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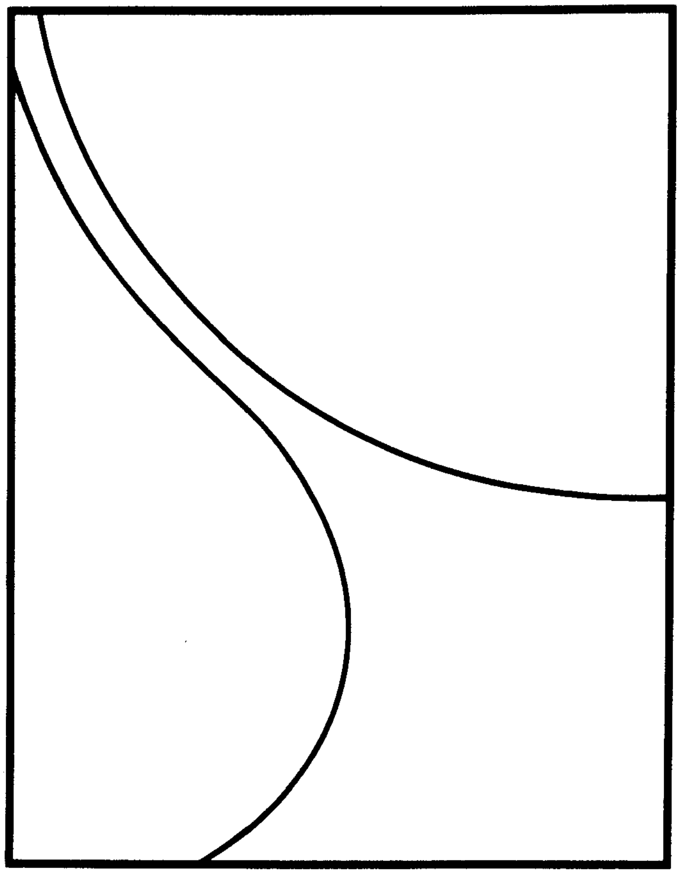

environmental impact of land use on water quality

-supplemental comments-

Final Report on the
Black Creek Project

November, 1977 EPA-905/9-77-007-D

ENVIRONMENTAL IMPACT OF LAND USE ON WATER QUALITY

Final Report
On the
Black Creek Project
(Supplemental Comments)

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To

ALLEN COUNTY SOIL & WATER CONSERVATION DISTRICT

U.S. Department of Agriculture, SCS, ARS
Purdue University, University of Illinois

DISCLAIMER

TABLE OF CONTENTS

INTRODUCTION

This volume concludes the final report on a project to investigate the enviornmental impact of land use on water quality, undertaken with funding from the U. S. Enviornmental Protection Agency -- Region V, in Allen County, Indiana.

Three other volumes provided an overview of the project, presented a detailed technical report, and provided extensive data collected during the project.

This volume presents some additional data not reported in the original three volumes. It also serves as a vehicle for personnel involved in the project to make observations and comments concerning its findings.

The theme of the Black Creek Project, as outlined in the previous three volumes, was to design a program of best management practices to reduce non-point pollution of the Black Creek. The project was designed to furnish information which could be useful in reducing agricultural non-point pollution in the Maumee River and in Lake Erie.

Under the direction of the Allen County Soil and Water Conservation District, with assistance from the Soil Conservaton Service and the Agricultural Research Service of USDA, and with research assistance from Purdue University and the University of Illinois, various aspects of the problem of non-point source pollution were investigated.

Authors of papers presented in the volume have, for the most part, been associated with the Black Creek project for a considerable period of time. In order of the appearance of the papers they are:

James Karr --Karr is associate professor in the Department of Ecology, Ethology, and Evolution at the University of Illnois. He has been responsible for biological investigations throughout most of the project.

Dan Dudley --Dudley, an aquatic biologist, was employed by the Allen County Soil and Water Conservation District to work with Dr. Karr on studies of the biology of the Black Creek system.

James Lake --Lake was director of the Black Creek project for five years. He is currently a water quality specialist with the National Association of Conservation Districts.

R. E. Williams --Williams is special projects director of the National Association of Conservation Districts.

Darrell Nelson --Nelson is professor of Agronomy at Purdue University. He operated the laboratory at Purdue which analyzed water and soil samples. He has also investigated several aspects of nutrient and sediment dynamics.

R. A. Dorich --Dorich is a graduate student in the Department of

Agronomy at Purdue.

David Beasley --Beasley worked on the project as a graduate instructor at Purdue University. His Phd dissertation involved the ANSWERS model of sediment transport and detatchment developed as a part of the project. He is currently an associate professor in the Department of Agricultural Engineering at Purdue.

Dan McCain --McCain, an employee of the Soil Conservation Service, was district conservationist in Allen County throughout the Black Creek Project. As district conservationist, he was responsible for planning for the application of best management practices and for overseeing the technical assitance provided to individual landowners.

Del Bottcher --Bottcher investigated tile flow in the Black Creek area while doing research for a Phd. He is currently a member of the Agricultural Enginering Department at the University of Florida, Gainesville.

Ed Monke --Monke is professor of agricultural engineering at Purdue. He has been involved with the modeling effort on the project and with other investigations of sediment dynamics.

Larry Huggins --Huggins, professor of agricultural engineering at Purdue, has been involved with modeling and with remote data acquisition.

BIOLOGICAL INTEGRITY OF A HEADWATER STREAM:

EVIDENCE OF DEGRADATION, PROSPECTS FOR RECOVERY

by

James R. Karr* and Daniel R. Dudley**

ABSTRACT

Although detailed knowledge of the structural and functional dynamics of natural ecosystems is not yet available, sufficient information is available to suggest that land use in the headwaters of major rivers has impact on the quality of the water resource throughout a river system. The major functional attributes of streams seem to derive from the form of energy inputs. In natural headwater streams organic matter produced outside of the stream provides the major energy source, generally in the form of leaves and twigs. Heavily shaded stream channels limit plant growth in the stream. Insect communities are dominated by shredders and collectors which process the coarse particulate organic matter which is of terrestrial origin. Dominant fish are usually invertivores. Modifications of watersheds result in shifts in these attributes of headwater streams to attributes more typical of larger streams. These include high in-stream plant production (especially algae), benthic communities dominated by grazers and collectors, and fish communities dominated by omnivores. Environmental conditions associated with intense agricultural activities include: high nutrient availability; modified inputs of organic material; increased input of sunlight; imbalance in temperature and dissolved oxygen characteristics; modified habitat structure; and seasonal low flows. The presence of autotrophic rather than hetertrophic communities signals the loss of a naturally functioning headwater stream. All of these result in degradation of water resource quality in both headwaters and downstream areas. Efforts at recovery and restoration are both possible and likely to be profitable if they improve stream conditions for the three primary variables which affect the biological integrity of a stream. These variables are energy source, water quality characteristics, and habitat structure.

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INTRODUCTION

Public Law 92-500 sets forth a goal of restoring and maintaining the physical, chemical and biological integrity of the nation's waters. This task requires knowledge of the structural and functional characteristics of natural aquatic ecosystems.

In this paper we outline some of the basic principles associated with running water systems, with emphasis on the biology of natural streams. We follow with a discussion of the characteristics of the stream ecosystem in Black Creek, a heavily agricultural watershed in the Maumee River basin. Finally, we outline some general principles which are important in consideration of plans for recovery and restoration of headwater streams modified as a result of high intensity agriculture. Obviously, a complete restoration to pristine conditions is not a viable alternative in today's society. However, an understanding of natural stream systems can lead to rational decision making in determining the degree of natural integrity necessary to optimize the broadest range of societal needs.

PERSPECTIVE ON LOTIC ECOSYSTEMS

The running water or lotic environment exhibits continuity over time. Climatic and geological processes effect many changes on streams but major drainage patterns persist despite the movements in the precise location of channels. In contrast, lakes often disappear as their basins are reduced through natural successional processes. In this sense, streams are the most stable, long-lasting, freshwater environments.

On a small scale, however, the streams of a region may suffer extreme environmental stresses due to droughts, floods or temperature extremes. Many species can be entirely eliminated from a stream due to such naturally occurring events. However, the loss is only temporary because aquatic life has evolved mechanisms to reinvade the decimated areas. Even these extreme fluctuations in environmental conditions have not prevented many species from inhabiting the most temporary headwater streams. In the words of ichthyologist Carl L. Hubbs, "where there is water, there are fishes..." and, we could add, at least a modest array of aquatic life upon which fishes depend.

Life in running waters has undergone a tremendous diversification over many millenia. This great diversity of aquatic and semi-aquatic organisms is possible, in part, due to the wide variety of habitats present in natural stream systems. Many physical, chemical and biological factors act together to create this habitat diversity. A familiar example known to aquatic biologists for many years involves the association of organisms with submerged objects found in swiftly flowing water. The variations of current velocities around an object (e.g. a rock) result in a zonation of plant and animal species according to their current preferences (Hynes, 1970). Thus, on a single substrate type, current diversity affords several habitat niches, each with its own set of species. Current is also responsible for eroding or depositing the substratum and thereby creates a patchy network of substrate (bottom) types cross-wise and length-wise in the stream channel. This phenomenon typically creates the pool-riffle complexes of natural stream systems. Due to the persistence of the lotic environment through time, the adaptation of aquatic life to reinvade decimated streams, and the interaction of many environmental factors, the running water environment supports a biological system of extreme complexity.

Streams have many characteristics besides the biota they contain. Excess water is carried from the land in moist times and streams recharge groundwater in times of drought. A variety of substances are carried downstream with the water. The impact of the raindrop on the land's surface and the overland flow of rainfall runoff dislodge soil particles. Soil material reaching stream channels is referred to as sediment. Sediment is a rather dynamic element of running water systems for it can be suspended in water, transported as bedload or permanently deposited in the channel or floodplain. In any of these modes, sediment is an important component of the physical, chemical and biological properties of a stream. Generally, raindrop impact is of minor importance in generating sediment from well-vegetated natural watersheds. However, as man modifies watersheds, exposing the soil surface, sediment transport increases, thus altering many stream characteristics.

Water reaching streams through sub-surface percolation and groundwater contains various dissolved ions. The amount and concentrations of these are dependent on local soil types and the parent rock material. Streams also receive inputs of organic matter from the terrestrial environment. Studies of the Hubbard Brook ecosystem have shown that 1% of the nutrients cycling in a mature forest are lost through stream export (Likens et al. 1977). Export of nutrients and energy (in the form of organic matter) from the terrestrial environment provides many essential requirements for aquatic life. Ecological changes begin when these loss rates increase beyond the capability of the stream biota to assimilate and process them. When man precipitates this problem we have cultural eutrophication.

BIOLOGICAL INTEGRITY

The biological integrity of stream ecosystems has been viewed from two primary perspectives: structural and functional attributes. Structural characteristics include such parameters as number of species, number of individuals per species, and the kind of species present. These can be measured relatively quickly for many groups of organisms and, thus, have been more frequently used than functional attributes. Early approaches in this area involved the identification of indicator species; presence of sludge worms (Tubificidae), for example, instead of stoneflies (Plecoptera) indicates a polluted stream.

Other researchers have used various diversity indexes to evaluate the biota and hence the quality of a water resource. Typically, the higher the number of species (or the more similar the abundance among species in two faunas with the same number of species), the lower the pollution in an area. While these simplistic measures are indicative, they often involve only one or two community attributes and attempts to generalize from them can be misleading. More importantly, they may be useful indexes for monitoring stream quality but they do not explain the causal relationships responsible for "polluted" biota. Without knowledge of the causal relationships the indexes are subject to major error.

In recent years studies of the functional attributes of stream ecosystems have been pioneered by Cummins and his associates at Michigan State University (Cummins 1974). This approach stresses a more dynamic view of stream ecosystems in evaluating process-oriented attributes such as production, respiration , energy flow, nutrient cycling, and trophic dynamics. It is a fundamental postulate that many process-oriented attributes of running water ecosystems change as streams increase in size from headwaters to mouth.

A classification system developed by Kuehne (1962) is commonly used by aquatic biologists to discuss the progressive increase in stream size. According to this system, the smallest streams in a watershed are first order. When two first-order streams join, they form a second order stream; when two second-order streams join, they form a third order stream; etc. Ecological discussions of streams typically consider three lumped size classes: the headwaters (1st to 3rd order), intermediate-sized rivers (4th to 6th order), and large rivers (7th and larger orders).

The transition from small headwater areas to major rivers is referred to as the stream continuum. Structural and functional attributes of natural stream ecosystems change along this continuum (Table 1). These attributes serve as reference points to assess the status of the stream ecosystem in any location. Measured attributes conforming to theoretical foundations suggest a functionally intact ecosystem, while divergence from those attributes indicates a degraded ecosystem.

Before presenting a more detailed assessment of the Black Creek and Maumee River systems, we present a brief primer on stream biology for those not familiar with the general patterns characteristic of natural streams.

A PRIMER ON STREAM BIOLOGY

The focus of the process-oriented functional approach to the study of ecosystems is energy. In stream ecosystems the form and source of the energy and nutrients are especially important in determining ecosystem characteristics. The energy contained in the chemical bonds of organic matter is one form of energy. Organic matter is the basic food for animals, fungi and many bacteria. The process of breaking the chemical bonds to release energy and simpler compounds is respiration. Production is the reverse process in which energy in the form of solar radiation and simple compounds are converted into complex organic compounds. Obviously, plants are the major producer organisms and high production rates are dependent upon abundant sunlight and essential nutrients. The fundamental energy relationship can be expressed by the production (P) to respiration (R) ratio: $P/R > 1$ when production exceeds respiration, $P/R < 1$ when respiration excedes production. In streams, this basic energy flow characteristic is sensitive to the organic loading from the terrestrial environment, the amount of sunlight

Table 1. General characteristics of running water ecosystems according to size of stream. Modified from Cummins, 1975.

Stream size	Primary energy source	Production (trophic) state	Light and temperature regimes	Trophic status of dominant: Insects	Trophic status of dominant: Fish
Small headwater streams (stream order 1-3)	Coarse particulate organic matter (CPOM) from the terrestrial environment Little primary production	Heterotrophic P/R <1	Heavily shaded Stable temperatures	Shredders Collectors	Invertivores
Medium sized streams (4-6)	Fine particulate organic matter (FPOM), mostly Considerable primary production	Autotrophic P/R >1	Little shading High daily temperature variation	Collectors Scrapers (grazers)	Invertivores Piscivores
Large rivers (7-12)	FPOM from upstream	Heterotrophic P/R <1	Little shading Stable temperatures	Planktonic collectors	Planktivores

and nutrients and also the form or availability of nutrients (simple compounds vs. complex organic compounds).

Headwater streams in a natural watershed are heterotrophic. That is, they have production to respiration ratios (P/R) of less than 1.0 and are dependent on food produced outside of the stream (allocthonous material). Instream production is minor, generally from small populations of moss or periphytic algae (algae attached to rocks or other substrates). One study in a New Hampshire watershed (Fisher and Likens 1973) showed that 99% of the energy requirements for the biota of a headwater stream was of allocthonous origin. A very different watershed in Oregon demonstrated the same general pattern (Sedell et al. 1973). In this situation the persistence of the biotic community depends on a regular input of food (organic matter) from external sources. The terrestrial environment supplies much of the energy input in the form of leaf litter shed in the fall when temperatures are low. To effectively process and utilize this energy, stream organisms must be capable of processing large volumes of organic matter at reasonable rates. Since much of the processing occurs in the fall at low temperatures, Cummins (1974) refers to this as an energy compensated ecosystem.

The particle size of organic matter entering a stream is just as important to stream ecosystem functioning as the amount, type or timing of energy input. In undisturbed headwater areas, the terrestrial environment produces particulates of relatively large size (such as leaves, twigs, etc.), referred to as coarse particulate organic matter (CPOM). Bacteria and fungi quickly colonize the CPOM and, as a result of their metabolic activity, speed the process of fragmentation into smaller particles--fine particulate organic matter (FPOM). (Any organic particle less than 1 millimeter in diameter is considered FPOM, regardless of its source.) The breakdown process of CPOM is accelerated by benthic invertebrates, primarily aquatic insects, which ingest and further fragment (or shred) the CPOM. Organisms with this functional capacity are called shredders. Shredders utilize some of the energy contained in the CPOM along with the rich growths of attached bacteria and fungi. But most of the CPOM is simply converted to FPOM and is available for use by another functional group of aquatic organisms called collectors. Collectors either filter FPOM from the water or gather it from the sediments (Cummins 1973). Because of structural adaptations, most collector organisms utilize FPOM only within a narrow size range, thus illustrating the critical nature of organic matter particle size in stream ecosystems. The natural association of shredder and collector organisms in headwater streams results in a highly efficient utilization of energy (organic matter) input. Cummins (1975) has estimated that the biota processes about 80% of the particulate organic matter (POM) and 50% of the dissolved organic matter (DOM) in natural first to third order streams.

Functional attributes are markedly different in undisturbed intermediate sized rivers. The stream becomes autotrophic ($P/R > 1$) as the stream becomes less shaded and algae and vascular plants increase in abundance. CPOM inputs are reduced, resulting in decreased shredder abundance. Incoming allocthonous material is primarily FPOM from headwater areas and a variety of collector organisms are common. The autotrophic status of the stream accounts for the presence of a third functional group of aquatic macroinvertebrates. These are the scraper or grazer organisms that exploit the energy source of the abundant periphytic algae and vascular plants. As the name implies, many of the organisms harvest the plant material by scraping it from submerged objects. A few scrapers can always be found in natural headwater streams but their abundance is severely limited by the low rate of primary production.

Further downstream in large rivers (7th to 12th order) the stream again becomes heterotrophic due primarily to increasing turbidities reducing light penetration and, therefore, the potential for photosynthesis. The primary production that does occur is generated by phytoplankton (free-floating algae). Free-floating collectors (zooplankton) are also present, utilizing the phytoplankton and suspended FPOM as food. Collectors also predominate in the sediments as FPOM is the major energy source. Few scrapers or shredders occur in a large river environment.

This review has followed the stream continuum from headwaters to mouth, stressing the major impact of energy inputs on the functional attributes of the macroinvertebrate communities of running water. The fish fauna also reflects the energy sources available in a stream. However, fish can be more directly related to the value in human terms of the water resource (commercial and sport fish, shellfish, etc.). Cummins (1975) categorized the functional attributes of fish communities according to the food habits of the dominant fish. Predominant food habits are somewhat different for the three major ecological areas of an undisturbed river system. In headwater streams, fishes that feed upon macroinvertebrates (invertivores) are dominant. Invertivores along with piscivores (fish that consume other fish) dominate intermediate-sized rivers. (Because few fish are entirely piscivorous, we have classified all predominantly piscivorous fish as invertivores/piscivores, while the invertivore category was reserved for strict invertivores.) Finally, in large rivers dominant members of the fish community are planktivores (fishes feeding upon both phytoplankton and zooplankton). Two additional categories of fish according to food habits are omnivores (consuming both plant and animal matter in approximately equal portions) and herbivores (consuming primarily plant material). These functional groups are rarely dominant in natural running water systems.

We might now shift to an examination of the situation in Black Creek. When stream conditions diverge from those outlined above, we assume this is an indication of a degraded ecosystem.

THE BIOTA OF BLACK CREEK

Our review of lotic ecosystems has pointed out several key points concerning natural headwater stream structure and function. Two principles have specific bearing on interpreting the status of the Black Creek ecosystem, a headwater area within the Maumee River basin. First, shredder organisms are common in headwater streams and they process CPOM into FPOM that is utilized by other organisms. Secondly, there is very little primary production in headwater areas and therefore very few grazer or scraper organisms that utilize algae. We know that a combination of major changes in the watershed landscape caused by agriculture and urbanization has altered the natural headwater characteristics of the Black Creek basin. In addition, recent channelization or stream bank protection work has created extremely unnatural channel configurations throughout much of the watershed. An examination of the aquatic macroinvertebrate and fish communities illustrates the severe nature of these alterations and the nearly total loss of natural headwater ecosystem structure and function.

Macroinvertebrates.

Aquatic insects were collected for two years as part of the Black Creek Project (McCafferty 1976, Lake and Morrison 1978). We have examined those data to provide information on the structural and functional characteristics of the aquatic ecosystem of Black Creek. Unfortunately, biomass data are not available so only a qualitative approach is possible. The relative occurrence of various taxonomic groups was noted on a scale of 0.0 to 1.0 by dividing the number of stations at which the group was reported by the total number of stations sampled in the Black Creek watershed (12). This index is not representative of numerical abundance but does yield a rough estimate of the importance of each taxonomic group in making up the total aquatic insect fauna. All except two taxonomic groups were classified according to the trophic categories of Cummins (1973). Lack of species identification and insufficient food studies prevented trophic category classification for Chironomidae and Stratiomyidae. We believe the exclusion of these groups from our qualitative analysis has no significant effect on our conclusions concerning the structure and function of the ecosystem based on the other 25 taxa.

Shredder organisms, the processors of CPOM, are very rare in Black Creek (Fig. 1). This may be due to a combination of several factors related to the man-induced alterations of the Black Creek watershed; an alteration in the kind of CPOM input, a reduction in the amount of CPOM input, and insufficient opportunity for shredder colonization of CPOM. An alteration in the kind of CPOM seems an inevitable result of converting woodland to agricultural uses. The fact that most CPOM has nearly equivalent caloric and protein values suggests that the shift in the kinds of CPOM input alone should have minor influences on shredder populations (Cummins 1973). Some reduction in amount of CPOM may result as land use changes from woodland to agriculture, although input of CPOM continues in the form of crop residue, grasses, and leaf litter. A more important factor creating low shredder populations in Black Creek seems to be the limited opportunity for shredder organisms to colonize CPOM. The natural habitat or micro-environment for most shredder organisms is a leaf pack. Packs form around obstacles in the stream channel or in slack water and consist of leaf litter and other detritus. The uniform, unobstructed channels in Black Creek offer few locations where leaf packs can form. Therefore, a substantial amount of the CPOM input to streams like Black Creek is never subject to shredder colonization and processing within the stream. Instead, it is washed from the headwaters to downstream areas where biotic communities must cope with the material.*

Another indicator of the degraded Black Creek ecosystem is the number of herbivorous taxa in the scraper or grazer category (Fig. 1).

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*Studies show that sediment particle size has a significant influence on the rate of CPOM breakdown (Reice, 1974). Silt and sand substrates retard the conversion of CPOM to FPOM while the conversion is most efficient on gravel and rock substrates. A lack of the natural heterogenity (i.e. patchy distribution) of sediment particles in recently channelized streams thus retards the efficient processing of CPOM that remains in the system.

Such grazer populations are indicative of a high level of primary productivity not characteristic of natural headwater streams. Greater primary production in disturbed watersheds results from the increased availability of nutrients and sunlight. Similarly, collector taxa are abnormally abundant. Since little CPOM is converted to FPOM in Black Creek, these collectors probably utilize FPOM resulting from primary production and the processing of the grazer organisms. Finally, a substantial organic loading from septic tank effluent and storm water runoff may be an important source of FPOM for collector organisms.

Fishes.

Perturbations of the Maumee River fish fauna since 1850 have been described by Trautman (1957). Of paramount importance in the decline of many commercially important game fishes was the ditching and drainage of the Black Swamp, a vast lowland area in northwest Ohio. The natural streams and wetland areas of the Black Swamp were vital spawning grounds for the muskellunge, northern pike, lake sturgeon, walleye, smallmouth bass, and several species of suckers (Trautman and Gartman 1974). These fishes, once abundant, have been extirpated from the basin or have been greatly reduced in numbers. Coinciding with the decline in commercially valuable fishes has been the increased abundance of rough fishes--carp, quillback, gizzard shad, drum, and buffalo fish. Man's activities in the Maumee River basin have probably not significantly altered the total numbers or biomass of the fish community. However, man-induced alterations have drastically changed the species composition. We have examined the data available on species composition within the Maumee River basin. We will now relate these changes to the basic transitions in community functions along the stream continuum. Briefly reviewing the transitions of food habits, natural fish communities are dominated by invertivores in headwater streams, invertivores and piscivores in moderate-sized rivers, and planktivores in the largest river sections.

A 90-year series of observations on the fishes of Gordon Creek, a headwater tributary of the Maumee River, is available and provides valuable information on long-term trends in fish populations (Trautman 1939, Trautman and Gartman 1974). Our fish studies in Black Creek, only 20 miles from Gordon Creek, are an excellent supplement to this record because we can offer insights into the short term fluctuations of headwater stream fishes. Our data has been supplemented by that from other published sources to compile Appendix 1, a listing of the pertinent information concerning each species of the Maumee River basin fauna. To stress the functional changes that have occurred in Black Creek and the Maumee River, a summary table based on food habit classification is provided in Table 2, including the native fauna and introduced species. Species that we consider lost from the native fauna have been extirpated or so greatly reduced in numbers that they are insignificant in the current structure and function of the fish community.

The drastic shift in species composition (community structure) mentioned above has been paralleled by a basic alteration in the functional composition of the fish community. The most significant functional changes appear to be in the mid-river fauna (Table 2). Nine species (including northern pike, smallmouth bass and walleye) of invertivores/piscivores have been lost from the system or have declined in abundance. Although deteriorating water quality was undoubtedly a contributing factor in the

Table 2. Summary of population trends since 1850 by stream size and food type for the fish fauna of the Maumme River.

	Stream size		
	Headwaters	Mid-river	Large river
Food habits of dominant species in native fauna	Invertivores	Invertivore-Piscivores	Planktivores
Number of species with decreasing populations	6 Invertivores 2 Invertivore-Piscivores 2 Omnivores 1 Herbivore	6 Invertivores 8 Invertivore-Piscivores[a]	1 Invertivore-Piscivore
with increasing populations	2 Invertivores 2 Omnivores 1 Herbivore	1 Invertivore 1 Invertivore-Piscivore[c] 1 Omnivore[c]	2 Planktivores[b]
lost	4 Invertivores 3 Omnivores	5 Invertivores 1 Invertivore-Piscivore	1 Invertivore 1 Invertivore-Piscivore
introduced	3 Invertivores 1 Invertivore-Piscivore	3 Invertivore-Piscivores 2 Omnivores[d]	1 Invertivore-Piscivore 1 Planktivore

[a]Declining abundances of these top predators reduces their spawning migrations and, thus, their impact on headwater ecosystems.

[b]These species invade headwater and mid-river segments as drainages are modified.

[c]Shifting headwater ecology results in invasion of headwaters by these species.

[d]These species are common invaders, at least seasonally, in upstream areas.

disappearance of some species, for other species the destruction of headwater spawning habitat has been the critical factor (Trautman and Gartman 1974). Some remaining invertivore/piscivore species of the mid-river fauna continue to face this problem in the upper Maumee River. Currently, northern pike seek out a few remaining areas of marginal spawning habitat within the Black Creek watershed. Spawning success has been observed but recruitment of young into the next generation must surely be limited in many areas by the rarity of adequate nursery habitat. This is one way in which conditions in headwater streams can affect the structural and functional composition of the downstream or mid-river fisheries. The functional aspects of the alteration may be particularly disruptive to the fish community because the top predators are reduced thus removing a natural check on forage and rough fish populations.

A native species (drum) and three introduced species have partially filled the functional gap left by the decline or loss of the nine species of mid-river invertivores/piscivores. (It is interesting to note that the drum does not utilize headwater areas for spawning.) However, the dominant mid-river fauna has shifted away from the natural condition of invertivores and piscivores to dominance by omnivores--the carp, quillback, and goldfish (Table 2). Again, as with the disappearance of some species, certain water quality characteristics are related to the abundance of these rough fish. However, observations in Black Creek and Gordon Creek suggest a contributing factor in carp and quillback abundance is their use of headwater streams for spawning grounds.

The harsh environmental conditions of many headwater streams cannot be tolerated by desirable game fishes (i.e., northern pike), but can still be suitable for the spawning of carp and quillback. In the late spring hundreds of these rough fish can be found in the small first and second order streams, 10-15 km upstream from the river. Success in spawning is variable and appears to be highly weather-dependent--high water is needed to reach the spawning areas but a subsequent low flow period is required to insure survival of eggs and larval fish. Five years of record in the Black Creek watershed reveals that if successful spawning is achieved, the young carp and quillback dominate the headwater fish community until September or October when they migrate to larger streams and rivers. This is a second way in which the headwater stream environment dramatically influences the mid-river fish community, both in terms of functional composition (omnivores dominant vs. invertivore/piscivores dominant) and in terms of resource value (rough fish vs. game fish).

Impoundments on the Maumee River have contributed to the increased abundance of the characteristic large river fauna--the planktivores (gizzard shad and buffalo fish). The importance of headwater areas to the spawning of these two species is minimal but numerous young gizzard shad are consistently captured in Black Creek each fall. The same phenomenon holds for the spotfin shiner and possible the drum--two abundant mid-river species. These species appear to utilize headwater streams as a supplemental food resource, perhaps in response to population pressures. The relative importance of the headwaters to these fish species is currently unknown.

We have stressed changes in the species composition of the Maumee River basin's mid-river fauna and have pointed out the disruption of natural community functioning. Conditions in the headwater streams are seen as important contributing factors in these changes. Are there changes in the functional relationships of the headwater fish fauna? Yes, and the invasion by mid-river omnivores is the major reason (Table 2). As mentioned above, carp and quillback young dominate the community in years when good spawning success is achieved (Table 3). However, in poor spawning years the resident fish fauna is more abundant and dominated by invertivores. If the invasion of downstream omnivores is ignored, there has been no change in the dominant functional group of headwater fishes. The records from Gordon Creek and elsewhere in the Maumee basin reveal the loss of species intolerant of degraded water quality (especially high turbidity and elevated water temperature) but this decimation has not been selective towards one functional group.

Table 3. Total number of species and individuals and number and percent of individuals of rough fish (carp, carpsucker, and shad). Note that the spawning success of the rough fish varies from year to year.

Sample	Total number of species	Total number of individuals	Number of rough fish	Percent rough fish
Station 12 - July				
1974	12	127	10	7.9
1975[a]	14	206	3	1.5
1976	17	348	13	3.7
1977	15	286	167	58.4
Station 29				
July 1976	17	348	13	3.7
July 1977	16	372	190	51.1
August 1976	18	1138	378	33.2
August 1977	16	407	191	46.9

a Means for 2 samples

<u>Other indications of resource degradation</u>.

While considerable effort has been expended to document the functional attributes of natural streams, few studies have examined the detailed characteristics of lotic ecosystems in areas of high intensity agriculture. During the past five years of working in Black Creek we have identified ecological factors which seem to be tied to the declining integrity of stream ecosystems.

1. <u>Allocthonous organic matter inputs</u>: FPOM input from sewage and stormwater runoff is substantial as evidenced by high bacterial contamination (Dudley and Karr 1979). This change along with the modification in form and content of CPOM discussed earlier results in major structural and functional changes in the stream ecosystem.

2. <u>Nutrient availability</u>: Concentrations of simple nutrient forms (PO_4, NO_3, NH_4) are high. In addition, inputs of complex organic compounds associated with CPOM are not effectively processed.

3. Sunlight availability: A predominance of unshaded stream channels results in high solar energy input. Coupled with available nutrients (#2 above), this results in buildup in algal populations (CPOM) which is either subject to slow decay in the headwaters or is washed downstream in large quantities during high flows. These algal blooms add to the organic load of the aquatic system and change the physical characteristics of the stream environment (reducing current velocities, covering natural substrates, etc.).

4. Temperature and dissolved oxygen imbalance: Seasonal and daily patterns of temperature and dissolved oxygen are exagerated and poorly buffered from environmental influences (weather extremes, organic loading, etc.).

5. Stream habitat characteristics: The diversity and stability of high quality stream habitat is low (Gorman and Karr 1978). The ditching and drainage efforts prevalent in some agricultural watersheds perpetuates this problem.

6. Seasonal low flows: The loss of natural vegetation and installation of complex drainage networks results in rapid runoff instead of slow release of excess water. As a result extreme lowflows during dry periods, especially in late summer and early fall, place considerable stress on aquatic ecosystems.

All these factors contribute to degradation in water resource quality in agricultural watersheds. But the causal interactions among these variables and biological integrity remain poorly understood. Detailed studies of these functional relationships of disturbed headwater streams are needed.

In summary, our ecological assessment of the Black Creek system reveals autotrophic community attributes instead of the normal heterotrophic community to be expected. This fundamental shift in energy flow signals the loss of a naturally functioning headwater stream. This appears to be a common phenomenon throughout intensive agricultural areas. Major downstream impacts on the fishes of the Maumee River occurred nearly a century ago but we have shown the headwater environment continues to influence the mid-river fish community. It is imperative that some measure of natural headwater community function be maintained if we are to preserve and restore valuable downstream aquatic resources.

RECOVERY AND RESTORATION

A critical problem in water resource management is our inability to view streams as biological systems with natural functional, structural, and stability properties. Stream channels are too frequently viewed (and put to work) as drainage pipes or conduits in both urban and agricultural settings. The benefits of enhanced drainage are often cited as reduced flooding and improved crop production but little thought is given to the preservation of benefits lost through short-circuiting of the natural processing potential of our stream ecosystems. The result of this short-circuiting is manifest in a number of downstream problems involved in declining water-resource values. To solve these problems innovative stream management policies are needed in headwater areas. The Black Creek project was not designated to utilize such a stream management approach but perhaps we can learn from its shortcomings in this area.

A considerable portion of project money and effort was expended on stream channel related activities (streambank protection and stabilization). Motivations for these activities were threefold: reducing erosion by stabilizing stream banks, enhancing the drainage efficiencies of the stream network, and winning favor amoung the agricultural community by installing popular practices. In the Black Creek watershed the first two motives cannot justify the majority of stream channel work done. Mildner (1976) found that only 5% of the sediment exported from Black Creek originates from streambank sources clearly showing a poor return on money spent to reduce streambank erosion. [In other watersheds, streambank sources may generate 50% of the sediment therefore improving the cost-benefit ratio (Evans and Schnepper 1977). The point is the magnitude of the problem should be investigated on a case by case basis]. Although quantitative data are lacking, project designers admit that in only a few cases was streambank work necessary to maintain or improve the drainage characteristics of Black Creek. Thus, agricultural production was not significantly affected by stream channel activities. [Again, this conclusion is not universally true, but in very few cases is the issue explored by designers.] This leaves as valid justification only the winning of favor among the farm community and thereby gaining support for other conservation practices. Black Creek project administrators point to this as a requirement for obtaining a high degree of participation in agricultural conservation programs. While it does have merit, this reasoning results in a trade-off of water-resource values--stream ecosystem functions are sacrificied to obtain reduced pollution from cropland runoff. Innovative approaches are needed that encompass headwater stream functioning and pollutant loading for both are essential to downstream water-resource values.

