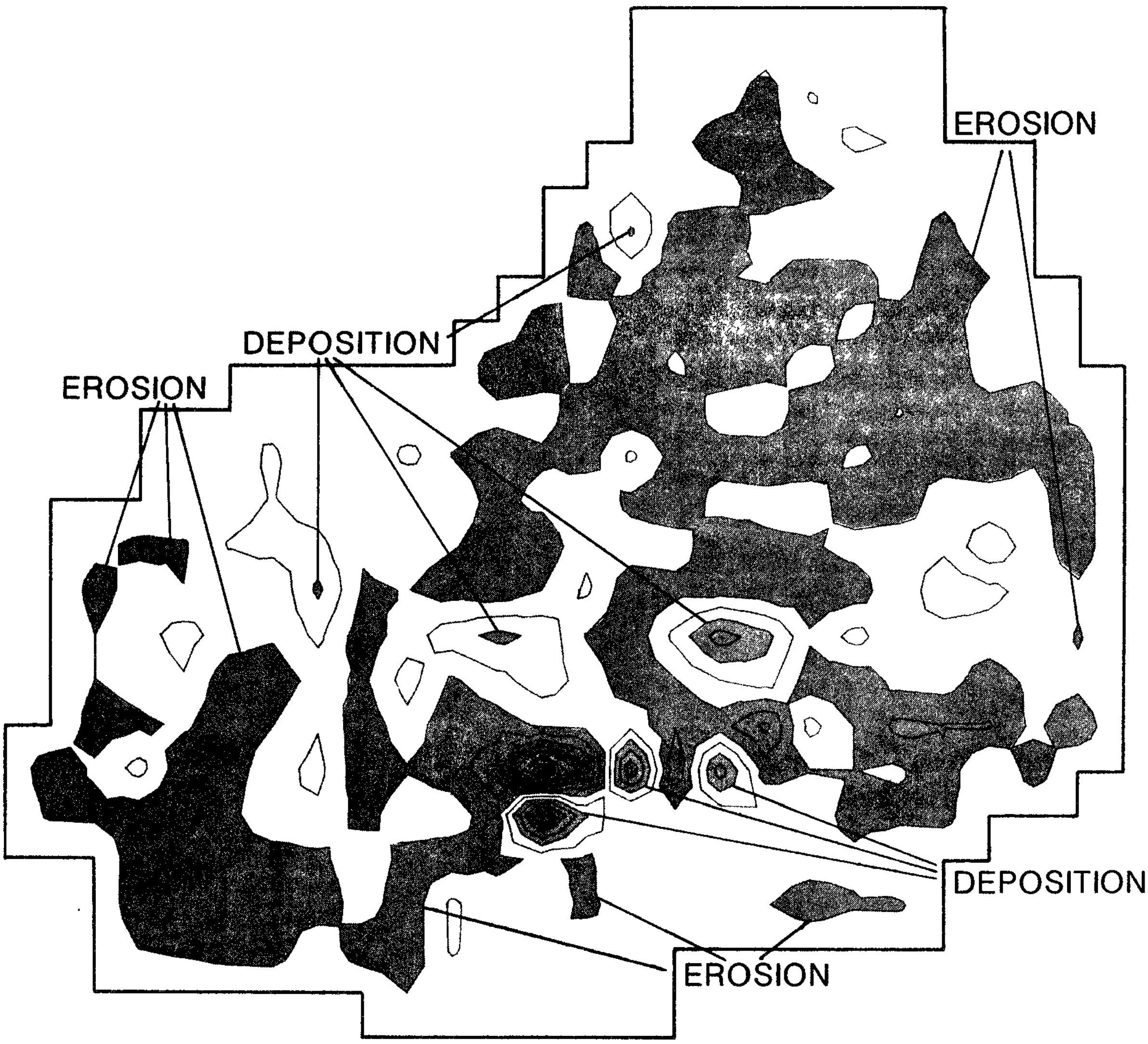



Figure 4. Example output from CONTUR program
(Closely spaced contours indicate high deposition/erosion areas)

Creek Study area, which is about 35 kilometers away. The a priori ability of ANSWERS to describe the responses of the various hydrologic and erosion components is used to produce water, sediment and nutrient yield predictions for a variety of hypothetical management strategies.

The evaluation example gives some insight into using the ANSWERS model for the purpose of interpreting monitored data. Two different comparisons are made concurrently: (1) the improvement in water quality from 1975 to 1978 and (2) the improvement in water quality from the west side of the watershed to the east side. All of the simulations used monitored data to verify and give credence to the results.

Planning Example

As an example of using ANSWERS as a tool for planning BMP systems, let us consider an actual situation, the Marie Delarme watershed located in northeastern Indiana. This watershed is composed of almost 500 ha of predominately (60 percent) poorly drained Blount, Crosby and Hoytville silty clay loams, with the remainder being moderately permeable Haskins and Rensselaer silt loams. Element slopes range from 1 to 6 percent and have an average of 1.9 percent. Because of the moderate relief, an element size of 2.6 ha was chosen as adequate for modeling purposes. The resulting watershed representation is shown in Figure 5.

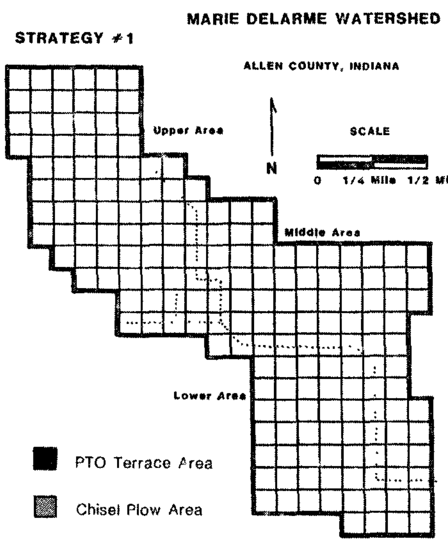



Figure 5. Elemental watershed representation

In order to rank the effectiveness of alternative control strategies, some frame of reference or "baseline condition" was required. To remove effects of particular land use and management practices from the baseline condition, all tillable land (in this case, the entire watershed) was assumed to be planted to conventionally tilled corn.

In addition to choosing a land use pattern, a time frame must also be selected. Average annual conditions are usually used. Since ANSWERS is an event-based model, simulations are performed on a storm-by-storm basis. While it is certainly possible to simulate all the storms of a "typical" year and then sum the results, this is not necessary in most situations. Many research results have shown that most of the sediment and associated chemicals are produced by the largest one or two storms for the year. Monitored data from the Black Creek watershed in northeastern Indiana also indicate that average annual yields can be approximated, for that region, by simulating a single 1.5 hour duration, B-distribution storm which has a recurrence interval of 8 years. This hypothetical storm was assumed to occur approximately one month after planting, with antecedent soil moisture at field capacity. Simulating these conditions will approximate average annual yields for sediment and sediment-related nutrients. However, soluble chemical transport is underestimated. Because this single storm yields only 10 percent of the expected annual water yield, annual soluble nitrogen yields were not accurately predicted by the single storm simplification.

Having decided upon a set of baseline conditions, the next step was to simulate the response of the Marie Delarme watershed to those conditions. The result of that effort is shown in Figure 6. It shows the distribution of net sediment transported from each element for the baseline condition. Note that the values, ranging from a loss in excess of 5000 kg/ha to deposition of more than 1000 kg/ha, represent net transport from each 2.6 ha element. Local erosion rates would generally be much higher that the rates of transported sediment. These net transport rates are predicted by ANSWERS without resorting to a delivery ratio concept which is very difficult to quantify. Instead, the specified watershed topography, land use and surface runoff rates determined transport capacity within the watershed.

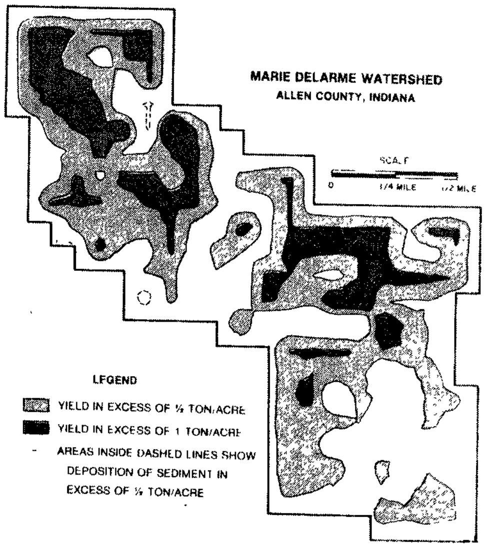



Figure 6. Net sediment yield

Figure 6 gives information important for devising alternative control strategies. It shows that the highest sediment and associated nutrient yields occur in the upper third of the watershed and gradually decrease toward the outlet. While anyone knowledgeable about soil erosion and familiar with the watershed could have predicted this general trend without a simulation analysis, a distributed model is required to quantify actual yields in the manner shown. More importantly, as the following results demonstrate, such a model can predict relative impacts of alternative control strategies.

Figures 7a through 7d depict four alternative control strategies. While many other strategies, possibly even more effective than those chosen, could have been selected, they illustrate the scope of information made available and the manner in which simulation can be used as an effective planning tool.

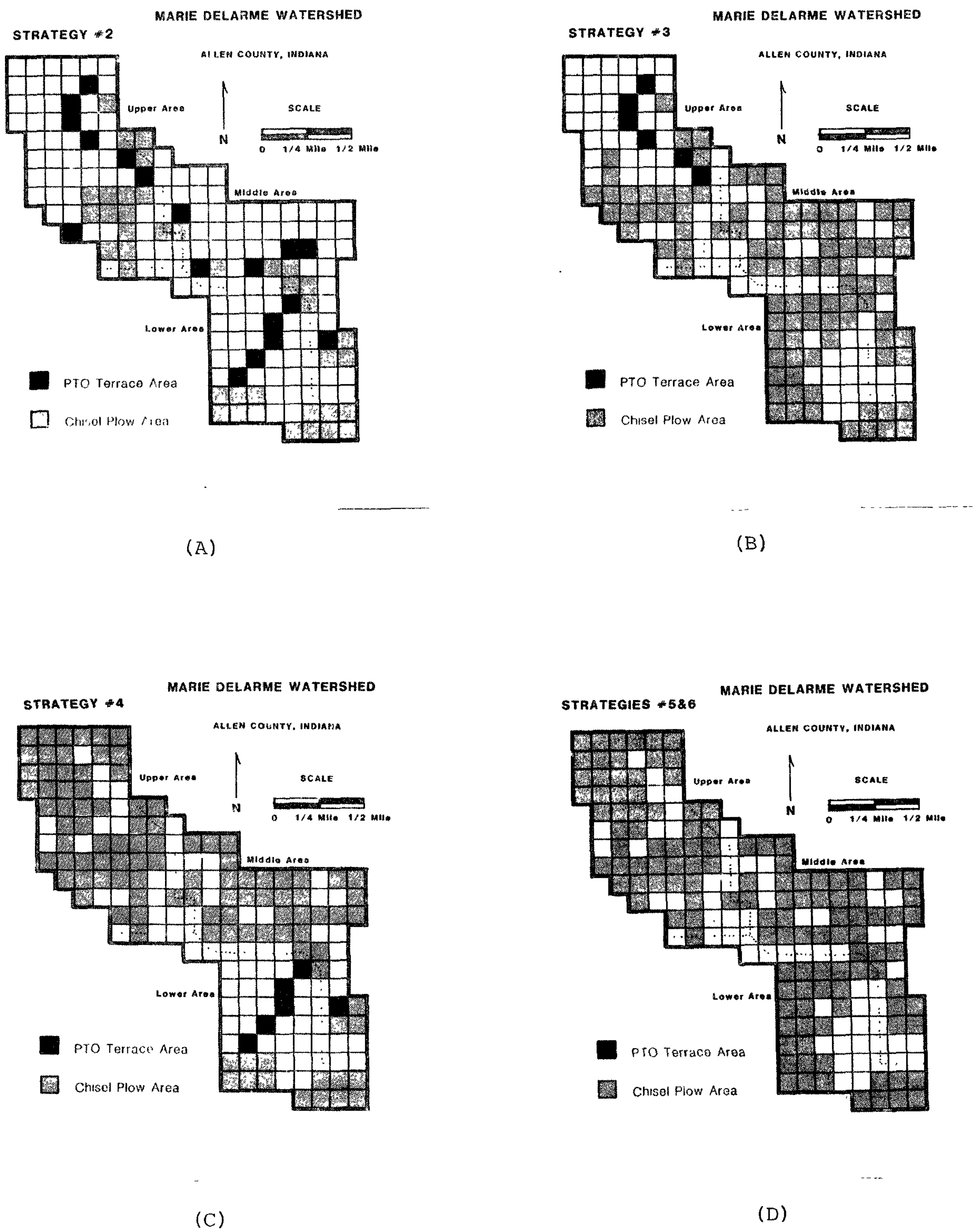



Figure 7. Locations of BMPs for Alternative Strategies.

Table 1 summarizes simulation results from all strategies considered. It illustrates the complicated nature of ranking alternative programs for NPS pollution control. The position of a particular strategy is very dependent upon the ranking criteria used. For example, Strategies 2-5 have been listed in terms of decreasing effectiveness for reducing sediment yield at the outlet of the watershed. However, the ranking would be quite different if annual unit cost of achieving a sediment yield reduction is employed. Still different results would be obtained if nutrient yields or concentration levels in the stream are chosen. All of these water quality improvement criteria and others are valid for developing a control program. Generally, several of them would be given some consideration. It is the ability of a comprehensive simulation model to provide information on such a wide range of factors that makes it such an attractive and even essential tool for planning NPS pollution control.

The ranking of strategies is also influenced by the choice of baseline conditions, as illustrated in Table 1 by Strategy 6. The only difference between results for Strategies 5 and 6 is the severity of the hypothetical storm used to simulate the baseline condition. For Strategy 6, a storm with 25 percent lower intensities and total volume was used. This gave a sediment yield of 640 kg/ha for the same land use as in Strategy 1. When simulation results from Strategy 5 are compared to that baseline instead of Strategy 1, they show lower absolute reductions (110 kg/ha vs. 170 kg/ha), but an increased percentage reduction. The unit cost of reducing sediment yield was also higher when the less intense baseline storm was used. This again illustrates the complexity of analyzing NPS pollution and its control.

Evaluation Example

As an example of the use of ANSWERS for interpreting monitored data, let us consider its use in the Black Creek Project. The 4860 ha study watershed, located in northeastern Indiana, is composed of relatively heavy soils associated with glacial till and an old glacial lake. The land use is almost entirely agricultural except for a small community of about 500 persons. Its soils and land use distribution are representative of those in the Maumee Basin.

The Allen County Soil and Water Conservation District, with the technical assistance of the Soil Conservation Service, developed a cost-sharing program to encourage installation of appropriate BMPs. Purdue University and the University of Illinois were responsible for monitoring the physical/chemical and biological water quality impacts of installed BMPs. Figure 8 depicts locations at which physical/chemical monitoring has been conducted for periods ranging from 3 to 6 years. An even more extensive network of biological monitoring locations was established.

The Black Creek project has utilized automated, continuous monitoring of stream water conditions near the outlet and at selected subwatershed points for about 5 years. This comprehensive data base has established a reliable indication of water quality conditions within the watershed. However, it is impossible from such data to answer the question: "What have been the benefits from individual classes of BMPs installed during the project?" This is a result of the many uncontrolled factors which influence levels of NPS

Table 1. Simulation Results for Alternative Strategies

| Strategy* | Area Affected by BMPs PTO | Area Affected by BMPs Chisel | Total Yield at Watershed Outlet Sediment | Total P | Avail. P | Sed. N | Sol. N | Sediment Reduction | Cost** |
|---|---|---|---|---|---|---|---|---|---|
| | (ha) | (ha) | (kg/ha) | (kg/ha) | (kg/ha) | (kg/ha) | (kg/ha) | (%) | ($/tonne reduced) |
| 1 | 0 | 0 | 1530 | 2.1 | .6 | 13 | 1.0 | | |
| 2 | 285 | 104 | 650 | .8 | .2 | 6 | .6 | 57 | 34.70 |
| 3 | 85 | 213 | 1080 | 1.5 | .3 | 10 | .8 | 29 | 22.00 |
| 4 | 91 | 272 | 1220 | 1.6 | .4 | 11 | .8 | 20 | 35.30 |
| 5 | 0 | 321 | 1340 | 1.8 | .4 | 12 | .9 | 13 | 7.50 |
| 6 | 0 | 321 | 520 | .6 | .1 | 4 | .4 | 19 | 11.60 |

*1. Baseline condition: Fall moldboard plowed, no BMPs.
2. PTO terraces installed where most of the sediment yield was in excess of 2.25 tonne/hectare. In addition, those areas with sediment yield in excess of 1.12 tonne/hectare not benefited by terraces were chisel plowed.
3. PTO terraces installed in the upper 1/3 of the watershed only. All areas with sediment yield in excess of 1.12 tonne/hectare not benefited by terraces were chisel plowed.
4. PTO terraces installed in the lower 1/3 of the watershed only. All areas with sediment yield in excess of 1.12 tonne/hectare not benefited by terraces were chisel plowed.
5. All areas with sediment yield greater than 1.12 tonne/hectare chisel plowed.
6. Same as Strategy 5 except that a storm with 25% lower intensity and total volume was used. The "baseline condition" for this storm gave a total sediment yield of 640 kg/ha.

** Cost information was based on 1979 construction costs for PTO terrace systems in Allen County, Indiana. The cost is based on total area benefited (both above and below terraces). The figure used in these calculations was $510.80 per hectare benefited. A 10-year life was assumed, which yielded an annual cost of $51.08 per hectare benefited. The chisel plow was also assumed to have a 10-year life. The average annual cost per hectare, based on the cost of a new plow, was $2.17. Since the "design storm" used in this example produced approximately the annual sediment yield, the cost per tonne of reduced yield at the watershed outlet is, essentially, the annual cost. However, due to simplifying assumptions and unique local conditions, these cost figures should not be considered to be generally applicable to other planning situations. They were included in an effort to give the reader a feeling for the type of analysis which can be performed by ANSWERS.

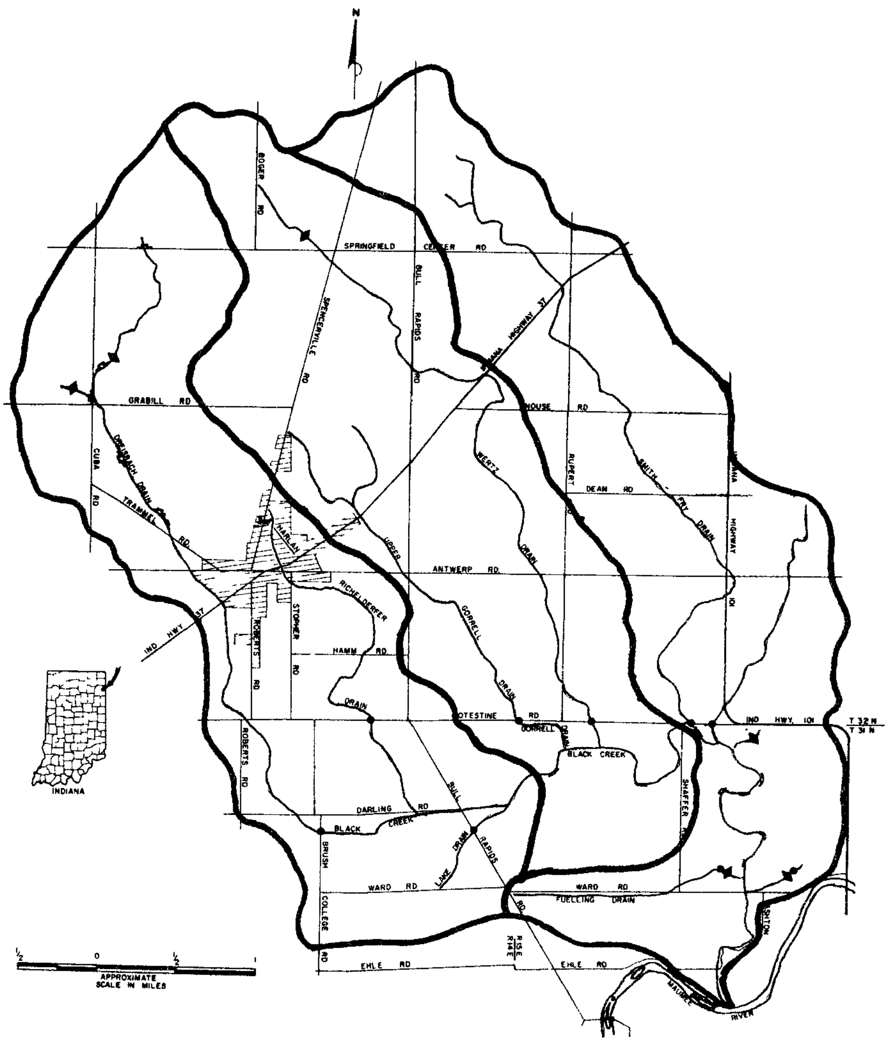



Figure 8. Black Creek monitoring locations and primary subwatersheds

pollution and the diversity of BMPs, crops and annual management changes which occur on a watershed scale. Such a question can be answered using simulation analysis because it is possible to hypothetically hold all factors, especially hydrologic conditions, constant and change only the applied BMPs.

Figure 8 shows the Black Creek watershed subdivided into three major subwatersheds of approximately equal size. A deliberate effort was made to encourage the installation of BMPs within the western subwatershed. This decision was made to more clearly differentiate BMP impacts and to demonstrate the magnitude of water quality change which was feasible. As a result, a pattern of decreasing practice density occurs as one goes eastward. The initial development of the ANSWERS model was undertaken as a part of the Black Creek Project as it became apparent that monitored data alone was inadequate to quantify impacts of the combinations of installed BMPs.

The BMPs installed within Black Creek were primarily structural in nature: parallel tile-outlet terraces (PTO), field borders, grass waterways and livestock exclusion. Despite the demonstrated water quality benefits of reduced tillage systems, only limited utilization was achieved. This was the result of farmer concern about wetness during the spring on the heavy soils of the area.

The area of land directly affected by installed BMPs ranged from 6 percent in the western subwatershed to less than 2 percent in the eastern subwatershed. ANSWERS simulations, using patterns of land use change and BMPs installed between 1975 and 1978 with assumed constant hydrologic conditions, indicated that BMPs installed within the western subwatershed would reduce annual sediment yield about 30 percent. The reduction for the medium density middle subwatershed was about 20 percent, dropping to only about 10 percent for the minimum treatment level on the eastern subwatershed. Watershed scale impacts from a single installation are also available, but such results are extremely location dependent.

One additional result of general interest was determined. When the installed structural BMPs for the western subwatershed were hypothetically augmented with chisel plowing in selected critical areas, the projected reduction of annual sediment yield was increased to 50 percent.

## REFERENCES

1. Beasley, D.B., L.F. Huggins and E.J. Monke. 1980. ANSWERS: A model for watershed planning. Transactions of the ASAE (23)4:938-944.

2. Beasley, D.B. and L.F. Huggins. 1980. ANSWERS user's manual. Agric. Eng. Dept. Purdue Univ., 55p.

3. Lake, J. and J. Morrison. 1977. Environmental impact of land use on water quality: final report of the Black Creek project--technical report. U.S. Envir. Prot. Agency, Region V, Chicago, IL. EPA-905/9-77-007-B. 274 p.

# TILE DRAINAGE STUDIES

E.J. Monke, A.B. Bottcher, E.R. Miller, L.F. Huggins,
D.B. Beasley, D.W. Nelson, R.E. Land

## ABSTRACT

In the first study, sediment pesticide (1977 only) and nutrient losses were measured from a 17 ha subsurface drainage system for the years 1976-79 using automatic sampling equipment. The monitored drainage system was installed in the early 1950's on a nearly flat Hoytville silty clay with limited surface runoff due to raised field borders. Dynamic responses of the drainage system are graphically presented and discussed as they related to field management practices and climatic variations. Sediment yields were generally low averaging 81 kg/ha for the four years of record. A comparison was also made between this system with its low surface runoff and a more normal situation with much greater surface runoff. For the 17 ha system, runoff per unit area was substantially lower resulting also in less sediment and nutrient losses.

In the second study, the sediment movement in the backfill profile of Hoytville silty clay was compared to that for two other soils found in the Maumee Basin. One soil was Latty clay which is a true lacustrine soil from the center portion of the basin. It is marginally suited for subsurface drainage. The other soil was Blount silt loam, a glacial till soil, found around the periphery of the basin. It is mostly drained by random tile systems since the topography is gently rolling. The study was conducted using a laboratory set-up to measure the sediment yield from vertically downward movement of water through the backfill profiles. The average sediment loss for Latty clay was about 20 percent greater and that for the Blount silt loam about 75 percent less than for Hoytville silty clay. If the sediment yield for Hoytville silty clay in the first study is representative of the Maumee Basin, the yields and associated chemical transport for the other two soils are also likely to be low. As another part of the second study, none of five envelope materials had any effect on sediment movement from Hoytville silty clay backfill profiles.

## INTRODUCTION

The major cause of accelerated eutrophication in many of our lakes and streams has been identified as nutrient enrichment, particularly phosphorus. Nutrient enrichment in many areas has been attributed to runoff from agricultural lands which is related to fertilizer usage, cropping practices and water management. A large portion of the nutrients are associated with sediments being transported from fields. Therefore, an obvious abatement procedure is the use of practices to reduce soil erosion which generally has the effect of increasing subsurface drainage. However, before any such practice can be identified for nonpoint source pollution control, we need to know how a particular practice affects the type, form or amount of nutrients being transported and how water yields and concentration differences impact on loading rates.

With respect to subsurface drainage, Baker and Johnson (1976) indicate that nitrate concentrations are higher in subsurface waters than surface waters. Also, Schwab, Nolte, and Brehm (1977) found significant sediment losses from tile drains. Nutrient data collected during the Black Creek project (Lake, 1977) showed that in all cases the average soluble forms of nitrogen and phosphorus were higher in subsurface drainage waters than in surface waters. The high nutrient concentrations likely to be found in tile drainage waters and the extensive and rapidly increasing acreage of subsurface drainage reinforces the need to better understand the transport and transformation processes involved with this practice. In addition, subsurface drainage may have to be associated with water quality or erosion control practices in order to maintain productivity.

In the past, most methods of reducing sediment movement have been concerned with sand and coarse silt in preventing clogging of drainage lines. Installation practices were developed to lengthen and improve the operational life of subsurface drainage systems. In recent years, however, the emphasis on reducing surface sediment movement has been extended to include the overall subsurface contribution of sediments and nutrients to our rivers and lakes. This additional emphasis on improving water quality has shown the need for better practices of stabilizing silts and clays near drain lines since the small soil particles have large surface areas which can adsorb and transport soil nutrients into the drains. The stabilization of heavy soils surrounding drainage lines involves recognizing some of the possible causes for their movement.

Schwab (1975), working with heavy soils in the Maumee Basin, proposed that the main mechanism of sediment movement is due to suspended particles in the soil water that move through the soil profile or the backfill material into subsurface drains. His results also showed that the sediment concentration increases significantly with antecedent moisture content of the soil profile. Monke and Beasley (1975) also noted turbid discharge from some tile outlets during spring thaws when the seepage water in the largely saturated profile was quickly released to the tile drains.

A mechanical analysis of the sediment losses during a field evaluation of drain envelopes by Taylor and Goins (1976) indicated that the sediment reassembled the A horizon more than any other part of the profile. Its composition was probably developed by sorting during transport in the drainage channels of the horizons above the drain. They also noted extensive channeling (possibly caused by incomplete settling of the backfill rather than shrinkage cracks) in the soil adjacent to the tile lines installed in Crosby silt loam.

In both cohesive and non-cohesive soils, the mechanism of piping has also been a significant contributor to sediment movement into subsurface drains. Zaslovsky and Kassiff (1965) defined piping as the condition in which the forces of drag and gravity on soil particles overcame their maximum resisting force of cohesion. Such an unstable hydraulic condition occurs at locations of excessive hydraulic gradients resulting from the effects of convergence at drain pipe perforations. The limiting form of soil bridging from edge and convergence effects tends toward a hemisphere which allows the gradients over the surface of the hemisphere to become lower and more uniform.

Walker (1978) noted that the hemisphere formed in well-graded cohesive soil by bridging collapsed when the exit gradient for the flow rate exceeded the characteristic critical failure gradient of the soil. Walker demonstrated experimentally that the critical failure gradient was a function of soil properties and not that of the restraining envelope material. Thus, for filter and envelope materials, criteria which reduce excessive exit gradients from convergence or the hydraulic gradients at the soil-envelope interface to levels that prevent initial soil movement is very appropriate in determining their application.

## I. MOVEMENT OF NUTRIENTS AND SEDIMENT FROM A SUBSURFACE DRAINAGE SYSTEM

### OBJECTIVE

The objective of this study was to determine the overall water quality impact associated with the waters discharged during the period 1976-79 from a subsurface drainage system on a field with minimum surface runoff.

### SITE DESCRIPTION

The monitored tile system drained a 17.4 ha field located two miles south of Woodburn, Indiana. The field was very flat (< 1% slope) and had raised field borders. The field borders were the result of ditching around the field and effectively prevent most surface runoff. Ninety-five percent of the field consisted of a Hoytville silty clay (fine, illitic, mesic Mollic Ochraqualfs) with the remaining area being a Nappanee silt loam (fine, illitic, mesic Alric Ochraqualfs).

The drainage system was installed in the early 1950's at a depth of one to two meters. The drain lines were clay drains with topsoil blinding except under observed wet spots where stone envelopes were placed. The main line was thirty-centimeters in diameter. A layout of the drainage system as obtained from construction records kept by the owner is shown in Figure 1. The cropping and fertilizer history for the field is given in Table 1.

### DATA COLLECTION

The subsurface drainage system outlet was monitored for flow and water quality parameters using automatic sampling and recording equipment (see Figure 2). The flow was determined by recording the depth of water behind a weir crest with a bubble-tube stage recorder. Free fall was assured over the weir by pumping the discharge into the outlet ditch.

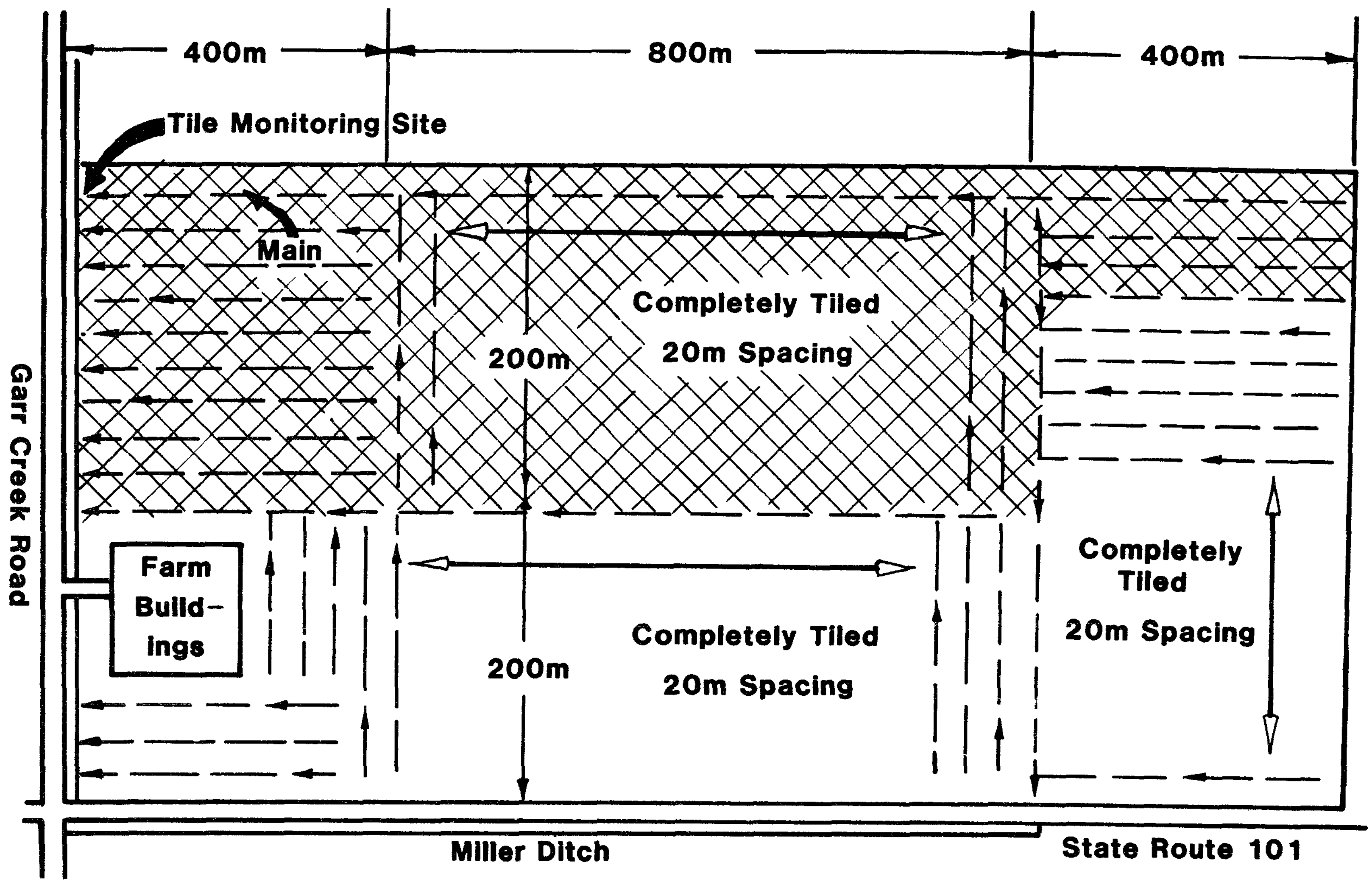



Figure 1. Subsurface Drainage System Layout (Hatched Area Represents Portion of Field Which Drains to the Monitored Outlet)

Table 1. Field Cropping and Fertilization for Subsurface Drainage Field

| Year | Crop | Area (hectare) | Fertilization (kg/ha) | (Type) |
|---|---|---|---|---|
| 1971 | Oats | 17.4 | 150 | 16-16-16 |
| 1972 | Corn | 17.4 | 50 | N-45 urea |
| | | | 300 | 0-26-26 fall plow-down |
| 1973 | Soybeans | 17.4 | 60 | 10-34-0 starter |
| 1974 | Corn | 8.7 | 100 | 10-34-0 starter |
| | | | 100 | N-28 solution |
| | | | 300 | 0-26-26 fall plow-down |
| | Wheat | 8.7 | 100 | N-28 solution |
| | | | 300 | 5-24-24 fall plow-down |
| 1975 | Beans | 8.7 | 100 | 10-34-0 starter |
| | Corn | 8.7 | 100 | 10-34-0 starter |
| | | | 100 | N-45 urea |
| | | | 300 | 0-26-26 fall plow-down |
| 1976 | Wheat | 8.7 | 300 | 16-16-16 |
| | | | 50 | N-45 urea |
| | Soybeans | 8.7 | 100 | 10-34-0 starter |
| | Soybeans | 17.4 | 400 | 0-25-26 fall plow-down |
| 1977 | Corn | 17.4 | 180 | 10-34-0 starter |
| | | | 170 | N-45 Urea |
| | | | 10 | Manganese |
| | | | 200 | 0-0-60 fall plow-down |
| 1978 | Soybeans | 17.4 | 120 | 10-34-0 starter |
| | Wheat | 17.4 | 300 | 0-26-26 fall plow-down |
| 1979 | Wheat | 17.4 | 175 | N-56 urea (56%) |
| | (Clover) | | 400 | 0-9-48 fall plow-down |
| | | | 250 | 82-0-0 (11/14 with N-Serve) |
| 1980 | Corn | 17.4 | 240 | 10-34-0 starter |

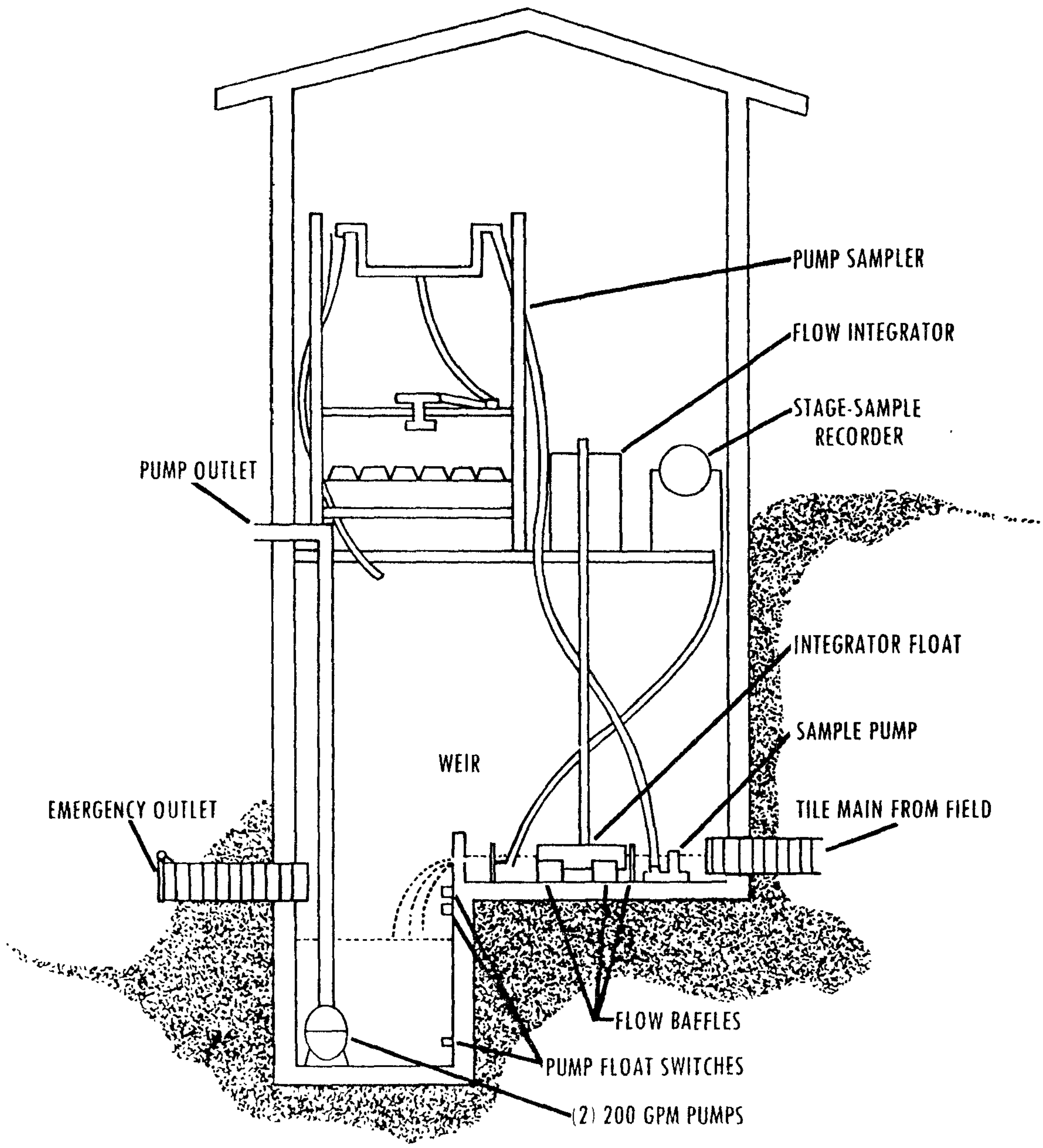



Figure 2. Tile Flow Sampling Station

Discrete (500 ml) water samples were collected at a rate proportional to the tile outflow. A flow integrater was constructed to vary the sampling rate with flow. The sampler (designed by authors) had a capacity of 72 samples before servicing was required. The sampling rate varied from one sample for each forty minutes at maximum flow to one sample for each twelve hours at low flow rates. Samples were frozen within 24 hours of collection for later laboratory analysis. Standard laboratory procedures were used and are described in the final report of the Black Creek Project (Lake, 1977).

## RESULTS AND DISCUSSION

Selected flow periods during 1977 were chosen for detailed analyses of the flow rate, rainfall and various nutrient and sediment concentrations and yields. However, data for the remaining years of record are also available in the same detail. Summaries of all the data from 1976 through 1979 are presented.

### Water Yield

The flow response of the subsurface drainage system for the months of February, March, and April 1977 is shown in Figure 3. This is the period when the soil profile is normally the wettest resulting in the highest tile outflow. Later in the spring and on into the summer and early fall, little tile flow occurs as the result of high evapotranspiration rates which increases the available water storage in the profile and lowers the water table. In several cases, two or four centimeter rainfall events during this period resulted in no tile flow at all. In general, tile flow in the Midwest can be considered mostly a winter and early spring phenomenon.

The freezing and thawing conditions during this high flow period may complicate the mechanics of water flow. Flows can go from zero to near full pipe flow within a few hours during an initial flush in early spring. The magnitude of the initial flush depends on the depth of the freeze line and the amount of water stored in and above the soil profile. Then when the freeze line "breaks", which it does uniformly, large amounts of free water are released to the tile drains. Furthermore, temporary freezing of the ground surface may reduce the tile flow rate by interfering with the groundwater pressures. Since temporary freezing likely occurs during the night, flow fluctuations show up as a diurnal cycle. An example of this phenomena can be seen in Figure 3 following the initial flush event.

Another characteristic of the tile flow was the rapid hydraulic response of the tile system which can be noted by the sharpness of the leading edges of the hydrographs. To simulate these responses, an average soil profile conductivity of 3.0 cm/hr was used (Bottcher, Monke and Huggins, 1978). This indicates that the reported hydraulic conductivity 2-6 cm/hr above and 0.1-2.0 cm/hr below the plow layer) of Hoytville soil in the county soil survey report may be either too low or that the years of subsurface drainage and good soil management have changed the hydraulic characteristics of this soil profile.

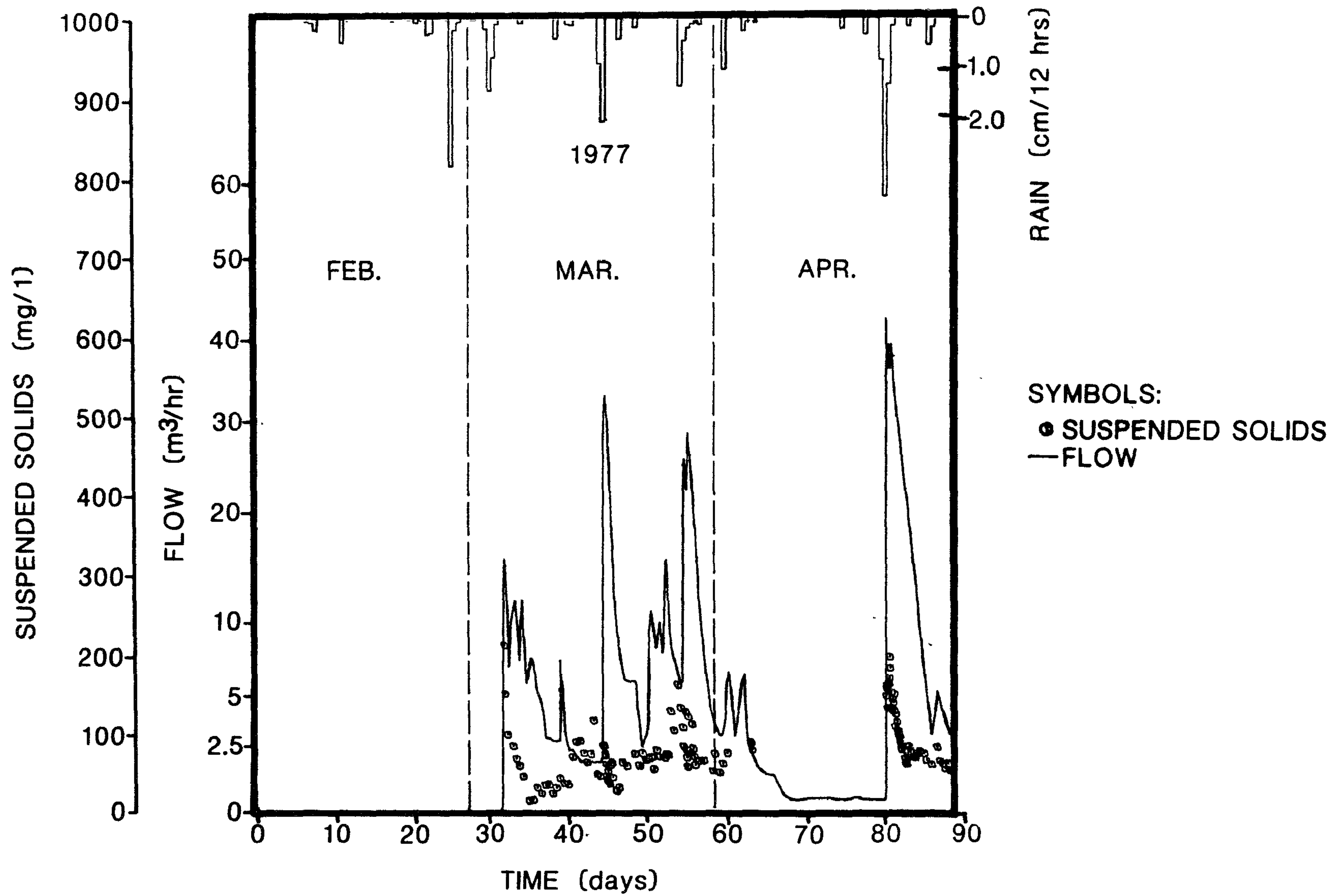



Figure 3. Sediment Concentration and Tile Flow vs Time

## Sediment Data

The sediment concentration (total suspended solids) data showed two major characteristics. The first was the relatively high sediment concentration (all concentrations were rather low) at the start of most tile flow events which began from zero flow, and secondly, the relatively constant sediment concentration after a rapid decay of the initial concentrations. However, some exceptions occurred during the early spring or late winter period possibly due to freezing and thawing action. The high sediment concentration during the initial flow may have resulted from some water flowing directly through the unsaturated zone to the tile drains as the result of channelization. This could easily occur especially for that region of the soil profile directly above the tile line. This rapid flow of water directly to a tile line is substantiated by the detection of both a herbicide and an insecticide in the tile water shortly after surface application of these chemicals. Deep cracking of the soil was also observed during the drier summer months which could account in part for direct channelization of flow. The rapid movement at times of nutrients through the soil profile also is consistent with this observation.

The initial high sediment concentrations may be caused partially because the cohesive strength of the soil is a function of the water content. A dry soil profile would exhibit lower cohesive bonding and therefore might be more erosive until the soil matrix became wetter.

The rather consistent sediment concentration which occurs after an initial event (see Figure 4) is in line with surface erosion characteristics, but exceptions to this observation make it very difficult to explain actual transport mechanisms. However, the particle detachment theory presented by Bottcher, Monke, and Huggins (1978) does address this problem.

The actual loadings and concentrations of sediment in the subsurface drainage waters were very small as seen in Tables 2 and 3. The average loss per year was less than 100 kg/ha. The sediment concentration in the tile outflow was not well correlated to flow rate for the four years of data. Sediment concentration was more of a function of the antecedent soil conditions than flow.

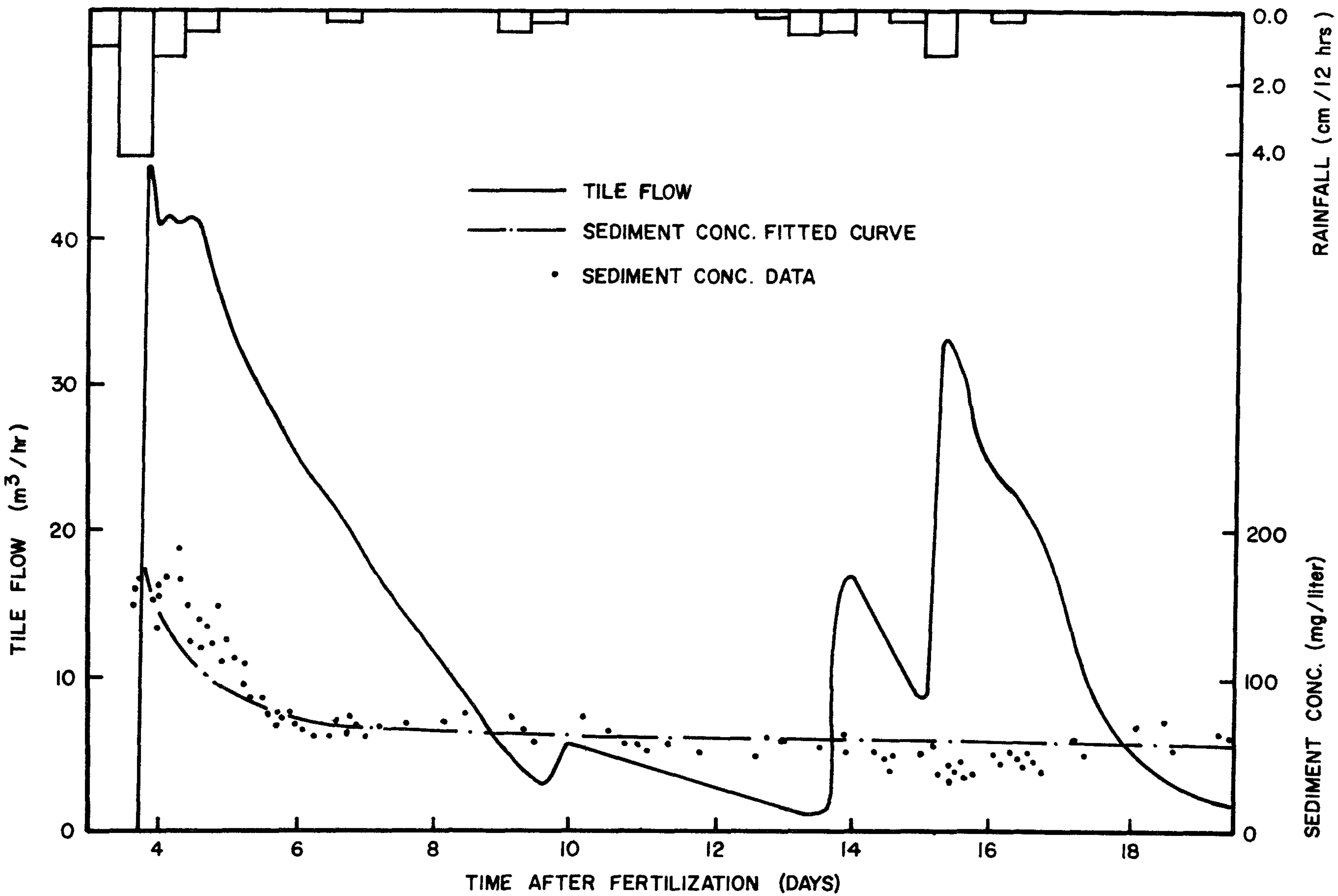



Figure 4. Flow and Sediment Concentration vs Time (Day Zero is April 19, 1977)

Table 2. Water, Sediment and Nutrient Yields from the Subsurface Drainage system

| Component | 1976 | 1977 | 1978 | 1979 | Average |
|---|---|---|---|---|---|
| | | | cm | | |
| Rainfall | 66 | 98 | 75 | 82 | 78 |
| Runoff | 1.2 | 12 | 9.9 | 5.2 | 7.1 |
| | | | kg/ha | | |
| Sediment | 21 | 120 | 140 | 43 | 81 |
| Sol. Inorg. P | .002 | .073 | .029 | .013 | .029 |
| Sol. Org. P | .005 | .040 | .034 | .006 | .021 |
| Sediment P | .02 | .32 | .15 | .05 | .14 |
| Ammonium N | .01 | .32 | .11 | .07 | .13 |
| Nitrate N | .68 | 14. | 4.8 | 5.0 | 6.1 |
| Sol. Org. N | .05 | 3.6 | .32 | .27 | 1.1 |
| Sediment N | .11 | 1.1 | .91 | .21 | .58 |

Table 3. Sediment and Nutrient Concentrations from the Subsurface Drainage System

| Component | 1976 | 1977 | 1978 | 1979 | Average |
|---|---|---|---|---|---|
| | | | mg/l | | |
| Sediment | 170 | 98 | 140 | 83 | 123 |
| Sol. Inorg. P | .02 | .06 | .03 | .03 | .035 |
| Sol. Orgn. P | .04 | .03 | .03 | .01 | .03 |
| Sediment P | .22 | .26 | .15 | .10 | .18 |
| Ammonium N | .09 | .27 | .11 | .13 | .15 |
| Nitrate N | 5.6 | 12 | 4.9 | 9.6 | 8.0 |
| Sol. Org. N | .44 | 2.9 | .33 | .52 | 1.0 |
| Sediment N | .92 | .94 | .93 | .40 | .80 |

## Nitrogen Data

Only seven percent of the total nitrogen loss was associated with the sediment. This would be expected because of the relatively low total sediment yield from the tile drainage system. However, the sediment bound nitrogen data does show that the source of the particles being transported varies during a storm event. Figure 5 shows sediment N to be initially very high which indicates nitrogen rich surface particles are reaching the tile line. However, later in the event when the soil profile was closed off to direct channelization paths, the sediment nitrogen concentration went to near zero. This indicates the particles in the drainage water after direct channelization has stopped are originating from the nitrogen starved lower profile.

As seen in Table 2, the majority of the soluble nitrogen being transported was in the form of nitrate. Nitrates accounted for seventy-ninety percent of the total nitrogen loss for each of the four years even though

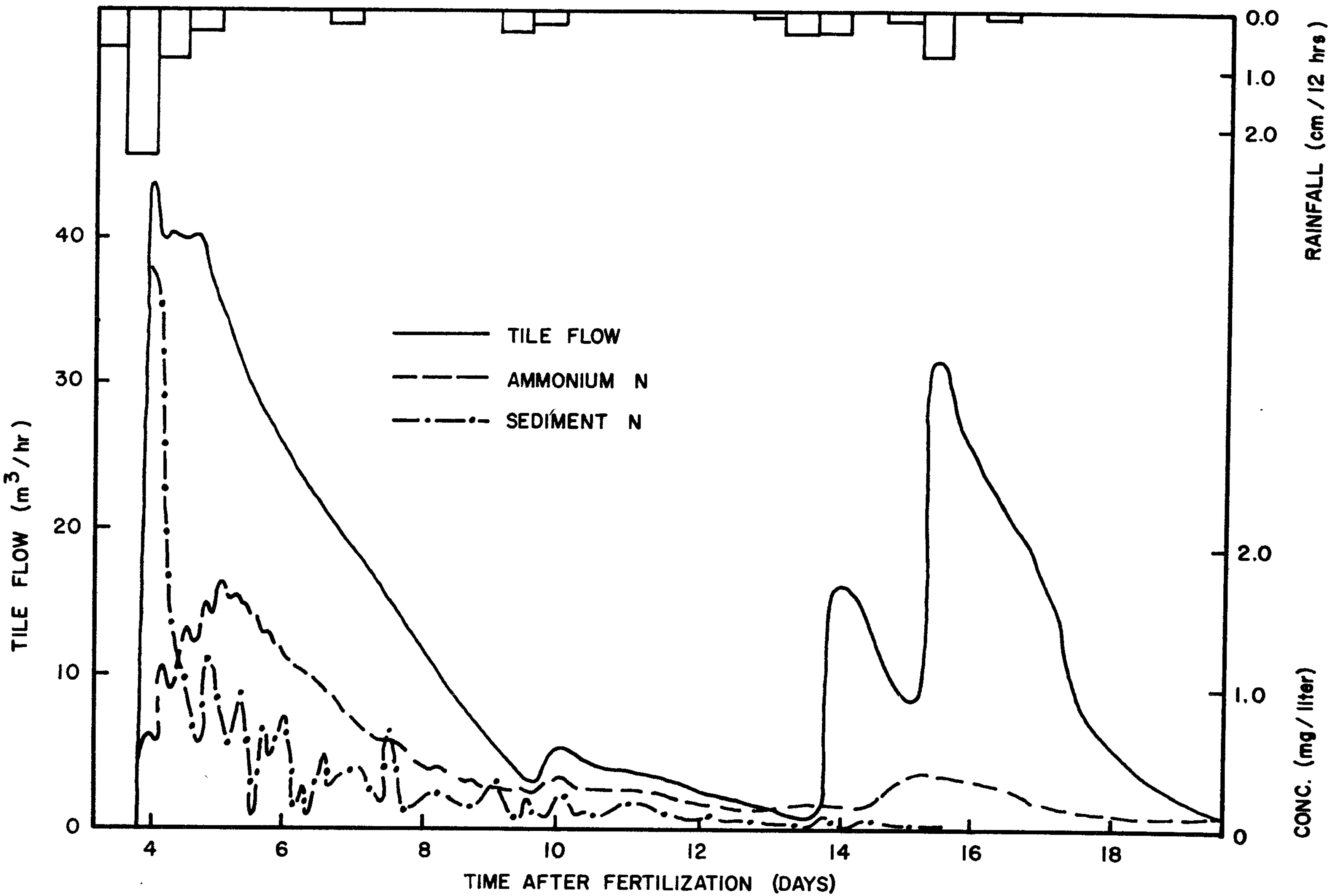



Figure 5. Ammonium N and Sediment N Losses vs Time (Day Zero is April 19, 1977)

total nitrogen varied significantly between years. The high nitrogen loss during 1977 was mostly the result of heavy rainfall occurring immediately after fertilizer application.

The difference between total and nitrate nitrogen in 1977 was mostly in the form of soluble organic nitrogen. The higher percentages of organic nitrogen loss in 1977 was caused by very heavy rains occurring shortly after surface application of urea on April 19. Approximately two percent of the applied urea was lost as urea during this one storm. The urea (organic form of nitrogen) obviously moved directly through the soil profile during this high flow period. This is shown in Figures 6 and 7 by the rapid response to flow of the soluble organic N concentrations, while nitrate concentrations were only moderately affected. However, about fifteen days later in early May, a large event occurred again and this time the majority of nitrogen lost was in a nitrate form (Figure 6).

The high concentration level of nitrate during the May event was a delayed reaction resulting from nitrification of the April 19 fertilizer application. The fifteen day period between April 19th when urea was applied and the May 4th storm event provided ample time for absorption, ammonification, mineralization, and nitrification to tie up or transform the organic forms of N to inorganic forms, primarily nitrate. As also seen in Figure 6, the organic nitrogen was almost totally bound or transformed within 6 days following the urea application, allowing the later high nitrate losses. Therefore soluble organic nitrogen will likely be very low unless a rain event occurs very close to the application date.

The low yields of ammonia resulted from the ammonium ion being easily nitrified or attached to the cation exchange complex. The rise in ammonia concentrations during the late April event (see Figure 7) was probably due to direct passage of ammonia to the tile drains from the ammonification of the applied urea fertilizer. Also, since ammonia is not highly absorbed, equilibrium of the ammonium ion within the lower soil profile would not have time to occur at the higher flow rates.

The higher concentration of all nutrients (except for soluble inorganic phosphorus) during 1977 was primarily the result of higher total fertilizer application for that year. Corn was grown during 1977 which requires very high fertilization rates. Soybeans during 1976 and 1978 on the other hand required almost no nitrogen and reduced amounts of phosphorus (see Table 1).

Phosphorus Data

The phosphorus concentration data is quite different from nitrogen because approximately seventy percent of the phosphorus lost was associated with sediments compared to 10 percent or less for nitrogen (see Table 2). The same percentage occurred every year. As seen in Figure 8, sediment bonded phosphorus varied similarily to the sediment curve. However, soluble inorganic phosphorus concentration correlate well with tile outflow rate.

The soluble organic phosphorus varied very little both during and between different storm events. Both the soluble organic and inorganic forms of phosphorus were very low in concentration and yielded insignificant loadings. The

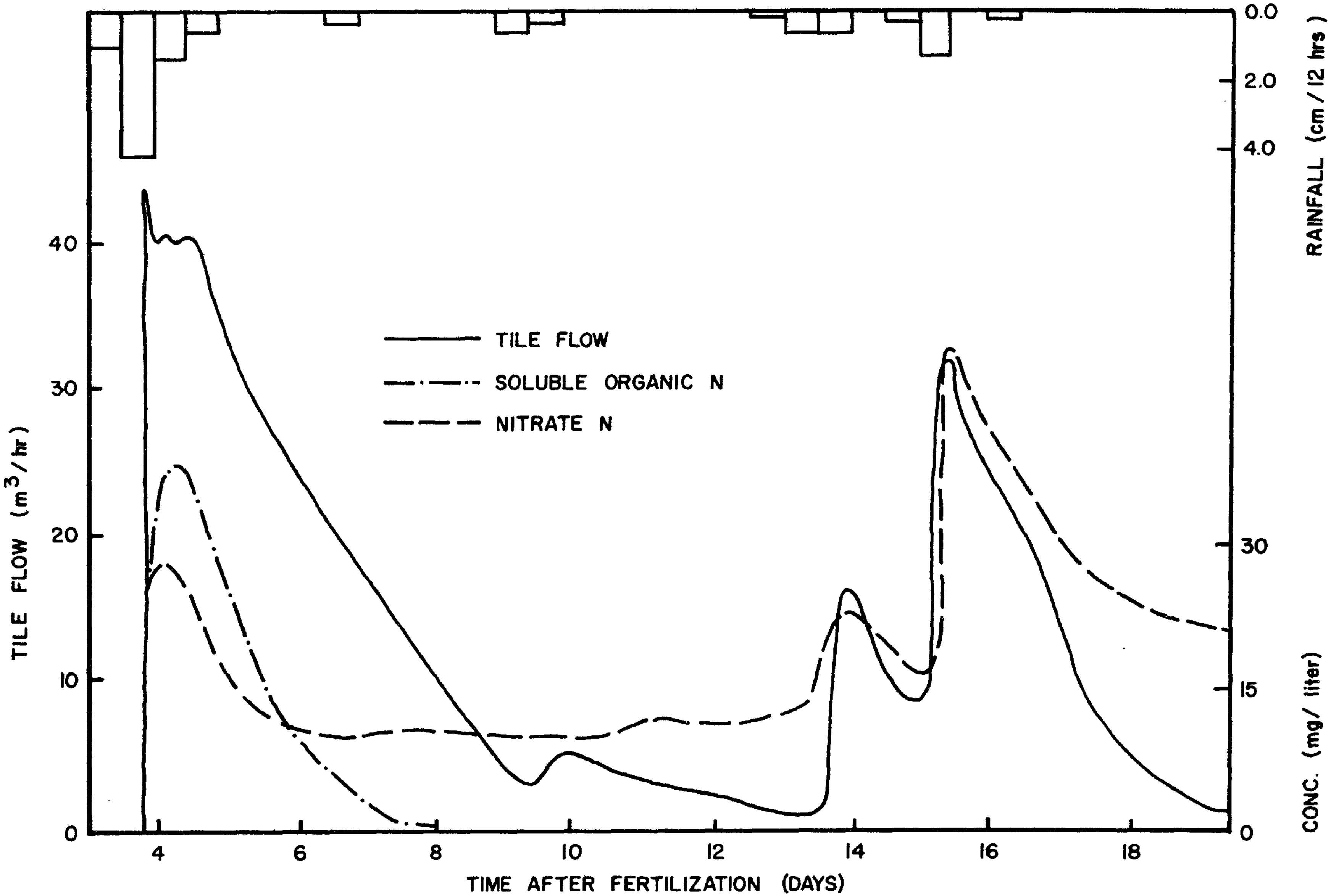



Figure 6. Soluble Organic and Nitrate N Concentrations vs Time (Day Zero is April 19, 1977)

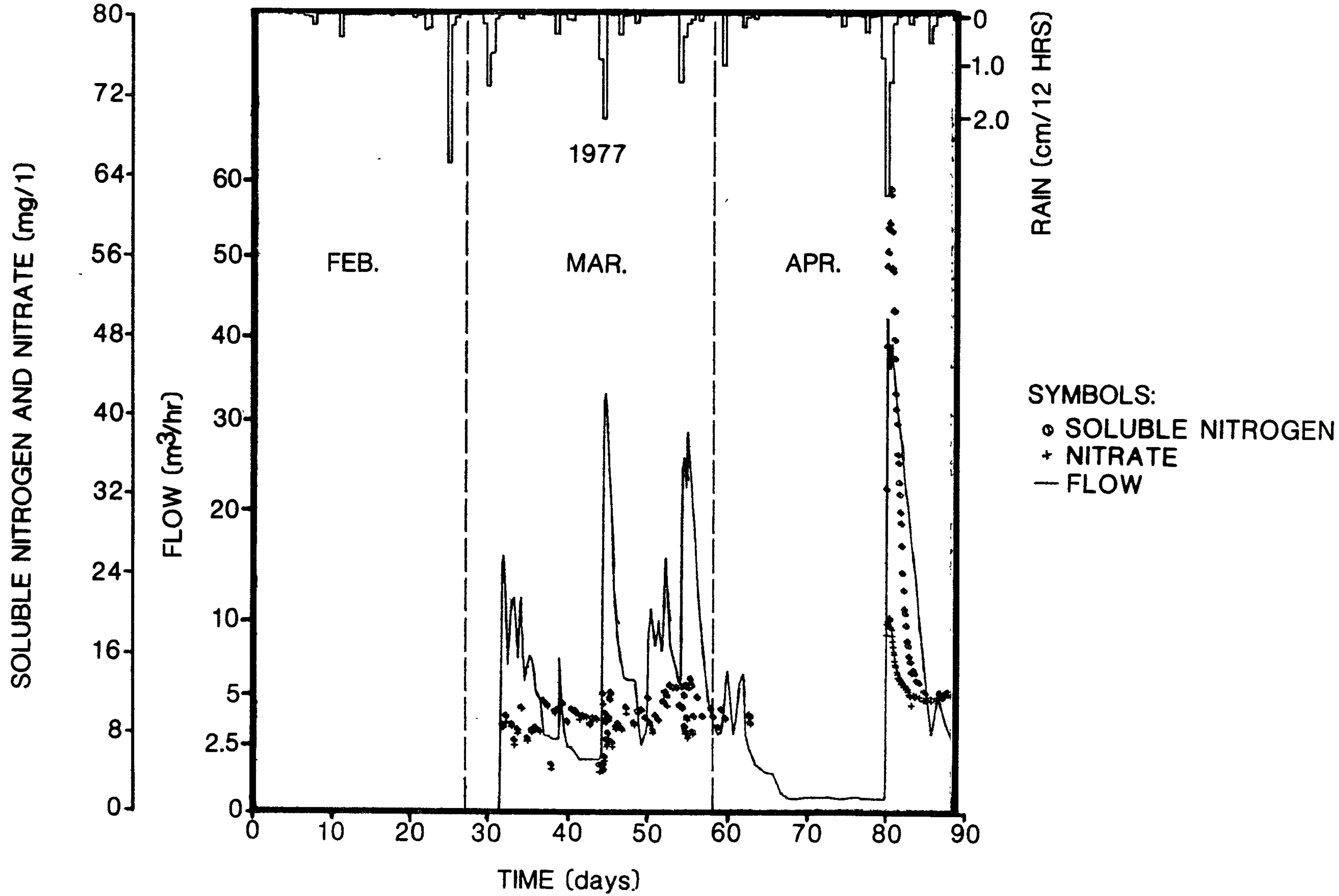





Figure 7. Soluble and Nitrate N vs Time (Soluble and Nitrate N are Equal Before Late April)

sediment bound phosphorus was also quite low and would not be considered an environmental concern.

