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LAKE ERIE WASTEWATER MANAGEMENT STUDY, METHODOLOGY REPORT.(U)

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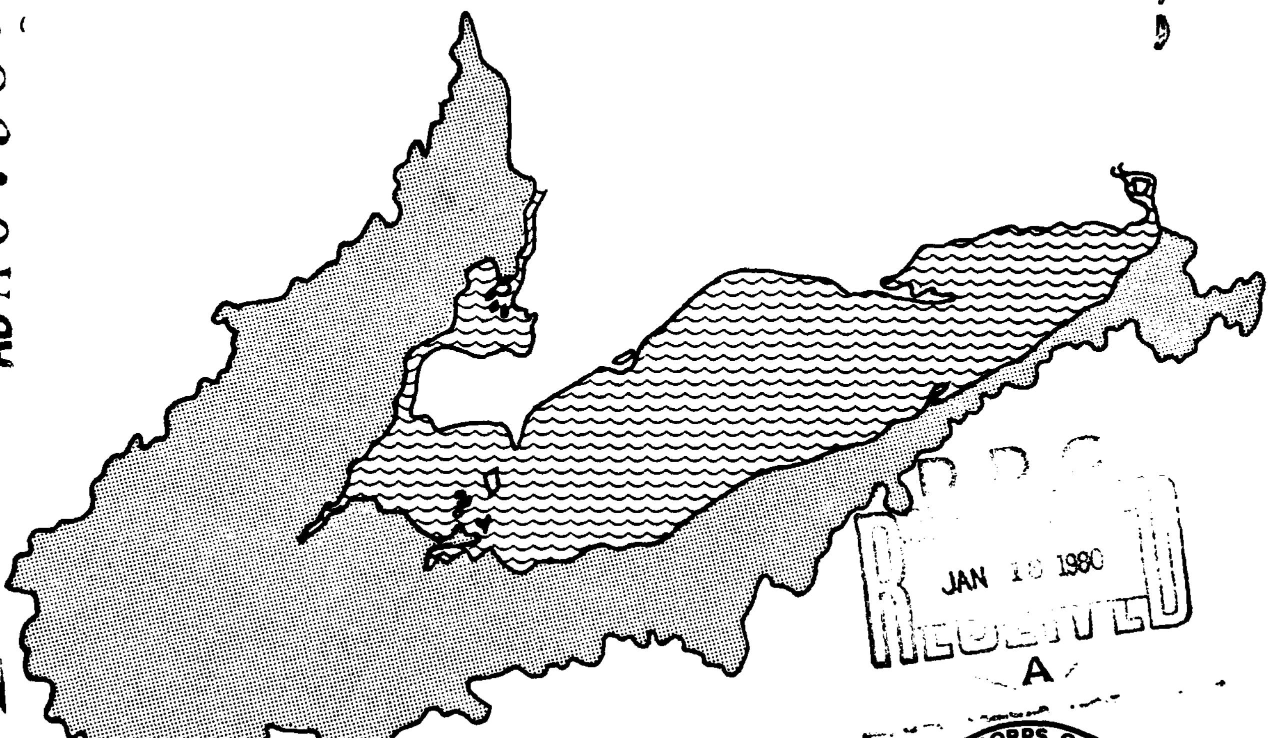
LAKE ERIE WASTEWATER MANAGEMENT STUDY METHODOLOGY REPORT



LAKE ERIE WASTEWATER
MANAGEMENT STUDY
U.S. ARMY ENGINEER DISTRICT, BUFFALO

MARCH 1979

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This Methodology Report deals with the second phase of the Corps of Engineers study effort to develop a recommended wastewater management program to restore and rehabilitate Lake Erie. The Preliminary Feasibility Report of Phase I stated that control of diffuse sources of phosphorus would be required to restore Lake Erie. This conclusion has not changed and this report presents alternative management scenarios for control of diffuse sources.

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Land management options designed to reduce sediment export from the drainage basin have been analyzed and evaluated, with regard to their effect on phosphorus export from the drainage basin and their effect on farm income. The use of land in the Lake Erie drainage basin is described and its role in the generation of pollutants has been evaluated. The process by which pollutants are removed from the land and transported by the tributary system to the lake has been analyzed.

LAKE ERIE WASTEWATER
MANAGEMENT STUDY
METHODOLOGY REPORT

March 1979

U.S. ARMY CORPS OF ENGINEERS
BUFFALO DISTRICT

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Stephen M Yaksich

STEPHEN M. YAKSICH, Ph.D
Project Manager

SYLLABUS

LAKE ERIE WASTEWATER MANAGEMENT STUDY
PRELIMINARY FEASIBILITY REPORT

This Methodology Report deals with the second phase of the Corps of Engineers study effort to develop a recommended wastewater management program to restore and rehabilitate Lake Erie. The Preliminary Feasibility Report of Phase I stated that control of diffuse sources of phosphorus would be required to restore Lake Erie. This conclusion has not changed and this report presents alternative management scenarios for control of diffuse sources.