From the principles outlined above we can suggest general approaches which might be developed to improve the biological integrity of water resources. Three sets of variables are known to have a major impact on the integrity of a stream biota (Figure 2). These are the nature of the energy source (Cummins 1974, this paper), physical and chemical characteristics of water (Hynes 1974, Warren 1971), and structural aspects of stream habitat (Allen 1975, Gorman and Karr 1978). Each of the primary variables includes a complex array of factors. A partial list of the components of these variables that are of obvious significance follows:

Energy Source:	allocthonous organic matter vs. primary production in the stream; particle size distribution of particulate organics.
Water Quality:	temperature; dissolved oxygen content; soluble organics and inorganics; heavy metals, toxic substances; water volume; temporal distribution (seasonality and low flows) of water availability.
Habitat Structure:	bottom type; water depth; current velocity; availability of spawning, nursery, and hiding places; diversity of "habitats" in small scale areas.

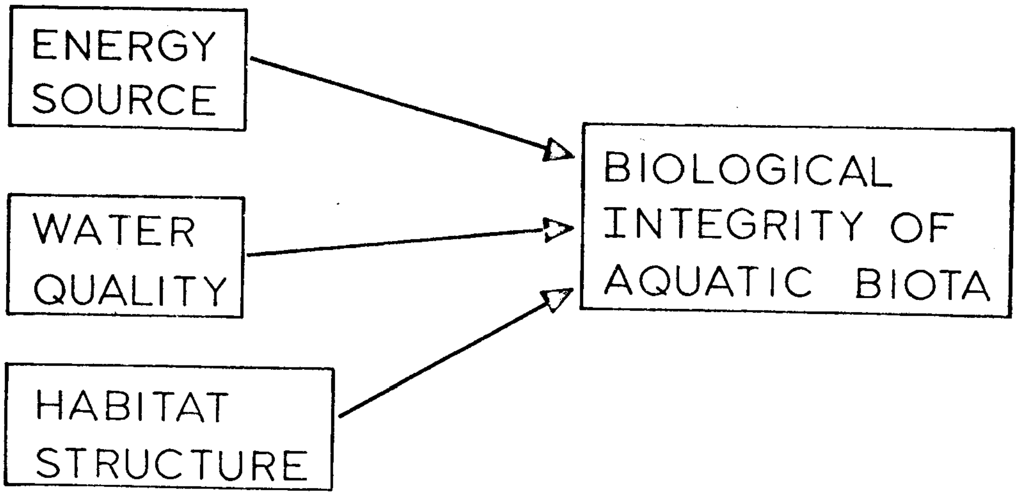

Figure 2. Primary variables affecting the structural and functional aspects of the biota of a headwater stream.

As has been emphasized in earlier papers (Gorman and Karr 1978, Karr and Schlosser 1978), a patchwork approach attacking only one of these areas will be doomed to failure if other factors also limit the biotic community; comprehensive efforts to improve the biological integrity of our waterways must evaluate and alleviate problems existing in all of these areas.

At the same time we must recognize that a variety of societal and resource constraints limit our ability to protect and/or restore all headwater streams. Agricultural productivity must be improved to meet growing food and fiber demands. But can we affort to maximize production in entire basins such as the Maumee River, the largest tributary entering the Great Lakes and the second largest drainage in Ohio? To do so is to sentence much of the water resources of the Great Lakes Basin to continued degradation.

The preservation or recovery of natural streams in selected headwater areas of a river basin may sacrifice agricultural productivity in a small area but yield substantial improvements in downstream water resources. Studies from a number of areas (Cairns et al. 1977) have shown that recovery and restoration is not only possible but profitable from a societal perspective. Successes in the Thames River in England (Gameson and Wheeler 1977) and Lake Washington near Seattle (Edmondson 1977) give cause for optimism. The only question remaining, in our opinion, is: Are we up to the challenge?

REFERENCES

Allan, J. D. 1975. The distributional ecology and diversity of benthic insects in Cement Creek, Colorado. Ecology. 56: 1040-1053.

Allison, D. and H. Hothem. 1975. An evaluation of the status of the fisheries and the status of other selected wild animals in the Maumee River basin, Ohio. State of Ohio, Department of Natural Resources, Division of Wildlife, Columbus. 15 pp.

Cairns, J. Jr., K. L. Dickson, and E. E. Herricks (eds.). 1977. Recovery and restoration of damaged ecosystems. Univ. Press of Virginia, Charlottesville. 531 pp.

Carlander, K. D. 1969, 1977. Handbook of freshwater fishery biology Vols. I, II. Iowa State Univ. Press, Ames. 752 pp., 431 pp.

Cummins, K. W. 1973. Trophic relations of aquatic insects. Ann. Rev. Ent. 18: 183-206.

Cummins, K. W. 1974. Structure and function of stream ecosystems. BioScience. 24: 631-641.

Cummins, K. W. 1975. The ecology of running waters: theory and practice. Pp. 277-293 in Proc. Sandusky River Basin Symp. Int. Ref. Grp. on Great Lakes Pollution from Land Use Activities, International Joint Commission. 277-293.

Dudley, D. R. and J. R. Karr. 1979. Concentration and sources of fecal and organic pollution in an agricultural watershed. Water Resources Bulletin. In press.

Edmundson, W. T. 1977. Recovery of Lake Washington from eutrophication. Pp. 102-109 in Cairns, J. Jr., K. L. Dickson, and E. E. Herricks (eds). Recovery and restoration of damaged ecosystems. Univ. Press of Virginia, Charlottesville.

Evans, R. L. and D. H. Schnepper. 1977. Sources of suspended sediment: Spoon River, Illinois. North-Central Section Geological Society of America, Southern Illinois Univ., Carbondale. 10 pp, mimeo.

Fisher, S. G. and G. E. Likens. 1973. Energy flow in Bear Brook, New Hampshire: an integrative approach to stream ecosystem metabolism. Ecol. Monogr. 43: 421-439.

Gameson, A. L. H. and A. Wheeler. 1977. Restoration and recovery of the Thames Estuary. Pp. 72-101 in Cairns, J. Jr., K. L. Dickson, and E. E. Herricks (eds.). Recovery and restoration of damaged ecosystems. Univ. Press. of Virginia, Charlottesville.

Gorman, O. T. and J. R. Karr. 1978. Habitat structure and stream fish communities. Ecology. 59: In press.

Hubb, C. L. and K. F. Lagler. 1958. Fishes of the Great Lakes region. Cranbrook Inst. Sci., Bull. 26: 1-213.

Hynes, H. B. N. 1970. The ecology of running waters. Univ. Toronto Press, Toronto. 555 pp.

Hynes, H. G. N. 1974. The biology of polluted waters. Univ. Toronto Press, Toronto. 202 pp.

Karr, J. R. and O. T. Gorman. 1975. Pp. 120-150 in Effects of land treatment on the aquatic environment. U. S. Environmental Protection Agency, Chicago. EPA 905/9-75-007.

Karr, J. R. and I. J. Schlosser. 1978. Water resources and the land-water interface. Science 201: 229-234.

Kuehne, R. A. 1962. A classification of streams, illustrated by fish distribution in an eastern Kentucky creek. Ecology. 43: 608-614.

Lake, J. and J. Morrison (eds.). 1978. Environmental impact of land use on water quality: Final report on the Black Creek project (Data Volume). U. S. Environmental Protection Agency, Chicago. EPA-905/9-77-007-C.

Likens, G. E., F. H. Bormann, R. S. Pierce, J. S. Eaton, N. M. Johnson. 1977. Biogeochemistry of a forested ecosystem. Springer-Verlag, New York. 146 pp.

McCafferty, W. P. 1976. The aquatic macroinvertebrates of Black Creek, Allen County, Indiana. Final Report. Dept. of Entomology, Purdue University, West Lafayette, IND. 61 pp.

Mildner, W. 1976. Streambank erosion in Black Creek watershed, Indiana. Prep. by USDA Soil Conserv. Servic. An assigkment of the U.S. Task C. work group of the International Reference Group on Great Lakes Pollution from Land Use Activities. 5 pp. + 2 appendices, mimeo.

Pflieger, W. L. 1975. The fishes of Missouri. Missouri Dept. of Conservation, Jefferson City, Missouri. 343 pp.

Reice, S. R. 1974. Environmental patchiness and the breakdown of leaf litter in a woodland stream. Ecology. 55: 1271-1282.

Sedell, J. R., F. J. Triska, J. D. Hall, N. H. Anderson, and J. H. Lyford. 1973. Sources and fates of organic inputs in coniferous forest streams. streams. Cont. 66, Coniferous Forest Biome, IBP, Oregon State Univ. 23 pp. Cited in Cummins, 1974. BioScience.

Trautman, M. B. 1939. The effects of man-made modifications on the fish fauna in Lost and Gordon Creeks, Ohio, between 1887-1938. Ohio J. Sci. 39: 275-288.

Trautman, M. B. 1957. The fishes of Ohio. Ohio State Univ. Press. Columbus. 683 pp.

Trautman, M. B. and D. K. Gartman. 1974. Re-evaluation of the effects of man-made modifications on Gordon Creek between 1887 and 1973 and especially as regards its fish fauna. Ohio J. Sci. 74: 162-173.

Warren, C. E. 1971. Biology and water pollution control. W. B. Saunders, Philadelphia. 434 pp.

Appendix I. Abundances, Population Trends, and Ecological Classifications for All Fish Found in the Maumee River Basin, excluding Petromyzontidae, Salmonidae, and Anguillidae.

	Current Relative Abundance[a]	Population Trend Since 1850[b]	Typical Stream Size[c]	Food Habits[d]
ACIPENSERIDAE				
Lake Sturgeon - *Acipenser fulvescens*	E	E*	LR	1
LEPISOSTEIDAE				
Spotted Gar - *Lepisosteus oculatus*	E	D**	MR	2
Longnose Gar - *L. osseus*	U	D**	LR, MR	2
AMIIDAE				
Bowfin - *Amia calva*	U	D**	MR	2
CLUPEIDAE				
Alewife - *Alosa pseudoharengus*	U	N+	LR	3
Gizzard Shad - *Dorosoma cepedianum*	VC	I**	LR, MR	3
OSMERIDAE				
Rainbow Smelt - *Osmerus mordax*	R	N+	LR, MR	2
HIODONTIDAE				
Mooneye - *Hiodon tergisus*	R-E	D**	LR	1
UMBRIDAE				
Central Mudminnow - *Umbra limi*	U	E*	HW	4
ESOCIDAE				
Grass Pickerel - *Esox americanus*	U	D**	MR, HW	2
Chain Pickerel - *E. niger*	R	N++	MR	2
Northern Pike - *E. lucius*	C	D*	MR	2
Muskellunge - *E. masquinongy*	R-E	E*	MR	2

Appendix I. (cont'd.)

CYPRINIDAE				
Stoneroller - *Campostoma anomalum*	C	I*	MR, HW	5
Goldfish - *Carassius auratus*	C	N*	MR	4
Southern Redbelly Dace - *Phoxinus erythrogaster*	U	D**	HW	5
Carp - *Cyprinus carpio*	VC	N*	MR	4
Silverjaw Minnow - *Ericymba buccata*	C	S*	MR, HW	1
Bigeye Chub - *Hybopsis amblops*	U	D**	HW, MR	1(?)
Silver Chub - *H. storeriana*	E	E^{++}	MR, LR	?
River Chub - *Nocomis micropogon*	U	S^{++}	MR	1
Horneyhead Chub - *N. biguttatus*	U	E*	HW	1
Golden Shiner - *Notemigonus crysoleucas*	U	D**	LR, MR	4
Emerald Shiner - *Notropis atherinoides*	C	S^{++}	LR, MR	1
Popeye Shiner - *N. ariommus*	X	E	MR	?
Blacknose Shiner - *N. heterolepis*	X	E	HW	?
Bigeye Shiner - *N. boops*	R-E	E*	MR, HW	1
Common Shiner - *N. cornutus*	VC	S*	HW	1
Pugnose Minnow - *N. emiliae*	R-E	E**	MR	1
Spottail Shiner - *N. hudsonius*	C	S^{++}	LR, MR	1
Silver Shiner - *N. photogenis*	U	D^{++}	MR	?
Rosyface Shiner - *N. rubellus*	U	D**	MR	1
Spotfin Shiner - *N. spilopterus*	A	I*	MR, HW	1
Sand Shiner - *N. stramineus*	U	I*	MR, HW	1
Redfin Shiner - *N. umbratilis*	A	I*	HW	1
Mimic Shiner - *N. volucellus*	U	E*	MR	4
Suckermouth Minnow - *Phenacobius mirabilis*	U	N*	MR, HW	1
Bluntnose Minnow - *Pimephales notatus*	A	S*	HW, MR	4
Fathead Minnow - *P. promelas*	C	I*	HW	4
Blacknose Dace - *Rhinichthys atratulus*	U	D***	HW	4
Creek Chub - *Semotilus atromaculatus*	VC	S*	HW	1
CATOSTOMIDAE				
Quillback - *Carpiodes cyprinus*	C	I*	MR	4
White Sucker - *Catostomus commersoni*	VC	S*	MR, HW	1
Creek Chubsucker - *Erimyzon oblongus*	U	S*	HW	1
Lake Chubsucker - *E. sucetta*	E	D^{++}	HW	1

Appendix I. (cont'd.)

CATOSTOMIDAE (cont'd.)				
Northern Hog Sucker - Hypentelium nigricans	C	S++	MR	1
Bigmouth Buffalo - Ictiobus cyprinellus	VC	I**	LR, MR	3
Harelip Sucker - Lagochila lacera	X	E	MR	1
Spotted Sucker - Minytrema melanops	U	D**	HW	1
Golden Redhorse - Moxostoma erythrurum	C	S*	MR	1
Shorthead Redhorse - M. macrolepidotum	U	S**	MR	1
Greater Redhorse - M. valenciennesi	R-E	D*	MR	1
Silver Redhorse - M. anisurum	R	D++	MR	1
Black Redhorse - M. duquesnei	R	S*	MR	1
ICTALURIDAE				
Channel Catfish - Ictalurus punctatus	C	S**	MR	4
Black Bullhead - I. melas	C	S*	MR, HW	1
Yellow Bullhead - I. natalis	C	S*	MR, HW	1
Brown Bullhead - I. nebulosus	C	S*	MR, HW	1
Tadpole Madtom - Noturus gyrinus	U	E*	HW	1
Brindled Madtom - N. Miurus	U	D++	HW	1(?)
Stonecat - N. flavus	C	S**	MR, HW	1
CYPRINODONTIDAE				
Banded Killifish - Fundulus diaphanus	E	D++	HW	1
Blackstripe Topminnow - F. notatus	C	I*	HW	1
POECILIIDAE				
Mosquitofish - Gambusia affinis	R	N++	HW	1
PERCOPSIDAE				
Trout-Perch - Percopsis omiscomaycus	R	E**	MR	1
APHREDODERIDAE				
Pirate Perch - Aphredoderus sayanus	E	E*	HW	1
PERCICHTHYIDAE				
White Bass - Morone chrysops	C	S**	LR	2

Appendix I. (cont'd.)

CENTRARCHIDAE				
Rock Bass - Ambloplites rupestris	C	S++	MR	2
Bluegill - Lepomis macrochirus	C	N*	MR	2
Green Sunfish - L. cyanellus	VC	S*	HW	2
Orangespotted Sunfish - L. humilis	C	N*	HW-MR	2
Longear Sunfish - L. megalotis	U	D*	MR, HW	2
Pumpkinseed Sunfish - L. gibbosus	C	S*	MR, HW	2
Redear Sunfish - L. microlophus	R	N++	MR, HW	1
Warmouth Sunfish - L. gulosus	R	D++	MR, HW	2
Largemouth Bass - Micropterus salmoides	C	N*	LR, MR	2
Smallmouth Bass - M. dolomieui	C	D*	MR	2
Black Crappie - Pomoxis nigromaculatus	C	S++	LR, MR	2
White Crappie - P. annularis	C	S++	LR, MR	2
PERCIDAE				
Eastern Sand Darter - Ammocrypta pellucida	R-E	D**	MR	1
Greenside Darter - Etheostoma blennioides	C	S++	MR	1
Rainbow Darter - E. caeruleum	C	S++	HW & MR	1
Iowa Darter - E. exile	R-E	S++	MR, HW	1
Fantail Darter - E. flabellare	U	S**	HW & MR	1
Least Darter - E. microperca	U	D**	HW	1
Johnny Darter - E. nigrum	C	S*	MR, HW	1
Orangethroat Darter - E. spectabile	U	S*	HW	1
Yellow Perch - Perca flavescens	C	S++	LR, MR	2
Logperch Darter - Percina caprodes	C	S++	MR & HW	1
Channel Darter - P. copelandi	E	D++	MR	1
Gilt Darter - P. evides	X	E	MR	1
Blacksided Darter - P. maculata	C	S*	HW	1
Sauger - Stizostedion canadense	R	D++	MR & LR	2
Blue Pike - S. vitreum glaucum	X	E++	LR	2
Walleye - S. vitreum vitreum	C	D*	MR	2
SCIAENIDAE				
Freshwater Drum - Aplodinotus grunniens	C	I**	MR & LR	2

Appendix I. (cont'd.)

COTTIDAE				
Mottled Sculpin - Cottus bairdi	U	E***	HW	1
ATHERINIDAE				
Brook Silverside - Labidesthes sicculus	C	S**	MR	1

[a]Current relative abundances; from Allison and Hothem 1975
- A - Abundant. A species so numerous as to be usually one of the dominant species.
- VC - Very common. A species which is readily catchable, usually in large numbers.
- C - Common. A species, which, considering its catchability under various conditions and times, is found usually in moderate to large numbers.
- U - Uncommon. A species occuring rather regularly in collections, but usually in small numbers.
- R - Rare. A species recorded only once or very infrequently, and invariably in small numbers.
- E - Endangered. Indicates that the species is also on the list of endangered wild animals of Ohio.
- X - Extinct in watershed.

[b]Population trend since 1850
- S - Stable. No major change in abundance.
- I - Increase. Significant increase in abundance.
- D - Decrease. Significant decrease in abundance.
- N - Introduced. Non-native species now present through release or invasion and native species whose presence is due primarily to stocking and escape from ponds.
- E - Lost. Species whose numbers have been so drastically reduced they are considered extirpated or extremely rare.

Source of information
- * faunistic surveys, Trautman and Gartman 1974
- ** life history and habitat data, Pflieger 1975
- *** faunistic surveys, Trautman 1939
- + life history and habitat data, Hubbs and Lagler 1958
- ++ faunistic surveys, Allison and Hothem 1975

[c]Major habitat; stream size category
- HW - headwaters
- MR - Intermediate-sized rivers
- LR - Large rivers

[d]Food habit category based on information found in Pflieger 1975, Hubbs and Lagler 1958, and Carlander 1969, 1977
- 1 - Invertivore
- 2 - Invertivore/Piscivore
- 3 - Planktivore
- 4 - Omnivore
- 5 - Herbivore

CONSERVATION DISTRICT INVOLVEMENT IN 208 NONPOINT SOURCE IMPLEMENTATION

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The activities of conservation districts have been on-going for more than forty years in the United States.

The conservation movement began in 1937 when model legislation was furnished to the states by President Roosevelt providing for the creation of conservation districts by state law. Since that time all states, Puerto Rico and the Virgin Islands have adopted such laws. Some 3,000 conservation districts have been created throughout our nation.

Most state's district laws provide for establishment of districts as political subdivision of the state. Although state laws governing conservation districts vary in some respects, their purposes are the same everywhere; that is, to focus attention on land, water, and related resource problems; to develop programs to solve those problems; and to enlist the support and cooperation from all public and private sources to accomplish district goals.

Conservation districts are managed by local citizens who know their local problems. Usually districts have from five to seven officials who are either elected or appointed depending on the laws of the particular state. There is a growing trend to provide for the election of these governing bodies at the general election. Over 17,000 men and women now serve as district officials. Originally, conservation districts primarily served agricultural cooperators; cities and towns not being included within most districts' boundaries. However, in recent years, conservation districts have either by amendment to the district law or by the redefining of district boundaries included the entire soil and water resource areas encompassing urban and city dwellers as well.

Most conservation officials are farmers and ranchers, however, they are being joined more and more in recent years by bankers, homeowners, sportsmen, businessmen, county officials, and many other citizens concerned about natural resources. An increasing number of states are requiring representation on district governing bodies by urban and non-farm interest.

In every district, officials develop and continually maintain a long range plan which contains facts about the soil, water, and related resource problems of their district. The long range plan also outlines measures that can be taken to correct the problems identified. The long range plans must continually be updated in order to provide current resource information that is needed to assess current problems and to provide a base for setting new priorities. All districts prepare an annual plan of operations to guide the current year's activities. To accomplish the goals spelled out in the long range plan and the annual plan of operations, district officials have developed working agreements with many local, state, and federal agencies.

Through a memorandum of understanding, districts receive federal assistance from the United States Department of Agriculture's Soil Conservation Service to provide technical assistance to individual landowners and land users for planning and installing conservation practices needed on their lands. Districts also have memorandums of understanding and cooperative arrangements with many other federal, state, and local agencies.

There are now over 2 million district cooperators throughout the nation. These cooperators have been working with conservation districts voluntarily to apply conservation practices (many are synonymous with Best Management Practices) on their land for the last 40 years. However, with all these indications of success, the fact still remains that there is a tremendous job to be accomplished in soil and water conservation. New problems continue to arise, and millions of acres of our valuable cropland are still unprotected and are eroding at a rate accelerated by man's activities that will deplete the soil resource if it continues. Furthermore, the resulting sediment is recognized as the largest single polluter of our streams by volume. In addition, it is recognized that water quality can be further degraded by the excessive nutrients and pesticides carried by sediment.

In 1977, the General Accounting Office reported in a survey of the effectiveness of conservation work throughout our country. The report indicated that the Soil Conservation Service estimated an average of 9 tons of soil per acre per year was being lost from our nation's croplands, and that a significant amount of cropland losing soil in excess of the tolerable soil loss limits has not been protected by the application of erosion control practices. In fact, the report indicated that 42% of the 335 million acres of cropland harvested in 1975 did not have adequate erosion control techniques applied.

In recent years, attention has turned toward the effects of erosion and related pollutants on water quality. Several major events over the past few years have led to the involvement of conservation districts in 208 water quality planning. In 1970, a National Sediment Conference identified sediment as a serious polluter of our nation's waters. Conservation districts became more concerned about those water quality problems that might be created by agricultural activities. In 1972, the National Association of Conservation Districts, EPA, the Council of State Governments, SCS, and others worked to develop a Model State Act for Soil Erosion and Sediment Control to be considered for use throughout the country. The Model Act was published by the Council of State Governments in its 1973 Suggested State Legislation. Following this, NACD received a grant from EPA to assist individual states hold sediment control institutes. The purpose of these institutes was to discuss the problems related to sedimentation and water quality; to discuss potential legislation and sediment control programs that could be implemented to reduce these problems; and to educate individual district officials as to the seriousness of erosion, sediment, and related water quality problems. Forty-five sediment institutes were held in cooperation with State Soil and Water Conservation agencies, SCS, State associations, conservation districts, and others throughout the country.

As of 1977, 15 states, the Virgin Islands and the District of Columbia had adopted various forms of sediment control legislation. The legislation in these states is quite diverse and may vary a great deal from the model legislation introduced in 1972. However, the control of erosion and sediment is an important feature of all of these laws.

A brief summary of the sediment control laws in three of these states follow:

Virginia

The efforts of Virginia's Soil and Water Conservation Commission and the Erosion and Sediment Control Task Force of the Governor's Council on the Environment in 1971-72 resulted in the 1972 enactment of a bill for erosion and sediment control on land disturbing projects other than agricultural or silvicultural.

The purpose of the law was to establish and implement a statewide, coordinated program to control erosion and sediment and, to conserve and protect the land, water, air, and other natural resources of Virginia. The State Soil and Water Conservation Commission was assigned responsibility for administering the law.

Guidelines, standards, and criteria were adopted by the Commission and became effective July 1, 1974. Local control programs consistent with the state program are developed and carried out by (1) the soil and water conservation district; (2) where appropriate, by counties, cities, and incorporated towns; or (3) by a joint venture between a district and a county, city or town. These local programs are approved by the Commission.

If any county, city, town, or district fails to fulfill these requirements, the Commission develops and adopts a program to be carried out by the district, or if there is no district, by the county, city, or town.

The local programs require an erosion and sediment control plan approved by the local government before land disturbing activities can begin. The local authority can require an applicant to insure that emergency measures for appropriate conservation be taken at the applicant's expense. To insure this, the authority can require a letter of credit, cash escrow, performance bond, or other legal arrangement before issuing the permit.

Iowa

Iowa's erosion and sediment control law requires abatement of erosion when a complaint is filed with the commissioners of a conservation district, provides for adoption of soil loss limit regulations by districts, and provides for state financed cost-sharing for installing necessary work within specified time limits.

Iowa was the first state in which districts experienced this new responsibility governing agricultural lands. A key stipulation in the Iowa law is that cost-sharing and technical assistance must be available before a landowner can be required to install measures to meet the requirements of the law.

Maryland

Maryland's Statewide Sediment Control Act was adopted in 1970 by the Maryland General Assembly. The Department of Natural Resources is the responsible agency. The Act requires that before land is cleared, graded, transported, or otherwise disturbed for any purpose (except agriculture and single-family dwelling construction) the proposed earth change shall first be submitted to and approved by the appropriate soil conservation district. State projects, federal projects or projects on state-owned lands are approved by the Department of Natural Resources. Under the Act, each county and municipality is required to adopt grading and sediment control ordinances and have them approved by the Department of Natural Resources (DNR). All 23 counties and Baltimore City adopted ordinances by the end of 1972. The Maryland Attorney General has ruled that "protective stormwater measures may be imposed by the Soil Conservation District" under the 1970 Sediment Control Law.

In 1972, when Congress passed amendments to the Clean Water Act, P.L. 92-500, it possibly enacted the most significant legislation involving conservation districts since their creation. Never before in the 40 plus years of conservation district activities in this country have the challenges and opportunities been greater than they are today as a result of Section 208 of that law. Section 208, as you know, requires that each state develop state or areawide plans for controlling pollution from both point and nonpoint sources. Nonpoint sources include such areas as agriculture, silviculture, surface mined areas, and construction sites. Districts, because of their experience, became directly involved in nonpoint planning for these activities in many states. Some of the key provisions of Section 208 that have provided the opportunity for district involvement are: the emphasis on local involvement, the requirement for identification of water quality problems by source, and the need for development of best management practices that will help solve the identified nonpoint source water quality problems. The provisions also require that the agency or agencies to manage the nonpoint program be designated by the governor. All of these provisions led very naturally to the involvement of conservation districts.

The language of Section 208 also spells out that the programs are to be carried out at the local and state levels with local public participation playing a major role in formulation and implementation of the 208 plans. Soil Conservation districts are the key local agency for involving rural landowners and concerned citizens. As local landowners themselves, district officials provide the grass roots contact between government at all levels and the local people.

In addition, districts have perfected working arrangements which allow the integration of federal, state, and local governmental agencies. Through this cooperation, conservation districts also have the technical expertise to provide landowners assistance in making decisions affecting nonpoint source pollution control on their land. They also have a tremendous amount of necessary resource information such as soil surveys, resource maps, Conservation Needs Inventory data, soil loss information (Universal Soil Loss Equation) that is needed to identify the critical areas where water quality problems do exist.

In addition, districts with the technical assistance of SCS have the expertise to assist landowners with the development of plans outlining Best Management Practices on their lands. Many existing and well-known conservation practices that have been used for years such as grassed waterways, terraces, erosion control structures, minimum tillage, pasture land management, and many others are "Best Management Practices" whenever they are identified as the best known means of control for agricultural nonpoint source water quality problems addressed in a 208 plan. Just because we have developed a new term which describes those measures to be applied to solve water quality problems related to agriculture, it doesn't mean that we scrap all the existing technical methods that we have used in the past. Instead, we will be focusing on how to use our technical experience more efficiently in addition to searching out new methods of control which will also be recognized as Best Management Practices to improve water quality.

Districts have some real challenges to meet, and in some cases changes to make, in their own organization, in order to accomplish the objectives of the nonpoint source control efforts under Section 208. To meet these challenges, districts will need to, and are, reassessing their priorities. The days of the "first-come-first-serve" approach for assistance are numbered. Setting priorities for conservation planning and application is a responsibility of conservation districts. Not only is this an important aspect of 208 planning, but of on-going district programs as well. The Soil Conservation Service has agreed to provide technical assistance in accordance with the priorities set by district officials. This means that technical assistance should, and will be, available to landowners and operators on a "worst-first" basis in the future. It will mean, that instead of working with the most aggressive landowners who request assistance for relatively minor problems, the Soil Conservation Service, and other district cooperating agencies such as the Cooperative Extension Service, must concentrate on working with the less progressive operators who, usually have the more difficult problems, but are more hesitant to request assistance. As a result of this approach, implementation will be accomplished in the critical areas first in order to have the greatest and most immediate impact on water quality.

With the growing responsibilities conservation districts are being asked to assume, the need for additional district administrative and technical staff is critical. In many states, county and state government provide funds to enable districts to fill at least part of this manpower need.

Federal personnel ceilings limit the number of SCS and other agency personnel available to districts. If some additional manpower needs can be met from state and local sources, better use of SCS technical assistance can be made in solving critical land protection and water quality problems.

Districts will need to continually improve their educational and information programs in the future in order to show the need for additional support.

Districts are demonstrating their ability to make these adjustments as well as their ability to manage programs for the installation of Best Management Practices in several programs already underway in the country. The following programs are illustrative of districts' abilities to manage programs in the future. The three examples that will be briefly discussed are the Pennsylvania Clean Streams Program, the Montana National Streambed and Land Preservation Law, and the Black Creek Demonstration Project in Indiana.

PENNSYLVANIA CLEAN STREAMS PROGRAM

Several developments in Pennsylvania revealed the need for an expanded program for erosion and sediment control. These included the erosion and sediment problems created by industrial development and urbanization; a growing interest in, and citizen support for, total watershed management programs; and the general recognition that sediment was the largest single pollutant, by volume, of water sources.

On September 21, 1972, following study by the Environmental Quality Board (EQB) and public hearings, rules and regulations for erosion and sedimentation control were adopted by the EQB pursuant to the existing Clean Streams Law. Under the regulations, all earth-moving activities, regardless of size, must have an erosion and sedimentation control plan. In addition to an erosion and sedimentation control plan, earthmoving activities greater than 25 acres must, with certain exceptions, have an erosion and sediment control permit from DER.

The Department of Environmental Resources developed an operating procedure that would utilize conservation district expertise in the program. The staffs of the Bureau of Water Quality Management, the Bureau of Soil and Water Conservation, and the Bureau of Litigation and Enforcement jointly developed this procedure.

On projects requiring departmental permits, an application for an erosion and sedimentation control permit is submitted to the conservation district along with an erosion and sediment control plan. The conservation district has 45 days during which to act upon the application. Following technical review, the conservation district board, at an official meeting, takes action to recommend to the department that a permit should either be issued or denied. This recommendation is forwarded to the department's regional office where the permitting process takes place.

Through a department policy established by the Secretary of the Department of Environmental Resources, the Bureau of Soil and Water Conservation is to provide technical support on erosion control matters to other bureaus within the Department. Inspection and enforcement activities are handled by the Office of Deputy for Protection and Regulation and Deputy for Enforcement within the Department. Included in the operating procedures is a provision that the Department may delegate portions of the enforcement program to local jurisdictions.

The resources management portion of the program has been assigned to the Bureau of Soil and Water Conservation and the 66 conservation districts. The Bureau's Division of Soil Resources and Erosion Control implements the Department's program through informational, training, administrative, and liaison activities. Districts provide information, planning assistance, plan review, and land-use monitoring assistance to the Department of Environmental Resources. Twenty-three districts have requested and have been delegated authority in the inspection portion of the program to date.

MONTANA NATIONAL STREAMBED AND LAND PRESERVATION LAW

In 1975, the Montana Legislature passed the Natural Streambed and Land Preservation Act, referred to as S.B.310. This law provides that conservation districts must review and approve all proposed projects which affect perennial streams such as channel change; new diversions; rip rap; jetties; new dams and reservoirs; commercial, industrial and residential developments; snagging; dikes; levees; debris basins; grade stabilization structures; bridges and culverts; recreation facilities; commercial agriculture; and certain farming, grazing and recreation activities. Conservation districts have the option of modifying this list to meet local needs.

When a district receives a proposed project, the Department of Fish and Game (DFG) is notified. If the DFG or the district requests it, a review team consisting of representatives of the district, DFG, and the private landowner examines the site of the proposal. If agreement is not reached, the District Court is asked to appoint an arbitration board. Technical assistance is provided by the Soil Conservation Service to all members of the team.

Under S.B. 310, the conservation districts held hearings on their proposed rules and regulations. There was substantial publicity on the new program in the newspapers, the special articles appeared in farm livestock magazines.

In 1976, the first year the law became effective, Montana districts processed some 2,000 proposals.

THE BLACK CREEK STUDY, Allen County, Indiana

The Black Creek study was undertaken in 1972 by the Allen County Soil & Water Conservation District as a result of a grant from the

Environmental Protection Agency, Region V, Chicago. Technical assistance was provided by the Soil Conservation Service and research support was provided by Purdue University, the Agricultural Research Service, and the University of Illinois.

The project demonstrated the ability of a Soil & Water Conservation District to efficiently administer an extensive program for non-point pollution control. The reliance on the local conservation district for the administration was shown to be a very important aspect of public acceptance and voluntary participation.

The Allen County Conservation District also demonstrated the ability of a district of efficiently handle cost sharing funds and to carry out long term contracts with private landowners.