During certain storms, such as one occurring in the latter part of May 1977, the sediment-bound phosphorus to sediment ratio was much higher than normal even though the majority of the phosphorus lost was still sediment-associated. The sediment-bound phosphorus to sediment ratio for the two storm events (late April and early May) shown in Figure 8 were .005 and .007, respectively, whereas the late May event (not shown) had a ratio of.016. Since the soil in the upper part of the profile is more phosphorus enriched than the soil in the lower part of the profile, it seems likely that surface particles are reaching the drain lines.

Part of the high phosphorus concentrations in the late May event may have been caused by a delayed migration of the heavy applications of fertilizer in April. The first major rainfall event (late April) following the fertilizer application moved a substantial amount of phosphorus into the tile drains because the sediment rate was then also high. On the next major event (early May) very little sediment and consequently very little phosphorus attached to the sediment occurred over that previously attached. This was probably caused by a response lag due to the slow movement of soil fines in the profile.

## Pesticide Data

A herbicide (Lasso II) and an insecticide (Furadan) were also applied on April 19, 1977. As seen in Figure 9, these chemicals were also detected in the tile drainage waters. Direct passage of some surface water to the tile drains must have occurred since these chemicals are normally absorbed quickly by the soil. The total loss of the pesticides was on the order of one tenth of one percent of the applied, 8 and 13 kg/ha of Lasso II and Furadan, respectively. Concentrations of the herbicide were not detected after the April storm event; however, concentrations of the insecticide, which were initially much higher than for the herbicide, were still detectable during an early May storm.

## WATER QUALITY IMPACT

The water quality impact of the well-managed 17 ha field with tile drainage can be evaluated by comparing water, sediment and nutrient yields on a unit area basis with a more typical drainage saturation in the area. Surface runoff from a 942 ha watershed (Smith-Fry Drain) just 12 km to the north of the tile drained field had been measured and sampled over the same time period as part of the Black Creek Project (Lake, 1977). However, difference between these drainage areas should be noted. First, there is an obvious difference in size. Also the larger area has a more diversified land use and is in general not as well managed. Approximately 70 percent of the soils in the larger drainage area are similar to those in the 17 ha field, but the remainder are mostly gently rolling glacial till soils. Also the larger area is only 50 percent tile drained while complete subsurface drainage exists for the studied field. Still such a comparison may be beneficial because it will reveal what ultimately might be attained from subsurface drainage or total

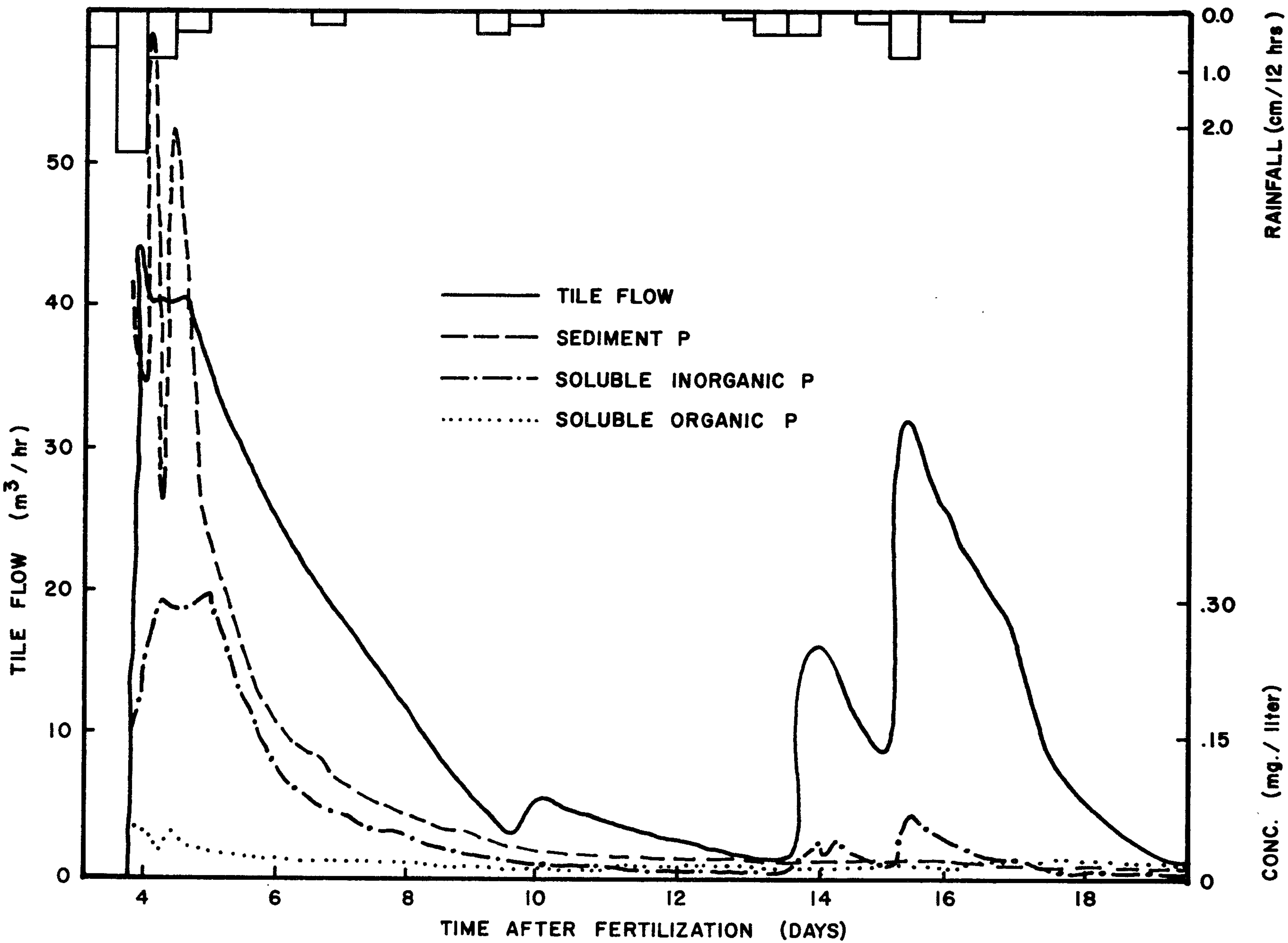



Figure 8. Sediment, Soluble and Inorganic Soluble P vs Time (Day Zero is April 19, 1977)

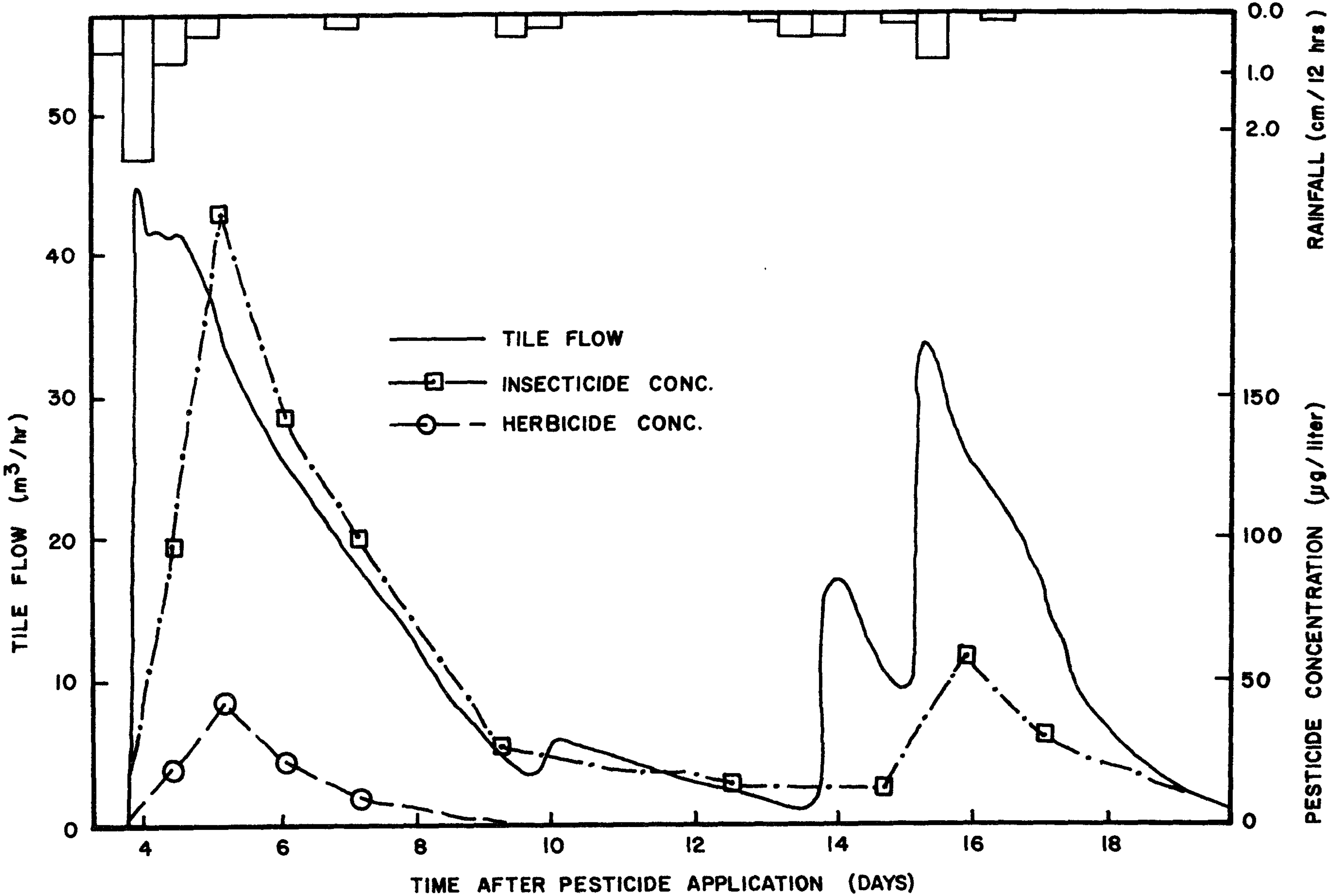



Figure 9. Pesticide Losses from the Monitored Tile Drainage System (Day Zero is April 19, 1977)

elimination of surface soil erosion to abate nonpoint source pollution from cropped fields.

## Water Yield

The water yield was much lower (57 percent for 1976-1978) from the 17 ha field with its extensive subsurface drainage system than for the larger drainage area although total annual rainfall for the two locations were similar (see Table 4). The reduced water yield from the 17 ha field indicates that more water was being stored in the soil profile for potential later evapotranspiration. Some of the moisture difference may also be accounted for through deep seepage,

Table 4. Percent Difference in Unit Loadings and Concentrations of Rainfall, Water Loss, Sediment and Nutrients Between Discharge from the Well-Managed 17 ha Field and a More Normal Drained Area (Smith-Fry Drain).

| Component | Percent Difference | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1976 | | 1977 | | 1978 | | Average | |
| | Loading | Conc. | Loading | Conc. | Loading | Conc. | Loading | Conc. |
| Rainfall | 0 | - | +2 | - | N/A | - | +1 | - |
| Water Loss | -89 | - | -35 | - | -46 | - | -57 | - |
| Sediment | -97 | -67 | -72 | -58 | -83 | -32 | -83 | -62 |
| Sol. Inorg. P | -97 | -60 | -47 | -14 | -86 | -74 | -79 | -56 |
| Sol. Org. P | -83 | +33 | -27 | 0 | -58 | -31 | -63 | -13 |
| Sediment P | -98 | -72 | -81 | -71 | -77 | -57 | -87 | -74 |
| Ammonium N | -98 | -81 | -45 | -13 | -85 | -73 | -80 | -62 |
| Nitrate | -88 | +24 | -9 | +42 | -42 | +9 | -37 | +38 |
| Sol. Org. N | -84 | +76 | +230 | +380 | -81 | -63 | -10 | +33 |
| Sediment N | -97 | -71 | -76 | -62 | -85 | -72 | -89 | -75 |

i.e., increased recharge. However, this would be small since most of the runoff difference occurs during the summer months when et is high and there is little tile outflow. Two to four centimeter rainfall events during July and August resulted in sufficient surface runoff in the Smith-Fry Drain but no subsurface drainage from the studied field. The reduced water yield will also have a direct impact on sediment and nutrient loadings since loadings are equal to concentration times flow. Therefore, even if the concentrations of soluble nutrients are increased, as well they might with subsurface drainage, loadings may still be reduced.

## Sediment and Nutrient Yields

As shown in Table 4, sediment and nutrient loadings were usually much lower from the 17 ha field than from the larger drainage area even though some of the soluble nutrients had higher concentrations. Although there was evidence that some soil fines had migrated through the soil profile to the tile drains, the amount was small and in no way approximated the sediment loads found in the surface runoff. Loadings of nitrate and soluble organic nitrogen were not significantly reduced during 1977 mostly because of the heavy rainfall event which occurred shortly after the 170 kg/ha urea application. However, the average fertilization rates were twice as high for the tiled field than for the surface drained area. In general, the studied field had a significant reduction of sediment and nutrient loadings and moderate reductions for concentration of nutrients, except for nitrate and soluble organic nitrogen. Phosphorus loading reductions were more pronounced than for total nitrogen and especially for nitrates. These findings point out that good fertilization management including the use of less susceptible nitrogen forms to runoff, better placement, and timely application are also needed to enhance the already good water quality characteristics of the subsurface drainage system. A note of caution should be given here about looking only at loadings in judging the water quality benefits of a particular practice. For instream effects, concentration levels may be more important than loadings, whereas large water bodies generally are more impacted by total loadings.

## SUMMARY AND CONCLUSIONS

Flow, sediment and nutrient data were collected for four years from a 17 ha field with complete subsurface drainage. These data were subsequently analyzed. The field had limited surface runoff which made the drainage system a very effective water quality management practice. The data from the subsurface drainage system were also compared to data collected from a more typical drainage area with more surface runoff in order to evaluate the potential impact of drainage practices for nonpoint source pollution abatement.

The following conclusions are drawn from the analysis of the outflow from the subsurface drainage system:

1. The majority of the subsurface drainage from the 17 ha field occurred as the result of winter moisture accumulation.

2. Hydraulic conductivity of a soil profile may be increased by long term good soil management which includes subsurface drainage.

3. Over seventy percent of the nitrogen lost in the drainage water was in nitrate form.

4. Approximately seventy percent of the phosphorus losses were in the form of sediment-bound phosphorus.

5. Sediment, sediment-bound phosphorus and pesticides were all able to move through the soil profile, indicating the presence of direct flow channels during initial periods of a storm.

6. Heavy rainfall occurring shortly after fertilizer is applied can greatly increase losses of nitrogen and to a lesser degree phosphorus through a subsurface drainage system.

7. Good fertilizer management can reduce the amount of soluble nutrients reaching tile drains.

The following conclusions were drawn from a comparison of the data from the 17 ha subsurface drainage system with data from a nearby watershed where surface runoff was also an important factor:

1. The 17 ha field with a complete subsurface drainage system and restricted surface runoff significantly reduced water and sediment losses as compared to the more normal drainage situation for this area of the Maumee Basin.

2. The better drained area also provided a significant reduction in sediment-bound nutrient loadings particularly as affecting phosphorus.

3. Concentrations of nitrate-nigrogen and soluble organic nitrogen were higher in the runoff water from the well-drained 17 ha field than from the more normal drained area. However, these higher concentrations may not lead to increased loadings.

4. A complete subsurface drainage system on recommended soil types may well be thought of in terms of a water quality management practice, except when instream nitrogen concentrations are of a concern.

## II. SEDIMENT MOVEMENT INTO SUBSURFACE DRAINS FROM BACKFILL PROFILES

### OBJECTIVE

The objective of this study was to investigate the effect of various envelope materials and soil conditioners on sediment movement from backfill profiles of Hoytville silty clay. The soil was contained in a laboratory apparatus which closely duplicated the opening between two adjoining tile drains and the constructed trench above the drains which would be backfilled with the excavated soil material. In addition, sediment losses from the simulated trenches backfilled with Hoytville silty clay, Latty clay and Blount silt loam were also evaluated and compared.

### SOILS

Hoytville, Blount, and Latty soils were selected for the experiment on the basis of their clay content and location within the Maumee Basin (Figure 10). These soils provided an opportunity to observe the contrast in sediment losses from soils with a relatively wide range in clay contents. A quantity of each soil was collected in the fall of 1977 to a depth of 90 cm and then mixed similarly to a field trenching operation. Later, the soils were screened to ensure an aggregate size of 5 cm or less.

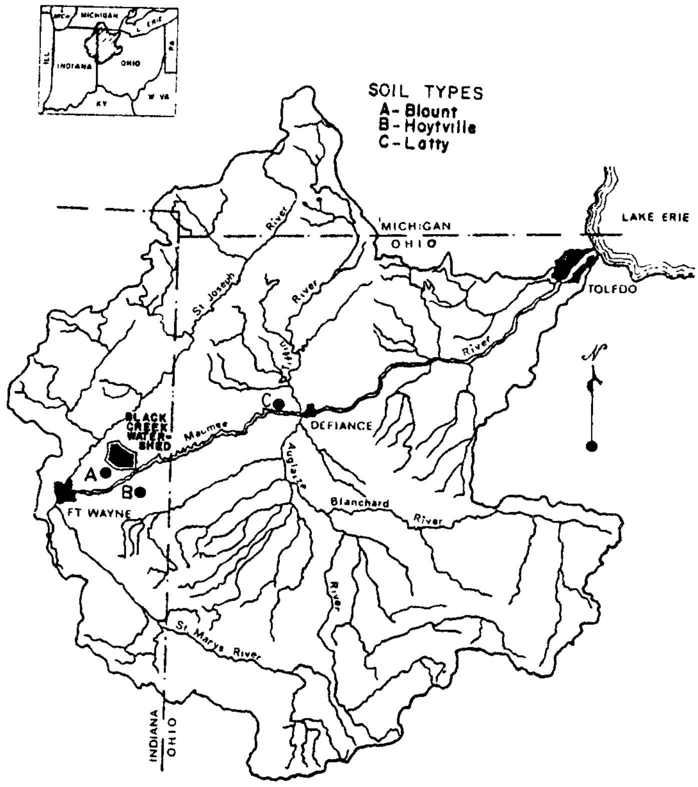



Figure 10. Soil Locations

Hoytville silty clay soils are depressional and nearly level with very poor drainage. They are classified as Mollic Ochraqualf and have a clay content of 33 to 48 percent with a moisture content of 19 to 26 percent (dry basis) over the 90 cm depth. Initial flows from a monitored drainage system in this soil after a storm event sometimes have a milky appearance indicating fine sediment in the effluent.

Blount silt loam soils are somewhat poorly drained with nearly level to gently undulating relief in upland positions. Blount is classified as Aeric Orhraqualf with a clay content of 13 to 36 percent and moisture range of 13 to 24 percent (dry basis) over the 90 cm profile.

Latty clay is classified as a Typic Halplaquept with a clay content of 40 to 53 percent and moisture range of 24 to 34 percent (dry basis) over the profile. These soils were developed in a heavy lacustrine clay layer and are very poorly drained.

ENVELOPE MATERIALS

In this study, five different envelope materials were tested with the Hoytville soil to evaluate their effectiveness for reducing sediment losses. Topsoil and its combination with two different soil conditioners, gravel and a synthetic fabric, were selected as the envelope and filter envelope materials.

Topsoil is probably the most common envelope material used around tile and plastic subsurface drain lines in the Midwest to prevent misalignment and damage during backfilling operations. Because the organic content of topsoil stabilizes the aggregate structure, Hoytville topsoil with 6 percent organic matter has the potential of providing and maintaining a porous envelope around a drain tube. Topsoil from the upper 18 cm of the Hoytville profile was collected, air dried for two days, and then crushed so that all the soil passed through a 3 cm screen. An appropriate quantity was then placed by hand at the bottom of selected soil bins and packed so that the 8 cm enveloped at the bottom of the bin was under an equivalent overburden pressure of 100 $gm/cm^2$ (equal to a 67 cm depth of Hoytville backfill).

Two soil conditioners, Petroset and Portland cement, were applied to screened, air-dried Hoytville topsoil. Soil conditioners are additives which artificially stabilize soil aggregates externally rather than internally. Although these conditioners have been usually applied on soil surfaces to prevent wind and water erosion from freshly earth cuts during construction, similar materials have been demonstrated by Dierickx et al. (1976) and Bishay et al. (1975) to improve the permeability and aggregate stability around tile drains under saturated conditions in clay loams.

Petroset is a commercially available rubber emulsion that possesses hydrophobic properties. An emulsion was sprayed on the topsoil at a 5 percent ratio of emulsion/soil by weight for saturated conditions and according to the aggregate size range. The conditioned topsoil was then placed at the bottom of a soil bin as previously described.

Portland cement has also been employed successfully in the past to modify and stabilize soils for construction purposes. Ahuja and Swartzendruber (1972) observed significant structural aggregate stability of Russell silt loam under saturated conditions when the cement was applied at low rates and allowed to cure properly. In this experiment, Portland cement was applied to the screened air-dried topsoil at the rate of 1 percent by weight with 15 percent by weight of water sprayed on the coating to start the curing process. The conditioned soil was then placed in two soil bins, packed to uniform depth of 8 cm, and allowed to cure for fourteen days before Hoytville soil was placed on top of the envelope.

Of the many envelope materials available, sand and gravel are probably used more extensively than other materials to improve hydraulic entry conditions, bedding conditions, and/or filtration. They are usually pit-run rather than specifically designed according to some standard criteria. Both Winger and Ryan (1971) and Luthin et al. (1967) proposed a design criteria for gravel envelopes that is based on gradients being less than one. According to them, the graduation of the envelope did not play as significant a role as the thickness and permeability of the envelope in reducing the convergence effects of ground water on drainage lines. Walker (1978) reinforced their conclusion by observing that the critical failure gradient was a function of the soil properties rather than the retaining envelope once minimum mechanical support for soil bridging over the envelope voids was provided. In the Maumee Basin, #11 pea gravel has been frequently used whenever a gravel envelope has been recommended. Although it is not generally used with soils having a high clay content, an 8 cm thickness of #11 pea gravel was nevertheless placed in two soil bins to evaluate its effect on sediment losses.

In the past 20 years, synthetic fabrics have been developed and utilized as filter envelopes for subsurface drains. Where plastic drain pipe is installed and soil conditions permit, fabric filters have emerged as the common alternative to conventional aggregate envelopes of sand and gravel because of their reasonable cost and handling convenience.

Although many nylon socks and other commercially available synthetic fabric sheets have been used to protect drains in the sand soil areas of the Maumee Basin, Mirafi 140, a product of the Celanese Corporation, was selected to evaluate its potential for reducing sediment losses with Hoytville silty clay. Mirafi 140 is composed of nylon covered polypropylene fibers randomly fused together into a thin sheet with an average thickness of 0.75 cm, effective pore size of 0.085 mm, density of 140 $gm/m^3$, and permeability of $5x10^{-2}$ cm/sec. A 15 cm by 30 cm rectangle was cut and glued around the outside edge to the soil bin bottom to prevent sediment and water from by-passing the sheet at the tile crack. Marks (1975), testing Mirafi 140 against woven fabric sheets of polyester and aggregate envelopes of sand and gravel in soils ranging from fine sands to silty clays, indicated the development of a filter cake layer at the boundary of the fabric. The over-all permeability of both fabric and filter cake was comparable to the tested aggregate envelope.

## APPARATUS AND PROCEDURE

Sixteen backfill profile soil bins, 90 cm deep with base dimensions of 15 cm by 30 cm, were constructed side by side to represent portions of the backfill trench in the field. The base dimensions resulted from the symmetry of the streamlines longitudinally between butted 15 cm diameter by 30 cm long drain tile and the approximately parallel streamlines above the tile drain. A 1.6 mm (one-sixteenth inch) crack width across the bottom of each soil bin represented the nominal opening between tile sections. A schematic drawing of a single backfill profile model is shown in Figure 11.

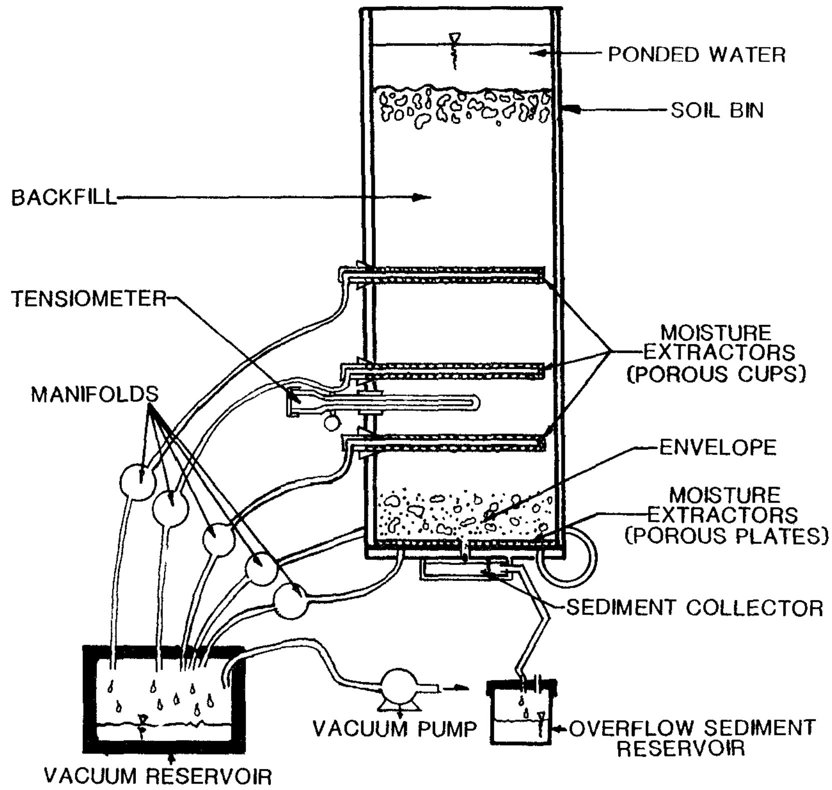



Figure 11. Backfill Profile Model

Each of the sixteen soil bins was filled in a random order with either Latty; Blount; Hoytville; one of the five envelope materials under a Hoytville backfill; or one of the replications for each treatment. Each backfill was then compacted slightly to reduce the initial settlement after water was applied.

Initially, 3200 ml (equal to a 3-inch ponding depth) of snow melt water was applied twice to the top of each profile over a two week conditioning period to bring all backfill replications to approximately the same antecedent moisture condition and to induce settlement. At the end the two week period, ceramic porous cup moisture extractors were inserted into the profile along with tensiometers to monitor moisture changes (see Figure 11). Four days after their installation, suction was applied to the porous cups and previously installed porous plates at the bottom of each soil bin in preparation for further experimentation.

The study consisted of five cycles with a four-day wetting phase followed by a ten-day drying phase to simulate the wetting and drying process in the field. Such a wetting and drying process could cause sediment movement in and through the profile by possible slaking, piping, and turbulence. The quantities of gravitational water and sediment loss from the bottom of each profile were collected, measured, and recorded after each application of water.

## RESULTS AND DISCUSSION

The sediment yield, water, and water transient times through the profile after each application of water for the initial conditioning period and five wetting and drying cycles are shown in Tables 5 and 6. A water balance for each cycle was also maintained on the assumption that all the applied water was removed. After the first complete cycle of wetting and drying, approximately one-half of the water added during each of the remaining cycles was recovered as gravitational water. The rest of the water was either removed by extraction or evaporation. The evaporation from the soil surface and water vapor loss through the vacuum pump tended to increase with successive cycles because of an average ambient temperature rise of 13°C during the test period. Since transient times after the second cycle had become fairly constant, distinct channels through the profile apparently were established.

Table 5. Sediment Loss (gm), Water Loss (ml) and Percolation Time (sec or min) for Wetting and Drying Cycles on Hoytville Silty Clay, Blount Silt Loam, and Latty Clay

| Bin and soil* | Unit | Wetting and Drying Cycle 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| 2H | gm | 0.75 | 0.41 | 0.32 | 0.27 | 0.29 |
| | ml | 2130 | 2090 | 1670 | 1650 | 1670 |
| | sec | 32 | 46 | 55 | 65 | 73 |
| 10H | gm | 0.93 | 0.41 | 0.33 | 0.30 | 0.33 |
| | ml | 2250 | 1740 | 1690 | 1670 | 1640 |
| | sec | 29 | 37 | 44 | 44 | 44 |
| 1B | gm | 0.12 | 0.072 | 0.080 | 0.051 | 0.072 |
| | ml | 2170 | 610 | 780 | 760 | 870 |
| | min | 280 | 40 | 65 | 75 | 72 |
| 13B | gm | 0.29 | 0.082 | 0.026 | 0.045 | 0.026 |
| | ml | 2160 | 860 | 990 | 960 | 1020 |
| | min | 235 | 30 | 38 | 41 | 40 |
| 6L | gm | 0.92 | 0.46 | 0.39 | 0.39 | 0.42 |
| | ml | 2370 | 1950 | 1850 | 1840 | 1910 |
| | sec | 32 | 24 | 35 | 40 | 36 |
| 16L | gm | 1.27 | 0.49 | 0.43 | 0.40 | 0.43 |
| | ml | 2550 | 1950 | 1850 | 1840 | 1910 |
| | sec | 24 | 25 | 23 | 23 | 23 |

*H=Hoytville silty clay, B=Blount silt loam, L=Latty clay

Table 6. Sediment Loss (gm), Water Loss (ml) and Percolation Time (sec) for Wetting and Drying Cycles on Hoytville Silty Clay with Different Envelope Materials

| Bin and material* | Unit | Wetting and Drying Cycle 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| 2H | gm | 0.75 | 0.41 | 0.32 | 0.27 | 0.29 |
| | ml | 2130 | 2090 | 1670 | 1650 | 1670 |
| | sec | 32 | 46 | 55 | 65 | 73 |
| 10H | gm | 0.94 | 0.41 | 0.33 | 0.30 | 0.33 |
| | ml | 2250 | 1740 | 1690 | 1670 | 1640 |
| | sec | 29 | 37 | 44 | 44 | 44 |
| 3T | gm | 0.65 | 0.35 | 0.31 | 0.31 | 0.32 |
| | ml | 2230 | 1770 | 1570 | 1560 | 1620 |
| | sec | 35 | 37 | 42 | 44 | 53 |
| 7T | gm | 0.50 | 0.27 | 0.28 | 0.25 | 0.27 |
| | ml | 2220 | 1590 | 1560 | 1540 | 1600 |
| | sec | 41 | 45 | 40 | 43 | 58 |
| 4P | gm | 0.61 | 0.38 | 0.25 | 0.20 | 0.17 |
| | ml | 2290 | 1690 | 1680 | 1630 | 1660 |
| | sec | 36 | 40 | 55 | 49 | 58 |
| 9P | gm | 0.62 | 0.34 | 0.32 | 0.29 | 0.38 |
| | ml | 2220 | 1760 | 1700 | 1700 | 1690 |
| | sec | 37 | 60 | 53 | 49 | 48 |
| 5C | gm | 0.94 | 0.51 | 0.34 | 0.36 | 0.32 |
| | ml | 2400 | 1730 | 1720 | 1720 | 1680 |
| | sec | 40 | 49 | 53 | 47 | 68 |
| 11C | gm | 0.61 | 0.31 | 0.27 | 0.28 | 0.28 |
| | ml | 2370 | 1670 | 1680 | 1750 | 1690 |
| | sec | 46 | 48 | 65 | 47 | 72 |
| 8G | gm | 0.92 | 0.46 | 0.42 | 0.38 | 0.43 |
| | ml | 2440 | 1960 | 1860 | 1810 | 1830 |
| | sec | 37 | 56 | 55 | 55 | 65 |
| 15G | gm | 0.82 | 0.43 | 0.30 | 0.43 | 0.47 |
| | ml | 2332 | 1840 | 1820 | 1800 | 1700 |
| | sec | 33 | 36 | 41 | 36 | 40 |
| 12F | gm | 0.93 | 0.22 | 0.25 | 0.29 | 0.32 |
| | ml | 2410 | 1660 | 1520 | 1540 | 1640 |
| | sec | 50 | 70 | 65 | 52 | 83 |
| 14F | gm | 0.53 | 0.32 | 0.31 | 0.28 | 0.26 |
| | ml | 2370 | 1710 | 1750 | 1680 | 1700 |
| | sec | 37 | 51 | 53 | 55 | 68 |

*H=control, T=topsoil, P=Petroset, C=cement, G=gravel, F=fabric

## ENVELOPE ANALYSIS

The average sediment losses and concentrations for the experiments with envelope materials are plotted in Figures 12 and 13. Statistical tests at the 5 percent level showed no significant effects on the reduction of sediment losses by the envelopes, especially once sediment losses approached a steady state condition. Moreover, gravel might have even shown a detrimental effect on the stability of the backfill and envelope interface if the experiment had been continued.

For near steady state conditions, the sediment losses and concentrations averaged about 0.3 gm and 175 mg/l, respectively. The amount of sediment loss seemed to increase with the amount of gravitational water passing from the backfill profile.

Although sediment losses through the fabric filter were about the same as for the control of Hoytville without an envelope, the fabric pore size apparently limited the sediment size to less than 0.085 mm. However, no noticeable reduction in permeability over time occurred from blockage of the fabric pores.

The effect of successive wetting and drying cycles had a significant influence on sediment losses initially but diminished as the losses approached a steady state condition. As the soil profiles settled with successive cycles of operation, the transient time of water flow through the profile increased indicating a decrease in permeability.

## SOIL TYPE ANALYSIS

The average sediment losses and concentration for Hoytville, Blount, and Latty soils are plotted in Figure 14. Sediment losses from the three soils showed a similar trend with time. A statistical analysis of the data showed a significant difference in sediment losses between Hoytville and the other soil types, especially once the sediment losses approached a near steady state condition.

The average sediment loss for Blount was about 75 percent less than that for Hoytville with an average sediment loss and concentration over the steady state conditions of 0.05 gm and 60 mg/l, respectively. The low losses for Blount may be partially attributed both to the greater consolidation of the profile and to the smaller quantity of effluent during the wetting phase. The finer pores of Blount reduced the erosive potential of the gravitational water by causing the water to percolate through the profile slowly.

Both Hoytville and Blount had extensive surface cracking at the end of each drying phase in the laboratory. These cracks extended into the profile from a few millimeters to over 15 cm. During the collection of the Hoytville soil, drying cracks were noted from the soil surface to the bottom of the trench. The most recent cracks had an average width of 6 mm. Older cracks, which were sometimes filled with the dark topsoil, had similar widths and depths. Such cracks intercepting the drainage line could affect the overall sediment and nutrient loadings in the drain effluent.

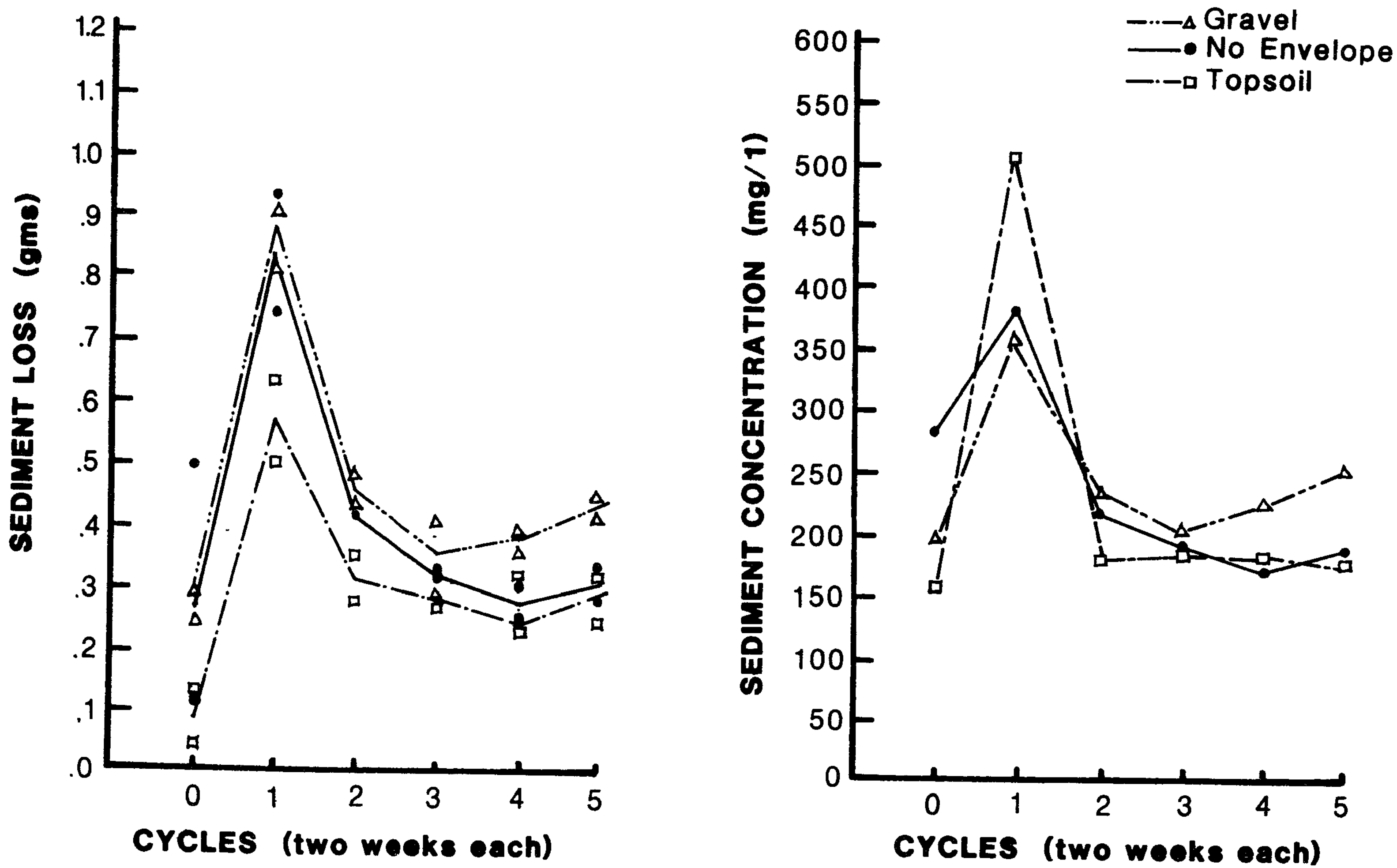



Figure 12. Sediment Loss and Concentration vs Wetting and Drying Cycles for Various Envelope Materials with Hoytville Silty Clay

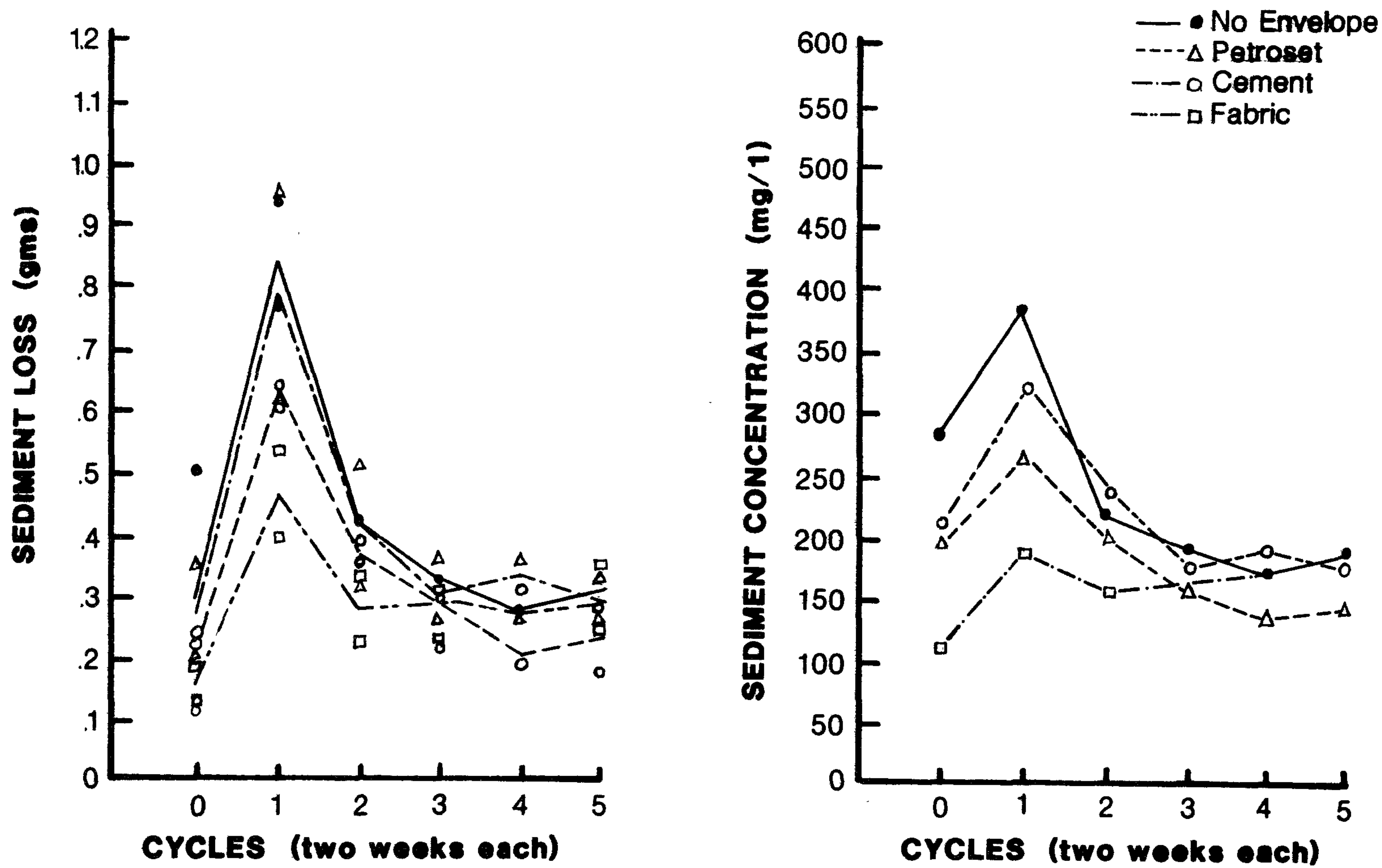



Figure 13. Sediment Loss and Concentrations vs Wetting and Drying Cycles for Various Envelope Materials with Hoytville Silty Clay

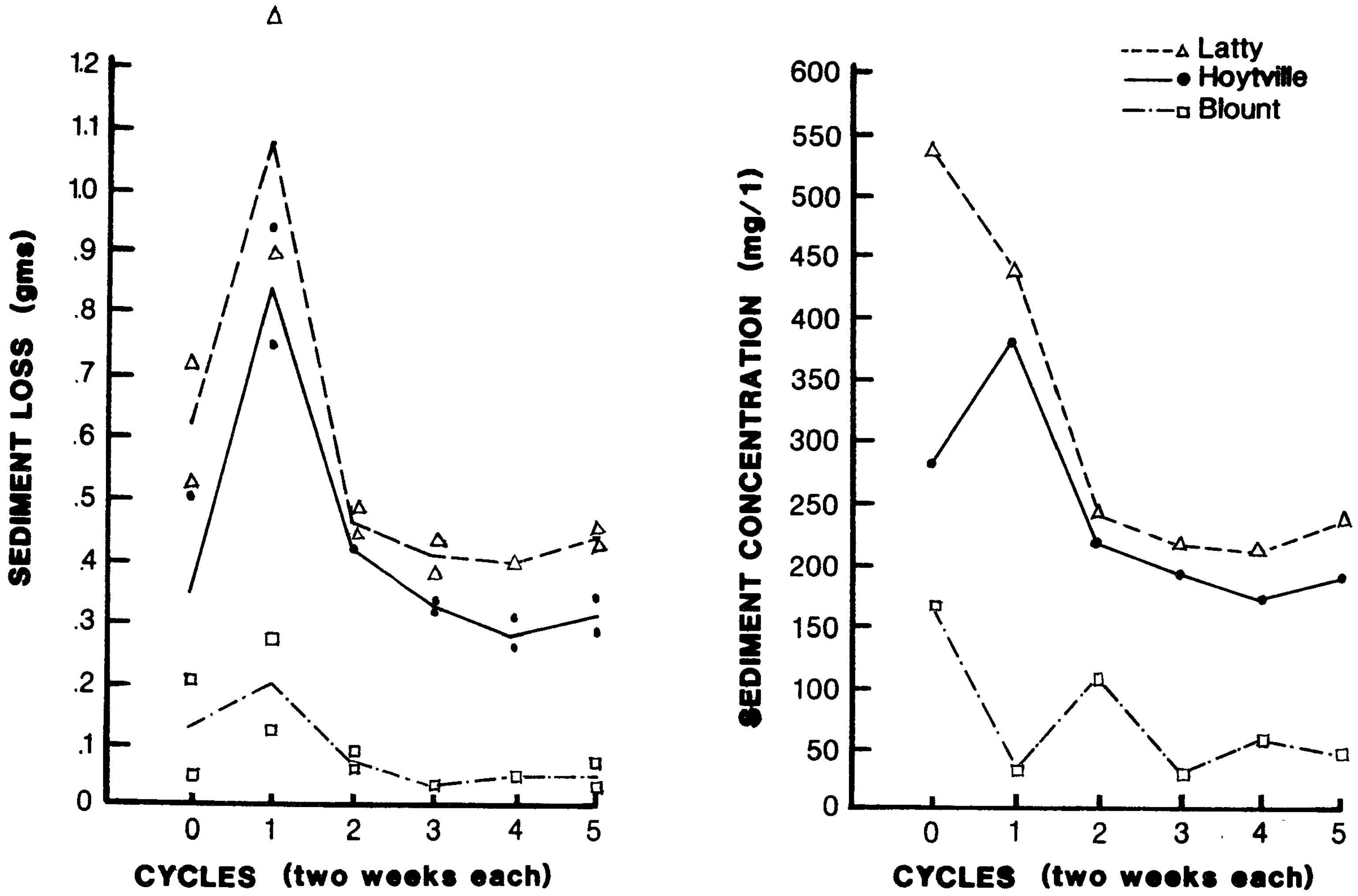



Figure 14. Sediment Loss and Concentrations vs Wetting and Drying Cycles for Latty Clay, Hoytville Silty Clay and Blount Silt Loam

For Latty, the average sediment loss and concentration was about 20 percent more for each cycle of wetting and drying than for Hoytville with an average sediment loss of 0.4 gm and concentration of 225 mg/l. These larger losses were probably due in part to the highly porous condition of the backfill caused by the heavy clay aggregates maintaining their blocky structure. This condition allowed water to move through the profile rather rapidly providing opportunity for less absorption of the water and greater soil detachment than with the other soils.

## SUMMARY

The average sediment loss from Blount silt loam was about 75 percent less than from Hoytville. This difference may be attributed in part to the complete settlement of the Blount profile and the subsequent low hydraulic conductivity of the column. However, Latty averaged about 20 percent more sediment than Hoytville. This difference was probably due in part to the incomplete breakdown of the large clay aggregates in the Latty profile and the associated large channels which then occurred around the aggregates. The effluent from the Hoytville and Latty was always cloudy in appearance while that from the Blount was clear.

The five envelope materials did not significantly reduce sediment losses from the Hoytville soil. The gravel envelope even showed a potential for increasing sediment losses. The gravel may have reduced soil bridging at the envelope and backfill interface allowing soil particles to move into and through the envelope more rapidly.

## REFERENCES

1. Ahuja, L.R. and D. Swartzendruber. 1972. Effect of Portland cement on clay aggregation and hydraulic properties. Soil Sci. 114(5):359-366.

2. Baker, J.L. and H.P. Johnson. 1976. Impact of subsurface drainage on water quality. 3rd National Drainage Symposium. Amer. Soc. of Agr. Engrs., St. Joseph, MI. pp. 91-98.

3. Bishay, B.G. and W. Dierickx. 1975. Drainage efficiency in a low permeable clay-loam soil through physical modification of the trench backfill. Pedologie 25(3): 179-189.

4. Bottcher, A.B., E.J. Monke and L.F. Huggins. 1980. Subsurface drainage model with associated sediment transport. Trans. ASAE 23(4): 870-876.

5. Dierickx, W. and D. Gabriel. 1976. Stabilizing backfill of drain pipes and drainage efficiency. Third International Symposium of Soil Conditioning, Mededelingen Fakultett Landbouw-Wetenschappen Rijksuniversitet Gent. 41(1):293-301.

6. Lake, J. 1977. Environmental impact of land use on water quality. EPA-905/9-77-007-B, Final Report on the Black Creek Project (Technical). Region V, USEPA, Chicago. 280 p.

7. Luthin, J.N., G.S. Taylor and C. Prieto. 1968. Exit gradients into subsurface drains. Hilgardia 39(15):418-428.

8. Marks, B.D. 1975. The behavior of aggregate and fabric filters in subsurface applications. Report, Department of Civil Engineering, University of Tennessee. 149p.

9. Monke, E.J., D.B. Beasley and A.B. Bottcher. 1975. Sediment contributions to the Maumee River. EPA-905/975-007, Proc. Non-Point Source Pollution Seminar. Region V, USEPA, Chicago. 71p.

10. Schwab, G.O., B.H. Nolte and R.D. Brehm. 1977. Sediment from drainage systems for clay soil. Trans. ASAE 20(5):866-868.

11. Taylor, G.S. and T. Goins. 1967. Field evaluations of tile drain filter in a humid region soil. Res. Ctr. 154, Ohio Agr. Res. and Dev. Ctr., Wooster, Ohio.

12. Walker, R.E. 1978. The interaction of synthetic envelope materials with soil. M.S. Thesis. Utah State University.

13. Winger, R.J. and W.F. Ryan. 1971. Gravel envelopes for pipe drains -- Design. Trans. ASAE 14(3):471-479.

14. Zaslavsky, D. and G. Kassiff. 1965. Theoretical formulation of piping mechanism in cohesive soils. Geotechnique 15(3):305-314.

# ALGAL AVAILABILITY OF PHOSPHORUS ASSOCIATED WITH SUSPENDED STREAM SEDIMENTS OF THE BLACK CREEK WATERSHED

by

R. A. Dorich and D.W. Nelson

During the past 2 decades the quality of water in Lake Erie has come under severe scrutiny, and review of pertinent data has shown a steady decline. Although other data have demonstrated the steady decline in water quality, algal cell numbers, P loading history and hypolimnial oxygen levels data seem to exemplify one of the major problems. Davis (1964) presented data that showed that between 1919 and 1963 there has been a consistent increase in the average number of phytoplankton in Lake Erie. The average number of cells increased from 81/ml in 1929 to 2423/ml in 1962. The intensity and length of the periods of maximum cell counts have also increased, while the minimums have become shorter, less pronounced, and in some cases, failed to appear. Williams et al. (1976) analyzed P in sediment cores from six sites in Lake Erie and correlated depth below the sediment:water interface with time of deposition. Results show a gradual increase in the concentration of sediment P since 1948. Some samples showed a doubling in non-apatite P in the last 10 years. However, there were indications of vertical migration of P upward. Dobson and Gilbertson (1972) presented hypolimnial oxygen level data for the years 1929, 1949, and 1969. When 1929 data and 1969 data are compared, the results show that from the beginning of the stratified period the rate of oxygen depletion has significantly increased, and the onset of deoxygenated conditions in the bottom water has occurred earlier.

The dangers of anoxic conditions include the death of fish and other aerobic organisms, the production of odorous and unpalatable water, the fouling of water treatment facilities, and because nutrients are released from sediments during anoxic or reduced conditions, the possibility exists of cyclic self-fertilization process being initiated (Burns and Ross, 1972a).

The indicators of serious eutrophy discussed above did, in fact, point directly to approaching problems in Lake Erie. The Federal Water Pollution Control Administration (FWPCA) estimated in 1968 that approximately 2600 square miles of the 5650 square miles of hypolimnion of the central basin of Lake Erie was oxygen deficient (< 2 mg/l). A 1970 study was initiated to determine the causes and effects of oxygen depletion in Lake Erie, and the results were presented in a 1972 report (Burns and Ross, 1972b).

In July of 1970 a massive algal bloom occurred in the Central basin of Lake Erie which depleted the phosphorus concentration to near undetectable levels in 80% of the surface water of the basin, and subsequent sedimentation and death caused a layer of algae about 2 cm thick to blanket approximately 70% of the basin floor. Aerobic decomposition of the July bloom combined with additional blooms accounted for 88% of observed oxygen depletion during the month of August, 1970. The onset of anoxic conditions in mid-August brought an eleven-fold increase in P regeneration rates (from 22 μmoles P $m^{-2}$ $day^{-1}$ to 245 μmoles P $m^{-2}$ $day^{-1}$). The indirect cause of the extensive oxygen depletion was massive algal blooms. Furthermore, since P is often the limiting nutrient for algae in Lake Erie, it was projected that if P inputs were decreased so that algal glooms were limited, oxygenated conditions would be maintained for a longer period and the Lake would return to an "acceptable state" (Burns and Ross, 1972c).

The sources of P input into Lake Erie were also investigated (Gilbertson, et al., 1972). Although agricultural runoff inputs quite probably did contribute a portion of the total P, this study based its judgements only on municipal and residential inputs. However, a more recent report by the International Joint Commission (IJC) (1980) presented data which showed "land use" activities contributed nearly half of the total P load to Lake Erie in 1976, 20% of which was unrelated to agricultural activities.

Inputs of P up to the present have largely been based upon total P transported, but as indicated above, the important portion of the total sediment P to the Lake Erie system is that portion which becomes available for algal growth. Therefore, in order to properly assess the impact of P in agricultural drainage or runoff upon an aquatic ecosystem the algal availability of the total P transported must be determined.

In regard to the P availability problem Ryden et al. (1973) states:

> "At present it is difficult to estimate the impact of runoff- and stream-derived P on standing waters, and such considerations can only be made if the forms of P relevant to biological productivity are measured".

The IJC (1980) concurred when it stated:

> "...the Commission recommends a reassessment of surveillence and research activities to ensure the development of a data base adequate to address the question of relative biological availability of phosphorus in the Great Lakes from the various direct and tributary point and nonpoint sources, so that the efficacy of point versus nonpoint source control measures can be more precisely determined".

In order to properly address a major objective of the Black Creek Watershed Project; that is, to assess the role of agricultural activities along the Maumee River in the pollution of Lake Erie, the availability to algae of P derived from eroded soils within the watershed should be determined. The general purpose of this study, therefore, is the determination of the quantities of algal available P in drainage water of the small agricultural watershed in northeastern Indiana, the Black Creek Watershed (Fig. 1) which is typical of subwatersheds within the Maumee River basin. This data will indicate the water quality of the effluent of the watershed in regard to one parameter of water quality. The effect of the addition of this water to the receiving body, in this case, the western basin of Lake Erie can be, therefore, more easily

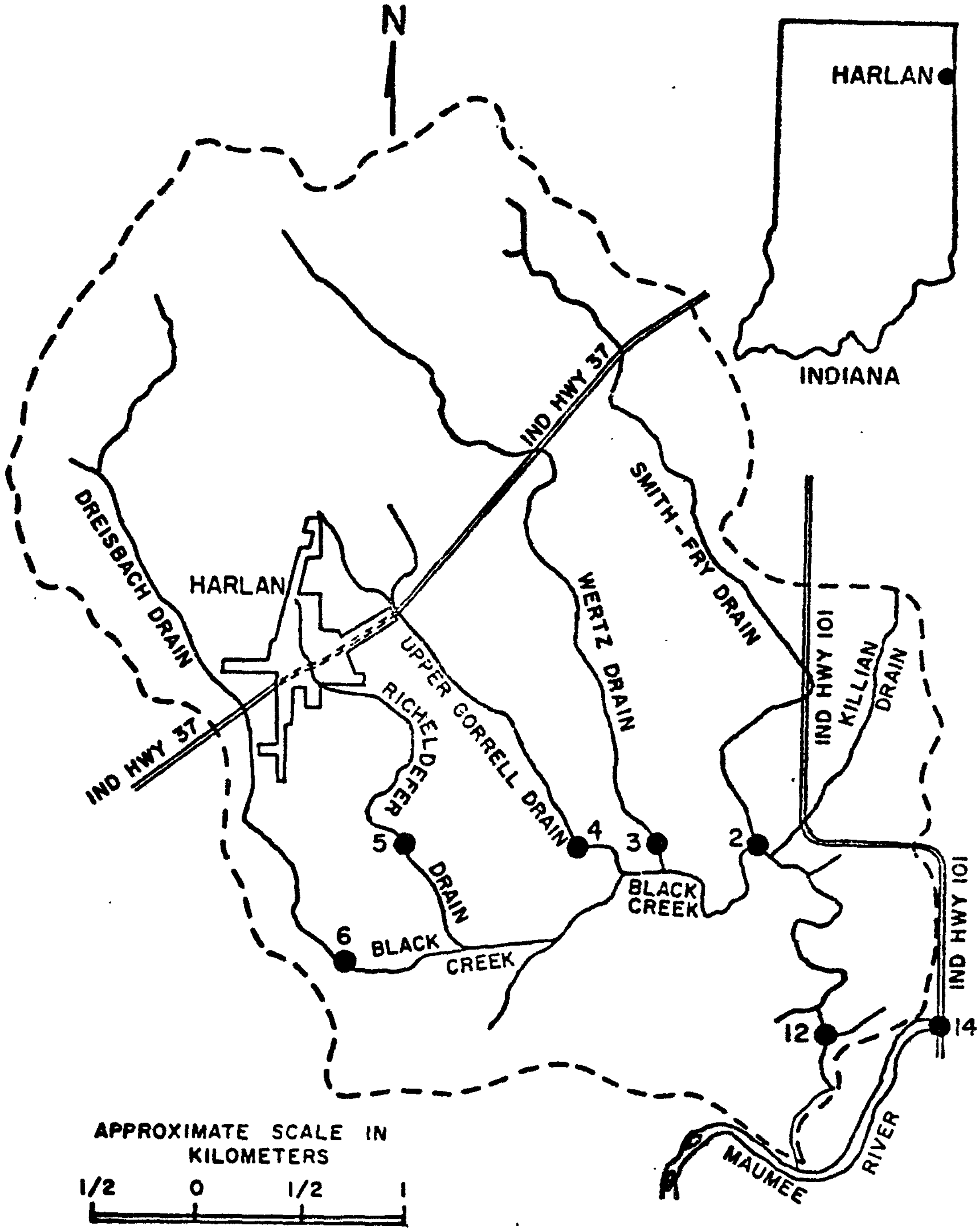



Figure 1. The Black Creek study area, Allen County, Indiana.

evaluated. Other aspects of this study will ensure that the data collected can be more easily evaluated with respect to data presented by investigators associated with other similar projects.

The specific objectives include (1) the determination of the availability of sediment-bound P to algae (2) the determination of the proportions of sediment Pi and total sediment P (TP) which are available for algal assimilation and (3) the comparison of various methods of assessing algal available P in sediments.

## LITERATURE REVIEW

The most available form of P to algae in lakes and streams is soluble inorganic P (Sol Pi) (Vollenweider, 1968; Bartsch, 1972), although not all Sol Pi as determined by chemical analysis of drainage water of the Black Creek watershed is available to algae (Dorich[1]). Sediment P most likely behaves as a buffer or "pool" for replenishment of Sol Pi when it is removed from solution (Porcella et al., 1970; Li et al., 1974; Fillos and Swanson, 1975; Sagher et al., 1975; Cowen and Lee, 1976a; Golterman, 1976; Moshiri and Crumpton, 1978; McCallister and Logan, 1978; Oloya and Logan, 1980; Dorich et al., 1980). The major obstacle to overcome in studying the availability of sediment P to algae directly is the separation of P associated with algae and that associated with sediment when sediment is acting as the only source of P during incubation with algae. Although methods have been proposed earlier, the majority of studies which mark advances in the determination of sediment P availability to algae have occurred during the past decade, and their method of overcoming the obstacle mentioned above have varied from ignoring it completely to separation of algae and sediment by semipermiable membranes to correction techniques.

Gerloff and Skoog (1954) proposed a method for addressing the problem of nutrient availability to algae which circumvented the necessity for incubating algae and sediment together. The method consisted of direct analysis of algae removed from their native environment and relating the cell content of a nutrient necessary for maximum growth to that found in the organism. In other words, the cell P content was found to increase with external supply over a wide range, but over a significant portion of this range, growth remained constant. Therefore, levels of P inside the cell in excess of the critical level necessary for maximum growth reflected the abundance of the external supply. However, the method has a disadvantage. The cell content reflects only the conditions under which the cell developed, and yields no information concerning maximum protentially available nutrient levels, which is a primary concern.

---

[1]R.A. Dorich. 1978. Algal availability of soluble and sediment phosphorus in drainage water of the Black Creek watershed. M.S. Thesis. Purdue University, West Lafayette, IN. 76 p.

Fitzgerald and Nelson (1966) evaluated a different procedure which enabled conclusions to be drawn about nutrient status in an aquatic system by analysis of the algae growing in it. Fitzgerald (1966) found that the amount of Pi removed from algae by a 60 minute boiling water extraction was proportional to the level of Pi of the growth medium when Pi levels limited algal growth. Data indicated that when < 0.008 mg P/100 mg algae was extracted by the 60 minute boiling water procedure, growth of algae had been likely limited by P availability. In the same study, alkaline phosphatase activity was measured as a function of Pi level in the growth medium. Alkaline phosphatase is an extracellular enzyme which serves to cleave Pi from molecules or substrates which do not yield Pi otherwise (i.e., organic forms of P). Its production by the cell is induced by low levels of Sol Pi. The activity of alkaline phosphatase was found to be 5 to 25 fold higher in algae whose growth was limited by Pi.

Porcella et al. (1970) conducted a long-term (164-209 days) microcosm study in which sediments were placed in the bottom of plexiglass cylinders and incubated with algae. The sediments were analyzed prior to and following incubation for P according to Jackson's (1958) extraction scheme, including dilute acid-fluoride soluble phosphate. Porcella et al. (1970) found that between 60 and 80% of the dilute acid-fluoride extractable Pi in sediments was lost from sediments during incubation indicating uptake by algae. However, reagents used to extract Pi from sediments following incubation may have removed Pi associated with biomass produced in the sediments during incubation. Therefore, sediment P at the end of the incubation period could have been overestimated and the available fraction underestimated.

Fitzgerald (1970) attempted to estimate available P (AP) by utilizing a dialysis tubing to contain the sediment during incubation with algae. No algal response was evident even when 2000 μg of sediment P was present. Similar results were reported later by Golterman (1976). Conversely, Wildung and Schmidt (1973) used a similar system in which algae and sediment were incubated separately in two glass half-cells with a membrane filter between. Algae assimilated 11 to 25% of the sediment Pi present.

Sagher et al. (1975) assessed the availability of sediment P in Wisconsin lake sediments by growing P-deficient algae (Selanastrum capricornutum) in contact with sediment over a 4 week period, and determining the P incorporated into algal biomass through fractionation of sediment Pi. Correction of Pi levels in various fractions for Pi removed from algal cells by extraction of the sediment:algal mixture was made by measuring Pi extracted from a sediment-free cell culture. Sagher et al. (1975) concluded that NaOH-extractable Pi (i.e., Al- and Fe-bound Pi) was the most available for algal growth over a 28 day incubation period, and 53 to 83% of the Pi was AP. Sagher[2] used a similar procedure to determine AP in

---

[2] A. Sagher. 1976. Availability of soil runoff phosphorus to algae. Ph.D. Thesis. University of Wisconsin, Madison, WI. 162 p.

the clay-size fraction of soil to S. capricornutum over a 2 day incubation period. The clay fraction and short incubation time were used because these particles are most subject to erosive processes, typically contain a large proportion of the P transported by erosion, and are in the euphotic zone of a lake for a sufficient period of time (24-48 hrs.) to provide P to plankton. The amount of AP in clay fractions in short-term incubation closely agreed with levels of NaOH-extractable Pi.

Huettl et al. (1979) using Sagher's[2] sediment samples showed that an hydroxy-Al resin removed amounts of P similar to that shown to be assimilated by algae in Sagher's[2] sediment:algal incubation. Specifically, Huettl et al. (1979) demonstrated that resin removed an amount of P that was, on the average, 98% of that assimilated by algae in water systems.

Cowen and Lee (1976a) used a strict bioassay technique which resembled the basic approach of the algal assay bottle test (Miller, 1978) to evaluate urban runoff particulate P (total P-total soluble P) availability to algae. The method involved the incubation of S. capricornutum with particulate material and direct counting of cells after 19-22 days. Comparison of cell numbers resulting from the incubation of algae with particulate P to cell numbers resulting from incubation of algae grown in medium containing known amounts of Pi resulted in their AP estimate. The method makes the assumption that algal growth in a strictly solution culture is similar to that in sediment:media culture. Cowen and Lee (1976a) then compared their AP estimate to levels of NaOH-, resin-, and HCl-extractable P found in sediments prior to incubation, although analysis of incubated sediments was not conducted. Cowen and Lee (1976a) found that levels of NaOH- and resin-extractable Pi agreed most closely with the quantity of AP (30% of the particulate P). Cowen and Lee (1976b) used a similar procedure to estimate the algal availability of particulate P in the Genessee River and several Lake Ontario tributaries. The amounts of particulate P found to be available to algae in the Genessee River samples by bioassay were very similar to the amounts of resin- and NaOH-extractable P. The range of particulate P which was available to algae was 1 to 24% (ave. = 9%). However, Lake Ontario tributary samples showed availabilities of < 6%. Bioassay analyses of the tributary sediments were comfounded with interferences from the native microbial populations. Autoclaved samples showed bioassay-determined AP levels of 36 to 41% of TP. The resin extraction which was similar to the algal available fraction in other samples, removed 6 to 31% of the particulate P.