The in-lake phosphorus concentration objectives of Phase I have been replaced with a whole lake phosphorus loading objective of 11,000 metric tons per year. It has been projected that if this loading objective is met, the anoxic area in the central basin of Lake Erie would be reduced by 90 percent and would essentially eliminate nutrient release from the sediments. This loading objective can be achieved through a combination of point and diffuse source load reductions. Inputs from Lake Huron and the atmosphere are assumed to be uncontrollable and constant.

Further study has been made of the relative importance of nonpoint (diffuse) sources to point sources of pollution in terms of their effect on in-lake water quality, including the availability of nutrient loadings for biological uptake in the lake. The use of land in the Lake Erie drainage basin is described and its role in the generation of pollutants has been evaluated. The process by which pollutants are removed from the land and transported by the tributary system to the lake has been analyzed. Sediment was found to be an important agent for transport of nutrients. Therefore, land management options designed to reduce sediment export from the drainage basin have been analyzed and evaluated, with regard to their effect on phosphorus export from the drainage basin and their effect on farm income.

The following conclusions are based on Phase II findings:

PHASE I CONCLUSION THAT DIFFUSE SOURCE CONTROL IS NECESSARY IS STILL VALID.

If only municipal point sources with a flow greater than one million gallons per day are required to reach effluent phosphorus concentrations of one mg/l or 0.5 mg/l, it is estimated diffuse sources of phosphorus must be reduced accordingly to 47 and 33 percent (4,500 and 3,200 MT/yr) to reach the loading objective of 11,000 metric tons per year. Inclusion of all point sources will change these reductions to 42 and 26 percent (4,100 and 2,500 MT/yr).

These diffuse source reductions are calculated for an average hydrologic year.

For the scenarios considered above, the anoxic area of the Central basin will be reduced by 90 percent but the western basin would still remain eutrophic.

THE BULK OF THE PHOSPHORUS FROM DIFFUSE SOURCES AND INLAND POINT SOURCES REACHES LAKE ERIE IN ASSOCIATION WITH SUSPENDED SEDIMENT TRANSPORTED DURING STORM EVENTS.

Tributary monitoring has shown that an average of 83 percent of the total phosphorus load from diffuse sources was sediment phosphorus for 1976 and 1977.

Soluble phosphorus from point sources is rapidly removed from the water column and subsequently transported as sediment phosphorus during high flow events.

The bulk of phosphorus from diffuse sources is attached to eroded soil particles, especially the clay fraction.

Most nonpoint source phosphorus is delivered to the lake during runoff events, particularly during the major late winter-early spring periods.

Dissolved orthophosphate derived from nonpoint sources and delivered to the lake during storm flows form a significant component of the orthophosphate loading to the open water of the lake. This fraction of the nonpoint phosphorus loading to the lake may not be significantly affected by farm management practices.

Through analysis of individual events, deposition and resuspension of point source phosphorus has been documented. However, changes in annual load resulting from removal of point source phosphorus have not been measured in agricultural river basins.

While some of the sediment phosphorus is directly delivered to the lake, a substantial portion reaches the lake through a series of deposition and resuspension events.

Delivery losses, i.e. long-term losses of sediment and associated phosphorus, occur along the main stem channels of the river. These losses occur when sediments settle behind dams and on flood plains.

Hydrologic modifications resulting from agricultural practices such as tile drainage, parallel tile outlet terraces, and reduced tillage will reduce peak flows which will reduce the transport of phosphorus to Lake Erie.

Analysis of individual storms indicate that control of sheet erosion will not increase channel erosion.

THE BIOLOGICAL AVAILABILITY OF SEDIMENT BOUND PHOSPHORUS VARIES CONSIDERABLY WITH FLOW AND BETWEEN RIVER BASINS.

Suspended sediments from the more urbanized tributary areas in Michigan and eastern Ohio and those from the high clay agricultural basins in western Ohio have the highest percentage of immediately and potentially available phosphorus.

Suspended sediments from New York tributaries were lowest in immediately and potentially available phosphorus.

The rate at which phosphorus becomes available appears to be more of a limiting factor in supply of phosphorus to algae than the total amount of potentially available sediment P.

Phosphorus control at inland point sources is much less effective in reducing bioavailable phosphorus loading into Lake Erie than phosphorus removal at point sources emptying into the lake.

The high total annual sediment load in Western basin rivers together with high bioavailable sediment phosphorus point to these rivers as large contributors of bioavailable sediment phosphorus. In addition, the discharge of these sediments into the shallow western basin of Lake Erie make their impact on algal production even more significant. In the Central and Eastern basins the contribution of sediment phosphorus to algal growth is diminished for two reasons: lower sediment loads and lower bioavailable sediment phosphorus, and shorter contact time between algae and sediment because of settling.