Some of the major points substantiated and highlighted by the Black Creek study were that:

* The cost of achieving treatment on every acre of land to improve water quality would be extremely high. It probably would not be physically possible regardless of cost; therefore, water quality improvement must be approached by treating the critical areas first. It is therefore obvious that the critical areas must be identified for any watershed before treatment efforts begin.

* Once critical areas are identified, Best Management Practices need to be selected for treating the critical areas. Best Management Practices for the Black Creek Watershed were identified by the District Board of Supervisors with assistance from the Soil Conservation Service staff. These included: field borders, grade stabilization structures, grassed waterways, livestock exclusion, pasture planting, sediment control basins, terraces, limited channel protection, and tillage methods which increase crop residue and surface roughness.

* Farm-by-farm Conservation Plans were found to be essential in programs of water quality improvement. The plans should be simple in format and selective in approach. Obligations of participating farmers must be clearly delineated.

* A voluntary program with sufficient incentive payments and technical assistance, can achieve significant land treatment aimed at improving water quality. Regulations or the threat of regulation may be required to achieve treatment on land owned by the relatively small number of non-cooperators.

* Traditional cost-sharing programs, based on a fixed percentage payment for every practice, are not adequate to sell best management practices for water quality improvement. While an overall average might be set, local districts should have the responsibility to set the rate for individual practices within the limitations.

* Public information is critical to a successful land treatment programs. Landowners and the general public should be kept up to date

on all phases of a program from conception through planning to implementation.

A recent significant opportunity for district involvement in Best Management Practice Implementation arises out the new amendments to the Clean Water Act signed by the President on December 15, 1977. The agricultural cost-sharing section introduced by Senator Culver of Iowa authorizes $200 million in fiscal year 1979 and $400 million in fiscal year 1980 to be used for cost-share assistance for implementation of Best Management Practices in rural areas having significant nonpoint water problems identified in the 208 water quality plan.

The amendment passed the Senate and House with very little dissent. Districts are identified in the law as the local governmental agency responsible for determining (in cooperation with the Secretary of Agriculture) priority among individual landowners and operators requesting assistance to assure that the most critical water quality problems are addressed first, and for approving cooperator's plans outlining Best Management Practices to be installed on their land with cost-sharing pursuant to long-term contracts. This important legislation has specifically named conservation districts for direct involvement in carrying out the law.

The program which is being developed pursuant to this legislation will be called the Rural Clean Water Program. The Secretary of Agriculture has designated the Soil Conservation Service as the lead agency responsible for carrying out this program.

In order for landowners to be eligible for participation in the program, their land must be identified as part of the critical areas addressed in a 208 plan certified by the governor of that state and approved by EPA.

Since this program is directed at designated critical areas with significant water quality problems, it is necessary that priorities be set, and funds assigned accordingly both on a national and state basis. For this reason, not every district or county will be included in the program.

The Rural Clean Water Program provides four options to the Secretary of AGriculture through SCS for carrying out the program at the state and local levels. These include entering into agreements for administration for all or part of the program with:

1. Soil Conservation Districts, or
2. State Soil Conservation Agencies, or
3. State Water Quality Agencies, or

If none of the above, then

4. Transfer of funds from SCS to ASCS for administration of the program.

Regardless of the option selected, district officials will be jointly responsible for setting the priorities for assistance as well as be soley responsible for approving plans on which contracts for cost-sharing will be based.

Districts have been working with state and areawide agencies to develop the nonpoint source phase of 208 plans for some time now. In fact, in over half the states, the state conservation agencies are preparing the agricultural nonpoint plans under contracts from the state water quality agencies. In many other states, districts are actively assisting in the development of the agricultural nonpoint plan through cooperative agreements.

As a result of this participation, and the fact that they have the expertise and working tools to accomplish implementation, conservation districts are being identified in many plans as the management agency for implementing the agricultural nonpoint plan.

In summary, the outlook for conservation districts as a result of the 208 water quality effort is excellent. The opportunity for districts to get conservation on the land has never been greater. The changes taking place in district operations are all positive changes toward meeting modern needs, more efficient use of resources, people, and tax dollars to protect both our soil and water resources.

Quality of Black Creek Drainage Water: Additional Parameters

Darrell W. Nelson and David Beasley

The Black Creek Project was initiated to measure the effects of land use activities and crop production systems on drainage water quality from an agricultural watershed. Emphasis has been placed on measurement of sediment, N components, and P components in drainage water. However, the scale of the study permitted measurement of a number of other important water quality parameters on a weekly basis to arrive at a more complete picture of water quality in the watershed.

METHODS AND MATERIALS

Duplicate water samples were taken on a weekly basis during the period January 1, 1975 to December 31, 1977 at 19 sites within the watershed and at locations on river systems in Allen County. Samples were taken with a plastic pail and subsamples transferred to 500 ml plastic bottles. Subsamples were taken to the field laboratory where measurements of pH, turbidity, carbonate alkalinity, and bicarbonate alkalinity were performed within three hours of collection. At the time of sampling, the water temperature and dissolved oxygen concentration were measured in situ with a Yellow Springs Dissolved Oxygen Meter. All quantitative measurements were performed as outlined by the U. S. Environmental Protection Agency (1971).

Data on water quality parameters was transferred to and stored on magnetic tape. Data was stored by sampling station, sampling data, and parameter. A plotting routine was used to present the data as the water quality parameter versus time.

RESULTS AND DISCUSSION

Figures 1 through 9 are water quality data obtained from Site 2 (Smith Fry Drain at Notestine Road) during the period January 1, 1975 to December 31, 1977. The results indicate the pH was very uniform throughout the period (average about 7.3). Turbidity values reflected the relationship of the sampling time to the most recent rainfall event. Samples with high turbidity were taken during or immediately after a rainstorm, whereas those with low turbidity were taken during base flow conditions. Water temperature closely parallelled the air temperature seasonal variation. Water temperatures between 24 and 28 degrees centigrade were commonly measured during the summer months. Dissolved oxygen concentrations normal,y varied between 4 and 9 mg/l, however, high values (>10 mg/l) were observed consistently during the spring of 1977. Essentially no carbonate alkalinity was present in water samples collected from Site 2. Bicarbonate alkalinity normally was 200-300 mg/l. However, values as high as 900 mg/l were measured during October, 1975.

Figures 10 through 18 are water quality data from Site 6 (Black Creek at Bush College Road) during the three-year sampling period.

Turbidity and pH data are similar to those for Site 2. However, turbidity values were more consistent than those for Site 2. It is interesting that the pH values were almost identical to those for samples taken from Site 2 (average of 7.2). Temperature and dissolved oxygen data are very similar to those from Site 6. At no time did the dissolved oxygen concentration fall below 2.5 mg/l and was generally between 5 and 10 mg/l. Water temperatures as high as 31.5 degrees centigrade were observed during the summer of 1975. Alkalinity concentrations in water samples were almost identical to those in samples from Site 2. A peak in bicarbonate alkalinity was observed in October, 1975, however, the maximum obtained was 900 mg/l. Alkalinity values normally ranged between 200 and 400 mg/l.

Figures 19 through 27 provide water quality data from Site 14 (Maumee River at State Highway 101 bridge) during the period January 1, 1975 to December 31, 1977. Water pH values were similar to those observed at Sites 2 and 6 (i.e., 7.2 to 7.4), however, a low pH (<5.0) was measured during early March, 1976. The low pH was likely the result of industrial discharges because at no time during the study were low pH values observed in drainage water from agricultural land. Turbidity in the Maumee River was more consistent with time than in drainage water measured at Sites 2 and 6. However, the turbidity values reflected the time period between the last major runoff event and the sample collection. Dissolved oxygen content of the Maumee River was normally in the range of 3 to 5 during the summer, however, values as low as 2 were obtained on two occasions. Water temperature parallelled air temperature changes with season. Peak water temperatures of 27-28 degrees centigrade were observed during summer months in 1975 and 1977. Bicarbonate and total alkalinity values were normally between 200 and 300 mg/l, however, high alkalinity (900 mg/l) were measured during October, 1975.

The water quality parameters measured in Black Creek drainage water and the Maumee River suggest that reasonable water quality is present during much of the year. High temperatures and relatively low dissolved oxygen concentrations obtained in summer months may limit development of a cold water fishery. However, at no time did the dissolved oxygen content dip below 2.5 mg/l in agricultural drainage water. The water quality in the agricultural watershed was at least as good as, and often better, then that in the Maumee River in terms of suitability for biota. The portion of the agricultural watershed impacted by septic tank discharges (Site 6) had water quality which was not greatly different from that of a purely agricultural part of the watershed (Site 2) when pH, alkalinity, dissolved oxygen, and temperature are the criteria.

ALGAL AVAILABILITY OF SOLUBLE AND SEDIMENT PHOSPHORUS IN DRAINAGE WATER OF THE BLACK CREEK WATERSHED*

by

R. A. Dorich and D. W. Nelson**

Phosphorus (P) has been shown to be the nutrient most limiting algal growth in surface waters of the Great Lakes Region of the United States. Furthermore, addition of P to many bodies of water in this region induces accelerated growth of aquatic organisms and ultimately results in an algal bloom and nuisance weed accumulation. Following the death of these photosynthetic organisms, degradation of the cells by aerobic bacteria leads to rapid depletion of dissolved oxygen in a portion or all of the water column in the lake and numerous water quality problems result. Development of anaerobic conditions in a lake system is a key characteristic of an advanced state of eutrophication.

The death of photosynthetic organisms and subsequent aerobic breakdown of dead biomass was the major cause of oxygen depletion in over 6600 square kilometers of the hypolimnion of the central basin of Lake Erie in 1970. The excessive algal growth in Lake Erie was assumed to result from high P loadings to the lake from municipalities, industries, and nonpoint sources. Therefore, P input into Lake Erie has received considerable attention in recent years. Although point source discharges were identified as major contributors of pollutants to Lake Erie, agricultural activities in the Maumee River Basin were suggested as a major contributor of sediment and related pollutants to Lake Erie. In response, a cooperative project involving the Allen County (Indiana) Soil and Water Conservation District, the Soil Conservation Service and Purdue University was initiated (funded by a U.S. Environmental Protection Agency Demonstration Grant) to assess the role of agriculture in pollution of the Maumee River and to evaluate management alternatives in crop production to minimize impacts on water quality.

The Black Creek Drainage Basin, Allen County, Indiana was used as a test watershed for the project because it is typical of small subwatersheds along the Maumee River. Chemical measurements of P loading can be used to indicate the quantities of P transported from soil to water systems. However, the majority of P deposited in waters is sediment bound. In order to effectively quantitate the impact of P input on the water quality of the Maumee River (and ultimately to Lake Erie), the proportion of total P transported which is available to algae must be determined. Therefore, the objectives of this study were: (i) to determine the quantities and proportions of soluble and sediment-bound P which were available to algae and (ii) to determine the availability of sediment-bound P fractions to algae.

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MATERIALS AND METHODS

PAAP Bottle Test for the Algal Availability of Soluble Phosphorus

Four-liter water samples were obtained following rainfall events on March 28 and June 30, 1977 from seven sites (Figure 1) within the Black Creek Watershed, Allen County, Indiana. Following centrifugation to separate the sediment from the water, water samples were filtered through a 0.45 micrometer mean-pore diameter Millipore filter. The method used in determining the quantity of soluble inorganic phosphorus (SIP) available to algae was a modification of the Provisional Algal Assay Procedure Bottle Test (PAAP) (USEPA, 1971). The PAAP method is based on Liebig's Law of the Minimum, i.e., "growth is limited by the substance that is in minimal quantity in respect to the needs of the organism." When all the growth requirements of an organism are met with the exception of one nutrient, the organisms potential for growth is controlled by the limiting nutrient. Therefore, the effect of a nutrient's concentration can be assessed by supplying a nutrient in varying concentrations to an organism given all other growth requirements and evaluating the growth response of the organism. The quantity of available P in the Black Creek Water sample was calculated by comparing the population of a selected alga (*Selanastrum capricornutum*), grown for 4 days in a water sample to a standard curve (algal population plotted against the concentration of soluble P) generated by growth of *S. capricornutum* in PAAP nutrient medium containing known levels of P (ranging from 0.0 to 0.20 microgram P/l). Furthermore, by adding a specific nutrient directly to water samples (a nutrient spike) under study and quantifying the growth response of *S. capricornutum*, a comparison to the assay organism's growth in water samples spiked with a nutrient over that of the organism grown in the unamended water sample indicates that the specific nutrient was deficient in the sample in respect to the needs of the organism. To determine the nutrient limiting algal growth in water samples, phosphorus (0.1 mg P/l) and micronutrients (complete range used in PAAP medium) were added to separate aliquots of all samples and the effect of the added nutrients on the growth of *S. capricornutum* determined.

Algal Availability of Sediment-Bound Phosphorus

Sediment collected by centrifugation of each water sample was resuspended in deionized water, diluted to 50 ml to create a sediment suspension concentrate, and sterilized by exposure to 4 megarads of gamma radiation. Aliquots of the sterilized sediment suspension concentrates were used to prepare the sediment-algal cell mixtures for incubation. An attempt was made to add a constant quantity (37.2 microgram of total P per flask) of sediment-bound P to 250 ml flasks containing 60 ml of PAAP minus P medium. After a two week incubation at 26 +- 1 degrees C and 4300 lux (flourescent light), the entire contents of each flask were analyzed for P components.

The method used to determine the quantity and fraction (ammonium flouride, NaOH, or HCl-extractable) of sediment-bound P available to

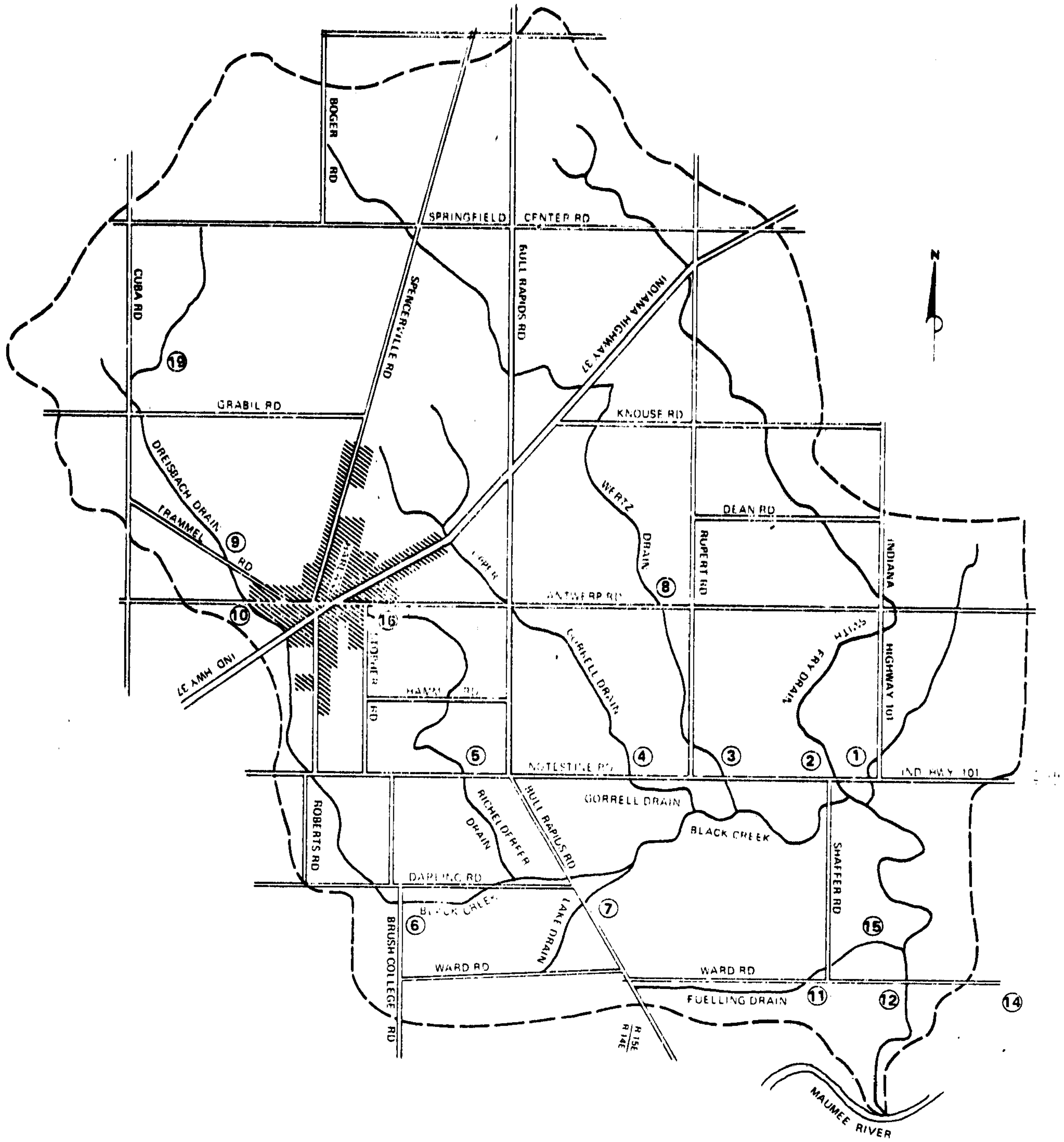

Figure 1. Water sampling sites within the Black Creek Watershed, Allen County, Indiana.

algae was a modification of a method developed by Sagher and Harris (1975). The Sagher and Harris method consists basically of a two-part test system: (i) a sediment-algal incubation (in PAAP minus P medium) to assess the quantity of available sediment P by following changes over a 4-week period in the amounts sediment P sequentially extracted with ammonium flouride (0.5 N, pH 7), NaOH (1N) HCl (0.5M) and (ii) a sediment-free algal incubation in PAAP medium (containing 0.2 mg P/l which corresponds to partial availability of sediment P in sediment-algal incubations) to asses the extractability of algal P by the same sequential ammonium flouride, NaOH and HCl procedure. Because part of the phosphorus extracted from the sediment-algal mixture originated from algal cells, the results of extractions of the sediment-free incubation were used to correct values obtained from the extraction of the sediment-algal incubations.

RESULTS AND DISCUSSION

Algal Availability of Soluble Phosphorus

Selanastrum capricornutum exhibited a typical sigmoid growth rate at medium and high levels of P (0.05, 0.075, 0.1, and 0.2 mg P/l) in the growth medium. Figure 2 illustrates the growth rate of S. capricornutum in medium containing 0.1 mg P/l. At the 0.015 mg/l concentration of P, the algal growth rate curve overall was flatter and the portion normally labelled as "logrithmic" was less steep than those of higher P levels. The stationary phase of growth was initiated after 96 hours of incubation for all treatments, but occurred at lower cell densities for each decrease in P concentration.

Figure 3 shows the relationship between cell density after 96 hours and initial P concentration of the PAAP medium. The cell density remained relatively constant at P concentrations greater than 0.1 mg/l. A similar growth response has been observed by other investigators who have shown maximum algal growth at a P concentration of 0.075 mg/l (Fitzgerald and Uttormark, 1974). This level (0.1 mg/l) represents the P concentration at which cells were apparently fulfilled in their need for P for the rate at which they were growing in these incubations. This leveling of algal growth at P concentration above 0.1 mg/l may be looked upon in this experimental system as the critical level of P or that level of available P at which nearly maximum cell production takes place. Furthermore, data observed throughout this study indicates that S. capricornutum did not respond when incubated for four days in PAAP medium containing 0.005 mg P/l. The lack of response at the P level of 0.005 mg/l and positive response at 0.015 mg/l suggests that the lower threshold of sensitivity of the alga for P lies between 0.005 and 0.015 P/l.

Table 1 provides data on the amounts of available P in water samples determined by the algal bioassay procedure (Figure 3) in unamended and spiked water samples. The available P levels in the March and June samples averaged 0.096 (range was 0.076 to 0.128 mg/l) and 0.031 mg/l (range was 0.012 to 0.052 mg/l), respectively. The available P as

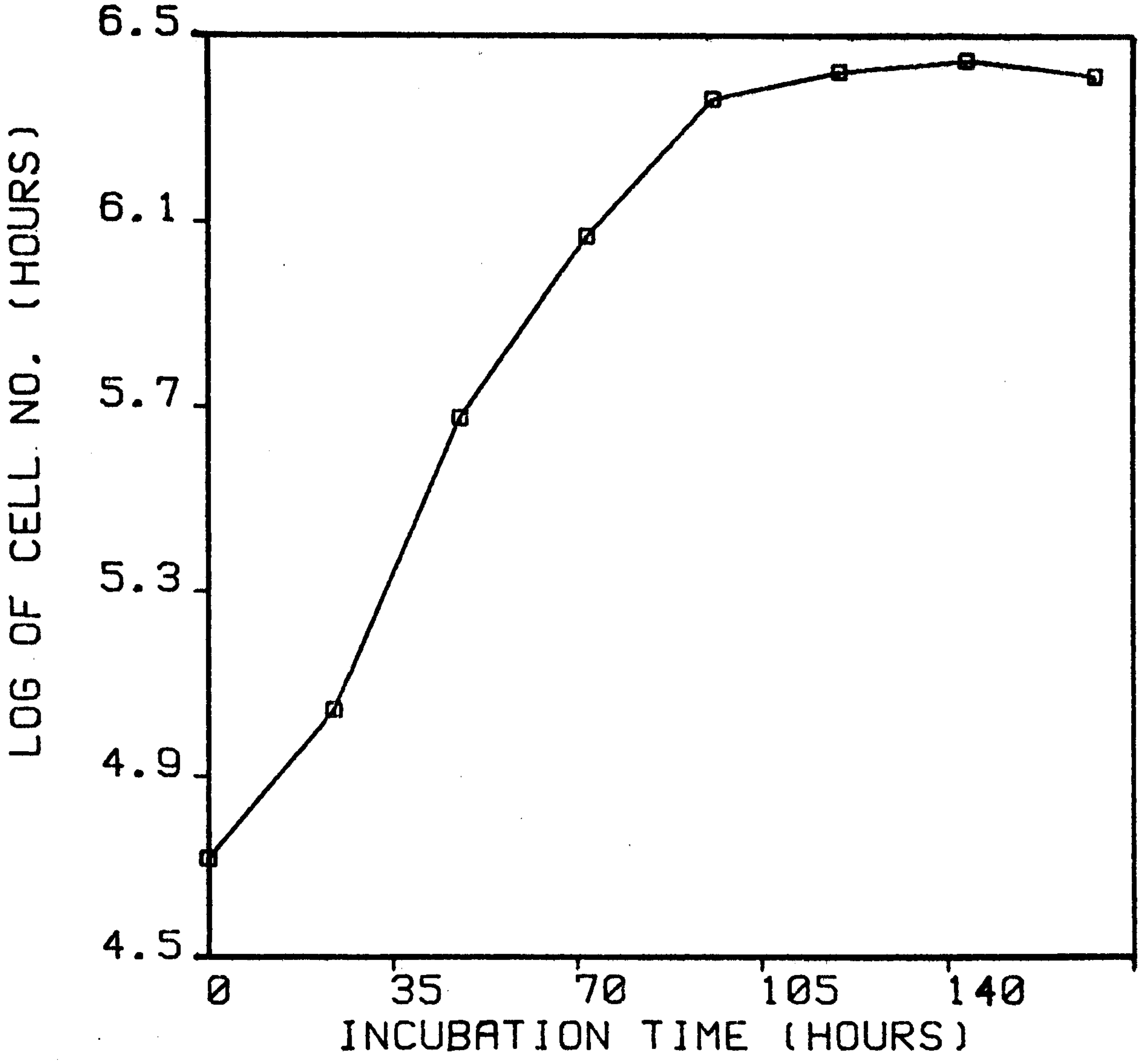

Figure 2. Growth curve of S. capricornutum in PAAP medium (0.1 mg P/l).

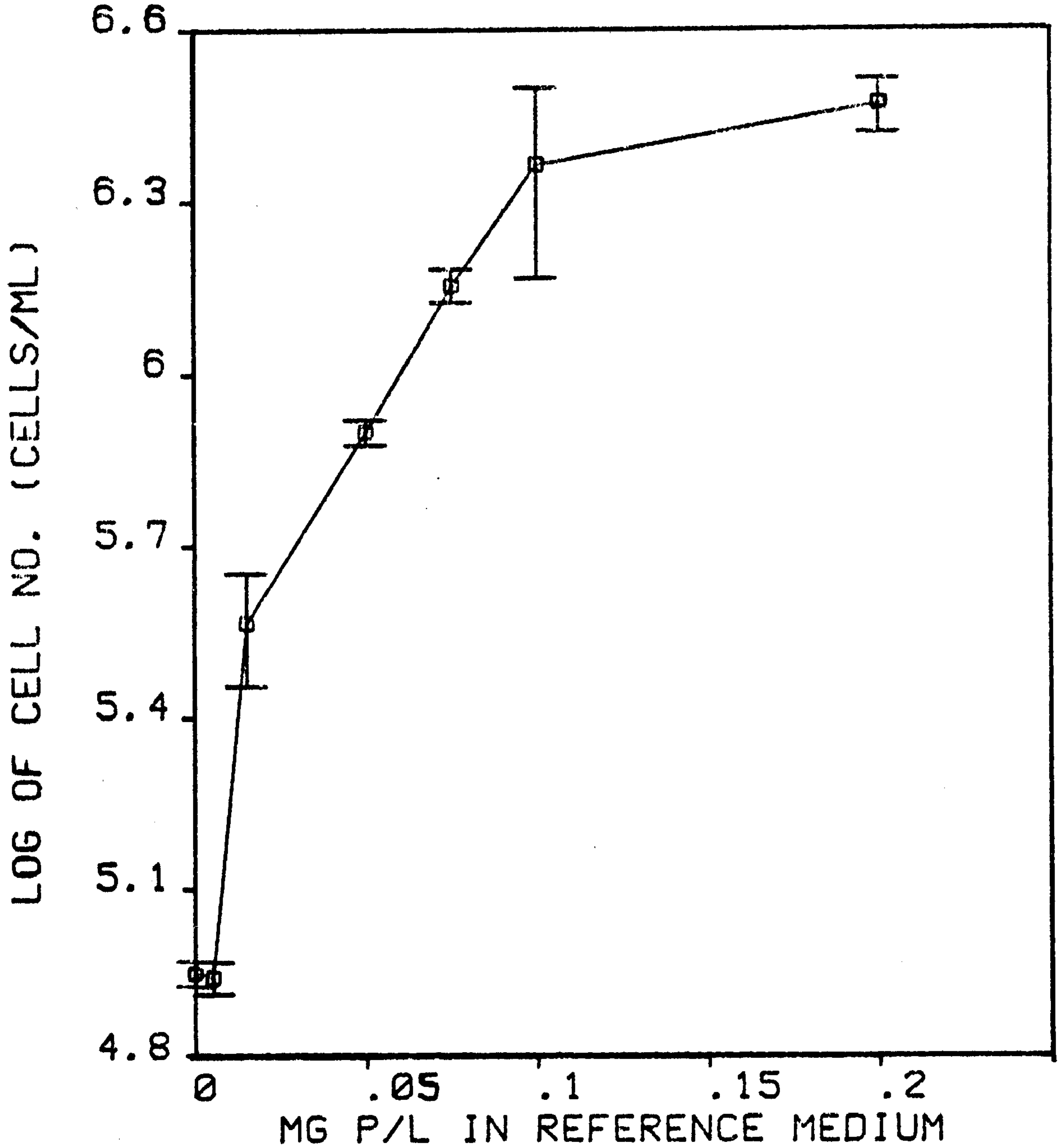

Figure 3. The effect of initial phosphorus concentration on cell numbers of after a four day incubation in PAAP medium. Bars represent the sandard deviation of the mean.

quantitated by bioassay never exceeded the soluble inorganic P (SIP) or total soluble P levels in unamended water samples obtained in March and June. Fitzgerald and Uttormark (1974) found that creek water often contains P compounds which are included in chemical determinations as soluble phosphorus, but which are not biologically available.

TABLE 1
Availability to algae of soluble phosphorus in stream water as affected by initial phosphorus centrations, and phosphorus and micronutrients amendments.

Site no.	Initial P concentration in water SIP	TSP	Available P in water as determined from cell count of bioassay of:* U**	P	MN
March					
2	0.106	0.123	0.080 a	0.084 a	0.097 a
3	0.121	0.150	0.076 a	0.032 b	0.100 a
4	0.121	0.139	0.109 a	0.108 a	1.107 a
5	0.171	0.173	0.128 a	0.105 a	0.106 a
6	0.250	0.443	0.110 a	0.068 a	0.105 a
12	0.135	0.153	0.086 a	0.063 a	0.110 a
14	0.131	0.148	0.083 a	0.095 a	0.128 b
Ave.	0.149	0.190	0.096 a	0.079 a	0.107 a
June					
2	0.069	0.100	0.030 a	0.016 a	0.036 a
3	0.038	0.063	0.015 a	0.031 b	0.015 a
4	0.045	0.075	0.027 a	0.038 a	0.039 a
5	0.053	0.072	0.035 a	0.120 a	0.043 a
6	0.072	0.091	0.045 a	0.094 b	0.039 a
12	0.047	0.171	0.012 a	0.015 a	0.016 a
14	0.161	0.190	0.052 a	0.042 a	0.265 b
Ave.	0.069	0.109	0.031 a	0.051 a	0.064 a

* U, unamended water samples; P, water samples spiked with 0.1 mg P/l; MN, water sample spiked with micronutrients

**Numbers in a row followed by the same letter are not statistically different (at the 95% level of significance).

On the average, P addition did not affect the amounts of algal available P present in the March of June samples. One sample (Site 3) taken in March exhibited a decrease in available P as a result of P addition. Hutchinson (1957) previously has shown inhibition in algal growth upon amendment of water samples with P. In contrast, two P-amended June samples (Sites 3 and 6) contained higher amounts of available P as compared to the unamended samples indicating that growth of S. capricornutum in these samples was limited to an extent by low available P concentrations. In one sample (Site 6), the amount of available P found after P addition was nearly equal to the 0.1 mg/l critical level suggesting that P was the major factor limiting growth. The addition of P to June samples from Site 3 resulted in slightly increased P availability; however, the response was much less than that expected if growth was only limited by low P concentration.

On the average, addition of micronutrients to the growth medium did not affect the ability of algae to utilize P in water samples. However, in two of the fourteen samples a significant increase in apparent available P was observed as a result of micronutrient addition. These results were obtained in both the March and June samples of Site 14 (Maumee River) which suggests that micronutrient deficiencies were limiting the growth of S. capricornutum in these samples and addition of the micronutrients enabled the algal cells to better utilize the P which was present. The finding that micronutrient (B, Mn, Zn, Co, Cu, Mo, or Fe) deficiencies may limit that growth of algae in stream waters in supported by Scherfig et al., (1973) who observed limitation of algal growth by low concentrations of iron in similar incubation systems, and by Fitzgerald and Uttormark (1974) who reported that low iron concentrations commonly limit algal growth in surface waters. In addition, other investigators have not been able to detect soluble iron in Black Creek water samples taken during the period from 1974 through 1977 (unpublished data, D. W. Nelson).

Samples taken in March and June from the rural portion of the watershed (the area only affected by agricultural activities) contained lower quantities of available soluble P than did samples from the rural-urban portion (the area affected by agricultural activities as well as septic tanks). Furthermore, for the June period a higher proportion of SIP present in samples from the rural-urban area was available to algae as compared to that present in samples from strictly agricultural areas. However, the proportion of SIP present in Maumee River samples was higher than that in any samples collected within the Black Creek Watershed.

Availability of Sediment-Bound Phosphorus to Algae

Table 2 summarizes the concentration of suspended solids and P components initially present in the sediment used for bioassay. Although the amount of soluble (desorbed) inorganic P was significant initially (2-4 micrograms P/flask). Variations in total sediment P recovered initially for each treatment (Table 2) may result from the method used to add the sediment slurry to the incubation flask. The type of suspended material and the difficulty in maintaining homogeneity during the removal of aliquots from the sediment solution concentrate may be additional sources of error. Table 3 provides data on the final cell densities and the proportions of total sediment P immobilized by algal cells from each sample during a two-week incubation in PAAP minus P medium. On the average, the proportion of sediment P which was available for algal assimilation was similar in March and June samples. In March samples, the proportion of total sediment P which was algal available ranged from 9.8 to 29.0% (average 20%), whereas the range in June samples was 15.9 to 30.8% (average 21.4%). These proportions are slightly higher than results reported by Wildung and Schmidt (1973) using lake sediments in a dialysis assay system. There were no apparent relationships between algal cell densities and the proportion of total sediment P assimilated by algae.

TABLE 2
Forms and amounts of phosphorus present initially in sediment bioassay samples.

Site no.	Sampling date	Suspended solids	Total P	Sediment inorganic P		Sediment organic P		Soluble P	
			PAAP-P Medium						
2	March	98	27.31	12.96	47.4	11.86	41.2	2.49	9.1
3	March	119	27.78	13.57	48.8	11.77	42.4	2.44	8.8
4	March	339	29.20	17.47	59.8	9.20	31.5	2.44	8.3
5	March	29	31.33	19.66	62.7	7.89	25.5	2.04	6.5
6	March	25	27.33	15.74	57.6	7.01	25.6	4.58	16.7
12	March	28	28.50	15.26	53.5	10.10	35.4	3.15	11.0
14	March	20	30.31	16.11	52.3	11.06	35.9	3.64	11.8
Ave.	—	94	28.89	15.82	54.7	9.77	33.8	2.97	10.3
2	June	26	30.65	15.07	49.2	11.45	37.3	4.13	13.5
3	June	42	29.00	15.62	53.9	9.44	32.9	3.83	13.2
4	June	36	23.36	13.59	58.2	7.95	34.0	1.82	7.8
5	June	37	26.25	12.00	45.7	11.38	43.4	2.87	10.9
6	June	60	29.11	21.73	74.6	4.92	16.9	2.45	8.4
12	June	50	34.41	19.85	57.7	12.05	35.0	2.51	7.3
14	June	27	27.97	15.61	57.9	7.05	26.1	5.31	19.7
Ave.	—	40	28.53	16.21	56.8	9.19	32.2	3.27	11.5

The proportion of sediment inorganic P immobilized by algae cells and cell numbers observed after a two week incubation period are presented in Table 4. A higher percentage of sediment inorganic P was available to algae in June samples than in March samples (33.0 as compared to 27.0%, respectively). However, for three of the five sampling sites studies, no difference in availability of sediment inorganic P were observed when comparing March samples to June samples. Two June samples (Site 4 and 6) show increases (19 and 7%, respectively) in the percentage of sediment inorganic P which was immobilized into algal cells as compared to results from the March samples. The large increases in inorganic P available in samples from these sites resulted in the average increase when all sites were considered. The average proportions of sediment inorganic P which were available are lower than the 53 to 83% values reported by Sagher and Harris (1975) for lake sediments.