Fekete et al. (1976) utilized a direct bioassay technique with the aquatic plant, Lemna minor, or common duckweed, to measure the available P in sediments. Lemna minor is a free floating, vascular plant typically found in high numbers in shallow, protected areas of lakes high in nutrients. The total number of fronds/plant, frond diameter, and dry weight consistently reflected P concentration in solution. Sediments were analyzed for Bray P1 and TP, and bioassays were conducted on solutions of medium which had been incubated over sediment for a one week period under both aerobic and anaerobic conditions. The incubation of solution over sediment occurred three times and Lemna grown on each of the three solutions to evaluate the available P level. As would be expected, more Pi was released to the medium from the sediment under anaerobic conditions than was released under aerobic conditions.

Golterman (1976) measured available P in shallow lake sediments of the Netherlands using the green alga, Scenedesmus quadricauda. Golterman's (1976) method for separating algae and sediment consisted of dispersing sediment in agar which was sliced into blocks and incubated with algae. Algal growth rates were less in some cases with this method than with algae in direct contact with sediment. The amounts of P taken up by algae was estimated by cell counts (1 mg phosphate-P$\cong 10^{10}$ cells), and compared to several extraction schemes. In most cases, the use of strongly alkaline or acid extractants as in that of Jackson (1958) proved unsatisfactory in both replication and correlation with algal availability. Golterman (1976) suspected that milder extractants which would chelate the cations $Fe^{+3}$ and $Ca^{+2}$ would be more appropriate. After trials with NTA (nitrilotriacetic acid), EDTA (ethylene diaminetetraacetic acid), and DTPA (diethylene-triaminepentaacitic acid), NTA was found to satisfactorally separate out the Fe- and Ca-bound Pi Golterman was striving for and best simulate the quantities of Pi removed by algae. Algae removed an amount of P which was ca. 99% of the amount of P removed with 0.01M NTA in 3 sequential extractions Furthermore, Golterman (1976) found that an additional, nearly equivalent amount of sediment P could be assimilated by algae when the agar:sediment blocks which had been incubated with algae were removed and reinoculated with algae a second time.

Verhoff et al. (1978) studied the rate of P availability from suspended river sediments by allowing the growth and natural succession of the indigenous microbial population in large capacity test vessels (12-14 ℓ),over a long period (9 months), and attempting a mass balance for P in the system. Samples (1-1.5 ℓ) were removed initially and periodically thereafter for analysis of P and volatile solids. It was assumed that all volatile solids were algal and that the sediment associated P originally in the sample was evenly distributed among the suspended solids. Verhoff et al. (1978) found that the indigenous population was able to removed between 0.092 and 0.191 mg P/gm solids, and between .087 and .268% of TP/day. This data is also reported by Logan et al. (1979). However, Logan et al. (1979) went on to report data on the chemical fractionation of the sediments prior to and following incubation. Logan et al. (1979) observed a decrease in the NaOH-extractable fraction.

Williams et al. (1980) studied the availability of Lake Ontario and Lake Erie sediment P to the green alga, in 12 day incubations. Available P in sediment samples incubated with algae was estimated both by cell numbers, as well as by decreases in a single HCl-extractable fraction, considered a measure of the sediment Pi. Corrections for Pi extractable from algae by the HCl extraction of the sediment:algal mixture was accomplished by the method of Sagher et al. (1975) discussed previously. Williams et al. (1980) went on to correlate the maximum cell numbers achieved in sediment:algal incubations with the quantities of TP, NTA-extractable P, non-apatite P (CDB + NaOH-extractable Pi), apatite P (HCl-extractable), and organic P added. Williams et al. (1980) reported that the relationship of cell numbers and TP was linear at levels greater than 90 μg added TP little algal growth was observed in TP levels less than 90 μg added P. Pronounced linearity was shown in the relationship between cell counts and nonapatite P with concentrations greater than 25 μg added P, and little growth shown below 25 μg added P. Similar results were shown for plots of cell numbers vs. NaOH-, resin-, and NTA-extractable P. Williams et al. (1980) concluded from this data that apatite P was not utilized by algae, while only a portion of the non-apatite P was assimilated by algae. Available P data arrived at by following the decrease in the single HCl extractable P level and comparison to initial levels of Pi, non-apatite Pi, and NaOH-extractable Pi indicated an average uptake of ca. 75% (38 to 83%) of the amount of non-apatite Pi, nearly all of the amount of NaOH-extractable Pi (which was ca. 69% of the non-apatite Pi) and 8 to 50% of the TP.

Dorich et al. (1980) studied the AP levels in suspended stream sediments in runoff water of an agricultural watershed (the Black Creek watershed) in the Maumee River basin in much the same manner as Sagher et al. (1975). The study of Dorich et al. (1980) differed from that of Sagher et al. (1975) in the length of incubation (2 rather than 4 weeks) and in the extraction procedure used to fractionate P in sediment:algal incubations (sequential $NH_4F$, NaOH, and HCl rather than sequential NaOH and HCl). Dorich et al. (1980) found that the two week incubation resulted in the assimilation of all the AP and an additional 2 weeks of incubation resulted in increases in Sol P and sediment P. Dorich et al. (1980) found that the majority of the AP (30% of Pi and 21% of TP) originated in the $NH_4F$-extractable fraction (43%) while NaOH- and HCl-extractable fractions accounted for less (37 and 20%, respectively). Ammonium fluoride-, NaOH-, and HCl-extractable P fractions contributed 60, 27, and 13%, respectively, of their amounts present initially to the pool of available P. Dorich's et al. (1980) finding that HCl-extractable P contributed significantly to the AP pool was in conflict with most results of other studies (Sagher et al., 1975; Sagher[1]; Logan et al., 1979; Williams et al., 1980), but other results reported show HCl-extractable Pi availability (Sagher[1]; Logan et al., 1979).

Studies have been reported in the literature in which an "available" fraction is evaluated based upon a simple chemical extraction. However, caution must be exercised in the interpretation of such studies. For instance, Wentz and Lee (1969a) presented a procedure in which a dilute HCl-$H_2SO_4$ extractant was used to estimate "available P". The dilute HCl-$H_2SO_4$ extraction was recommended due to the fact that P sorption is maximized at neutral to slightly acidic conditions, and minimized at low and high pH's. Therefore, the acid extractant would supposedly release sorbed Pi, which is available to algae. As shown above in later studies, neutral $NH_4F$- and/or NaOH-extractable Pi provides the largest portion of the AP (Sagher et al., 1975; Sagher[1]; Logan et al., 1979; Williams et al., 1980; Dorich et al., 1980). On the other hand, the HCl-$H_2SO_4$ extractant would remove most of the Pi extractable with the $NH_4F$ and NaOH, as well as most of the Pi associated with $Ca^{+2}$, which is considered to be largely unavailable. Therefore, the "available" P as outlined by Wentz and Lee (1969a) would overestimate available P, and, drastically so, in calcareous sediments. In short, unless a fraction of Pi (i.e., NaOH-extractable) has been shown to provide Pi to algae in a bioassay study such as Sagher et al. (1975), Logan et al. (1979) or Dorich et al. (1980) it is questionable to use the method as a measure of AP. Wentz and Lee (1969b) evaluated the depositional history of "available P" (estimated by their dilute HCl-$H_2SO_4$ extraction) in Lake Mendota, a eutrophic, calcareous lake in Madison, Wisconsin. Wentz and Lee (1969b) found 50% of the TP to be extractable with HCl-$H_2SO_4$.

Since a number of studies (Sagher et al., 1975; Sagher[2]; Golterman, 1976;

Williams et al., 1980; Dorich et al., 1980) have made direct measurements of decreases in specific fractions of sediment P as a result of algal uptake, the chemically extractable fractions found to supply P to the AP pool have been taken to be an estimate of the AP. Allan and Williams (1978) studied the historical levels of various forms of sediment P present. Allan and Williams (1978) determined CDB-extractable P as the bioavailable fraction and cite that the concentration would be slightly greater than that determined by direct bioassay as determined by Golterman (1976). Surprisingly enough, the levels of bioavailable or CDB-extractable P in the presettlement era of some lakes was higher than that occurring in present-day, culturally eutrophied sediments in Lake Erie.

Logan et al. (1979) in his P extraction studies with various suspended stream sediments evaluated sequential NaOH-, CDB-, and HCl-extractable P. Logan et al. (1979) cited the NaOH-extractable fraction as an estimate of short-term available fraction and the NaOH + CDB-extractable fraction as the long-term or total, potentially available fraction. Logan et al. (1979) found NaOH-extractable P to range from 14 to 42% and NaOH + CDB-extractable from 42 to 89% of the TP.

Armstrong et al. (1979) evaluated AP in several rivers with access to the Great Lakes. Two chemical extraction methods, 0.1N NaOH and anion exchange resin desorption, were used to estimate maximum algal AP and readily available P, respectively. Sodium hydroxide extractable P ranged from 14 to 37% of TP and resin extractable from 7 to 17% of TP. Maximum AP in the clay fraction, which may remain in suspension indefinitely, ranged from 16 to 53% of the TP. He continues by stating that about 50% of the U.S. tributary loadings of P to the Great Lakes is in the available form (50% of which is particulate and 50% dissolved).

The effects of agricultural activities along the Maumee River upon the pollution of Lake Erie relative to P availability has been a point of contention. However, the effect of agriculture must be studied in a watershed which is unique in its domination by such activities. The opportunity to study availability of P in a strictly agricultural watershed presents itself in the Black Creek watershed. The amount of work related to the direct measurements of AP in suspended river sediments is minimal (Logan et al., 1979; Armstrong et al., 1979; Dorich et al., 1980), and those making direct estimates of the availability of sediment P in runoff from strictly agricultural watersheds is even less (Dorich et al., 1980). Furthermore, comparisons of various methods of AP determinations have been made in lake sediments (Williams et al., 1980), but not in suspended stream sediments. In view of these facts, the specific objectives of this study will be concerned with determining in samples from several sites within the Black Creek Watershed: (1) The algal availability of P associated with suspended sediments as determined in both long-term (2 weeks) and short-term (2 days) sediment:algal incubations in studies similar to Sagher et al. (1975), and Dorich et al., (1980). (2) The proportions of Pi and TP which are available for algal uptake as determined in long- and short-term sediment:algal incubations and (3) The relationships between the quantity of AP and resin-, NTA-, and sequential $NH_4F$-, NaOH-, and HCl-extractable P levels.

## MATERIALS AND METHODS

### Basic Experimental Design

The objectives of this study were (1) to determine algal availability of suspended stream sediment P in drainage water of the Black Creek watershed in both 2 week and 2 day bioassays (2) to determine the proportions of Pi and TP in suspended stream sediments which are available to algae in 2 week and 2 day bioassays and (3) to determine the relationships between AP and resin-, NTA-, and sequential $NH_4F$-, NaOH, and HCl-extractable Pi in suspended sediments in drainage water of the Black Creek watershed.

Availability of sediment P has been determined in all samples by direct measurement of P fractions in sterile sediments prior to and following incubation with S. capricornutum. The difference in the quantity of P in various Pi fractions initially and at the end of the incubation period is assumed to have been assimilated by S. capricornutum. Availability of sediment P to algae has been determined in both 2 week and 2 day incubation periods similar to those systems described first by Sagher et al. (1975). The value of AP determined in incubation of sterile sediment with algae has been compared to levels of resin-, NTA-, and sequential $NH_4F$-, NaOH-, and HCl-extractable P in sterile sediments which have not undergone incubation with algae.

### Sediment Collection and Treatment

Suspended sediments were collected as water grab samples in 2.5 liter sterile glass containers at the peak of the hydrograph immediately following rainfall events on 4/14/80, 6/2/80, 7/22/80, and 8/20/80. Sampling included 7 sites within the Black Creek watershed (Figure 1). Sites 2, 3, and 4 are primarily drainage from cropland while sites 5 and 6 are affected by sewage from the town of Harlan, IN. Sites 12 and 14 represent the Black Creek and Maumee River, respectively. Samples were returned to Purdue University and stored at $4^oC$ until processed.

Because the concentration of suspended sediments is not normally high enough to conduct bioassays, it was necessary to concentrate the sediments. Suspended sediments were concentrated by slow rate continuous flow centrifugation (9,000 x g), and diluted to between 100 and 500 ml depending upon the relative concentration of sediment in the water sample. The concentrated sediment samples were then sterilized by 3 megarads of $\gamma$ radiation ($^{60}Co$ source, ca. 7200 rads/minute, and an exposure time of ca. 8 hrs.). Preliminary studies found this exposure was adequate to ensure sterilization. Following sterilization, concentrated sediment samples were stored at $4^oC$ until used in bioassay measurements.

### Stock Culture

A stock culture of Selanastrum capricornutum (a single-celled member of the Chlorophyceae family) was acquired from the U.S. Environmental Protection Agency, Pacific Northwest Water Laboratory, Corvallis, Oregon. Algal cells were cultured in 200 ml of synthetic nutrient medium (PAAP)

(Miller, 1978) in 1000 ml Erlenmeyer Flasks at 26 ± 1$^{o}$C with fluorescent light intensity of ca. 5500 lux for 2-3 weeks. The pH of the culture was adjusted periodically with HCl to pH 6.8.

P-deficient Inoculum for 2 Week Sediment: Algal Bioassays

When cultures of *S. capricornutum* achieved maximum cell densities, the cells were havested by centrifugation, rinsed in P-free PAAP and resuspended in P-free PAAP. The cells were then incubated for 3-5 weeks (Sagher, 1975). Before used as an inoculum for the sediment:algal (SA) incubation, the cells were again rinsed in P-free PAAP medium to remove Pi which may have been released from senesced cells. Cells were then counted.

P-deficient Inoculum for 2 Day Incubations

When cultures of S. capricornutum reached maximum cell densities, cells were harvested by centrifugation, rinsed in PAAP, and resuspended in 600 ml of PAAP in a 2 liter Erlenmeyer flask and incubated until cell densities were sufficient for use as an inoculum. This procedure achieved the high cell densities that were necessary for the massive inoculum required for the 2 day incubation experiments. Cells were again havested by centrifugation, rinsed in P-free PAAP, and resuspended in 600 ml of P-free PAAP in a 2000 ml Erlenmeyer flask. The cells were incubated for 3-5 weeks (Sagher, 1975). Before used as an inoculum for SA incubations, cells were agin rinsed in P-free PAAP, and counted.

Bioassay Conditions

Sediment:algal incubations were conducted to evaluate the availability of sediment P to algae. All incubations were conducted in 50 ml of P-free PAAP to provide all essential nutrients but P, an aliquot of sterile suspended sediments containing 35-45 µg total sediment P, diluted to 60 ml with deionized water in a 250 ml Erlenmeyer Flask, and stoppered with a cotton plug. Each flask was inoculated with P-deficient *S. capricornutum* to arrive at an initial cell density in the bioassay flask of $5 \times 10^4$ cells/ml for the 2 week SA bioassays and $2 \times 10^6$ cells/ml for the 2 day SA bioassays.

General Information Concerning Extraction and Analyses

The following information pertains to the extractions and analyses performed on all inoculated and uninoculated sediment samples. The analysis of inoculated sediment or SA cultures initially and after the incubation period served as a direct measurement of the decrease in sediment P as a result of uptake by algae (Sagher *et al.*, 1975; Sagher[2]; Dorich *et al.*, 1980). Sediment-free algal incubation flask contents were extracted in order to determine extractability of P in algal cells. This data was used to correct the amount of P extracted from sediment:algal mixtures to arrive at the actual amount of P extracted from sediment. Uninoculated sediments were extracted with various reagents reputed to remove amounts of P from sediments similar to that used by algae. These values were compared to available P measured directly in inoculated sediments.

All sediment P extractions were carried out in tared 50 ml polypropylene centrifuge tubes. Following extraction (shaking on reciprocating shaker), centrifugation (12000 rpm at 9,000 x *g* for *ca*. 20 minutes), and decanting by suction, the amounts of liquid carryover to the next extraction was determined gravimetrically. The quantity of P determined in the subsequent extraction was corrected accordingly.

Solution:sediment ratio (v/w) were maintained as near to 500 as possible. Therefore, the volume of extractant varied among samples, and depended on the weight of sediment in the tube. The sediment pellet in the tube and extractant was shaken by hand prior to being placed on the shaker to ensure complete dispersion of the sample in the extractant.

All colormetric Pi determinations were conducted in 25 ml volumetric flasks. The phosphomolybdate color was developed according to Murphy and Riley (1962) for all extracts and digests following neutralization with HCl or NaOH with ρ-nitrophenol as the indicator with the exception of the $NH_4F$ extract. Aliquots (10 ml) of the $NH_4F$ extracts were treated with 7.5 ml of $H_3BO_3$(50 g/ℓ) and the pH adjusted with HCl using 2,4-dinitrophenol as the indicator. Phosphomolybdate color was developed with $SnCl_2$ as the reductant. The determination of Pi in $NH_4F$ extracts was as recommended by Jackson (1958).

When the decision has to be made whether to use one large single aliquot or two smaller replicate aliquots for Pi determination in the available extract of a replicate flask contents, the decision was made in favor of the larger aliquot for a more precise single measurement. Therefore, the Pi levels reported were a result of the averaging of the single measurements made in each of 3 replicate flasks. Color intensity was measured as absorbance with a Beckman model 24 visible spectrophotometer equipped with a automatic filling 1 cm cell at 850 nm.

Residual P following Pi fractionation was determined following sequential $HNO_3$ and $HClO_4$ digestion (Sommers and Nelson, 1972) in 50 ml calibrated Folin-Wu digestion tube.

<u>Extraction and Analysis of Sediment:Algal Bioassay Samples</u>

Sediment:algal bioassay solutions and sediment-free algal solutions were sequentially analyzed for soluble, NaOH-, and HCl-extractable, and residual P initially and at the end of the incubation period (i.e., 2 weeks and 2 days).

Fractions of sediment Pi were determined initially and at the end of the incubation period colormetrically following sequential extraction with NaOH and HCl, and digestion of the residue. In detail, the contents of the SA incubation flasks was transferred into a 50 ml polypropylene centrifuge tube and centrifuged. The solution phase was decanted and analyzed for Sol Pi. To the sediment in the centrifuge tube the appropriate volume (to give an extraction ratio of 500:1) of 0.1<u>N</u> NaOH was added and the solution shaken for 17 hrs. Following extraction with NaOH, the sample was centrifuged, the extract decanted, and Pi determined in an aliquot. To the sediment remaining in the centrifuge tube, the appropriate volume of 1 <u>N</u> HCl was added and shaken for 1 hr. Following extraction the solution was centrifuged, the extract decanted and Pi determined in an aliquot. The residue in the centrifuge tube was transferred to a Folin-Wu digestion tube and the Pi determined colormetrically following digestion.

Extraction and Analyses of Uninoculated Sediment Samples

Sediment samples which had not been incubated with algae, but treated identically otherwise, were subjected to various Pi extractants and the quantity of Pi in the extracts determined for comparison to quantities of AP. Sequential $NH_4F$-, NaOH-, and HCl-extractable Pi was determined as outlined by Dorich et al. (1980). An amount of the sterilized, concentrated sediment containing between 35 and 45 μg TP was added to the centrifuge tube, the solution centrifuged, the liquid decanted and Sol Pi determined. To the sediment remaining in the centrifuge tube, an appropriate volume of neutral 0.5N $NH_4F$ was added and the contents shaken for 1 hr. Following extraction, the tube was centrifuged, the extract decanted, and Pi determined in an aliquot of the extract as indicated earlier, according to Jackson (1958). To sediment in the centrifuge tube, the proper volume of 0.1N NaOH was added and the tube shaken for 17 hrs. Following centrifugation and decanting of extract, Pi was determined in the extract. The appropriate volume of 1 N HCl was added to the sediment pellet in the centrifuge tube and shaken for 1 hr. Following centrifugation and decanting of extract, Pi was determined in the extract. Residual P was determined following $HNO_3$ and $HClO_4$ digestion as discussed previously.

Sediments were also subjected to Golterman's (1976) sequential 0.01 M NTA extraction. Golterman (1976) found that 3 successive 20 ml extractions with 0.01 M NTA (pH 7) removed amounts of sediment Pi similar to that removed by algae. An aliquot of concentrated sediment solution containing between 35 and 45 μg TP was added to a centrifuge tube. The tube was centrifuged, the supernatant decanted, and an aliquot of the supernatant analyzed for Sol Pi. Twenty ml of 0.01 M NTA was added to the centrifuged sediment and the tube shaken for 2 hrs. Following centrifugation supernatant was decanted. Two additional such extractions were performed on the same sample and the 3 supernatants combined. The combined extracts were titrated to pH 1.5 with HCl to precipitate organic matter and NTA and the volume of titrant recorded (Nnadi and Tabatabai, 1975). The titrated extract was allowed to stand overnight and then vacuum filtered through a 0.45 μ Nucleopore membrane. Inorganic P was determined in an aliquot colormetrically according to the method of Murphy and Riley (1962) with a 2.5 hr. color development rather than 30 min., although others have indicated NTA interferes with Murphy and Riley (1962) color development (Nnadi and Tabatabai, 1962; Golterman, 1976; Williams, 1980). Unpublished studies conducted in our laboratory show that although color development according to Murphy and Riley (1962) is not complete after the recommended 30 minutes, full and linear color development is attained after 2.5 hrs. with up to 10 ml of 0.01 M NTA present. After the supernatant from the third extraction has been decanted, the sediment was transferred to a digestion tube and digested with $HNO_3$ and $HClO_4$. Phosphorus was determined in the digest as discussed previously.

Non-incubated sediments were also subjected to the resin extraction procedure of Huettl et al. (1979). Resin preparation was according to that specified by Corey (Professor of Agronomy, University of Wisconsin, personal communication, 1979), and will be discussed below. The resin used was Dowex 50W-X2,20-50 mesh (wet) and wet sieved to remove particles smaller than 40 mesh prior to beginning chemical preparation. Following sieving, % moisture was determined on a sample of resin (ca. 5 g) to obtain an accurate dry weight. Cation exchange capacity of the resin was determined by saturation of a 10 g (wet) sample with acid (stirring for 15 minutes with 1 N HCl). The resin placed in a vacuum filter holder and washed several times with deionized water. The resin was then rinsed several times with separate portions of a 25 ml aliquot of 0.5 N KCl. The acidity of two 10 ml aliquots of the KCl eluent was titrated with standardized NaOH (ca. 0.5 N) with phenophthalein as the indicator. Once the CEC of the resin had been calculated based upon the N and volume of the standardized NaOH titrant, preparation of the bulk of the resin was initiated.

In a column the resin was leached with dilute $AlCl_3 \cdot 5H_2O$ (1 N Al or more dilute). Since the purpose of the $AlCl_3 \cdot 5H_2O$ leaching was to ensure saturation of the resin with Al, excess was applied. The excess Al was removed by copious leaching with several bed volumes of deionized water.

The Al-saturated resin was transferred to a 4 ℓ beaker where a $NaHCO_3$ solution was slowly added (over several hours) with stirring to allow for diffusion into the beads. The total $NaHCO_3$ added was sufficient to neutraluze 2/3 of the original sites, and stirring was not ceased until $CO_2$ evolution had stopped.

The resin was transferred back to the column, where it was leached with enough 0.5 N $AlCl_3 \cdot 5H_2O$ to saturate the entire CEC with Al. The resin was then rinsed with several bed volumes of deionized water. This concluded chemical preparation of the resin.

Concentrated sediment samples containing between 35 and 45 μg TP were placed in centrifuge tubes, and the suspension centrifuged. Following decantation of the supernatant Sol Pi was determined. A quantity of resin containing a total CEC of 2.5 meq and 20 ml of 0.001 M $CaCl_2$ was added to the sediment in the tube and the mixture shaken for 24 hrs. Following the 24-hour extraction period, the contents of the centrifuge tube were wet sieved through a 60 mesh sieve to separate the resin and sediment. Sediment passing through the sieve was trapped in a 50 ml digestion tube. Followed by evaporation and $HNO_3$-$HClO_4$ digestion, the amount of P remaining in the sediment was determined. The resin trapped on the sieve was transferred to a vacuum filter apparatus where the extraction of Pi from the resin took place. The resin in the filter apparatus was rinsed several times with separate portions of a 50 ml aliquot of 0.2 N HCl and entire rinse volume recovered. Inorganic P was determined in an aliquot of the rinse following neutralization.

Calculations

Corrections for P removed from algae were made upon the amount of P extracted from incubated sediment:algal mixtures in the following manner. The proportion of Pi extracted by NaOH and HCl from sediment-free algal cultures was determined based upon known levels of P in cells. The amount of P in cells in sediment:algal mixtures or available sediment P was calculated based upon the difference in fractions initially and after incubation period (2 days or 2 weeks) and proportions removed from cells in the sediment-free algal cultures.

## RESULTS AND DISCUSSION

Sediments used in incubations with algae were sequentially extracted with NaOH and HCl initially and after the incubation period (2 weeks and 2 days). Decreases in inorganic P fractions over the incubation period served as the basis for the determination of the quantities of sediment P removed by algae during incubation. Initial levels of P in various fractions of stream sediment P are presented in Table 1. As indicated in Table 1 significant quantities of inorganic P (Pi) are desorbed when the sediment is added to the P-free PAAP medium. As a % of total P (TP) in the system, averages of 9 to 14% were desorbed. The average concentration of NaOH-extractable P for the four sampling times ranged between 295.5 and 390.5 μg/g (avg. = 326.1 μg/g), or as a % of TP between 26 and 34% (avg. = 30%). Average HCl-extractable P levels ranged between 154.9 and 284.7 μg/g (avg. = 206.2 μg/g) or as a % of total P between 17 and 22% (avg. = 18%). Average Pi levels (the sum of soluble Pi, NaOH-, and HCl-extractable P) ranged between 554.7 and 827.1 μg/g (avg. = 671.3 μg/g), or as a % of total P, between 58 and 65% (avg. = 61%). The significance of the various Pi fractions and total Pi in sediment relative to algal available Pi has been demonstrated in the past (Sagher, 1975; Sagher[3]; Dorich et al., 1980). Both Sagher (1975) working with lake sediment and Dorich et al. (1980) working with Black Creek watershed stream sediments have found that only Pi is available to algae, and that the majority of the available Pi originates in the NaOH-extractable fraction, which is defined as P sorbed on the surfaces of hydrous Fe and Al oxides (Syers et al., 1973). Dorich et al. (1980) also demonstrated contributions of the HCl-extractable fractions to the pool of available P.

Following correction for P extracted by NaOH and HCl from algal cells which populated the sediment:algal mixtures after the incubation period, available P was calculated based upon differences in levels of NaOH- and HCl-extractable P initially and after 2 days or 2 weeks of incubation. Available P in stream sediments is presented in Table 2. The average concentration of available P in stream sediments for the 4 sampling dates ranged between 190.3 and 349.2 μg/g (avg. = 289.8 μg/g) and between 278.8 and 430.2 μg/g (avg. = 333.4 μg/g) as measured in 2 day and 2 week incubation periods, respectively. As a % of Pi, these values represent a range of 33.9 to 45.7% (avg. = 40.8%) and 48.3 to 51.5% (avg. = 50.4%) as measured in 2 day and 2 week incubation periods, respectively. As a % of TP, average available P concentration, in stream sediments ranged between 19.7 and 27.5% (avg. = 24.6%) and between 27 and 34.4% (avg. = 30.3%) as measured in 2 day and 2 week incubation periods, respectively. As indicated in Table 2, algae consistently assimilated more P from sediment when the incubation period was increased from 2 days to 2 weeks. However, in most cases, as the averages bear out, the vast majority of available sediment P was assimilated within the first 2 days of incubation. The average additional sediment P which was removed by algae in the period between 2 days and 2 weeks ranged from 5.1 to 16.8% (avg. = 9.6%) and 1.0 to 11.6% (avg. = 5.7) of the Pi and TP, respectively. If the assumption is made that most of the P-bearing particles (small diameter) remain in the photic zone of a lake for a period of 2 days where algal assimilation is maximum (Sagher, 1976), then it appears that sediments transported from the Black Creek watershed and deposited in Lake Erie are capable of releasing the majority of

Table 1. Quantities of P present in various fractions in stream sediment used in 2 day and 2 week incubations.

| Date | Site No. | Initial sediment P found in fractions*: | | | | | |
|---|---|---|---|---|---|---|---|
| | | SIP | NaOH | HCl | Inorg | Org | Total |
| | | μg/g | | | | | |
| 4/14 | 2 | 109.7 | 396.7 | 271.0 | 777.4 | 586.1 | 1363.5 |
| | 3 | 150.4 | 371.9 | 175.4 | 697.7 | 476.8 | 1174.5 |
| | 4 | 101.1 | 277.9 | 113.6 | 492.6 | 308.6 | 801.2 |
| | 5 | 106.3 | 363.3 | 159.9 | 629.5 | 475.7 | 1105.2 |
| | 6 | 108.3 | 353.2 | 137.9 | 599.4 | 418.7 | 1018.1 |
| | 12 | 150.9 | 258.6 | 241.0 | 650.5 | 521.9 | 1172.4 |
| | 14 | 141.9 | 306.3 | 195.4 | 643.6 | 423.8 | 1067.4 |
| | Avg. | 124.1 | 332.6 | 184.9 | 646.6 | 458.8 | 1100.3 |
| 6/2 | 2 | 150.7 | 265.0 | 191.1 | 606.8 | 535.5 | 1142.3 |
| | 3 | 60.1 | 131.2 | 84.7 | 276.0 | 236.4 | 512.4 |
| | 4 | 153.2 | 336.6 | 127.0 | 616.8 | 476.2 | 1093.0 |
| | 5 | 189.0 | 326.4 | 309.0 | 824.4 | 521.1 | 1345.5 |
| | 6 | 222.5 | 476.5 | 191.5 | 890.5 | 589.8 | 1480.3 |
| | 12 | 186.1 | 288.3 | 275.9 | 750.3 | 515.8 | 1266.1 |
| | 14 | 131.1 | 244.6 | 222.1 | 597.8 | 414.7 | 1012.5 |
| | Avg. | 156.1 | 295.5 | 200.2 | 651.8 | 469.9 | 1121.8 |
| 7/22 | 2 | 69.8 | 285.0 | 145.2 | 500.0 | 393.7 | 893.7 |
| | 3 | 85.3 | 317.9 | 154.6 | 557.8 | 365.5 | 923.3 |
| | 4 | 77.6 | 349.7 | 110.4 | 537.7 | 366.0 | 903.7 |
| | 5 | 82.2 | 273.2 | 121.2 | 476.6 | 357.6 | 834.2 |
| | 6 | 101.7 | 392.7 | 149.4 | 643.8 | 374.5 | 1018.3 |
| | 12 | 68.4 | 284.8 | 161.3 | 514.5 | 393.7 | 908.2 |
| | 14 | 113.0 | 297.4 | 241.9 | 652.3 | 323.7 | 976.0 |
| | Avg. | 85.4 | 314.4 | 154.9 | 554.7 | 367.8 | 922.5 |
| 8/20 | 2 | 138.7 | 386.5 | 236.5 | 761.7 | 462.6 | 1224.3 |
| | 3 | 137.8 | 389.7 | 256.5 | 784.0 | 514.9 | 1298.9 |
| | 4 | 120.0 | 245.7 | 314.6 | 680.8 | 404.5 | 1085.3 |
| | 5 | 185.2 | 377.0 | 311.3 | 873.5 | 449.4 | 1322.9 |
| | 6 | 176.3 | 559.3 | 265.5 | 1001.1 | 419.3 | 1420.4 |
| | 12 | 160.5 | 346.5 | 286.0 | 793.0 | 432.0 | 1225.0 |
| | 14 | 144.4 | 428.6 | 322.6 | 895.6 | 458.6 | 1354.2 |
| | Avg. | 151.8 | 390.5 | 284.7 | 827.1 | 448.8 | 1275.9 |

*Values shown here are overall averages found initially in 2 day and 2 week incubations.

Table 2. Levels of available P in stream sediments as measured by bioassay (2 day and 2 week incubations).

| | | Bioassay incubation period | | | | | |
|---|---|---|---|---|---|---|---|
| Date | Site No. | 2 day available P | | | 2 week available P | | |
| | | μg/g | % of Pi | % of TP | μg/g | % of Pi | % of TP |
| 4/14 | 2 | 740.3 | 70.6 | 43.1 | 284.3 | 51.1 | 26.0 |
| | 3 | 345.1 | 50.5 | 30.0 | 411.9 | 60.3 | 34.4 |
| | 4 | 282.7 | 43.5 | 27.3 | 162.7 | 48.4 | 28.8 |
| | 5 | 250.3 | 38.6 | 23. | 362.2 | 59.4 | 32.3 |
| | 6 | 263.0 | 39.8 | 25.0 | 373.0 | 50.7 | 27.8 |
| | 12 | 212.4 | 37.3 | 21.1 | 337.6 | 46.1 | 25.2 |
| | 14 | 265.8 | 39.5 | 23.1 | 255.0 | 41.5 | 25.2 |
| | Avg. | 337.1 | 45.7 | 27.5 | 312.4 | 51.1 | 28.5 |
| 6/2 | 2 | 222.7 | 35.7 | 19.8 | 263.6 | 44.8 | 22.7 |
| | 3 | 129.7 | 46.6 | 25.7 | 112.2 | 41.0 | 21.5 |
| | 4 | 279.0 | 44.1 | 25.4 | 308.2 | 51.2 | 28.3 |
| | 5 | 367.9 | 43.6 | 28.1 | 407.6 | 50.0 | 29.0 |
| | 6 | 496.5 | 51.9 | 31.8 | 495.5 | 60.1 | 35.4 |
| | 12 | 296.9 | 37.3 | 23.5 | 318.4 | 45.2 | 25.1 |
| | 14 | 184.4 | 31.5 | 18.7 | 278.6 | 45.6 | 26.8 |
| | Avg. | 282.4 | 41.5 | 24.7 | 312.0 | 48.3 | 27.0 |
| 7/22 | 2 | 111.7 | 22.2 | 12.0 | 253.5 | 51.0 | 29.6 |
| | 3 | 215.9 | 38.3 | 21.8 | 284.0 | 51.5 | 32.6 |
| | 4 | 134.0 | 25.0 | 14.2 | 286.9 | 53.2 | 32.9 |
| | 5 | 200.0 | 42.3 | 23.1 | 252.7 | 52.6 | 31.4 |
| | 6 | 216.4 | 33.2 | 20.6 | 342.1 | 53.8 | 34.7 |
| | 12 | 175.5 | 34.7 | 19.6 | 257.5 | 49.3 | 28.4 |
| | 14 | 278.3 | 41.3 | 27.2 | 275.0 | 43.6 | 29.6 |
| | Avg. | 190.3 | 33.9 | 19.7 | 278.8 | 50.7 | 31.3 |
| 8/20 | 2 | 305.6 | 38.9 | 23.8 | 365.8 | 49.6 | 31.5 |
| | 3 | 373.9 | 44.9 | 27.7 | 356.1 | 48.4 | 28.6 |
| | 4 | 266.4 | 38.9 | 24.0 | 304.9 | 45.0 | 28.8 |
| | 5 | 307.5 | 39.0 | 23.8 | 551.3 | 57.6 | 40.8 |
| | 6 | 471.1 | 46.6 | 31.6 | 578.5 | 57.9 | 42.5 |
| | 12 | 345.3 | 42.8 | 27.3 | 398.4 | 51.1 | 33.6 |
| | 14 | 374.9 | 41.6 | 26.9 | 456.3 | 51.2 | 34.7 |
| | Avg. | 349.2 | 41.9 | 26.4 | 430.2 | 51.5 | 34.4 |

their available P within that period of time if sufficient algal populations are present. The maximum differences in available P between sampling dates as a % of Pi and TP, are 11.8 and 3.2%, and 7.8 and 7.4% as measured in 2 day and 2 week incubations, respectively.

Several chemical extraction methods have been proposed to remove quantities of P from sediments similar to that assimilated by algae. Of these suggested extractants which have been correlated with available P, Sagher's (1975, 1976) NaOH-extraction, Dorich's et al. (1980) sequential $NH_4F$, NaOH, and HCl extraction, Huettl's et al. (1979) resin extraction, and Golterman's (1976) NTA extraction appear to be most promising. The quantities of P removed by NaOH from stream sediments for the four sampling dates are presented in Table 1 while that extracted by the sequential $NH_4F$, NaOH, and HCl extractions, resin, and NTA are presented in Table 3. As a fair basis for comparison in this description the sum of soluble Pi + NaOH-extractable P concentrations will be used because (1) essentially all the Sol P in this experimental system is assimilated by algae in addition to the majority of NaOH-extractable P (Sagher, 1975; Sagher, 1976; Dorich et al., 1980), and (2) the Pi found as soluble Pi initially in this experimental system would be detected as NaOH-extractable P in routine extraction procedures. The average NaOH-P + soluble Pi (heretofore referred to as NaOH-extractable P) ranged between 399.8 and 542.3 μg/g (avg. = 455.5 μg/g). These concentrations represent a range between 61 and 72% (avg. = 67%) and between 39 and 43% (avg. = 41%) of the sediment Pi and TP, respectively. Average Pi levels for the 4 sampling periods determined as the sum of soluable Pi, NaOH- and HCl-extractable P ranged between 58 and 65% (avg. = 61%) of sediment TP. Sodium hydroxide-extractable P appears to slightly overestimate the actual quantity of available P as determined in both 2 day and 2 week incubations of the sediments sampled. The overestimation of available P by the NaOH-extractable fraction makes sense, because not all of this P should be readily available to algae.

Presented in Table 3 are the concentrations of Pi extractable with sequential $NH_4F$, NaOH, and HCl, resin, and NTA. For the same reasons as indicated for comparisons of NaOH-extractable to available P, levels of $NH_4F$-extractable P discussed will include the amounts of soluble Pi detected. Average $NH_4F$-extractable P for the 4 sampling dates ranged between 205.2 and 409.0 μg/g (avg. = 281.1 μg/g). As a % of inorganic P and TP, $NH_4F$-extractable P constituted between 33.8 and 42.0% (avg. 37%), and 18.8 and 27.6% (avg. = 22.9%), respectively. On a quantitative basis $NH_4F$ appears to simulate the 2 day available P level in stream sediments which averaged 40% of Pi and 24.6% of TP, and underestimate the 2 week available P which averaged 50.4% of Pi and 30.3% of TP. The average sums of the Pi extractable with $NH_4F$- and the subsequent NaOH reagent ranged between 309.7 and 498.2 μg/g ( avg. = 386.5 μg/g) which constituted between 48.3 and 54.7% (avg. = 52.1%) and between 27.9 and 36.6% (avg. = 31.8%) of the Pi and TP, respectively. The sum of $NH_4F$- and NaOH-extractable P may be considered as similar to available P levels (50.4% and 30.3% of Pi and TP, respectively) measured in 2 week incubations of the stream sediments.

Resin extractable P (the sum of soluble Pi + resin-extractable P) averages for the 4 sampling days ranged between 145.7 to 316.8 μg/g (avg. = 228.3 μg/g). As an average this underestimates both 2 day and 2 week available P. However, it should be noted that there does not appear to be a

Table 3. Quantities of P in stream sediments extracted with sequential $NH_4$, NaOH and HCl; resin, and NTA.

| | | Extractant | | | | |
|---|---|---|---|---|---|---|
| | | Sequential | | | | |
| Date | Site No. | $NH_4F^+$ | NaOH | HCl | Resin$^+$ | NTA$^+$ |
| | | μg/g | | | | |
| 4/14 | 2 | 170.8 | 89.6 | 280.7 | 101.2 | 489.2 |
| | 3 | 206.8 | 97.2 | 275.6 | 152.7 | 628.5 |
| | 4 | 200.9 | 223.8 | 233.2 | 113.5 | 320.7 |
| | 5 | 200.5 | 171.3 | 306.3 | 188.0 | 482.1 |
| | 6 | 196.8 | 111.3 | 184.0 | 319.1 | 344.8 |
| | 12 | 216.2 | 44.8 | 353.4 | 197.9 | 840.1 |
| | 14 | 244.3 | 46.0 | 316.0 | 322.2 | 721.6 |
| | Avg. | 205.2 | 112.0 | 278.5 | 199.2 | 546.7 |
| 6/2 | 2 | 258.8 | 53.8 | 298.3 | 547.5 | 652.8 |
| | 3 | 105.0 | 26.9 | 131.4 | 78.8 | 290.8 |
| | 4 | 260.8 | 92.5 | 216.0 | 278.8 | 657.9 |
| | 5 | 305.2 | 62.9 | 411.8 | 195.8 | 894.1 |
| | 6 | 398.6 | 123.7 | 284.9 | 360.3 | 827.4 |
| | 12 | 253.3 | 32.0 | 296.2 | 135.5 | 747.2 |
| | 14 | 167.9 | 27.0 | 359.2 | 164.8 | 490.0 |
| | Avg. | 249.9 | 59.8 | 285.4 | 251.6 | 651.5 |
| 7/22 | 2 | 217.2 | 143.1 | 264.1 | 151.0 | 355.0 |
| | 3 | 238.9 | 160.1 | 354.8 | 145.0 | 481.4 |
| | 4 | 220.0 | 236.3 | 277.1 | 110.5 | 359.1 |
| | 5 | 236.4 | 167.5 | 262.5 | 139.3 | 341.0 |
| | 6 | 351.9 | 216.1 | 324.6 | 194.7 | 546.1 |
| | 12 | 225.7 | 143.2 | 362.1 | 184.3 | 389.0 |
| | 14 | 331.3 | 57.7 | 490.8 | 95.0 | 524.6 |
| | Avg. | 260.2 | 160.6 | 333.7 | 145.7 | 428.0 |
| 8/20 | 2 | 381.6 | 178.6 | 571.7 | 219.2 | 653.3 |
| | 3 | 378.6 | 93.7 | 426.8 | 250.5 | 673.5 |
| | 4 | 261.1 | 80.5 | 683.9 | 190.3 | 535.6 |
| | 5 | 430.5 | 65.0 | 456.7 | 415.6 | 790.7 |
| | 6 | 566.7 | 62.4 | 440.6 | 505.1 | 915.0 |
| | 12 | 388.0 | 84.2 | 662.8 | 271.8 | 695.2 |
| | 14 | 456.2 | 46.1 | 513.5 | 365.0 | 886.2 |
| | Avg. | 409.0 | 87.2 | 536.6 | 316.8 | 735.6 |

$^+$Includes SIP

consistant relationship between the quantity of available P and the quantity of resin-extractable P in these sediments. The reason for what appears to be erratic extraction which removes widely varying proportions of sediment P, might actually be more a result of poor recovery of P sorbed on resin after extraction for several reasons: (1) Poor recovery of P sorbed on resin by the HCl rinse, and/or (2) Poor recovery of the resin itself after extraction, since some resin did appear to pass through the 60 mesh sieve or become trapped in the sieve during separation of sediment and resin, and/or (3) High concentrations of precipitate are formed in the aliquot of HCl rinse taken for analysis when the pH is adjusted to 7 prior to addition of colorimetric reagent. The source of the precipitates are probably compounds or ions (i.e., $Al^{3+}$) removed from the resin by the acid. Although these precipitates redissolve when colorimetric reagents are added (pH dropped), an ionic chemical interference may be occurring. Although Huettl et al. (1979) reported a very good relationship between available P and resin-extractable P, the erratic results we obtained and potential for problems in the handling of the resin make the resin-extraction procedure (Huettl et al., 1979) a questionable choice for a routine estimator of available P.

The range in the average concentration of P extractable with NTA (+ soluble Pi) for the 4 sampling periods was between 428.0 and 735.6 µg/g (avg. = 540.5 µg/g). These concentrations represent 38 to 47% (avg. = 42.5%) of the sediment TP, which is a sizeable overestimation of measured available P (avg. = 30.3% of TP).

Linear regression was used to define statistical relationships between sediment available P measured in 2 day and 2 week incubations and chemically extractable P fractions. Linear regression correlation coefficients from such comparisons are presented in Table 4. A reasonably significant ($r$ = 0.75 and 0.77, respectively) relationship existed between $NH_4F$-extractable P (+ soluble Pi) and both 2 day and 2 week available P levels in stream sediments. Therefore, it appears that $NH_4F$ removes amounts of P similar to that removed by algae in 2 day incubation periods over the range of concentrations and sediments tested in this study, and even though $NH_4F$-extractable P underestimated 2 week available P, it appears that the quantity extracted by $NH_4F$ was linearly related to 2 week available P. Furthermore, even though averages presented earlier indicate a substantial relationship between quantities of Pi extracted by algae in 2 weeks and sequential $NH_4F$ and NaOH linear regression of values obtained for each site in 4 sampling periods showed only a mildly significant relationship. The relationship between Pi resulting from sequential $NH_4F$, NaOH, and HCl extraction was only a weakly significant one.

The sequential NaOH and HCl extraction performed prior to the 2 day incubation resulted in two high correlation coefficients in relation to 2 day available P. Both NaOH-extractable P and total sediment Pi resulted in correlation coefficients of 0.90 or greater, indicating that although both NaOH-extractable Pi and Pi overestimate available P, they are both linearly related to 2 day available P. Linear regression analysis of the same variables obtained initially in the 2 week incubations versus 2 week available P produced correlation coefficients greater than 0.9. The same conclusions may be drawn. Linear regression comparisons of NTA-extractable

Table 4. Relationships between available P measured by bioassay (2 day and 2 week incubation periods) and chemically extractable P initially present in stream sediments.

| Parameter | Incubation period | |
|---|---|---|
| | 2 day* | 2 week |
| | ------- r++ | -------- |
| Sequential $NH_4F$: | | |
| $NH_4F$-P + SIP+ | 0.75 | 0.77 |
| $NH_4F$-P + NaOH-P + SIP | 0.57 | 0.59 |
| Inorganic P | 0.52 | 0.61 |
| Sequential NaOH (2 day): | | |
| NaOH-P + SIP | 0.90 | -- |
| Inorganic P | 0.92 | -- |
| Sequential NaOH (2 week): | | |
| NaOH-P + SIP | -- | 0.91 |
| Inorganic P | -- | 0.94 |
| NTA: | | |
| NTA-P + SIP | 0.75 | 0.78 |
| Resin: | | |
| Resin-P + SIP | 0.52 | 0.59 |
| Total Sediment P | 0.83 | 0.80 |

*All correlations involving the available P levels obtained from 2 day incubations were calculated with the omission of the site 2 sample taken on 4/14.

+SIP = soluble inorganic P

++At the 0.1 confidence level a $r > 0.463$ indicates statistical significance.

P and 2 day and 2 week available P resulted correlation coefficients of 0.75 and 0.78 indicating that although NTA-extractable P overestimates available P, there appears to be a relatively consistant relationship. The low r values obtained in regressing resin-extractable P against 2 day and 2 week available P (r = 0.52 and 0.59, respectively) bear out conclusions drawn earlier concerning the use of the resin extraction in estimating available P. There appears to be direct relationship between the concentration of TP and available P as indicated by r values of 0.83 and 0.80 for 2 day and 2 week incubations, respectively.

## CONCLUSIONS

The following conclusions may be cited from the data collected during the course of this study:

1) Available sediment P as measured by incubation for 2 days with algae was ca. 41% of Pi and 25% of TP. The 2 day available P represents the amount of P which might become immediately available upon entering the receiving body of water if conditions are optimum for the growth of algae.

2) Most (87%) of maximum, potentially available sediment P became available within the first 2 days of incubation.

3) Maximum available sediment P was measured in sediments incubated for 2 weeks with algae and amounted to 50% of Pi and 30% of TP.

4) Of the extractants tested, $NH_4F$ extraction of sediment best simulated the quantity of Pi removed by algae during the 2 day incubations. Therefore, it appears that a single $NH_4F$ extraction of sediment could be used to estimate immediately available sediment P.

5) Sequential $NH_4F$ and NaOH was, in turn, a good estimator of the total, potentially available sediment P.

6) The single NaOH-extractable fraction, a triple NTA-extractable fraction, inorganic P, and TP all contain levels of P which are linearly related to 2 day and 2 week available P.

LITERATURE CITED

1. Allan, R. J. and J. D. H. Williams. 1978. Trophic status related to sediment chemistry of Canadian prairie lakes. J. Environ. Qual. 7:99-106.

2. Armstrong, D. E., J. J. Perry, and D. E. Flatness. 1979. Availability of pollutants associated with suspended or settled river sediments which gain access to the Great Lakes. Great Lake National Program Office, U.S. Environmental Protection Agency. Chicago, Illinois. EPA-905/4-79-028. 106 p.

3. Bartsch, A. F. 1972. Role of phosphorus in eutrophication. U.S. Environmental Protection Agency, Office of Research and Monitoring. Washington, D.C. EPA-R3-72-001. 45 p.

4. Burns, N. M. and C. Ross. 1972a. Project Hypo - an introduction p. 1 In. N. M. Burns, C. Ross (Eds.). Project Hypo...An intensive study of the Lake Erie Central Basin hypolimnion and related surface water phenomena. Canada Centre for Inland Waters (Paper No. 6). Burlington, Ontario and U.S. Environmental Protection Agency, Region V. (Technical Report TS-OS-71-208-24). 182 p.

5. Burns, N. M. and C. Ross. 1972b. Project Hypo - discussion of findings p. 124, In. N. M. Burns, C. Ross (Eds.) Project Hypo--- An intensive study of the Lake Erie Central Basin hypolimnion and related surface water phenomena. Canada Centre for Inland Waters (Paper No. 6). Burlington, Ontario and U.S. Environmental Protection Agency, Region V. (Technical Report TS-OS-71-208-24). 182 p.

6. Burns, N. M. and C. Ross. 1972c. Oxygen-Nutrient relationships within the central basin of Lake Erie p. 118. In. N. M. Burns, C. Ross (Eds.) Project Hypo...An intensive study of the Lake Erie Central Basin hypolimnion and related surface water phenomena. Canada Centre for Inland Waters (Paper No. 6). Burlington, Ontario and U.S. Environmental Protection Agency, Region V. (Technical Report TS-OS-71-208-24). 182 p.

7. Cowen, W. F. and G. F. Lee. 1976. Phosphorus availability in particulate materials transported by urban runoff. J. Water Pollut. Control Fed. 48:580-591.

8. Cowen, W. F. and G. F. Lee. 1976b. Algal nutrient availability and limitation in Lake Ontario during IFGYL. Part 1. Office of Research and Development, U.S. Environmental Protection Agency. Duluth, Minnesota. EPA-600/3-76-094a. 218 p.

9. Davis, C. C. 1964. Evidence for the eutrophication of Lake Erie from phytoplankton records. Limnol. Oceanog. 9:275-283.

10. Dobson, H. H. and M. Gilbertson. 1972. Oxygen depletion in the hypolimnion of the central basin of Lake Erie, 1929 to 1970. p. 6. In N. M. Burns and C. Ross (Eds.) Project Hypo...An intensive study of the Lake Erie Central Basin hypolimnion and related surface water phenomena. Canada Centre for Inland Waters (Paper No. 6), Burlington, Ontario and U.S. Environmental Protection Agency Region V. (Technical Report, TS-05-71-208-24). 182 p.

11. Dorich, R. A., D. W. Nelson and L. E. Sommers. 1980. Algal availability of sediment phosphorus in drainage water of the Black Creek watershed. J. Environ. Qual. 9:557-563.

12. Fekete, A., D. N. Riemer, and H. L. Motto. 1976. A bioassay to evaluate the release of available phosphorus from pond sediments. Journal of Aquatic Plant Management. 14:19-25.

13. Fellos, J. and W. R. Swanson. 1975. The release rate of nutrients from river and lake sediments. J. Water Pollut. Control. Fed. 47: 1032-1042.

14. Fitzgerald, G. P. and T. C. Nelson. 1966. Extractive and enzymatic analyses for limiting or surplus phosphorus in algae. J. Phycol. 2:32-37.

15. Fitzgerald, G. P. 1970. Aerobic lake muds for the removal of phosphorus from lake waters. Limnol. Oceanog. 15:551-555.

16. Gerloff, G. C. and F. Skoog. 1954. Cell contents of nitrogen and phosphorus as a measure of their availability for growth of Microcystis aerugenosa. Ecology 35:348-353.

17. Gilbertson, M., H. H. Dobson and T. R. Lee. 1972. Phosphorus and hypolimnial dissolved oxygen in Lake Erie. In. N. M. Burns, C. Ross (Eds.). Project Hypo...An intensive study of the Lake Erie Central Basin hypolimnion and related surface water phenomena. Canada Centre for Inland Waters (Paper No. 6). Burlington, Ontario and U.S. Environmental Protection Agency, Region V. (Technical Report TS-05-71-208-24). 182 p.

18. Golterman, H. L. 1976. Sediments as a source of phosphorus for algal growth. In, H. L. Golterman (Ed.). Interactions between sediments and freshwater. Proc. 51L-UNESCO Conf. Junk and Pudoc, The Hague, Netherlands.

19. Huettl, P. J., R. C. Wendt, and R. B. Corey. 1979. Prediction of algal-available phosphorus in runoff suspensions. J. Environ. Qual. 8:130-132.

20. International Joint Commission. 1980. Pollution in the Great Lakes Basin from land use activities. International Joint Commission, Great Lakes Regional Office. Windsor, Ontario. 141 p.

21. Jackson, M. L. 1958. Soil Chemical Analysis. First course. Prentice-Hall, Inc. Sixth printing. 1970, by the author, Dept. of Soil Sci., Univ. of Wisconsin. Madison, WI 498 p.

22. Li, W. C., D. E. Armstrong, J. D. H. Williams, R. F. Harris, and J. K. Syers. 1972. Rate and extent of inorganic phosphate exchange in lake sediments. Soil Sci. Soc. Amer. Proc. 36:279-285.

23. Logan, T. J., F. H. Verhoff, and J. V. Depinto. 1979. Biological availability of total phosphorus. Lake Erie Wastewater Management Study. U.S. Army Engineer District, Buffalo, NY. 62 p.

24. McCallister, D. L. and T. J. Logan. 1979. Phosphate adsorption-desorption characteristics of soils and bottom sediments in the Maumee River basin of Ohio. J. Environ. Qual. 7:87-92.

25. Miller, W. E., J. C. Greene, and T. Shiroyama. 1978. The Selanastrum capricornutum Printz algal assay bottle test. Office of Research and Development, U.S. Environmental Protection Agency, Corvallis, Oregon. EPA-600/9-78-018. 126 p.

26. Moshiri, G. A. and W. C. Crumpton. 1978. Certain mechanisms affecting water column-to-sediment phosphate exchange in a bayou estuary. J. Water Pollut. Control Fed. 51:392-394.

27. Murphy, J. and J. R. Riley. 1962. A modified single solution procedure for determination of phosphate in natural waters. Anal. Chem. Acta. 27:31-36.

28. Nnadi, L. A., M. A. Tabatabai, and J. J. Hanway. 1975. Determination of phosphate extracted from soils by EDTA and NTA. Soil Sci. 119: 203-209.

29. Oloya, T. O. and T. J. Logan. 1980. Phosphate desorption from soils and sediments with varying levels of extractable phosphate. J. Environ. Qual. 9:526-531.

30. Porcella, D. B., S. K. Kumazar, and E. J. Middlebrooks. 1970. Biological effects on sediment-water nutrient interchange. J. Sanitary Eng. Div., Am. Soc. Chem. Eng. 96:911-926.

31. Ryden, J. C., J. K. Syers, and R. F. Harris. 1973. Phosphorus in runoff and stream. Adv. Agron. 25:1-45.

32. Sagher, A., R. Harris, and D. A. Armstrong. 1975. Availability of sediment phosphorus to microorganisms. Water Resource Center, University of Wisconsin, Madison, WI. Wis WRC 75-01. 56 p.

33. Sommers, L. E., and D. W. Nelson. 1972. Determination of total phosphorus in soils: A rapid perchloric acid digestion procedure Soil Sci. Amer. Proc. 36:902-904.

34. Syers, J. K., R. F. Harris, and D. E. Armstrong. 1973. Phosphate chemistry in lake sediments. J. Environ. Qual. 2:1-13.

35. Verhoff, F. H., M. Heffner, and W. A. Sack. 1978. Measurement of availability rate for total phosphorus from river waters. LEWMS. U.S. Army Corps of Engineers, Buffalo District. Buffalo, NY. 32 p.

36. Vollenweider, R. A. 1968. Scientific fundamentals of eutrophication of lakes and flowing waters with particular reference to nitrogen and phosphorus as factors in eutrophication. Organization for Economic Cooperation and Development, Paris. Report DAS/CSI/68.27. 159 p.

37. Wentz, D. A. and G. F. Lee. 1969a. Sedimentary phosphorus in lake cores-analytical procedure. Environ. Sci. Tech. 3:750-754.

38. Wentz, D. A. and G. F. Lee. 1969b. Sedimentary phosphorus in lake cores-observations on depositional pattern in Lake Mendota. Environ. Sci. Tech. 8:754-759.

39. Wildung, R. E. and R. L. Schmidt. 1973. Phosphorus release from lake sediments. Office of Research and Monitoring, U.S. EPA. Washington, D.C. EPA-R3-73-04. 185 p.

40. Williams, J. D. H., T. P. Murphy, and T. Mayer. 1976. Rates of accumulation of phosphorus forms in Lake Erie sediments. J. Fish. Res. Board Can. 33:430-439.

41. Williams, J. D. H., H. Shear, and R. L. Thomas. 1980. Availability to Scenedesmus quadricauda of different forms of phosphorus in sedimentary materials from the Great Lakes. Limnol. Oceanog. 25:1-11.

# ACCOUNTING FOR NITROGEN DISPOSITION WITHIN A WATERSHED

R.F. Davila
L.F. Huggins
D.W. Nelson

The adaptability of existing nitrogen cycle models to be used in conjunction with the ANSWERS watershed simulation model to directly evaluate the fate of this agricultural nutrient was investigated. Field data for several of the processes in the nitrogen cycle were collected from three of the Black Creek subwatersheds and used to evaluate the accuracy of the selected nitrogen model.

## 1. Introduction

The availability of nitrogen is of prime importance to growing plants, since they are dependent on an adequate supply of nitrate and ammonium for synthesis of their nitrogenous constituents. When plant and animal residues are added to the soil, the nitrogen containing compounds in these residues undergo numerous transformations. Some of these work in opposite direction; the net result being that not all of the total nitrogen is in an available form at any one time.

Nitrogen in the soil exists in organic and inorganic forms. The inorganic fraction is the one used by plants. Inorganic nitrogen rarely exceeds 2 to 3 percent of the total soil nitrogen (Bear, 1964). Transformations from one form to the other occur continuously as a result of biochemical reactions. Fertilizers are added to supplement the nitrogen in the soil, especially when the rate of conversion of organic to inorganic nitrogen is not great enough to satisfy plant needs. Figure 1 is a diagram of the inputs, outputs and losses of nitrogen in the soil-plant system.

As seen in the figure, sources of nitrogen are: fertilizers, fixation of atmospheric nitrogen, precipitation and residues. The organic nitrogen is mainly the result of manure and plant residues. Nitrogen not used by plants is lost; the principal losses being denitrification, ammonia volatilization and leaching of nitrate. Additionally, considerable losses of nitrogen may result from runoff.

Probably the most undesirable losses of nitrogen result from runoff and leaching. These not only represent an economic loss, since the nitrogen is never used by plants, but also create a pollution problem in the receiving waters.

A lot is known about nitrogen in the soil, water and atmosphere (Porter, 1975; Bartholomew et al.,1965; Nielsen et al., 1978). However, this body of knowledge has been concentrated on individual processes. During the last few years these processes have been studied together and the system has been looked at as a whole rather than by parts (Endelman et al., 1972).

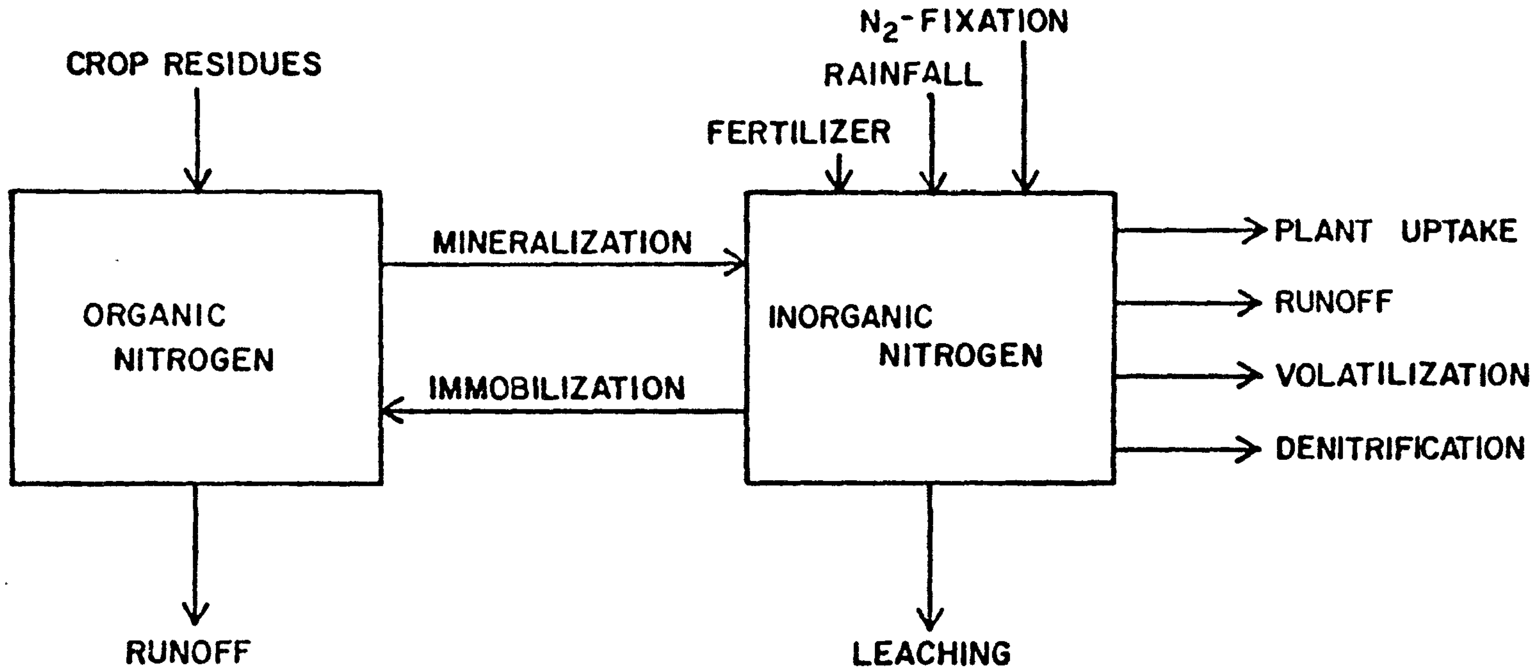



Figure 1. Inputs, Outputs and Losses of Nitrogen in the Soil-Plant System

## 1.1 Fertilizer

Fertilizer is by far the largest of the nitrogen inputs to the soil-plant system. It may be added in the ammonia, ammonium, nitrate or urea form. Ammonia and urea react with water to form ammonium which, under aerobic conditions, is oxidized to nitrate which is one of the forms of nitrogen used by plants.

Due to the inconvenience of applying fertilizer on a grown crop, it has traditionally been applied all at once in an early stage of growth. Of the fertilizer applied this way, less than 50% is assimilated by the crop. The rest is lost through various transport mechanisms (Harmsen et al., 1965). This problem has been addressed by researchers in trying to develop slow release fertilizers (Gould et al., 1978). Although some products are commercially available, the technology has not been completely developed yet. Essentially, these products prevent nitrification from occurring all at once.

## 1.2 Precipitation

The quantity of nitrogen added to the soil in rain and snow depends on location. Extreme values have been reported between 1.8 and 22.3 kg of inorganic nitrogen per hectare per year (Allison, 1965). In rural areas the values will be closer to the lower end. Most of the nitrogen contributed by rain is in the inorganic form.

Acid rainfall refers to rainfall produced by absorption of oxidized sulfur and nitrogen compounds by moisture in the air. The resulting rainfall is a weak acid. In a study conducted over the Great Lakes by the PLUARG group it was reported that acid precipitation had no measurable effect at the time of the study except in two isolated embayments over the area covered by the study (PLUARG Study, 1978).

Measurements in the Black Creek Watershed show the amount of ammonium and nitrate in rainwater to be 0.46 to 0.59 mg/l (3.72 to 4.77 kg/ha/yr) respectively (EPA-905/9-77-007-B).

## 1.3 Nitrogen Fixation

Fixation is the biological transformation of nitrogen gas from the atmosphere to organic forms. Historically, leguminous crops such as alfalfa are known for their ability to synthesize their own nitrogen fertilizers. Purdue researchers estimate tha 70,000 kg of nitrogen were fixed annually within the Black Creek watershed during 1976 and 1977 by soybeans and forage legumes (EPA-905/9-7-007-B). A complete discussion of bacterial nitrogen fixation is available from Nutman (1965).

## 1.4 Crop Uptake

Crop uptake is the principal mechanism by which nitrogen is removed from the soil. Each kind of crop and soil situation results in a unique removal pattern. Estimates indicate that, on the average, 50% of the applied nitrogen fertilizer is used by plants (Harmsen et al., 1965).

Most of the nitrogen absorbed by plants is in the nitrate form. Applied nitrogen, if not in the nitrate form, is transformed to it and is made available for uptake by plants. Generally, fertilizers are applied at one time early in the cropping period and are made available to plants within the next few days after application; at this time the mineralization rate is the fastest. Depending on the crop's demand at this particular time, part of the nitrate will be absorbed; the rest will either be stored as nitrate or in some other form or lost.

Besides being dependent on the particular crop, the amount of nitrogen uptake will also depend on environmental factors such as temperature, pH, moisture and aeration. Much work have been done in this area (Hargrove et al., 1979; Terman and Allen, 1978; Shumway and Atkinson, 1978) in order to optimize fertilizer applications, but crop uptake is hard to predict and most recommendations are based upon practical knowledge of the area rather than on theoretical reasoning.

In Indiana, a corn crop is expected to utilize from 136 to 269 kgs. of nitrogen per hectare, depending on the yield. Wheat is expected to uptake from 79 to 209 kgs. per hectare (Extension Service, Purdue University #PIH-25).

## 1.5 Runoff

One of the most undesirable losses of nitrogen is in runoff. Highly soluble nitrate as well as ammonium and organic forms are all removed by water flowing over the soil. Studies have shown that reduction in rainfall amount reduces runoff which in turn reduces nutrient losses (Black Creek Study, 1977). The amount of the loss is dependent on land use, conservation practices and season of the year.