The highest proportion (averaging 37.7 and 46.2% for March and June samples, respectively) of available sediment inorganic P was phosphate sorbed an amorphous Al and Fe oxide complexes (extractable with 0.5 N ammonium flouride, pH 7). In addition, a significant percentage (averaging 56.2 and 62.3% for March and June samples, respectively) of

TABLE 3
Population of S. capricorntum and Proportion of Total Sediment Phosphorus Immoblized by Cells Growing for Two Weeks in Sediment: PAAP Systems.

	Sampling time			
	March		June	
Site no.	Cell density	Algal available P	Cell density	Algal available P
2	8.529	29.0	5.175	15.2
3	9.599	15.0	8.551	18.0
4	4.242	9.8	5.954	21.5
5	5.225	24.7	5.000	15.9
6	6.500	21.3	6.591	30.8
12	---	---	5.900	20.4
14	---	---	8.408	28.2
Ave.	6.819	20.0	6.511	21.4

TABLE 4
Population of S. capricornutum and proportions of sediment inorganic phosphorus immobilized by cells growing for two weeks in sediment: PAAP systems.

	Sampling time			
	March		June	
Site no.	Cell density	Available P	Cell density	Available P
2	8.520	26.7	5.175	26.7
3	9.599	27.9	8.551	29.0
4	4.242	15.0	5.954	34.1
5	5.225	34.8	5.000	31.1
6	6.500	30.7	6.591	37.7
12	---	---	5.900	32.7
14	---	---	8.408	40.9
Ave.	6.819	27.0	6.511	33.1

the ammonium flouride extractable fraction of sediment inorganic P was assimilated by algal cells. Significant proportions (averaging 33.1 and 40.8% for March and June samples, respectively) of the available sediment inorganic P were present as iron complexed phosphate extractable with N NaOH. Furthermore, during the two week incubation, a substantial percentage (averaging 23.6 and 30.0% for March and June samples, respectively) of the NaOH-extractable P was immobilized into algal cells. A higher proportion of sediment inorganic P was available to algae in samples taken in March and June from the rural-urban portion of the watershed (32.7 and 34.4%, respectively). The highest proportion of sediment inorganic P which was assimilated by algae was observed in the Maumee River sample collected in June.

IMPLICATIONS

The Black Creek project was in part initiated to evaluate the impacts of agricultural drainage on water quality in the Maumee River and Lake Erie. Therefore, an assessment is required as to the relative impact of soluble and sediment-bound P in drainage water upon the potential for water entering Lake Erie to support algal growth. Numerous assumptions are required to calculate the input of algal available P into the western basin of Lake Erie from the Maumee River watershed. These assumptions are listed in Table 5.

TABLE 5
Information used in calculating algal available P discharge into Lake Erie from the Maumee River.

Parameter	Value	Citation
Sediment loads of Maumee River	495 kg/ha	Monke et al. (1975)
Water discharge from Maumee River watershed to Lake Erie	23 cm/yr	Monke et al. (1975)
Maumee River Watershed area	1,711,500 ha	Monke et al. (1975)
SIP concentration in Maumee River water	0.076 mg P/l	Sommers et al. (1975)
Total P concentration suspended sediment	1990 mg/kg	Sommers et al. (1975)
Volume of water in western basin of Lake Erie	70 cubic km	Blanton and Winklhofer (1972)

As indicated by the information in Table 5, the total amounts of sediment and sediment-bound P discharged to Lake Erie by the Maumee River average 847,000 and 1,685 metric tons per year, respectively. Assuming 20% of the total sediment P is ultimately available to algae (as found in this study), approximately 337 metric tons of available P will be discharged with sediment loads each year into Lake Erie.

Approximately 3.94 times ten to the twelfth liters of water containing 299 metric tons of SIP are discharged into Lake Erie each year from the Maumee River. The SIP discharge value is based upon a SIP concentration of 0.076 mg/l, the average level measured in numerous water samples collected at Site 14 (Figure 1). It is possible that the SIP concentration in the Maumee River watershed entering Lake Erie is lower than that measured at Fort Wayne, Indiana. However, no information was available to adjust the SIP concentrations used in the calculations. Assuming that 50% of the SIP is available to algae (as was found in this study), about 150 metric tons of available SIP are discharged to Lake Erie annually.

Considering both soluble and sediment-bound P forms, approximately 487 metric tons of algal available P are discharged into Lake Erie each year. These calculations suggest that sediment-bound and soluble P provide 69.2 and 30.8% of the P available to algae in Maumee River discharge, respectively. It is unlikely that the concentration of SIP in agricultural drainage water can be reduced below 0.06 mg/l, therefore control of soil erosion (sediment input into streams) is essential to lower amounts of algal available P discharged into surface waters of midwestern United States.

The above approximations of P inputs into Lake Erie from the Maumee River can be used to estimate the impact of the Maumee River on the concentrations of soluble, sediment-bound, and available P in the western basin of Lake Erie. The estimate made herein also uses the following assumptions: (i) The phosphorus inputs (both soluble and sediment) from the Maumee River becomes uniformly distributed throughout the volume of the western basin of Lake Erie, (ii) The volume of the western basin of Lake Erie is 70 cubic km (Blanton and Winklhofer, 1972) and (iii) All P entering Lake Erie is retained during the year. Under these conditions, the estimated increases in concentrations of SIP, available SIP, sediment P, and available sediment P in the western basin of Lake Erie after 1 year would be 3.9, 2.0, 26.2, and 5.2 micrograms/l, respectively. These increases in available P concentrations may result in significant increases in algal growth when initial available P levels in water are 25 micrograms/l or less. At high initial P concentrations, algal growth would be influenced to a limited extent by these increases in available P. Furthermore, not all of the added available P will be utilized by aquatic plants because the water in Lake Erie has a short residence time with the annual flow through the Lake being equal to 1/3 of the Lake volume.

CONCLUSIONS

The following conclusions may be drawn from data obtained during this study:

(1) Not all of the soluble P in water samples was available to algae. The level of soluble P available to algae never equalled the SIP or total soluble P concentration in any of the 14 samples collected from the Black Creek Watershed or the Maumee River. In samples containing less than 0.1 mg SIP/l, only about 50% of the soluble P in water samples was available for algal uptake.

(2) A deficiency of one or more micronutrients limited algal growth in water samples collected from the Maumee River. If this

deficiency persists throughout the length of the Maumee River, algal growth rates in the western portion of Lake Erie may be lower than predicted by P loading data.

(3) Sediment in agricultural drainage water contained substantial concentrations of algal available P. Excellent algal growth was observed in media with sediment as the only source of P. However, maximal algal growth rates (as compared to PAAP) were not achieved in PAAP minus P media containing sediment. On the average, 20% of the total sediment P and 30% of sediment inorganic P were available for algal uptake.

(4) Phosphate loosely sorbed on amorphous Al and Fe oxide complexes supplied the highest proportion of P assimilated by algae. A higher proportion of the quantity of the P originally present in the amorphous Al and Fe oxide complex was taken up by algae than in the other fractions investigated. The quantity of P loosely sorbed on amorphous Al and Fe oxide complexes is most important in determining the overall availability of sediment P to algae.

(5) Intensive crop production systems did not lead to increased availability of soluble and sediment-bound P in drainage water when compared to Maumee River water. Higher availability of P to algae was measured in water samples collected from the Maumee River and portions of the watershed influenced by septic tanks as compared to samples collected from agricultural portions of the watershed.

(6) A greater quantity of algal available P is discharged annually to Lake Erie as sediment-bound P than is discharged as soluble P. This finding suggests that erosion control measures in the watershed which would lead to reduced sediment discharge in Lake Erie may result in decreased algal growth in the western basin.

LITERATURE CITED

Blanton, J. O. and Winklhofer. 1972. Physical Processes Affecting the Hypolimnion of the Central Basin of Lake Erie, 1929-1970. In Project HYPO: An Intensive Study of the Lake Erie Central Basin Hypolimnion and Related Surface Water Phenomena. Canada Centre for Inland Waters (also Paper No. 6) and United States Environmental Protection Agency (also Technical Report TS-05-71-208-24), p.141.

Fitzgerald, G. P. and P. D. Uttormark. 1974. Applications of Growth and Sorption Algal Assays. Office of Research and Development, United States Environmental Protection Agency. (Also EPA 660/3-73-023).

Hutchinson, G. E. 1957. A Treatise on Limnology, Vol. I. Geography, Physics and Chemistry. John Wiley & Sons, Inc. N.Y., p. 1015.

Monke, E. J., D. B. Beasely, and A. B. Bottcher. 1975. Sediment Contributions to the Maumee River. In Non-Point Source Population Seminar (Progress Report). United States Environmental Protection

Agency. (Also EPA-90. 5/9-75-007). Office of Great Lakes Coordinator, p.72.

Sagher, A. and R. Harris. 1975. Availability of Sediment Phosphorus to Microorganisms. Water Resource Center (also Technical Report WIS WRC 75-01), Madison, Wis.

Scherfig, J., P. S. Dixon, R. Appleman, C. A. Justice. 1973. Effects of Phosphorus Removal Processes on Algal Growth. Office of Research and Monitoring. United States Environmental Protection Agency. (Also EPA-660/3-73-015).

Sommers, L. E. and D. W. Nelson. 1972. Determination of Total Phosphorus in Soils: A Rapid Perchloric Acid Digestion Procedure. Soil. Sci. Soc. Amer. Proc. 36: 902-904.

United States Environmental Protection Agency. 1971 In A. F. Bartsch Algal Assay Procedure Bottle Test. Washington, D. C. Eutrophication Research Program.

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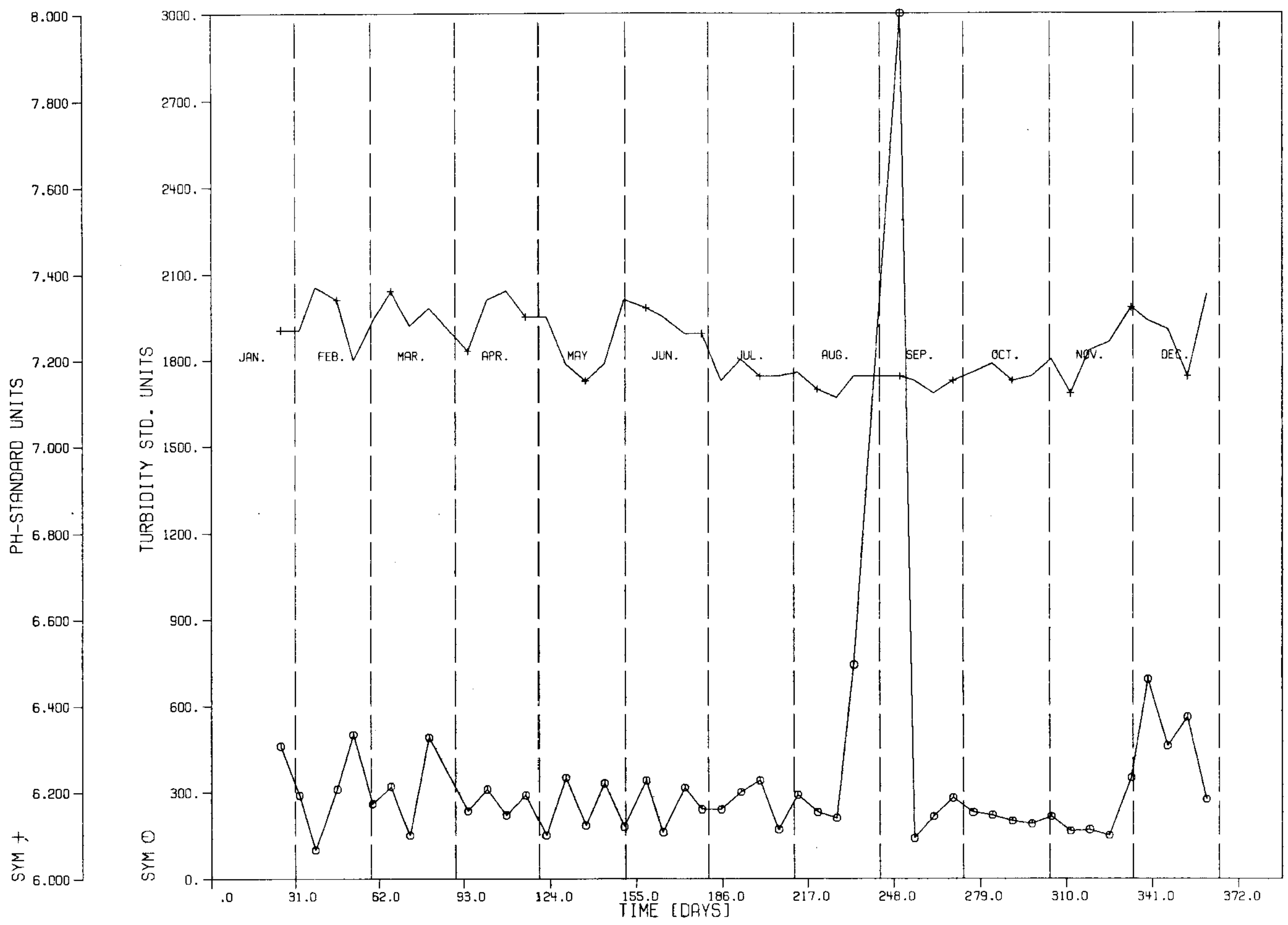

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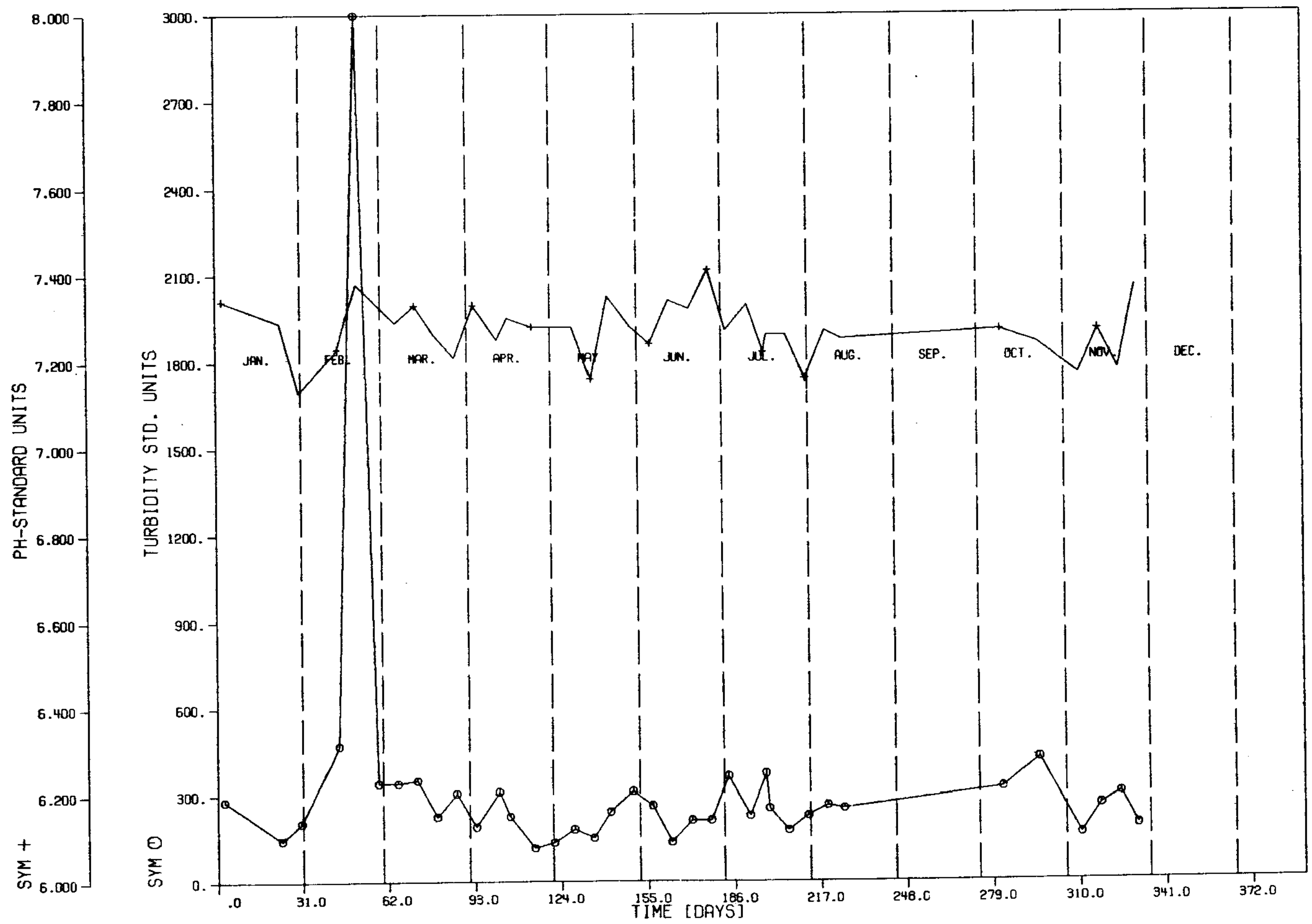

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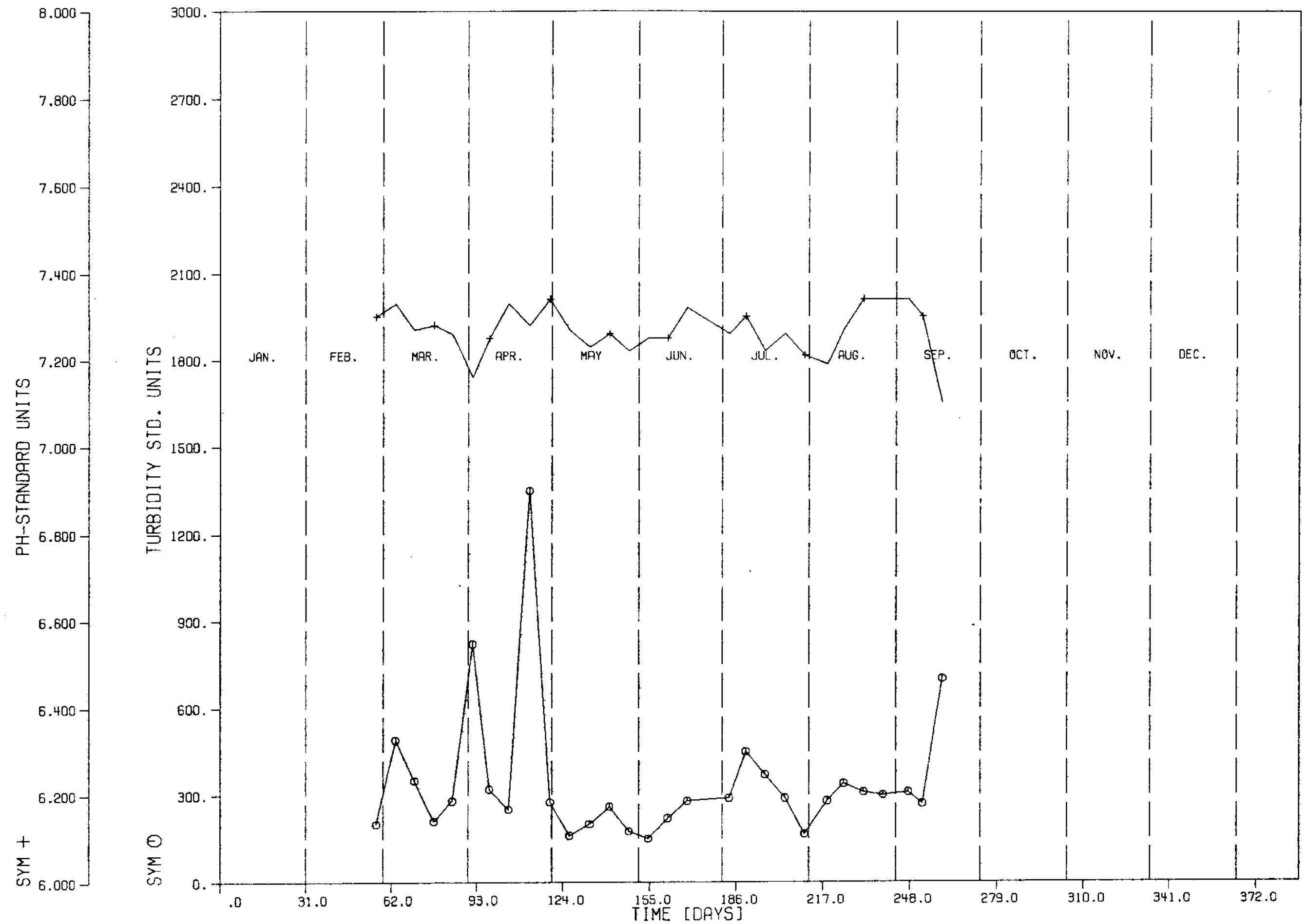

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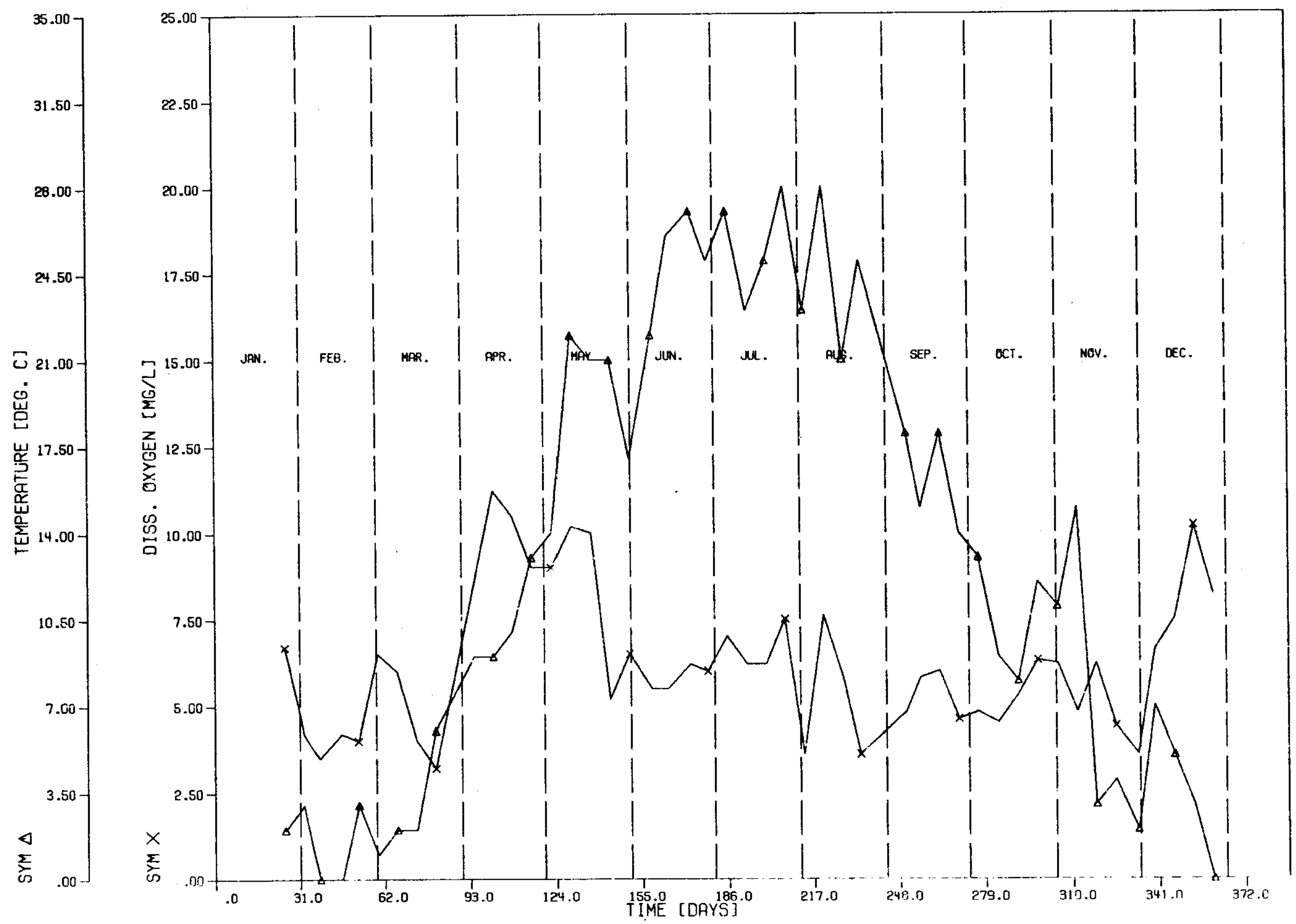

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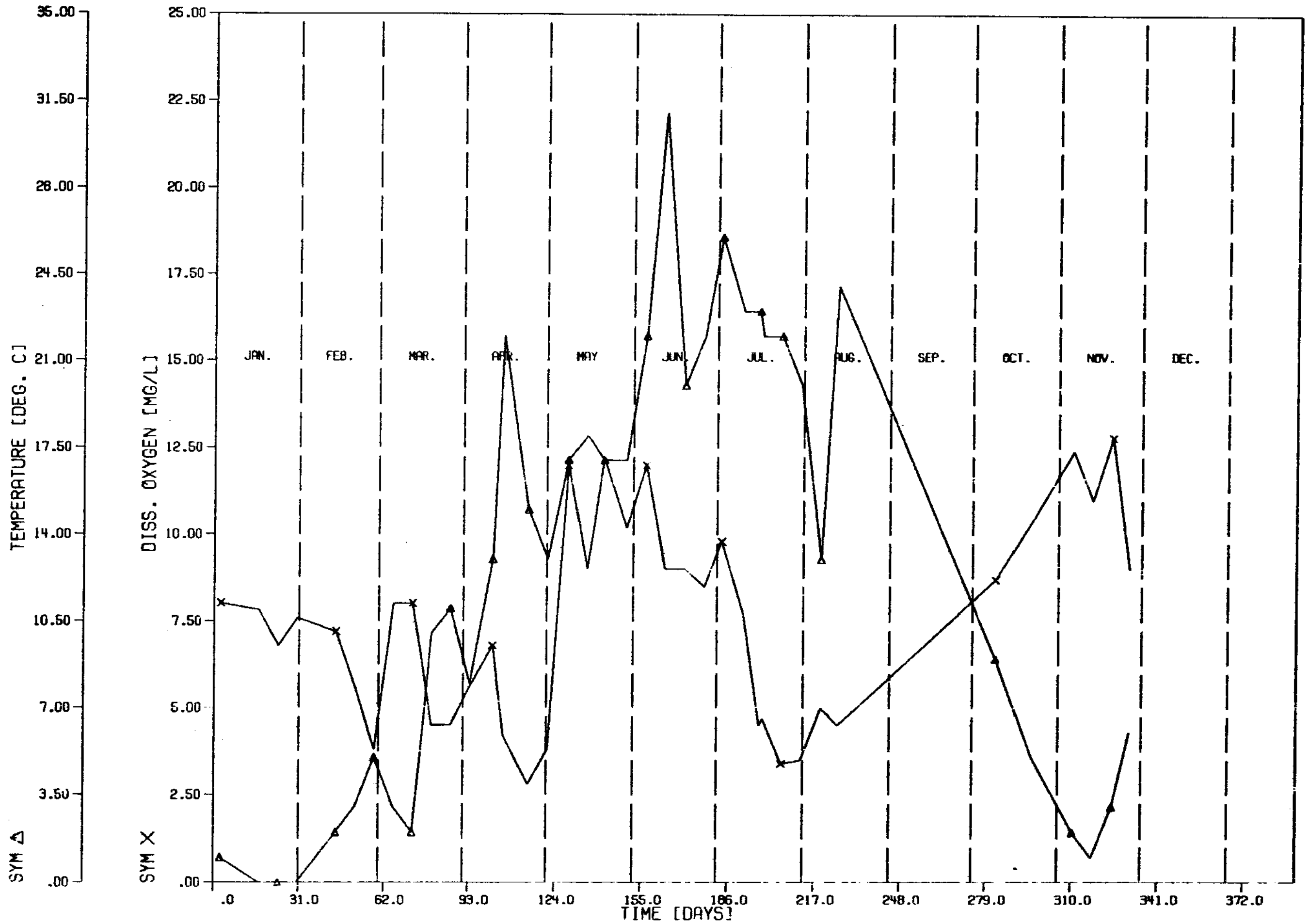

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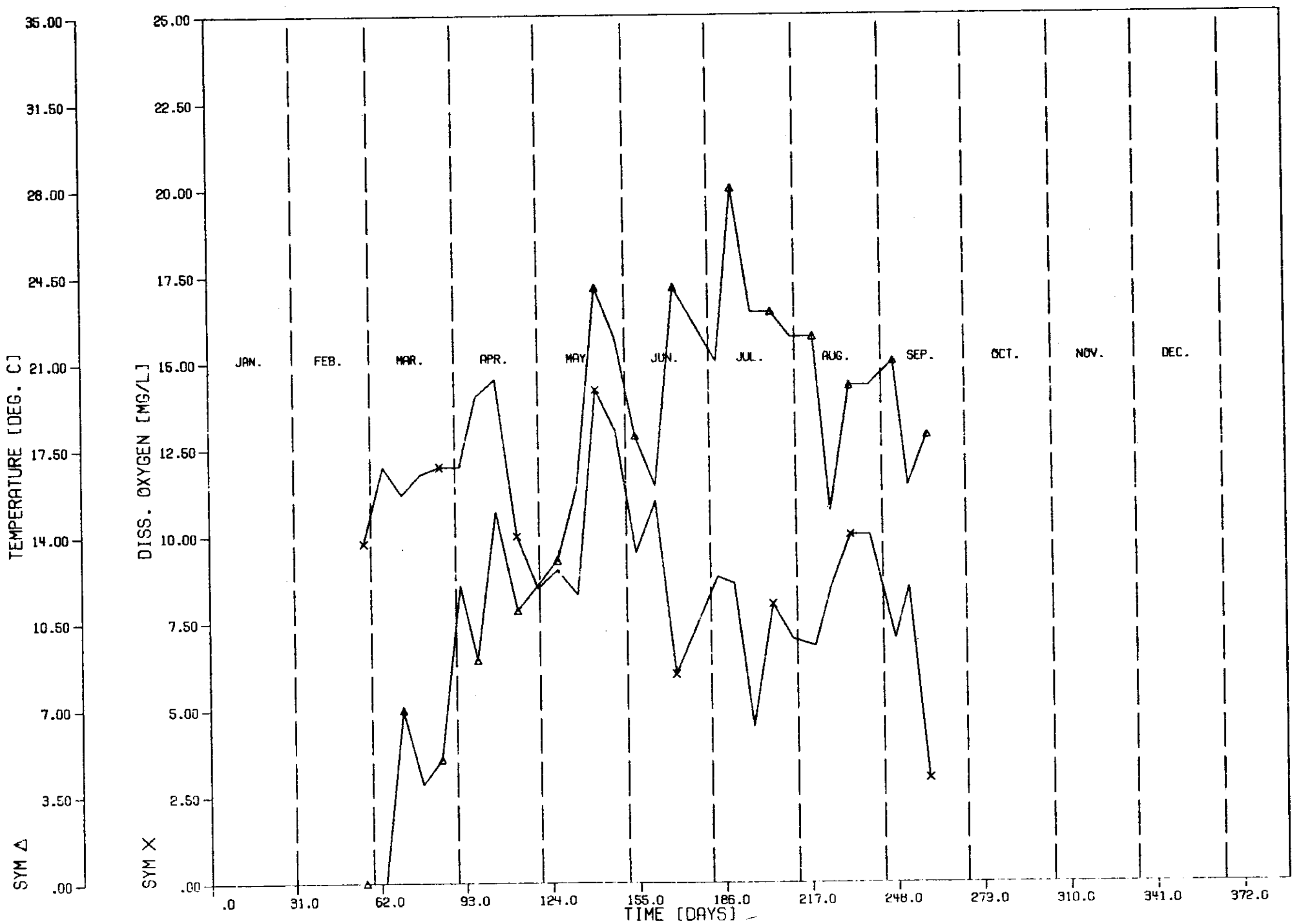