Allison (1965) cites Lipman and Conybeare with an average of 27.2 kgs. per hectare per year of nitrogen lost by erosion from cropland in the United States. An additional problem with nitrogen, besides the high solubility of nitrate, is that rain may float organic matter present in the soil and the nitrogen content of this organic matter lost may be higher than what is left behind.

## 1.6 Gaseous Losses

Gaseous nitrogen losses from the soil may occur as ammonia, elemental nitrogen, oxides of nitrogen and by plants as organic compounds. Of these forms, ammonia is by far the most severe. Under natural conditions, ammonia does not occur in great quantities in the soil; however, under certain conditions ammonia which escapes to the atmosphere can be produced in significant amounts. Ammonia production is favored by high temperature and high pH values. Two conditions under which ammonia could be produced in considerable quantities are application of urea and of manure to a field.

Denitrification is the process by which nitrate is microbially reduced to elemental nitrogen and to nitrous oxide. From the standpoint of the microbial population, denitrifing microorganisms compete for nitrate with plants (Smith, 1979). The gaseous products of denitrification are volatilized, hence lost from the soil. Denitrification is affected by environmental factors. It has been reported that denitrification is affected by excessive moisture; a critical level being 60% of the water holding capacity of the soil (Allison, 1965). Under moisture conditions which favor denitrification, the limiting factor is the amount of organic material percent. Denitrification losses are favored in an anaerobic soil environment, i.e. waterlogged soils.

### 1.7 Mineralization and Immobilization of Nitrogen

A large portion of the soil nitrogenous material is in organic form. In order for this material to be used by plants it must be mineralized to ammonia or nitrate (inorganic forms). These inorganic forms of nitrogen, besides being used by plants, are subject to leaching and volatilization. In order to keep the soil reserves of nitrogen from being depleted, at the same time that the organic fraction is being mineralized, the inorganic fraction is immobilized; the inorganic nitrogen not used or lost is returned to the organic form.

The reate of these two opposing processes, besides being controlled by the total nitrogen status of the soil and the inorganic nutrient supply, is also dependent on a number of environmental factors such as moisture, pH, aeration and temperature. The carbon:nitrogen ratio of added organic residues also affects mineralization and immobilization. Usually the term mineralization implies net mineralization. Optimum moisture for mineralization is between 50 and 75% of saturation (Beas, 1964). In waterlogged soils, aeration is reduced and soils tend to go anaerobic; under anaerobic conditions immobilization does not occur and net mineralization is highly positive.

Temperatures most suitable for mineralization have been reported at about 35 degrees C (Nielsen and McDonald, 1978). When temperatures drop to freezing, mineralization stops (Endelman et al., 1972). Mineralization is also favored by pH near neutral. The carbon:nitrogen ratio of organic matter in the soil has also been used as a criteria for mineralization. This criteria is usef\ul in cases when crop residues or manure are added to the soil. The C:N ratio of stable soil organic matter is about 10:1. It has been reported that, as a general rule, when residues yielding a C:N ratio greater than 30 is added to the soil, immobilization is favored in the initial stage of the decomposition process (Gilliam et al., 1978). If the C:N ratio is less than 20, mineralization is favored. For values between 20 and 30 there may be immobilization or mineralization.

## 2. Model Description

The soil-plant-nitrogen system is a complex one. As previously mentioned, knowledge about individual processes making up the system were not integrated until recently. It wasn't until the last few years that the system has been simulated as a whole.

ANSWERS is an event-oriented simulation model. That is, it simulates dynamic watershed processes occurring during and immediately following a storm event. In order to incorporate nitrogen transport into its computations, the antecedent levels of the various nitrogen forms must be specified. Thus, the search for a suitable existing nitrogen model was concerned with finding one which would simulate long-term seasonal trends of each nitrogen form throughout a watershed. The output of such a model could then serve to define antecedent values for subsequent ANSWERS storm simulations.

After reviewing several models (Davila, 1980), the model developed by Mehran and Tanji (1974) was selected. This model ties a long-term hydrologic submodel to a nitrogen transport submodel to provide the moisture gradient for nitrogen transformations. The model is based on mass balance and steady state conditions. First order kinetics are assumed for the nitrogen transformations. In its most recent version, the model includes a storage term which makes it suitable to simulate sites in which permeability is low (Tanji et al, 1979).

The latest published version of the Mehran-Tanji model assumes that effective precipitation (actual precipitation - runoff losses) not lost through evapotranspiration is lost through leaching; hence, no moisture accumulation terms are included. For this study, the model was subsequently modified to include a water accumulation term. The other major modification made to the published version of the model was to reduce its time scale from an annual to a monthly basis.

The nitrogen transport submodel is also based on the principle of mass balance. This submodel uses flows predicted by the water submodel as a gradient for nitrogen movement. Nitrogen transformations are assumed to follow first order kinetics. In reducing the time scale from yearly to monthly, nitrogen transformations were neglected in the months of November, December, January and February. The nitrogen submodel includes a nitrogen storage term to account for organic nitrogen not mineralized and inorganic nitrogen not taken up by the crop or demineralized.

The plant uptake component has been rearranged so that instead of supplying an annual value, plant uptake is calculated from the percentage of total nitrogen uptake and the available nitrogen in the soil on a monthly basis. Neither nitrogen gaseous losses of fertilizer nor losses due to nitrogen carried in runoff were independently included in the model. Some of these losses are implicit in the "denitrification and other losses coefficient".

The depth of soil used through this study has been one meter. The model considers this one meter depth as a unit volume on a per hectare basis. The mass balance takes place in this unit volume. Nitrogen processes simulated are assumed to take place uniformly within this unit volume. Leaching concentrations predicted represent concentrations just below the one meter depth. Remaining nitrogen concentrations represent the average nitrogen concentration in the first meter of soil (surface to depth one meter) at the end of the month. After the leaching component is calculated, the flows are divided into interflow and deep percolation. In a field with a subsurface drainage system, interflow represents expected effluent from the tile system. Deep percolation represents flows to the water table. Schematic descriptions of the water and nitrogen submodels are given in Figures 2 and 3.

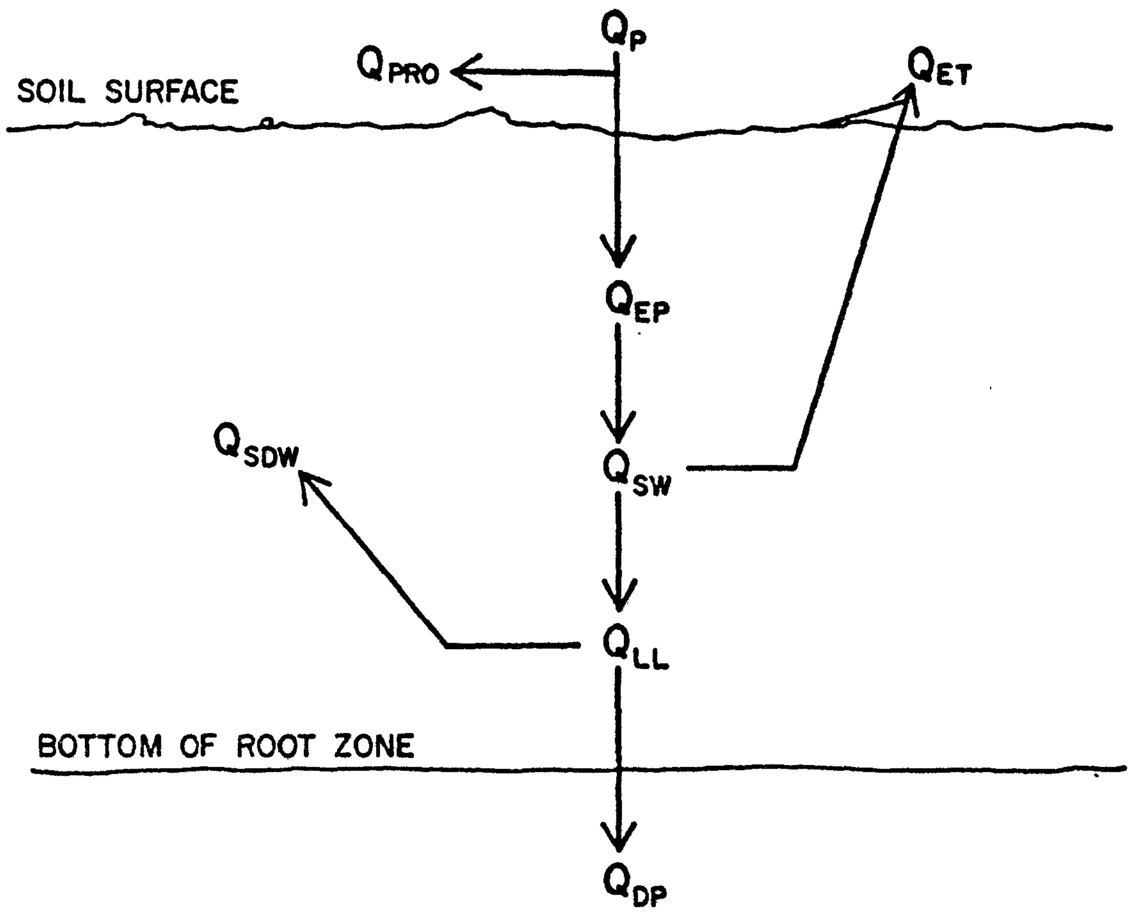



Figure 2. Schematic Description of Water Submodel

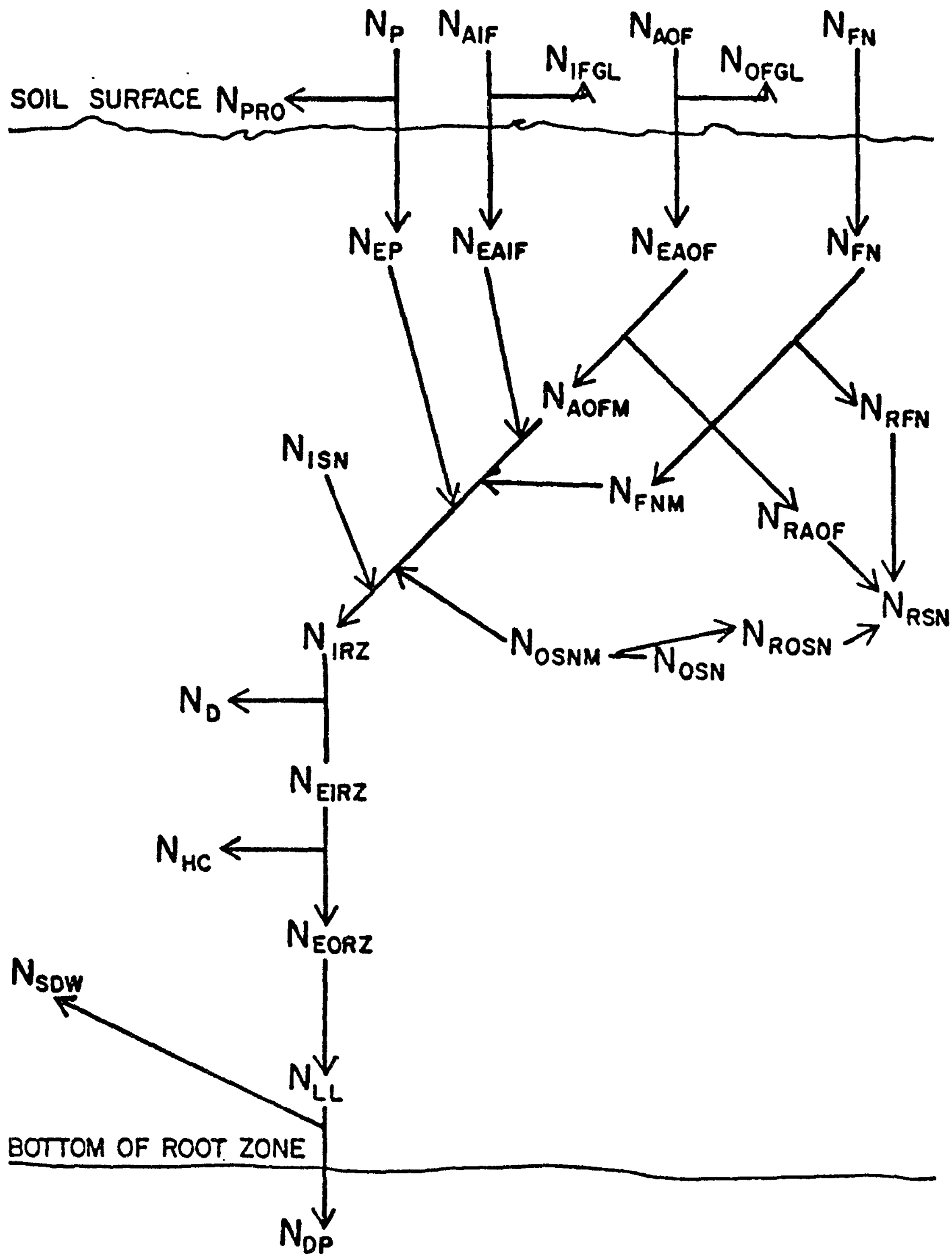



Figure 3. Schematic Description of Nitrogen Submodel

3. Field Investigation

Soil samples, approximately 500 gms. wet basis, were collected using a hand sampler from the surface at 33 centimeters intervals to 1 meter of depth from each of the three subwatersheds studies. Where row crops were present, sites 51 and 55, three cores were taken at each sample location: one in the row and the other two to each side of the row. The side cores were sampled at the surface, 33 cm. and 66 cm., but not at 1 meter. In places where row crops were not present three cores were also taken, but the side cores were taken about 66 centimeters from the center core, at depths up to 66 centimeters.

Instead of designing a grid system for sample locations, which would have made the number of samples extremely large, an S pattern was followed on each site and sample locations were chosen arbitrarily within the S pattern. This system kept the number of samples reasonable and at the same time gave an acceptable representation of the site. The number of locations within a site varied from 9 (site 20) to 11 (site 51). Figure 4 shows this methodology.

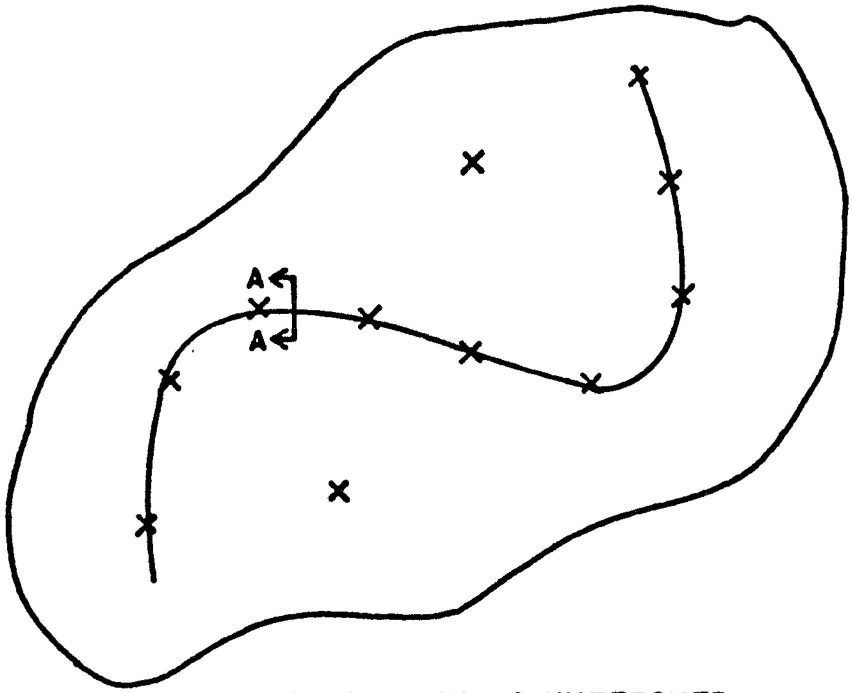
The samples were collected in paper bags in the field. In the laboratory each sample was divided into two parts, one part was frozen and the other was air dried. The samples to be frozen were put in plastic bags. After being air dried, the second part was also kept in plastic bags until ready to be analyzed. Sampling was done in June, August and October of 1979. Sample locations were measured so that sampling could be done in the same place at a later date.

Analyses performed on the samples were: net mineralization rate, ammonium content and nitrate content. The first was done on the frozen samples and the last two on the air dried samples. Mineralization rate tests were done using the aerobic method proposed by Bremner (Methods of Soil Analysis, Part II, 1965). The freezing of the samples was used to stop mineralization until the samples were ready to be analysed as discussed by Gasser (1958). Ammonium and nitrate were determined using the steam distillation method (Methods of Soil Analysis, Part II, 1965).

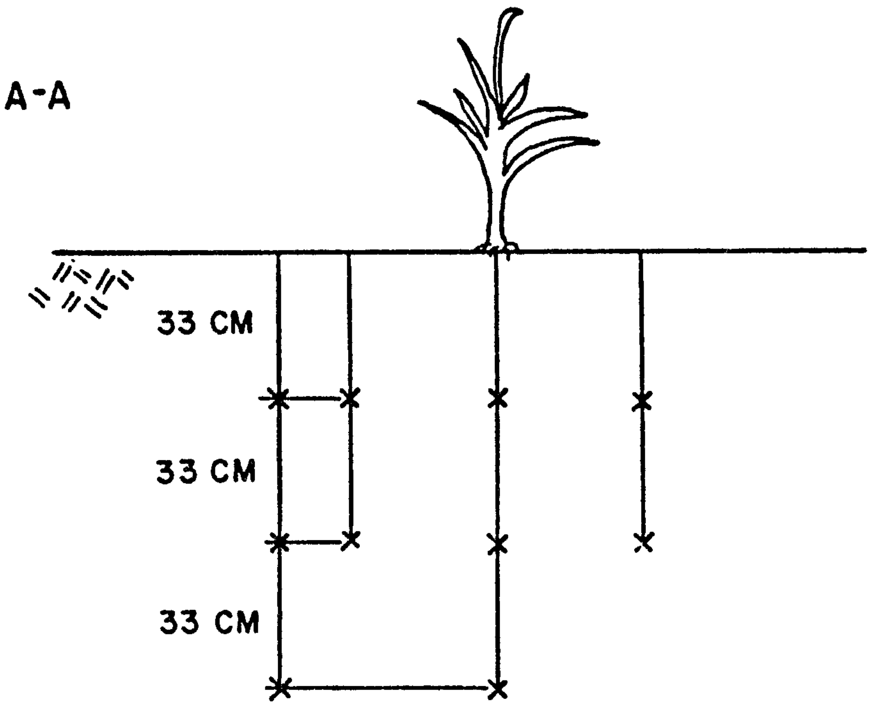
Figures 5 to 7 show the inorganic nitrogen content of the soil vs time for the three sites studied at the four levels measured. The farming operation is also given in the top portion of each figure. The time scale for the farming operation is the same as for the inorganic nitrogen content. Inorganic nitrogen is the sum of ammonium and nitrate measured. The values presented are average values. The samples at each location within each site were composited before analysis.

From these three figures the following general observations are obtained: inorganic nitrogen content decreases with depth, inorganic nitrogen depletion is slow when the crop is just planted and is faster when the crop gets closer to maturity.

The data for site 20, depicted in Figure 5 shows the inorganic nitrogen content decreasing with depth for samples taken in June and November. Samples taken in August show the amount of inorganic nitrogen higher in the second level than in the first. A reason for this might be the fact that samples were taken from a field which had been harvested and the sampling was done




LAYOUT OF SAMPLING POINTS WITHIN A WATERSHED




SAMPLES TAKEN AT EACH SAMPLING POINT

Figure 4. Sampling Methodology

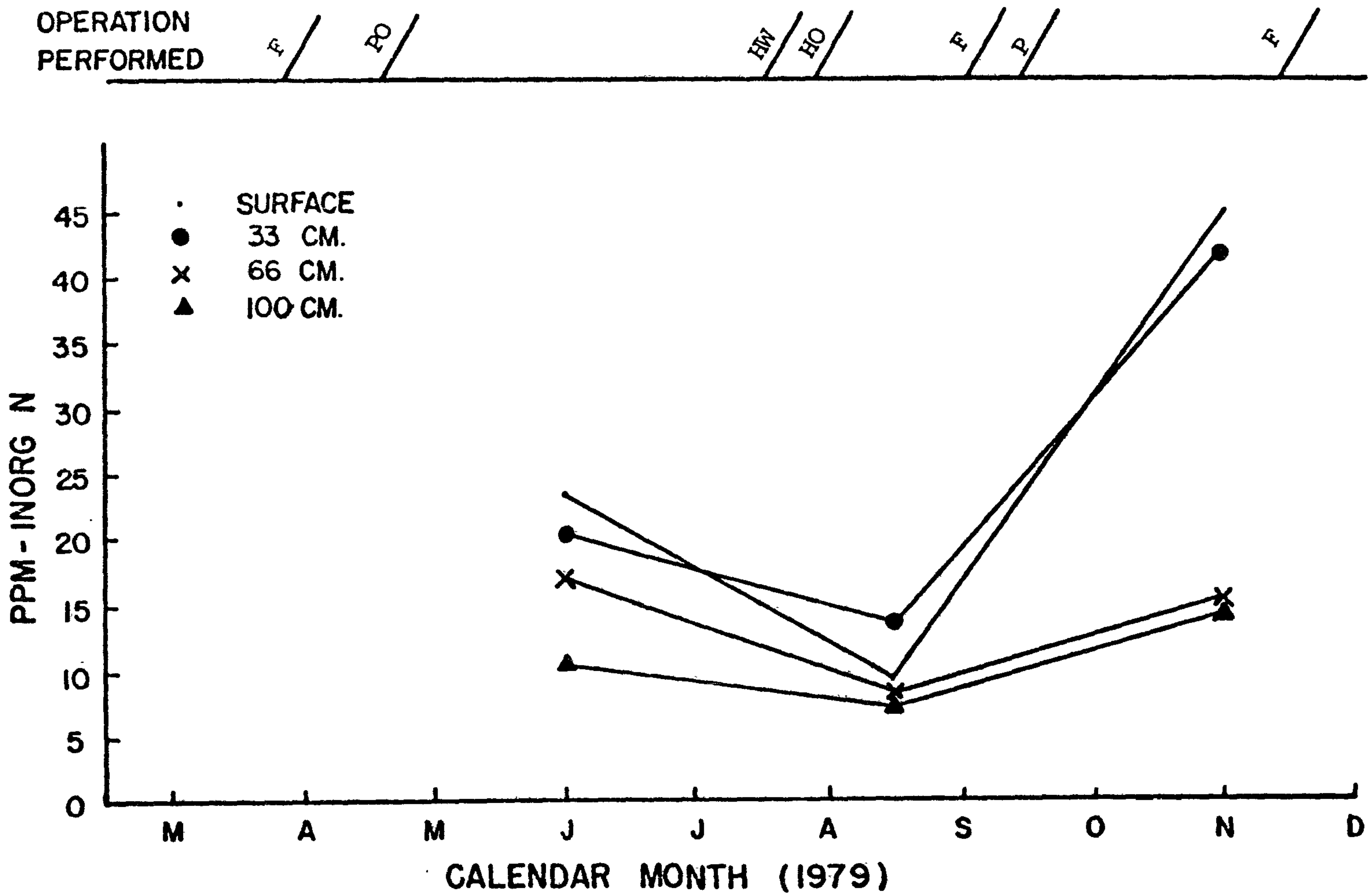



Figure 5. Soil Inorganic Nitrogen Content vs. Calendar Month for Site 20

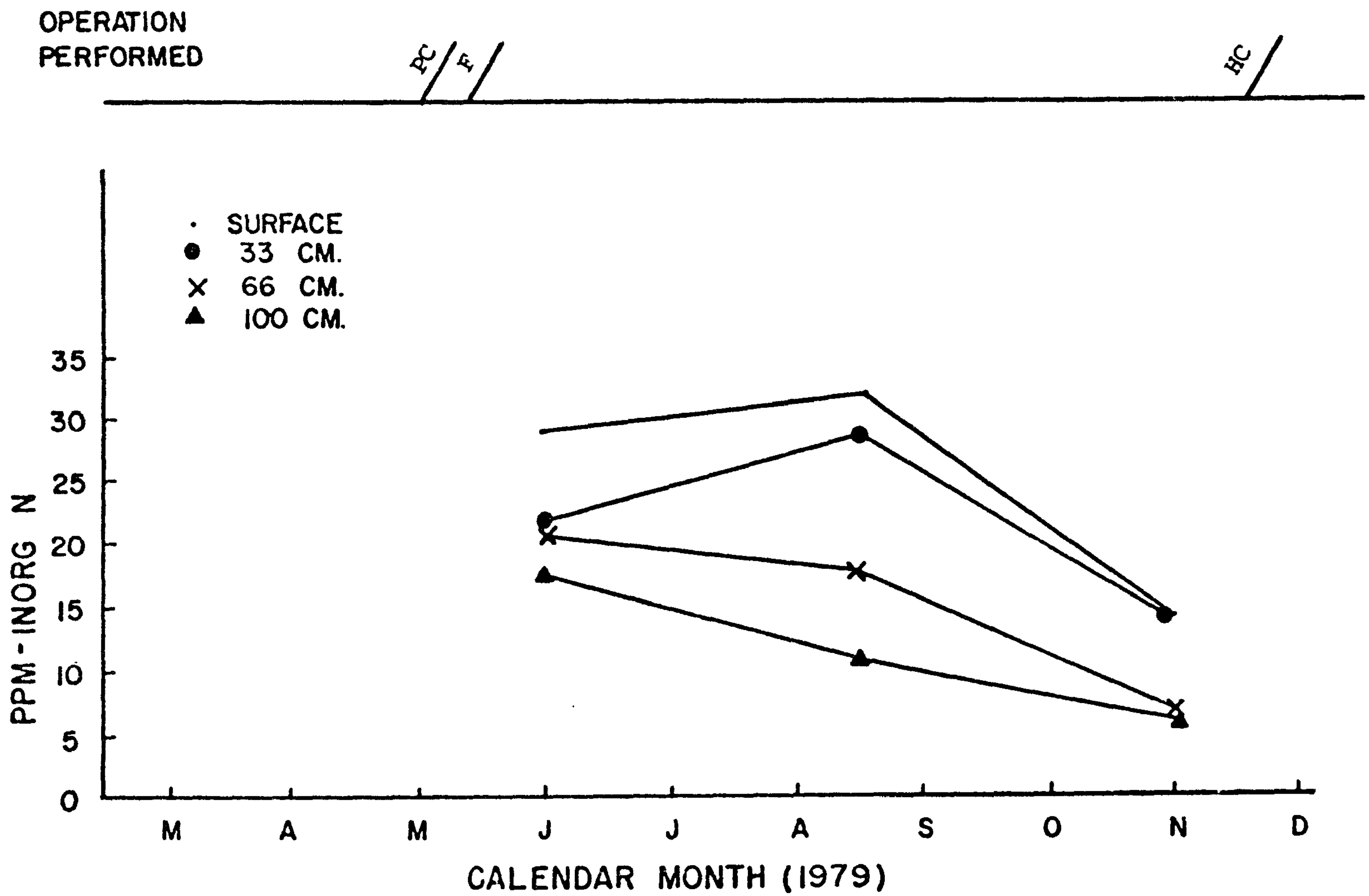



Figure 6. Soil Inorganic Nitrogen Content vs. Calendar Month for Site 51

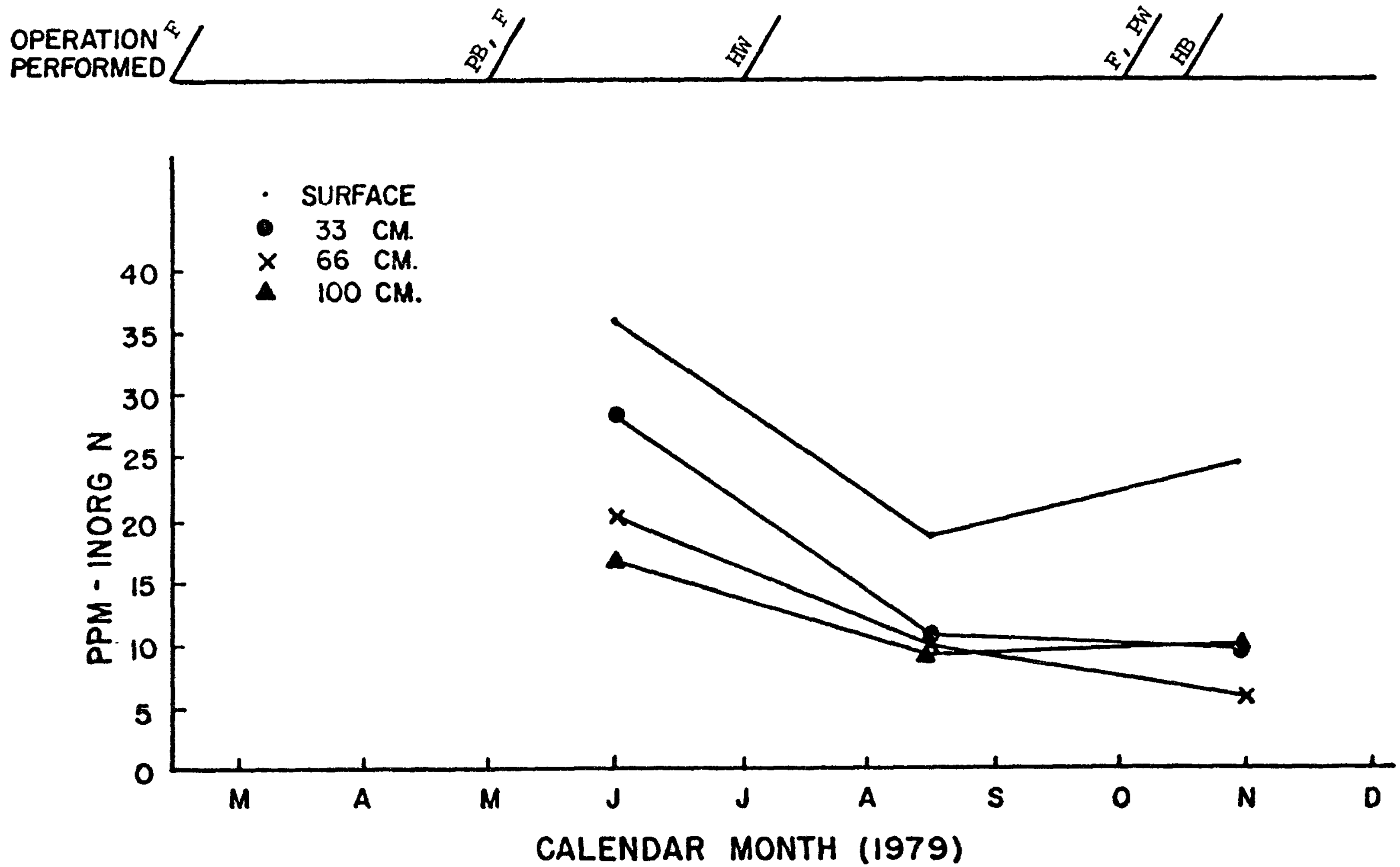



Figure 7. Soil Inorganic Nitrogen vs. Calendar Month for Site 55

during the period of highest precipitation in the year. During this period surface loses of nutrients are expected to be the higher.

Samples taken at site 20 in November also show a considerably higher inorganic nitrogen content than in the previous sampling. This is understandable since the field had been fertilized in early September and no crops; were planted; therefore, depletion was minimal during the period since the previous sampling.

At site 51, data shown in Figure 6, the inorganic nitrogen content decreases with depth during the first and second samplings and in the last sampling the results for the first and second level are the same. At this site fertilization was done in the first part of May. At this time the crop was in its early stage and the depletion during the subsequent period until the next sampling was not as fast as the inputs to the inorganic nitrogen pool, thus leading to higher inorganic nitrogen values in the second sampling. As the crop matured the nitrogen requirements increased and the inorganic nitrogen pool was depleted, as seen in the results for November.

At site 55, Figure 7, the same general trend is followed in the first and second samplings, but in November inorganic nitrogen in the fourth level is higher than expected although very close to the values for the second and third levels.

Figure 8 is a plot of net mineralization rate vs depth for the three sites studied. The results shown are averages for the field and the three measurements done during the growing season. Normally mineralization will be expected to decrease with depth in a field of uniform permeability characteristics.

The soil at site 20 is a deep soil of low permeability decreasing with depth. The top layer, the layer of cultivation, is more permeable. As a result of this permeability, mineralization in the second level is higher than in the first, although subsequent levels follow the expected decrease with depth.

Mineralization rate at site 51 decreases with depth as expected. At site 55 the pattern is as expected until the third level where it is slightly higher. This variation in the third level amounts to 0.050 ppm/day more than in the second level.

Table 1 shows organic-N and mineralization rate data for three sites. Data used to generate the optimun N mineralized is included in appendix B. The soil bulk density used was 1.5 gms/$cm^3$. The organic nitrogen concentrations were measured in the top 33 cm. Optimum mineralization rate constants (K) were calculated assuming a first order decay rate.

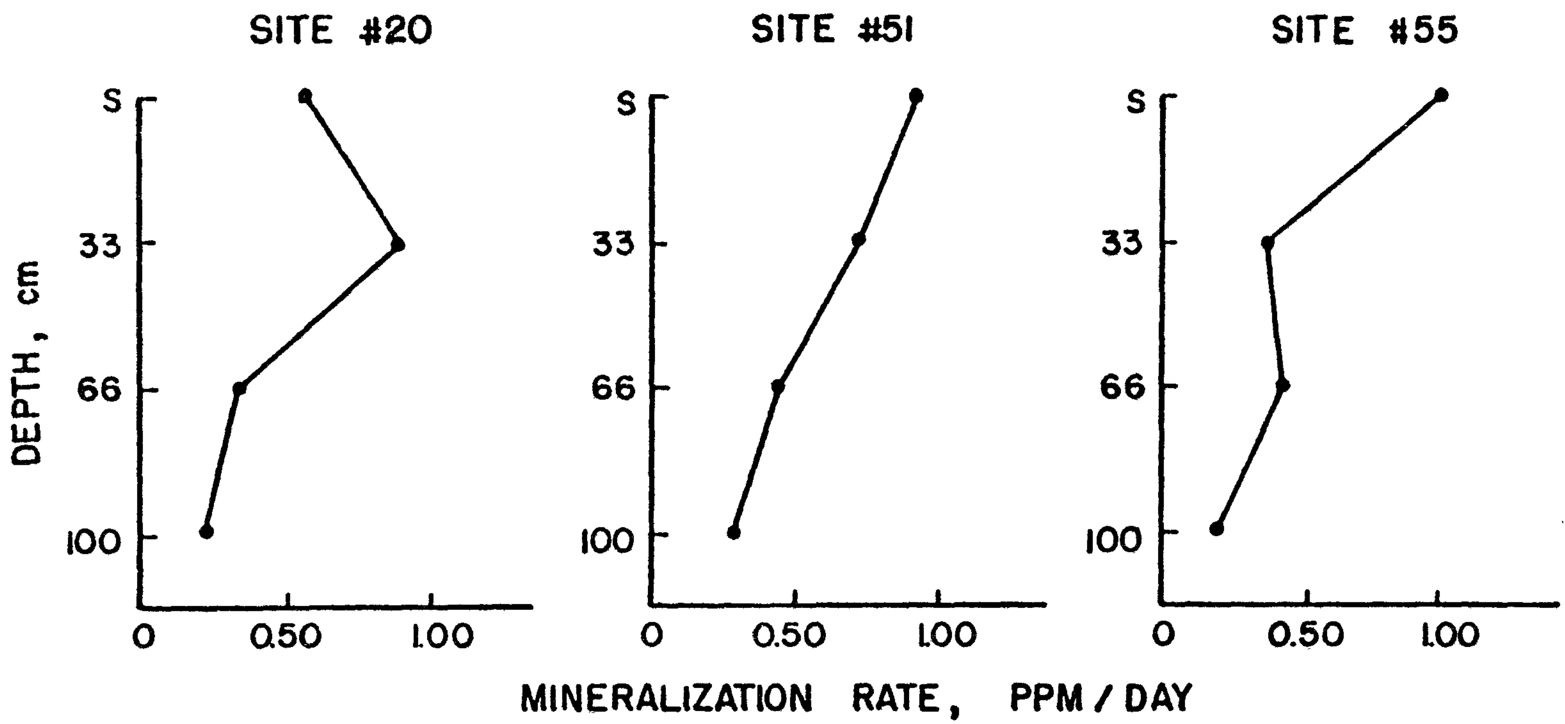



Figure 8. Net Mineralization Rate vs. Depth.

Table 1. Mineralization Rate Data

| | Site 20 | Site 51 | Site 55 |
|---|---|---|---|
| Organic-N conc. (0-33 cm), μg/g | 2095 | 1033 | 1677 |
| Organic-N in profile, kg/ha | 10470 | 5165 | 8385 |
| Optimum N mineralized, μg/g/day | 0.29 | 0.32 | 0.36 |
| Optimum K, weeks$^{-1}$ | $9.7\times10^{-4}$ | $2.17\times10^{-3}$ | $1.48\times10^{-3}$ |

In theory, a first order decay rate is expected for most nitrogen transformations; the decay constant can be expected to change through the year. In order to fully characterize this first order decay with a sampling procedure like the one used in this study, the time between samplings needs to be greatly reduced. In a laboratory type situation in which the nitrogen inputs could be controlled in experimental plots and the number of samplings during the growing season increased, this decay could be observed.

## 4. Model Testing

A discussion of all model evaluations completed is available elsewhere (Davila, 1980). Results from final tests are given in Tables 2 to 4. The measured inorganic nitrogen content in the soil is compared to simulation results.

At site 20, predicted and observed inorganic nitrogen agreed within 20% in July and September. In May there is considerable difference between observed and predicted data. Leaching losses took place at site 20 in March and April. In March and April the soil water capacity was exceeded causing leaching. The amount of leaching depends on the amount of nitrogen available to be leached and on the amount of water that exceeds the soil moisture capacity.

Results for site 51 show agreement between predicted and measured inorganic nitrogen data within 20% in July and September. May values agree within 30%. Leaching took place in March and April. The peak concentration of nitrogen leached was in March which coincides with results from site 20.

At site 55, predicted and observed results of inorganic nitrogen agreed within 20% in July and September, the agreement in May is within 40%. Leaching at this site started in February and continued until April.

The amount of nitrogen leached at site 20 for the year was less than 3% of the total fertilizer applied. At site 51, 13% of the applied fertilizer was leached. At site 55, more than 50% of the fertilizer was leached.

Nitrogen percolated for all sites was calculated as 5% of the amount leached. The amount of nitrogen in interflow is the difference between nitrogen percolated and leached. Variations of nitrogen in interflow and nitrogen percolated follow the same pattern as variations in leaching.

Table 2. Final Simulation - Site 20

| Month | Fertili-zation (kg/ha) | N-Leached (kg/ha) | Dentrifi-cation and other losses (kg/ha) | Crop uptake (kg/ha) | Soil Organic N mineralized (kg/ha) | Inorg-N (kg/ha) Predicted | measured |
|---|---|---|---|---|---|---|---|
| Jan | 0 | 0 | 0 | 0 | 0 | 75.4 | - |
| Feb | 0 | 0 | 0 | 0 | 0 | 75.5 | - |
| Mar | 44.3 | 9.4 | 9.3 | 14.4 | 14.1 | 99.6 | - |
| Apr | 28.9 | 4.1 | 10.2 | 42.6 | 17.1 | 89.2 | - |
| May | 0 | 0 | 8.3 | 62.0 | 28.5 | 48.0 | 85.0 |
| June | 0 | 0 | 6.2 | 39.3 | 39.8 | 43.0 | - |
| July | 0 | 0 | 6.0 | 14.0 | 42.4 | 66.1 | 55.0 |
| Aug | 57.8 | 0 | 7.5 | 0 | 39.6 | 99.1 | - |
| Sept | 0 | 0 | 9.3 | 0 | 33.0 | 122.9 | 135.0 |
| Oct | 0 | 0 | 10.0 | 0 | 19.9 | 133.2 | - |
| Nov | 234.6 | 0 | 0 | 0 | 0 | 368.5 | - |
| Dec | 0 | 0 | 0 | 0 | 0 | - | - |

Table 3. Final Simulation - Site 51

| Month | Fertilization (kg/ha) | N-Leached (kg/ha) | Dentrification and other losses (kg/ha) | Crop uptake (kg/ha) | Soil organic N mineralized (kg/ha) | Inorg-N (kg/ha) Predicted | Inorg-N (kg/ha) measured |
|---|---|---|---|---|---|---|---|
| Jan | 0 | 0 | 0 | 0 | 0 | 70.3 | - |
| Feb | 0 | 6.0 | 0 | 0 | 0 | 70.5 | - |
| Mar | 0 | 0.8 | 6.9 | 0 | 15.4 | 73.5 | - |
| Apr | 0 | 0 | 7.4 | 0 | 18.9 | 84.7 | - |
| May | 51.6 | 0 | 13.5 | 3.9 | 31.4 | 150.8 | 110.0 |
| June | 0 | 0 | 15.6 | 19.6 | 43.3 | 159.5 | - |
| July | 0 | 0 | 16.5 | 88.4 | 45.9 | 101.1 | 120.0 |
| Aug | 0 | 0 | 11.6 | 53.0 | 42.6 | 79.8 | - |
| Sept | 0 | 0 | 9.2 | 23.6 | 35.2 | 82.3 | 65.0 |
| Oct | 0 | 0 | 8.3 | 7.9 | 21.3 | 87.9 | - |
| Nov | 0 | 0 | 0 | 0 | 0 | 88.4 | - |
| Dec | 0 | 0 | 0 | 0 | 0 | - | - |

Table 4. Final Simulation - Site 55

| Month | Fertili- zation (kg/ha) | N-Leached (kg/ha) | Dentrifi cation and other losses (kg/ha) | Crop update (kg/ha) | Soil organic N mineralized (kg/ha) | Inorg-N (kg/ha) Predicted | Inorg-N (kg/ha) measured |
|---|---|---|---|---|---|---|---|
| Jan | 0 | 0 | 0 | 0 | 0 | 75.5 | - |
| Feb | 40.4 | 3.9 | 0 | 0.8 | 0 | 111.4 | - |
| Mar | 0 | 19.8 | 10.3 | 5.5 | 17.1 | 93.5 | - |
| Apr | 0 | 6.9 | 9.2 | 30.6 | 21.0 | 68.4 | - |
| May | 9.2 | 0 | 9.0 | 31.0 | 34.7 | 72.9 | 125.0 |
| June | 0 | 0 | 9.8 | 18.1 | 48.1 | 94.0 | - |
| July | 0 | 0 | 11.7 | 50.6 | 51.3 | 83.9 | 70.0 |
| Aug | 0 | 0 | 10.6 | 47.9 | 47.6 | 74.4 | - |
| Sept | 0 | 0 | 9.1 | 14.8 | 39.6 | 90.2 | 80.0 |
| Oct | 3.0 | 0 | 9.4 | 3.7 | 24.1 | 104.6 | - |
| Nov | 0 | 0 | 0 | 0 | 0 | 105.4 | - |
| Dec | 0 | 0 | 0 | 0 | 0 | - | - |

## 4.1 Parameter Sensitivity

Site 51 was chosen as a case study to illustrate how model predictions change as a result of incremental changes for individual parameter values. The parameters changed were: mineralization rate constant (K), denitrification and other losses coefficient (C) and initial soil water content (STOO).

The response of nitrogen leached to variations in the mineralization rate constant is shown in Table 5. Results of these simulations show that the amount of nitrogen leached is fairly sensitive to order of magnitude changes in K. Increasing K causes an increase of inorganic nitrogen production, therefore an increase in nitrogen available to be leached. This situation is favored by high temperature in the summer months. A decrease in K works the opposite way, decreasing the inorganic nitrogen produced and the nitrogen that could be subject to leaching. This situation is favored by low temperatures.

Table 5. Leaching Response to Variations in K for Site 51.

| | K (Week $^{-1}$) | | |
|---|---|---|---|
| | 0.000217 | 0.00217 | 0.0217 |
| Month | N - Leached, (kg/ha) | | |
| Jan | 0 | 0 | 0 |
| Feb | 0 | 0 | 0 |
| Mar | 5.0 | 6.0 | 15.4 |
| Apr | 0.5 | 0.8 | 3.2 |
| May | 0 | 0 | 0 |
| | ⋮ | ⋮ | ⋮ |
| Dec | 0 | 0 | 0 |

The response of nitrogen leached to variations in C is shown in Table 6. As expected, an increase in C decreases the nitrogen amount in leaching, but the magnitude of change is relatively small. An increase in C increases nitrogen losses and as a result a decrease in the nitrogen pool in the soil. A decrease in the nitrogen pool in the soil reduces the nitrogen that could be leached. A decrease in C decreases nitrogen losses and, as a result, nitrogen that could be leached.

Table 6. Leaching Response to Variations in C for Site 51.

| | C | | |
|---|---|---|---|
| | 0.02 | 0.08 | 0.20 |
| Month | N - Leached, (kg/ha) | | |
| Jan | 0 | 0 | 0 |
| Feb | 0 | 0 | 0 |
| Mar | 6.4 | 6.0 | 5.2 |
| Apr | 0.9 | 0.8 | 0.6 |
| May | 0 | 0 | 0 |
| | ⋮ | ⋮ | ⋮ |
| Dec | 0 | 0 | 0 |

Variations in the initial soil water parameter (STOO) on nitrogen leached are shown in Table 7. These results demonstrate the very substantial effect of the initial soil moisture condition on the amount of nitrogen leaching that occurs. Unfortunately, this quantity was not measured for the field test subwatersheds. Thus, the uncertainty associated with this parameter could account for some of the discrepancy between simulated and measured conditions.

Table 7. Leaching Response to Variations in Initial Soil Water Content for Site 51.

| | Initial Soil Water Content (cm) | | |
|---|---|---|---|
| | 8.0 | 14.0 | 20.0 |
| Month | N - Leached, (kg/ha) | | |
| Jan | 0 | 0 | 13.2 |
| Feb | 0 | 0 | 4.5 |
| Mar | 0 | 6.8 | 6.6 |
| Apr | 0 | 0.8 | 0.6 |
| May | 0 | 0 | 0 |
| | ⋮ | ⋮ | ⋮ |
| Dec | 0 | 0 | 0 |

## 5. Summary and Conclusions

A data base was developed which provided inputs and outputs of nitrogen in the soil-plant system of three subwatersheds in the Black Creek area. This data base was analysed, supplemented with data from the literature and used with a slightly modified form of an existing nitrogen fate model (Tanji, et.al., 1979). The most significant modifications made to the model were the addition of a water storage term in the water submodel and changing from a yearly to a monthly time scale.

Some of the model parameters were varied and the effect of these variations on the predicted amounts of nitrogen leached observed. Parameters varied were: the mineralization rate constant (K), the denitrification and other losses coefficient (C) and the initial soil water content (STOO). Variations in K and STOO produced the most significant changes in the amount of nitrogen leached.

K proved to be a fairly sensitive parameter in determining the amount of nitrogen leached. A positive variation in K increased the inorganic nitrogen pool and, as a consequence, the amount of nitrogen leached. The importance of STOO is related to the timing with which nitrogen is available for leaching. A high value of STOO will cause leaching earlier in the year. Early in the year the crop's nitrogen requirements are low. Most leaching occurs at this time and nitrogen required to meet the crop's need at a later time is lost.

The modified version of the Tanji model gave good agreement between predicted and observed data. However, uncertainties in some of the model parameters and the neglect of others precludes conclusive evidence on the validity of the model. The effect of having only estimated the initial soil water suggests deficiencies in the data base. The initial soil water proved to be a key parameter in predicting nitrogen leached.

Approaching the problem of simulating the soil-plant nitrogen cycle with the principle of mass transfer was a very effective approach. Acceptable results were obtained at a computer cost of $0.25 per run. From an economic standpoint this tool is good.

Other deficiencies encountered in the model toward which future work should be directed were:

The model does not take into account farming practices. The effect of farming practices on the amount of nitrogen in the field should be considered.

The effect of precipitation is treated as a single unit in the model. Modifications should be made so that rainfall and snowfall are treated separately. In reality, higher values of leaching are expected in the period of thawing than in the rest of the year. Interflow does not occur when the soil is frozen. Precipitation as snow in December, January and February usually does not become soil water until late March in this part of the country.

In most cases, fertilizer doesn't become nitrate immediately after being applied. The model does not account for this effect. This deficiency causes overprediction of nitrogen concentration in leaching at the end of the month in which fertilization takes place.

Future work should also be directed toward strengthening the data base by making more frequent field measurements. As done for this study, it is recommended that the data base be obtained from watersheds in which more than one crop is cultivated and different farming practices are used.

## LIST OF REFERENCES

Allison, F.E. 1965. Evaluation of Incoming and Outgoing Processes that Affect Soil Nitrogen. Soil Nitrogen, Monograph No. 10. American Society of Agronomy, Inc., Madison, Wisconsin.

Bartholomew, W.V. 1965. Mineralization and Immobilization of Nitrogen in the Decomposition of Plant and Animal Residues. Soil Nitrogen, Monograph No. 10. American Society of Agronomy, Inc., Madison, Wisconsin.

Bear, F. E. 1964. Chemistry of the Soil. American Chemical Society, Monograph Series No. 160.

Bremmer, J.M. 1965. Inorganic Forms of Nitrogen. Methods of Soil Analysis Part II: Chemical and Microbiological Properties, C.A. Black (ed.), American Society of Agronomy, Madison, Wisconsin.

Davila, R.F. 1980. Predicting the Nitrogen Leached in the Black Creek Watershed. MS Thesis. Purdue Univ. W. Lafayette, IN.

En dleman, F.J., M.C. Northup, D.R. Kenney, J.R. Boyle and R.R. Hughes. 1972. A Systems Approach to an Analysis of the Terrestial Nitrogen Cycle. Journal of Environmental Systems, Vol. 2,(1) pp. 3-19.

Gasser, J.K.R. 1958. Use of Deep-Freezing in the Preservation and Preparation of Fresh Soil Samples. Nature Vol. 181.

Gilliam, J.W., S. Dasherg, L.J. Lund and D.D. Focht. 1978. Denitrification in Four California Soils: Effect of Soil Profile Characteristics. Journal of Soil Science Society of America, Vol. 42: 61-66.

Gould, W.D., F.D. Cook and J.A. Bulat. 1978. Inhibition of Urease Activity by Heterocyclic Sulfur Compounds. Journal of Soil Science of America, Vol. 42.

Hargrove, W.L. and D.E. Kissel. 1979. Ammonia Volatilization from Surface Applications of Urea in the Field and Laboratory. Journal of Soil Science, 43:359-363.

Harmsen, G.W., G.J. Kolenbrander. 1965. Soil Inorganic Nitrogen. Soil Nitogen, Monograph No. 10. American Society of Agronomy, Madison, Wisconsin.

International Joint Commission, PLUARG. 1978. Nitrogen Transformation Processes in Agricultural Watershed Soils, Windsor, Canada.

International Joint Commision, PLUARG. 1978. Environmental Management Strategy for the Great Lakes Systems, Final Report, Windsor, Canada.

Mehran, M. and K.K. Tanji. 1974. Computer Modeling of Nitrogen Transformations in Soils. Journal of Environmental Quality, Vol. 3, No. 4.

Nielsen, D.R. and J.G. MacDonald (eds.). 1978. Nitrogen in the Environment, Vol. 1 and 2. Academic Press, New York.

Nutman, P.S. 1965. Symbiotic Nitrogen Fixation. Soil Nitrogen. Monograph No. 10. American Society of Agronomy, Madison, Wisconsin.

Porter, K.S. 1975. Nitrogen and Phosphorus Food Production, Waste, The Environment. Ann Arbor Science Publishers, Inc.

Purdue University, Cooperative Extension Service, Fertilizer Value of Swine Manure. Publication # PIH-25.

Shumway, J. and W.A. Atkinson. 1978. predicting Nitrogen Fertilizer Response in Unthinned Stands of Douglas-Fir. Communications in Soil Science and Plant Analysis, 9 (6) 529-539.

Smith, O.L. 1979. Application of Soil Organic Matter Decomposition Model. Soil Biology and Biochemistry, Vol. 2. pp. 607-618.

Tanji, K.K., F.E. Broadbent, M. Mehran and M. Fried. 1979. An Extended Version of a Conceptual Model for Evaluating Annual Nitrogen Leaching Losses from Croplands. Journal of Environmental Quality, Vol. 8, No. 1.

Terman, G.L. and S.E. Allen. 1978. Crop Yield - Nitrate-N and Total N and K Concentration Relationship: Corn and Fescuegrass. Communications in Soil Science and Plant Analysis, 9 (9): 827-841.

U.S. Environmental Protection Agency. 1977. Environmental Impact of Land Use on Water Quality. Black Creek Project Report, EPA-905/9-77-007-B.

U.S. Environmental Protection Agency. 1978. Simulation of Nitrogen Movement, Transportation and Uptake in Plant Root Zone. EPA-600/3-78-029.

# TEMPORAL INSTABILITY IN THE FISHES OF A DISTURBED AGRICULTURAL WATERSHED

by

Louis A. Toth[1], James R. Karr[1], Owen T. Gorman[2] and Daniel R. Dudley[3]

ABSTRACT

Eight years of data on the fishes of Black Creek are analyzed to evaluate potential effects of stream alterations and other watershed modifications. During this period 44 species of fish were captured but most samples contained less than 20. Benthic (bottom feeding) species numerically dominated the community. Species composition was very unstable, particularly during summer months. Only three species, Semotilus atromaculatus, Pimephales promelas, and P. notatus consistently maintained populations in the watershed during the entire year. Others migrated to and from the Maumee River. The most important migrants were Notropis spilopterus, Dorosoma cepedianum, Catastomus commersoni, Cyprinus carpio, and Carpiodes cyprinus. Adults of the latter three species generally remained in the watershed only long enough to spawn, but their young dominated the fauna along with young D. cepedianum during summer months. Recent trends suggest increases in abundances of Notropis stramineus, N. cornutus- N. chrysocephalus, and N. umbratilis. These increases are matched by earlier declines in populations of Etheostoma spectabile, Campostoma anomalum, and especially Ericymba buccata. Factors responsible for these instabilities include short-and long-term effects of stream alterations and other watershed modifications resulting in extreme variation in flow regimes and choking algal blooms. In addition, fish kills, fish migration and within-stream movements, and temporal and spatial variation in recruitment and mortality result in highly variable fish communities. The relative importance, duration and time of effect of these factors varies among fish species. Knowledge of these patterns is essential for more informed programs of watershed management, and, thus, better water resource systems.

Key words: Agricultural impacts, Black Creek, channelization, fish communities, perturbation, stability, streams, stream alteration, water resources.

---

1. Department of Ecology, Ethology, and Evolution, 606 E. Healey Vivarium Bldg., University of Illinois, Champaign, IL 61820

2. Museum of Natural History, University of Kansas, Lawrence, KA 66045

3. Division of Survellance, Ohio Environmental Protection Agency, 361 E. Broad, Columbus, Ohio 43215

# INTRODUCTION

The primary goals of the Black Creek project were to develop and implement plans for controlling soil erosion and to evaluate the effectiveness of traditional conservation programs in improving the quality of a water resource. Recent clean water legislation defines the water quality goal as physical, chemical, and biological integrity. Hence, the success of the Black Creek project must be viewed not only in light of sediment and nutrient loads but also with respect to effects on the biota of the water resource system.

Fish were selected as the primary group for evaluation of project impacts on the aquatic biota. In this report we present a summary of fish population data from the Black Creek watershed. We summarize data on community structure beginning with preliminary sampling conducted in 1973 and continuing to the collection of the most recent samples (June 1980). In addition, we discuss the spatial and temporal patterns of variation in species richness and species diversity in the fishes of the watershed.

One of the problems of this type of analysis is the complex array of variables, both man-altered and natural, that govern structure and function in the aquatic community. Thus, we are often not able to definitively demonstrate causal links between community change and specific human activities. However, strong inferences can often be made. In general, we explore those links in this paper where possible but we leave many of the details of such links to an analysis in an integrative Black Creek Report to be completed in 1982.

Although it is not the intent of this report to evaluate effects of project activities on the physical integrity of Black Creek and its tributaries, it is clear that the intensive application of structural conservation practices modified stream channels throughout the watershed. A number of studies (see Karr and Gorman 1975 for a review) have shown that similar perturbations, particularly ditching and channel straightening, severely alter the structure and stability of existing fish communities, at least over the short term. Advocates of these practices commonly assume that these effects are temporary; the biota will recover and perhaps even be enhanced as water-quality benefits accrue.

Few studies have evaluated the long-term effects of stream modification. Gorman and Karr (1978) suggest that community complexity (diversity) may recover relatively quickly while stability either requires a longer period or may never be attained. Hence, we attempt to summarize eight years of sampling in the Black Creek watershed and evaluate the origins of changes that have occurred in the fish community during this period.

# METHODS

## Fish Sampling.

Twenty-five fish sampling stations were established in the Black Creek watershed (Fig. 1). However, since most of the sampling effort focused upon the main channel, only data from stations 6, 18, 17, 28, 29, 15, and 12 were intensively analyzed. Each station was 100 m in length. Extensive algal blooms and extremely low flows (Table 1) sometimes prevented the entire station from being sampled. Samples covering less than 100 m were rather infrequent, however, and did not distort the data significantly enough to warrant special treatment.

Sampling frequency was not uniform among stations but generally included at least four main channel sites on each sampling date. Sampling frequency also varied among years. Initial samples were taken at sites 6 and 12 during July 1973. From 1974 to 1978 samples were taken at monthly intervals although some bi-weekly samples were taken during 1975 and 1976. Sampling was less frequent in 1979 but included collections from spring, summer, and fall. The last sample was taken in June 1980.

Sampling was conducted using 3.1 or 6.2 mm mesh minnow seines with block nets at the upper and lower ends of the station. However, in April 1979 fish were sampled with an electric seine powered by a gasoline generator. After capture, fish were either identified, counted, and released or preserved in 10% formalin for laboratory analysis. In addition, fish were often measured to the nearest 1 mm (total length) to monitor the age structure of populations.

## Data Analysis.

Fish species diversity patterns were evaluated during the course of the study using the Shannon-Weiner index (H).

$$H = -\sum_{i=1}^{N} P_i \log_e P_i$$

where $P_i$ is the proportion of species i in a sample of N species. This index is sensitive to shifts in the number of species and distribution of individuals among the species. H increases as the number of species or their equitability increases.

To evaluate short-term (i.e., month to month) changes in community structure, a sample similarity index (PS) was calculated whenever samples were taken during consecutive months from any given station on the main channel of Black Creek. The index expresses the degree (%) to which two samples are alike in quantitative representation of species (Whittaker 1975) and was calculated as follows:

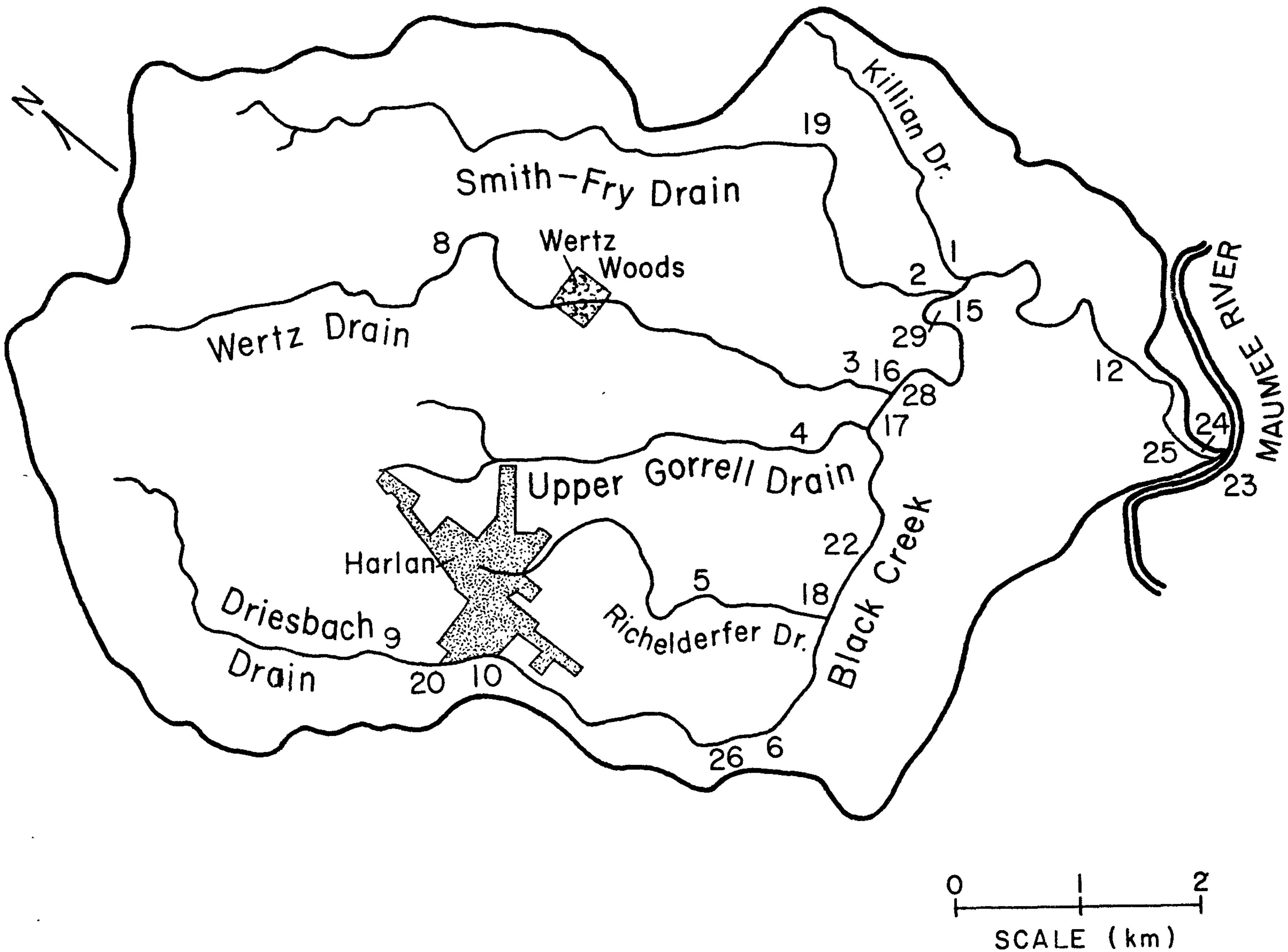





Figure 1. Map of the Black Creek watershed showing the locations of streams and sampling sites discussed in text.

Table 1. Environmental conditions (based upon temperature and precipitation records) and perturbations in the Black Creek watershed.

| | Season | | | |
|---|---|---|---|---|
| Year | Winter | Spring | Summer | Fall |
| 1973 | Mild | Normal | Normal<br>Some channel alterations upstream | Normal |
| 1974 | Mild | Wet | Dry | Dry |
| | | - Extensive channel alterations ------ | | |
| | | | Algal blooms upstream | |
| 1975 | Mild | Normal<br>Bridge construction downstream | Normal<br>Algal blooms upstream | Normal |
| 1976 | Mild | Dry | Dry<br>Some channel alterations upstream | Dry |
| | | - - - Extensive algal blooms - - -- | | |
| 1977 | Severe | Normal<br>Algal blooms | Wet | Normal |
| 1978 | Severe | Wet | Dry | Dry |
| | | | --- Algal blooms --- | |
| 1979 | Severe | Dry | Normal | Dry |
| | | | Algal blooms upstream | |

$$PS = 1 - 0.5\Sigma\left|P_a - P_b\right| \text{where}$$

$P_a$ = the number of individuals of a given species expressed as its proportional importance in the community during month (a)

$P_b$ = the number of individuals of the same species expressed as its proportional importance in the community during the following month (b)

When more than one sample was taken during a given month, similarity values were calculated for each combination of samples from consecutive months. Sample similarity was then given as the mean of all similarity values for that period.

Temporal variability and diversity patterns were dissected by evaluating these parameters among benthic and pelagic guilds, delimited primarily according to feeding locales (Table 2). Independent diversity and sample similarity measures were calculated based upon the proportional representation of a given species within its respective guild.

Habitat conditions during the study period are summarized in Table 1.

## COMMUNITY STRUCTURE

In this section we outline the status of fish populations at each of the main channel stations. We begin at upstream areas and proceed downstream discussing the data year-by-year with a brief summary for each station. A list of the species known from the watershed and their guild assignments is provided in Table 2.
Figs 2 - 10 and Table 3 show the changing populations for several more abundant species. A more detailed analysis of the *Ericymba buccata* population is provided in another paper (Toth et al. 1981).

### Station 6-26.

1973 - *Pimephales promelas* was the most abundant species and *E. buccata*, *P. notatus* and *C. carpio* (recruits) were common in a preliminary sample taken in July 1973. The presence of numerous young *C. carpio* is signficant since it indicates that this species spawned in the watershed prior to the project-related habitat alterations.

1974 - *Pimephales promelas* was even more abundant and again dominant in March 1974. Large adults of *N. cornutus-N. chrysocephalus*, *C. commersoni*, and especially *S. atromaculatus* were also numerous. Although there was a marked decline in fish density in April, *P. promelas* was still fairly abundant. Only ten fish were caught here in May-- soon after this stretch of stream was channelized and the fauna remained rather depauperate in July. However, a large number of *E. buccata* yearlings were caught in algae-choked water during this month. Although no quantitative samples were taken during the fall, dip-net samples indicated that *N. spilopterus* was common in September and October.