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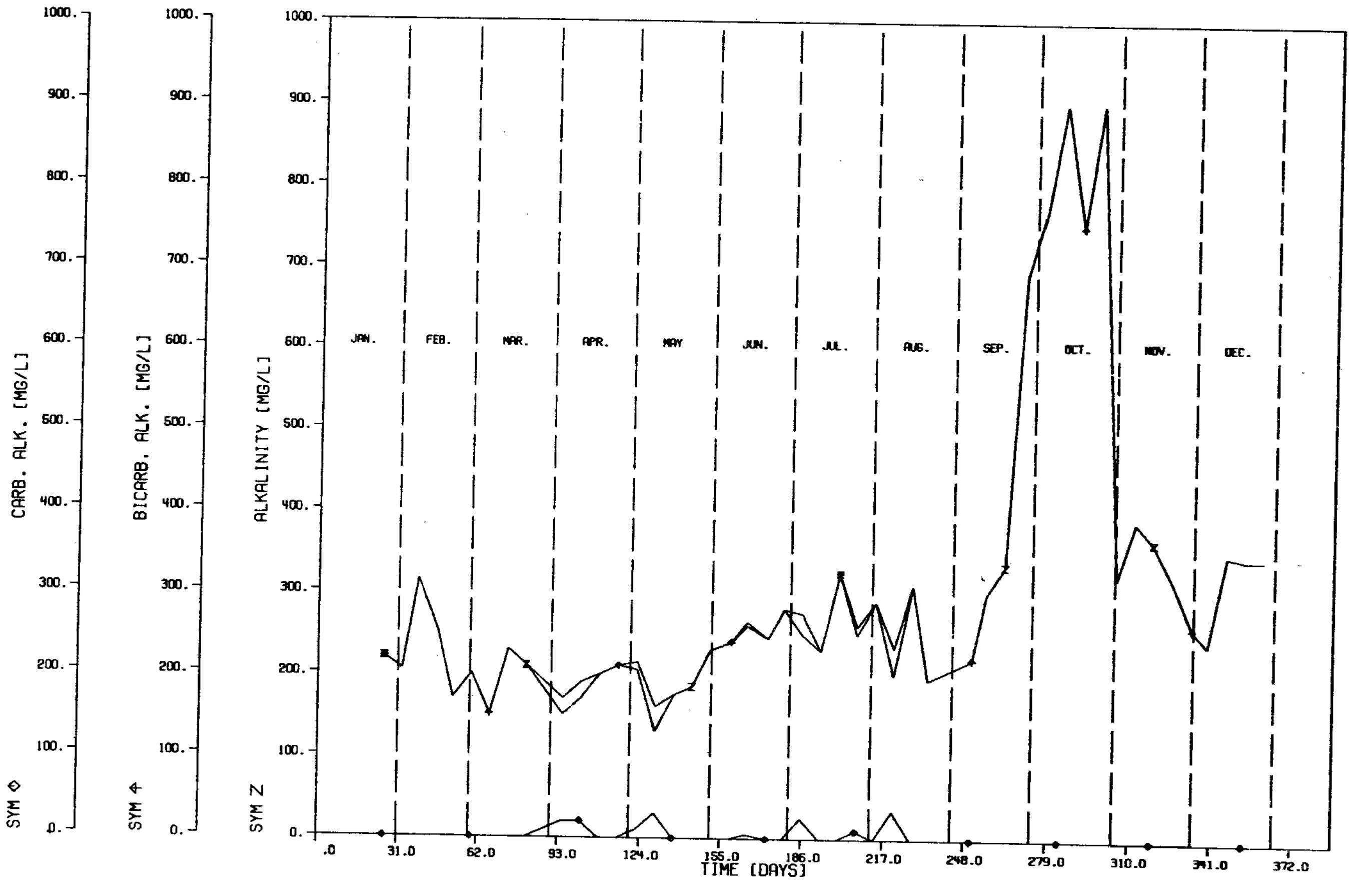

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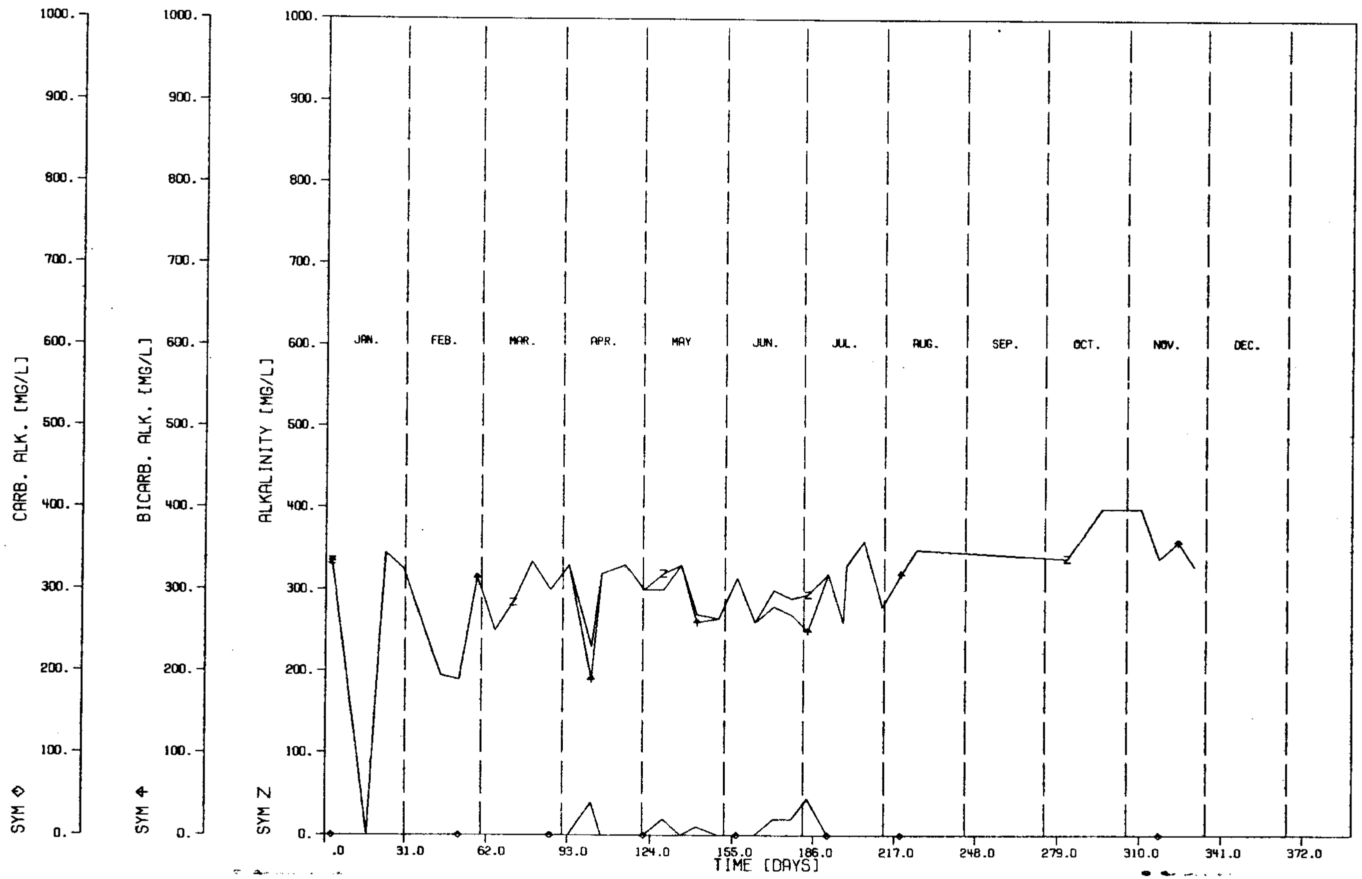

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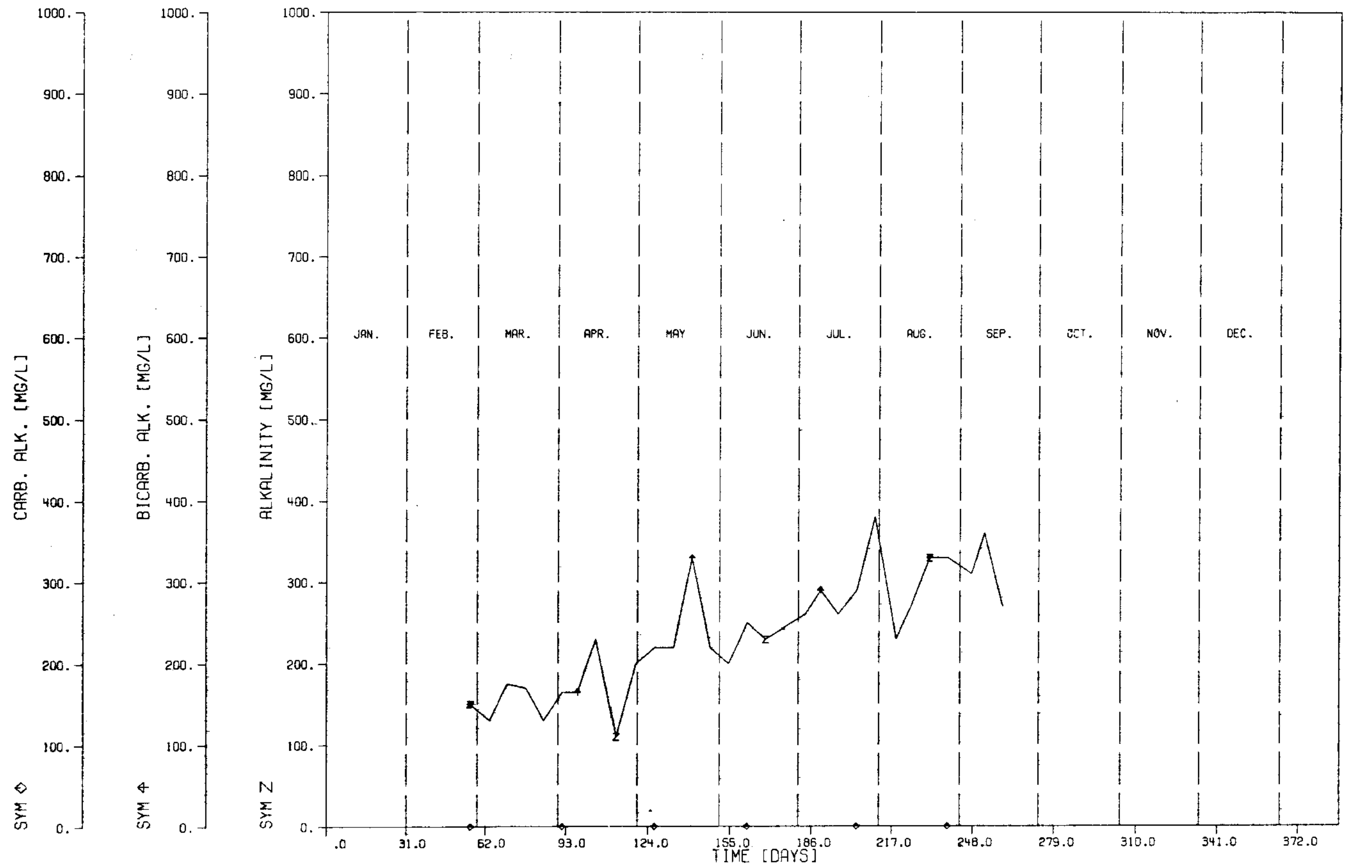

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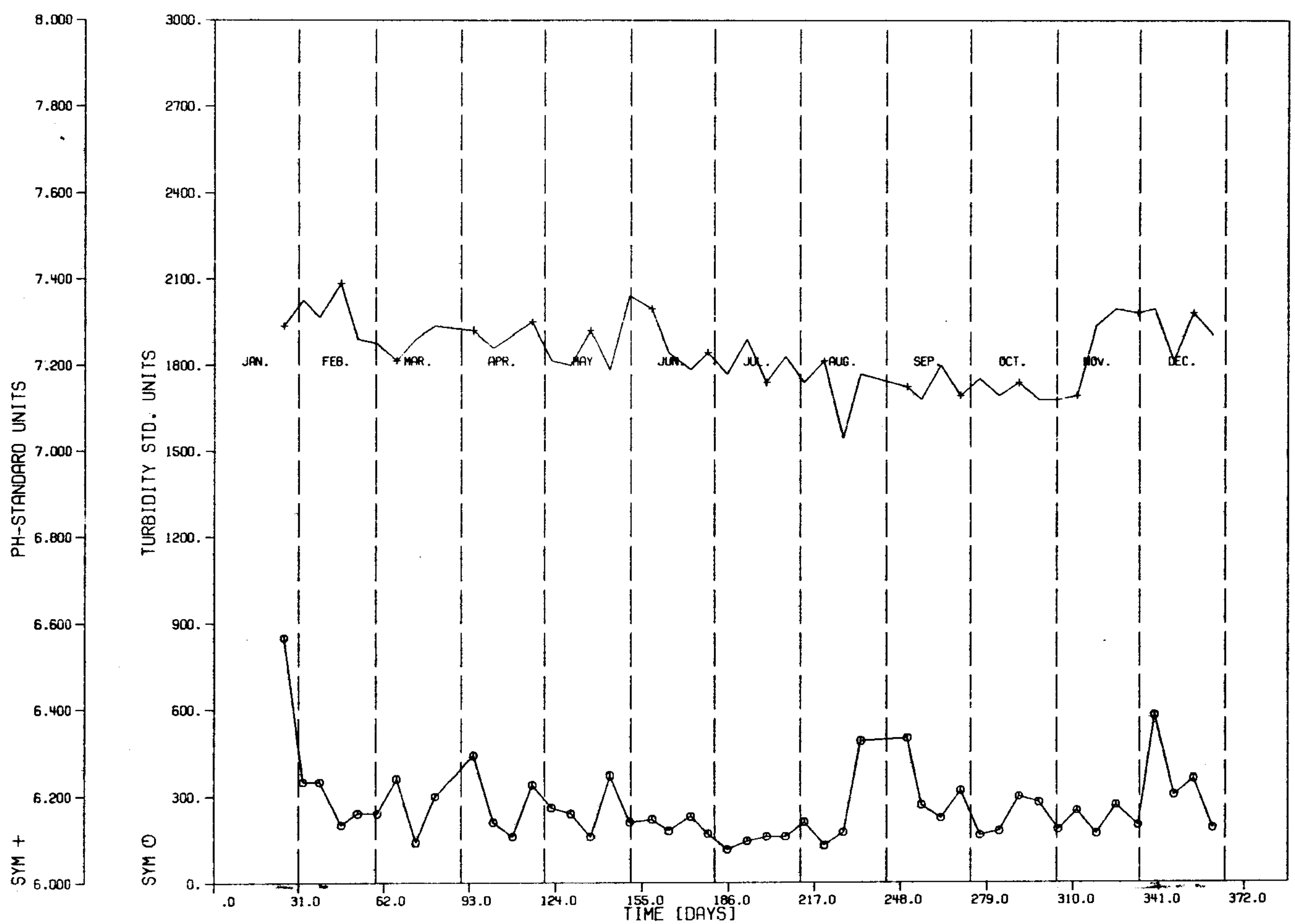

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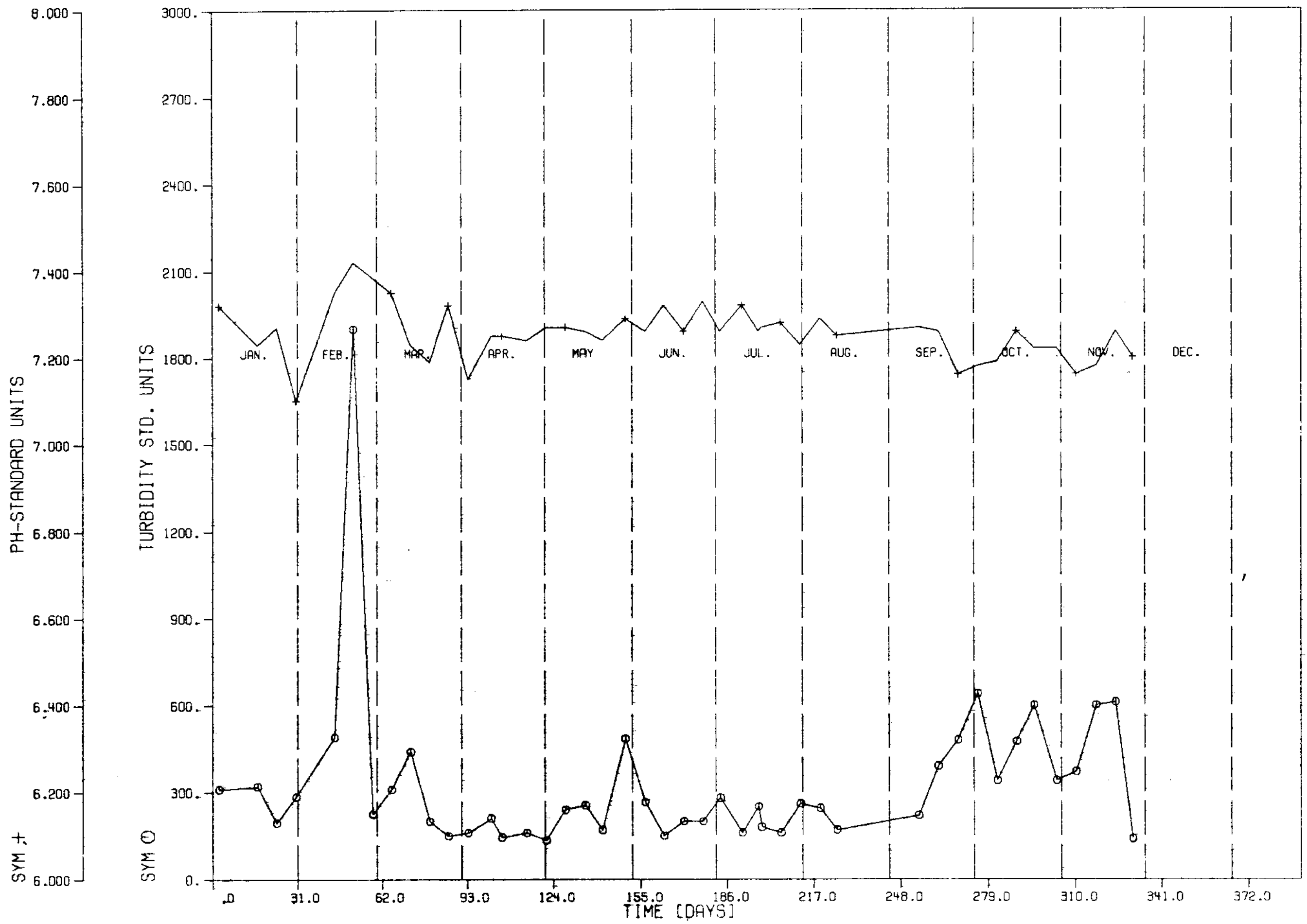

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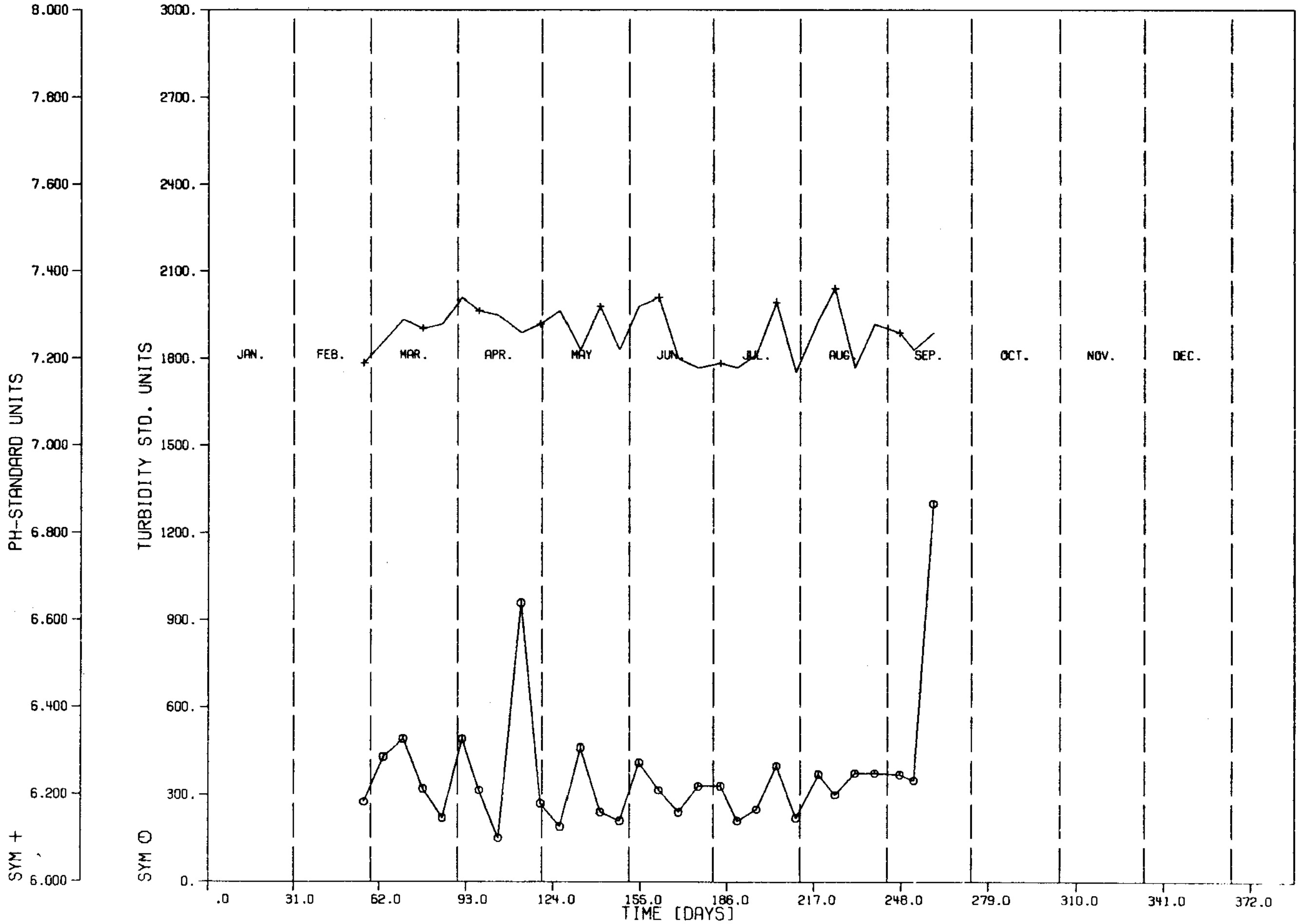

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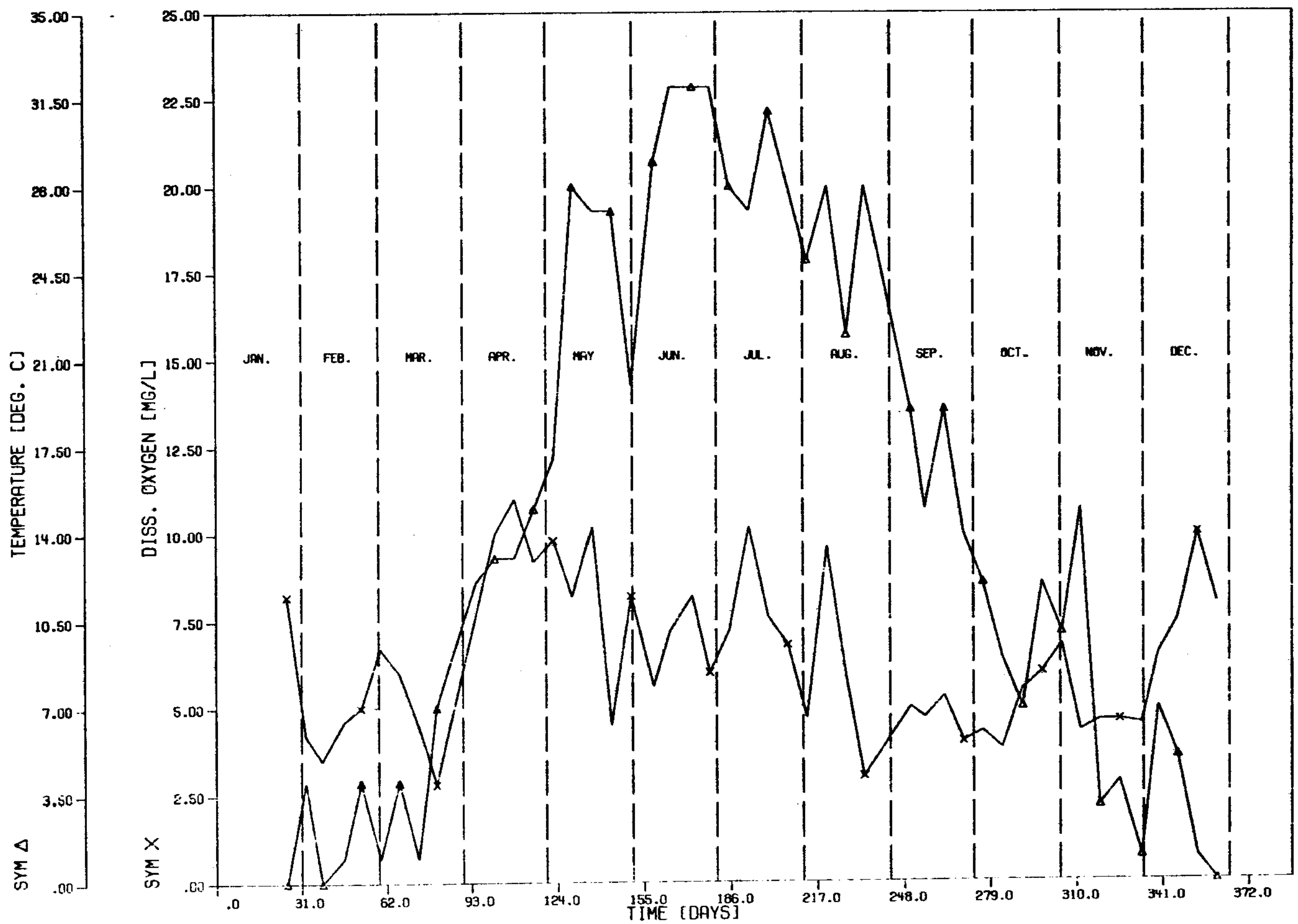

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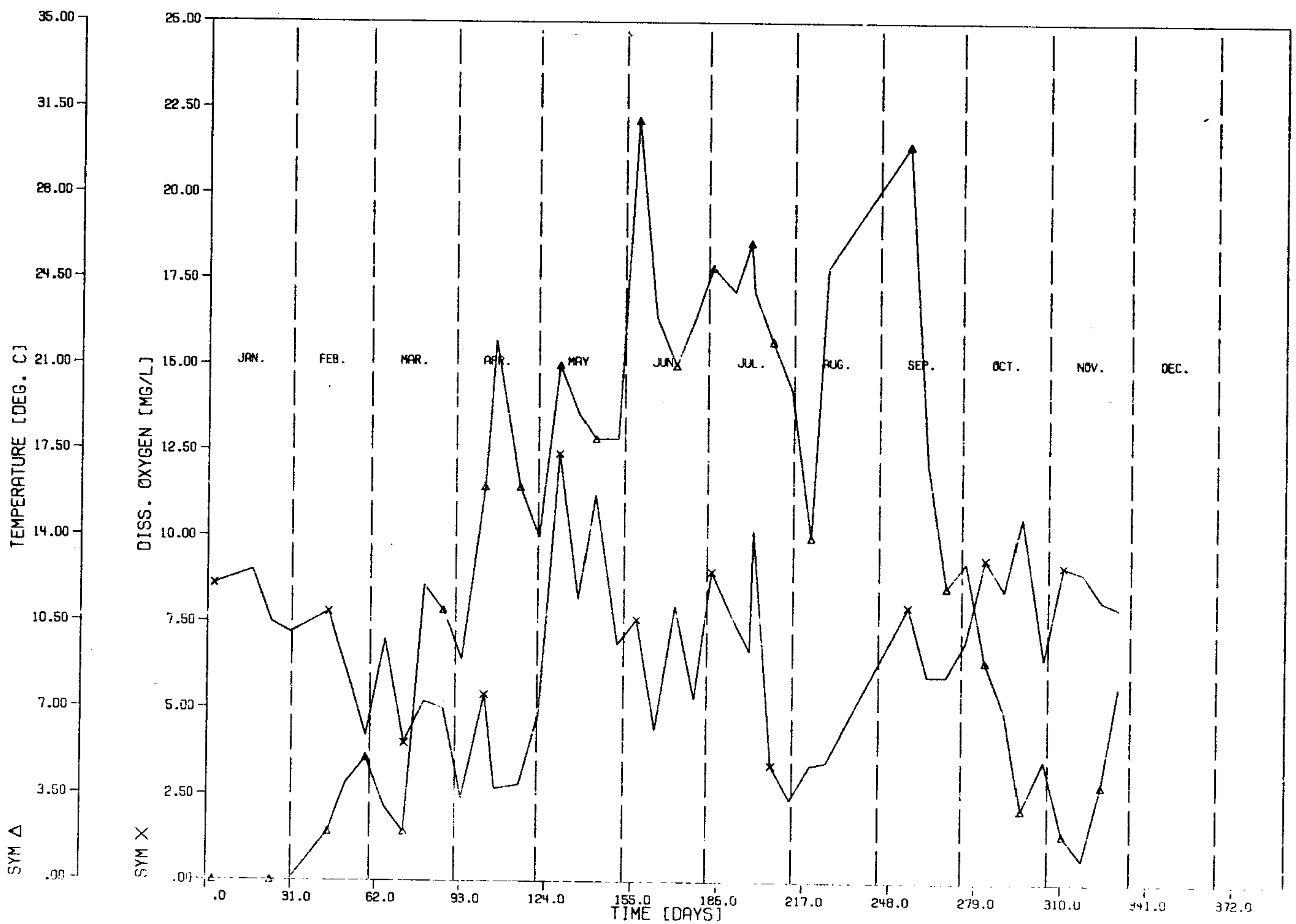

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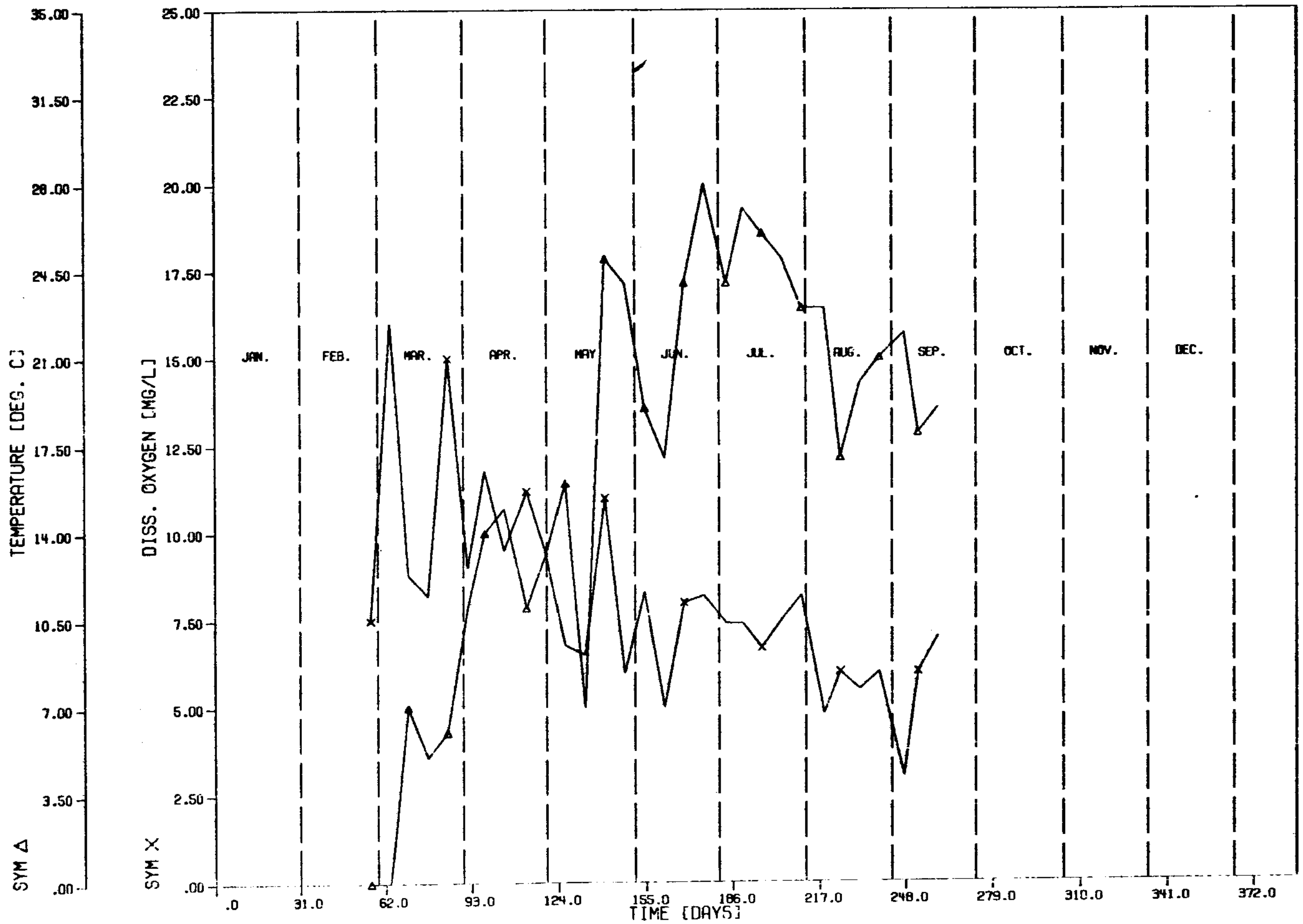

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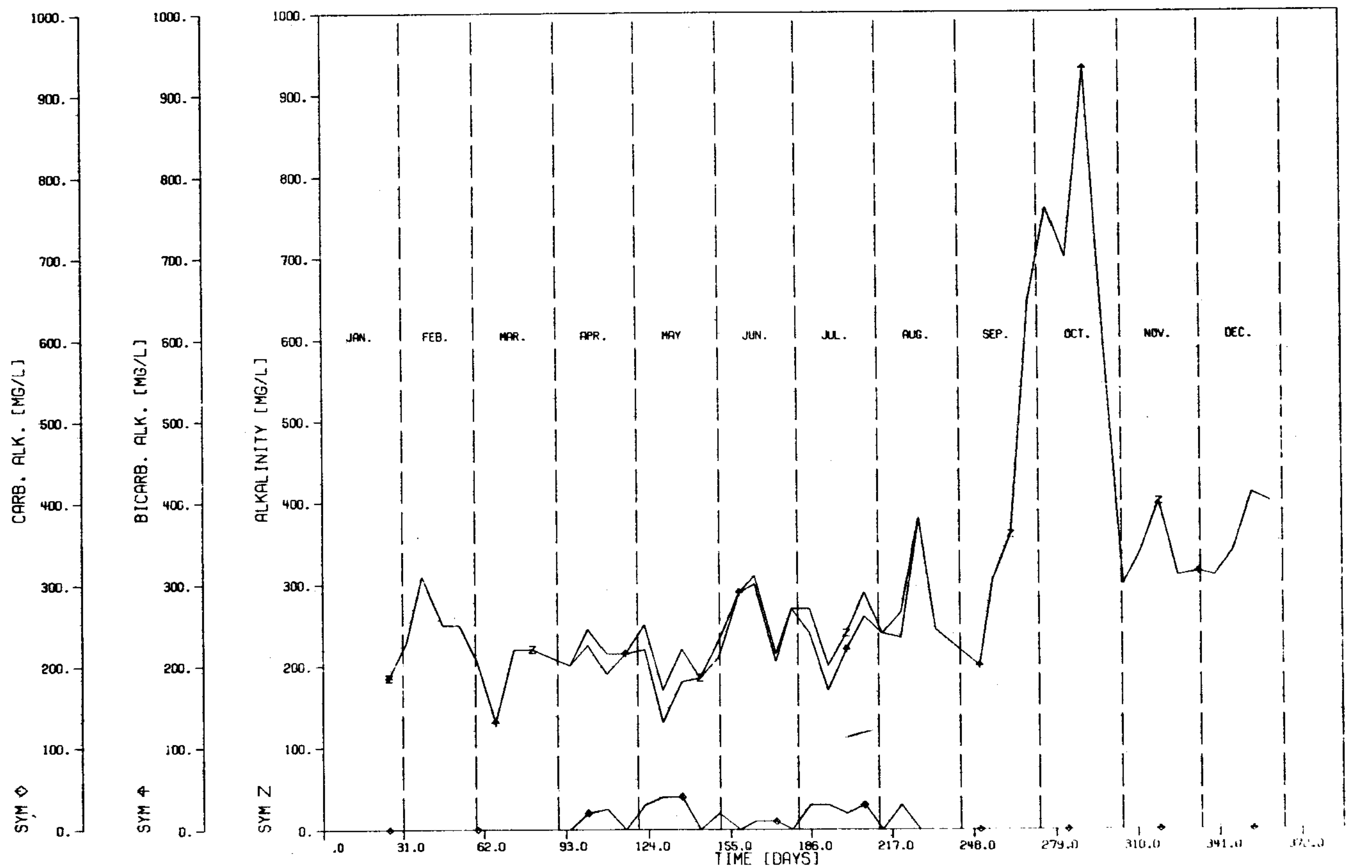

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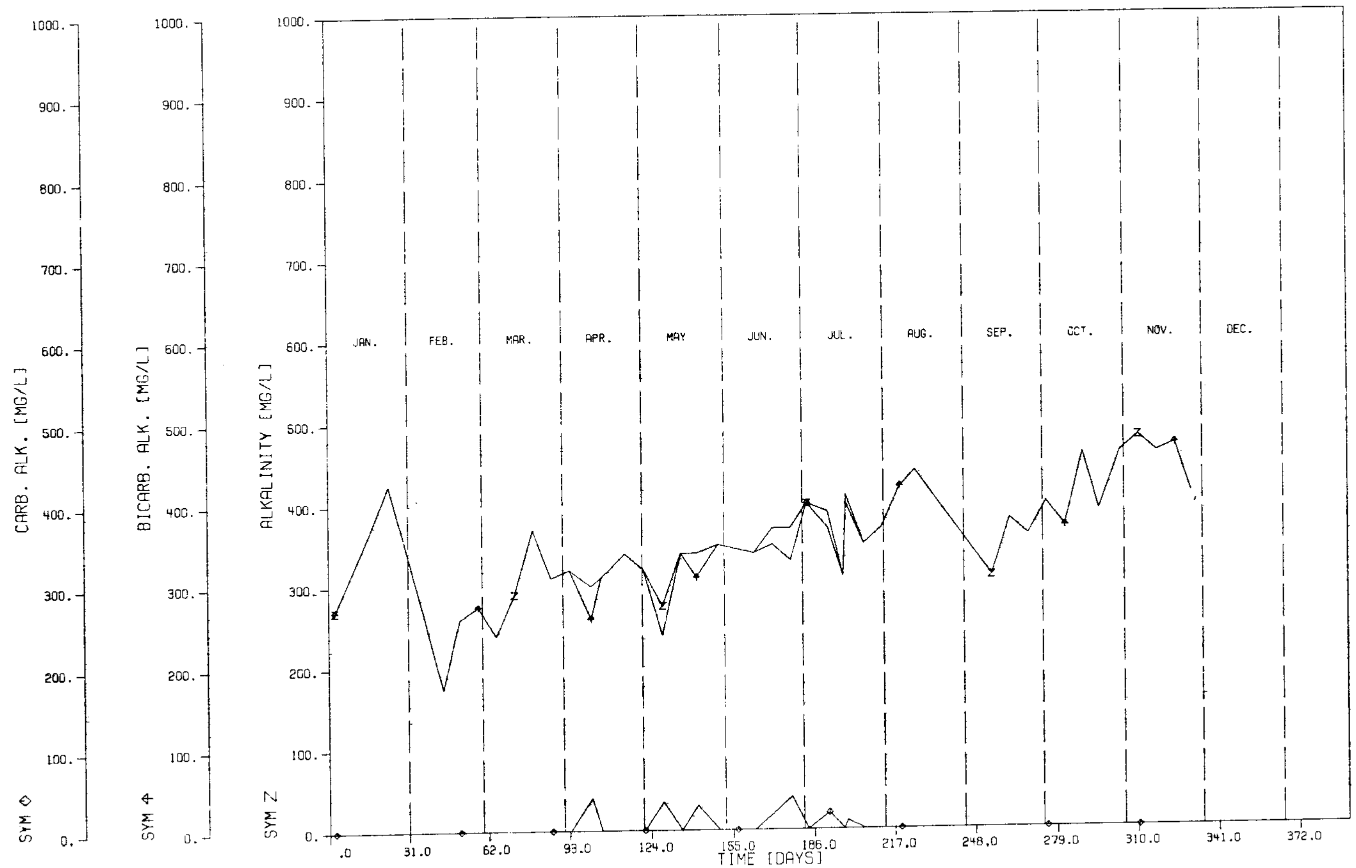

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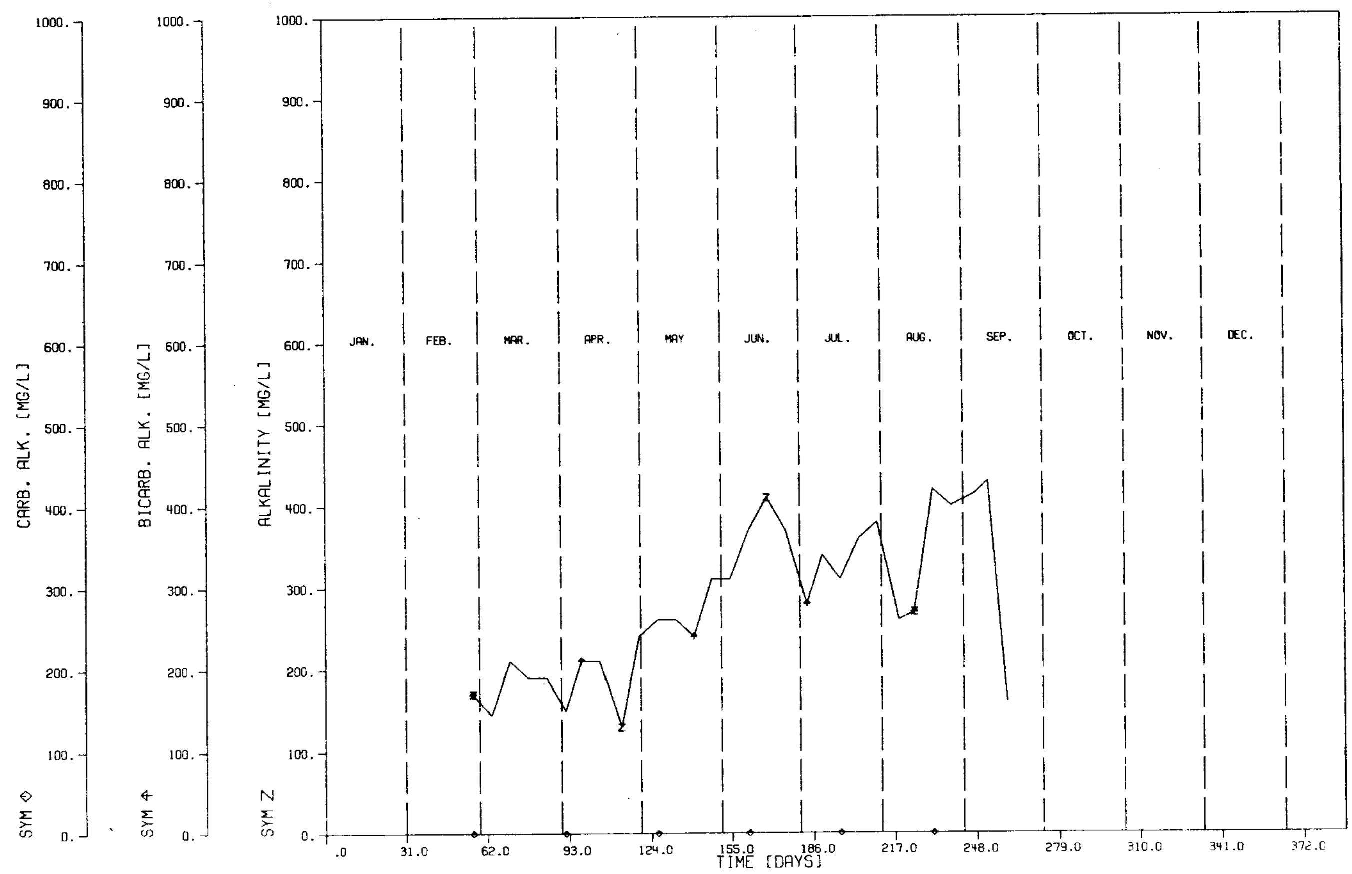

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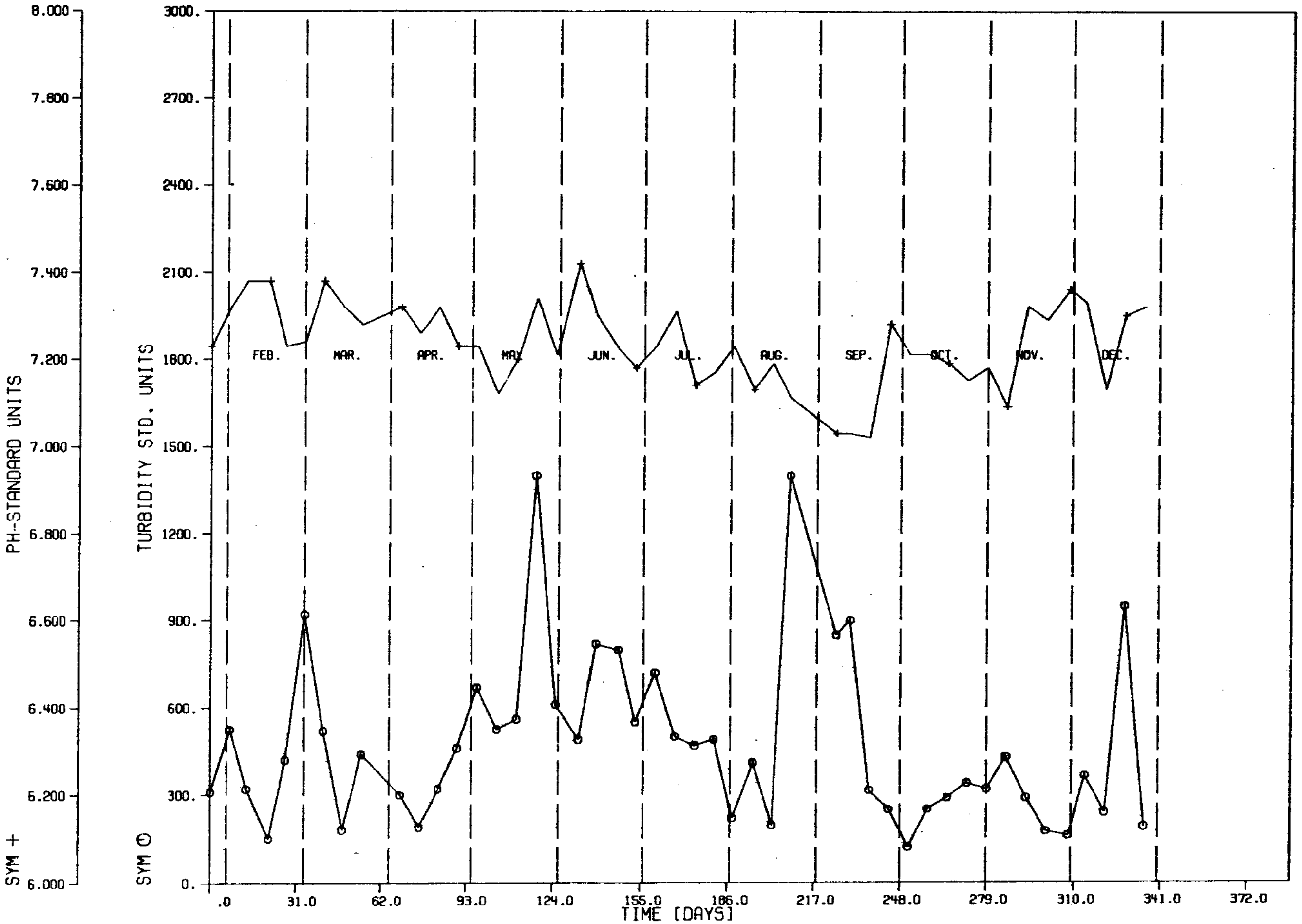

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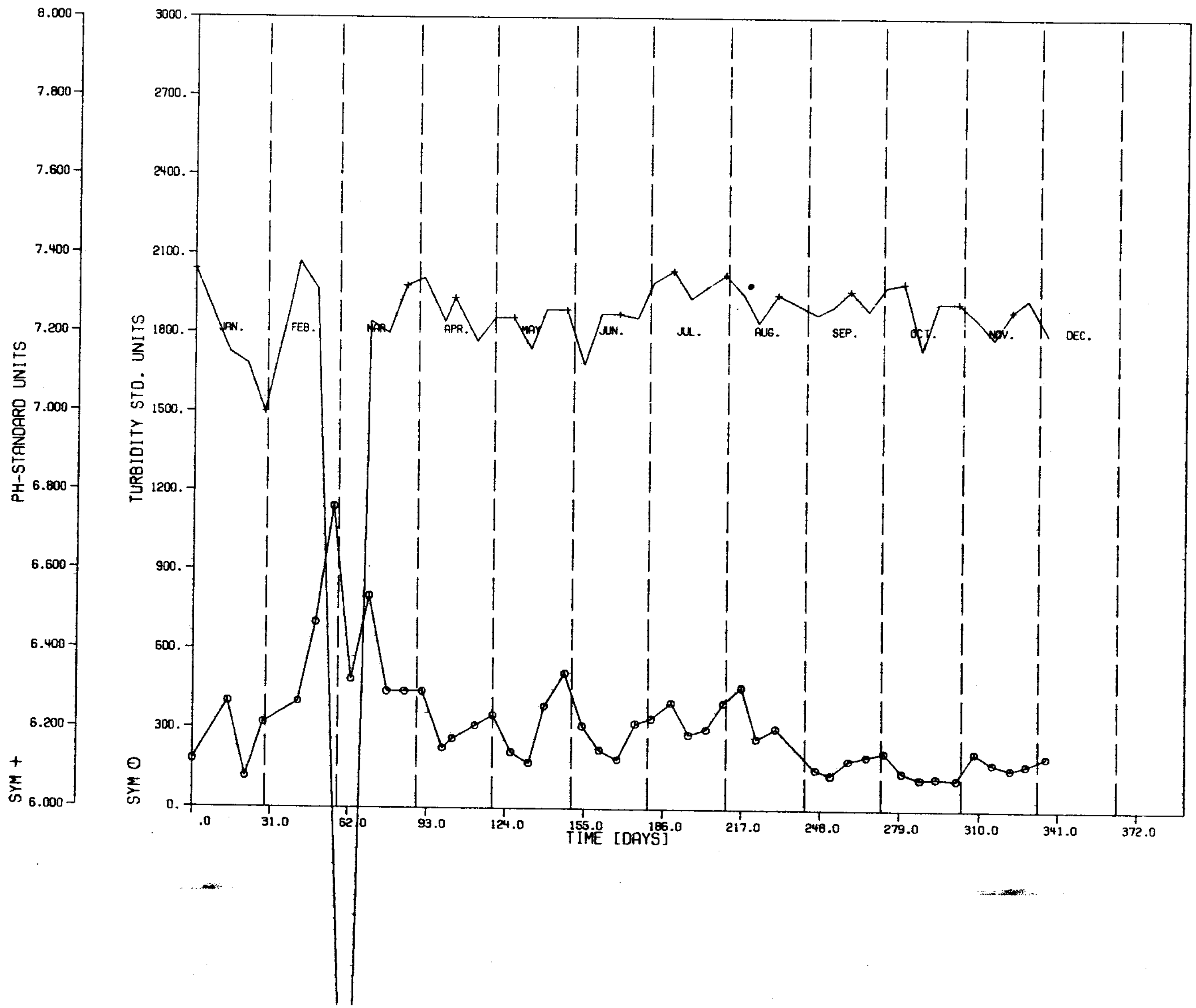

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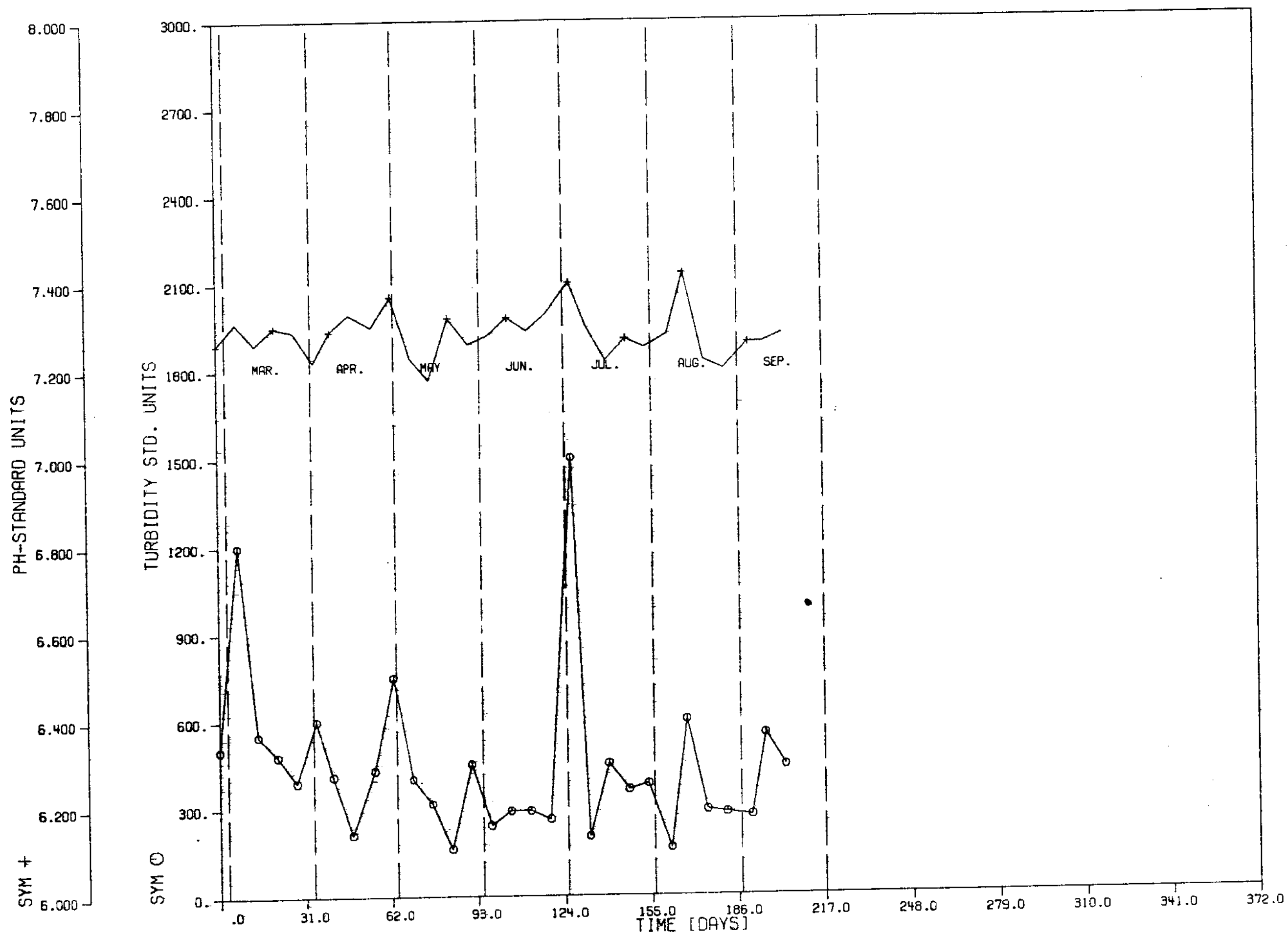

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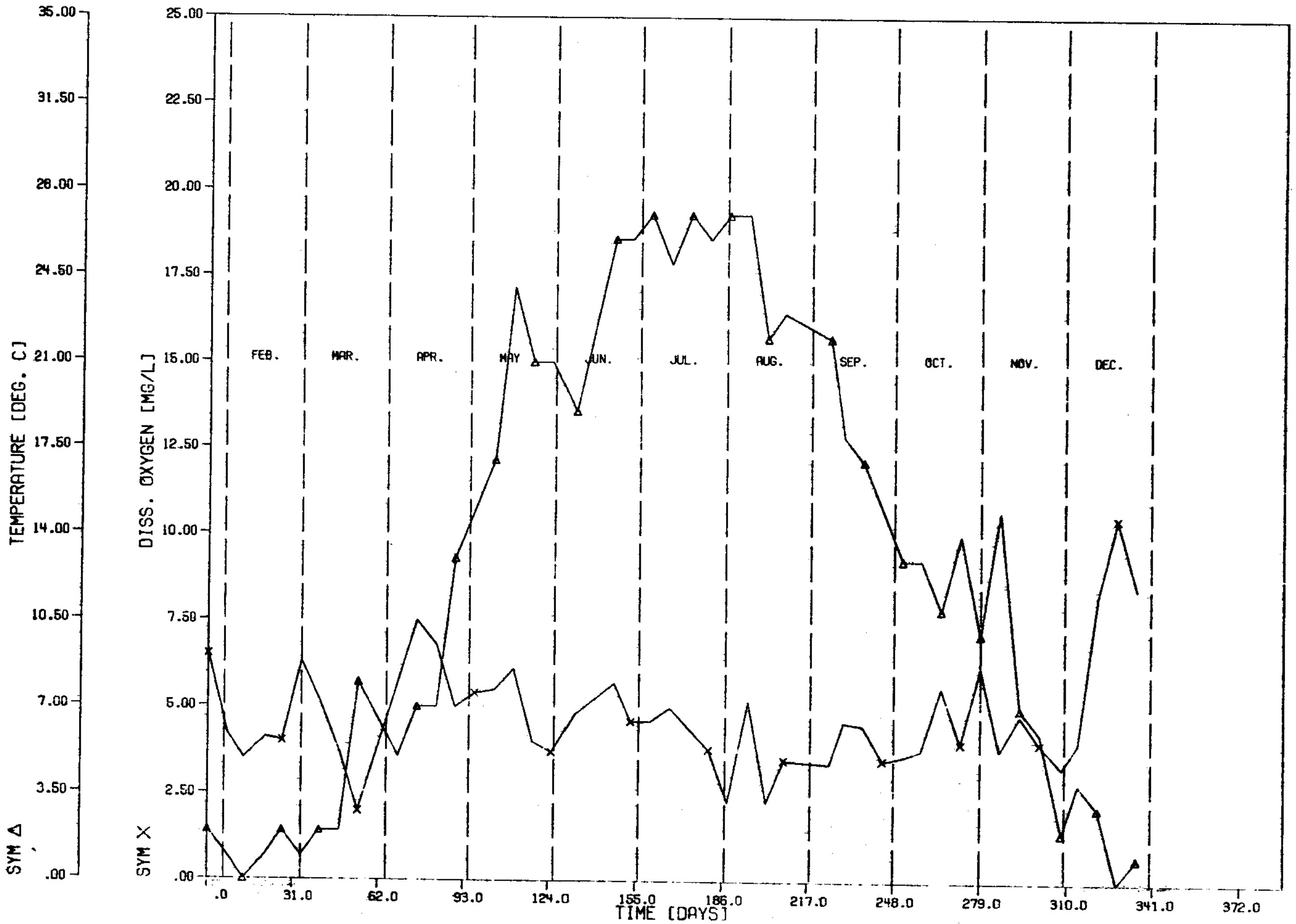

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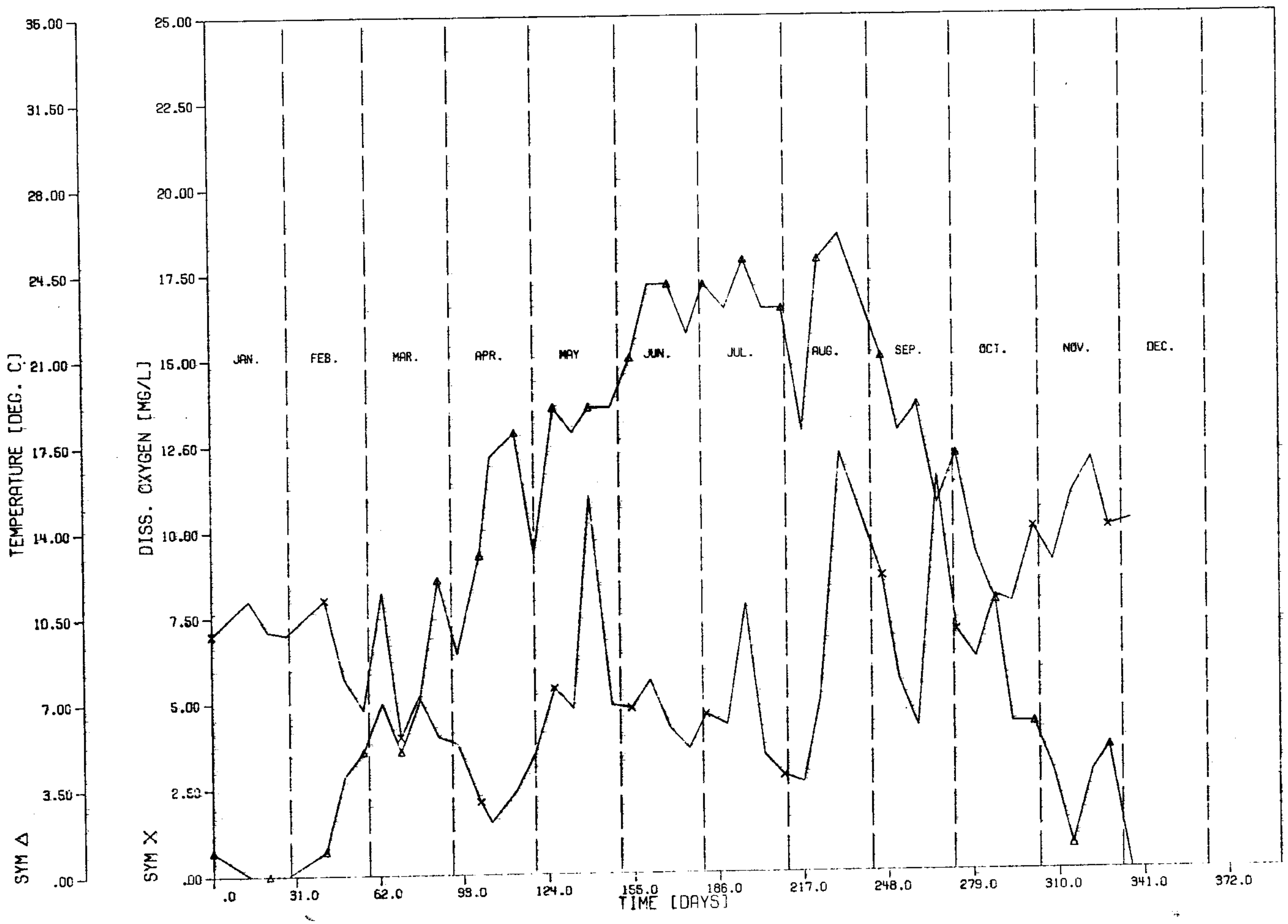

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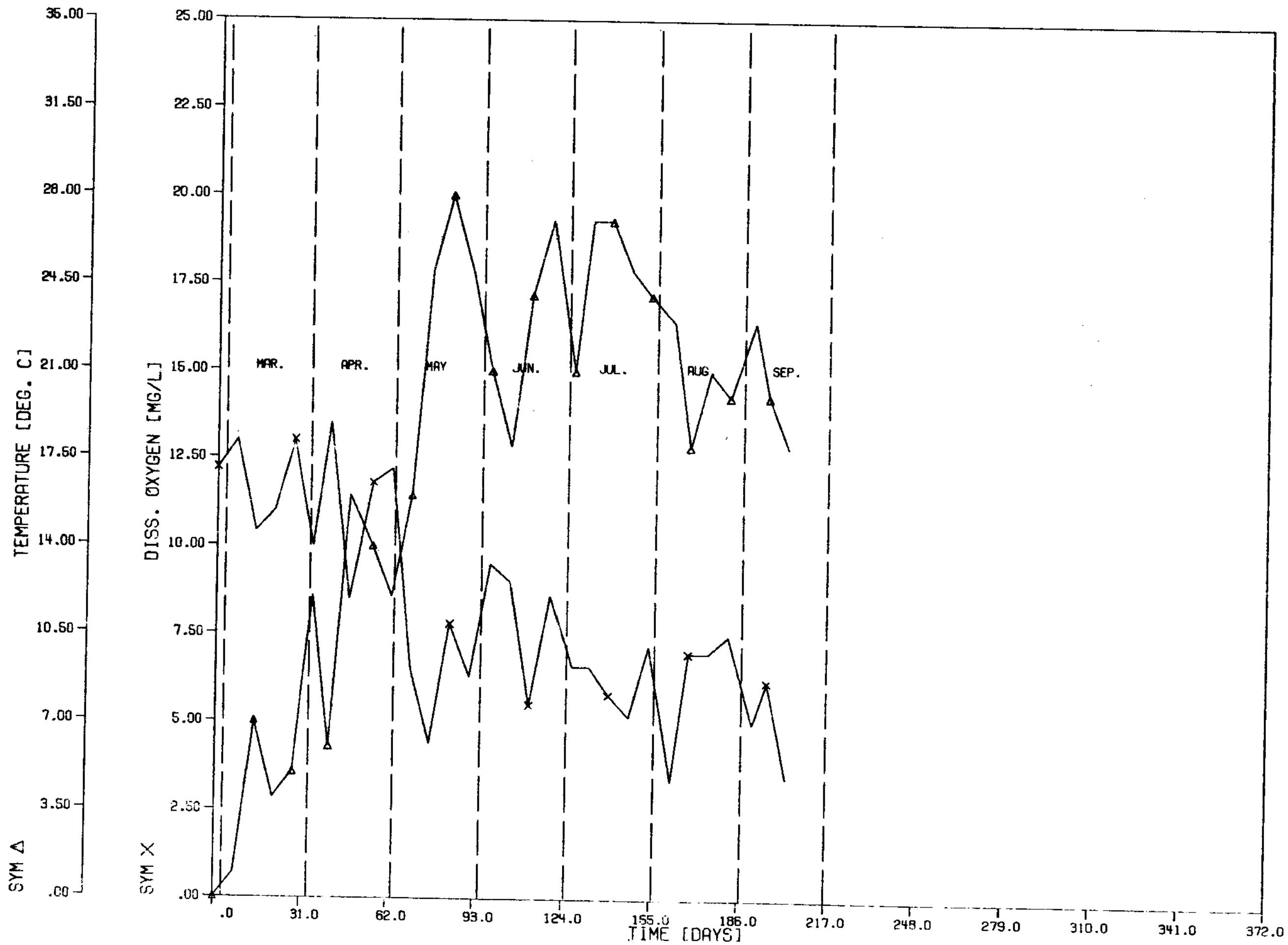

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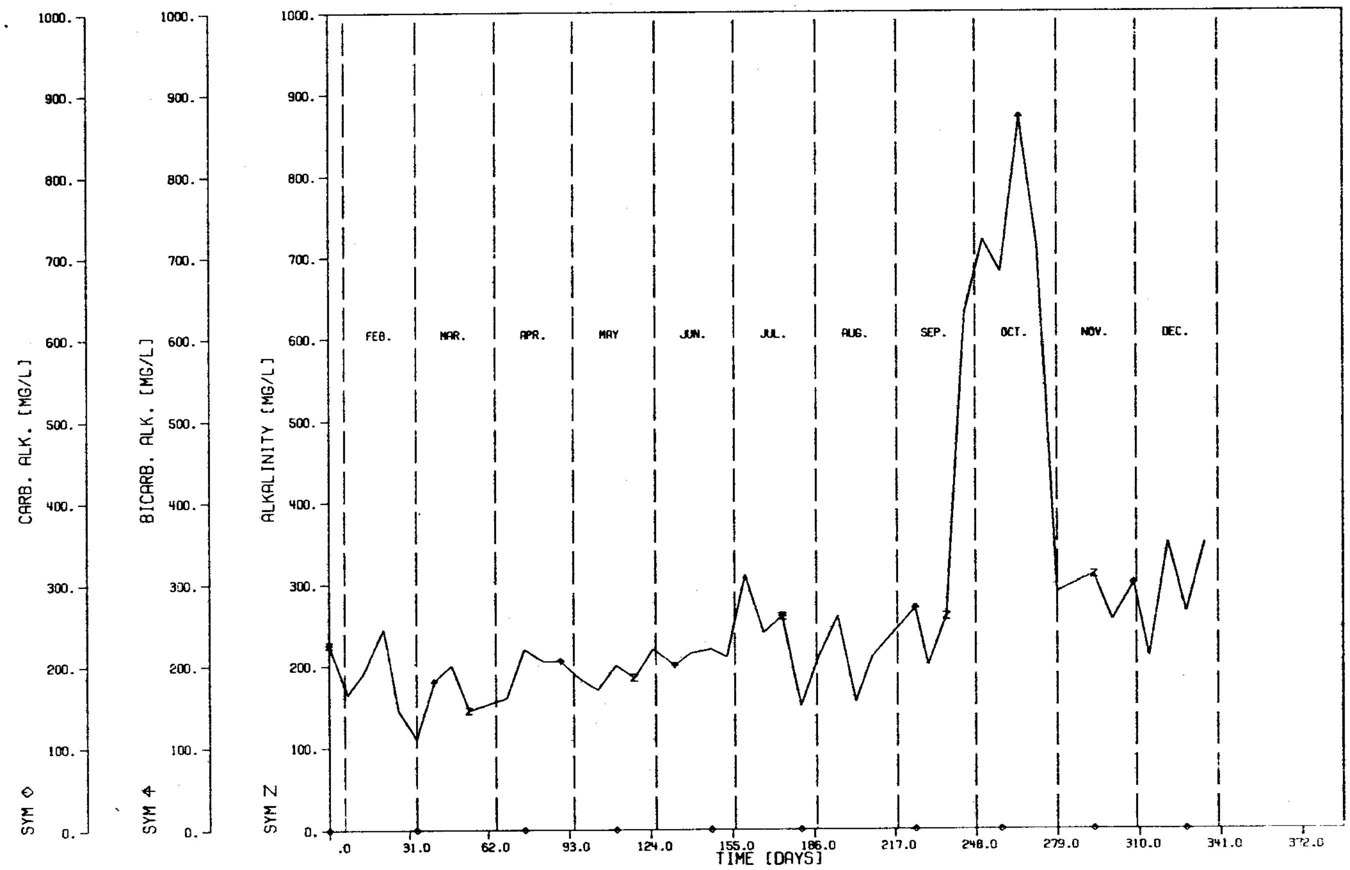