Table 2. Guild assignments (based upon feeding habitat) of all fish species that were caught in the Black Creek watershed from 1973 - 1980. Benthic species feed on or near the substrate while pelagic species forage higher in the water column or at the surface.

| | |
|---|---|
| | **Benthic Guild** |
| *Dorosoma cepedianum* | Gizzard Shad |
| *Umbra limi* | Central Mudminnow |
| *Campostoma anomalum* | Common Stoneroller |
| *Carassius auratus* | Goldfish |
| *Cyprinus carpio* | Carp |
| *Ericymba buccata* | Silverjaw Minnow |
| *Notropis stramineus* | Sand Shiner |
| *Phenacobius mirabilis* | Suckermouth Minnow |
| *Pimephales notatus* | Bluntnose minnow |
| *Pimephales promelas* | Fathead Minnow |
| *Carpiodes cyprinus* | Quillback |
| *Catostomus commersoni* | White Sucker |
| *Erimyzon oblongus* | Creek Chubsucker |
| *Ictiobus cyprinellus* | Bigmouth Buffalo |
| *Minytrema melanops* | Spotted Sucker |
| *Moxostoma spp.* | Redhorse |
| *Ictalurus melas* | Black Bullhead |
| *Ictalurus nebulosus* | Brown Bullhead |
| *Ictalurus natalis* | Yellow Bullhead |
| *Etheostoma blenniodes* | Greenside Darter |
| *Etheostoma nigrum* | Johnny Darter |
| *Etheostoma spectabile* | Orangethroat Darter |
| *Percina maculata* | Blackside Darter |
| *Aplodinotus grunniens* | Freshwater Drum |
| | **Pelagic Guild** |
| *Esox lucius* | Northern Pike |
| *Notemigonus crysoleucas* | Golden Shiner |
| *Notropis atherinoides* | Emerald Shiner |
| *Notropis chrysocephalus* | Striped Shiner |

Table 2. (continued)

| | Pelagic Guild Cont. |
|---|---|
| *Notropis cornutus* | Common Shiner |
| *Notropis spilopterus* | Spotfin Shiner |
| *Notropis umbratilis* | Redfin Shiner |
| *Semotilus atromaculatus* | Creek Chub |
| *Fundulus notatus* | Blackstripe Topminnow |
| *Labidesthes sicculus* | Brook Silverside |
| *Ambloplites rupestris* | Rock Bass |
| *Lepomis cyanellus* | Green Sunfish |
| *Lepomis gibbosus* | Pumpkinseed |
| *Lepomis humilis* | Orangespotted Sunfish |
| *Lepomis macrochirus* | Bluegill |
| *Lepomis microlophus* | Redear Sunfish |
| *Micropterus salmoides* | Largemouth Bass |
| *Pomoxis annularis* | White Crappie |
| *Pomoxis nigromaculatis* | Black Crappie |
| *Perca flavescens* | Yellow Perch |

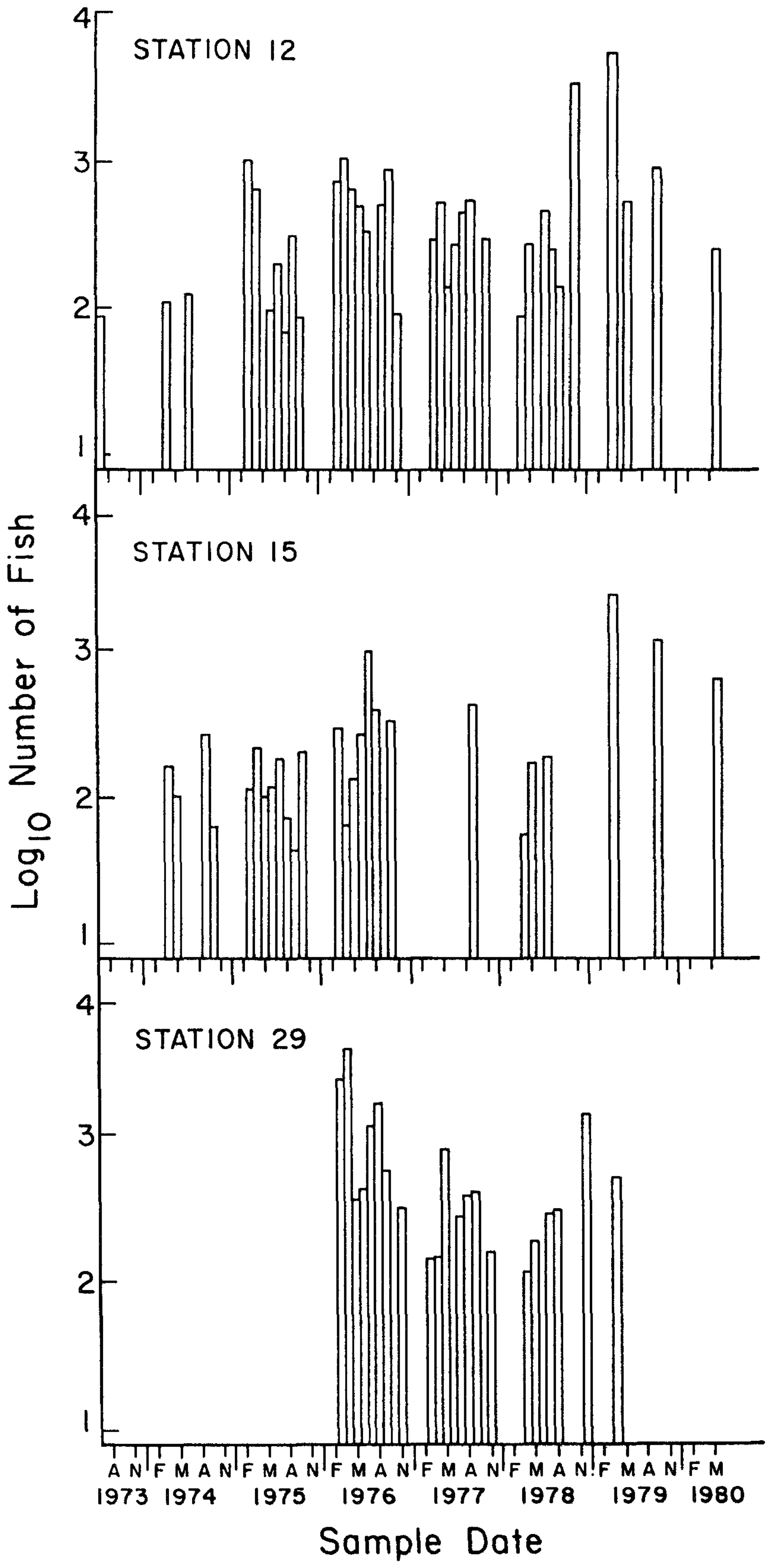



Figure 2a. $Log_{10}$ number of fish at Station 12, 15, and 29 in the Black Creek Watershed, 1973-1980.

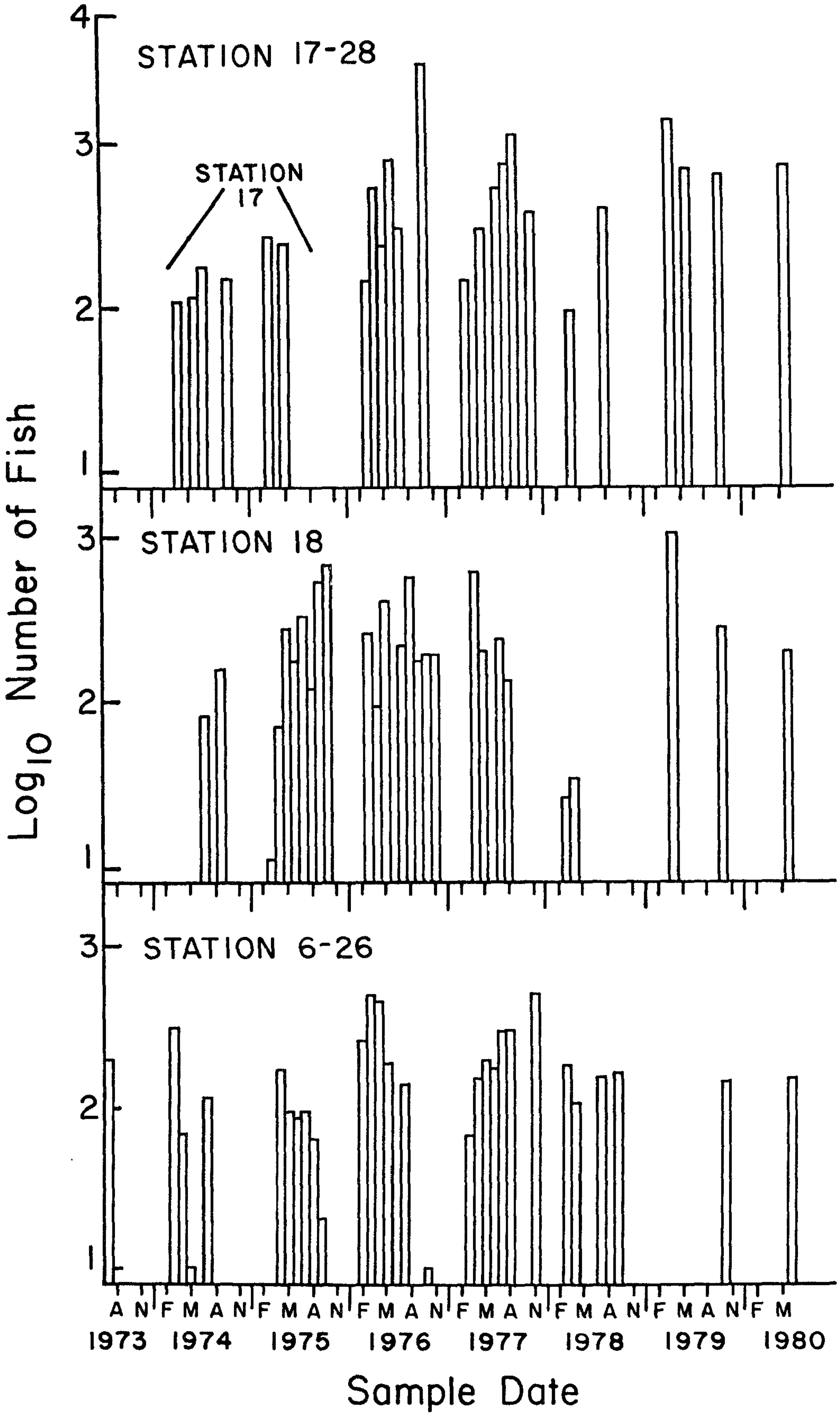



Figure 2b. $Log_{10}$ number of fish at Stations 17-28, 18, and 6-26 in the Black Creek Watershed, 1973-1980. Samples were taken at Station 26 from February - May 1976 only.

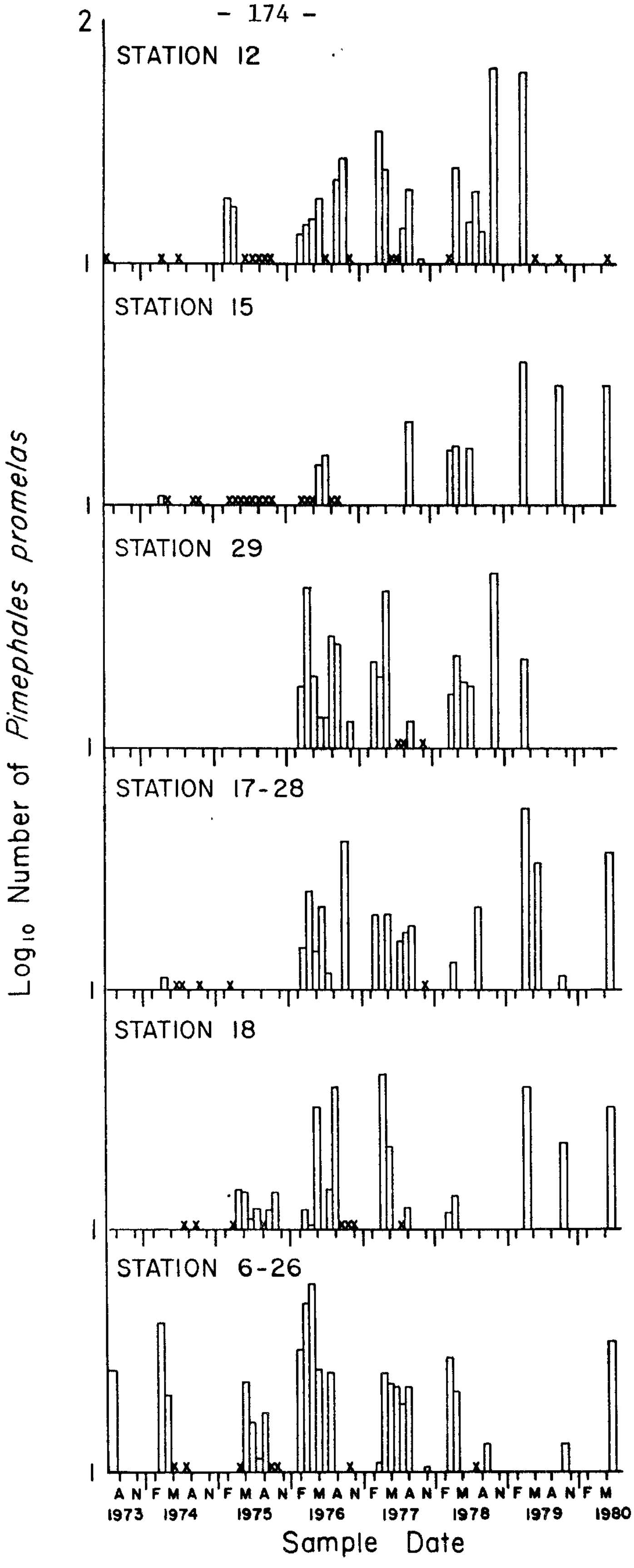



Figure 3. $Log_{10}$ number of Pimephales promelas at main channel stations in the Black Creek Watershed, 1973-1980. Station 26 sampled from February - May 1976 only.

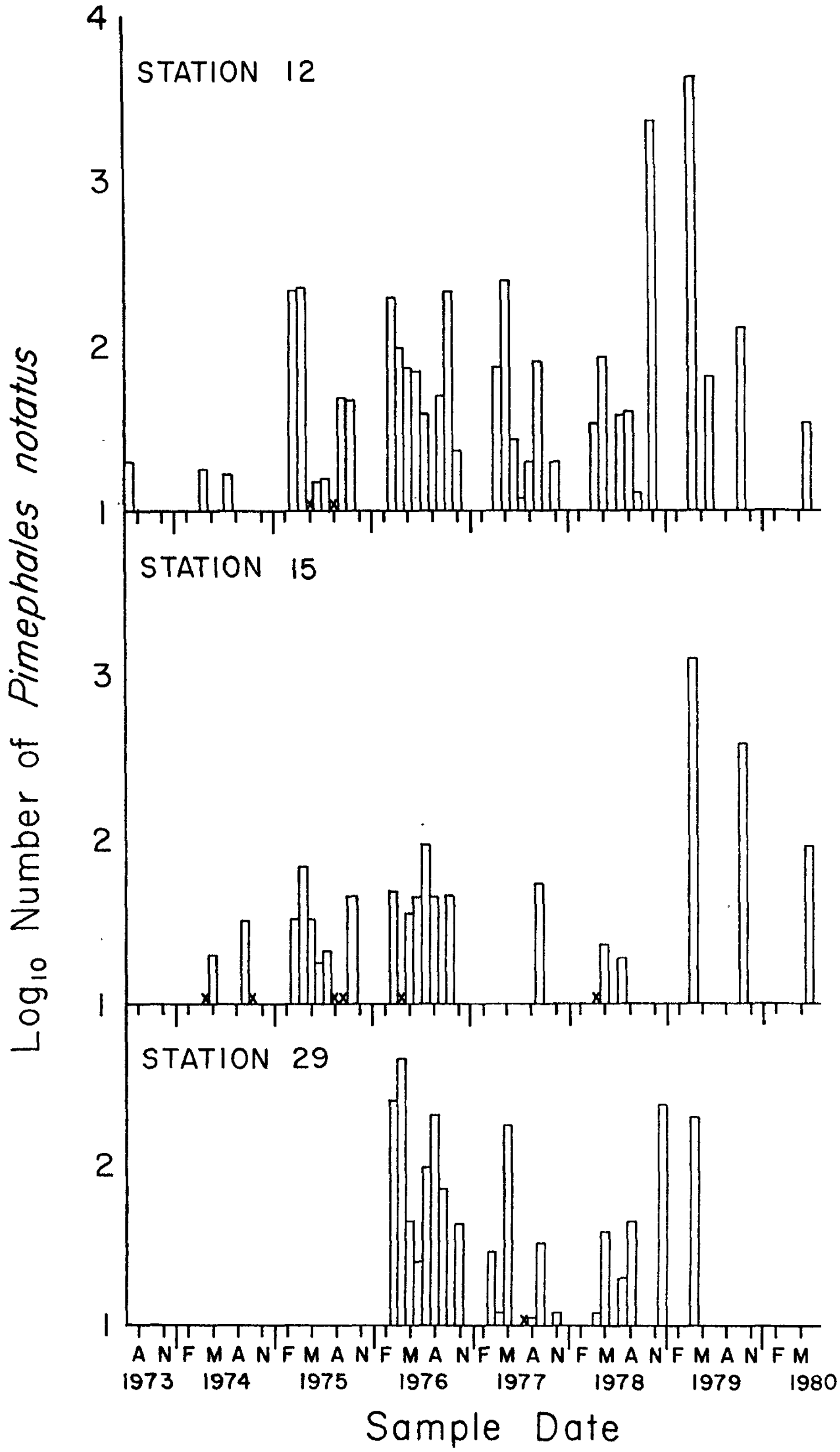



Figure 4a. $Log_{10}$ number of Pimephales notatus at Stations 12, 15, and 29 in the Black Creek Watershed, 1973-80.

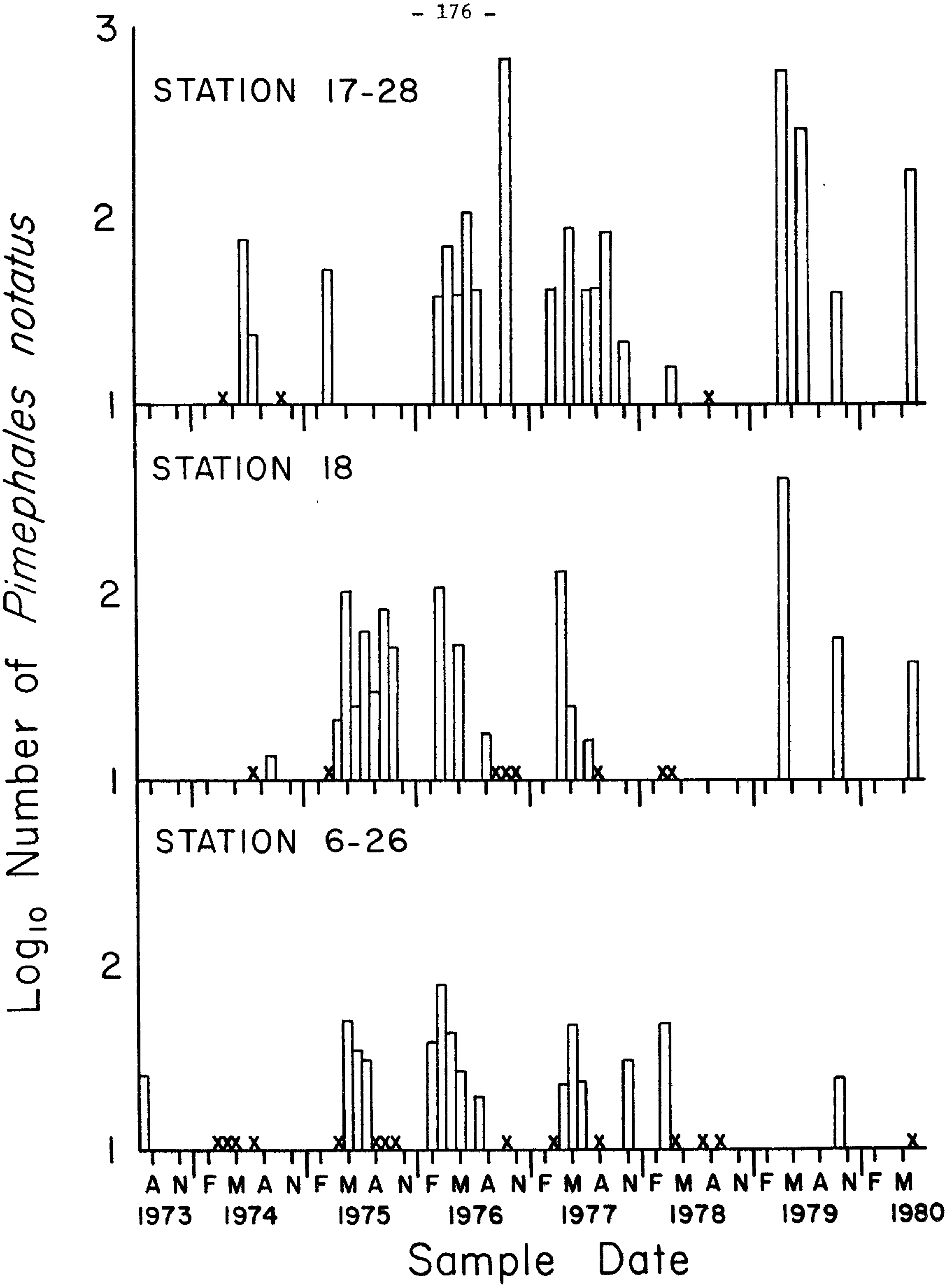



Figure 4b. $Log_{10}$ number of Pimephales notatus at Stations 17-28, 18, and 6-26 in the Black Creek Watershed, 1973-80. Station 26 sampled February - May 1976 only.

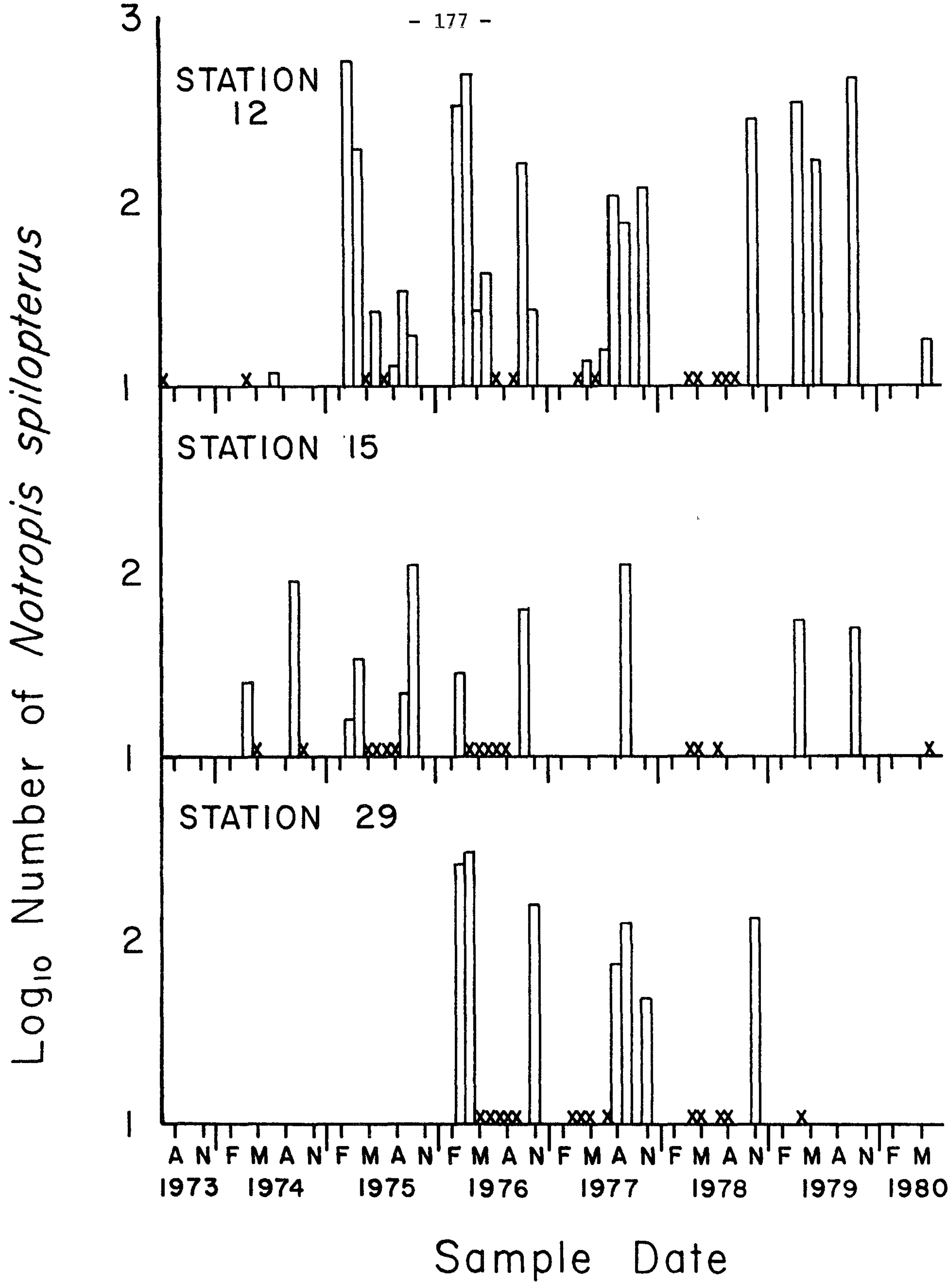



Figure 5a. $Log_{10}$ number of Notropis spilopterus at Stations 12, 15, and 29 in the Black Creek Watershed, 1973-80.

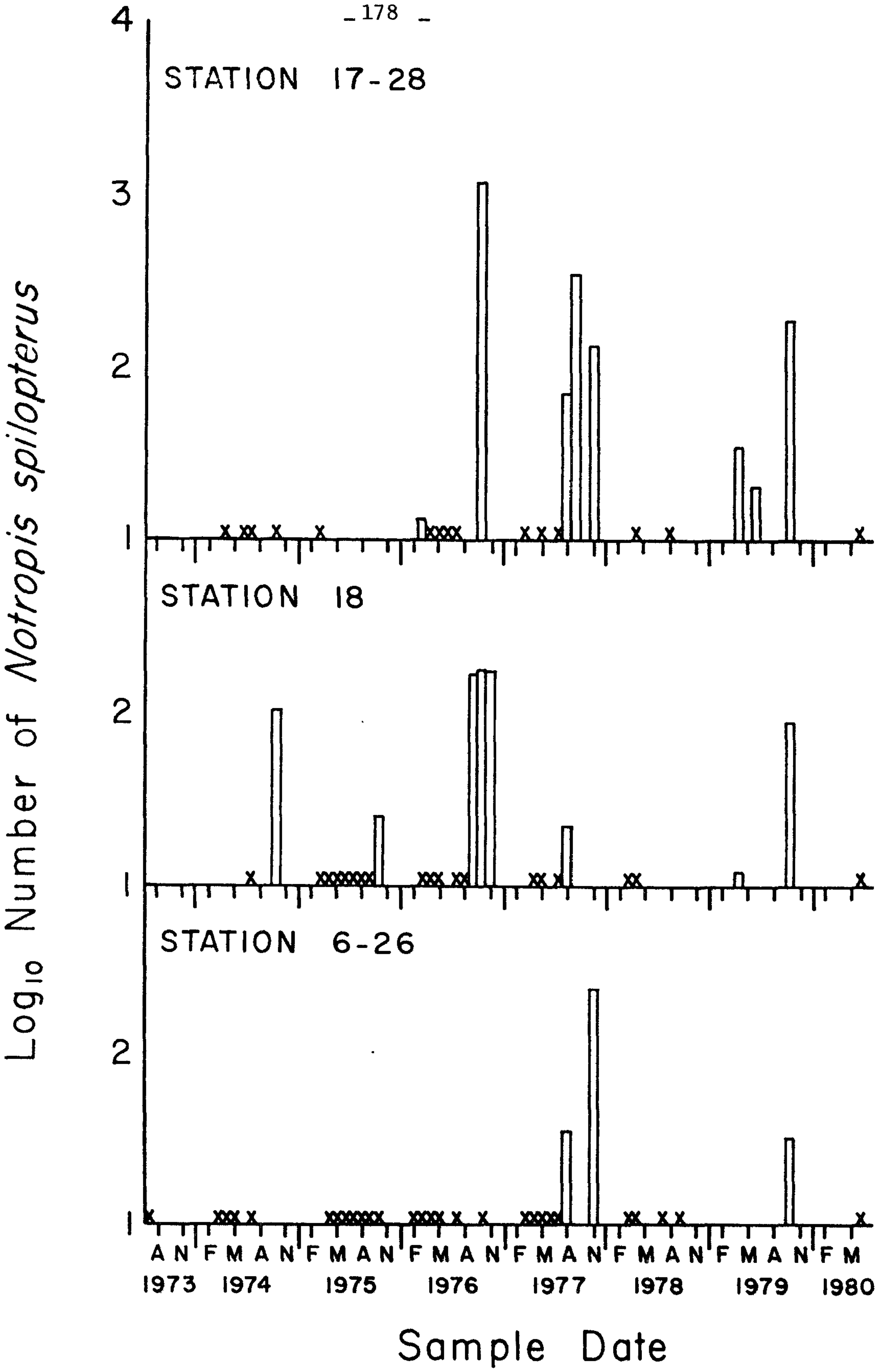



Figure 5b. $Log_{10}$ number of Notropis spilopterus at Stattions 17-28, 18, and 6-26 in the Black Creek Watershed, 1973-1980. Station 26 sampled February - May 1976 only.

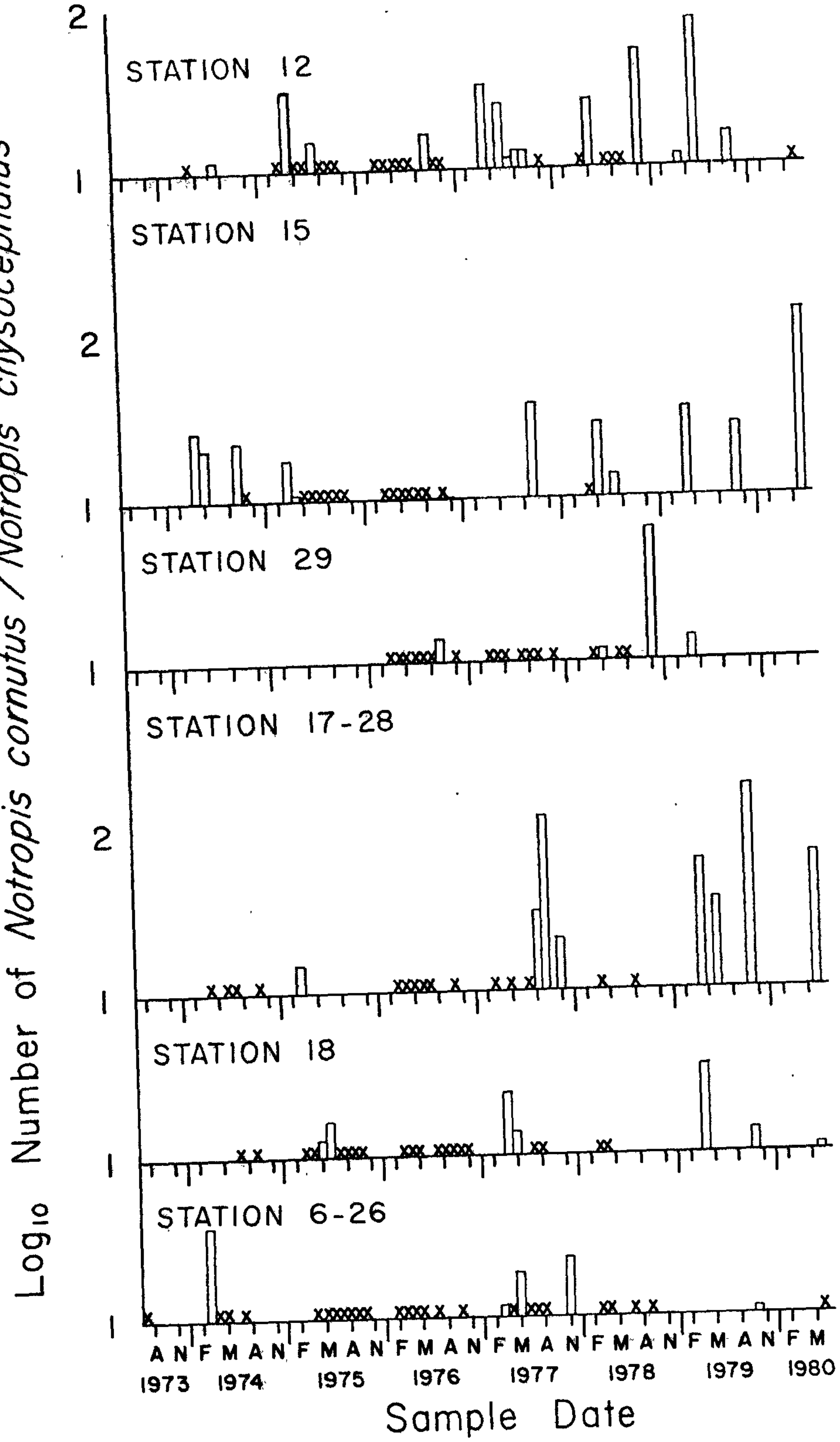



Figure 6. $Log_{10}$ number of Notropis cornutus/Notropis chrysocephalus at main channel stations in the Black Creek Watershed, 1973-1980. Station 26 sampled February - May 1976 only.

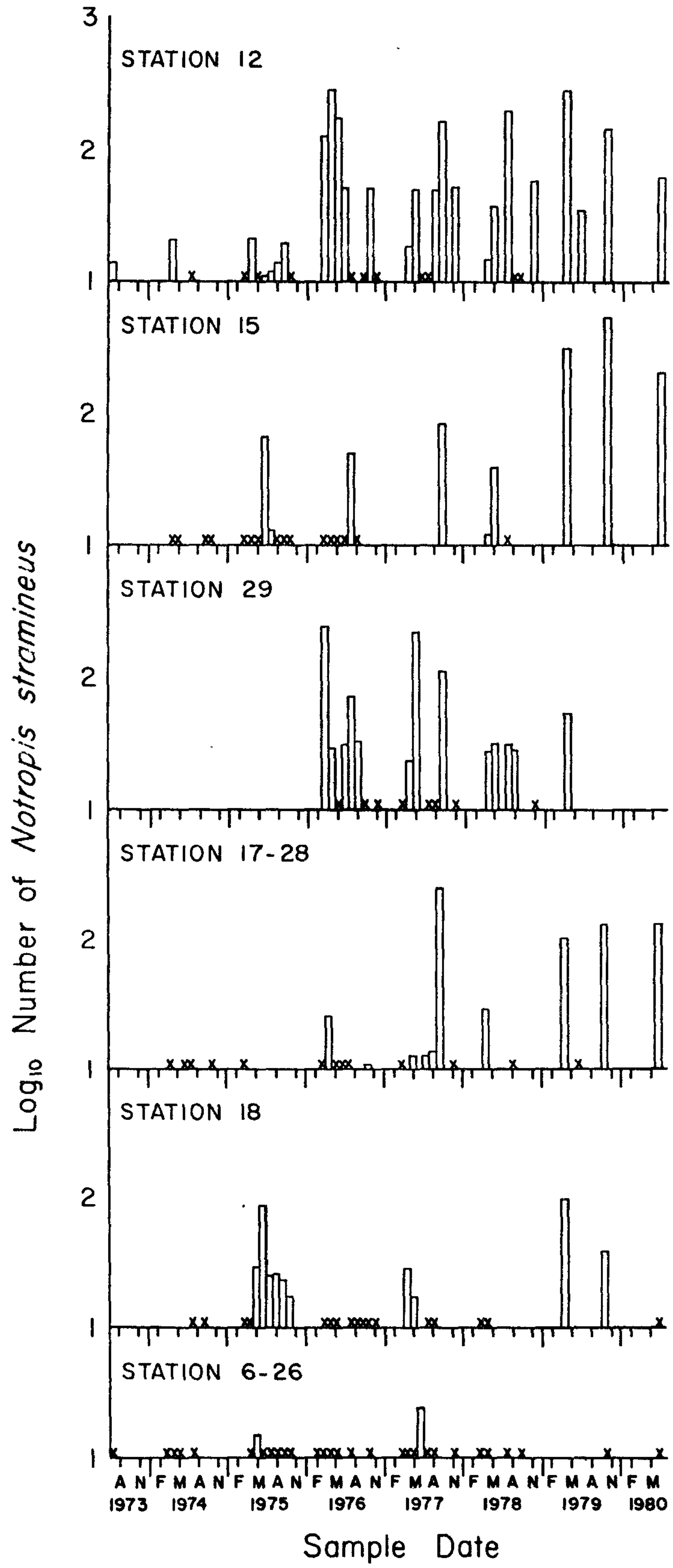



Figure 7. $Log_{10}$ number of Notropis stramineus at main channel dtations in the Black Creek Watershed, 1973-1980. Station 26 sampled February - May 1976 only.

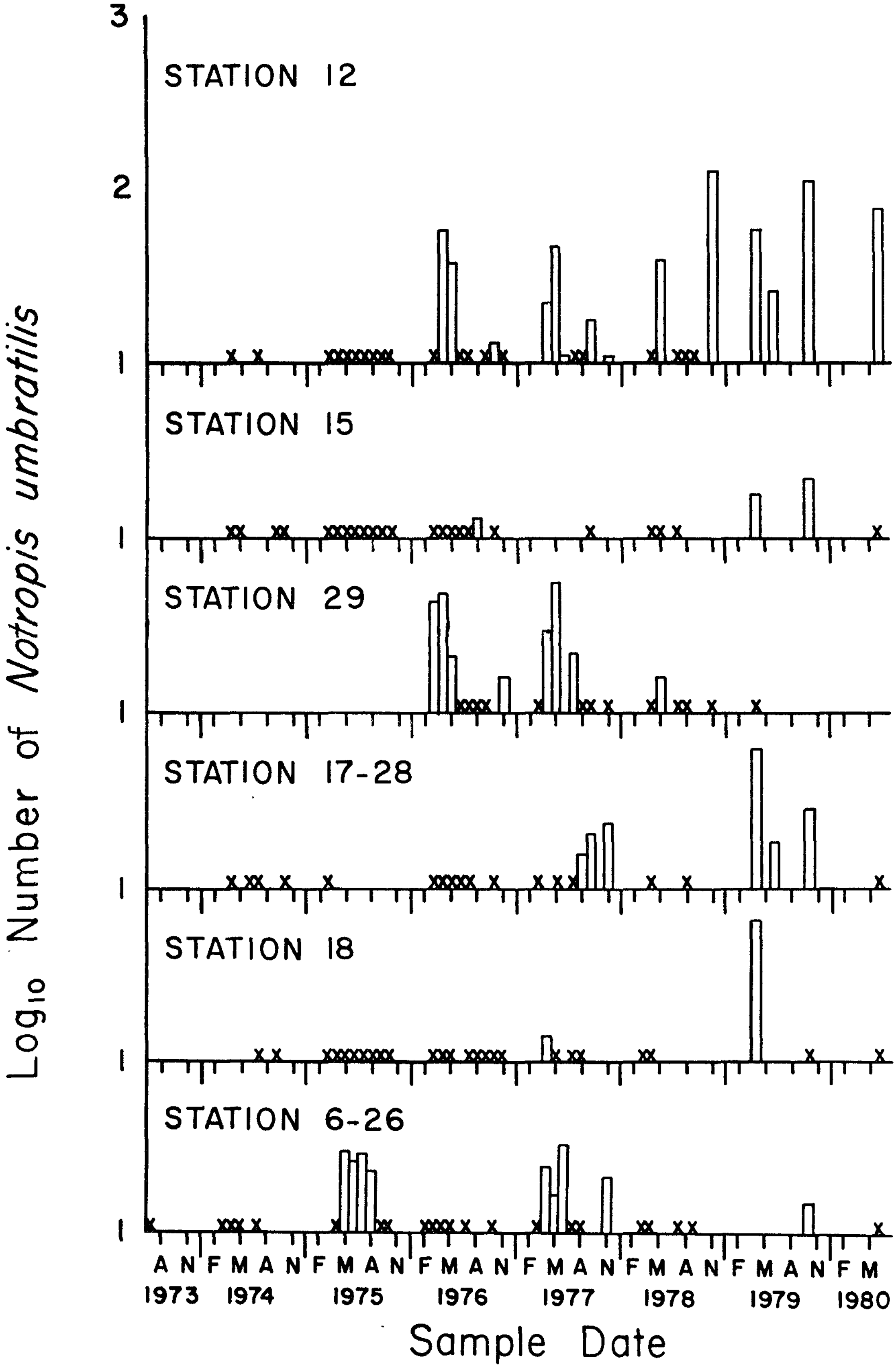



Figure 8. $Log_{10}$ number of Notropis umbratilis at main channel stations in the Black Creek Watershed, 1973-1980. Station 26 sampled February - May 1976 only.

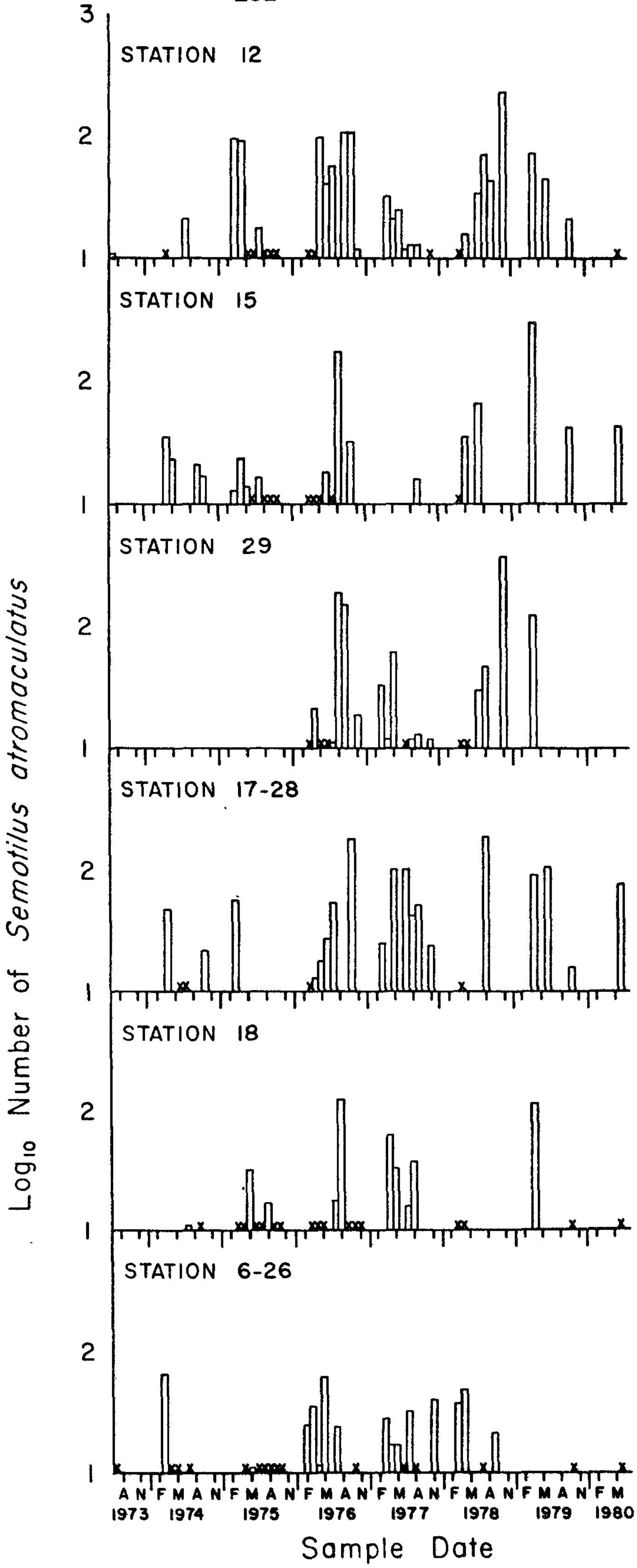



Figure 9. $Log_{10}$ number of Semotilus atromaculatus at main channel stations in the Black Creek Watershed, 1973-1980. Station 26 sampled February - May 1976 only.

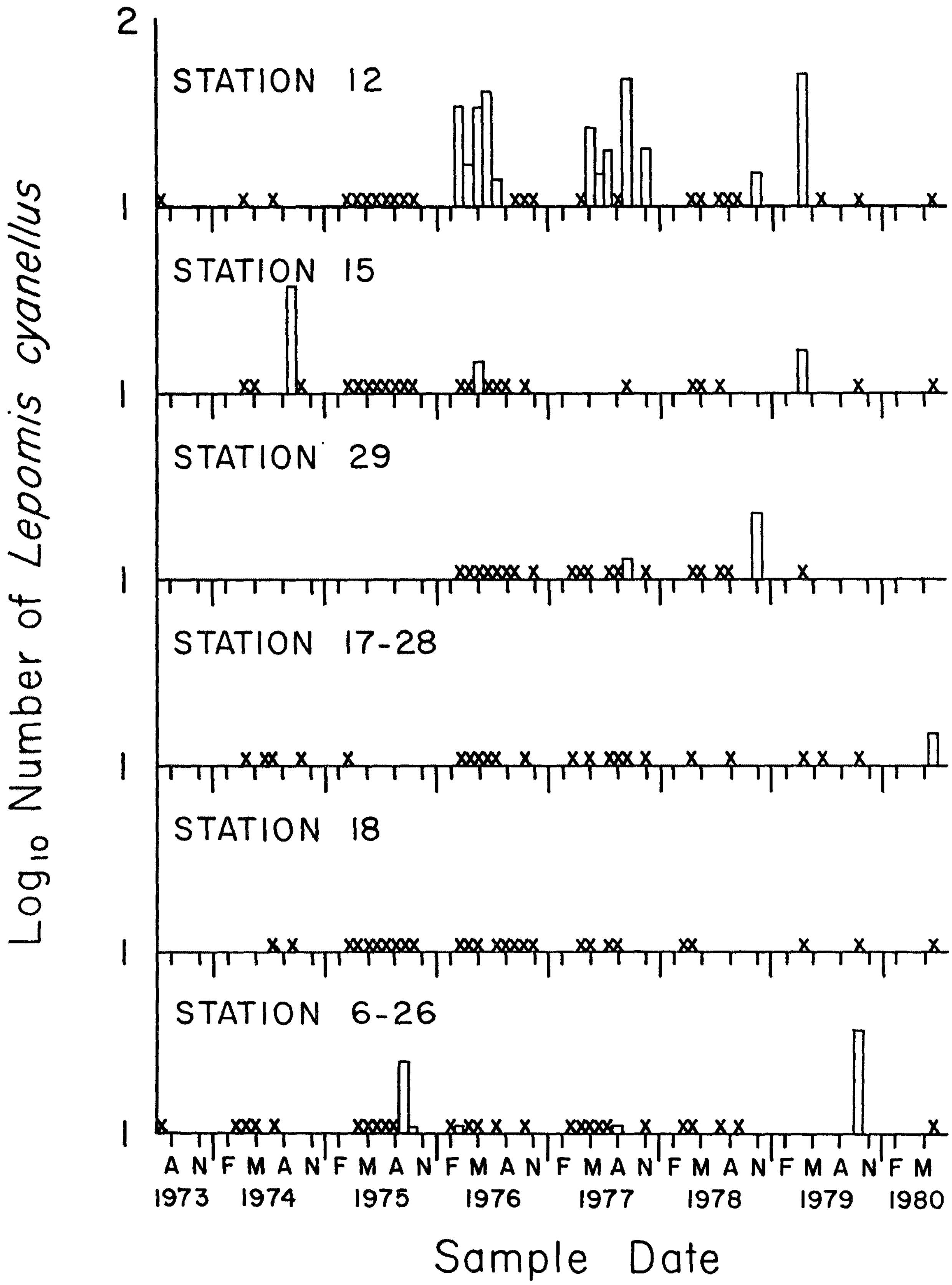



Figure 10. $\text{Log}_{10}$ number of Lepomis cyanellus at main channel stations in the Black Creek Watershed, 1973-80. Station 26 sampled February - May 1976 only.

Table 3. Seasonal abundance of migrant species in Black Creek. The data given are the mean number of individuals (± SE) per sample, based upon the average seasonal abundance of each species at the six main channel sampling stations.

| | Cyprinus carpio | Catostomus commersoni | Carpiodes cyprinus | Dorosoma cepedianum |
|---|---|---|---|---|
| 1974 | | | | |
| Mar - May | 0 | 7.3± 1.9 | 0 | 0 |
| Jun - Aug | 0 | 3.4± 2.9 | 3.0± 2.4 | 0 |
| Sept - Nov | 0 | 0.8± 0.8 | 0.7± 0.7 | 4.3± 1.2 |
| 1975 | | | | |
| Mar - May | 0 | 0.6± 0.5 | 0.1± 0.1 | 0 |
| Jun - Aug | 0.2± 0.1 | 0.1± 0.1 | 0.4± 0.3 | 5.5± 3.1 |
| Sep - Nov | 0.3± 0.3 | 0 | 0 | 25.6± 25.5 |
| 1976 | | | | |
| Mar - May | 0.7± 0.4 | 0 | 0 | 0 |
| Jun - Aug | 6.9± 4.2 | 13.5 ± 6.9 | 14.7± 14.6 | 21.8± 19.1 |
| Sept- Nov | 0 | 14.8 ± 7.5 | 4.1 ± 2.0 | 1.3± 1.0 |
| 1977 | | | | |
| Mar - May | 1.2± 1.1 | 4.7 ± 1.7 | 0.4 ± 0.4 | 0 |
| Jun - Aug | 35.7± 11.0 | 8.0 ± 2.7 | 58.9 ± 17.9 | 67.8± 19.3 |
| Sept- Nov | 7.0± 2.4 | 12.8 ± 3.1 | 16.1 ± 5.7 | 50.1± 13.3 |
| 1978 | | | | |
| Mar - May | 0.6± 0.3 | 4.5 ± 1.6 | 0 | 0 |
| Jun - Aug | 44.0± 22.0 | 33.6 ±12.0 | 11.9 ± 4.8 | 4.1 ± 2.5 |
| Sept- Nov | 50.7± 36.6 | 37.7 ±27.3 | 6.7 ± 3.8 | 0 |
| 1979 | | | | |
| Mar - May | 8.6 ± 3.3 | 34.4 ±11.4 | 0 | 0 |
| Jun - Aug | 0.5 ± 0.5 | 27.0 ±20.0 | 0 | 0 |
| Sept- Nov | 0.2 ± 0.2 | 2.0 ± 1.1 | 0 | 1.0 ± 1.0 |

1975 - Very few fish were caught during the early spring of 1975, apparently because a newly installed weir below the station prevented fish from moving into this region during the prevailing low flow conditions. As water levels rose in May, this area was repopulated by P. promelas, P. notatus, and N. umbratilis. The density of each of these species remained about the same (i.e., <50) through July but all other species were rare. A substantial decrease in the abundance of P. notatus in August preceded a similar decline by P. promelas and N. umbratilis in September. During this month, E. buccata and L. cyanellus were the most common species. Only 20 fish, 11 of which were L. cyanellus, were caught in October.

1976 - The density of fish, particularly that of P. promelas, was high from February through April 1976. Two other species, P. notatus and E. buccata, were also abundant during this period; however, the density of E. buccata declined considerably in late March. A fair number of large adult S. atromaculatus were caught during February and March. The density of fish was much lower in May when this entire section of stream was algae-choked. During this time, P. promelas and S. atromaculatus were the dominant species and P. notatus and E. buccata were common. In contrast to the early spring samples, most of the S. atromaculatus caught in May were yearlings. Algae was flushed out by July when P. promelas was again dominant while S. atromaculatus, P. notatus, and E. buccata remained common. This region nearly dried up completely during August and September and only ten fish were caught in October when algae again choked the stream.

1977 - Fish densities were not particularly high but more species were caught in the late spring of 1977 than in any previous sample at this station. From March through June, P. promelas was again the most abundant species but P. notatus, S. atromaculatus, N. spilopterus, and N. stramineus were also common. In addition, adult C. commersoni, C. carpio, and C. cyrpinus were also caught during this period. In July, the community was dominated by a very large number of C. carpio recruits and the only other common species were P. promelas and S. stromaculatus. Another major shift in community structure occurred in August when there was an influx of D. cepedianum migrants. Notropis spilopterus also began to invade this area during August and P. promelas remained common. During November, D. cepedianum was still abundant but was replaced by N. spilopterus as the dominant species. Although only a few P. promelas were caught, S. atromaculatus, N. cornutus-N. chrysocephalus, N. umbratilis, P. notatus, and young of C. carpio and C. commersoni were common.

1978 - The fish community was again rather depauperate in 1978. Pimephales promelas, P. notatus (March only), and S. atromaculatus were the only abundant species in two spring samples and C. carpio recruits represented 84% of the fish collected in July and 73% of those found in September. Pimephales promelas and S. atromaculatus were also common in September.

1979 - The only sample at this station in 1979 was taken in October and consisted of a small number of N. spilopterus, L. cyanellus, P. notatus, P. promelas, N. umbratilis, and N. cornutus-N. chrysocephalus. The last sample was taken during June 1980 when the community was overwhelmingly dominated by P. promelas.

Summary.

With the exception of 1977, the fish community at this station was very depauperate. Pimephales promelas was clearly the most abundant species, particularly during the spring months. Pimephales notatus and both large adult and yearling S. atromaculatus were also consistently common during the spring.

During the summer months, P. promelas remained relatively abundant; however, the fauna was dominated by recruits of C. carpio and D. cepedianum migrants in 1977, and by young C. carpio again in 1978. Cyprinus carpio recruits were also present, though not as abundant, in a July 1973 sample. Other common species found during the summer months included E. buccata, P. notatus, S. atromaculatus, and less frequently, N. umbratilis and N. spilopterus.

No samples were taken during the fall in 1973 and 1974 and fish densities were extremely low during this period in 1975 and 1976. Fish were more abundant during the fall of 1977-1979 but only one sample was taken during each of these years. Notropis spilopterus was dominant in November 1977 but D. cepedianum was also fairly abundant. Young C. carpio were dominant in September 1978. No species was particularly abundant in October 1979 but N. spilopterus was common. Other common species that were frequently collected during the fall months included L. cyanellus, S. atromaculatus, P. notatus, P. promelas, N.umbratilis, and N. cornutus-N. chrysocephalus.

Station 18.

1974 - A large percentage of young E. buccata were found in a somewhat unreliable sample taken in algae-choked waters in July 1974. Although E. buccata remained common in September, N. spilopterus migrants dominated a rather depauperate community.

1975 - The fauna was still sparse during the early spring of 1975 when P. promelas and P. notatus were the most common species. Pimephales notatus emerged as the most abundant species in May but E. buccata, S. atromaculatus and N. stramineus also increased in density. The influx of N. stramineus continued through June and it temporarily became the dominant species. However, a large number of primarily one-year-old E. buccata dominated the samples from July through October. Notropis stramineus and especially P. notatus were also fairly common during this period.

1976 - Although more than twice as many fish were caught here in March 1976 than during the early spring of 1975, two species, P. notatus and E. buccata, comprised about 85% of the sample. Ericymba buccata continued to dominate the community through July while the density of P. notatus declined. Adult P. promelas became temporarily abundant during May but most of these fish were gone by July. However, a large number of small P. promelas and young-of-the-year S. atromaculatus were found in August, making these species co-dominants with E. buccata. A dramatic change in community structure occurred in September when N. spilopterus migrated into this region and P. promelas, S. atromaculatus, and E. buccata all apparently moved out. In fact N. spilopterus consistently made up 98% of the monthly fish samples from September through November 1976. Much of the impetus for this shift was undoubtedly tied to the dense algal blooms and low water level conditions that began in August and prevailed through this period.

1977 - Like the previous spring, a large number of fish were again caught here during April 1977. Pimephales promelas was the most abundant species but P. notatus an E. buccata, the dominant species during the spring of 1976, were also very abundant. In addition, N. stramineus, N. cornutus-N. chrysocephalus, and especially S. atromaculatus were fairly common. A major shift in community structure occurred in July when the density of P. promelas and P. notatus declined significantly and the fauna was dominated by C. cyprinus recruits. Although E. buccata remained abundant in July, it exhibited a marked decrease in density along with C. cyprinus in August. No species was particularly abundant during this sampling period; however, S. atromaculatus, N. spilopterus, and D. cepedianum were common.

1978- Very few fish were caught here during March and April 1978, but many adult C. commersoni, C. carpio, and C. cyprinus were sighted in this region in late April and May.

1979 - Fish densities, particularly those of P. notatus, P. promelas, S. atromaculatus, and N. stramineus were high again during the spring of 1979. In addition, for the first time during the course of sampling at this station, N. umbratilis was also abundant. Other common species collected in April included N. cornutus-N. chrysocephalus, F. notatus, E. spectabile, adult C. commersoni, and young C. carpio. In October, N. spilopterus, P. notatus, and P. promelas were the most abundant species, while N. stramineus was also common.

1980 - A sample taken in June 1980 revealed a somewhat depauperate, though seasonally typical, fish community dominated by P. promelas and a fair number of P. notatus.

Summary.

Although densities of individual species fluctuated somewhat, the spring fauna showed very little structural variation between years. Pimephales notatus, P. promelas, and, prior to 1978, E. buccata were consistently the most abundant species. However, during two recent years (1977 and 1979) S. atromaculatus has become much more abundant in spring samples. Furthermore, a similar increase in the density of N. stramineus and N. umbratilis occurred during 1979. The schools of adult C. commersoni, C. carpio, and C. cyprinus observed during the spring of 1978 is also noteworthy, since it indicates that these species probably spawn in this region.

During the summer months fish community structure was much more variable both within and between years. Furthermore, there were no general patterns to this variability except that one of the dominant species from 1974 through 1976, E. buccata, declined in importance thereafter. Species that were dominant for short periods of time included N. stramineus (June 1975), P. promelas and S. atromaculatus (August 1976), and C. cyprinus recruits (July 1977). Pimephales promelas was also the dominant species in the sample taken in June 1980 and P. notatus was abundant on limited occasions. In contrast to the lower stations, D. cepedianum migrants and recruits of C. commersoni, C. carpio, and C. cyprinus did not form a significant component of the summer fauna even though the latter three species appear to spawn nearby.

With the exception of 1975 when E. buccata was dominant, N. spilopterus was consistently the most abundant species during the fall months; however, only one fall sample was taken here after 1976. In this sample (October 1979), P. promelas, N. stramineus, and P. notatus were also fairly common. Pimephales notatus was also abundant in the fall of 1975.

Station 17.

1974 - Fish densities were low and community composition was poor during each of the four sampling dates in 1974. There was also considerable temporal instability, with S. atromaculatus dominating the fauna in April, P. notatus in June, and E. buccata in July and October. It is likely that extensive habitat perturbations throughout this year and an algal bloom in the fall were largely responsible for the depauperate fish community.

1975 - Considerably more fish were found here in March 1975 and, although E. buccata remained the domanant species, S. atromaculatus and P. notatus were also abundant. The presence of numerous one-year-old S. atromaculatus during the spring of 1974 and 1975 suggests that these young fish may be overwintering in this region. The final sample taken at this station was in May and yielded about the same number of fish as were caught in March; however, the species composition was not recorded.

Station 28.

1976 - In contrast to the temporal instability typically exhibited by the Black Creek fish fauna, community structure at this station underwent only minor changes in monthly samples from March through July 1976. During this period, E. buccata was the dominant species and P. notatus and P. promelas were consistently abundant; however, the density of P. promelas did decline considerably in July. In addition, owing to the recruitment of young, the number of S. atromaculatus increased steadily during June and July when it emerged as the second most abundant species. Other fairly common species, whose relative abundance also fluctuated significantly during this period, included N. stramineus in April, F. notatus in April and June, and C. anomalum and E. spectabile in June. The presence of about 80 mostly young E. spectabile in June is particularly noteworthy since it represents the greatest number of darters ever captured in a sample during the course of the study. In October, this area appears to have supported the highest density (>3000) of fish in the watershed. Although this included 14 species of fish, eight were represented by less than 20 individuals. Notropis spilopterus was the dominant species but over 700 P. notatus, 500 E. buccata, and about 180 individuals each of P. promelas, C. anomalum and S. atromaculatus were also captured.

1977 - Relative to the preceding fall, the fauna was rather sparse during the spring of 1977. Pimephales promelas, P. notatus, and S. atromaculatus were the most abundant species with the latter two species exhibiting substantial increases in density in May. The number of fish continued to increase, and the community underwent a significant change in July. Although S. atromaculatus maintained the same density as in May, equivalent numbers of E. buccata, D. cepedianum, and C. cyrpinus (young) were also found, while P. promelas, P. notatus, and young of C. carpio were common. In August the community was dominated by D. cepedianum and N. spilopterus migrants as well as recruits of C. cyprinus and C. carpio. The densities of S. atromaculatus and E. buccata declined during this month but both of these species remained fairly common along with P. promelas, P. notatus, N. cornutus-N. chrysocephalus, and young of C. commersoni. Migrants from the Maumee River continued to invade this area in September and included large numbers of N. spilopterus, N. stramineus, and D. cepedianum. Pimephales notatus and N. cornutus-N. chrysocephalus were also among the most abundant species captured. In fact, the density of N. cornutus-N. chrysocephalus was the highest recorded for this species to date. Other common species included S. atromaculatus, P. promelas, E. buccata, and young of C. cyprinus. Although the fauna was probably decimated by a fish kill in late September, N. spilopterus and D. cepedianum were still abundant in November. Semotilus atromaculatus, N. cornutus-N. chrysocephalus, P. notatus, and N. umbratilis were also common but N. stramineus showed a marked decline in density.

1978 - The density of fish was lower in April 1978 but N. stramineus re-invaded and was the dominant species along with P. notatus and P. promelas. Fifteen large, adult C. commersoni were also caught during this month. Semotilus atromaculatus was the dominant species and P. promelas, E. buccata and young of C. commersoni and C. carpio were common in August, the only other sampling date in 1978.

1979 - In contrast to the previous springs, a large number of fish, about half of which were P. notatus, were found here during April 1979. Pimephales promelas, N. stramineus, and S. atromaculatus were also very abundant while N. cornutus-N. chrysocephalus, N. umbratilis, N. spilopterus, and E. buccata were relatively common. A small number of young C. commersoni were also captured. With the exception of a significant decline in the density of N. stramineus, fish community structure was very similar in June when P. notatus, P. promelas, and S. atromaculatus were again the most abundant species. As was the case during October 1976, 14 species were again found here in October 1979, but only three species, N. spilopterus, N. cornutus-N. chrysocephalus, and N. stramineus, were abundant and only two others, P. notatus and N. umbratilis, could be considered common. The rest were represented by fewer than 20 individuals each.

1980 - Community composition during June 1980 was similar to that of June 1979 except N. stramineus and, to a lesser extent, N. cornutus-N. chrysocephalus were more abundant. Notropis stramineus was a co-dominant with P. notatus and P. promelas while S. atromaculatus and N. cornutus-N. chrysocephalus were the next most abundant species. In addition, about 20 large adult C. commersoni were still present.

Summary (17 - 28).

Fish densities were generally lower at Station 17 than at Station 28, particularly during 1974 when this area was subjected to extensive habitat perturbations. Although sampling was conducted somewhat infrequently in recent years, densities appear to have been consistently higher during 1979-80 than during previous years. In addition, more frequent samples in 1976 and 1977 reveal a seasonal pattern, characterized by an increase in density from spring to summer.

Species compositions and relative abundances were remarkably similar during the spring months both within and between years. The major long-term change that has occurred involves the population decline by E. buccata and a recent increase in the relative importance of N. stramineus, N. cornutus-N. chrysocephalus, and N. umbratilis. Ericymba buccata was particularly abundant here prior to its decline, and was the dominant species during the spring of 1975 and 1976. Pimephales notatus, P. promelas, and S. atromaculatus were also abundant during the first three years of sampling and remained so through the last spring sample in 1979. The density of P. notatus was particularly high during April, 1979. Although N. stramineus was fairly common in a spring sample in 1976, it was much more abundant in samples taken during April of 1978 and 1979. Notropis umbratilis and N. cornutus-N. chrysocephalus were also significantly more abundant in April, 1979 than during any previous spring.

To a large extent community structure during the summer months of 1974 and 1976 mirrored that of the spring of these years. Ericymba buccata, for example, was the dominant species and P. notatus and S.

atromaculatus were also abundant. From 1977 through 1980 the latter two species played an ever more prominent role in the community although the density of P. notatus generally declined as the summer progressed. In contrast, E. buccata, though it was still a dominant species in July 1977, was never very abundant thereafter. The increase in fish density that occurred during the summer of 1977 and 1978 was largely due to the recruitment of C. cyprinus, C. carpio, and C. commersoni, and immigration of N. spilopterus and D. cepedianum, all of which were dominant species in samples during these years. Pimephales promelas, another common species during the summer months of 1976 through 1978, showed a signficant increase in density in June samples during 1979 and 1980. Notropis cornutus-N. chrysocephalus and especially N. stramineus were also more abundant in June 1980 than in any previous summer sample.

After October 1974, when E. buccata was the dominant species, N. spilopterus was consistently the most abundant species in the fall samples. However, an unusually large concentration of fish were found here during the fall of 1976 and also included high densities of E. buccata, P. notatus, P. promelas, C. anomalum, and S. atromaculatus. All of these species except C. anomalum were also common during the fall of 1977 and/or 1979. Co-dominant species with N. spilopterus in recent years included D. cepedianum during 1977 and N. stramineus and N. cornutus-N. chrysocephalus during both 1977 and 1979.

Station 29.

1976 - During March - April 1976, more than eight times as many fish were caught here than at nearby Station 15. This large concentration of fish consisted primarily of two-year-old E. buccata and marked the height of this species' population explosion in the watershed. A large number (>200) of P. notatus, N. spilopterus, N. stramineus, and P. promelas were also caught during this period. The density of P. promelas, although not very high in March, increased substantially in April when N. stramineus apparently moved downstream. The density of fish declined significantly during May - June but E. buccata remained the dominant species and P. notatus, P. promelas, and N. stramineus were still common. The number of E. buccata rose again during July with the recruitment of the 1975 year class and influx of adults from upstream. Pimephales notatus and N. stramineus also exhibited slight increases in abundance and recruits of C. carpio and C. commersoni became common. A significant change in community structure occurred in August when, in addition to E. buccata, four other species reached dominant status. These included a school of young D. cepedianum migrants from the Maumee River, recruits of S. atromaculatus and C. cyprinus, and an influx of P. notatus adults from upstream. Evidence of downstream movement was also exhibited by P. promelas and may have been a response to deteriorating habitat conditions upstream brought about by the severe drought. Notropis stramineus and young C. anomalum, C. commersoni, and F. notatus were also common. A marked decline in the E. buccata population was evident by September but it remained a co-dominant species with S. atromaculatus. Although about 350 D. cepedianum were captured here in August, none were found in the September sample, illustrating the transient nature of this species in Black Creek. Pimephales notatus and C. cyprinus also exhibited substantial declines in density but P. notatus and P. promelas were still fairly abundant. Due to sampling inadequacies, a November sample give an unreliable picture of community structure, but documents the immigration of N. spilopterus and suggests that it was probably the dominant species at that time.