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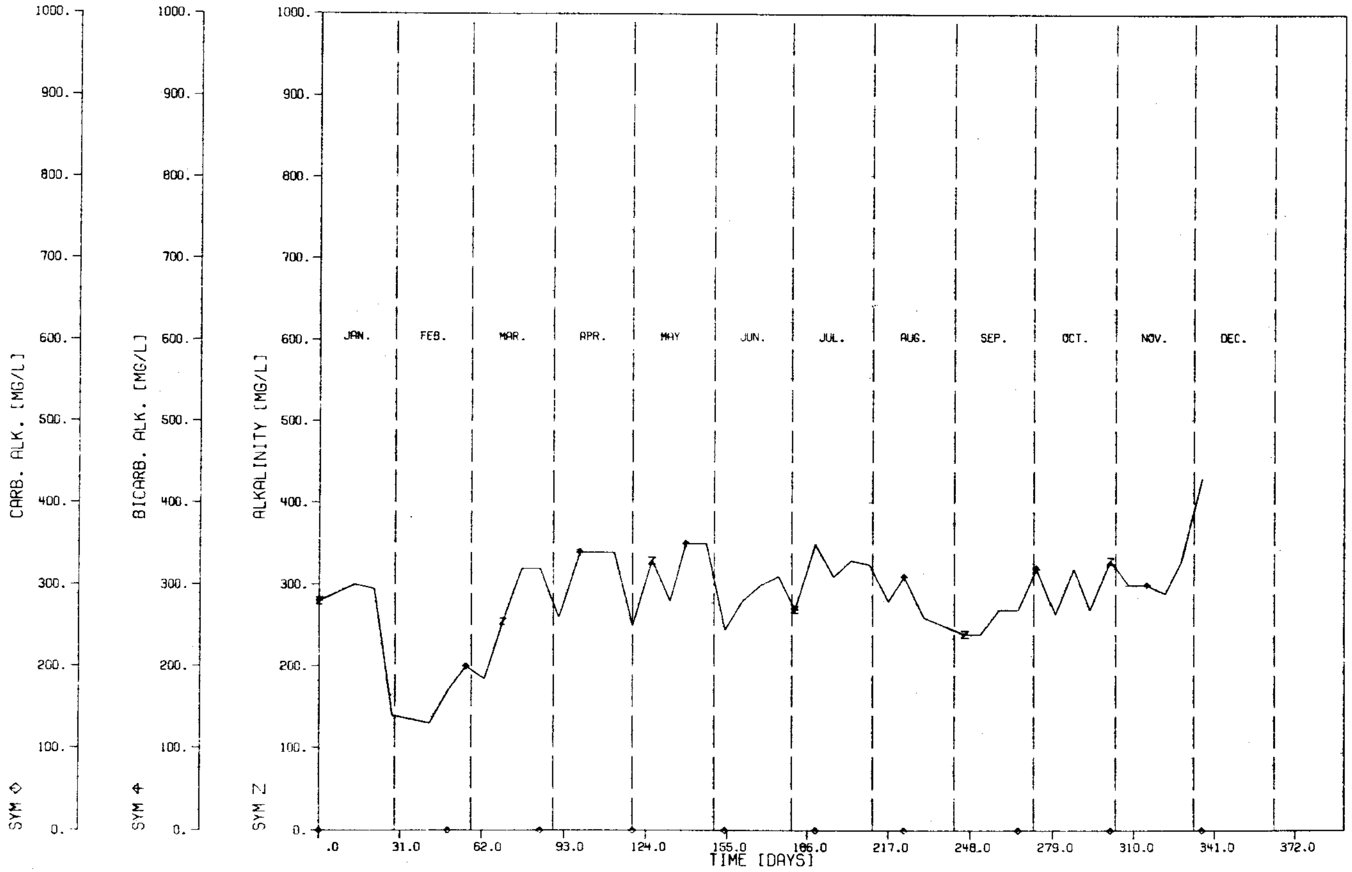

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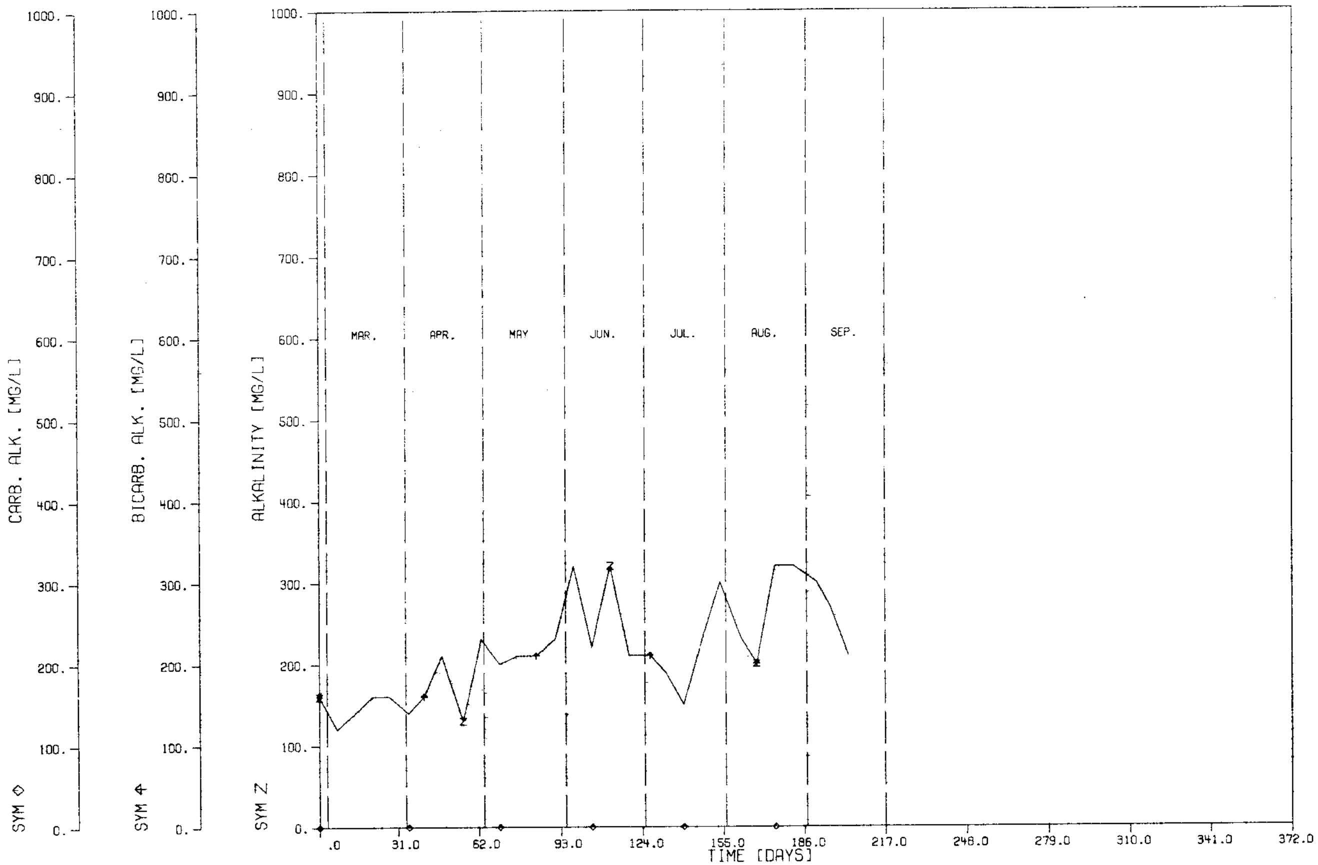

METALLIC CATION CONCENTRATIONS IN WATER SAMPLES

Darrell W. Nelson

Selected water samples collected from sites within the Black Creek Watershed were filtered through a 0.4 micrometer mean pore diameter Nucleopore membrane filter and the filtrate analyzed for metallic cations by atomic absorption spectrophotometry. A Varian AA6 spectrophotometer with deuterium background corrector and an air-acetylene flame was use for the analyses.

The results demonstrated that the concentrations of soluble Pb, Cu, Fe, Ni, and Al in the samples were below that detectable by atomic absorption. Detection limits for Pb, Cu, Fe, Ni, and Al were 0.15, 0.063, 0.3, 0.04, and 0.1 microgram/ml, respectively. The mean Mg concentrations at various sampling sites varied from 7.5 to 40.4 microgram/ml, whereas average Ca concentrations varied from 32.2 to 73.3 micrograms/ml. Mean Zn concentrations at various sampling sites varied from found to vary from 0.001 to 0.009 microgram/ml. It was concluded that soluble metallic cation concentrations are low in drainage water from the Black Creek Watershed.

TABLE 1
Concentration of soluble magnesium in filtered water samples collected from the Black Creek Watershed.

Site no.	N	$\bar{X}$	Range	SD*
		-----------	mg/l	-----------
1	9	13.7	2.2 - 39.5	10.82
2	11	24.6	2.0 - 51.7	18.41
3	16	31.3	1.7 - 78.8	25.00
4	15	22.1	1.8 - 84.7	22.73
5	17	27.4	2.1 - 64.8	23.47
6	13	30.3	1.7 - 49.2	20.32
7	7	11.2	2.5 - 20.4	6.16
8	8	9.5	1.6 - 19.9	6.04
9	13	22.0	1.7 - 51.7	19.84
10	25	40.4	1.7 - 73.1	26.34
11	10	12.4	1.9 - 32.7	9.21
12	14	31.8	2.2 - 59.4	20.18
13	18	20.4	3.3 - 41.9	13.53
14	19	16.7	2.5 - 30.4	8.67
15	3	10.8	9.7 - 11.3	0.92
16	3	8.3	7.7 - 9.3	1.04
17	10	21.8	11.7 - 32.7	8.08
18	14	16.7	2.8 - 24.0	8.59
19	2	7.5	7.5	0

*SD, standard deviation

TABLE 2
Concentration of soluble calcium in filtered water samples collected from the Black Creek Watershed.

Site no.	N	$\bar{X}$	Range	SD*
		---------------mg/l---------------		
1	9	66.5	45.5 - 131.1	26.25
2	11	62.2	31.6 - 84.2	16.11
3	16	54.0	29.6 - 73.4	13.45
4	15	50.8	32.9 - 78.4	15.71
5	17	69.5	28.3 - 113.7	25.29
6	13	70.1	32.2 - 92.6	20.10
7	7	51.0	38.9 - 71.9	11.89
8	8	50.4	26.5 - 79.6	18.28
9	13	62.0	27.6 - 113.7	30.93
10	25	68.4	34.2 - 113.7	23.33
11	10	55.2	41.2 - 101.8	19.32
12	14	54.4	32.9 - 81.1	15.03
13	18	55.0	30.6 - 84.2	17.73
14	19	52.9	32.9 - 78.4	13.81
15	3	37.3	29.9 - 41.5	6.43
16	3	32.2	31.6 - 32.6	0.51
17	10	73.3	43.8 - 113.7	28.68
18	14	43.1	30.6 - 66.9	15.31
19	2	32.5	32.3 - 32.6	0.21

*SD, standard deviation

TABLE 3
Concentration of soluble zinc in filtered water samples collected from the Black Creek Watershed.

Site no.	N	$\bar{X}$	Range	SD*
		-----------	mg/l	-----------
1	9	0.029	.000 - .076	0.026
2	11	0.044	.020 - .077	0.017
3	16	0.048	.000 - .256	0.063
4	15	0.031	.000 - .102	0.031
5	17	0.033	.000 - .153	0.037
6	13	0.039	.000 - .102	0.024
7	7	0.029	.000 - .076	0.028
8	8	0.038	.000 - .084	0.029
9	13	0.036	.000 - .102	0.031
10	25	0.031	.000 - .059	0.018
11	10	0.037	.000 - .079	0.029
12	14	0.041	.000 - .144	0.033
13	18	0.046	.000 - .122	0.035
14	19	0.030	.000 - .070	0.025
15	3	0.017	.000 - .030	0.015
16	3	0.027	.000 - .060	0.031
17	10	0.028	.000 - .049	0.016
18	14	0.034	.000 - .085	0.024
19	2	0.025	.010 - .040	0.021

*SD, standard deviation

TABLE 4
Concentration of soluble cadmium in filtered water samples collected from the Black Creek Watershed.

Site no.	N	$\bar{X}$	Range	SD*
		mg/l		
1	9	0.005	0.000 - 0.034	0.012
2	11	0.008	0.000 - 0.059	0.016
3	16	0.009	0.000 - 0.059	0.016
4	15	0.007	0.000 - 0.034	0.010
5	17	0.005	0.000 - 0.042	0.010
6	13	0.006	0.000 - 0.029	0.008
7	7	0.000	0.000	0.000
8	8	0.000	0.000 - 0.003	0.001
9	13	0.003	0.000 - 0.023	0.006
10	25	0.005	0.000 - 0.049	0.010
11	10	0.002	0.000 - 0.018	0.006
12	14	0.004	0.000 - 0.014	0.006
13	18	0.004	0.000 - 0.029	0.008
14	19	0.004	0.000 - 0.029	0.008
15	3	0.000	N.D.	0.000
16	3		N.D.	
17	10	0.001	0.000 - 0.004	0.002
18	14	0.005	0.000 - 0.029	0.008
19	2		N.D.	

*SD, standard deviation

by T. Dan McCain
Soil Conservation Service

INTRODUCTION:

The Soil Conservation Service participated in the Black Creek Program by offering accelerated technical assistance to the 175 landowners in this 12,000 acre agricultural watershed and then working with 121.

The assistance was geared to analyzing the "traditional approach" to conservation land treatment. Thirty-three practices were identified so that conceivably all possible land uses, treatment methods and environmental concerns could be covered.

At the conclusion of this five-year project, 87% of the land area was under cooperative agreement, 79% of the watershed was covered by conservation plans with landusers under contract and 66% of the watershed was treated by applying one or more of the 33 practices.

HOW PLANNING WAS APPROACHED

Plans were developed by Soil Conservationists and applied by technicians. Many early plans and contracts were extremely lengthy. Later application of these thorough plans lead to difficulty and inefficiency as far as application of best management practices was concerned.

The concentrated effort under the traditional conservation approach was to "treat each acre." At the same time there was a compulsion to make a "showplace of applied conservation" for all to see and appreciate.

Plans were often lengthy because "options" were listed and allowed for payment and because these were not separated from the "mandatory" contractual committments. It is now recognized that less than half of the watershed (5,750 acres) was deemed critical and needing treatment to improve water quality. It could therefore be concluded that manpower, money, and time could have been spared if a simpler "best management practice" (BMP) approach had been utilized. Most early plans listed contractual committments through the last year of application. We were committed to an annual follow-up contact during the winter (Jan-Mar) months. At that time we were often trying to "clean up" and transfer committments to following years to keep cooperators from being out of compliance. When the final year arrived, many second, third and fourth year committments had been delayed to the limit. It was then that we decided "mandatory and optional" status of planned practices, based upon which procedures were necessary to control excessive erosion.

Actually the original planner had made determinations of mandatory needs to meet the basic Universal Soil Loss Equation (USLE) requirements for specific soils. What happened is now simple to understand. Landowners, when given an open account and a catalog of nice practices, will committ themselves beyond their real needs. Most plans contained nice-to-have or non-essential practices.

Most later plans were written to cover essential practices; however, it wasn't until after Black Creek's first five years that simplifed planning format was accomplished. A simplified plan is being used in the Fort Wayne SCS Field Office on all ACP referral work for 1978. Early results are encouraging. Plans are never longer than one page. Annual follow-up is automatic and the cooperator always has an updated copy of his committment decisions. From our experiences in the Black Creek Project some general conclusion can be made as related to planning of conservation practices that result in improvement of water quality.

Understanding needs, treatment costs, critical areas, water quality goals and working relationships with farmers are all important in gettin conservation practices applied to improve water quality. If all else fails, use the "KIS" approach -- Keep It Simple.

Treating only areas of the watershed that are critical areas makes sense. You work harder, sooner with fewer people and accomplish more water quality improvements, more efficiently, and at a considerable savings in cost-sharing monies. Evidence of this potential savings can be derived from Figure 33, page 249 Black Creek Final Report Vol. II. This chart plots costs for 4 broad practice catigories. Elimating production practices and other treatment (recreation, wildlife and woodland) on non-essential areas could reduce the overhead considerably.

The drawback to planning with the traditional approach has now been recognized by the SCS. Changing times and the emphasis on water quality has helped the national revision of the SCS Conservation Planning Manual (Oct. 1978)

Influence we need to generate with large farmers should be toward Best Management Practices. They should understand water quality objectives and then be able to make decisions affecting the outcome.

Treating each acre is too meticulous unless this treatment is needed to control excessive erosion. As far as water quality is concernded, If we expect to "clean the waters" for fishing and swimming by 1983 or even 1993 we must use an efficient, effective methods, on those areas needing treatment.

Subsurface Drainage Model with Associated Sediment Transport

A. B. Bottcher, E. J. Monke and L. F. Huggins

ABSTRACT

A computer model using GASP IV simulation language to simulate the water flow and sediment concentration from a subsurface drainage system was developed. The model used a one-dimensional form of the Richard's equation and an existing tile flow formula by Toskoz and Kirkham to express the water movement process. The particle detachment model, based on a force balance relationship, is driven directly by the output of the flow model. Data required by the model includes rainfall distribution, evapotranspiration, soil hydraulic properties, and the drainage system layout.

Calibration and verification were accomplished using data collected on a seventeen hectare tile drainage system located on a flat Hoytville silty clay soil. A comparison of the simulated and observed results indicate that the model will reliably predict water yield, sediment yield and the sediment concentration curve. However, some difficulty occurred in simulating the actual shape of the flow hydrograph.

INTRODUCTION

The movement of rainfall through a soil profile to a subsurface drain line is a very complex hydraulic and transport problem. Water, as it moves through the profile, can pick up fine soil particles and chemicals which may ultimately reach our lakes and streams. Many factors, such as saturated or unsaturated flow, hydraulic gradient, physicochemical effects on soil particle bonding, absorption-desorption, diffusion, and chemical and biological transformations can influence transport. At the field level, factors such as soil cracking, freeze-thaw conditions, non-homogenity and varied plant growth serve to further complicate efforts to conceptionalize, much less model subsurface drainage transport systems. Most of these factors have been studied either in the laboratory or theoretically for ideal-controlled conditions. However, for the field scale and multi-variable systems, knowledge is still quite limited.

Existing research has dealt primarily with water movement since root zone moisture control has been the primary incentive for subsurface drainage. However, recent studies have shown that subsurface drain outflow is not necessarily clean water and may indeed be contributing to the degradation of the water quality in lakes and streams (Baker and Johnson, 1976; Schwab, Nolte and Brehm, 1977).

This paper explores the impact of subsurface drainage as a sediment source and describes a model that may be used to predict both flow and sediment concentration as a function of time for a single storm event or series of such events. The ability to determine sediment loading potentials of drained fields with varying soil types by using available soil properties data will help to facilitate '208' planning efforts. Also, significant amounts of nutrients are associated with the sediment (Lake, 1977). In addition, a reliable water flow and sediment transport model will provide a solid basis for more complex nutrient or pesticide transport models yet to be developed.

FLOW MODEL

In general both unsteady and steady subsurface flow models are based on a numeric technique to solve Richard's equation, in two-dimensional as (Amerman, 1976; Hillel and van Bavel, 1976; and Nature, King and Jeppson, 1975):

$$\frac{\delta}{\delta x} [K(\Theta) \cdot \frac{\delta \tau}{\delta z}] - \frac{\delta K(\Theta)}{\Theta z} = \frac{d\Theta}{dt} \qquad (1)$$

where τ is the tension head, K the hydraulic conductivity, Θ the water content, and t time.

Water balance techniques have also been used when large scale (field or watershed size) subsurface flow problems were to be solved (Bird and McCorquadale, 1971). However, water balance models do not provide the detailed picture of water movement within the soil profile that theoretical models such as those based on Richard's equation provide.

The flow model presented in this paper uses a one-dimensional form of Richard's equation in the unsaturated zone above the watertable and uses the tile flow formula developed by Toskoz and Kirkham (1961) to move water from the watertable to the drain line. According to Toskoz and Kirham,

$$qt = Ks \cdot H/(S \cdot F + H) \qquad (2)$$

where qt is flow into drain line per unit length, Ks is the saturated hydraulic conductivity of the lower profile, H is the height above the drain line to the midpoint of the watertable, S is the drain line spacing, and F is a function given by:

$$F= \frac{1}{\pi} \ (\ in(S/\pi \cdot R)) \ + \qquad (3)$$

$$\sum_{m=1}^{\infty} \frac{1}{m} \ (\cos(\pi \cdot 2 \cdot R/S) \cdot \cos(m \cdot \pi) \cdot (\text{cohtan}(2 \cdot m \cdot \pi \cdot D/S)-1)$$

where R is the drain line radius and D is the depth to the impeding layer below the drain line. This formula was chosen because it yields the equilibrium watertable height during a constant rainfall intensity, thereby assuring continuity of flow at the unsaturated-saturated flow interface.

The unsaturated flow regime is solved numerically by dividing the soil profile into N layers of which only the layers above the current watertable height are considered (Figure 1). The change in water content in each layer is determined by combining the following finite difference forms of the two fundamental relationships from which Richard's equation is founded, namely:

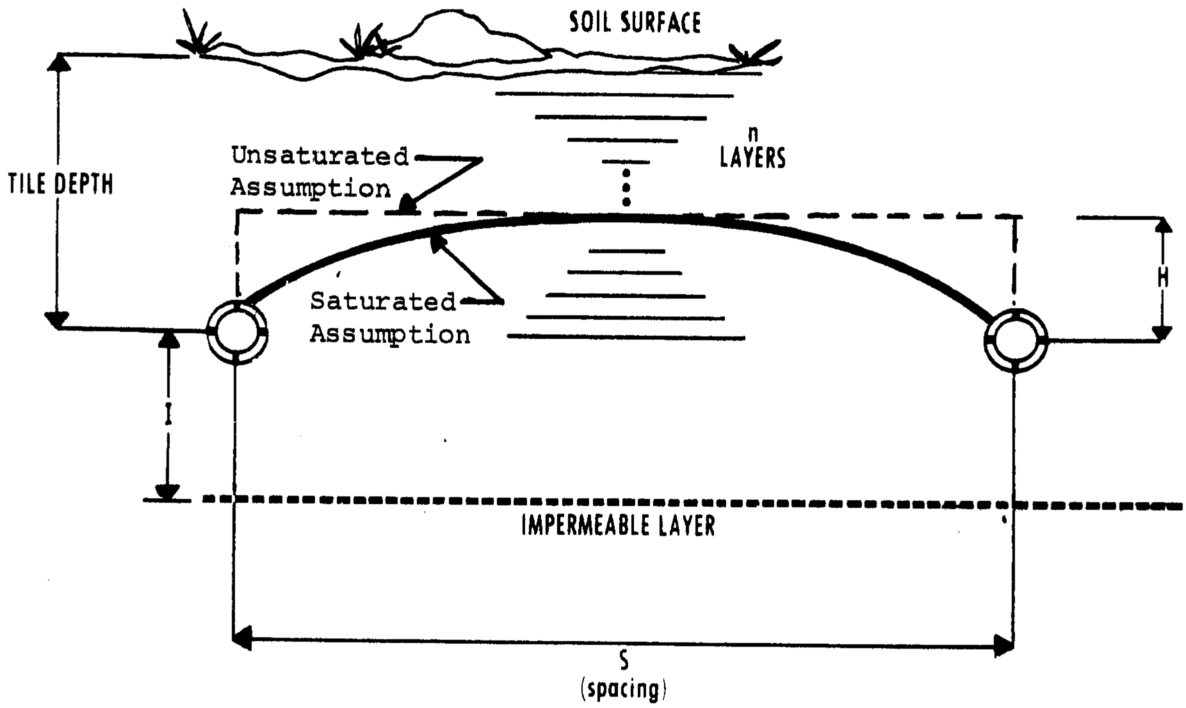

Figure 1. Soil Profile of Tile Drainage System

Darcy's Law (vertical flow),

$$q = -K(\theta)\left(\frac{\Delta\tau}{\Delta z}+1\right) \tag{4}$$

and the equation of continuity,

$$\frac{\Delta\theta}{\Delta t} = \frac{\Delta q}{\Delta z} \tag{5}$$

Combining equations (4) and (5) and inserting layer notation yields the water content rate of change in the ith layer:

$$\frac{\Delta\theta i}{\Delta t} = [K(\theta_{1,i+1})\ (tau_i - \tau_{i+1} + \Delta z)\Delta z] - [K(\theta_{i,i-1})\ (\tau_{i-1} - \tau_i\ \Delta z)\Delta z] \tag{6}$$

where layers are labeled from the surface downward such that the drain line layer is the Nth layer. The above set of L (number of layers above watertable) finite difference equations are solved simultaneously by the Runga-Kuttu-England algorithm available in the GASP IV simulation language (Pritsker, 1974).

The following assumptions were made to facilitate the description and solution of the unsaturated flow portion of the problem:

1. Vapor movement of water is negligible for the duration of a storm period.
2. Flow is isothermal.
3. Osmotic gradients are not present.
4. Biological effects are negligible.
5. Water is homogeneous in nature.
6. Hydraulic conductivity is isotropic and is a linear function of water content.
7. Tension is a linear function of water content.
8. Hysteresis does not exist in either the tension or hydraulic conductivity relationships with water content.
9. Hydraulic conductivity is the same for all layers.
10. The tension versus water content relationship is the same for all layers.
11. The watertable surface is rectangular in shape.
12. Hydraulic gradient and hydraulic conductivity change linearly between the center points of two adjacent layers.

The linear assumptions were used to reduce computer costs for the initial modeling effort. Also, metal tests showed little difference in simulated results when nonlinear relationships were used. The model can be extended to allow tension and hydraulic conductivity relationships to be different in each layer. However, Data is normally lacking to describe a soil profile in this detail.

The boundary conditions used to solve the set of finite difference equations of the form shown by equation (6) were determined for the surface layer by evapotranspiration (ET), rainfall rate (RR) and the profile moisture deficit (MD), and for the lowest unsaturated layer by the tile flow formula.

ET was computed by a diurnal expression which required the monthly average evapotranspiration, ET_{ma}. The expression used to describe ET was:

$$ET = ET_{ma} \ (1 - \cos \ (t \cdot C_1) \cdot C_2) \tag{7}$$

where C_1 and C_2 are constants which provide for a 24 hour cycle and a relative daily fluctuation, respectively. Evapotranspiration rates and daily fluctuation were determined from data given in the literature (Linsley, Kohler and Paulhus, 1975; Schwab, Frevert, Edminster and Barnes, 1966). The expression for the MD replenishment rate (MDR) was determined empirically during the calibration procedure of the model. The MDR expression used was:

$$MDR = C_3 \times e^{(C_4 \cdot WD - 1)} \tag{8}$$

where C_3 and C_4 are constants which represent the relative direct channelization (caused by soil cracking or well developed soil structure) and the variable setting of aggregation between flow channels, respectively. Rainfall was determined from observed recording raingage records.

The upper boundary condition was set by controling the water input to layer one by the following procedure:

> $q\ in_1 = 0$, if (RR - ET) <= MDR and profile water content <= equilibrium water content (MD > D).

or

> $q\ in_1$ = RR - ET - MDR for all other cases except if surface water storage exists, in which case an imaginary surface layer is set equal to the saturated water content and $q\ in_1$ is solved directly.

When $q\ in_1 = 0$, MDR is set equal to -ET. This serves to build up the moisture deficit during periods of no rainfall.

The lower boundary condition is determined by setting the outflow of the lowest unsaturated layer equal to the tile outflow as predicted by the tile flow formula. The position of the unsaturated-saturated flow interface (watertable) is adjusted accordingly to maintain continuity between the two flow regimes.

PARTICLE DETACHMENT

The particle detachment portion of the model is based on theory developed by Zaslavsky and Kassiff (1965) for cohesive soil piping and a probabilistic point force relationship developed in this paper. Zaslav- sky, in describing the force balance for particles in cohesive soils, showed an implied inter-relationship of flow gradients to the detachment of fine particles. He found that for a given particle size a threshold (critical level for piping to occur) flow level must be reached before particle detachment would occur. Zaslavsky's theory was developed for surface piping problems, but his basic concepts should also apply within the soil profile.

Zaslavsky's force balance for a single soil particle had three components: (1) cohesive resistant force, Fc, (2) gravitational force, Fg, and (3) hydraulic drag forces Fh. The cohesive resisting force which he considered to be the only force to prevent piping of small particles is the tensile stresses per unit area,

$$Fc = a_2 \cdot A \cdot \sigma t \tag{9}$$

where a_2 is a geometric coefficient, A is the area of the projection of the particle normal to the direction of the driving force and σt is the tensile strength of the soil

The gravitation force which can either enhance or resist detachment depending on direction of flow is simply the submerged weight of the particle,

$$Fg = -V \cdot (\gamma s - 1) \cdot (1-n) \cdot \gamma w \cdot \cos(\alpha) \tag{10}$$

where V is the volume of the particles, γs and γw are the specific weight of the particle and water, respectively, n is the porosity of the particle, and α is the angle of the flow direction from vertical. Zaslavsky considered only vertically upward flow.

Hydraulic drag forces were assumed to be the pressure head loss due to flow resistance of the soil. These drag forces were considered proportional between the macroscopic and the microscopic particle environment as given by the expression:

$$Fh = a_1 \cdot V \cdot \gamma w \cdot q/K \tag{11}$$

where a_1 is a shape factor and K is the hydraulic conductivity of the soil. Equation (11) could have been obtained from a more complete microscopic consideration of the drag and lift forces on an individual particle since these forces are also directly proportional to q. An expression yielding critical flow values, Q_c, was then derived as:

$$Q_c = \frac{\pi \cdot b \cdot \sigma t}{2 \cdot d \cdot \gamma w} \cdot K \cdot D^2 \tag{12}$$

where b is a general geometric factor, D is the hole or channel diameter where water exists in the soil, and d is the particle diameter. The coefficient of KD^2 was approximately constant for a given soil so that the values remaining on the right side of equation (12) can be lumped together into a single coefficient which is measurable in the laboratory.

Advancement of Theory

The theory as presented in the previous section considered piping as a surface phenomenon which progresses into the soil as failure continues. However, internal detachment of soil particles will also occur in some subsurface drainage systems. This internal erosion rarely causes failure of the soil profile, or of the drain line itself but does contribute to the degradtion of water quality.

Internal erosion may be viewed as a surface phenomenon on a microscopic scale. Therefore, it is possible to use the basic force balance relationship developed by Zaslavsky with the following modifications. First, point forces which are the forces of physical contact between particles need to be considered, and secondly, the cohesive forces need also to be viewed on a microscopic scale. The effect of soil water chemistry on cohesive forces between soil particles are neglected because, at best, only general trends are presently known for these relationships (Sarguman, 1973).

Zaslavsky's cohesive force relationship was expanded to provide for a cohesive force determination for each particle size. This was done by assuming that the cohesive force on a particle is proportional to the square inverse of the particle size and directly proportional to tensile strength of the soil. However, the actual functional relationship between particle size and cohesive forces can vary considerably because of different types of attractive and repulsive forces (hydration, Van de

Waals, electrostatic, osomotic and orientation) coming into play at various times (Landau, 1974). An estimate of the mean cohesive force on particles with a given size are as follows:

$$f_c(d) = CK \cdot \sigma t/d^2 \qquad (13)$$

with

$$CK = 1/\sum_i N \cdot (1/d_i^2) \cdot f_i \qquad (14)$$

where N is the total number of particles in the layer of shear in which tensile strength is determined, i represents a particle size interval and f_i is the fraction of the N particles which are in the interval i. These equations are based on the assumption that cohesive forces are responsible for the tensile strength of a soil.

Point forces, Fp, are those forces of physical contact between particles. The net point force on a particle is the sum of all physical contact forces on the particle just before the particle could be detached by hydraulic forces. The size of the particle influences these forces as well as the matrix configuration around the particle. Therefore, a distribution of point forces must be determined for a given particle diameter. Figure 2 provides a hypothetical point force distribution which can be described for some particle sizes by the function relationship, fp(Fp).