1977 - Relative to March - April 1976, the density of fish was much lower during the early spring of 1977. By May, community structure was more comparable but notable contrasts with the previous year were still evident. In 1977, for example, the abundance of N. stramineus increased from March through May when it became the dominant species, but declined through the same period in 1976. The low numbers of E. buccata and N. spilopterus found during the entire spring of 1977 is even a more striking contrast. In addition to N. stramineus, P. promelas and P. notatus were also particularly abundant during May 1977. Furthermore, like N. stramineus, these species along with S. atromaculatus and N. umbratilis all increased in density from March through May. The community changed drastically in July when, coincident with an influx of D. cepedianum and recruitment of young C. carpio and C. cyprinus, all cyprinids became scarce. A fairly large number of N. spilopterus immigrated in August but D. cepedianum remained dominant and C. carpio and C. cyprinus young were still common. Many D. cepedianum appear to have left the watershed by the end of September but were replaced by an immigrating school of N. stramineus which, along with N. spilopterus, became the dominant species. Although a devastating fish kill affected this area a day after the September sample, representatives of most of the same species were found in November. However, their densities (particularly that of N. stramineus) were much lower.

1978 - Fish density remained rather low during April - May 1978 and, as was the case during the spring of 1977, P. notatus, N. stramineus, and P. promelas were the most abundant species (though not nearly as abundant as during the previous spring). About 30 large adult C. commersoni were also caught during late April, apparently as they were moving upstream to spawn. The density of P. notatus, P. promelas, and N. stramineus remained the same during July and August when a similar number of S. atromaculatus adults and C. commersoni and C. carpio recruits were also caught. Consequently, during this period the eveness component of species diversity was high. This changed somewhat during November, however, when a much larger number of fish were caught than during any of the prior sampling dates in 1978. At that time, S. atromaculatus, P. notatus, and P. promelas emerged as dominant species, but N. spilopterus, E. buccata, C. anomalum, N. cornutus-N. chrysocephalus, and C. commersoni (recruits) were also abundant.

1979 - Although the density of fish declined in April 1979, it was still considerably higher than during the previous two springs. Pimephales notatus and S. atromaculatus remained the dominant species but P. promelas and N. stramineus were also fairly abundant. As was also the case at stations 15 and 12, both young and adult C. commersoni were also captured, providing evidence that some individuals of this species overwintered in Black Creek.

Summary.

Fish densities in the spring of 1976 approached the highest levels ever recorded in Black Creek, but were not maintained or duplicated on subsequent sampling dates. Furthermore, this unusually high density of fish was largely due to a population explosion by E. buccata, which was particularly abundant here prior to its decline in the watershed. With the exception of E. buccata's numerical dominance and the presence of a large number of N. spilopterus in 1976, the structure of the fish community was remarkably similar during the spring of each year. Pimephales notatus, P. promelas, and N. stramineus were the most abundant species but S. atromaculatus was a co-dominant in April 1979. However, monthly variation in the density of these species was somewhat inconsistent between years and is likely attributable to different flow regimes.

Relative to the next two years, the density of fish was also abnormally high during the summer of 1976. However, in contrast to the spring of that year, four other species in addition to E. buccata formed significant components of this density. These included P. notatus, D. cepedianum, and recruits of C. cyprinus and S. atromaculatus. None of these species were particularly abundant during the summer months in subsequent years, but all except E. buccata were fairly common along with P. promelas, N. stramineus, N. spilopterus, and young of C. carpio, C. commersoni, C. anomalum, and F. notatus in at least one other sample during June through August.

Although their relative densities varied between years, S. atromaculatus, N. spilopterus, P. promelas, and P. notatus were the most abundant species during the fall months. Other fairly abundant species during this period included E. buccata in 1976 and 1978, N. stramineus in 1977, and C. anomalum, C. commersoni (young), and N. cornutus-N. chrysocephalus in 1978. The abundance of N. cornutus - N. chrysocephalus is somewhat unusual since prior to this, the maximum number of individuals of this species that were caught at this station was only 14. The presence of over 90 C. commersoni recruits in the late fall of 1978 is also noteworthy. It appears that many of these fish overwintered in this region.

Station 15.

1974 - Fish were not very abundant here during the spring of 1974, but the presence of 21 large adult C. commersoni is noteworthy and indicates a spawning run by this species was at least attempted during this year.

Adult S. atromaculatus and N. connutus- N. chrysocephalus were also common, though not abundant, in April and May samples. The density of fish doubled in September relative to May, mainly due to the immigration of N. spilopterus. Young L. cyanellus, S. atromaculatus, and adult N. connutus - N. chrysocephalus and E. buccata were also common.

1975 - In contrast to the previous spring, the most abundant species during March and April 1975 were P. notatus and E. buccata. Notropis spilopterus, N. cornutus- N. chrysocephalus, and one-year-old S. atromaculatus were also common. The density of N. spilopterus was similar to that found during the spring of 1974 (ca. 25 - 35). All species that were common in the spring declined in abundance during May - June and were replaced by immigrating N. stramineus. During July, N. stramineus declined in abundance and a large number (>100) of E. buccata fry were caught. Pimephales notatus and S. atromaculatus were also common. The fauna was depleted by a fish kill in early August and did not begin to recover until October when there was an influx of P. notatus, E. buccata, and especially N. spilopterus.

1976 - Although E. buccata was very abundant, the fish community remained rather poor through the spring of 1976. The only other common species were N. spilopterus (March) and P. notatus (March and May). Ericymba buccata remained dominant through July when P. notatus, P. promelas, N. stramineus, F. notatus, and recruits of C. carpio and C. commersoni also became abundant. During August the density of E. buccata declined sharply and the community was dominated by a large number of S. atromaculatus recruits. Pimephales notatus, F. notatus, and D. cepedianum were also fairly abundant during this month, but the density of N. stramineus, C. commersoni and C. carpio fell dramtically. Ericymba buccata, along with N. spilopterus, became dominant again in October as the density of S. atromaculatus declined. Campostoma anomalum and F. notatus were also fairly common during this month.

1977 - The only sample during 1977 was taken in September when N. spilopterus and N. stramineus were the dominant species. Pimephales notatus, P. promelas, N. cornutus- N. chrysocephalus, D. cepedianum, and C. cyprinus were also fairly abundant.

1978 - The community was again somewhat sparse during the spring of 1978. The most common species were S. atromaculatus, N. cornutus - N. chrysocephalus, P. notatus, P. promelas, and N. stramineus. During July the fauna was dominated by a mixture of both young and adult S. atromaculatus. Pimephales promelas, P. notatus, C. anomalum, N. cornutus - N. chrysocephalus and C. commersoni recruits were also common.

1979 - In contrast to all previous years, a large concentration of fish was found here in April of 1979 but was primarily composed of P. notatus. Other very abundant species included P. promelas, N. stramineus, and S. atromaculatus. Catostomus commersoni was also abundant and included both young and large adults. Notropis spilopterus, N. cornutus - N. chrysocephalus, E. buccata, P. maculata, E. spectabile, C. anomalum, the end of April indicating that their emigration back into the Maumee River was nearly complete. During March and early April all captured S. atromaculatus were one-year-olds; however, older individuals were caught later in April. It is therefore likely that many of the young were leaving Black Creek as the adults enter to spawn. Pimephales promelas, E. buccata, N. stramineus, and N. cornutus-N. chrysocephalus were also common during the spring months. A fish kill decimated the fauna at the end of May and recolonization proved to be very slow during June. A fairly large number of E. buccata recruits (ca. 100) were caught during July but no other species was particularly abundant. The region was depleted by another fish kill in early August and recolonized by N. spilopterus, N. stramineus, P. notatus, and D. cepedianum. The community was still depauperate in September and dominated by D. cepedianum. In October only P. notatus and N. spilopterus were common.

1976 - As in the spring of 1975, a large number of fish were caught in March-April 1976 and N. spilopterus was again a dominant species. Pimephales notatus was also abundant; however, unlike the previous year S. atromaculatus was not abundant and N. stramineus was a co-dominant species during the early spring in 1976. Notropis umbratilis, E. buccata, P. promelas, and L. cyanellus were also common during March-April. Notropis stramineus remained very abundant during May while the density of N. spilopterus decreased significantly. High densities of E. buccata and S. atromaculatus were found in late May and N. umbratilis, P. promelas, and L. cyanellus remained common. With the apparent emigration of N. stramineus and adult S. atromaculatus during June, E. buccata emerged as the dominant species. The density of N. umbratilis also decreased during this month but eight other species, including recruits of C. commersoni were common. The major changes in July were a marked decrease in density of P. notatus, P. promelas, E. buccata, N. stramineus, N. spilopterus, and L. cyanellus, and the recruitment of young C. carpio, I. natalis, and C. commersoni. Young S. atromaculatus were also common. Recruits of C. commersoni and I. natalis increased in abundance in September. This sample also consisted of large numbers of C. anomalum and both young and adult S. atromaculatus and a fair number of P. promelas and P. notatus. October was marked by the immigration of large numbers of N. stramineus and N. spilopterus. Over 100 individuals of S. atromaculatus, E. buccata, and P. notatus were also caught. P. promelas and C. anomalum remained common but most I. natalis and C. commersoni appeared to have emigrated into the Maumee. It is likely that many of the S. atromaculatus, P. promelas, P. notatus, and E. buccata found here during September - October were seeking refuge from severe drought conditions in upstream tributaries.

1977 - Possibly as a result of a severe winter, only about half as many fish were found here during the spring of 1977 as were caught at this time during the two previous years. Large numbers of N. spilopterus, in particular, were notably absent. The dominant species during April and May were P. promelas and P. notatus, respectively. Also common during these months were S. atromaculatus, N. stramineus, N. umbratilis,

N. umbratilis, and L. cyanellus were common. The dominant species during October were N. stramineus and P. notatus. Also abundant were S. atromaculatus, N. cornutus - N. chrysocephalus, N. spilopterus, N. umbratilis, and especially P. promelas.

1980 - During June 1980 N. stamineus was again dominant but N. cornutus - N. chrysocephalus, P. promelas, and P. notatus were also abundant. Other common species included S. atromaculatus, F. notatus and E. buccata.

Summary.

Up until recently, the fish fauna was generally rather sparse during the spring months and rarely consisted of large numbers of any species. Pimephales notatus and E. buccata (prior to its decline in the watershed) were the most abundant species during this period and S. atromaculatus, N. cornutus - N. chrysocephalus, N. spilopterus, and N. stramineus were common. Fish were much more abundant in the spring of 1979 when P. notatus was the dominant species. The density of P. promelas, S. atromaculatus, and N. stramineus was also significantly higher in April 1979 than during any of the previous springs. In addition, the presence of a large number of both young and adult C. commersoni suggests that perhaps for the first time during the course of sampling, a small population of this species may have overwintered in Black Creek.

Analysis of long-term trends in community structure during the summer months is hindered by infrequent sampling from 1977 to 1980 and the fish kill that affected this area in 1975. The most abundant species during this period were N. stramineus, both young and adult S. atromaculatus, P. notatus, P. promelas, and on limited occasions D. cepedianum, F. notatus, and recruits of C. commersoni and C. carpio.

During the fall months, N. spilopterus was consistently one of the most abundant species but never reached particularly high densities (e.g. >200). However, the fall density of N. stramineus increased steadily from 1977 to 1979 when over 500 individuals were captured. This trend coincides with the population decline of E. buccata - the dominant species during the fall of 1976. Pimephales notatus was also relatively abundant during most years and emerged as a co-dominant species with N. stramineus in October 1979. Other common fall species included S. atromaculatus, P. promelas and N. cornutus - N. chrysocephalus.

Station 12.

1973 - 1974 - Initial samples in July 1973 and April and July 1974 did not yield a very large number of fish (90-130) and no species was particularly dominant on any of the three dates.

1975 - During March - April 1975 there was a large concentration of fish (500 - 1000) consisting primarily of N. spilopterus, P. notatus, and S. atromaculatus. The number of N. spilopterus decreased significantly by

L. cyanellus, L. macrochirus, and L. microlophus. The density of fish declined considerably during June, probably in response to a dense algal bloom affecting this region. Both Pimephales species, N. stramineus, and N. umbratilis showed significant decreases in abundance and no species was dominant. July was marked by the recruitment of young C. carpio and C. cyrpinus and the immigration of D. cepedianum. Notropis stramineus and N. spilopterus invaded this region along with more D. cepedianum during August. By September, N. stramineus was the dominant species but P. promelas, P. notatus, D. cepedianum, N. spilopterus, and L. cyanellus, and recruits of C. commersoni and C. cyprinus were all common. The species composition was similar in November but N. stramineus, P. promelas, P. notatus, and C. cyprinus were considerably less abundant.

1978 - As in 1977, large number of N. spilopterus and fish in general were again not found during the spring of 1978. Community structure was also very similar to the previous spring with P. promelas, P. notatus, N. stramineus, N. umbratilis, and N. cornutus-N. chrysocephalus the most common species. However, the sunfish (Lepomis spp) were considerably less abundant than they were in 1977. Two samples in July clearly illustrate the vicissitude of the Black Creek fish fauna. During the first week in July a large number (>400) of N. stramineus were caught along with a fair number of E. buccata (47), P. notatus (64), F. notatus and recruits of C. carpio, C. commersoni, and C. cyprinus. At the end of July the abundance of the latter four species remained about the same; however, only 12 P. notatus, 1 E. buccata, and no N. stramineus were caught. In addition, a small number of I. natalis and I. melas recruits were found and P. promelas and S. atromaculatus showed significant increases in density. In contrast, with the exception of an influx of a few D. cepedianum and a decrease in the abundance of C. commersoni and C. cyprinus young, the fish community showed little change through September. However, a tremendous number of fish, especially P. notatus recruits, were found in November. Pimephales promelas, S. atromaculatus (recruits), N. spilopterus, and N. umbratilis were abundant and N. stramineus and N. cornutus-N. chrysocephalus were common. This was the first year that such a large number of young (particularly P. notatus, P. promelas, and N. umbratilis) were found here during the fall.

1979 - The species composition and density was similar in April 1979, except S. atromaculatus, N. umbratilis, and N. cornutus-N. chrysocephalus were not as abundant while the number of F. notatus and L. cyanellus increased slightly. The presence of young I. melas and C. commersoni is also noteworthy for this time of the year. It appears that for the first time young C. commersoni overwintered in Black Creek. The density of fish, particularly P. notatus, P. promelas, and N. stramineus dropped precipitously in June. However, relative to this date during previous years, there was an unusually large number of N. spilopterus, N. cornutus-N. chrysocephalus, and adult C. commersoni present. In addition to these species, S. atromaculatus, F. notatus, and N. umbratilis were fairly common. During October, N. spilopterus was the dominant species but large numbers (>100) of N. stramineus and young of P. notatus and N. umbratilis were also caught. Other common species included S. atromaculatus, N. cornutus-N. chrysocephalus, F. notatus, and L. macrochirus (young).

1980 - During June 1980 the dominant fish were N. umbratilis and N. stramineus. Pimphales notatus, N. spilopterus, F. notatus, and C. commersoni were common.

Summary.

Limited sampling during 1973 and 1974 yielded considerably less fish than were usually caught at this station from 1975-1980. During these latter years fish density was generally high in the spring, lower in the summer, and high again in the fall. Lower densities than usual were encountered during the spring of 1977 and 1978, possibly due to heavy mortality during the severe winters that preceded these samples. Large numbers of N. spilopterus, a dominant species during other springs, were notably absent in 1977 and 1978. Other abundant species found during the spring months (March - May) include P. notatus, P. promelas, S. atromaculatus, N. stramineus, and E. buccata. The degree of dominance exhibited by these species and N. spilopterus varied from early to late spring as well as between years. Other fairly common species found during the spring months include N. umbratilis, N. cornutus-N. chrysocephalus, L. cyanellus, and less frequently, L. macrochirus, L. microlophus, and F. notatus. The summer months (June - August) were characterized by the presence of numerous recruits and a decrease in abundance of most species that were common during the spring. The decline in density of N. spilopterus and N. stramineus is particularly striking as these species migrate out of Black Creek and back into the Maumee River. The dominant species during the summer include recruits of C. carpio, C. commersoni, C. cyprinus, I. natalis, I. melas, and S. atromaculatus. In addition, large numbers of D. cepedianum young commonly migrate into Black Creek during July or August. Another significant change in community structure occurs in the late summer or fall and is marked by the immigration of N. spilopterus and N. stramineus. Other abundant species found during the fall include P. notatus, P. promelas, D. cepedianum, S. atromaculatus, and less freqeuently, E. buccata, C. anomalum, C. commersoni (young), I. natalis (young), C. cyrpinus (young), N. cornutus- N. chrysocephalus, N. umbratilis (young), L. cyanellus, and L. macrochirus (young). The presence of numerous young P. notatus, P. pomelas, L. macrochirus, and especially N. umbratilis is a recent (1978-1979) occurrence. An increase in the abundance of F. notatus (especially during the summer months) and the presence of young C. commersoni during the spring are also noteworthy recent developments.

## SPECIES RICHNESS AND DIVERSITY

As in the previous section we describe the fish fauna from the headwaters to downstream areas. Species richness is the number of species in a sample while diversity is indexed by the Shannon-Weiner function (see Methods).

Station 6 - 26 - During most years this station supported an average of 7-8 species; however, species richness was much lower in 1974 after channelization (Fig. 11). It was also above normal in 1977 when 14 - 19

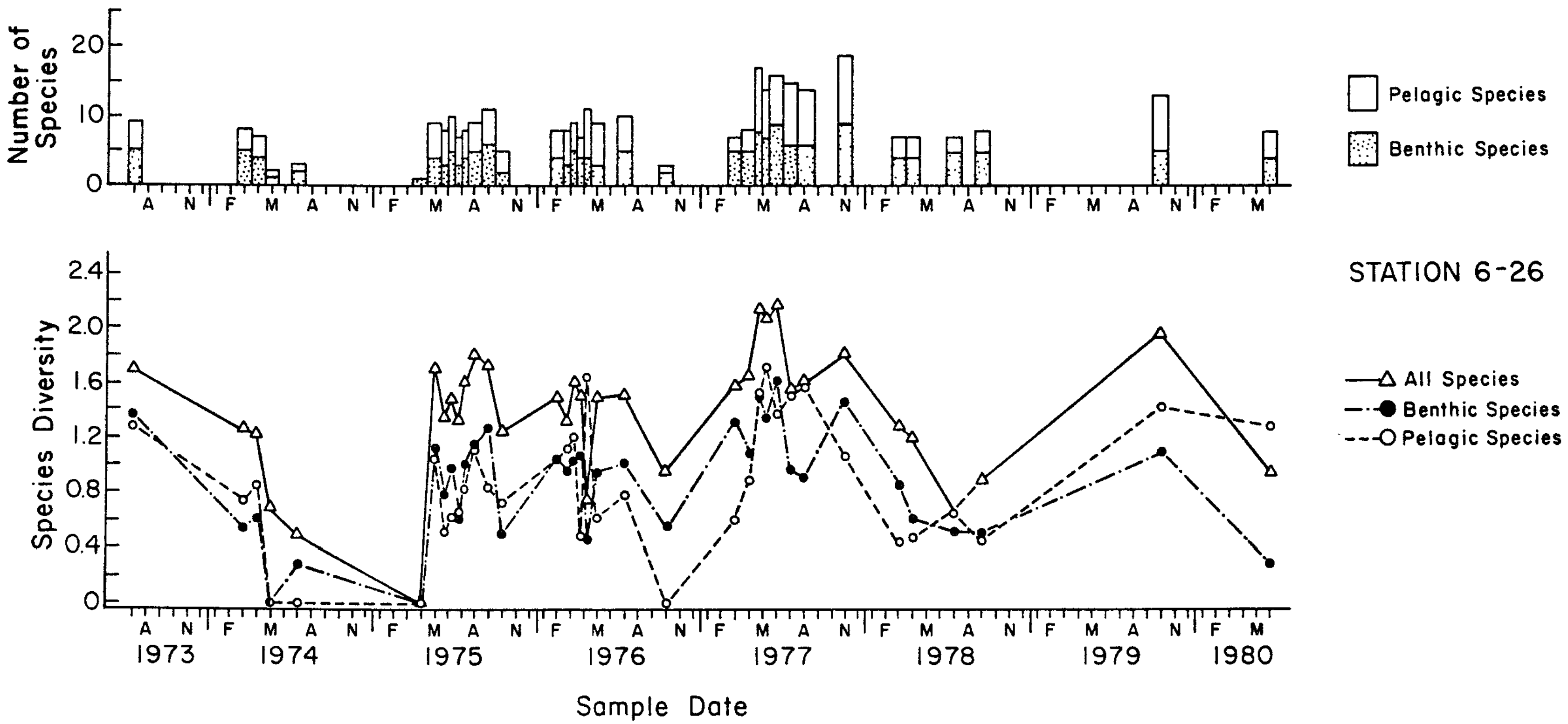



Figure 11. Number of species and species diversity for fish at Station 6-26 in the Black Creek Watershed, 1973-1980. Station 26 sampled February - May 1976 only.

species were caught on all six sampling dates from May through November. No seasonal trends were discernable and the species composition was generally evenly divided between benthic and pelagic forms. The most common benthic species were P. promelas, P. notatus, E. buccata, C. carpio, and C. commersoni. The most common pelagic species were S. atromaculatus, N. cornutus - N. chrysocephalus, N. umbratilis, N. spilopterus, and L. cyanellus.

Species diversity was maintained between 1.2 and 1.9 during about 70% of the sampling dates but fell to fairly low levels (<1.0) during May and July 1974, April 1975, April and October 1976, July and September 1978 and June 1980. The highest levels of diversity (2.0 - 2.2) occurred during May and June 1977, owing primarily to the relatively large number of species present. There were clearly no definitive seasonal patterns. The diversity of benthic and pelagic species was remarkably similar during most sampling dates and hence mirrored the total species diversity curve. Extremely low levels of species diversity were either due to low numbers of fish present (April and July 1974, April 1975, and October 1976) or dominance by a benthic species (P. promelas - 22 April 1976 and 26 June 1980, C. carpio - July and September 1978).

Station 18.

Infrequent sampling after 1977 hinders long-term evaluations of species richness patterns at this station, but it appears that the number of species present has increased in recent years (Fig. 12). Although species richness was very low during the spring of 1978, 11-15 species were caught here during every other sampling date from 1977 - 1980. During extensive sampling in 1975 and 1976 an average of only about 8 species/sample were caught. During most sampling dates there were slightly more benthic species than pelagic species. The most common benthic species were P. notatus, P. promelas, E. buccata, and N. stramineus. The most common pelagic species were S. atromaculatus, N. cornutus - N. chrysocephalus, N. spilopterus, N. umbratilis, and F. notatus.

Species diversity fell below 1.0 during July 1974, September - October 1975 and September - November 1976 and reached its highest levels (1.8 - 2.1) during 1977 and 1979. From 1974 - 1976 benthic diversity and pelagic diversity differed markedly, but were fairly similar from 1977-1980. Relative to the downstream stations benthic diversity was more consistent and lacked distict seasonal peaks. Low levels of benthic diversity were caused by the dominance of E. buccata (July 1974 and September - October 1975) and P. promelas (June 1980) or low densities of benthic fish (September 1976 and March 1978). Extremely low levels of pelagic diversity recorded during 1974 - 1976 were due to low pelagic species richness and dominance by N. spilopterus during the fall months. Given the low numbers of individuals and species found here, it does not appear that this station provided very good habitat for pelagic species (at least prior to 1977) and accounts for the dramatic fluctuations in pelagic diversity. The greater stability exhibited by pelagic diversity measures

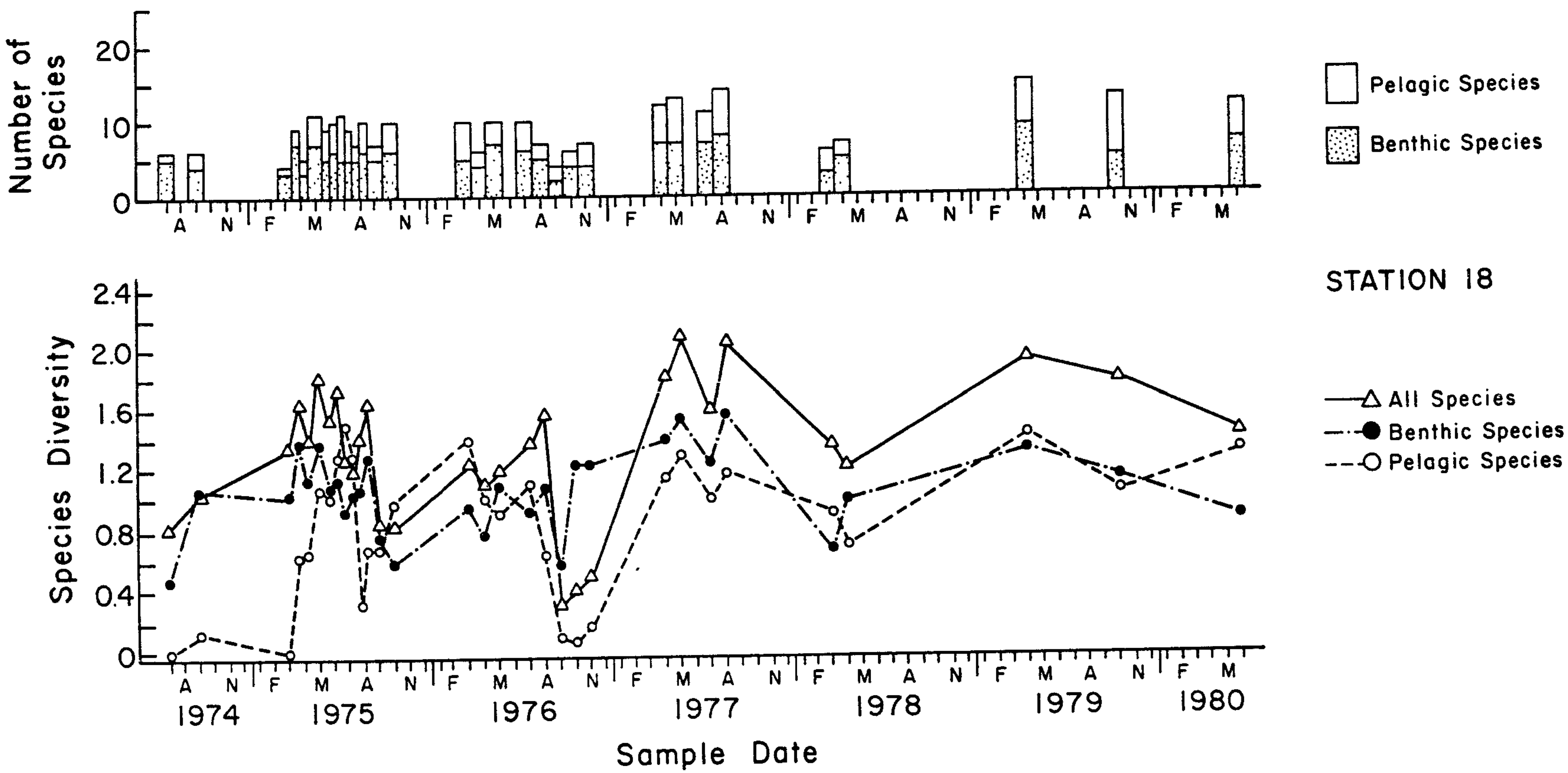



Figure 12. Number of species and species diversity for fish at Station 18 in the Black Creek Watershed, 1973 - 1980. Station 26 sampled February - May 1976 only.

in recent years appears to be due to improved conditions for pelagic species and has contributed to higher levels of total species diversity.

Station 17 - 28.

Species richness at Station 28 proved to be considerably higher than in Station 17 (Fig. 13) but could have been due to the habitat alterations that occurred during the first two years of sampling. Species richness at Station 28 ranged from 9 - 17 species with 17 species being captured on three separate occasions (8 August 1977, 19 April 1979, and 28 June 1979). Average species richness during 1976 appeared to be lower than during each of the following years and there was a slight increase in the number of species found during the summer months of 1976-1978. During most sampling periods benthic species were more numerous than pelagic species. The most common benthic species were P. promelas, P. notatus, E. buccata, C. anomalum, N. stramineus, C. carpio, C. commersoni, C. cyprinus, E. nigrum, E. spectabile, and D. cepedianum. The most common pelagic species were S. atromaculatus, N. cornutus - N. chrysocephalus, N. spilopterus, N. umbratilis, F. notatus, and L. cyanellus.

Species diversity at Station 28 was consistently above 1.4; however, much lower levels were recorded at Station 17 during 1974. The highest level of diversity (2.41) occurred on 24 August 1977. Benthic diversity basically mirrors the total species diversity curve, but exhibits more distinct peaks during the summer months of 1977 and 1978. These high levels of benthic diversity were brought about by the influx of D. cepedianum and recruitment of C. commersoni, C. carpio, and C. cyprinus. In contrast to benthic diversity, pelagic diversity showed rather sharp and erratic fluctuations. This can be attributed to the paucity of the pelagic fauna (at least through 1976) and shifts in dominance by S. atromaculatus and N. spilopterus. Although limited sampling in 1978 would indicate otherwise, the diversity of the pelagic fauna appears to have improved in recent years.

Station 29.

During each of the three years of intensive sampling (1976 - 1978) at this station species richness patterns were remarkably consistent, ranging from 10 - 18 species/sample with an average of about 13 species (Fig. 14). There was a clear seasonal trend with the number of species present, particularly benthic species, increasing from spring to summer and decreasing again during the fall. This was due to the recruitment of young C. commersoni, C. carpio, and C. cyprinus, and the influx of D. cepedianum. The most common benthic species found here were P. promelas, P. notatus, E. buccata, C. anomalum, N. stramineus, C. carpio, C. commersoni, C. cyprinus, and D. cepedianum while the most common pelagic species included S. atromaculatus, N. cornutus - N. chrysocephalus, N. spilopterus, N. umbratilis, F. notatus, and L. cyanellus.

As was the case at nearby station 15, species diversity was relatively low during the first half of 1976, but rose sharply in August 1976 and was maintained above 1.7 thereafter. The highest level (2.37) was recorded on 16 August 1978. Total species diversity measures also show a

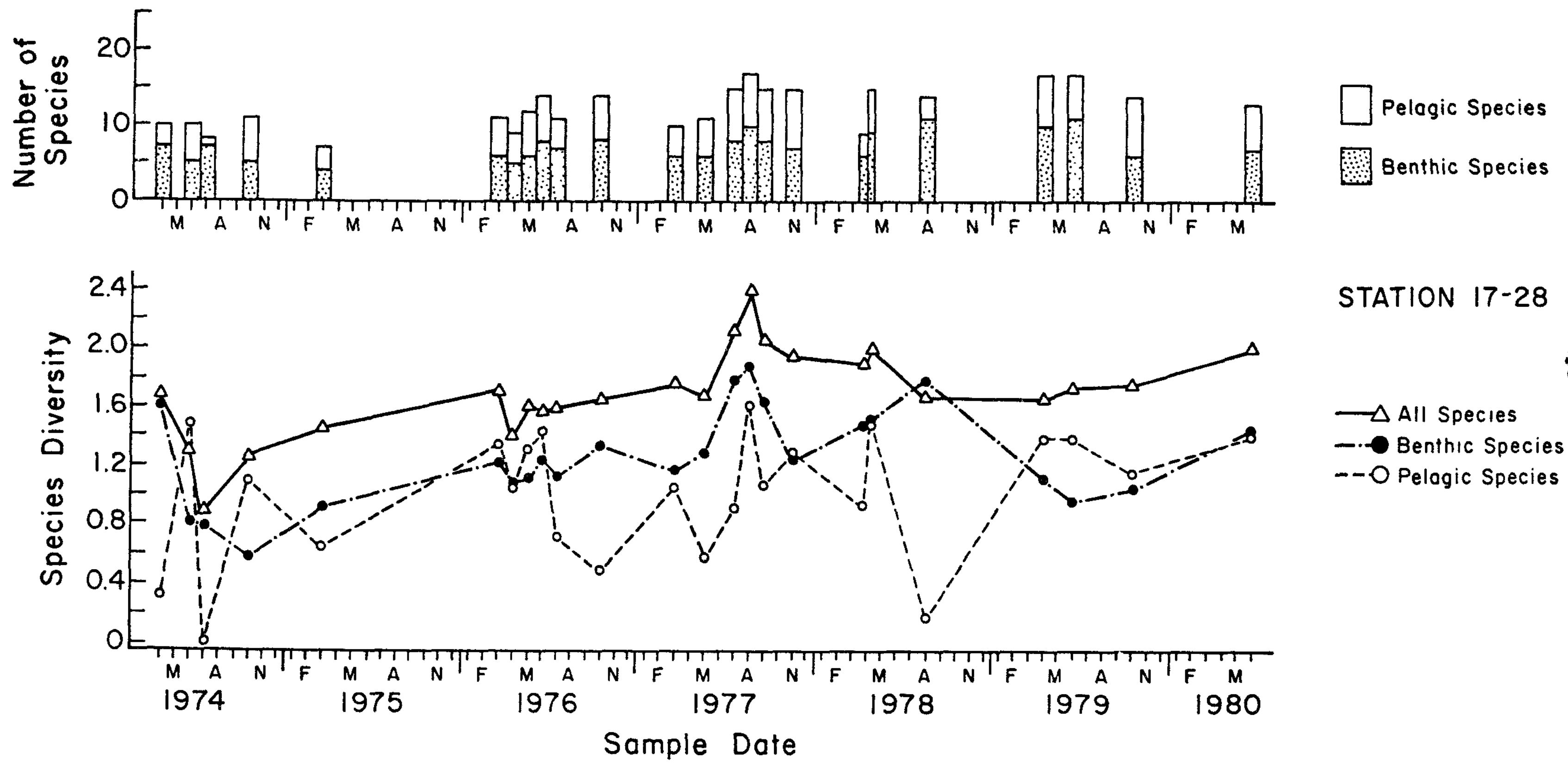





Figure 13. Number of species and species diversity for fish at Station 17-28 in the Black Creek Watershed, 1973 1980. Station 17 sampled in 1974 - 1975 and Station 28 sampled from 1976 - 1980.

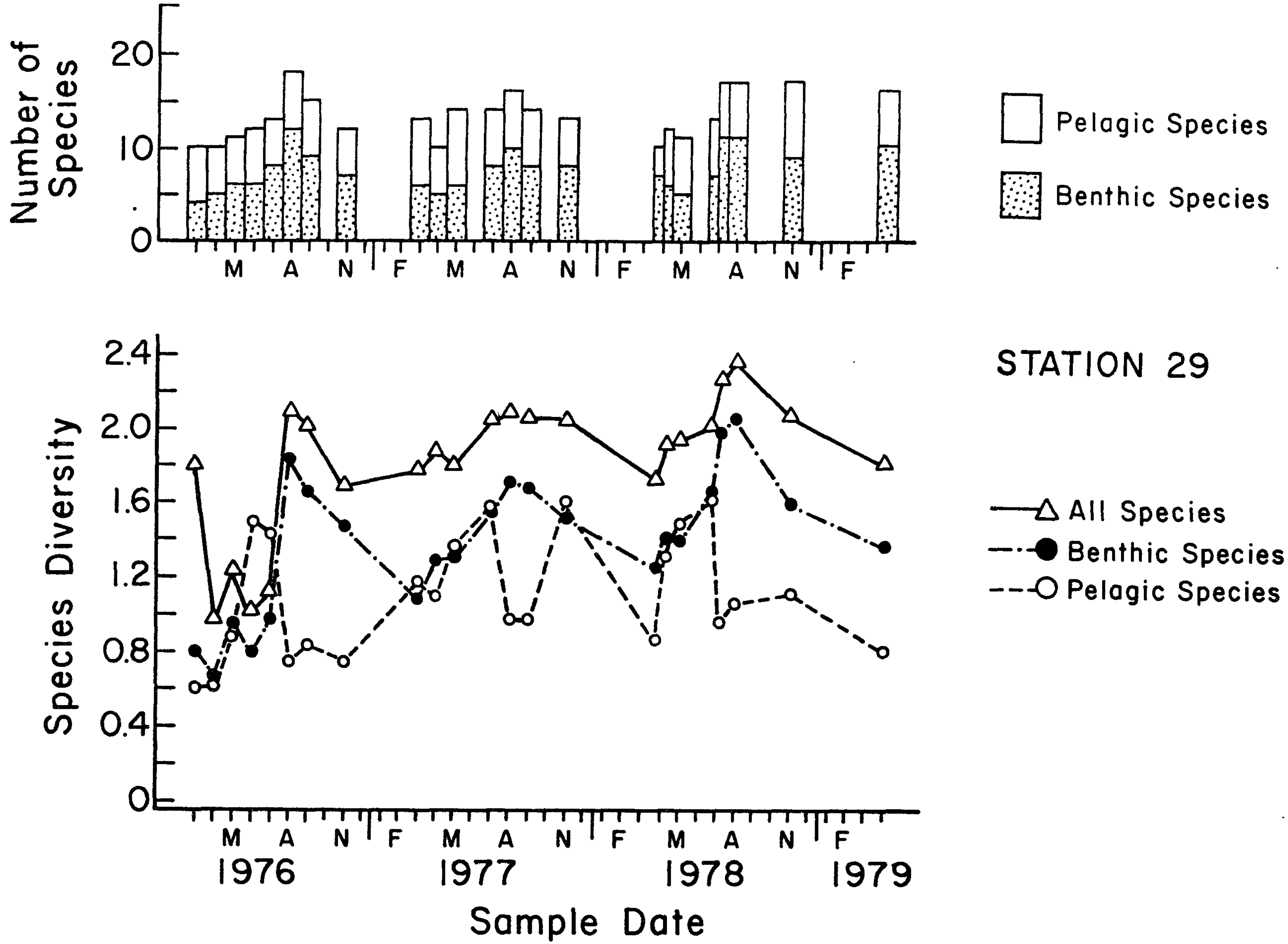





Figure 14. Number of species and species diversity for fish at Station 29 in the Black Creek Watershed, 1973-1980.

clear seasonal pattern but benthic diversity and pelagic diversity curves are more revealing. For example, owing primarily to an increase in species richness, benthic diversity exhibited a distinct peak in August of each year from 1976 - 1978. The low levels recorded from March through July 1976 were due to extreme dominance by E. buccata. In contrast, pelagic diversity reached its highest seasonal levels a month or two earlier than benthic diversity during a "turnover" period when there was a change in the dominant species within the pelagic fauna. For example, high levels of pelagic diversity were recorded when there was a shift in dominance from N. spilopterus in April 1976 to S. atromaculatus in August 1976, and from S. atromaculatus and N. umbratilis in May 1977 to N. spilopterus in August 1977. Although no pelagic species was dominant in early 1978, pelagic diversity rose with an increase in species richness in late April but fell again when S. atromaculatus became dominant in July.

Station 15.

Twenty-two species were found at this station when it was sampled with an electric seine on 20 April 1979 (Fig. 15); however, during years when more than two samples were taken, an average of only about 9 - 11 species was caught. In fact, species richness was consistently low from October 1974 through the spring of 1976, and during each of the three sampling dates in 1978. A seasonal trend, marked by an increasing number of benthic species occurring during the summer months, was evident during 1976 and 1978. This was due to the immigration of D. cepedianum, and recruitment of young C. carpio, C. commersoni, C. cyprinus and during 1976, E. nigrum and E. spectabile. In addition, the number of benthic species usually exceeded the number of pelagic species. The most common benthic species were P. promelas, P. notatus, E. buccata, C. anomalum, N. stramineus, and C. commersoni and the most common pelagic species were S. atromaculatus, N. cornutus - N. chrysocephalus, N. spilopterus, N. umbratilis, L. cyanellus and F. notatus.

Species diversity was fairly high during the initial sampling in 1974 but declined precipitously from June 1975 until 8 April 1976 when only three species were caught and diversity measured 0.39. Thereafter species diversity returned to previous levels and a high of 2.20 was recorded on 7 October 1976. Both benthic and pelagic diversity reflected the total species diversity curve through its decline in early 1976; however, during the recovery period benthic diversity generally exceeded pelagic diversity and was largely responsible for the shape of the total species diversity curve. Low levels of pelagic diversity from 1976 - 1978 were caused by the dominance of S. atromaculatus and N. spilopterus over a rather sparse pelagic fauna. Note that the large number of species (22) captured on 20 April 1979 did not produce a particularly high level of species diversity, reflecting extreme numerical dominance of P. notatus.

Station 12.

Relative to 1973 - 1975 there was a definite increase in species richness at this station from 1976 - 1980 (Fig. 16). The fewest

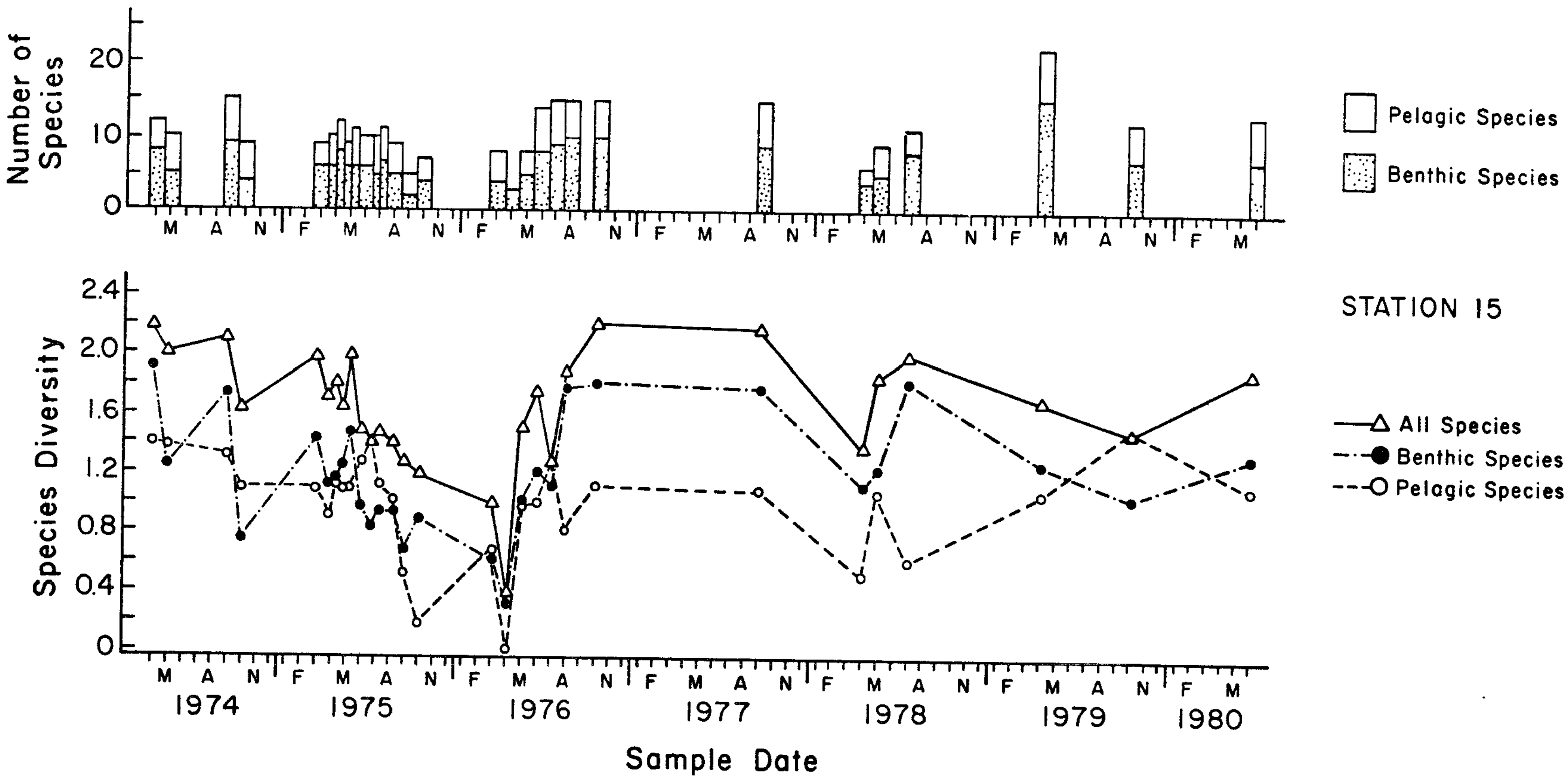



Figure 15. Number of species and species diversity for fish at Station 15 in the Black Creek Watershed, 1973 - 1980.

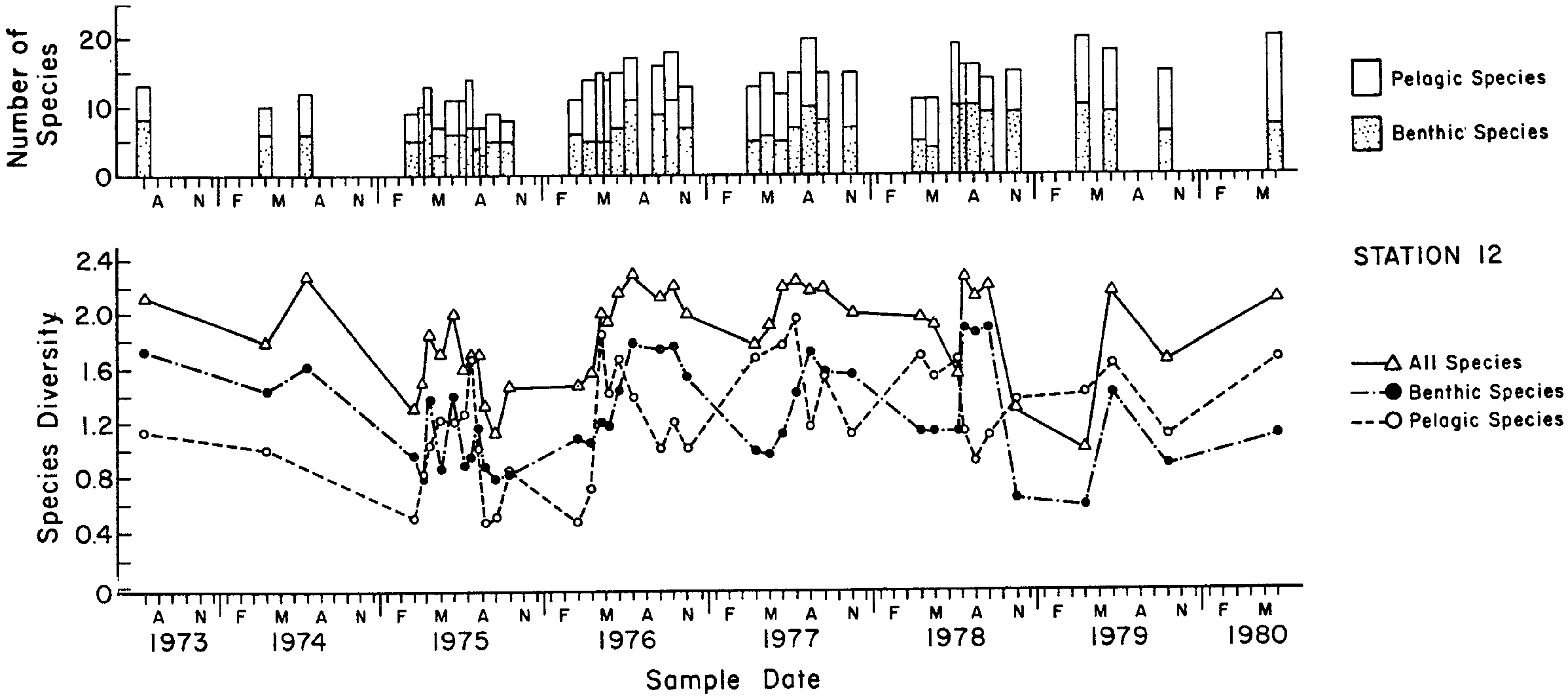



Figure 16. Number of species and species diversity for fish at Station 12 in the Black Creek Watershed, 1973-1980.

species were caught during August 1975 - October 1975, largely due to the fish kill that affected this area in early August 1975. However, during 1976 and each of the following years an average of about 15 species was caught and on three occasions (23 August 1977, 20 April 1979, and 26 June 1980) 20 species comprised the samples. In addition, during 1976-1978 when intensive sampling was terminated, a clear seasonal trend emerged with more benthic species caught during the summer months. However, in general, pelagic species slightly exceeded the number of benthic species at this station. The most common benthic species captured were P. promelas, P. notatus, E. buccata, N. stamineus, C. commersoni, C. cyprinus, C. carpio, and D. cepedianum while the most common pelagic species included S. atromaculatus, N. cornutus - N. chrysocephalus, N. spilopterus, N. umbratilis, F. notatus, L. cyanellus, and L. macrochirus.

As with species richness, species diversity reached its lowest levels at this station during 1975 and the effect of the August fish kill during that year is clear. Thereafter, about 78% of the sampling dates had diversity measures above 1.7. Species diversity also showed well defined seasonal patterns with high levels occurring during the summer months contrasting with the low levels found during the spring and fall. Benthic diversity closely paralleled the total species diversity curve but shows an even more pronounced seasonal pattern. This trend was primarily due to the recruitment of young C. commersoni, C. carpio, C. cyprinus, I. natalis, and I. melas, and the immigration of D. cepedianum during the summer months, and the numerical dominance of either E. buccata, N. stramineus, or, most commonly, P. notatus during the spring and fall. Pelagic diversity also exhibited a seasonal pattern but generally had highs a month or two in advance of the benthic diversity curve. During these pelagic diversity peaks the pelagic fish fauna had a more equitable species composition and could be considered more stable than before and after these periods when the pelagic fauna was usually dominated by migrant N. spilopterus or S. atromaculatus.

Summary.

Average species richness was highest at Station 12 and decreased steadily upstream. The maximum number of species caught on a single sampling date was 22 at Station 15 on 20 April 1979. Relative to the first few years of sampling, species richness appears to have improved during recent years, particularly at Station 12 and 28. Long-term trends of this nature at the upper regions of the watershed (e.g., Stations 6 and 18) are obscured by the overriding influence of annual variation in flow regimes. Seasonal changes in species richness occurred at Stations 12, 15, 29, and 28 and were largely attributable to the influx of migrant individuals of D. cepedianum from the Maumee River and recruitment of young C. carpio, C. commersoni, and C. cyprinus during the summer months.

In general, species diversity at Stations 12, 15, 29, and 28 was similar, and consistently higher than at Stations 18 and 6, where diversity frequently fell below 1.0. The highest diversity level at each station was recorded during or after 1976 and ranged from 2.08 at Station 18 to 2.41 at Station 28. The benthic guild generally exerted major control over patterns of species diversity, particularly seasonal trends. Summer peaks in species diversity observed at Station 12, 29, and 28, for example, reflected recruitment and immigration of benthic species. Furthermore, low levels of diversity were most often due to dominance by a single benthic species. Seasonal trends in pelagic diversity also occurred at Stations 12 and 29 but had peaks a month or two in advance of benthic diversity during "turnover" periods when dominance relationshps were shifting within the pelagic fauna. However, up until very recently when pelagic diversity has shown signs of marked improvement, the pelagic guild, with the exception of S. atromaculatus and N. spilopterus has formed a weak component within the Black Creek fish community.

## SHORT-TERM TEMPORAL VARIABILITY

Mean values of sample similarity for all main channel stations from 1974 through 1978 were considerably lower from June - July through August - September (Figure 17). In addition, similarity values for samples taken from June through October appear to be highly variable. Since these measures include samples taken at seven stations over a five-year period, a good deal of variability should be expected, but it does not explain the apparent seasonal trends.

In view of the asynchronous changes in diversity displayed by benthic and pelagic species and detailed in a previous section, further analysis of short-term variability in community structure was augmented by calculating independent sample similarity values for these guilds. The separate indices then, were based upon the proportional representation of a given species within its respective guild and as such, could behave somewhat differently both from one another as well as from the index that is based upon the entire community. This not only facilitated more accurate determinations of the nature and underlying causes of temporal variability patterns but also permitted detection of more subtle changes in community composition.

Mean values of sample similarity for both the benthic and pelagic guilds proved to be very similar to measures based on the entire community and were clearly within one standard deviation of that index (Fig. 17). However, the mean similarity value for pelagic species during August-September did not follow the general seasonal pattern displayed by the benthic guild as well as the overall community. Furthermore, from March through October temporal differences in the mean similarity index for the pelagic guild were relatively small, ranging from .528 to .634 while those of benthic species ranged from .509 to .742. In addition, during the spring months mean similarity values for benthic species were consistently higher than those of pelagic species, indicating that the benthic guild was more stable during this period. There were also differences between benthic and pelagic guilds in the variability of their respective similarity indices (Fig. 18). Similarity values for pelagic species, for example, were more

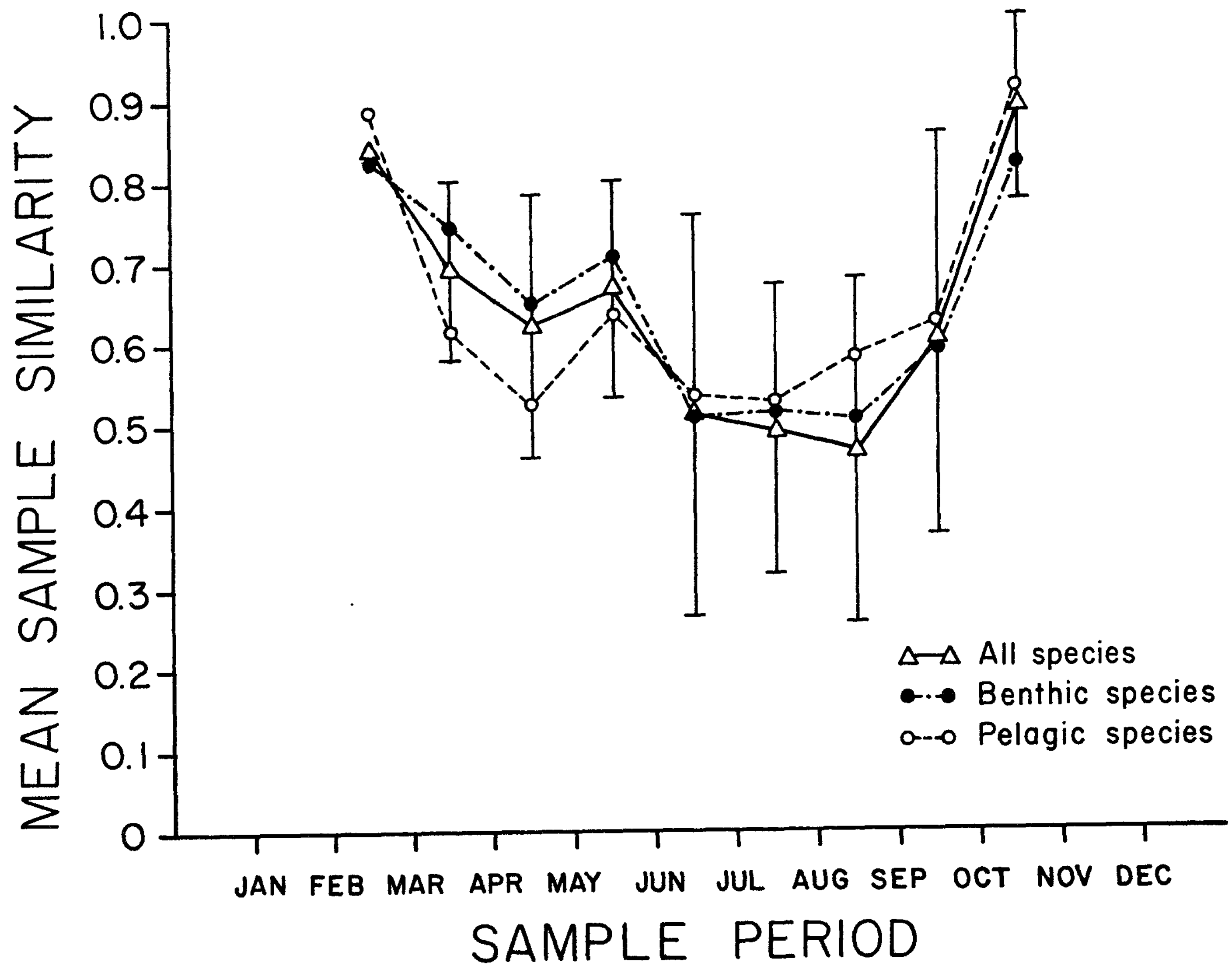



Figure 17. Mean sample similarity values for all species combined (± SD) between months for main channel stations in the Black Creek Watershed, 1973-1980.

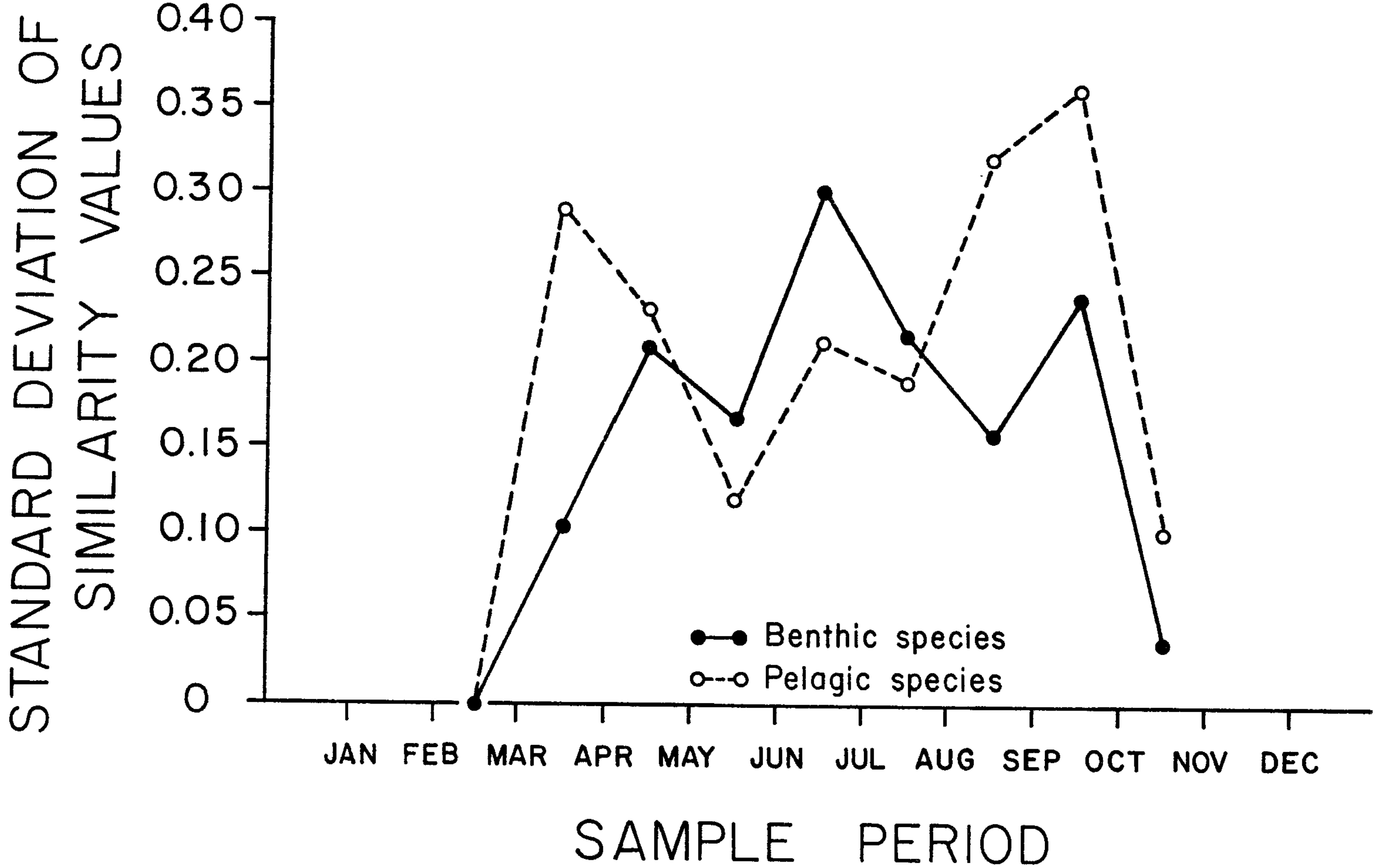



Figure 18. Standard deviations of similarity values for benthic and pelagic guilds at main channel stations in the Black Creek Watershed, 1973-1980.

variable than those of benthic species during March-April, August-September, and September-October. However, during June-July, sample similarity values among benthic species were more inconsistent than those of pelagic species.

In order to further dissect these patterns, significant changes in community structure, arbitrarily defined as changes resulting in sample similarity values less than or equal to 0.50, were examined in detail (Tables 4 and 5). Temporal variability within the benthic guild, at least according to the categorization criteria used here (see methods) was clearly of greater significance to overall community structure than were changes among pelagic species. Of the 25 significant changes in community structure that were detected from 1974 through 1978, 13 were due to short-term changes within both the benthic and pelagic guilds, 10 involved primarily benthic species, and only 2 were solely attributable to pelagic species. During 18 other periods, significant changes were measured within the pelagic guild while sample similarity values for the community exceeded 0.50. The frequency of these changes as well as their apparent insignficance was due to the low densities of pelagic species that were often encountered. The similarity index is particularly sensitive to changes in the relative abundance of species when densities are low.

The relative frequency of "significant" changes in the composition of benthic species (Table 6) largely reflected the temporal patterns displayed by the mean similarity values of this guild. For example, the frequency of these major changes ranged from 50% to 57% for sampling periods from June through October but did not exceed 21% during the other months. However, note that the frequency of these major changes during September - October (57%) was higher than what might be expected based upon the mean similarity index of the benthic guild for this period. There was less congruence between the mean similarity index and the frequency of major changes within the pelagic guild. Among these species, similarity values less than or equal to 0.50 occurred most often from June through August and during March-April and September-October (Table 6).

There were also considerable differences in the frequency of major changes within the benthic guild between years (Table 7). Temporal stability among these species appeared to be relatively low in 1974, 1975, and 1977 and high in 1976 and 1978. In addition, during 1974 and 1975 major changes in benthic guild structure occurred during the spring as well as the summer and fall months, but were limited to June through October from 1976 through 1978. Although the relative frequency of major short-term changes within the pelagic guild was similar between years, low sample similarity measures were more numerous during 1976 (Table 7).

Factors contributing to these changes in community structure include: fish kills, algal blooms, flow regimes, channelization and other habitat perturbations, fish migrations and within-stream movements, recruitment, and natural mortality (Table 4 and 5). Note that each of these factors

Table 4. Changes in benthic guild resulting in similarity values (PS) less than or equal to 0.50. Code numbers show the relationship between changes within this guild and overall community structure. 1) Indicates that short-term shifts in overall community structure were primarily due to changes in species composition within this guild. 2) Indicates that short-term shifts in overall community structure were due to changes in species composition within both the benthic and pelagic guilds. 3) Indicates that changes within this guild had a relatively small impact on overall community structure.

| Sampling Period | Year | Station | PS | Code | Nature of Change |
|---|---|---|---|---|---|
| February-March | -- | -- | -- | --- | ---- |
| March-April | -- | -- | -- | --- | ---- |
| April-May | 1974 | 15 | .478 | 3 | Low fish densities during both sample periods and some sampling problems due to high water in May. The major change involved the presence of large, adult *C. commersoni* during their spawning run in April and their absence in May. |
| | 1974 | 6 | .115 | 1 | Due to the scarcity of fish following channelization in early May. |
| | 1975 | 12 | .258 | 1 | Due to a fish kill that decimated the fauna in May. |
| | 1975 | 6 | .444 | 2 | Absence of fish in April due to a weir below the station which prevented fish from colonizing this area during prevailing low flow conditions. |
| May-June | 1975 | 15 | .366 | 1 | Immigration of a fairly large number of *N. stramineus* during June. |
| | 1978 | 18 | .496 | 3 | Movement of *P. notatus* and *E. buccata* out of this area in June, possibly in response to the immigration of a large number of *N. stramineus*. |
| June-July | 1974 | 17 | .219 | 2 | Recruitment of one-year-old *E. buccata* into the population in July. |
| | 1975 | 12 | .237 | 2 | Recruitment of one-year-old *E. buccata* into the population in July. This area was also still recovering from the May fish kill. |

Table 4 (continued)

| Sampling Period | Year | Station | PS | Code | Nature of Change |
|---|---|---|---|---|---|
| June-July | 1975 | 15 | .249 | 1 | Emigration of *N. stramineus* and recruitment of one-year-old *E. buccata* in July. Algae may have also contributed to low densities of some species. |
| | 1975 | 18 | .416 | 2 | Recruitment of one-year-old *E. buccata* and emigration of *N. stramineus* in July. |
| | 1977 | 12 | .133 | 1 | Recruitment of young *C. carpio* and *C. cyprinus*--and immigration of *D. cepedianum* in July. |
| | 1977 | 6 | .305 | 2 | Recruitment of young *C. carpio* and, to a lesser extent, the emigration of *N. stramineus* in July. |
| July-August | 1975 | 12 | .436 | 2 | A fish kill decimated the fauna in early August but there was an influx of *D. cepedianum* later this month. |
| | 1975 | 15 | .264 | 1 | A fish kill decimated the fauna in early August but there was an influx of *D. cepedianum* later this month. |
| | 1975 | 6 | .445 | 3 | Fish densities were low during the period apparently due to algae problems. A slight increase in the abundance of *P. notatus* accompanied a decline in the number of *P. promelas* during August. |
| | 1976 | 15 | .320 | 2 | Sharp decrease in the density of *E. buccata* in August, possibly reflecting heavy mortality sustained by this species during the prevailing drought. In addition, a fairly large number of *C. carpio* and *C. commersoni* recruits that were found in July apparently emigrated out of the watershed by August. There was also a sizable influx of *D. cepedianum* during this month. |
| | 1976 | 29 | .400 | 2 | Tremendous influx of *D. cepedianum* and recruitment of *C. cyprinus* young in August. Also evidence of downstream movement of fish, particularly *P. notatus*, into this area in response to deteriorating habitat conditions upstream brought about by the drought. *Ericymba buccata* exhibited a significant decline in density in August, again likely due to heavy mortality. |

Table 4 (continued)

| Sampling period | Year | Station | PS | Code | Nature of change |
|---|---|---|---|---|---|
| July-August | 1977 | 18 | .287 | 1 | Downstream movement (out of this region) of C. cyprinus recruits and probably E. buccata, accompanied by the immigration of D. cepedianum in August. |
| | 1977 | 6 | .192 | 2 | Immigration of D. cepedianum and emigration of C. carpio recruits. |
| | 1978 | 12 | .407 | 1 | Emigration of N. stramineus. |
| August-September | 1975 | 15 | .179 | 2 | Very low densities of fish apparently due to low flow conditions and algae problems in September. This area was also recovering from a fish kill that decimated the fauna in early August. |
| | 1975 | 6 | .469 | 2 | Few fish present, apparently due to algae problems. |
| | 1977 | 12 | .491 | 3 | Immigration of N. stramineus and to a lesser extent, an influx of P. notatus (probably from upstream), accompanied by the emigration of D. cepedianum and C. cyprinus recruits in September. |
| | 1977 | 29 | .394 | 1 | Immigration of N. stramineus accompanied by the emigration of D. cepedianum and recruits of C. cyprinus and C. carpio in September. |
| | 1977 | 28 | .491 | 3 | Immigration of N. stramineus and to a lesser extent an influx of P. notatus accompanied by the emigration of D. cepedianum and recruits of C. carpio, C. commersoni, and C. cyprinus in September. |
| September-October | 1974 | 15 | .493 | 2 | Fish densities were low apparently due to frequent habitat perturbations (channelization) throughout this year. Pimephales notatus declined in abundance during October. |
| | 1975 | 12 | .274 | 1 | Emigration of D. cepedianum in October. This region was also still recovering from an August fish kill. |
| | 1976 | 12 | .480 | 2 | Emigration of C. commersoni and I. natalis recruits in October accompanied by the immigration of N. stramineus and influx of P. promelas, P. notatus, and E. buccata from upstream. The latter three species were probably seekingrefuge from severe drought conditions upstream. |

Table 4 (continued)

| Sampling period | Year | Station | PS | Code | Nature of Change |
|---|---|---|---|---|---|
| September-October | 1976 | 18 | .403 | 3 | Very few benthic fish present apparently due to drought conditions and algae problems. |
| October-November | -- | -- | -- | - | ---- |

Table 5. Changes in pelagic guild resulting in similarity values (PS) less than or equal to 0.50. Code numbers show the relationship between changes within this guild and overall community structure. 1) Indicates that short-term shifts in overall community structure were primarily due to changes in species composition within this guild. 2) Indicates that short-term shifts in overall community structure were due to changes in species composition within both the benthic and pelagic guilds. 3) Indicates that changes within this guild had a relatively small impact on overall community structure.

| Sampling Period | Year | Station | PS | Code | Nature of Change |
|---|---|---|---|---|---|
| February - March | -- | -- | -- | -- | ----- |
| March-April | 1976 | 15 | .000 | 3 | Only one pelagic fish was found here in April. With the exception of N. spilopterus, which was common in March, no other pelagic species recolonized this region since the August 1975 fish kill. Algae problems probably contributed to this in April. |
| | 1976 | 28 | .241 | 3 | The density of pelagic fish was fairly low probably due to a possible minor fish kill in March and algae problems in April. The major changes included the emigration of N. spilopterus and influx of F. notatus and S. atromaculatus in April. |
| | 1976 | 18 | .398 | 3 | Low density of pelagic species. |
| | 1977 | 29 | .485 | 3 | Immigration of N. umbratilis and movement of S. atromaculatus out of this area during its spawning run in April. |
| | 1977 | 6 | .479 | 1 | Immigration of N. umbratilis during April. |
| | 1978 | 18 | .500 | 3 | Low densities of pelagic species possibly due to high water levels. |
| April-May | 1975 | 6 | .000 | 2 | Absence of fish in April due to a weir below the station which prevented fish from colonizing this area during prevailing low flow conditions. |
| | 1976 | 12 | .292 | 3 | Emigration of N. spilopterus and apparent immigration of S. atromaculatus adults in May. |

Table 5 (continued)

| Sampling Period | Year | Station | PS | Code | Nature of Change |
|---|---|---|---|---|---|
| April-May | 1976 | 15 | .192 | 3 | Very low densities of pelagic fish probably due to algae |
| | 1976 | 29 | .165 | 3 | Emigration of *N. spilopterus* and movement of *S. atromaculatus* out of this area during their spawning run in May. |
| | 1978 | 12 | .444 | 3 | Low densities of pelagic fish in April possibly due to heavy siltation during the spring flooding. Immigration of *N. cornutus-N. chrysocephalus* and *N. umbratilis* in May. |
| | 1978 | 29 | .416 | 3 | Low densities of pelagic fish during both months. Minor decrease in the number of *S. atromaculatus* and influx of *N. cornutus-N. chrysocephalus* in May. |
| May-June | 1976 | 15 | .450 | 3 | Low densities of pelagic fish probably due to algae. Increase in the number of *F. notatus* in June. |
| | 1976 | 29 | .442 | 3 | Very low densities of pelagic fish, probably due to algae. Emigration of *N. umbratilis* in June. |
| June-July | 1974 | 17 | .333 | 2 | Very low densities of pelagic fish possibly due to effects of channelization. |
| | 1975 | 12 | .195 | 2 | Low densities of pelagic fish due to fish kill in late May. Apparent influx of adult *S. atromaculatus* from upstream in July. |
| | 1975 | 18 | .424 | 2 | Low densities of pelagic fish. Emigration of *N. cornutus-N. chrysocephalus*. |
| | 1976 | 29 | .482 | 3 | Very low densities of pelagic fish probably due to algae and/or low flow conditions. |
| | 1977 | 6 | .261 | 2 | Influx of adult *S. atromaculatus* and downstream movement of *N. umbratilis* in July. |
| July - August | 1975 | 12 | .323 | 2 | Low densities of pelagic fish due to a fish kill in early August and slow recolonization from the fish kill in late May. Immigration of *N. spilopterus* in late August. |

Table 5 (continued)

| Sampling Period | Year | Station | PS | Code | Nature of Change |
|---|---|---|---|---|---|
| July - August | 1975 | 18 | .478 | 3 | Very low densities of pelagic fish probably due to algae and/or low flow conditions. Slight increase in the abundance of S. atromaculatus in late August. |
| | 1976 | 15 | .367 | 2 | Recruitment of S. atromaculatus and to a lesser extent F. notatus in August. Low densities of pelagic fish in July. |
| | 1976 | 29 | .469 | 2 | Recruitment of S. atromaculatus and to a much lesser extent F. notatus in August. Low densities of pelagic fish in July. |
| | 1977 | 12 | .398 | 3 | Immigration of N. spilopterus in August. |
| | 1977 | 29 | .271 | 3 | Immigration of N. spilopterus accompanied by upstream movement or emigration of N. umbratilis in August. |
| | 1977 | 28 | .346 | 3 | Influx (from downstream) of N. cornutus-N. chrysocephalus and immigration of N. spilopterus accompanied by the movement of some S. atromaculatus young out of this region in August. |
| | 1977 | 6 | .431 | 2 | Immigration of N. spilopterus and downstream movement of S. atromaculatus in August. |
| August-Septebmer | 1975 | 15 | .372 | 2 | Very low densities of pelagic fish in August due to the fish kill. Immigration of N. spilopterus in September. |
| | 1975 | 6 | .229 | 2 | Low densities of pelagic fish probably due to algae. Increase in abundance of L. cyanellus (probably recruits) and decrease in abundance of N. umbratilis. |
| | 1976 | 18 | .000 | 1 | This region was heavily choked with algae in August and a series of isolated pools in September. Only two species were captured during each sampling period. During August S. atromaculatus young and F. notatus were abundant; however, both of these species were absent in September when N. spilopterus immigrants were dominant. |

Table 5 (continued)

| Sampling Period | Year | Station | PS | Code | Nature of Change |
|---|---|---|---|---|---|
| September-October | 1974 | 15 | .274 | 2 | Movement of *N. spilopterus*, *L. cyanellus*, and *N. cornutus-N. chrysocephalus* out of this region in October. |
| | 1975 | 18 | .051 | 3 | Very low densities of pelagic fish. Immigration of *N. spilopterus* in October. |
| | 1976 | 12 | .468 | 2 | Immigration of *N. spilopterus* in October. |

Table 6. Relative frequency of significant changes (PS≤.50) in the structure of the benthic and pelagic guilds throughout the year. These proportions are based upon the total number of sample similarity measures(n) during that period from 1974 - 1978.

| | February - March | March - April | April - May | May - June | June - July | July - August | August - September | September - October | October - November |
|---|---|---|---|---|---|---|---|---|---|
| Benthic Guild | 0 | 0 | .21 | .20 | .55 | .57 | .50 | .57 | 0 |
| Pelagic Guild | 0 | .43 | .32 | .20 | .46 | .57 | .30 | .43 | 0 |
| n | 1 | 14 | 19 | 10 | 11 | 14 | 10 | 7 | 2 |

Table 7. Frequency and relative frequency (based upon n sample similarity measuresduring that year) of significant changes (PS $\leq$ .50) in the structure of the benthic and pelagic guilds during each of the five years of intensive sampling.

| | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|
| Benthic Guild | 4 (.80) | 13 (.48) | 4(.13) | 7 (.39) | 1(.13) |
| Pelagic Guild | 2(.40) | 8(.30) | 13(.43) | 7 (.39) | 3(.38) |
| n | 5 | 27 | 30 | 18 | 8 |

did not always act alone or independently to produce the observed instability. In addition, their relative importance and timing often varied between guilds.

Three major fish kills are known to have occurred during the course of the study and since they severely reduced the density of fish in the affected region, only minor changes in species composition during the recovery phase commonly resulted in low sample similarity values. The first two kills occurred in May and August of 1975 and were fairly localized, directly affecting only stations 15 and 12. The benthic guild appeared to recover fairly rapidly (within a month) from the May kill but somewhat slower during the fall. In contrast, the structure of the pelagic guild following the May kill remained rather poor through October. The most devastating and widespread (affecting all stations downstream of station 6) kill occurred in late September 1977. Although no samples were taken in October, fish densities and species composition were fairly similar to pre-kill conditions by November at stations 12, 29, and 28.

The rate of recovery from these fish kills clearly varied among species and according to the time of the year during which they occurred. That is, not only are some species more vagile than others and hence more likely to recolonize a devastated area, but different species are also more mobile during certain seasons. In addition, it is likely that other factors such as habitat conditions also influenced recoveryrates. For example, the 1975 fish kills occurred relatively soon after the watershed was subject to massive habitat modifications, and flow regimes were somewhat different during the recovery periods in the fall of 1975 and 1977.

Algal blooms are common in disturbed agricultural watersheds which are enriched by nutrients in runoff and where solar input is high as a result of the clearing of riparian vegetation. Their occurrence and persistence in Black Creek appears to be determined by temporal variation in the amount of rainfall (Table 1). During years with substantial precipitation in the spring and early summer (e.g., 1974 and 1975), algal blooms are curbed by the flushing action of channel flow and are generally limited in occurrence to the summer months. However, during years with little rainfall (e.g., 1976) algal blooms develop as early as April and persist through the summer and early fall. Although the effects of algal blooms could not be entirely distinguished from those of low water levels, their occurrence generally resulted in a significant reduction in fish densities. In addition, on a few occasions community structure was directly altered as species like sunfish (Lepomis) attempted to avoid algae-choked areas whereas the black-striped topminnow, F. notatus, appeared to thrive in these conditions. In general, pelagic species seemed to be more adversely affected than benthic species. Low sample similarity values caused by reduced fish densities within the pelagic guild were at least partially attributable to algal blooms from July through September of 1975 and from April through August of 1976. Major changes of this nature within the benthic guild were less frequent and only occurred during the summer and early fall of 1975. It is likely, however, that more subtle effects of algal blooms on both guilds either went undetected due to less frequent sampling after 1976 or were confounded by the effects of other factors.

While major short-term changes in community structure could not always be unequivocally tied to flow conditions, direct and subtle impacts appeared to be assoicated with both extremes. High water levels in Black Creek were most common during the spring months, but are a somewhat unpredictable, yet integral, feature of the stream environment. For example, some of the distributional shifts and especially migrations to and from the Maumee River occurred during high water level conditions. The timing of the immigration of D. cepedianum, in particular, seemed to be linked to the occurrence of minor spates during the late summer or early fall. In addition, the success of spawning runs of many species may be dependent on the timing and extent of high flow periods. In this regard, it should be noted that flooding, especially during the spring, is generally more extreme in modified watersheds like Black Creek due to runoff from the adjacent land surface. The deposition of silt following such runoff events also alters habitat structure and appears to have contributed, in at least one instance, to a major shift in species composition associated with low densities of benthic fish. In view of all of this evidence, it is perhaps no coincidence that the frequency of major changes in the structure of the benthic guild was greatest during years in which there were numerous high flow periods (i.e., 1975 and 1977).

Low flow conditions had a more obvious effect on the fish community since they usually were accompanied by reduced fish densities, particularly among pelagic species. They also appear to have caused fish movements within the watershed but, as mentioned previously, both of these effects were often confounded with those of algal blooms. Nevertheless, many of the major changes in community structure resulting from downstream movement of fish were likely associated with low water levels upstream. Such conditions were most common during the summer months but varied in timing and duration among years. During the driest years (1976 and 1978) stability appeared to be lowest within the pelagic guild (Table 7). The low densities of pelagic fish that were frequently found throughout the year at station 18 were probably due to the low depths that are characteristic of this region. Hence, changes in the structure of the pelagic guild associated with these low densities cannot be considered dynamic and were, in fact, of minor import to the overall community. Like high flows, low flow conditions are generally more severe in modified watersheds due to the absence of riparian vegetation and the straight, uniform channels.

Short-term effects of the major channel modifications that were completed during 1974 went largely undetected due to infrequent sampling during that year. However, limited sampling at stations 15, 17, and 6, indicates that fish densities were very low and species richness was poor immediately following channelization. In addition, although the recovery period was less than adequately monitored during this year, repopulation by benthic species appeared to be particularly slow. This should be expected, perhaps, since guilds were delimited according to feeding locales, and substrates were highly modified, if not destroyed, by dredging operations.

The effect of these channel modifications on flow regimes should be reiterated and hence recognized as a contributing factor in temporal changes in community structure associated with high or low water level conditions. The interaction between flow regimes and habitat modifications was also evident when a weir below station 6 blocked fish movements during low flow conditions.

While movements of fishes within the watershed often directly resulted in major shifts in community structure, they were usually caused by environmental conditions. Within-stream movements are distinquished here from fish migrations in that the former did not appear to constitute movement into or from the Maumee River and hence involves only those species which maintained resident populations throughout the year. Within the benthic guild, major changes in species composition of this nature most often involved the downstream movement of P. notatus during the summer or fall months (Fig. 4). This was probably a response to unsuitable habitat conditions (e.g., low flows or algal blooms) upstream, but in a few cases may have been caused by an interaction with immigrating species. Ericymba buccata and P. promelas (Fig. 3) also showed signs of downstream movements for the same reasons.

Relative to the benthic guild, changes in the structure of the pelagic guild were more often due to movements by resident species. Movements by S. atromaculatus were particularly significant and included a spawning run upstream during the spring followed by the redispersal of adults throughout the watershed (Fig. 9). Additional distributional shifts by this species also occurred during the summer months in response to deteriorating habitat conditions (i.e., low flows) upstream. Similar shifts were exhibited by N. umbratilis (Fig. 8) and N. cornutus-N. chrysocephalus (Fig. 6) during low flow periods, but these species only appeared to maintain a resident population when water levels did not get excessively low during the summer months. Algal blooms probably also contributed to these shifts in pelagic community structure during low flow periods; however, whereas S. atromaculatus, N. umbratilis, and N. cornutus-N. chrysocephalus moved out of algae-choked regions, F. notatus appeared to invade such areas.

The major cause of short-term variation in the community structure of Black Creek fishes was migrations of both benthic and pelagic species into and from the Maumee River. Among the benthic species, spring immigrants included N. stramineus and large adults of C. commersoni, C. carpio, and C. cyprinus. The latter three species made a brief spawning run into the the Black Creek watershed but quickly returned to the river. Hence, although large schools of these species were observed, they proved to be difficult to capture and rarely contributed to significant changes in community structure during the spring months. However, when these spawning runs were successful, their young generally dominated the benthic fauna during the summer months. Major shifts in community structure then occurred when these recruits emigrated into the Maumee River during the late summer and fall. The immigration of N. stramineus appeared to occur during both the fall and spring (Fig. 7), but the fall influx probably had a greater impact on community structure. Although it is not clear whether these fall immigrants overwinter in Black Creek or perhaps leave during the winter and return again in the spring, individuals found in Black Creek during the spring definitely emigrate back into the Maumee during July or August.

The most profound migrations among the benthic species were carried out by D. cepedianum during the summer or early fall (Table 3). Large numbers of young D. cepedianum invaded Black Creek during minor spates as early as July (e.g., in 1977) and depending on flow conditions, remained in the watershed as late as November. Since these individuals appeared to travel in large schools they contributed to numerous significant changes in community structure during this period.

The emigrations of young of two other species, I. natalis and C. anomalum, were partially responsible for a few other shifts in species composition within the benthic guild (e.g., during the fall of 1976).

Among the pelagic species the immigration of N. spilopterus had the greatest impact on community structure. This species invaded the watershed during the late summer or fall, overwintered, and then emigrated back into the Maumee during the following spring (April-June) (Fig. 5). In addition, there was some evidence that N. umbratilis and N. cornutus-N. chrysocephalus immigrate into Black Creek as N. spilopterus leave. During dry years these species appeared to emigrate back into the Maumee soon after they attempted to spawn in early summer. However, when flow conditions were favorable they probably remained in Black Creek. It is also likely that the spring spawning run of S. atromaculatus included immigrants from the Maumee as well as resident adults. Although these migrations by N. umbratilis, N. cornutus-N. chrysocephalus, and S. atromaculatus were of relatively little consequence to the overall community, they accounted for much of the temporal variation within the pelagic guild during the spring and summer.

As mentioned earlier, the recruitment of young C. commersoni, C. carpio, and C. cyprinus (Table 3) had a significant impact on the structure of the benthic guild as well as on the overall community during the summer months. Prior to 1976, the recruitment of yearling E. buccata had a similar effect in July, and although it was not detected in this analysis, the recruitment of young P. notatus and P. promelas may have potentially altered community structure radically during the fall months. Among the pelagic species, the recruitment of young S. atromaculatus and, to a lesser extent, F. notatus, was important during the summer months while recruits of L. cyanellus contributed to a significant change on one occasion at an upper station during the fall.

Although non-catastrophic mortality (i.e., mortality not related to obvious fish kills) is difficult to detect, it is another potential cause of short-term changes in community structure. For example, a detailed analysis of the decline of the E. buccata population in Black Creek strongly suggests that mortality of this species was heavy during the drought in 1976. Hence, it is also likely that some of the other shifts in community structure that were attributed to movements and/or migrations, particularly those that appeared to be in response to severe habitat conditions, were at least partially due to mortality.

In summary, it is clear that very few species maintain resident populations throughout the year in Black Creek. Those that do must shift their distributions in response to harsh environmental conditions whereas other species leave the watershed as habitats begin to deteriorate. Although the headwater stream environment is typically rigorous and a number of its habitat parameters undergo extreme temporal fluctuations even in the natural state, the severity of living conditions is magnified by habitat modifications like those in Black Creek. However, while these perturbations have contributed to unfavorable conditions for some species, others have apparently been able to exploit the altered state. The influx of D. cepedianum, for example, appears to be linked to this species' capacity to utilize the heavy growths of algae that typically occur during the summer months and are a direct result of the clearing of riparian vegetation in the watershed. Similarly, the occurrence and success of the spawning runs by C. commersoni, C. carpio, and C. cyprinus probably reflects the ability of their young to also exploit this primary production. While the invasion of Black Creek by these species appears to be directly linked to the altered habitat conditions in the watershed, the immigration of these and other species is probably only possible because of the absence of a stable and integrated resident fish fauna. However, this loss of biological integrity is also a consequence of the habitat modifications that therefore appear to have bred much of the observed temporal instability in the fish community.

## DISCUSSION

Any attempt to summarize many fish samples collected from several stations over a seven-year period must involve oversimplications. We are certainly guilty of that here. Thus, we add a few notes of explanation to outline some general conclusions about individual species and to briefly explore methods of simplifying the data on fish communities of the Black Creek watershed.

### Status of Individual Species.

The foregoing discussion generally focussed on species at each site. At this point we view each of the major fishes within the watershed and evaluate their population trends at the watershed level.

Several species seem to be especially successful at maintaining populations in the watershed. These include S. atromaculatus, P. promelas, and P. notatus. The two Pimephales species are generally viewed as opportunistic omnivores that are regularly successful in headwater streams even after they are highly modified. Semotilus generally feeds at higher trophic levels and is especially successful at feeding on insects that fall into streams from terrestrial areas. This species seems to be present in the watershed both as a migrant and as a resident. As a resident, individuals seem to persist year around in areas of high quality habitat (Gorman and Karr 1978, Karr and Dudley 1980) such as in the Wertz Woods. In most other areas in the watershed, individual Semotilus are generally smaller (except in spawning periods when migrants enter from the Maumee River) and their presence is more transitory. Finally, they are often slower growing, and less vigorous looking. Their color, for example, is paler reflecting the less than optimal stream environment they occupy.

Three species seem to be relatively successful in using the Black Creek watershed as a nursery area. These are the white sucker (Catostomus commersoni), the introduced carp (Cyprinus carpio), and the carpsucker (Carpiodes cyprinus). During the spring, all three species migrate into the watershed from the Maumee River and large schools of adult C. commersoni and C. cyprinus, in particular, have been observed as they search for spawning sites. Spawning success is highly variable between years and individuals experience considerable fin damage as they try to clean spawning sites in gravel substrates of fine sediment and benthic algal growth. Successful recruitment in the Black Creek watershed seems to be linked to the ability of their young to exploit the rich algal growth that commonly occur during the summer months. The immigration of young D. cepedianum appears to occur for the same reason. Since most young and adults of all of these species migrate into the Maumee River during the fall, we suspect that small watersheds like Black Creek may be of considerable importance to the fishes of many of our major rivers.

Notropis umbratilis, N. cornutus- N. chrysocephalus, and another migrant species, N. stramineus, showed some signs of increasing abundance in the watershed in recent years but have yet to establish a strong resident population. Ericymba buccata, once an established resident, experienced a population increase early in the study but is now in danger of extirpation (see other paper on E. buccata in this report). Other species that seem to have declined beyond the point of recovery include the darter, E. spectabile, and the stoneroller, C. anomalum. Population declines by all of these species, but especially, E. spectabile, were at least partially due to increased siltation of substrates.

The Watershed Environment.

Our experience in a number of midwestern states indicates that the pattern of migration of fish into small streams is rather common. However, the specific circumstances in Black Creek should be reiterated. This water shed is composed of a stream that reaches, at most, third order before it enters a major river - the Maumee. Thus, the main river serves as a reliable source of colonists to replace local mortality and we expect that local extinctions due to natural or man-induced events may be easily countered by dispersers moving up from the river. Indeed, the regularity with which C. carpio, D. cepedianum, C. cyprinus, and N. spilopterus move well into the Black Creek watershed may be due to its proximity to the Maumee River. Unfortunately, sampling problems and financial resources have prevented us from sampling that major river component of the fishes which regularly utilize the Black Creek watershed.

Guild Structure.

For simplicity, we have chosen to describe only two guilds in this paper. This oversimplification is necessitated by a variety of circumstances. First, we want to try to minimize the detailed analysis that could be undertaken at this time. It is our plan to dissect selected patterns in more detail in the next year as the final integrative project report is formulated. Second, the extreme perturbations imposed by the man-induced alterations in Black Creek tend to reduce the differences in natural history among Black Creek fishes.

For example, it could be argued that our benthic guild is very heterogeneous. Indeed, species in the benthic guild feed on a variety of resources (herbivores, bottom filterers, carnivores) while virtually all of the pelagic species are carnivores. In addition, some of the benthic species, particularly P. promelas, may feed to a significant extent not directly in association with the bottom. Furthermore, species such as C. cyprinus , C. carpio, and C. commersoni filter the bottom ooze whereas other species such as Pimephales, E. buccata, and N. stramineus pick food items off the bottom substrate. For convenience in this presentation, all were grouped into the benthic guild.

Similarly, one might argue that the inclusion of Fundulus in the pelagic guild is an oversimplification. This is really a surface-feeding species found in shallow edge environments. It is also the major species associated with the algae-choked areas during low flow periods of summer and early fall.

Despite these weaknesses, we feel that general patterns in the watershed have emerged and plan to continue dissecting those patterns in the months ahead.

## LITERATURE CITED

Gorman, O. T. and J. R. Karr. 1978. Habitat structure and stream fish communities. Ecology. 59: 507-515.

Karr, J. R. and O. T. Gorman. 1975. Effects of land treatment on the aquatic environment. Non-point Source Pollution: Pollution Control in Great Lakes. USEPA-905/9-75-007. pp. 120-150.

Karr, J. R. and D. R. Dudley. 1980. Ecological perspective on water quality goals. Environmental Management. In press.

Toth, L. A., D. R. Dudley, J. R. Karr, and O. T. Gorman. 1981. Decline of a silverjaw minnow (Ericymba buccata) population in an agricultural watershed. This volume.

Whittaker, R. H. 1975. Communities and ecosystems. (2nd Edit.) Macmillan Publ. Co., N.Y. 385 pp.

# DECLINE OF A SILVERJAW MINNOW (*ERICYMBA BUCCATA*) POPULATION IN AN AGRICULTURAL WATERSHED

by

Louis A. Toth[1], Daniel R. Dudley[2], James R. Karr[1], and Owen T. Gorman[3]

ABSTRACT

During eight years of fish sampling in Black Creek, the silverjaw minnow, *Ericymba buccata*, exhibited wide fluctuations in density, including a population outbreak in 1976 followed by a rapid decline in abundance. Accompanying these fluctuations were changes in population structure that were linked to differential mortality and variations in recruitment. Factors responsible for this species demise in the watershed included: severe droughts during 1976 and 1978; consecutive harsh winters in 1976-77, 1977-78, and 1978-79; fish kills;and altered habitat conditions brought about by channelization and the removal of riparian vegetation.

Key words: Agricultural watershed, channelization, habitat, nonpoint pollution, population recuitment, silverjaw minnow

---

1. Department of Ecology, Ethology, and Evolution, 606 E. Healey, University of Illinois, Champaign, IL 61820

2. Division of Surveillance, Ohio Environmental Protection Agency, 361 E. Broad, Columbus, Ohio 43215

3. Museum of Natural History, University of Kansas, Lawrence, KA 66045

## INTRODUCTION

Fish populations in freshwater streams vary in space and time due to a variety of factors in both "natural" and man-altered environments. Because of the complexity of factors responsible for this variation, it is difficult to interpret the results of programs designed to minimize negative effects of man's activities on the biological integrity of water resources, particularly when only one or two years of data are collected. This report examines the decline of a silverjaw minnow (Ericymba buccata) population over an eight-year period in an agricultural watershed in northeastern Indiana. The study area was the target of an intensive application of soil conservation practices designed to reduce soil erosion and thereby improve water quality (Morrison 1977). Thus it was possible to evalute the population dynamics of Ericymba in light of natural environmental variability and human induced perturbations in the watershed.

Ericymba buccata is a common inhabitant of small, headwater streams in the midwest, where it lives and feeds in schools on or near the bottom (Trautman 1957, Hoyt 1970, Pflieger 1975, Wallace 1976, Smith 1978). It is most abundant in areas with sandy substrates and occurs in low densities over silt (Wallace 1972). In Indiana, spawning takes place from late April through July (Wallace 1973a).

## METHODS

The study was conducted in conjunction with an interdisciplinary demonstration project (Black Creek Project) carried out on a 48.5 $km^2$ watershed in Allen County, Indiana. The primary objective of the project was to develop and implement plans for controlling soil erosion and to evaluate the effectiveness of traditional conservation methods in improving water resources. This included analysis of the short- and long-term effects of project activities on the fish fauna of the watershed.

Twenty-five fish sampling stations were established in the Black Creek watershed (Fig. 1), but most of the sampling effort was focused upon the main channel (particularly stations 6, 18, 17, 28, 29, 15, and 12). Samples generally covered a distance of 100 m at each station and were taken using 3.1 or 6.3 mm mesh minnow seines with block nets at the upper and lower ends of the station.

Sampling frequency was not uniform throughout the study period but is believed to accurately reflect general population trends among adult (>1 year) Ericymba. Initial samples were taken at sites 6 and 12 during July 1973. From 1974 to 1978 samples were taken at monthly intervals, although not all stations were sampled during each period. Bi-weekly samples were taken at some stations during 1975 and 1976. Sampling was less frequent in 1979 but included collections from spring, summer, and fall. The last sample was taken in June 1980.

Captured Ericymba were either counted and released, measured to the nearest 1 mm (total length) and released, or preserved in 10% formalin for

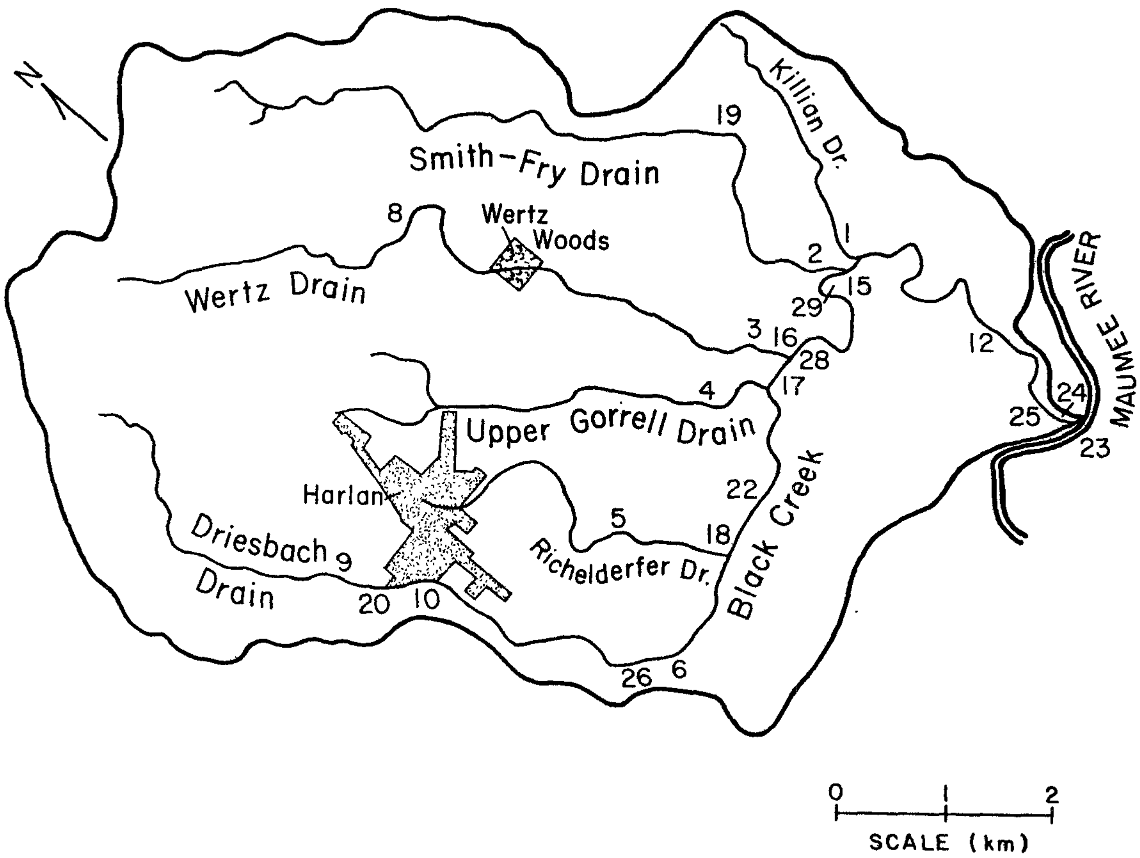



Figure 1. Map of the Black Creek Watershed showing the location of sampling sites.

laboratory analysis. Field processing of large samples in 1976 was expedited by assigning groups of *Ericymba* to 3-5 mm size classes. These fish were later distributed equally among 1 mm increments within their respective size classes. Length-frequency distributions and scale readings were used to establish the age structure of the population during the course of the study. Scales for age determination were taken from the first or second row of scales above the lateral line and just anterior to the dorsal fin of preserved fish, mounted in water between two microscope slides, and read using a microprojector.

Some environmental variables that may affect fish populations were also monitored during the course of the study. Stream discharge was measured with a stage recording device at station 6 from 1975 through 1978 and temperature and rainfall data were taken from monthly records of the Fort Wayne, Indiana weather station (approximately 20 km from the watershed). Quantitative substrate measurements were taken at fish sampling stations on the main channel of Black Creek during 1975-76 and 1978-79 according to methods outlined by Gorman and Karr (1978). Point samples of bottom types within these stations were grouped into either physical (e.g., silt, sand, clay) or biotic (e.g., vegetation, litter) categories.

## RESULTS

### Environmental Perturbations.

From 1973 to 1977 the stream environment of Black Creek underwent major alterations as a result of the concentrated application of structural conservation practices such as streambank protection and the establishment of grassed waterways throughout the watershed (Table 1). In the Black Creek project streambank protection consisted of grading and stabilizing streambanks on one or both sides of the channel, plus dredging and straightening the channel in selected locations. The stream had been previously channelized in 1941 so these project activities amounted to "re-channelization" that eliminated pool-riffle complexes, substrate sorting, and riparian vegetation that had recovered since 1941. Other commonly observed effects of channelization included rapid fluctuations in discharge, decreased water depths, greater daily and seasonal changes in water temperature, and increased turbidity (Karr and Gorman 1975).

Table 1. The amount of grassed waterway constructed and streambank protection work conducted in the Black Creek watershed, 1973 through 1976.

| | Upstream | | | Main Channel | |
|---|---|---|---|---|---|
| Year | Month(s) | Waterway (acres) | Streambank Protection (ft.) | Month(s) | Streambank Protection (ft.) |
| 1973 | September | 9.6 | 5,300 | | 0 |
| 1974 | April thru November | 2 | 7,175 | June thru September | 37,022 |
| 1975 | August thru September | 11 | 0 | | a |
| 1976 | June thru August | 10 | 9,400 | | 0 |

[a]bridge construction work near stations 12 and 15.

The majority of the structural conservation practices installed during the Black Creek project involved disturbance of the land surface near the main channel or its tributaries. Sediment delivery from these sites to the stream network was sometimes very high until vegetative cover was re-established. In one instance, sheet and rill erosion was so severe during the year following the construction of a grassed waterway and streambank protection work, that sedimentdeposition reduced the depths of pools one kilometer downstream in an unchannelized segment (Wertz Woods, Fig. 1) by as much as one meter. Substrate measurements also indicated that the deposition of sediment persistently altered the structure of habitats in Black Creek (Fig. 2). Gravel-sized particles that were exposed in 1975 were covered by sand and silt by 1978; this trend toward finer substrates continued through 1979. These changes appear to be due to the combined effects of erosion from the land surface and stream channel modifications that favor the extensive accumulation of sediment.

Substrate measurements also revealed that the distribution of silt in the watershed was highly dependent upon discharge rates. For example, during a high discharge period in the early spring of 1976 silt was apparently transported from upstream locations (e.g., station 6) and deposited at station 12, whereas the mid- and upstream stations experienced siltation during extended low flow periods (e.g., summer of 1978).

Water Quality and Fish Kills.

Water quality conditions in Black Creek have been reported elsewhere (Karr and Dudley 1976, Morrison 1977, Nelson and Beasley 1978, Dudley and Karr 1979, 1980). The stream receives organic pollutants from septic tank effluent and barnlot runoff. Overall nutrient enrichment is substantial and algal blooms occur where solar radiation is high as a result of the clearing of riparian vegetation. During prolonged low flow periods algal blooms alter substrate characteristics (Fig. 2) and reduce available habitat space. Solar radiation also raises water temperatures in shallow stream segments as high as $34^{\circ}$C. Diurnal dissolved oxygen patterns during the summer months suggested periods of high productivity and subsequent decay of algal biomass (unpublished data, DRD). Daily minimum dissolved oxygen concentrations were frequently below 5 mg/l in July and August and were depressed even further as a result of leaf litter input when low flow conditions persisted into the fall months.

Three major fish kills are known to have occurred during the course of the study. During the first incident (28 May 1975), probably caused by the application of herbicides, dead fish were found on the Smith-Fry drain downstream from station 19 and on the main channel from station 22 to the Maumee River (Fig. 1). A smaller kill of undetermined cause occurred in August 1975 and affected all stations downstream of the entrance of the Smith-Fry drain (i.e., stations 15 and 12). The most devastating kill occurred on 29 September 1977 when several thousand gallons of manure slurry were accidentally discharged into the main channel from an animal waste holding lagoon near station 6. Mortality was near 100% in 9 kilometers of stream below the spill (Dudley and Karr 1979).

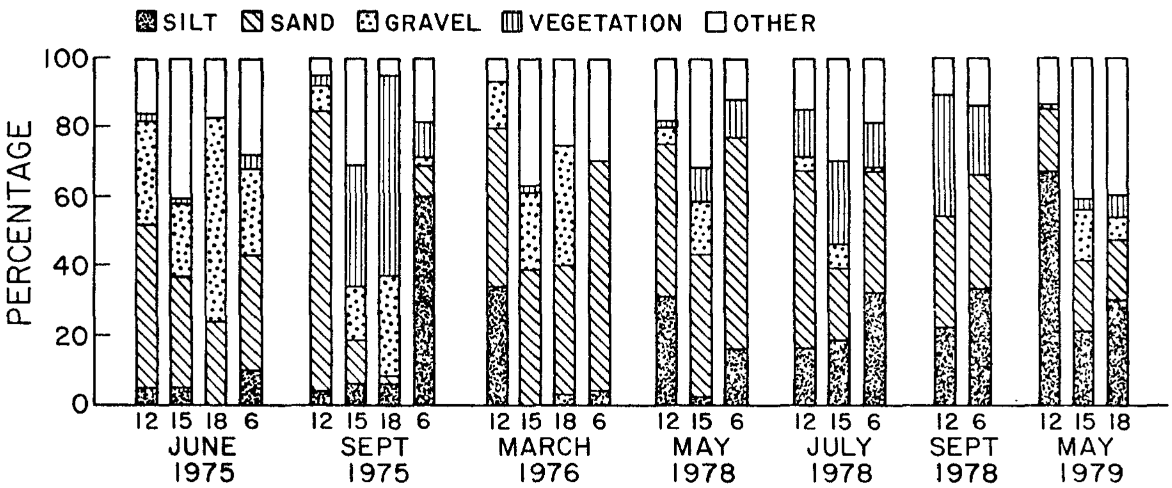



Figure 2. Proportional representation of substrate categories at sampling sites on the main channel of Black Creek.

Climatic Conditions and Stream Discharge.

Severe climatic conditions occurred during the study period (Fig. 3). Rainfall was below normal during each year except 1975 and 1977, and resulted in extended periods of low discharge during the summers of 1976 and 1978. A minimum base flow of approximately 0.1 to 0.5 cfs. was generally maintained in the lower 7 km of Black Creek by groundwater exfiltration. Beginning with the winter of 1976-1977 this region also experienced three consecutive harsh winters that caused many sections of stream to freeze solid. Snow and ice melt during the following springs resulted in temporary periods of high discharge.

Population dynamics and distribution of Ericymba

During the course of the study, Ericymba exhibited wide fluctuations in density, highlighted by a population outbreak in 1976 followed by a rapid decline in abundance in recent years (Fig. 3). Prior to this decline Ericymba was a dominant member of the Black Creek fish community, representing an average of 22% to 32% of the total number of individuals in each sample taken during 1973 through 1976 (Fig. 4). Its numerical importance fell below 5% in 1977 and measured only about 1% in 1979 and 1980 samples.

Seasonal and year to year variations in the density of Ericymba were linked to changes in population structure (Fig 5). Recruitment of one-year-old fish, for example, accounted for the increase in abundance during the summer and fall of 1974 and 1975 (Fig. 3). One-year-olds were first caught in July samples and are an indication of reproductive success during the previous year. Hence, it appears that the 1973 year class was fairly successful and responsible for the increase in population density during 1974. However, overwinter mortality primarily within this year class brought about a decline in density during the spring of 1975. In contrast, the highly successful 1974 year class survived well through the winter of 1975-76 and was solely responsible for the population explosion during 1976. The population began to decline during the late summer and fall of 1976 despite the high recruitment of the 1975 year class. Mortality during the severe winter of 1976-77 was heavy among all age groups and brought the population density to a low level from which it continued to decline.

Early in the study Ericymba exhibited complex seasonal distribution patterns with extensive use of upstream reaches. Although two of the five headwater streams (Fig. 1) offered poor quality fish habitat due to domestic pollution (Richelderfer) or heavy siltation (Dreisbach), and another (Smith-Fry) was subject to frequent fish kills (see above), numerous Ericymba, particularly yearlings, were found at upstream sites (e.g., stations 20, 5, 4, 16, 3 and Wertz Woods) during the summer and fall of 1974 and 1975. Ericymba was also widely distributed throughout the watershed during the spring of 1976 but, in contrast to the previous two years, decreased in abundance upstream during the summer and fall. Although a fairly large number were caught at station 18 in April 1977, Ericymba was rarely found above station 28 after July 1977.

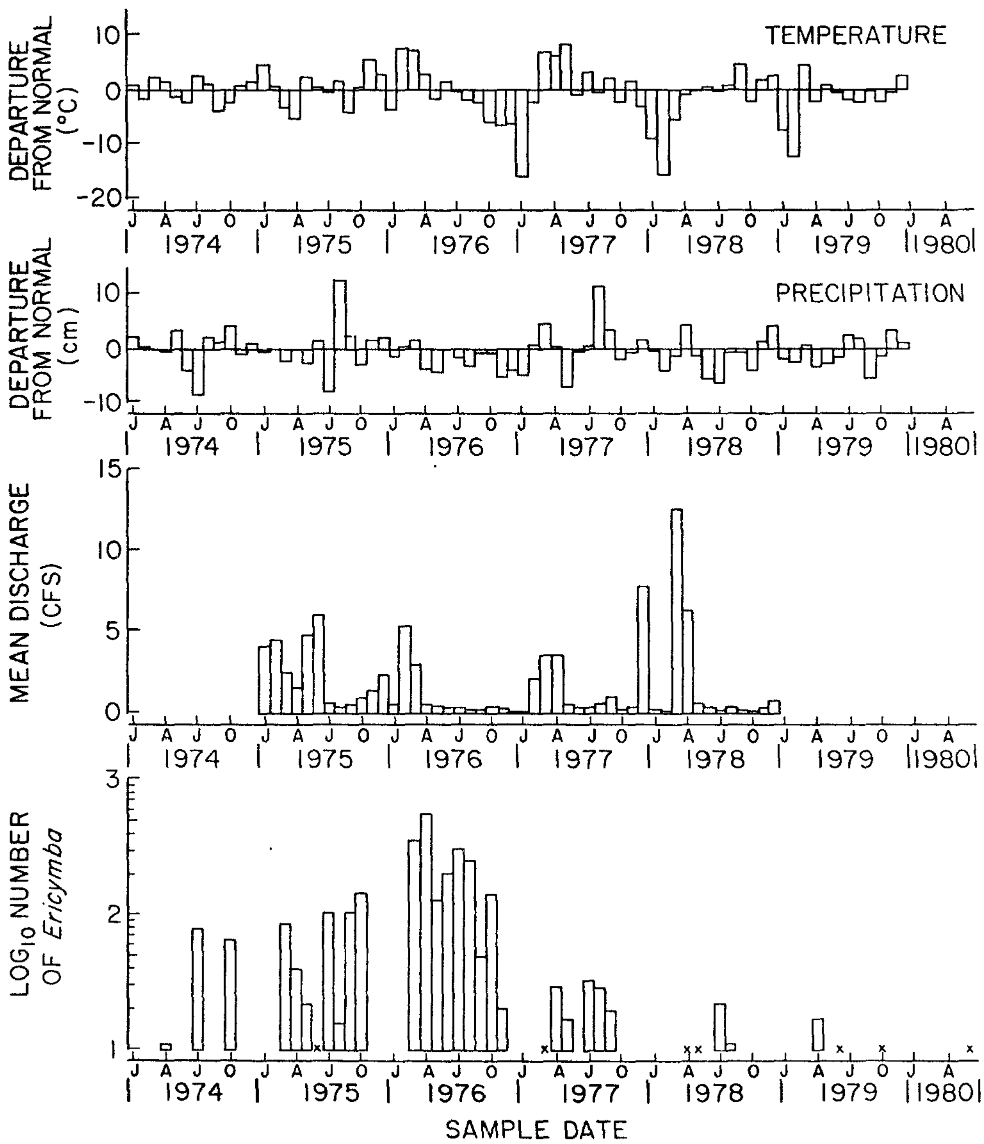



Figure 3. Climatic conditions, stream discharge, and the mean monthly number of Ericymba captured at sampling sites on the main channel of Black Creek. Temperature and precipitation data are monthly means expressed according to their departure from normal (based upon past records). Stream discharge is given as monthly averages from Station 6. Monthly averages of Ericymba captures were calculated for months in which three or more main channel stations were sampled and are expressed as the $\log_{10}$number per 100 m of stream. The symbol "x" denotes that an average of less than 10 individuals/ 100 m were captured.

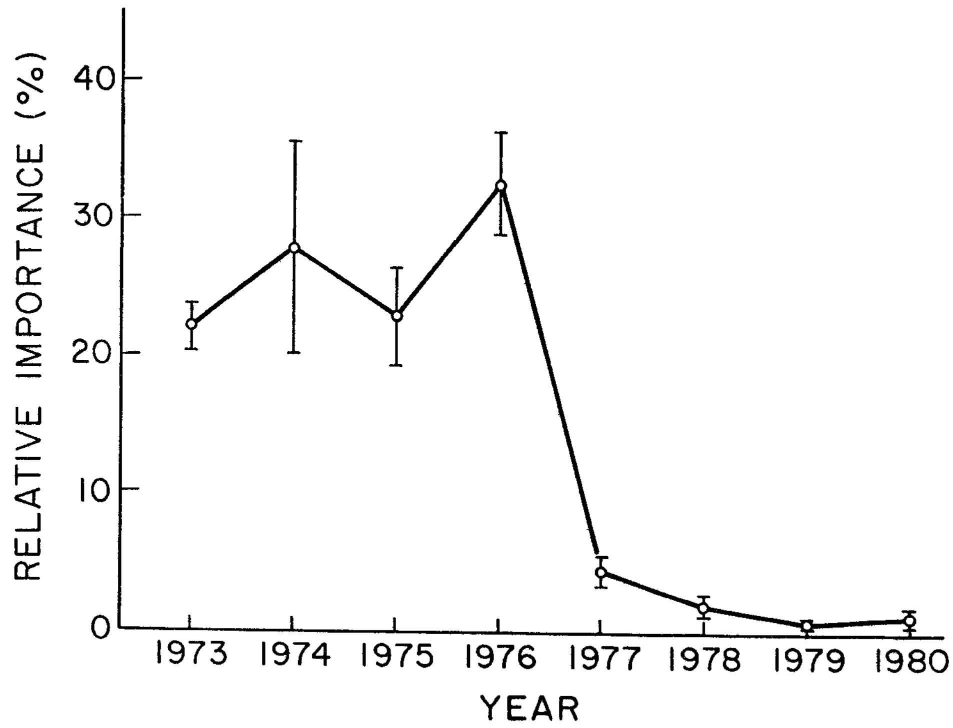



Figure 4. Mean proportional representation ($\pm$ 1 standard error) of Ericymba in fish samples taken at stations on the main channel of Black Creek.

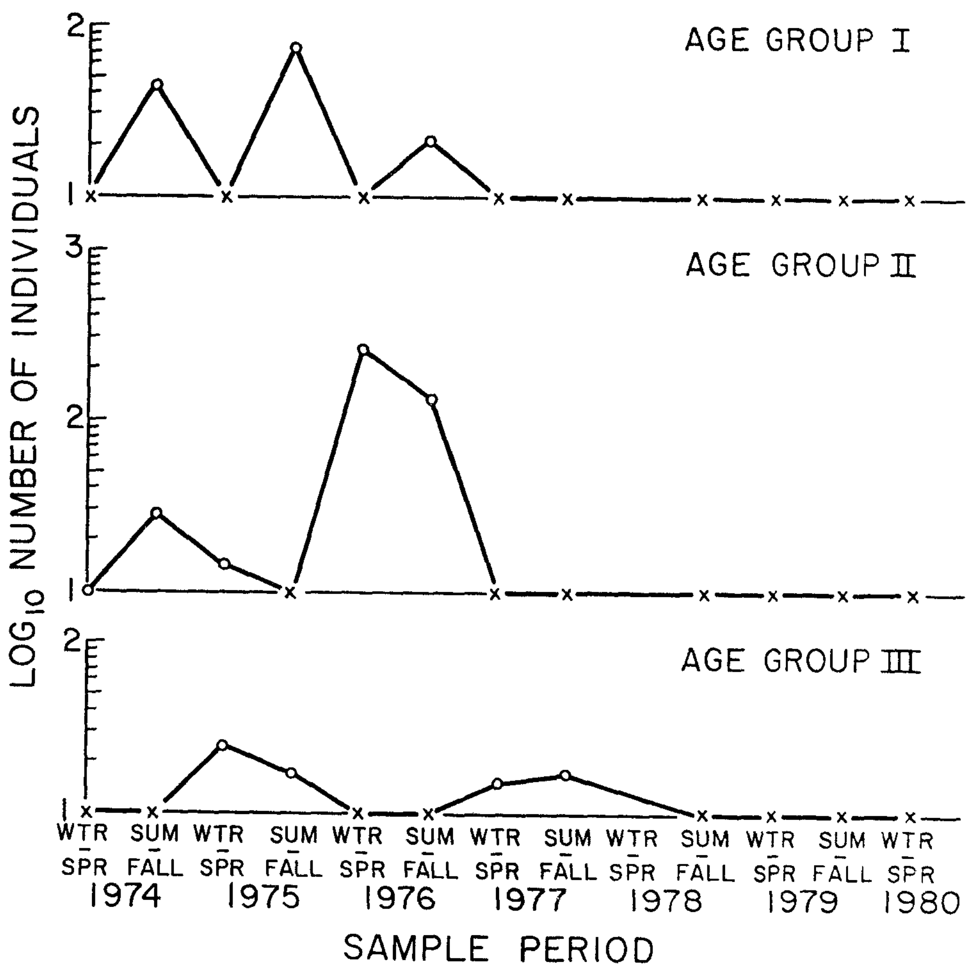



Figure 5. Average number ($\log_{10}$) of individuals within various age groups based upon the mean number of Ericymba/ 100 m (i.e., data given in Fig. 3) and the proportional representation of each age group in samples taken during that period. The symbol "x" denotes that an age group consisted of less than 10 individuals/100 m during that sampling period. Data on the age structure of the population were not taken during the winter and spring of 1978.

## DISCUSSION

Conditions in the Black Creek watershed appeared to be favorable for *Ericymba* during most of the first four years of sampling despite the extensive habitat perturbations that occurred during 1974. Except for some overwinter mortality during 1974-75, healthy population densities were maintained through the summer of 1976 and recruitment of one-year-olds indicated that reproductive success was fairly good during 1973 and 1975 and excellent in 1974. Little is known about the reproductive ecology of *Ericymba* but it presumably requires gravel or sand substrates that are free of silt (Pflieger 1975, Smith 1978). Quantitative habitat measurements in June 1975 indicated that these substrate types predominated in Black Creek through the spring of that year. The tremendous success of the 1974 year class was likely due to relaxed competition from other species. Project activities resulted in reduced population densities among other Black Creek fishes during 1974 and 1975 (Karr and Gorman 1975) and Smith (1978) has indicated that *Ericymba* is a pioneering species that quickly invades newly dredged streams.

A number of factors likely contributed to the rapid decline in the *Ericymba* population. Wallace (1972) and Smith (1978) indicated that *Ericymba* is intolerant of siltation which became an increasing problem in Black Creek as a result of the newly channelized stream morphology, increased sediment loads from near-stream perturbations, and low stream discharge rates. The altered substrates may have both limited the reproductive success of *Ericymba* and also affected its food supply (Muncy et. al. 1979).

Extreme environmental conditions caused mortality among adult *Ericymba* and may have also limited recruitment. For example, the heavy mortality that occurred during the late summer and fall of 1976 likely affected young of the 1976 year class as well as adults. During this period, population density was very high and habitat space was deteriorating at a rapid rate due to the prolonged drought and accompanying algal blooms. Hoyt (1970) noted that an *E. buccata* population experienced a high degree of stress in similar conditions in Kentucky. High water temperatures ($32^{o}$ - $34^{o}C$), accentuated by the lack of near-stream vegetation were an additional stress factor during the summer months. In a study on thermal discharges to the White River in Indiana, Proffitt and Benda (1971) found that *Ericymba* did not occur in areas where the water temperature exceeded $31.1^{o}C$. Thus shallow water and open canopies probably limited survivorship of *Ericymba* in many regions in the Black Creek watershed during the extended drought periods of 1976 and 1978.

Mortality among adult *Ericymba* was also high during the winter of 1976-77. This winter was hard on all resident fish populations due to the extreme temperatures and ice cover coupled with the buildup of decaying algae; however, *Ericymba* may have been particularly affected by the cold temperatures, since the population is near the northern edge of its range (Wallace 1973a). Furthermore, temperature-related winter mortality may have been even more severe among new recruits. There is good evidence

(Christie and Regier 1973) indicating that recruitment of smallmouth bass (*Micropterus dolomieui*) is limited by cold temperatures at the northern boundary of its range. Hence, during its population decline recruitment of *E. buccata* may have also been curbed by the three consecutive harsh winters that occurred in this region.

The large fish kill that occurred in September 1977 was another contributing element in the decline of the *Ericymba* population. Wallace (1972) reported that young-of-the-year and yearlings tend to concentrate in upstream areas in the summer months, but unfavorable flow conditions and siltation restricted *Ericymba's* distribution in Black Creek to mid-stream reaches after July 1977. Thus, because of its constricted distribution, the *Ericymba* population was devastated by the 1977 fish kill.

It is clear that the frequency of extirpations in aquatic environments, as well as the time-span required to produce them, has been influenced by man (Larimore and Smith 1963). The rapid decline of the *Ericymba* population in Black Creek illustrates the interplay between "natural" limiting factors and man-induced perturbations. Although it is difficult to separate the effects of these factors in this particular case, the deterioration of habitat brought about by man's activities in the Black Creek watershed not only added other stress factors, but perhaps more importantly, eliminated or at least severely taxed natural environmental buffers. The perturbations then can be thought of as a precondition for the collapse of the *Ericymba* population, reducing its resiliency (Holling 1973) to extreme manifestations of natural limiting factors and sources of mortality.

REFERENCES

Christie, W. J. and H. A. Regier. 1973. Temperature as a major factor influencing reproductive success of fish--two examples. Rapports et Proces-Verbaux des Reunion, Conseil Int. pour l'Exploration de la Mer 164: 208-218.

Dudley, D. R. and J. R. Karr. 1979. Concentration and sources of fecal and organic pollution in an agriculture watershed. Water Res. Bull. 15: 911-923.

Dudley, D. R. & J. R. Karr. 1980. Pesticides and PCB residues in the Black Creek watershed, Allen County, Indiana - 1977-78. Pestic. Monit. J. 13: 155-157.

Gorman, O. T. and J. R. Karr. 1978. Habitat structure and stream fish communities. Ecology 59: 507-515.

Holling, C. S. 1973. Resilience and stability in ecological systems. Ann. Rev. Ecol. Syst. 4: 1-23.

Hoyt, R. D. 1970. Food habits of the silverjaw minnow, *Ericymba buccata* Cope, in an intermittent stream in Kentucky. Am. Midl. Nat. 84: 225-36.

Karr, J. R. and D. R. Dudley. 1976. Determinants of water quality in the Black Creek watershed. In Best Management Practices for Non-Point Source Pollution Control Seminar. USEPA - 905/9-76-005. pp. 171-184.

Karr, J. R. and D. R. Dudley. In press. Biological perspective on water quality goals. Env. Management

Karr, J. R. and O. T. Gorman. 1975. Effects of land treatment on the aquatic environment. EPA-905/9-75-007. pp. 120-150.

Larimore, R. W. and P. W. Smith. 1963. The fishes of Champaign County, Illinois, as affected by 60 years of stream changes. Ill. Nat. Hist. Surv. Bull. 28: 299-382.

Morrison, J. B. 1977. Environmental impact of land use on water quality - final report on the Black Creek project. USEPA. EPA-905/9-77-07.

Muncy, R. J., G. J. Atchison, R. V. Bulkley, B. W. Menzel, L. G. Perry, & R. C. Summerfelt. 1979. Effects of suspended solids and sediments on reproduction and early life of warmwater fish: A review. USEPA EPA-600/3-79-042.

Nelson, D. W. and D. Beasley. 1978. Quality of Black Creek drainage water: additional parameters. In J. Lake and J. Morrison (eds.) Environmental Impact of Land Use on Water Quality: Supplemental Comments. EPA-905/9-77-007-D. pp. 36-78.

Pflieger, W. L. 1975. The fishes of Missouri. Missouri Department of Conservation. 343 pp.

Proffitt, M. A. and R. S. Benda. 1971. Growth and movement of fishes, and distribution of invertebrates, related to a heated discharge into the White River at Petersburg, Indiana. Indiana Univ. Water Res, Ctr. Rept. Invest. No. 5, 94 pp.

Smith, P. W. 1978. The fishes of Illinois. U. of Illinois Press, Urbana, IL. 314 pp.

Trautman, M. B. 1957. The fishes of Ohio. Ohio State Univ. Press, Columbus, Ohio. 683 pp.

U. S. Environmental Protection Agency. 1976. Quality criteria for water. Office of Water Planning and Standards, USEPA. Washington, D. C. 256 pp.

Wallace, D. C. 1972. The ecology of the silverjaw minnow, Ericymba buccata Cope. Am. Midl. Nat. 87: 172-190.

Wallace, D. C. 1973a. Reproduction of the silverjaw minnow, Ericymba buccata Cope. Tran. Am. Fish. Soc. 102: 786-793.

Wallace, D. C. 1973b. The distribution and dispersal of the silverjaw minnow, Ericymba buccata Cope. Am. Midl. Nat. 89: 145-55.

Wallace, D. C. 1976. Feeding behavior and development, seasonal and diet changes in the food of the silverjaw minnow, Ericymba buccata Cope. Am. Midl. Nat. 95: 361-376.

# The Sociological Study of Soil Erosion

by
Stephen B. Lovejoy and F. Dale Parent

Soil erosion is a national problem which affects all citizens, agriculturalists and non-agriculturalists. The erosion of soil affects everyone by reducing the fertility and productivity of our agricultural lands as well as by contributing to serious water quality problems.

The loss of valuable topsoil from cropland may lead to long-term productivity losses and possibly irrepairable damage to more sensitive land. Erosion of topsoil is becoming more serious as lower quality land is brought into production as well as the more intensive and erosive practices being utilized on existing cropland. While increased fertilizer usage has ameliorated the impacts of erosion upon yields and productivity in the short run, the long term consequences of significant erosion cannot be escaped.

In addition, eroded soil is transported into our water bodies (rivers, lakes, streams) along with a variety of chemicals attached to the soil particles. Erosion of agricultural land has been pinpointed as a primary contributor to the decline in water quality (GAO, 1977). The transported soil creates sedimentation problems in water bodies as well as promoting eutrophication in lakes and reservoirs as a result of increased levels of nutrients. Added to this is the problem of a variety of harmful chemicals which may be attached to the soil particles, thus degrading the natural environment as well as posing potential hazards to fish, wildlife and possibly mankind.

Many policies and programs have been enacted to deal with the problems associated with soil erosion, beginning with the conservation programs in the 1930's. The present myraid of programs to reduce soil erosion are administered by a variety of agencies including Soil Conservation Service, Agricultural Stabilization and Conservation Service, Environmental Protection Agency, Rural Clean Water Program, etc. One common attribute of all these programs is that the agencies have little, if any, coercive power to force participation in the program or compliance with recommended practices.

Programs designed to abate soil erosion have been primarily voluntary. Landowners who desired to participate were encouraged to do so by a variety of educational programs and financial incentives. The educational programs have been orientated toward providing information on the causes and consequences of erosion and thus the need for soil conservation. In addition, a great deal of information has been provided on the implementation of specific practices designed to abate soil erosion. The financial incentives have, historically, been offerred in the form of cost-shares, whereby the government agency shares with the farmer the costs of implementing the abatement practice. Both education and financial incentives reinforce the voluntary nature of these programs and strengthen the antipathy toward mandatory controls, regulations and coercive powers in general. However, little effort has been expended in determining the success of these programs or in determining the "best" mix of educational programs, technical assistance and financial incentives. Further, the scant literature available indicates that the effects of these programs are not equally distributed among agriculturalists and therefore the programs cannot be structured identically for all farmers regardless of geographic location, soil type, type of farm firm, etc.

Current programs have not been spectacularly successful for a variety of reasons including inadequate attention to the incentive structure established. If landowners are to retain their rights to voluntarily participate or not participate and we are to have successful abatement of soil erosion, we must very carefully construct incentive structures which will induce them to participate. Questions have been raised concerning the optimal rate of cost-sharing (e.g. Bouwes & Lovejoy, 1980; Lovejoy, et al., 1980) as well as the impact of the educational programs and technical assistance efforts (e.g. Klessig, and Lovejoy, 1980). In general, we have very little information concerning the effects of various program structures upon individuals and farm firms with differing predilections, preferences, values, attributes, etc. This type of information would be essential to construct policies and programs which would induce landowners to voluntarily participate in these soil erosion abatement programs.

While significant research has been done in the adoption of commercial practices in agriculture, the practices associated with erosion abatement seem quite different (see Taylor and Miller, 1979). Essentially, most do not have short-run financial benefits for the farm firm and therefore are not as attractive as other practices. This factor necessitates construction of a program which makes adoption an attractive option.

The problems associated with soil erosion will not diminish in the near future and government policies to control those problems will not dry up and blow away. If these programs are to be successful on a voluntary participation basis they need to be constructed with more attention to the desires and needs of the potential adopters, the ability of the individuals and farm firms to incorporate the practices into their farming operations as well as the consequences for the farmer and the farm firm of utilizing these practices.

Excessive soil erosion in the U.S. is the product of a social institution. This social institution is composed of the behavioral patterns of American farmers. The overall purpose of the Black Creek project was to reduce soil erosion by effecting changes in this social institution, or, in other words, by altering the practices (behavior) of farmers.

However, changes in social institutions are not straightforward. Alterations may be more difficult to enact than expected and once enacted may have secondary effects that were not anticipated. Such anticipated effects may have implications (positive or negative) for the soil erosion program, local residents and the local community as well as future programs by the agencies involved.

The Black Creek Project has been rather unique in that sociologists have been involved since the early stages of the project. Not only has this involvement provided a source of data for evaluation of the project but also assisted in dissemination of information and establishment of channels of communication in the early stages. Sociologists have aided in decisions concerning how to involve the local residents and the procedures to use in attempting to insure widespread acceptance of new agricultural practices.

In 1974, interviews were conducted with eight-nine (89) landowners in the Black Creek watershed. These landowners were questioned about their land use practices as well as numerous attitudinal measures. In 1976, a sample of those same landowners were again contacted and interviewed in an attempt to investigate the impacts of the project and changes in land use. Results of both earlier investigation are available in prior reports from the Black Creek Project.

The present study utilizes information obtained in interviews conducted during the summer of 1980. Attempts were made to contact all 89 respondents included in the 1974 study, but due to outmigration (15), mortality (5), illness (2), etc., only 54 were interviewed in 1980. The present report will detail the responses of those 54 respondents. For some measures, the 1980 responses will be contrasted with the 1974 responses in order to assess shifts in land use patterns, attitudes, etc. In other sections, the 1980 data will be utilized to assess differences between respondent groupings. Overall, the objectives of this report are as follows: 1) assess the consequences of an erosion abatement program for the local community and its residents, 2) to provide for a better understanding of the adoption process, especially in regard to environmental innovations and 3) to provide information necessary to a better structuring of similar projects.

This project has been a post-program evaluation of the success or failure of the program. We need to know the success or failure of the program as well as the reasons for the success or failure if the lessons learned from this demonstration project are to be useful. The other scientists on this project have indicated the changes or stability in a number of water quality parameters such as dissolved nitrogen as well as changes in the eco-system of the water bodies involved.

However, evaluation of the success or failure cannot stop there. Part of the evaluation of a project, especially a demonstration project, must deal with the acceptance of the project by the designated population, their cooperation and their use of recommended behavioral changes. This is essential from two perspectives. First, the costs and benefits of such projects cannot be limited to technological costs and environmental benefits but must indicate the personal costs paid by the affected firms and residents. Secondly, the knowledge gained from the social and economic evaluation will illustrate the aspects of the program which facilitate the primary goals and those that do not.

## Conservation Attitudes

Although changes in land use paractices are the best indicators of the success of a water quality program, they are not singular indicators of success. Water quality programs may effect the community and residents in a myraid of ways. Residents may react negatively to a program pushed too hard or in an incorrect manner, thus reducing their propensity to participate in any environmental program. The method of financial and technical assistance may not meet with residents desires and expectations. On the other hand, the program may predispose participants to enroll in other programs. Participation may improve the communication lines between residents and agency personnel. The environmental education may increase awareness of environmental problems. These and other attitudinal effects will affect how residents will view future programs as well as how they will behave in relation to adopted practices.

Let us begin looking at some of those attitudes (see Table 1). In 1974, 46% of respondents thought that conservation of soil was not a problem. By 1980, that percentage had dropped to 44%, indicating increasing awareness of the problems of soil conservation. This effect is larger when we consider just those respondents for whom we have data from both surveys (50% down to 44.4%). This suggests that these has been a slight change in views concerning soil conservation as a problem although fewer respondents thought stream pollution was a major problem, possibly indicating a view that the problem has been solved.

Fewer respondents in 1980 thought that landowners would lose from the soil and water development programs and a alisghtly greater number felt that landowners should pay for conservation practices adopted. In line with the above, fewer respondents felt that the federal government should play an important role in local soil conservation programs. The trend seems to be toward less federal involvement and greater monetary burdens on landowners, although this remains a minority viewpoint. Over all, the respondents increasingly suggested that the cost of water quality projects should be borne by state and local units of government as well as landowners (see Table 2). A possible explanation of this trend is the increased dissatisfaction with the opportunities for landowners to express their opinion in planning watershed projects.