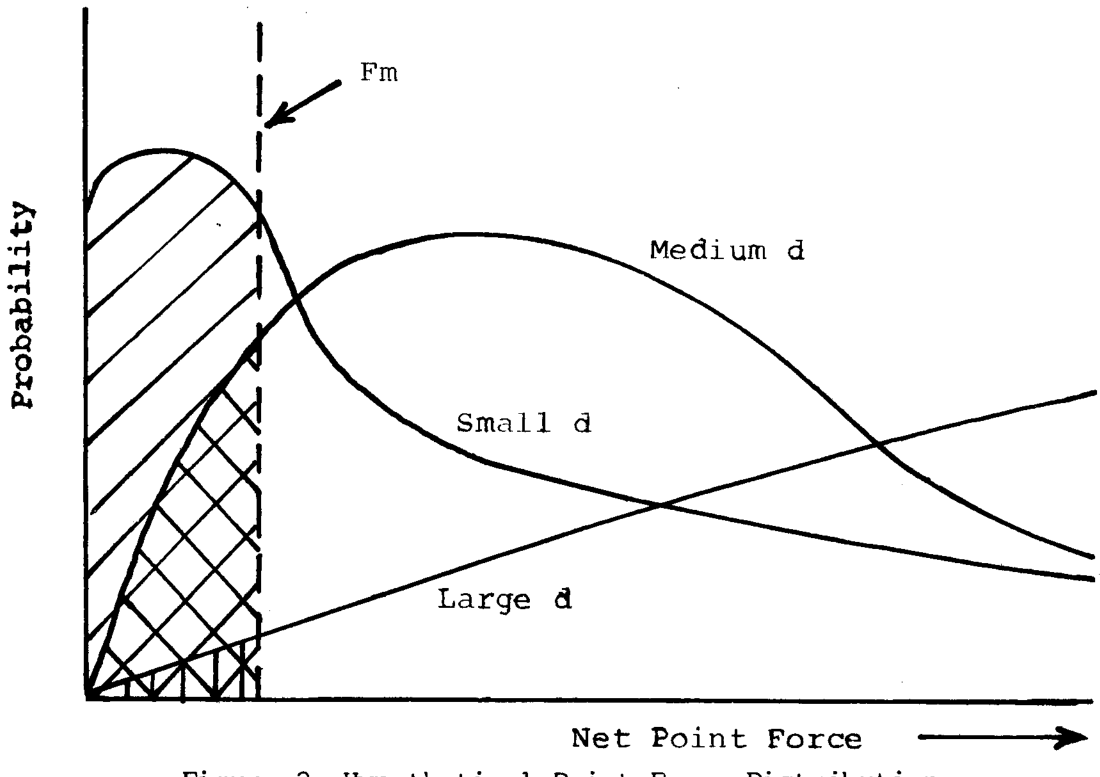

Figure 2. Hypothetical Point Force Distribution

As seen in Figure 2 particles sizes capable of being eroded are given by the area under the curve to the left of the detachment force, F_m. The detaching force, which is a function of d and q, is the difference between the hydraulic force and the component of the sum of the cohesive and gravitational force in the direction of the hydraulic force. Using these relationships a parameter for erosion per unit soil volume per unit time is defined as:

$$E_i = C3 \int_0^{F_m} fp_i \ (Fp) \cdot dFp \qquad (15)$$

where C3 is an empirically determined constant. The total area under the curve of fq(d) is defined to be unity.

To obtain the total soil movement per unit time, TE, the unit erosion parameter, E, must be summed over the entire profile, namely:

$$TE = \sum_i \int A \ E_i \cdot dA \qquad (16)$$

where A is the saturated section of the soil profile above the impeding layer. Equation (16) assumes unit thickness to provide for the volume integration of the two dimensional model. The erosion potential in the unsaturated zone is assumed zero.

In the expression for the total erosion rate, the only variable in its formulation that is a function of short term time is q which appears in the expression for Fh. This, plus the assumption that the saturated streamline pattern is relatively stable, allows the water flux in the saturated profile to be given as a function of the flow into the drain line only. Therefore, regardless of the streamline pattern shape, total erosion becomes a function of the single time dependent variable, qt, and the point force distribution.

The point force distribution is the controlling factor in the determination of the soil loss from a subsurface drainage system. It can be determined directly, if sediment loading data are available for the given system, by differentiating equation (15) which yields:

$$fp_i \ (Fp) = \frac{1}{C3} \cdot \frac{dE_i}{dF_m} \qquad (17)$$

The point force distribution and cohesive forces for the particle size interval will normally be very difficult to determine. Therefore, one is forced to use a lumped or equivalent particle size until better data becomes available. The assumption of an equivalent single particle size yields the following lumped point force distribution:

$$fp'(Fp) = C4 \frac{d(TE)}{d(qt)} \qquad (18)$$

where C4 is a constant to assure unit area under the distribution function. The ordinate of the fp' distribution is given as qt above, but as indicated F_m is a direct function of qt so equation (18) is the same as equation (17) for a single equivalent particle size.

MODEL CALIBRATION

Many parameters required by the model were readily available from observed data or literature, but a few were not. The unknown parameters and relationships were empirically determined to assure the model would simulate recorded events without losing the flexibility of a theoretically based model.

Several parameters were fixed and were not subject to change during calibration: tile lateral spacing, tile radius, depth of tile, area of the drainage system, tension versus water content curve, rainfall and evapotranspiration. The twenty-five year old drainage system layout was determined from records of the landowner. ET was determined from the literature. A recording weighting bucket raingage provided for a continuous rainfall intensity data file. The tension versus water content relationship was experimentally* determined and then approximated as a linear function. Saturated hydraulic conductivity, deep seepage and coefficients for the rate of replenishment of the moisture deficit were determined by calibration procedures. Moisture deficit was estimated at the start of a simulated run.

Calibration Procedures

The hydraulic conductivity (first parameter calibrated) was assumed to be a linear function of water content after multiple attempts, using nonlinear relationships, showed limited change in model predictions. Because of this linearization, saturated hydraulic conductivity was considered alone. The model was run repeatedly for different values of saturated conductivity holding other parameters constant. An initial estimate of the conductivity was made using data given in the Soil Survey Report. Best estimates were made for the other parameters yet to be determined. The characteristic being observed was the ability of the model to provide the hydraulic response of the leading edge of the hydrograph. Other parameters were observed to have an insignificant effect on this characteristic. The final saturated hydraulic conductivity selected was three centimeters per hour.

The second parameter calibrated was deep seepage. Deep seepage was varied significantly within a range of reasonable values (.00-0.01 centimeters/hour) and was observed to have a negligible effect on the model output. Therefore, deep seepage was arbitrarily set at .001 centimeters/hour.

The last parameters considered during calibration were constants of equation (8) needed to describe the replenishment rate. They were determined by systematic variation of their initial input values. The moisture deficit was determined by the actual moisture deficit

* Experiments were run by Edward R. Miller, graduate student at Purdue University.

replenished by rainfall during the selected calibration storm. C3 acted as a multiplier factor for the overall size of the tile outflow hydrograph. C4 had a more significant impact on the shape of the trailing edge of the tile hydrograph. After calibration, the accepted values were: C3 = 0.1, C4 = 0.8, and a moisture deficit equal to 4.2 centimeters. C3 and C4 should remain constant for a given profile. However, the moisture deficit must be estimated for each storm simulated if it has not already been provided by previous simulations. The moisture deficit would be zero for very wet antecedent moisture conditions.

All flow related calibration procedures were accomplished for a single well-behaved event in late June, 1977. This event was selected because it was an isolated storm resulting from a single strong rainfall event preceded by a relatively dry period. The dry antecedent conditions provided a significant response of the system to the moisture deficit relationship. Also, the time separation of this calibration period and the verification period assured less interference between the two periods. However, the sediment calibration of the model was based on all of the non-thaw periods of records.

The sediment erosion relationships used in the model were determined empirically from observed data and the particle detachment theory. The theory predicted sediment loading to be a function of tile flow as determined by the point force distribution fp(Fp). As observed with actual data, sediment concentrations remained nearly constant during periods of varying flow except for an initial flush of sediment following a prolonged dry spell. Otherwise the point force distribution was found to be constant according to equation (6) since the sediment loading was considered directly proportional to flow.

The reason for observed high initial sediment concentrations is not well understood. However, its behavior was easily described mathematically. The initial flush followed an exponential decay which was fairly consistent for all storms monitored. The peak sediment concentration was approximately three times the equilibrium concentration with a decay constant of approximately fifteen hours. The equilibrium sediment concentration was observed to be approximately sixty milligrams per liter.

Figure 3 shows the final output of the calibrated model compared with actual data from which it was calibrated. The remaining discrepancies between the actual and simulated curves are a result of the theoretical flow model not truly representing the actual flow mechanisms occurring in the field. The difference is particularly noticeable during the leading edge of the hydrograph where the flow theory deviates the greatest from the field situation.

COMPARISON OF SIMULATION RESULTS TO OBSERVED DATA

The validity of any model must ultimately be determined by comparing its output to observed data. Graphical results for water and sediment yields predicted by the developed computer model are shown in Figure 4.

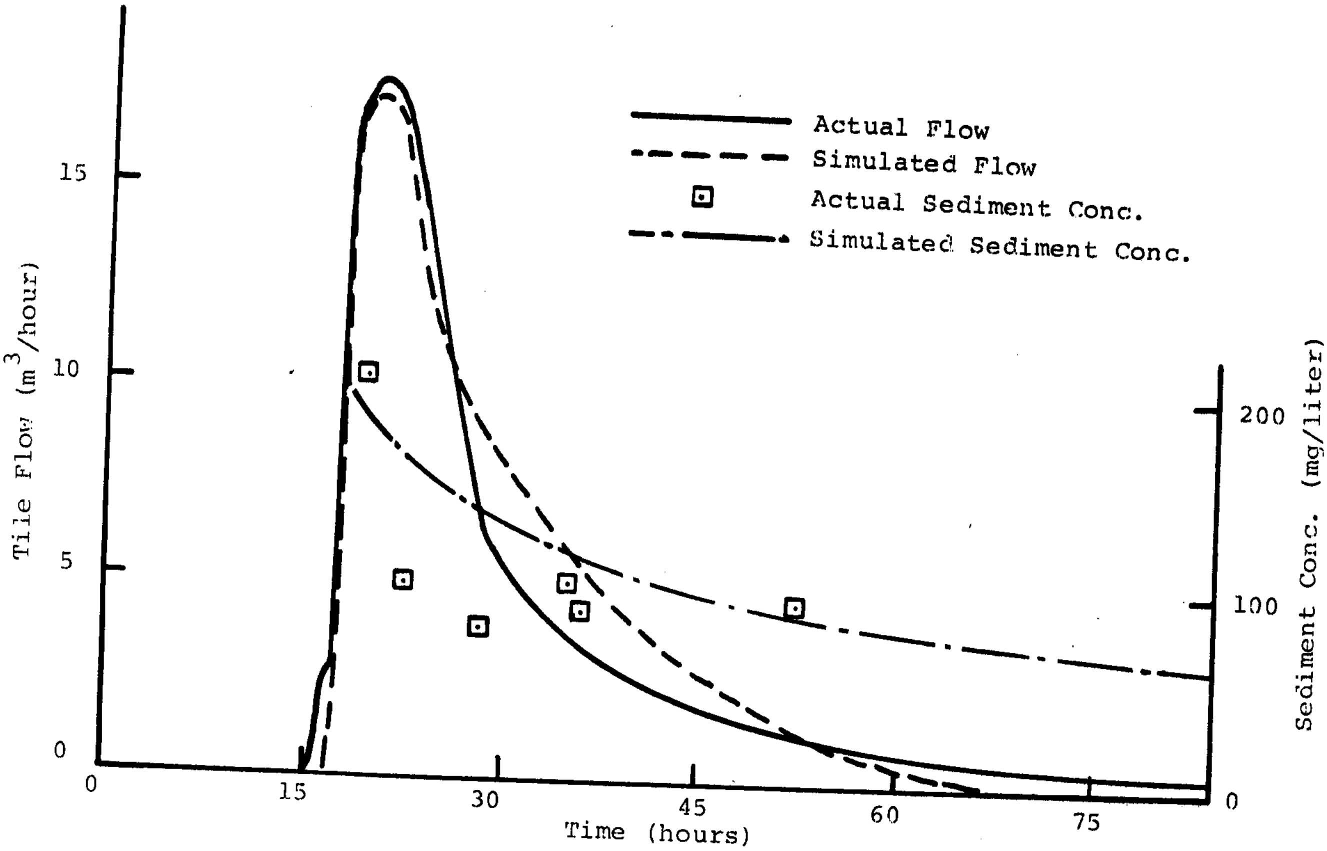

Figure 3. Actual vs Simulated Results for Calibration Storm

An 18-day period of record beginning at 9:00 AM on April 21, 1977, was used to verify the model. This period was chosen because it included the only significant multiple peak flow event recorded which was not the result of a freeze-thaw condition. The total tile discharge during the verification period represented nearly fifty percent of the total discharge for the two years of record.

Flow Prediction

General agreement between actual and simulated flow is seen in Figure 4. However, some differences did occur which were partially the result of assumptions and approximations made for soil properties that were not otherwise available. Even when performed in the laboratory, determination of soil properties such as hydraulic conductivity and the tension characteristic curve are subject to large error. This fact when combined with large field variations interferes with the acquisition of truly reliable data.

Non-uniformities in the field and a time variation of the soil system affecting flow would also cause the model to imprecisely predict the flow hydrograph. The latter was evident by direct channelization of flow which allowed water to bypass sections of the soil matrix. This resulted in a higher hydraulic conductivity until the profile became wet

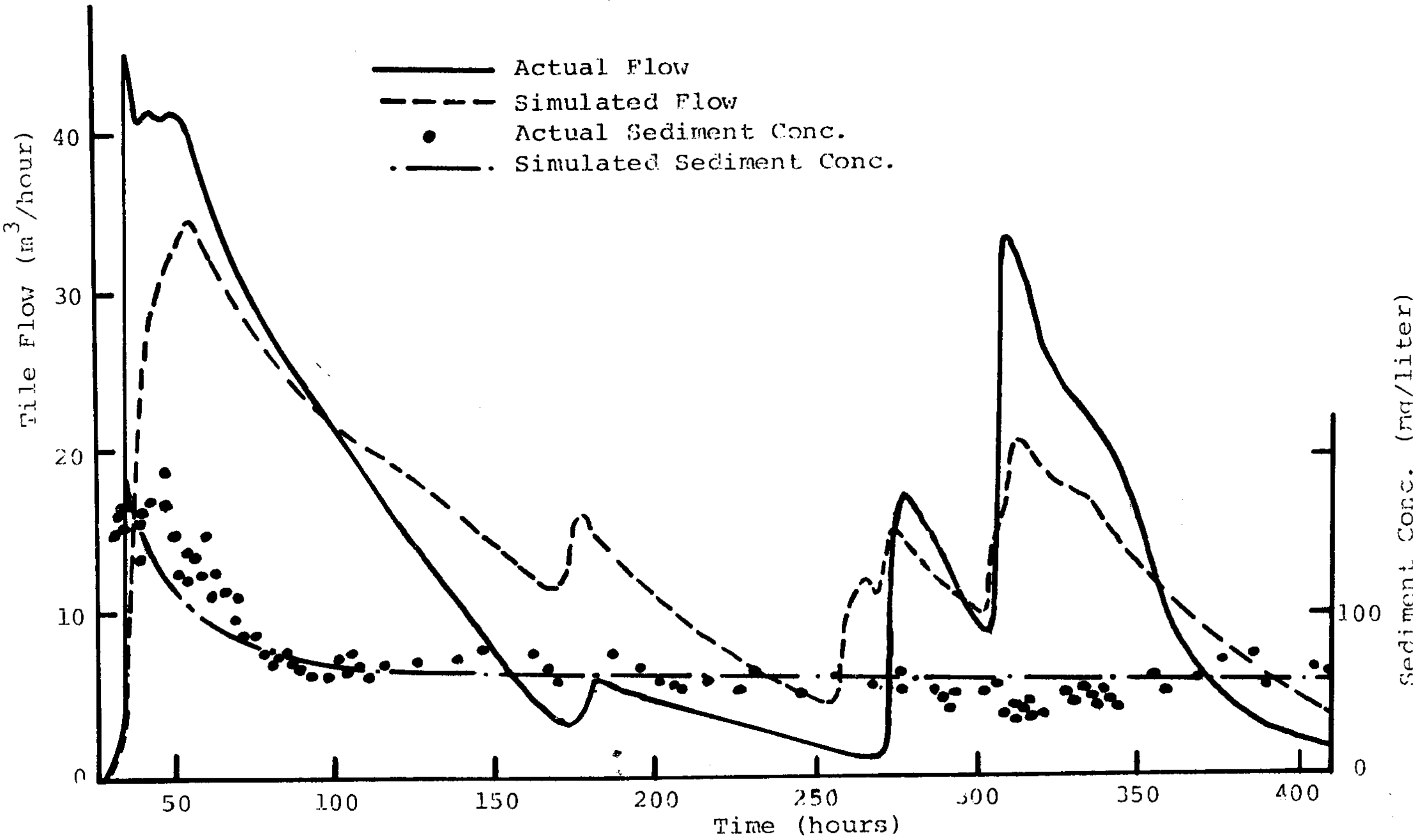

Figure 4. Actual vs Simulated Results of Tile Flow and Sediment Yield

at which time the channels either swelled shut or collapsed from erosion. This phenomenon was corrected by the use of the moisture deficit replenishment relationship.

The overall performance of the flow model was good. It predicted when and where flow events occurred and provided a very close approximation of the total volume of water discharged from the tile drainage system (3.00 and 3.28 centimeters equivalent depth for actual and simulated, respectively).

Sediment Concentration Prediction

The ability of the model to accurately predict the sediment concentration in the tile effluent was attributed to the relative stability of the sediment concentration during periods of varying flow and the consistent nature of the decay in the high sediment concentration at the beginning of an event. Total sediment yield was predicted well by the model (428 and 402 kilograms for actual and simulated, respectively).

SUMMARY AND CONCLUSIONS

Summary

A computer model programmed in the GASP IV simulation language was developed to predict flow and sediment loadings from a subsurface drainage system using natural rainfall data as input. In the flow portion of the model, the soil profile above the tile was divided into twenty (variable to 100) horizontal layers. A modified form of Richard's equation was used to describe the water movement between the unsaturated layers above the watertable and a tile flow formula developed by Toskoz and Kirkham was used below the watertable. The boundary condition at the soil surface was determined by rainfall, evapotranspiration and the moisture deficit of the soil profile. The boundary condition at the watertable was controlled by conservation of mass and the tile flow formula.

The sediment moment portion of the model was based on a particle detachment theory and an empirical analysis of the sediment flush observed at the beginning of flow events. The particle detachment theory predicted that the sediment yield from a subsurface drain was a function only of the drain outflow and a point force distribution which was found to be uniform. The initial flush was adequately described by an exponential decay function with a fifteen hour decay constant.

Calibration and verification of the model was completed using data collected from a seventeen hectare drainage system on a Hoytville silty clay soil. An automatic drain sampling station was constructed to collect water samples at a rate directly proportional to drain flow. Drain flow and rainfall were recorded continuously. A large storm event in late June, 1977, was used to calibrate the model. The varied parameters were the moisture deficit replenishment coefficients, deep seepage, and the saturated hydraulic conductivity.

Verification of the model was accomplished by simulating the most active flow period of the two years of record. The only variable requiring an initial estimate was the moisture deficit. Simulated results compared well with observed data.

Conclusions

The following conclusions are based on experiences gained in the model development and comparisons made between the simulated and actual data.

One-dimensional Darcyian flow theory provided only a fair representation of the actual flow mechanisms existing in the soil profile. The leading edge of a flow hydrograph deviated most from theory.

The model required values of hydraulic conductivity for Hoytville silty clay higher than previously reported in soil survey reports. Reported values of hydraulic conductivity would not allow the model to simulate the rapid hydraulic response of the tile drains to rainfall.

Linearization of both the tension and hydraulic conductivity versus water content relationships provides a reasonable representation of the actual data in view of the variability and reliability of this data. Nonlinear relationships did not significantly improve the ability of the model to simulate actual data. Nonlinear expressions also increased the computer run times significantly.

Direct or partial channelization of rainwater to the subsurface drains does exist. Water was observed reaching the drains long before the actual moisture deficit of the soil was replenished. This may in part be the result of deep cracking of the soil profile. The detection of surface applied chemicals in the drains shortly after application supported the presence of channelization.

The particle detachment theory was in agreement with observed data except during the initial period of sediment flush. The cause of the high sediment concentration at the beginning of a storm is not well-understood, but it does follow a well-described exponential decay pattern. However, the potential for the high sediment at the beginning of a storm is directly affected by the length of time the soil profile is at or below the equilibrium water content. It was found the greates initial flush of sedements ocurred after long dry periods. Using this potential relationship and the observed exponential decay relationship, the model predicted the sediment loading from a subsurface drainage system.

Point forces on soil particles which detach and move into the subsurface drains are negligible as indicated by the uniform point force distribution. Therefore, point force considerations may not be necessary for subsurface sediment transport models.

REFERENCES

1. Amerman, C. R. 1976. Soil water modeling I: A generalized simulation of steady, two-dimensional flow. Trans. ASAE 19(3): 466-470.

2. Baker, V. L. and H. P. Johnson. 1976. Impact of subsurface drainage on water quality. Proceedings 3rd National Drainage Symposium. Chicago, Ill. pp. 91-98.

3. Bird, N. A. and V. A. McCorquadale. 1971. Computer simulation of tile systems. Trans. ASAE 14(1): 175.

4. Hillel, D. and C. H. M. van Bavel. 1976. Simulation of profile water storage as related to soil hydraulic properties. Jour. SSSA. Div. S-1, 40(6): 807-815.

5. Lake, James. 1978 Environmental impact of land use on water quality. J. Morrison. (ed.) EPA-905/9-77-0007B, Region V, U. S. Environmental Protection Agency, Chicago, Ill.

6. Landau, H. G., Jr. 1974. Internal erosion of compacted cohesive soil. Ph.D. Thesis. Purdue University, W. Lafayette, Ind.

7. Linsley, R. K. Jr., M. A. Rohler and J. H. Paulhus. 1975. Hydrology for Engineer. McGraw-Hill, Inc., New York, N.Y. pp.179-184.

8. Natur, F. S., L. G. King and R. W. Jeppson. 1975. Unsaturated-saturated flow through heterogenous sloping lands. Utah Water Res. Report No. PRWG59C-9.

9. Pritsker, A. A. B. 1974. The GASP IV Simulation Language. John Wiley & Sons, New York, N. Y.

10. Richards, L. A. 1931. Capillary conduction of liquids through porous mediums. Physics, Vol. 1. pp. 318-333.

11. Sarguman, A. 1973. Physico-chemical factors in erosion of cohesive soil. Jour. ASCE. Vol. 99, No. HY3: 555:558.

12. Schwab, G. O., B. H. Nolte, and R. D. Brehm. 1977. Sediment from drainage systems for clay soils. Trans. ASAE 20(5): 860-868.

13. Schwab, G. O., R. K. Frevert, T. W. Edminster and K. K. Barnes. 1966. Soil and Water Conservation Engineering. John Wiley and Sons, New York, N. Y.

14. Toskoz, S. and D. Kirkham. 1961. Graphical solution and interpretation of a new drain-spacing formula. J. Geoph. Res. 66:509-516.

15. Zaslavsky, D. and G. Kassiff. 1965. Theoretical formulation of piping mechanisms in cohesive soils. Geotechnique, Vol. 15, No. 3. p. 305.

RECONCILING STREAMBANK EROSION CONTROL

WITH WATER QUALITY GOALS

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ABSTRACT

The reality of sediment as a pollutant and the obvious presence of streambank erosion in many areas has precipitated many streambank erosion control programs. But streambank erosion is a complex problem which may, in many cases, be a minor contributor to sediment loads. More comprehensive cost-benefit analysis must be undertaken before massive programs to stabilize streambank are implemented. The effects of streambank erosion control on sediment loads, drainage efficiency, and the biological integrity of downstream water resources must be carefully evaluated. A critical areas approach should be implemented to replace the wholesale modification of stream channels so common in the past.

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Sediment can act as a water pollutant in two primary ways. First, excessive sediment may cause direct damage to a variety of organisms (Sorensen et al. 1977). Second, even when present in moderate amounts, sediment serves as a vehicle for the transport of nutrients, pesticides, and other material in water (Stewart et al. 1975). The reality of sediment as a pollutant and the obvious presence of streambank erosion in many areas has prompted streambank erosion control programs by Soil and Water Conservation Districts and the Soil Conservation Service.

It is tempting to issue a blanket statement that all streambank erosion is a scar upon the landscape and that we should attempt to erase it. But streambank erosion is a more complex problem than it might appear at first glance. Arguments to proceed with caution include, simply, the exorbitant cost of treatment in addition to more complex issues. In this paper we consider three problems at the center of the streambank erosion controversy. These are the need to:

1. determine the magnitude of the problem relative to total sediment yield throughout a watershed;

2. determine the actual crop loss due to drainage impairment and loss of crop land; and

3. consider headwater-stream channels as complex biological systems with a multiplicity of functions that are vital to downstream water-resource values.

Two recent studies clearly demonstrate that the magnitude of streambank erosion varies among watersheds. A study by the Soil Conservation Service indicates that streambank erosion is not a major source of sediment pollution in the Black Creek watershed. This study (Mildner 1976) done in conjunction with the Black Creek project revealed that only 6% of the sediment reaching the Maumee River from Black Creek originated in stream channels. From these data it is hard to justify massive efforts to stabilize stream channels throughout a watershed on the premise of reducing sediment export.

For the farmer, laymen, and even some "experts" it is hard to reconcile this conclusion with observations of large volumes of soil washed from eroding banks. However, when considering streambank erosion it is important to remember a few facts to keep the proper perspective on the larger issue of sediment pollution. A cubic yard of soil weighs approximately one ton and a mile long reach of eroding streambank may lose 100 cubic yards or tons of soil in one year. (A rate nearly twice that estimated by Mildner for Black Creek.) This may sound like a considerable loss but it is small when considered from a watershed perspective. One hundred acres of cropland in the Black Creek watershed typically lose as much soil to streams as the mile long reach of eroding streambank. However, this type of erosional loss is simply not visually detectable; a 100 ton loss spread evenly over 100 acres of cropland equals approximately 0.01 inches of soil. Since only 23% of stream channels in Black Creek have erosion problems (Mildner 1976), the sediment contributions of cropland far outweigh streambank erosion.

In contrast, a study of the sources of suspended sediments in the Spoon River, Illinois (Evans and Schnepper 1977) demonstrates that streambank erosion may be a major contributor of suspended material in our waterways. They found that 44% of the sediment transported from the watershed of a 31 mile reach of the Spoon River came from the stream channel itself. These two studies clearly demonstrate that treatment of stream channel erosion, to be cost effective, must only be attempted in critical locations where such erosion contributes significantly to the sediment exported from the watershed.

A far more serious problem connected with streambank erosion is damage to crops caused by drainage impairments or actual loss of cropland. Individual losses or washouts of cropland and other property can be dramatic but are limited to a few isolated cases. Obviously, in such critical problem areas, streambank erosion control measures may be justified and quite effective in solving the immediate problem. However, impaired drainage caused by loss of tile outlets or the impedence of storm flows is far more commonplace. In many low gradient ditches throughout the Maumee basin tile outlets can be blocked by the accumulation of sediment in the ditch bottom. Often the source of this blockage comes from slipping banks and lack of sufficient water velocity to carry trapped sediment downstream.

Tile drainage can also be impaired when storm flows recede so slowly that the tile outlets are covered with water for extended periods of time. Again, a critical factor acting to slow storm runoff may be the accumulation of sediment within the channel. Sediment deposition reduces the capacity of the channel to hold water and also slows runoff by causing the water to meander from one side of the channel to the other.

After a stream has been channelized, progressive changes occur that lead to less than maximum drainage efficiencies. Fundamental physical laws governing natural processes dictate this reality (Yang 1971). Streambank erosion is but one of the complex factors involved in causing drainage impairment. Other factors include changes in bed roughness, pool-riffle frequency, meander frequency, and channel profile (Stall and Yang 1972). Within the constraints of the system (land topography, channel bottom material, etc.), these factors create channels with minimum rates of potential energy expenditure and less than maximum drainage efficiency.

In some streams, therefore, the maintenance of clean, straight ditches with maximum drainage efficiencies can be a costly and never ending battle (Maddock 1976, Karr and Schlosser 1978). To be cost effective, the benefits realized through increased crop yield must exceed the costs of maintaining a satisfactory level of drainage (through streambank erosion control and bottom-dipping). Unfortunately, such cost-benefit analyses are lacking in much drainage oriented work carried out by government agencies and the private landowner.

A third and vitally important consideration in streambank erosion control programs involves the headwater stream environment.

Throughout much of the Midwest, truly natural stream environments rarely exist because man has greatly altered the landscape to create productive cropland. Much of the productive farmland in the Maumee basin is dependent upon the drainage provided by channelized streams. Such streams are typically uniform in depth and width and have shifting sand bottoms. Woody vegetation is often removed from the banks, and snags and sand bars are removed periodically.

However, as we have already noted, streams have a tendency to return to a more natural condition. The uniform stream bed is readjusted to become a series of deep pools with sand or silt bottoms alternating with shallower, gravel-bottomed areas, called riffles. Unless kept in check, woody vegetation colonizes the banks. Weathering and storm flows create areas of bank erosion that impart a degree of meandering to the formerly straight channel. After a period of time (10-20 years) the channelized stream returns to a semi-natural stream environment.

What is the fate of the aquatic life that must face the environmental conditions of channelized vs. semi-natural streams? Biological studies conducted in Black Creek (Gorman and Karr 1978) and elsewhere (see Karr and Schlosser 1977 for references) have documented the unstable aquatic communities in channelized streams. In essence, the biota of headwater streams exists in a very degraded state in channelized areas.

As noted elsewhere in this volume (Karr and Dudley 1978) these degraded communities are important determinants of downstream water resource values. Fish communities in agricultural watersheds are as much a product of poor physical stream environment (uniform channels, shifting sand substrate, etc.) as any specific water pollutants (sediment, sewage, etc.). Fish populations and other aspects of aquatic life are healthier and more stable in a semi-natural stream environment. In short, aquatic life that evolved in the presence of meanders, pools and riffles, and the shade and cover of woody bank vegetation can only be maintained in the presence of these naturally occurring stream features. Efforts that seek to curtail all forms of streambank erosion (i.e. create maximum drainage) through constant re-channelization make the semi-natural stream environment with healthy, useful aquatic resources an impossibility.

Until these problems are given serious consideration, sound and rational programs to correct streambank erosion will not be forthcoming. Society has two basic choices for managing the total resource base in an agricultural area. The first is to achieve maximum agricultural production from the area independent of the consequences to other resources. Alternatively, we can strive to optimize the level of agricultural production with the conservation of the remaining resources, including minimizing downstream impacts. The second strategy means less than maximum farm production but is the only way to insure the sound conservation of all our nation's resources, including water. Current national laws (PL-92-500, the Clean Water Act of 1972) make it clear we must conserve our water resources. This means we cannot design streambank erosion control and drainage practices solely to maximize agricultural production.

Regrettably, no standards for evaluation and implementation of streambank erosion control programs that adequately consider these problems are available. However, some general guidelines can be suggested. Streambank erosion control should only be permitted where it will be cost effective; that is, where significant reductions in sediment transport can be obtained for the dollars spent. In general we feel this will involve a "critical areas" approach. Further, controlling streambank erosion in low gradient ditches is necessary to maintain crop productivity in flat land where tile drainage is needed. Programs with this goal should stress the development of stable bank slopes and vegetation cover to help stabilize the bank. Regular efforts to maintain bank protection can help to minimize radical and expensive efforts at longer time intervals.

Massive programs are often incompatible with clean water goals when they are carried out over entire watersheds. It is simply not possible to have a stream ecosystem with any degree of biological integrity in a watershed where 100% of the headwater channels have been modified to provide maximum drainage. The potential exists, however, for an acceptable level of biological integrity in watersheds with a relatively small percentage of natural or semi-natural headwater streams. Little or nothing is known about what that percentage should be.

The challenge to water resource planners, engineers, biologists, economists, and the farm community is to discover innovative ways to select and maintain the number of semi-natural streams needed to conserve water resources while continuing to provide adequate drainage for farm production needs.

LITERATURE CITED

Evans, R. L. and D. H. Schnepper. 1977. Sources of suspended sediment: Spoon River, Illinois. North-Central Section, Geological Society of America, Southern Illinois Univ., Carbondale. 10 pp, mimeo.

Gorman, O. T. and J. R. Karr. 1978. Habitat structure and stream fish communities. Ecology. 59: In press.

Karr, J. R. and D. R. Dudley. 1978. Biological integrity of headwater stream: evidence of degradation, prospects for recovery. In J. Lake and J. Morrison (eds.). U.S. Environmental Protection Agency, Chicago. EPA-905/9-77-007-D. In press.

Karr, J. R. and I. J. Schlosser. 1977. Impact of nearstream vegetation and stream morphology on water quality and stream biota. U.S. Environmental Protection Agency, Athens, GA. EPA-600/3-77-097. 103 pp.

Karr, J. R. and I. J. Schlosser. 1978. Water resources and the land-water interface. Science 201: 229-234.

Maddock, T., Jr. 1976. A primer on floodplain dynamics. J. Soil and Conserv. 31: 44-47.

Mildner, W. 1976. Streambank erosion in Black Creek watershed, Indiana. Prep. by USDA Soil Cons. Serv. An assignment of the U.S. Task C. Work Group of the International Reference Group on Great Lakes Pollution from Land Use Activities. 5 pp. + 2 Append., Mimeo.

Sorenson, D. L., M. M. McCarthy, E. J. Middlebrooks, and D. B. Porcella. 1977. Suspended and dissolved solids effects on freshwater biota: A review. U.S. Environmental Protection Agency, Corvallis, Oregon. EPA-600/3-77-042. 73 pp.

Stall, J. B. and C. T. Yang. 1972. Hydraulic geometry and low streamflow regimes. Univ. Illinois, Water Resources Cent., Res. Rept. No. 54, 31 pp.

Stewart, B. A., D. A. Wollhiser, W. H. Wishmeier, J. H. Caro, and M. H. Frere. 1975. Control of water pollution from cropland. Vol. I- A manual for guideline development. EPA-600/2-75-026a. 111 pp.

Yang, C. T. 1971. Potential energy and stream morphology. Water Resources Res. 7: 311-322.

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16. ABSTRACT

This is an addition to the Final Technical Report of the Black Creek sediment control project. This project is to determine the environmental impact of land use on water quality and has completed its four and one half years of watershed activity. The project, which is directed by the Allen County Soil and Water Conservation District, is an attempt to determine the role that agricultural pollutants play in the degradation of water quality in the Maumee River Basin and ultimately in Lake Erie.

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