Another aspect of any project in a community is it's potential capacity building effect. Some communities will become more effective in initiating and implementing local projects because of new leadership, improved organizational skills, etc. (see Klessig and Lovejoy, 1980). The local community in the Black Creek watershed seems to have increased its capabilities. Table 3 indicates a substantial change in attitudes toward the willingness of residents to get involved and in the degree of organization in the community. This suggests that the residents now have a better organized community and more responsive neighbors than they had prior to the Black Creek Project. This may prove to be a definite benefit in coping with future community problems and projects. The respondents who thought that soil and water development is a good investment increased, with all but 2 respondents agreeing. Contrary to the results in Table 2, fewer respondents agreed that the watershed program was being pushed too hard. This suggests that local residents do not feel pressured to enroll in this project but that control should remain at the local level.

Table 1: Attitudes Toward Erosion Control

| | Percent Agreeing | | |
|---|---|---|---|
| | 1974 | 1974* | 1980 |
| Conservation of soil is not a real problem in this area. | 46.1% | 50.0% | 44.4% |
| The average landowner in this county stands to lose more than he will gain by soil and water development programs. | 9.0 | 9.3 | 7.4 |
| The cost of soil erosion reducing programs (e.g., field borders, grassed waterways) should be borne entirely by those who adopt them. | 28.1 | 22.2 | 29.6 |
| The federal government should play an important role in soil conservation programs in this county. | 62.9 | 64.8 | 59.3 |
| Pollution of the streams is a major problem in this county. | 40.4 | 42.6 | 25.9 |
| Landowners have little opportunity to express their opinions in planning watershed projects. | 25.8 | 22.2 | 33.3 |
| N = | 89 | 54 | 54 |

Table 2: Who Should Pay For Efforts To Clean Up Water

| | 1974* | 1980 |
|---|---|---|
| X percent federal | 38.8% | 34.9% |
| X percent state | 26.21% | 28.6% |
| X percent local | 32.57% | 36.7% |

*Only includes those 54 respondents also interviewed in 1980.

Table 3: Attitudes Toward Local Community

| | Percent Agreeing 1974 | 1974* | 1980 |
|---|---|---|---|
| The people of this community are usually quick to respond when problems arise requiring action. | 55.1 | 46.3 | 85.2 |
| This community is well organized. | 32.6 | 29.6 | 79.6 |
| Spending money for soil and water development is a good investment. | 87.6 | 83.3 | 96.3 |
| The watershed program is being pushed too hard in this county. | 9.0 | 9.3 | 7.4 |
| N = | 89 | 54 | 54 |

*Only includes those interviewed in 1974 and 1980.

## Attitudes Toward Community and Agencies

Another important aspect of a project in a community is the effects upon the flow of information. Many stress the self-reliance and independence of the American farmer. We surveyed the farmers to determine how they handle problems they encounter or may encounter in their farming operations (see Table 4). The 1974 survey indicated that for most problems, the responsdents relied upon themselves or their neighbors. In the 1980 survey, respondents relied upon themselves or neighbors for only three (3) problem areas: crop rotation, farm management, and non-farm land uses. The role of small businesses/professionals and local governmental agencies has expanded in all problem areas except non-farm land uses. These data suggest that the farmers in the Black Creek are increasingly relying upon advice from professionals (public & private) in the operation of their farms. This trend may imply a movement away from traditional farming practices, a trend essential to adoption of new technologies including erosion control practices. However, the adoption of new practices does not necessarily imply that erosion control measures will be adopted. The new practices may be more erosive or polluting than traditional practices (e.g., continuous corn, greater reliance on insecticides and herbicides, etc.).

Another implication of the above trend is the increasing contact of these farmers with government agency personnel. Respondents were asked how many times in the past year they had contact with personnel from several governmental agencies. Table 5 indicates that respondents are increasingly having contact with agency personnel. The only agency to show decreases in contact is Purdue University, likely the result of fewer researchers in the area as the project has wound-down. The most dramatic increase in contact was with the Cooperative Extension Service (CES), whether this resulted from a new CES program or whether the respondents were seeking out CES agents is unknown.

Table 4: Who Do Respondents Contact for Assistance With Problems

| | Who Is Contacted | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Handle Myself | | Friend/ Neighbor | | Business/ Professional | | Government | | N* | |
| Problem | 1974 | 1980 | 1974 | 1980 | 1974 | 1980 | 1974 | 1980 | 1974 | 1980 |
| Crop Decrease | 29% | 7% | 14% | 4% | 30% | 41% | 27% | 48% | 77% | 54% |
| Insect Control | 28 | 13 | 6 | 6 | 42 | 44 | 24 | 37 | 79 | 54 |
| Machinery | 64 | 37 | 6 | 6 | 30 | 57 | -- | -- | 81 | 54 |
| Livestock | 37 | 13 | 5 | 10 | 58 | 77 | -- | -- | 65 | 31 |
| Crop Rotation | 83 | 70 | 4 | 7 | 4 | 4 | 10 | 19 | 82 | 54 |
| Farm Management | 80 | 74 | 9 | 9 | 4 | 2 | 7 | 15 | 82 | 54 |
| Soil Management | 51 | 26 | 4 | 6 | 24 | 9 | 21 | 58 | 80 | 53 |
| Fertilizer Usage | 53 | 30 | 6 | 8 | 39 | 53 | 2 | 9 | 83 | 52 |
| New Crop Varieties | 46 | 38 | 21 | 9 | 29 | 51 | 4 | 2 | 80 | 53 |
| Non-Farm Land Uses | 50 | 71 | 7 | 4 | 5 | -- | 38 | 25 | 60 | 52 |
| Potential Pollution | 41 | 33 | 8 | 2 | 5 | 6 | 47 | 59 | 64 | 51 |

*N size varies due to non-responses as well as lack of applicability.

Table 5: Number of Contacts With Agency Personnel

| | 1974* | | | | 1980 | | | |
|---|---|---|---|---|---|---|---|---|
| | 0 | 1-2 | 3+ | Total | 0 | 1-2 | 3+ | Total |
| Cooperative Extension Service | 74.7% | 14.0% | 11.5% | 100.0% | 37.7% | 15.1% | 47.2% | 100.0% |
| Agricultural Stabilization and Conservation Service | 51.7 | 26.4 | 21.8 | 100.0 | 43.4 | 15.1 | 41.5 | 100.0 |
| Soil and Water Conservation | 61.6 | 23.3 | 15.1 | 100.0 | 54.9 | 15.7 | 29.4 | 100.0 |
| Soil and Water Conservation Districts | 52.3 | 32.6 | 15.1 | 100.0 | 56.9 | 9.8 | 33.3 | 100.0 |
| Purdue University | 52.9 | 36.8 | 10.3 | 100.0 | 73.1 | 11.5 | 15.4 | 100.0 |

*Only indicates those interviewed in both 1974 and 1980.

A change which may be a more subtle effect of the project is the shifting preferences for methods to get people to cooperate (see Table 6). In 1974, 60 percent of the respondents thought education was the best mechanism, while in 1980, only 44 percent felt education was the best method. This suggests that some of those for whom education was a preferred method of assuring cooperation no longer prefer education. Financial incentives rose in popularity, possibly a result of the perceived success of the financial incentives offered by the Black Creek project.

Table 6: Best Method For Getting People to Cooperate in Soil and Water Conservation Programs

| | 1974 | | 1974 | | 1980 | |
|---|---|---|---|---|---|---|
| Method | Number | Percent | Number | Percent | Number | Percent |
| Education | 35 | 61.4% | 32 | 59.3% | 24 | 44.4% |
| Financial Incentives | 8 | 14.0 | 7 | 13.0 | 11 | 20.4 |
| Laws and Controls | 8 | 14.0 | 4 | 7.4 | 4 | 7.4 |
| Combination of Above | -- | --- | -- | --- | 4 | 7.4 |
| Other | 2 | 3.5 | 2 | 3.7 | 5 | 9.3 |
| No Response | 4 | 7.0 | 8 | 14.9 | 6 | 11.1 |
| N = | 57 | 100.0 | 54 | 100.0 | 54 | 100.0 |

Land Use

This section presents the farmers' responses to a variety of questions concerning their use of selected land use practices.

Table 7 provides a comparison of the percentage of farmers reporting their use of selected structural and management land use practices in both 1974 and 1980. The first column of Table 7 reports the responses of all 89 respondents interviewed in 1974, while the second column includes only those 54 individuals contacted in 1974 who were again contacted in 1980. An overall look at the table reveals that from 1974 to 1980, landowners increased the use of five of the practices and decreased use of four. Apparently, there has not been a steady increase in the adoption of all the management practices. Three of the four practices which declined in use, do not involve the installation of permanent structures. Practices such as conservation cropping, crop residue management, and livestock exclusion may be more conducive to discontinuation than practices which require structural modifications.

Table 7: Respondent's Use of Several Management Practices, 1974 and 1980 Percent of Respondent's Using The Practice

| Management Practice | 1974 | 1974* | 1980 |
|---|---|---|---|
| Conservation Cropping | 83.3% | 88.9% | 62.9% |
| Contour Farming | 2.2 | 1.9 | 5.6 |
| Crop Residue Management | 41.6 | 46.3 | 35.2 |
| Field Borders | 36.0 | 38.9 | 48.1 |
| Grade Stablization Structures | 18.0 | 14.8 | 18.5 |
| Grassed Waterway or Outlet | 33.7 | 27.8 | 44.4 |
| Holding Pond or Tank | 13.5 | 14.8 | 9.2 |
| Livestock Exclusion | 18.0 | 16.7 | 9.2 |
| Farm Pond | 18.0 | 16.7 | 18.5 |
| Strip-cropping | -- | -- | -- |

*Only includes those landowners who also responded in 1980.

The reduction in the use of conservation cropping provides one of the most interesting findings in Table 7. In 1974 over 80% of the landowners were using conservation cropping, while in 1980, only 62.9% of the landowners were using conservation cropping. This may suggest a trend towards mono-agriculture in the Black Creek area, where there is greater reliance on continuous cropping. Crop residue management, another practice that experienced a decline in use between 1974 and 1980, will be discussed in detail later because of its importance as a management tool in reducing soil erosion.

The use of grassed waterways or outlets illustrates the opposite trend exhibited by conservation cropping and crop residue management. There has been a rather significant increase in the implementation of grassed waterways since 1974. This may, in part, be the result of low capital costs and 80% cost-sharing by the Allen Co. SWCD. When focusing specifically on those 54 respondents who participated in both interviews (1974 and 1980) the increase in the use of grassed waterways rose from 17.8% in 1974 to 44.4% in 1980.

We now turn our attention to Table 8 which focuses directly on information gathered from the farmers in the 1980 survey. The first column of this table indicates the number and percentage of farmers reporting either the current use of or the past use of each land use practice. The practice most widely adopted (100%) by the landowners is that of tile drains. While, tile drains are an essential part of many of the farming operations in the Black Creek area, they have little value for water quality. Their main value is in terms of crop production. Therefore, it is not surprising to have such a high adoption rate among Black Creek area farmers especially when the district was cost-sharing at 70%. The The use of practices and structures depends, in part, upon local conditions and inducements offered.

The use of tile drains can be contrasted with stripcropping. Only one farmer reported using stripcropping on his farm. Further, only six individuals indicated that they had received any information about this practices. Such a low rate of use may be attributable to a lack of applicability of stripcropping to most of the area farms or lack of information regarding procedures and consequences.

Over sixty percent of the respondents indicated that they use a conservation cropping system, which makes it the second most utilized best management practice (BMP) among the Black Creek farmers. No other land management practice was reported being used by more than 50% of the farmers. However, field borders (48%) and crop residue management (37%) showed substantial rates of adoption. The low rate of adoption for some practices may result from some practices not being appropriate for all the farming operations. Two examples of this include, contour farming and livestock exclusion. Much of the land in the Black Creek area is relatively flat, thus not requiring contour farming. In addition, many of the hills are in permanent vegetation. In a similiar manner, livestock exclusion has no relevance to those farmers with a strictly cash-grain operation. Another consideration in examining adoption rates for various practices is the amount of assistance the farmer has received.

Each respondent was asked if he/she had received any technical or financial assistance in instituting each of the land management practices (see Table 8). The only practices in which less than 50% of the farmers, using the specified practice, had received technical assistance were: conservation cropping, contour farming, holding ponds or tanks and tile drains. However, conservation cropping and tile drains were established by many farmers, prior to the Black Creek Demonstration Project. Many of the landowners using conservation cropping indicated that this was the way they had learned to farm. Therefore, few reported receiving technical assistance in starting their conservation cropping system. Similarly, many respondents stated that tile drains were already on their land when they began farming. The percentage of those receiving technical assistance for contour farming and holding ponds or tanks was low. However, there were very few farmers utilizing these practices.

Table 8: Specific Information on Selected Best Management Practices

| Management Practice | Using or Used | | Received Technical Assistance | | Received Financial Assistance | | Increase In Profit | | Use Has Effect On Water Quality | | Have Never Used | | Never Used But Received Information | | Never Used, But Thought it Had Effect on Water Quality | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N | % | N | % | N | % | N | % | N | % | N | % | N | % | N | % |
| Conservation Cropping | 35 | 64.5 | 10 | 28.6 | 7 | 20.0 | 25 | 71.4 | 32 | 91.4 | 19 | 35.5 | 7 | 36.8 | 4 | 57.1 |
| Contour Farming | 3 | 5.5 | 0 | 0.0 | 0 | 0.0 | 2 | 66.6 | 3 | 100.0 | 51 | 94.5 | 16 | 31.3 | 16 | 100.0 |
| Crop Residue Management | 20 | 37.0 | 10 | 50.0 | 7 | 35.0 | 11 | 55.0 | 19 | 95.0 | 34 | 63.0 | 8 | 23.5 | 6 | 75.0 |
| Field Borders | 26 | 48.1 | 22 | 84.6 | 21 | 80.8 | 5 | 19.2 | 26 | 100.0 | 28 | 51.9 | 5 | 17.8 | 4 | 80.0 |
| Grade Stabilization Structures | 10 | 18.5 | 10 | 100.0 | 9 | 90.0 | 1 | 10.0 | 10 | 100.0 | 44 | 81.5 | 4 | 9.0 | 4 | 100.0 |
| Grassed Waterway or Outlet | 26 | 48.1 | 15 | 57.7 | 14 | 53.8 | 14 | 53.8 | 26 | 100.0 | 28 | 51.9 | 9 | 32.4 | 9 | 100.0 |
| Holding Pond or Tank | 5 | 9.3 | 2 | 40.0 | 2 | 40.0 | 4 | 80.0 | 4 | 80.0 | 49 | 90.7 | 9 | 20.4 | 9 | 100.0 |
| Livestock Exclusion | 6 | 11.1 | 4 | 66.7 | 2 | 33.3 | 1 | 16.6 | 5 | 83.0 | 48 | 88.9 | - | -- | - | -- |
| Farm Pond | 11 | 20.4 | 8 | 72.7 | 8 | 72.7 | 1 | 9.1 | 10 | 90.9 | 43 | 79.6 | 12 | 28.0 | 7 | 58.3 |
| Strip Cropping | 1 | 1.8 | - | -- | - | -- | - | -- | - | -- | 53 | 98.2 | 6 | 11.3 | 6 | 100.0 |
| Surface Drains | 14 | 26.0 | 10 | 71.4 | 10 | 71.4 | 10 | 71.4 | 14 | 100.0 | 40 | 74.0 | 5 | 12.5 | 5 | 100.0 |
| Tile Drains | 54 | 100.0 | 26 | 48.1 | 23 | 42.6 | 45 | 83.3 | 49 | 90.7 | - | 0.0 | - | -- | - | -- |

For most of the practices, approximately the same percentage of farmers who reported receiving technical assistance also said they had received financial aid to start the practices. The major discrepancies from this pattern were found among the adopters of livestock exclusion and crop residue management. This suggests that in the Black Creek area, financial assistance and technical assistance seem to have gone hand in hand. The need for these types of assistance is often based upon ideas of lack of knowledge concerning the practice and effects of adoption on farm profits.

Some land use practices, designed to control agricultural run-off, may reduce farm firm profits. This is obviously an effect which must be considered in persuading farmers to adopt such innovations. In addition to an objective appraisal, the farmers' own perceptions of how each practice has affected their income, can be very important with regard to their continued use and in the information transmitted to non-adopters. In order to determine adopting farmers perceptions, the following question was asked about each agricultural practice that had been adopted by a particular farmer: "How does or did it affect income or profit?"

The fourth column of Table 8 indicates the number of respondents reporting an increase in income or profits due to adoption of each land use practice. Conservation cropping and tile drains were both cited by a large percentage of farmers as increasing profits. Slightly more than half of those farmers utilizing crop residue management and grassed waterways also reported an increase in profit from the use of these practices. However, Table 7 indicated a decline in the use of conservation cropping and crop residue management.

The case of crop residue management is a particularly interesting and important one. The environmental nature of this practice might suggest that it negatively influences income. However, 55% of those using crop residue management attributed an increase in profit to its use. This point could be emphasized to potential adopters of this practice.

Very few respondents who were using grade stabilization structures or ponds said they had experienced monetary gains from their adoption. However, it should not be interpreted that these practices negatively affect income. Most users of both grade stablization structures and ponds said these practices simply had no influence on their income or profit.

Each adopter of a particular land use practice was asked if he felt the use of the practice had any effect on the quality of the water in our rivers, lakes, and streams. This was done in order to assess the farmers' awareness of the environmental implications of each of the land use practices. Table 8, indicates that over 80% of the adopting farmers, for any specific practice, believed it had affected water quality. The last two columns of the table reveal a similiar situation for nonadopters. Most of the respondents who had not adopted a specific management practice, but had received information about it, also felt the practice would affect the quality of our water resources. This demonstrates the successful communication of the impact of these land use practices upon the quality of our water resources. For most of those farmers contacted about a certain management practice, whether they had adopted it or not, they apparently understood its value in maintaining water quality.

Table 9 indicates the specific reasons given for initiating particular land use practices. An important point illustrated by the table is the significant number of persons citing erosion control as the reason for starting many of the practices. This suggests farmers who adopt these practices have an understanding of the need to control erosion and that it enters into this decision-making process.

We now turn our attention specifically to crop residue management, one of the more important methods for controlling soil erosion in the Black Creek watershed. Of the 54 respondents questioned in 1980, 19 said they were currently using crop residue management, one person indicated he had used this practice in the past, and the remaining 34 farmers waid they had never used crop residue management. Those persons who indicated that they were using crop residue management were asked if they were using chisel plowing, minimum till or no till systems. Fourteen (14) reported using chisel plowing, three were using a minimum till system, and one was using no till. Most of the farmers (84.2%) indicated they had adopted the practice of using crop residue management during the Black Creek Demonstration Project.

The reason mentioned most often by these farmers for adopting crop residue management was to reduce soil erosion. Two of the individuals cited business reasons for initiating the practice, while four said they started because it was recommended by others or because of financial aid received. When these individuals were asked how crop residue management specifically affected their income or profit the following responses resulted: four said it had no effect, three said it produced higher yield/ better crops, four indicated that it had generally reduced operating cost, one suggested it saved labor, anmd one landowner indicated that crop residue management had improved drainage. One respondent said crop residue management had contributed to a loss in profit as a result of later planting. Nineteen of the twenty farmers who had adopted crop residue management felt it has an effect on the quality of our water resources.

Eight of the 34 farmers who reported never using crop residue management, indicated that they had received some information about it. These eight farmers were asked why they had never used crop residue management. They responded as follows: four said there was no need for it on their land, one person thought fall plowing was better, another individual said it didn't work for a friend, and the remaining two indicated that they had no reason for not using the practice.

The conservation practices covered by the Black Creek project have a great deal of variance in terms of conservation of soil and in terms of wide applicability. However, one set of practices which seem to have wide utility is that of crop residue management. Crop residue management refers to the use of residue on the surface to discourage the runoff of water (which of course carries soil with it). The most common methods of crop residue management include chisel plowing, minimum tillage cropping and no-till cropping. These practices were promoted in the Black Creek project as BMP's which the farmer should adopt. Apparently, there was limited success at encouraging the adoption of these practices. Of the 54 farmers contacted in 1980, only 19 were using any of these BMP's, 14

Table 9: Respondent's Reason for Starting Several Management Practices

| Management Practice | Improve Drainage N | % | Reduce Erosion N | % | Keep Land Fertile N | % | Business Reason N | % | Recommended or Financial Aid N | % | Tradition/ Habit N | % | Misc.* N | % | Total N | % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Conservation Cropping | 1 | 2.9 | 2 | 5.6 | 18 | 51.4 | 3 | 8.6 | 3 | 8.6 | 7 | 20.0 | 1 | 2.9 | 35 | 100 |
| Contour Farming | - | -- | 1 | 33.3 | - | -- | - | -- | - | -- | - | -- | 2 | 66.6 | 5 | 100 |
| Crop Residue Management | - | -- | 8 | 40.0 | - | -- | 5 | 25.0 | 5 | 25.0 | - | -- | 2 | 10.0 | 20 | 100 |
| Field Border | - | -- | 18 | 69.2 | - | -- | 1 | 3.8 | 5 | 19.3 | - | -- | 2 | 7.7 | 26 | 100 |
| Grad. Stab. Structure | - | -- | 7 | 70.0 | - | -- | - | -- | 3 | 30.0 | - | -- | - | -- | 10 | 100 |
| Grassed Waterway or Outlet | 8 | 30.8 | 13 | 50.0 | - | -- | 2 | 7.7 | 2 | 7.7 | - | -- | 1 | 3.8 | 26 | 100 |
| Holding Pond or Tank | - | -- | - | -- | - | -- | 4 | 80.0 | - | -- | 1 | 20.0 | - | -- | 5 | 100 |
| Livestock Exclusion | - | -- | 2 | 33.3 | - | -- | 1 | 16.7 | 1 | 16.7 | - | -- | 2 | 33.3 | 6 | 100 |
| Farm Pond | 1 | 11.1 | 1 | 11.1 | - | -- | - | -- | - | -- | - | -- | 9* | 81.8 | 11 | 100 |
| Strip Cropping | - | -- | - | -- | - | -- | - | -- | - | -- | - | -- | - | -- | - | 100 |
| Surface Drains | 8 | 57.2 | 4 | 28.6 | - | -- | - | -- | 1 | 7.1 | - | -- | 1 | 7.1 | 14 | 100 |
| Tile Drains | 45 | 85.0 | 1 | 1.9 | 1 | 1.9 | - | -- | - | -- | 5 | 9.3 | 1 | 1.9 | 53 | 100 |

*Miscellaneous category for farm pond includes: Recreation 4, drinking for livestock 1, sediment basin 2, and needed the dirt, 2.

were using chisel plowing, 3 minimum tillage cropping and 2 no-till cropping. One other farmer indicated that he was using crop residue management, but the exact practice was not ascertained by the interviewer. Sixty-five percent (65%) of the farmers contacted had not adopted any of the crop residue management practices. While this has implications for the water quality and soil conservation goals of the project, it also has implications for the socio-economic consequences of participation in the Black Creek project. With that in mind, the adopters of crop residue management practices will be contrasted with non-adopters.

Adopters of Crop Residue Management and Non-Adopters

Respondents were, as illustrated previously, questioned about their use of several land use practices. For brevity, we decided to choose 1 practice for intensive investigation of the consequences of adopting a BMP. Since crop residue management practices are extensively involved with water quality protection and it is often purported to have consequences more significant than other practices, it was selected for intensive investigation. We begin by contrasting changing farm firm characteristics for adopters and non-adopters.

As indicated in Table 10, the average number of acres owned by our respondents increased from 1974 to 1980. Non-adopters, on the average, increased their land holdings by 24%, but adopters increased their holdings by 155%. The average adopting respondent farms over 4 times as many acres as the average non-adopting farmer. The adopters tend to be larger farmers and have grown more rapidly from 1974 to 1980 than non-adopting farmers. While non-adopters, on the average, own increased acreage in 1980, they have fewer acres in crops, 3% less acreage in corn and 11% less acreage in soybeans. Adopters, on the other hand, have increased their corn acreage by 55% and their soybean acreage by 86%.

While yields seem to have increased for both groups of respondents, the non-adopters have experienced greater percentage increases in yield although their corn yield is still below the adopters. Whether this difference in percentage yield increases in due to the use of crop residue management or is a spurious finding is unknown. Another anticipated benefit of inducing a farmer to adopt a conservation practice is the carryover to other practices. In other words, if he adopts one practice he will, presumably, be more likely to adopt other conservation practices. This anticipation seems to hold for adopters of crop residue management in Black Creek. For each of the other selected practices, farmers using crop residue management are more likely to be adopters of the other conservation practices. These results indicate that there is a correlation between use of crop residue management and other conservation practices, and suggests that getting a farmer to adopt one practice increases the probability of his adopting other practices.

The next question to be addressed is the differences in environmental and conservation attitudes between adopters and non-adopters. While we have indicated that adopters of one practice seem to be more likely to adopt other practices, we have not suggested any causal factor. One such causal factor could be that the adopters become more conscious of environmental and conservation problems and therefore change their attitudes about these problems and their solutions.

Table 10: Farm Firm Characteristics for Adopters and Non-Adopters

| Characteristic | Respondents using crop residue management in 1980 | Respondents not using crop residue management in 1980 |
|---|---|---|
| Acres Owned | | |
| 1974 (X) | 103.5 | 85.8 |
| 1980 (X) | 263.5 | 106.5 |
| Acres Farmed 1980 (X) | 523.4 | 116.7 |
| Acres in Crops | | |
| 1974 (X) | 105.2 | 97.7 |
| 1980 (X) | 473.6 | 91.9 |
| Corn for Grain - Acres | | |
| 1974 (X) | 87.2 | 37.0 |
| 1980 (X) | 136.0 | 35.9 |
| Corn for Grain - Yield in Bushels/Acre | | |
| 1974 (X) | 85.9 | 66.0 |
| 1980 (X) | 125.3 | 110.0 |
| Soybeans - Acres | | |
| 1974 (X) | 103.7 | 31.0 |
| 1980 (X) | 193.2 | 27.7 |
| Soybeans - Yield in Bushels/Acre | | |
| 1974 (X) | 32.1 | 29.8 |
| 1980 (X) | 39.9 | 42.4 |

Table 11: Use of Other Conservation Practices by Adopters and Non-Adopters of Crop Residue Management

| Other Conservation Practices | Crop Residue Management Adopter | Crop Residue Management Non-Adopter |
|---|---|---|
| Conservation Cropping | 65% | 62% |
| Contour Farming | 15% | -- |
| Crop Residue Management | 100% | -- |
| Field Borders | 60% | 41% |
| Grade Stabilization Structures | 35% | 9% |
| Grassed Waterway or Outlet | 60% | 35% |
| Holding Pond or Tank | 10% | 9% |
| Livestock Exclusion | 20% | 15% |
| Farm Pond | 15% | 21% |
| Strip-cropping | -- | -- |
| Surface Drains | 30% | 24% |
| Tile Drains | 100% | 97% |

Table 12 indicates that the adopters were more pro-environment in terms of utilizing available technology and Federal taxation. They were also less likely to agree that farmers must, primarily, be concerned with profits. However, a greater percentage of non-adopters agreed that it is very important to clean up the environment.

Table 12: Environmental Attitudes of Adopters and Non-Adopters

| Statement | Percent Agreeing with Statement Adopter | Percent Agreeing with Statement Non-Adopter |
|---|---|---|
| Even considering the cost, all available pollution control techniques should be used | 40% | 35% |
| Federal taxation to clean up our water completely wouldn't be too expensive to consider | 90% | 60% |
| It is very important to clean up the environment | 80% | 91% |
| Farmers are businessmen and therefore must be primarily concerned with profits | 70% | 85% |
| Farmers have a responsibility to preserve the land for future generations | 95% | 100% |

Comparing the attitudes of adopters in 1974 and 1980, a greater percentage indicated that conservation of soil is a problem (see Table 13). This suggests that the adoption of crop residue management and the accompanying education have changed the attitudes of these farmers. However, for non-adopters, fewer thought that soil conservation was a problem in 1980. This suggests the possibility that these farmers think the project has controlled or eliminated the problem. Adopters are also more likely to feel that pollution of streams is a problem in the county and to indicate that soil erosion contributes to water quality.

Table 13: Conservation Attitudes of Adopters and Non-Adopters

| Statement | Percent Agreeing with Statement | |
|---|---|---|
| | Adopter | Non-Adopter |
| Conservation of soil is <u>not</u> a real problem in this area | | |
| 1974 | 55% | 47% |
| 1980 | 30% | 53% |
| The average landowner in this county stands to lose more than he will gain by soil and water development programs | 5% | 9% |
| The cost of soil erosion reducing practices (e.g., field borders, grassed waterways) should be borne entirely by those who adopt them | 30% | 29% |
| The federal government should play an important role in soil conservation programs in this county | 70% | 53% |
| Pollution of the streams is a major problem in this county | 40% | 18% |
| Landowners have little opportunity to express their opinions in planning watershed problems | 20% | 41% |
| Soil erosion contributes to water pollution problems | 90% | 85% |

Table 13 also indicates that adopters are more likely to think that the federal government should play a role in soil conservation programs in the county. Even though adopters thought that the federal government should be involved, they were still less likely to feel that landowners cannot express their opinions in watershed projects. However, 20% of adopters and 41% of non-adopters felt that there was little opportunity for landowner input into projects in the watershed.

The attitude toward soil erosion and local watershed projects may also have effects upon the respondent's views concerning responsibility for the protection of water quality. Two important questions arise here, who is responsible for the protection of water quality in our lakes, rivers and streams and who should be? Tables 14 and 15 indicate the respondent's answers to the questions posed above. In terms of who is responsible, adopters did not overwhelmingly choose one answer, but 35% selected the landowners. Among non-adopters, the most conspicuous answer was "don't know", suggesting that they feel uninformed. Another interesting response was that the various levels of government and government agencies were not selected by numerous respondents.

Table 14: Who is Responsible for Protection of Water Quality

| Responsible Party | Adopters | Non-Adopters |
|---|---|---|
| Landowner | 35% | 18% |
| Local Unit of Government | 5 | 6 |
| State Government | -- | -- |
| Federal Government | 5 | 3 |
| SCS | 20 | 3 |
| ASCS | -- | 6 |
| SWCD | 10 | 12 |
| Don't Know | 25 | 53 |
| N = | 20 | 34 |

Table 15: Who Should be Responsible for Protection of Water Quality

| Responsible Party | Adopters | Non-Adopters |
|---|---|---|
| Landowner | 65% | 32% |
| Local Unit of Government | 5 | 21 |
| State Government | -- | -- |
| Federal Government | 5 | 3 |
| SCS | 20 | 6 |
| ASCS | -- | 6 |
| SWCD | -- | 18 |
| Don't Know | 5 | 15 |
| N = | 20 | 34 |

The more interesting results are the differences expressed between who is and should be responsible. Table 15 indicates that 65% of adopters think that the landowners should be responsible and 32% of non-adopters also feel that way. This suggests that adopters have accepted more of the responsibility for water quality protection than non-adopters. This is an especially important aspect for future environmental behavior, since taking personal responsibility is the first step in going from environmentally sound attitudes and values to environmentally sound behavior.

While adopters tend to indicate a greater sensitivity to environmental problems, they also tend to feel that pollution is under control in the Black Creek watershed. Table 16 indicates that 100% of adopters thought pollution was under control, while only 76% of non-adopters thought it was controlled. As would be expected, adopters were more likely to have personally benefitted from the Black Creek project and they were slightly more likely to feel that money spent for soil and water development was a good investment. Another interesting aspect is that adopters were more likely to feel that major decisions should be made by professional/technical staff. Possibly the non-adopters were reacting to their, previously discussed, feeling that landowners have little opportunity for input into the decision-making. The next section will outline the involvement of the respondents in the Black Creek Project.

Table 16: Attitudes Toward the Black Creek Project

| Question | Adopters | Non-Adopters |
|---|---|---|
| Percent who think that pollution control for Black Creek is now excellent or good | 100% | 76% |
| Percent who personally benefitted from Black Creek Project | 90% | 56% |
| Percent who thought that major decisions in the demonstration project should be made by professional/technical staff | 75% | 62% |
| Percent who felt that spending money for soil and water development is a good investment | 100% | 94% |

The adopters seem to have had a great deal of contact with project personnel and attended a number of public meetings concerning the project. Eighty percent indicated substantial contact and they attended, on the average, 8 public meetings. Non-adopters, on the other hand, attended fewer than 3 public meetings and nearly 60% had little or no contact with project personnel. In addition, this difference in involvement is indicated by differences in rates of discussions with neighbors. 85% of adopters had discussed the project some or a great deal with neighbors, while 44% of non-adopters had not discussed the project with neighbors or had had very little such discussion.

Holding public meetings and other educational activities are often aimed at giving farmers enough information to enable them to make wise decisions. Of course, project personnel hope that those decisions will be to adopt conservation practices. This process is a result of our dominant ideology which stresses that participation should be voluntary. Government can induce participation through use of education, technical assistance, and financial incentives. In earlier surveys among Black

Table 17: Involvement and Discussion of Black Creek Project

| Question | Adopters | Non-adopters |
|---|---|---|
| "How familiar are you with the Black Creek Demonstration Project in this county?" | | |
| Never heard of it | -- | -- |
| Heard, but no contact | 10% | 29% |
| Little contact | 10 | 29 |
| Contact w/various project representatives | 30 | 26 |
| Much contact and participation | 50 | 15 |
| Have you discussed the Black Creek Project with your neighbors? | | |
| A great deal | 35% | 18% |
| Some | 50 | 38 |
| Very little | 10 | 38 |
| Not at all | 5 | 6 |
| How many public meetings concerning the project have you attended in the past 7 or 8 years? (X) | 8.0 | 2.7 |

Creek respondents, they indicated that education was the best way to get people to cooperate in helping to protect water quality. However, in 1980, we saw some shifts in this attitude. Table 18 indicates that more respondents felt that financial incentives were a better way. Among adopters, support for education as a mechanism declined by 30% while support for financial incentives doubled. Among non-adopters, the major shift was away from a combined approach to the use of financial incentives. These results suggest some disillusionment with education as a motivator and increasing support for financial incentives as motivators.

Table 18: How to Get People to Cooperate

| "What do you think is the better way to get people to cooperate in helping to protect water quality in the Black Creek?" | Adopters | | Non-adopters | |
|---|---|---|---|---|
| | 1974 | 1980 | 1974 | 1980 |
| Education | 65% | 45% | 56% | 56% |
| Financial | 15 | 30 | 12 | 26 |
| Laws and Controls | 10 | 10 | 6 | 3 |
| Combination of above | 10 | 15 | 26 | 15 |
| N = | 20 | 20 | 34 | 34 |

We have outlined numerous differences between adopters and non-adopters including farm firm characteristics, attitudes and other land use practices. We have seen that adopters seem to prefer different types of inducements for getting cooperation. Part of these differences may be the result of differences in objectives. In other words, adopters may have different goals from non-adopters. In order to assess this, we asked the respondents to rank-order seven possible objectives which are common for farmers. Table 19 reports on the mean (average) ranking given each goal or objective by both adopters and non-adopters. Adopters are more likely to have stability and certainty of income as an objective when compared to non-adopters and to be slightly more concerned with yields and increases in the value of the farm. Non-adopters are more likely to be pursuing the goals of condition of the farm, time for family and non-work and high consumption. The differences in goals and objectives are vital for project planning and management. Programs designed to help the farmer move toward certain goals will not be successful with all farmers. Some will be concerned with consumption and increased farm values, while others will be concerned with stability or certainty of income, time for family or general condition or appearance of their farm. Tailoring of the product (e.g. the soil and water project) to help the client's (farmers) move toward his goals and objectives is a time honored principle of successful salesmanship and good business.

Table 19: Mean Ranks of Goals and Objectives of Adopters and Non-Adopters

| Goal or Objective for Farm Firm | Mean Ranking* Adopters | Mean Ranking* Non-Adopters |
|---|---|---|
| Stability of Income | 2.6 | 5.4 |
| High Level of Consumption | 5.6 | 5.4 |
| Fast Increase in Value of Farm | 4.6 | 5.0 |
| Time for Family and Non-work Activity | 4.9 | 4.6 |
| Certainty of Income | 2.5 | 3.2 |
| Condition of Farm (e.g. equipment, buildings, land) | 4.0 | 3.0 |
| Greatest Yields | 3.8 | 4.0 |

*Respondents were asked to rank these objectives from 1 to 7, with 1 being most important and 7 being least important.

<u>Social, Economic and Demographic Characteristics</u>. Adopters are younger, better educated and have higher incomes. They are less likely to have off-farm employment. They receive a greater proportion of their income from farming and are more likely to be cash-grain farmers. They also expend more labor on their farms, partially a function of size. They are, more likely to have a conservation plan with SCS although fewer indicated they have them now than in 1974. Adopters are also using more fertilizer herbicide and insecticide, a result expected from the technical studies of crop residue management.

In general, adopters are bigger, full time farmers with larger incomes and with less income from off-farm sources.

Leader-Nonleader Comparison

Opinion leaders informally influence the attitudes and behavior of other individuals in a community. Their leadership is not a result of any official position held in the community, but rather it is based on respect from their followers. Most research on adoption and diffusion of agricultural practices stresses the importance of opinion leaders in the dissemination of information. Therefore, any effort directed towards inducing change among a group of individuals should attempt to identify the informal leadership structure that exists within the group. Fortunately, we were able to determine the opinion leaders in the Black Creek area by asking the following question: "Who do you think is well respected in this area for his general agricultural practices and abilities?" Through this procedure 13 farmers were identified as opinion leaders.

Since the Black Creek Demonstration Project has officially ended, the role of the opinion leaders becomes increasingly important. It is through them that much of the continued success of the project's goals will depend. Therefore, is is imperative that we examine the current attitudes and behaviors of these individuals towards pollution control. Also, in order to assess their influence on the other farmers in the area, a comparison of the two group's attitudes and behavior is essential. However, before doing this it is necessary to compare certain farm related characteristics between the leaders and non-leaders. This is done, in part, to enhance our understanding of differences in attitudes and behavior that may exist between leaders and non-leaders. In other words, there may be certain characteristics that leaders possess that will tend to influence them toward forming different opinions about erosion control than non-leaders. One of these possible factors is the amount of acreage farmed.

There is a large difference in the average farm size of leaders and non-leaders in the Black Creek area. For leaders and non-leaders the average number of acres farmed is 573 and 170 respectively. Also, 10 percent more of the leaders than non-leaders reported farming more land in 1980 than they had in 1974 (Table 21). The percentage of time devoted to one's farming operation also seems to contribute to the leaders status in the agricultural community. This was affirmed by the farmers in the Black Creek area. Seventy percent of the non-leaders indicated having off-farm employment, while only 53.8% of the leaders reported off-farm employment.

In summary, these farmers perceived as leaders differ from the remaining farmers. Leaders tend to farm more land, on the average, than non-leaders. They have also shown a greater increase in acreage farmed since 1974. Opinion leaders tend to be more fully involved in farming than non-leaders, as revealed by the percentage of off-farm employment. These differences should be kept in mind as we compare these two groups in terms of environmental attitudes. A logical place to begin this comparison is with the farmers' perceptions of pollution as a problem.

Table 20: Social, Economic and Demographic Characteristics of Adopters and Non-Adopters of Crop Residue Management

| Characteristic | Adopters | Non-Adopters |
|---|---|---|
| Age - 1980 (X) | 49.4 | 53.9 |
| Years of Formal Education (X) | 12.1 | 9.4 |
| # in Household (X) | 6.4 | 4.7 |
| # children age > 18 (X) | 1.1 | 1.7 |
| # children age < 18 (X) | .2 | .7 |
| Income, 1979, Gross, Median | 51749.65 | 27499.50 |
| % with off-farm employment | 55% | 74% |
| % of income from farming (X) | 73.6% | 54.8% |
| % of income from spouse (X) | 3.0% | 5.2% |
| % of Farming Income (X) From: | | |
| Crops | 88.2 | 61.0 |
| Livestock | 11.8 | 38.6 |
| Reported Market Value of Land (X) $/acre | 2287.5 | 2354.3 |
| Hours of Operator Labor/week (X) | | |
| April to October | 53 | 39 |
| November to March | 34 | 22 |
| % with spouse providing farm labor | 50% | 56% |
| % using more ______ in 1980 than in 1974 | | |
| fertilizer | 35% | 29% |
| herbicide | 70% | 35% |
| insecticide | 40% | 12% |
| % indicating that they had a conservation plan with SCS | | |
| 1974 | 35% | 18% |
| 1980 | 30% | 15% |

Table 21: Are You Farming More Land, Less Land or the Same (Since 1974?)

| Response | Leader N | Leader % | Non-Leader N | Non-Leader % |
|---|---|---|---|---|
| More | 4 | 30.8 | 8 | 19.5 |
| Same | 9 | 69.2 | 31 | 75.6 |
| Less | 0 | 0.0 | 2 | 4.9 |
| | 13 | 100.0 | 41 | 100.0 |

Awareness of the erosion and water pollution problem is an essential first step in persuading farmers to adopt and maintain best management practices. With this in mind there was a major effort by the Black Creek Project to inform the landowners of the existing pollution problem. To determine the current level of awareness among the Black Creek farmers they were asked to agree or disagree with several statements pertaining to the pollution problems. The following statement, "Soil erosion contributes to water pollution," was presented to the respondents to find out their knowledge of the link between soil erosion and water pollution. As shown in Table 22, a large percentage of both leaders and non-leaders agreed with this statement.

Table 22. Soil Erosion Contributes to Water Pollution Problems.

| Response | Leader N | Leader % | Non-Leader N | Non-Leader % |
|---|---|---|---|---|
| Agree | 11 | 84.6 | 36 | 87.8 |
| Disagree | 1 | 7.7 | 3 | 7.3 |
| Don't know | 1 | 7.7 | 2 | 4.9 |
| | 13 | 100.0 | 41 | 100.0 |

However, knowledge of this link does not necessarily imply that the farmers are aware of any local soil conservation or water pollution problems. The farmers' perceptions of pollution as a problem in the Black Creek area are presented in Tables 23 and 24.

Table 23. Conservation of Soil is Not a Real Problem in This Area.

| Response | Leader N | Leader % | Non-Leader N | Non-Leader % |
|---|---|---|---|---|
| Agree | 4 | 30.8 | 20 | 48.8 |
| Disagree | 9 | 69.2 | 19 | 46.3 |
| Don't know | 0 | 0.0 | 2 | 3.7 |
| | 13 | 100.0 | 41 | 100.0 |

Table 24. Pollution of the Streams is a Major Problem in the County

| Response | Leader N | Leader % | Non-Leader N | Non-Leader % |
|---|---|---|---|---|
| Agree | 6 | 46.2 | 8 | 19.5 |
| Disagree | 6 | 46.2 | 30 | 73.2 |
| Don't know | 1 | 7.7 | 3 | 7.3 |
| | 13 | 100.0 | 41 | 100.0 |

As might be expected, a larger percentage of leaders than non-leaders perceive soil conservation as a real problem in the area (Table 23). Unfortunately, knowledge of the soil conservation problem has not completely filtered down from the leaders to the non-leaders. The two groups differed even greater in their opinions concerning pollution of the streams in their county (Table 24). Forty-six percent of the leaders felt water pollution was a major problem in the area, while only 19.5% of the non-leaders agreed with this conclusion. Although both groups see conservation of the soil as more of a local problem than pollution of the streams, this difference is much greater among non-leaders than leaders. This again shows that the communication channels and levels of information between the two groups is not identical.

In general, those individuals chosen as leaders exhibit more awareness of the local pollution problems. As suggested above, the information has not filtered down to the non-leaders. Therefore, future efforts designed to educate the public about pollution problem may want to consider more direct communication with as many individuals as possible.

Although awareness is essential for controlling the pollution problem, it does not guarantee the farmers' cooperation. One way of encouraging the use of pollution control techniques by farmers is through government involvement. However, the proper role of the government is not easily determined. The following section attempts to assess the leaders' and non-leaders' attitudes towards government involvement in pollution control.

In order to understand the willingness of farmers to accept outside intervention into this problem the farmers were asked to agree or disagree with the following statement: "The cost of soil erosion reducing practices should be borne entirely by those who adopt them." Although a majority of both groups disagreed with this statement, substantially more leaders than non-leaders thought that efforts to control soil erosion should be paid for by individual landowners (Table 25). However, this may simply represent the economic differences between leaders and non-leaders.

Table 25. The Cost of Soil Erosion Reducing Practices Should be Borne Entirely by Those Who Adopt Them.

| | Leader | | Non-Leader | |
|---|---|---|---|---|
| Response | N | % | N | % |
| Agree | 6 | 46.2 | 10 | 24.4 |
| Disagree | 7 | 58.8 | 28 | 68.3 |
| Don't know | 0 | 0.0 | 3 | 7.3 |
| | 13 | 100.0 | 41 | 100.0 |

As seen earlier, opinion leaders generally have larger farms than non-leaders. Therefore, they may be better able to afford the cost of erosion control practices. It is interesting to note however that while a larger percentage of leaders felt that soil erosion practices should be borne primarily by those who adopt them, over three-fourths said the federal government should play an important role in local soil conservation programs (Table 26). Among non-leaders, 53.7% agreed with this statement.

Table 26. The Federal Government Should Play an Important Role in Soil Conservation Programs in This County

| | Leader | | Non-Leader | |
|---|---|---|---|---|
| Response | N | % | N | % |
| Agree | 10 | 76.9 | 22 | 53.7 |
| Disagree | 3 | 23.1 | 16 | 39.0 |
| Don't know | 0 | 0.0 | 3 | 7.3 |
| | 13 | 100.0 | 41 | 100.0 |

Government involvement in pollution control programs can encompass a wide range of activities including financial and technical assistance. In order to assess the farmers attitudes towrds the extent to which federal taxation should be imposed to correct this problem the following statement was presented to the farmers: "Federal taxation to clean up our water completely wouldn't be too expensive to consider." The respondents were asked if they strongly agreed, agreed, disagreed or strongly disagreed with this statement. As seen in Table 27 no one strongly agreed with unlimited federal taxation to clean up our water resources. However, a large percentage (46.2%) of the opinion leaders expressed a positive response to this idea. This is contrasted with non-leaders in which only 29.3% agreed with this statement.

Table 27. Federal Taxation to Clean Up Our Water Completely Wouldn't be Too Expensive to Consider

| Response | Leader N | Leader % | Non-Leader N | Non-Leader % |
|---|---|---|---|---|
| Strongly Agree | 0 | 0.0 | 0 | 0.0 |
| Agree | 6 | 46.2 | 12 | 29.3 |
| Disagree | 5 | 18.5 | 22 | 53.7 |
| Strongly Disagree | 2 | 15.4 | 2 | 4.9 |
| Don't Know | 0 | 0.0 | 5 | 12.2 |
| | 13 | 100.0 | 41 | 100.0 |

While many opinion leaders think that pollution control practices should be born primarily by those who adopt them, they are also more inclined to favor federal involvement in soil and water conservation programs. This would seem to indicate more of an overall willingness by leaders to actively support soil and water development programs. However, the above findings do seem to suggest some question as to who should actually be responsible for controlling soil erosion and water pollution. It is, therefore, important that we examine more directly the farmers' opinions as to who should be responsible for controlling soil erosion. Landowners in the survey were asked to identify who they thought should be responsible for controlling the soil erosion problem. As illustrated in Table 28, nearly 70% of both the leaders and non- leaders indicated that either the individual landowner, local government or the local soil and water conservation district should be responsible for controlling the soil erosion problem. The leaders specifically mentioned the individual landowners more often than non-leaders. This finding suggests a clear bias towards local responsibility for the soil erosion problem. In summary, the notion of federal involvement in local pollution control, especially among opinion leaders, seems to be an acceptable idea, but both groups are more favorable towards local control of the situation. This section has dealt with government involvement in general, while the following section will focus specifically on attitudes towards the Black Creek Project.

Table 28. Who Should be Responsible for Controlling the Soil Erosion Problems?

| Response | Leader N | Leader % | Non-Leader N | Non-Leader % |
|---|---|---|---|---|
| Individual Landowner | 7 | 53.8 | 16 | 39.0 |
| Local Government | 0 | 0.0 | 3 | 7.3 |
| Local Soil and Water Conservation Districts | 2 | 15.4 | 10 | 24.4 |
| State Government | 1 | 7.7 | 2 | 4.9 |
| Federal Government | 0 | 0.0 | 1 | 2.4 |
| Other | 3 | 23.1 | 6 | 14.6 |
| Don't Know | 0 | 0.0 | 3 | 7.3 |
| | 13 | 100.0 | 41 | 100.0 |

Since the Black Creek Demonstration Project began, the opinion leaders have attended more public meetings concerning the project than non-leaders. Leaders have, on the average, attended over three times as many public meetings. As shown in Table 29, the leaders were also much more familiar with the project than their counterparts. Sixty-one percent of the leaders indicated much contact and participation in the Project. The percentage of non-leaders indicating similar involvement was considerably less (17.1%). Another very distinct contrast between the two groups appeared when they were asked how much they had participated in the planning and implementing of the Project (Table 30). Forty-six percent of the leaders indicated a great deal of participation while only 7.3% of the non-leaders indicated the same. Equally important is that 24 (58.2%) of the non-leaders said they had not participated at all in planning or implementating the Project and only one (7.7%) leader indicated a lack of involvement. In summary, it is clear that the informal opinion leaders in

Table 29. How Familiar Are You With the Black Creek Demonstration Project?

| Response | Leader N | Leader % | Non-Leader N | Non-Leader % |
|---|---|---|---|---|
| Never heard of it | -- | -- | -- | -- |
| Heard, but no contact | 1 | 7.7 | 11 | 25.8 |
| Little contact | 1 | 7.7 | 11 | 25.8 |
| Contact w/ various Project representatives | 3 | 23.1 | 12 | 29.3 |
| Much contact and participation | 8 | 61.5 | 7 | 17.1 |
| | 13 | 100.0 | 41 | 100.0 |

the Black Creek area had an active role in the Project. It is also important to see how this greater involvement of the leaders in the Project may have affected their attitudes towards the Project.

Table 30. Participated in Planning or Implementing this Project

| Response | Leader N | Leader % | Non-Leader N | Non-Leader % |
|---|---|---|---|---|
| Not at all | 1 | 7.7 | 24 | 58.5 |
| Very little | 2 | 15.4 | 3 | 7.3 |
| Some | 4 | 30.8 | 11 | 26.8 |
| A great deal | 6 | 46.2 | 3 | 7.3 |
| | 13 | 100.0 | 41 | 100.0 |

A larger percentage of both leaders and non-leaders agreed that almost everyone in the area would benefit from the Black Creek Demonstration Project (Table 31). However, when asked their overall reaction to the program, while almost everyone indicated approval, opinion leaders were more likely to say it was an excellent program (Table 32). Deaaling with a more substantive question, a majority of both groups felt that pollution control for Black Creek is currently in good shape (Table 33). Therefore, both leaders and non-leaders seem to have an overall positive reaction to the project.

Table 31. Almost Everyone in This Area Will be Benefitted From This Demonstration Project

| Response | Leader N | Leader % | Non-Leader N | Non-Leader % |
|---|---|---|---|---|
| Agree | 12 | 92.3 | 35 | 85.4 |
| Disagree | 0 | 0.0 | 2 | 4.9 |
| Don't know | 1 | 7.7 | 4 | 9.8 |
| | 13 | 100.0 | 41 | 100.0 |

Table 32. Overall Reaction Towards Program

| Response | Leader N | Leader % | Non-Leader N | Non-Leader % |
|---|---|---|---|---|
| Excellent Program | 5 | 38.5 | 4 | 9.8 |
| Good Program | 7 | 53.8 | 33 | 80.5 |
| Not a Very Good Program | -- | -- | -- | -- |
| Not a Good Program at All | -- | -- | 1 | 2.4 |
| Undecided | 1 | 7.7 | 3 | 7.3 |
| | 13 | 100.0 | 41 | 100.0 |

To gain insight into their individual perception of the project the respondents were asked: "Do you feel that you have personally benefitted from the Black Creek demonstration project?" Responses to this question reveal a much greater variation between the leaders and non-leaders (Table 34). One hundred percent of the leaders felt they had personally

Table 33. How Effective Do You Think Pollution Control for Black Creek is Now?

| Response | Leader N | Leader % | Non-Leader N | Non-Leader % |
|---|---|---|---|---|
| Excellent | -- | -- | 3 | 7.3 |
| Good | 13 | 100.0 | 30 | 73.2 |
| Fair | -- | -- | 4 | 9.8 |
| Poor | -- | -- | -- | -- |
| Don't Know | -- | -- | 4 | 9.8 |
| | 13 | 100.0 | 41 | 100.0 |

Table 34. Do You Feel That You Personally Have Benefitted from the Black Creek Demonstration Project?

| Response | Leader N | Leader % | Non-Leader N | Non-Leader % |
|---|---|---|---|---|
| Yes | 13 | 100.0 | 24 | 58.5 |
| No | -- | -- | 17 | 41.5 |
| | 13 | 100.0 | 41 | 100.0 |

benefitted from the project and only 58.5% of othe non-leaders felt they had benefitted. This large discrepancy between leaders and non-leaders in perceived personal benefits may be the result of the patterns of involvement with the project, especially the adoption of various best management practices.

In summary, leaders were much more involved and familiar with the Black Creek Project than non-leaders. Nevertheless, both groups perceive the project as generally successful. However, there were many non-leader who felt they had not personally benefitted from the project.

While the attitudes and opinions of the farmers toward pollution is important, their actions towards actually solving this problem are even more crucial. Thererfore, we compared the difference in adoption patterns between the leaders and non-leaders. Table 35 indicates the average number of land use practices adopted by each group. This average is based on ten selectecd practices. As can be seen leaders have a slightly higher rate of adoption than non-leaders. This may be the consequence of two factors. First, the opinion leaders tend to come from larger farms, and their land may simply be in need of more structures and practices to adate erosion. However, it could also be a result of the leaders' greate awareness of the pollution problems and methods to solve them. To help determine this we now turn to Table 36 which illustrates the specific practices adopted by each group of farmers.

Table 35. The Average Number of Land Use Practices Adopted by Leaders and Non-Leaders.*

| Response | Leader | Non-Leader |
|---|---|---|
| Mean | 3.538 | 2.195 |

*Based on ten selected practices.

As shown by Table 36, a significantly larger percentage of leaders are currently using crop residue management. This phenomenon is also true for field borders and grassed waterways or outlets. These are three practices that were heavily emphasized in the Black Creek Project. There fore, the difference between leaders and non-leaders is rather disappoint ing. The anticipated "filtering down" effect from leaders to non-leaders doesn't seem to have worked exceptionally well with regard to these practices. This is not to imply that the leaders had no effect on the non-leaders' decision to adopt these practices. However, their influence was not as strong as might be hoped.

Another important finding revealed in Table 36 is the number of non-leaders discontinuing to use of certain land management practices. Among the opinion leaders, this did not occur at all. The closer involvement of the leaders in the project may have influenced their decision to continue using the practices they had adopted. If this is the case, then there is probably some value in getting as many people as possible directly involved in the project.

Table 36. Selected Land Use Practices by Leaders and Non-Leaders

| | LEADERS | | | | | | | | NON-LEADERS | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Using | | Have Used | | Never Used | | N.A. | | Using | | Have Used | | Never Used | | N.A. | |
| | N | % | N | % | N | % | N | % | N | % | N | % | N | % | N | % |
| Conservation Cropping | 8 | 61.5 | -- | -- | 5 | 38.5 | - | -- | 26 | 63.4 | 1 | 2.4 | 14 | 34.1 | -- | -- |
| Contour Farming | 1 | 7.7 | -- | -- | 11 | 84.6 | 1 | 7.7 | 2 | 4.9 | 0 | 0.0 | 39 | 95.1 | -- | -- |
| Crop Res. Management | 8 | 61.5 | -- | -- | 5 | 38.5 | - | -- | 11 | 26.8 | 1 | 1.9 | 28 | 68.3 | 1 | 2.4 |
| Field Borders | 9 | 69.2 | -- | -- | 4 | 30.8 | - | -- | 17 | 41.5 | - | -- | 24 | 58.5 | -- | -- |
| Grade Stab. Structures | 4 | 30.8 | -- | -- | 9 | 69.2 | - | -- | 6 | 14.6 | - | -- | 35 | 85.4 | -- | -- |
| Grassed Waterways | 8 | 61.5 | -- | -- | 5 | 38.5 | - | -- | 16 | 39.0 | 2 | 4.9 | 23 | 56.1 | -- | -- |
| Holding Ponds or Tanks | 3 | 23.1 | -- | -- | 10 | 76.9 | - | -- | 2 | 4.9 | - | -- | 39 | 95.1 | -- | -- |
| Livestock Exclusion | 2 | 15.4 | -- | -- | 6 | 46.2 | 5 | 38.5 | 3 | 7.3 | 1 | 2.4 | 17 | 41.5 | 20 | 48.8 |
| Pond | 3 | 23.1 | -- | -- | 10 | 76.9 | - | -- | 7 | 17.1 | 1 | 2.4 | 33 | 80.5 | -- | -- |
| Strip Cropping | - | -- | -- | -- | 13 | 100.0 | - | -- | 40 | 97.6 | 1 | 2.9 | -- | -- | -- | -- |

Summary

Previous work in the Black Creek area has demonstrated the utility of sociological work in the early stages of a water quality project (Brooks and Taylor, 1974). The present study has investigated several dimensions of potential effects of such a project on the local community, and its residents as well as future water quality projects. The research suggests that such projects have substantial effects upon the attitudes and behavior of local residents in addition to any direct effects upon water quality.

From an evaluation point of reference, the Black Creek Project seems to have been rather successful. However, several areas were pinpointed which suggest that with proper planning, dissemenation of information and implementation, the project could have been more successful. In designing and implementing future projects, managers should carefull note the impacts the Black Creek Project had on the local community and residents.

References Cited

Bouwes, Nicolaas, Stephen Lovejoy, Lowell L. Klessig, and Douglas Yangeen
1980 "Benefits of Lake Protection to a Small Urban Community," in proceedings of International Lake Management Conference, Portland, Maine, October.

Bouwes, Nicholaas and Stephen B. Lovejoy
1980 "'Optimal' Cost Sharing and Nonpoint Source Pollution Control" Economic Issues, May, 1980.

Brooks, Ralph M. and David L. Taylor
1975 Impact of social attitudes on managing the environment. Proceedings of the point source pollution seminar. Chicago, Illinois.

General Accounting Office
1977 Report to the Congress by the Comptroller General of the United States, Washington, D.C.

Klessig, Lowell and Stephen Lovejoy
1980 "Necessary Conditions for Resource Allocation and Management," in proceedings of 45th North American Wildlife and Natural Resources Conference, March 22-26, 1980, Miami Beach, Florida.

Lovejoy, Stephen B., Lowell Klessig, and Nicholaas Bouwes
1980 "A Forkful Each: Cost-Sharing for Manure Handling" Journal of Soil and Water Conservation, January-February, 1980.

Lovejoy, Stephen B., and Nicolaas Bouwes
1979 "Subsidies and Agricultural Pollution (How Much Do We Have to Pay Farmers to Control Their ---- (Manure)?" Presented at the annual meetings of the Rural Sociological Society, September.

Southgate, Douglas, Basil Sharp, Stephen Lovejoy, and Nicolaas Bouwes
1980 "An Analysis of Cost-Sharing Arrangements to Induce the Adoption of Less Polluting Manure Handling Techniques," North Central Journal of Agricultural Economics, volume 2 (July).

Taylor, David L. and William L. Miller
1978 "The Adoption Process and Environmental Innovations: A Case Study of a Government Project." Rural Sociology 43 (Winter): 634-648.

# Black Creek Data Management System

P.K. Carter, D.B. Beasley, L.F. Huggins and S.J. Mahler

The Black Creek Data Management System (BCDMS) was developed to provide convenient, efficient, flexible retrieval of the data that has been gathered. BCDMS is a hierarchy of computer programs, macros, and data handling subroutines that can manipulate and retrieve information that has been collected from the Black Creek Project since late in 1973. The BCDMS is user-oriented, taking into account the various levels of personnel that it will be serving. It provides useful tools for all -- from those minimally familiar with terminal usage to the experienced programmer. BCDMS consists of data files, EZBASE, and "packaged" application programs. The subsequent sections will discuss each of these three components, individually.

## Data Files

With large amounts of data being collected, it became necessary to devise a file structure that would make application development faster, easier, and more flexible. To accomplish this end, the old master files were converted into a new, event-oriented format. This conversion led to simpler, more efficient access.

The data files consist of physical/chemical water quality (both grab and pump samples), stage, rainfall, and in site quality samples. Each file contains all the data for one site, with the records stored in chronological order. This feature (combining all the years into one file) permits one to analyze any period of time without being constrained by the previously imposed beginning and end of year boundaries.

Previously written programs need not be abandoned with the development of this new system. Recognizing the need to provide an interface with the past, a program was developed to convert the new files into STORET compatible files. The availability of this program is intended to ease transition, and allow continued use of existing programs whose performance would not justify revision. However, this capability should not stifle the system's growth by overemphasizing the "patching" of existing programs rather than development of new and improved methods for processing the data.

## EZBASE

EZBASE is a library of FORTRAN callable subroutines that interfaces the application programmer with the physical data files. It provides the programmer with powerful tools to retrieve and manipulate the data.

EZBASE's use is easy and understandable. It employs a number of common blocks that have been broken into logical divisions. These allow the programmer to use only those variables essential to his application. He simply declares the necessary common blocks in each of his modules that uses EZBASE routines.

The user is provided the capability of requesting that only specified data types (grab, pump, etc.) be considered in his program. This is done merely by calling a routine with the desired type numbers as parameters. He can easily find the most recently obtained values for any data element(s), at any point in time. He can also find interpolated values for any point in time.

The usr always has access to the last set of data values he requested. Thus, he is able to make comparisons, and compute differences without being burdened with setting up temporary storage facilities. Another feature built into EZBASE permits the programmer to request only that data which falls within a designated time period. By lengthening this time period, one can request all the data.

The features of EZBASE can be employed in a number of different combinations. Clever use of this library allows the application programmer a great deal of flexibility in data retrieval, serving a wide range of applications.

For further discussion and detailed instructions on using EZBASE, the EZBASE User Document should be consulted. This document explains how each of the commands is used, and the results it produces. Illustrative examples are included.

## "Packaged" Programs

To provide a facility for generating standard reports, the "packaged" programs were developed. They can be used with minimal effort by anyone from novice to expert.

Some analyses are done repeatedly with data from many different time periods and/or sites. For these analyses, the "packaged" programs prove invaluable. Their use is outlined below:

1) The user types the name of the macro designed to run the desired program.

2) He responds to the prompts displayed on the screen (e.g., SITE NUMBER (2/6/12/20)?, LINEAR INTERPOLATION DESIRED (Y/N)?, BEGINNING DATA — YEAR (2 Digit Integer)?, etc.). These inquiries permit the user to analyze the data in an infinite number of subsets.

The standard report created using macro BLKCR1 contains the following information:

1) Total transport, in kilograms and kilograms per hectare (of suspended solids, ammonia, nitrate, soluble organic and sediment bound nitrogen, and inorganic, soluble organic, and sediment bound phosphorus) passing the site during the specified time period.

2) Flow weighted concentrations, in milligrams per liter (for the parameters listed above).

3) Flow characteristics, including: peak and mean flow rates, volume of runoff, total runoff, and total rainfall for the period.

4) Statistical analysis of the concentrations, including: maximum, minimum, mean, median, and standard deviation.

This report can be varied by the user. It can be generated for any site, and for any specified period of time (from a span of days to years). Another features that allows variance is the ability for the user to request linear interpolation throughout the analysis. When dealing with a short time span, interpolation can give a clearer view of the situation at that particular time.

Presently, analysis of the data is only available with tabular representations. Packages that graphically depict the data and analyses are in the development and testing stages and will soon be available.

## Summary

The Black Creek Data Management System was organized to support diverse applications with varied data requirements. Designed with the increasing cost of programming and decreasing cost of storage in mind, BCDMS promotes simple application programming by hiding complexities. It was planned such that changes to it would not require revision of application programs (which can be extremely costly). This was accomplished by severing the application programmers' view of the data from it's physical representation. All of these factors considered, BCDMS is proposed to be a solid foundation for future applications to build on.

## TECHNICAL REPORT DATA

*(Please read Instructions on the reverse before completing)*

| | | |
|---|---|---|
| 1. REPORT NO. EPA-905/9-81-003 | 2. | 3. RECIPIENT'S ACCESSION NO. |
| 4. TITLE AND SUBTITLE Environmental Impact of Land Use on Water Quality Final Report on the Black Creek Project Phase II | | 5. REPORT DATE May 1981 |
| | | 6. PERFORMING ORGANIZATION CODE |
| 7. AUTHOR(S) Jim B. Morrison and James E. Lake ** | | 8. PERFORMING ORGANIZATION REPORT NO. |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS Allen County Soil & Water Conservation District Purdue University University of Illinois | | 10. PROGRAM ELEMENT NO. A42B2A |
| | | 11. CONTRACT/GRANT NO. G005335 |
| 12. SPONSORING AGENCY NAME AND ADDRESS Great Lakes National Program Office U.S. Environmental Protection Agency 536 South Clark Street, Room 932 Chicago, Illinois 60605 | | 13. TYPE OF REPORT AND PERIOD COVERED Final Report 1977-1980 |
| | | 14. SPONSORING AGENCY CODE US EPA-GLNPO |

15. SUPPLEMENTARY NOTES
** Each individual report has its own authors.
This report is to provide an update of all activites on the Black Creek Project.

16. ABSTRACT

The report is intended to consolidate and update materials collected during the eight year period, covered by the Black Creek Project. It concentrates primarily on the years between 1977 and 1980, and represents a major interim report in the total project. The organization of this report is a collection of research papers presented by project investigators. A final report, which synthesizes all of the work covered during these eight years and an additional two-year period, will be published in 1983.

The following sections are intended to summarize the research findings and implications as reported by the project investigators. Details which support their their conclusions are set forth in the individual papers.

17. KEY WORDS AND DOCUMENT ANALYSIS

| a. DESCRIPTORS | | b. IDENTIFIERS/OPEN ENDED TERMS | c. COSATI Field/Group |
|---|---|---|---|
| Permeability | Rural runoff | | |
| Denitrification | Erosion | | |
| Percolated | Agricultural watershed | | |
| Peak concentration | Water quality | | |
| Silty clay soils | Groundwater pressure | | |
| Latty clay | | | |
| Blount silt loam soils | | | |

| | | |
|---|---|---|
| 18. DISTRIBUTION STATEMENT Document is available to the public through the National Technical Information Service, Springfield, VA 22161 | 19. SECURITY CLASS (This Report) None | 21. NO. OF PAGES 286 |
| | 20. SECURITY CLASS (This page) None | 22. PRICE |

EPA Form 2220-1 (9-73)