REDUCING GROSS EROSION WILL REDUCE PHOSPHORUS LOADS TO LAKE ERIE.

The actual phosphorus load reduction will depend upon the soils, phosphorus enrichment ratio, sediment delivery, and type of erosion occurring.

The reduction in delivered phosphorus resulting from a given decrease in potential gross erosion, although substantial, can only be estimated and appears to be between 60 and 90 percent.

NONPOINT SOURCE PHOSPHORUS IS DERIVED PRINCIPALLY FROM AGRICULTURAL LAND USE, PARTICULARLY CROP PRODUCTION.

A program to reduce the delivery of sediment phosphorus to the lake should be based on erosion reduction programs for agricultural lands.

Sheet erosion is the major source of the bioavailable sediment phosphorus delivered to Lake Erie. Consequently, erosion reduction programs must center on sheet erosion even though gully and stream bank erosion create severe land problems and are also deserving of attention.

ADOPTION OF CONSERVATION TILLAGE AND NO-TILL PRACTICES APPEARS TO BE AN ECONOMICALLY FEASIBLE METHOD OF REDUCING POTENTIAL EROSION IN THE LAKE ERIE BASIN.

Adoption of conservation tillage and no-till practices as estimated by the Universal Soil Loss Equation can potentially reduce gross erosion in the basin by 47 to 69 percent.

Conservation tillage and no tillage practices are feasible for the soils which generally have the highest erosion rates in the basin.

Conservation and no-till practices have the greatest potential for reducing phosphorus loadings from diffuse sources to Lake Erie and will be more easily accomplished and accepted than basin-wide attempts to change cover, land use, or crop rotations.

Conservation tillage and no-till practices, with their surface residue protection, provide erosion control during: (1) the high erosion hazard (soil detachment) season of May through September; and (2) during the high runoff periods of January to May.

A MAXIMUM RURAL DIFFUSE SOURCE TOTAL PHOSPHORUS LOADING REDUCTION OF 4,100 TO 5,100 MT/YR WILL RESULT IF THE MAXIMUM REDUCED TILLAGE SCENARIO IS ACHIEVED AND IF POTENTIAL GROSS EROSION REDUCTION IS 90 PERCENT EFFECTIVE IN REDUCING TOTAL PHOSPHORUS.

If this reduction is achieved, the phosphorus loading objective will be met if municipal point sources with flows greater than one million gallons per day reach an effluent phosphorus concentration of one mg/l.

A MAXIMUM RURAL DIFFUSE SOURCE TOTAL PHOSPHORUS LOADING REDUCTION OF 2,800 TO 3,400 MT/YR WILL RESULT IF THE CHISEL PLOW REDUCED TILLAGE SCENARIO IS ACHIEVED AND IF POTENTIAL GROSS EROSION IS 90 PERCENT EFFECTIVE IN REDUCING TOTAL PHOSPHORUS.

If this reduction is achieved, the phosphorus loading objective will be met if municipal point sources with flows greater than one million gallons per day reach an effluent phosphorus concentration of 0.5 mg/l.

TILLAGE PRACTICES OTHER THAN CONSERVATION TILLAGE AND NO-TILL WERE SHOWN BY UNIVERSAL SOIL LOSS EQUATION ANALYSIS TO BE UNABLE TO ACHIEVE SIGNIFICANT REDUCTIONS IN POTENTIAL GROSS EROSION.

There is no significant difference in potential gross erosion between existing conditions and the adoption of fall plow, spring plow, or winter cover practices.

Although fall plow, spring plow, and winter cover appear to have little effect on potential gross erosion rates, the lack of winter cover due to fall plowing exposes soil during the high winter-spring sediment transport periods.

THE U.S.L.E. ANALYSIS SHOWS THAT DIFFUSE SOURCE PHOSPHORUS LOAD OBJECTIVES WILL NOT BE MET EVEN IF ALL SOILS MEET SOIL LOSS TOLERANCE LEVELS.

Reducing all existing conditions soil losses presently exceeding tolerable soil loss limits to tolerable soil losses, reduces potential gross erosion 40 percent. If potential gross erosion reductions are 90 percent effective in reducing total phosphorus, the phosphorus loading reductions would only be 2,400 to 3,000 MT/yr.

IN ADDITION TO CONSERVATION TILLAGE AND NO-TILL PRACTICES, OTHER CONTROLS OF SEDIMENTS AND PHOSPHORUS MUST BE APPROPRIATELY APPLIED:

These controls may include animal waste runoff and disposal systems, gully erosion control via waterways and structures, and use of total farm conservation plans where needed.

Increased storm water infiltration and reduction of surface runoff through improved subsurface drainage system effectively reduce erosion and soil loss via storm runoff.

In many Lake Erie basin soils, plant available phosphorus is adequate to achieve maximum production. Therefore, phosphorus application rates could be reduced accordingly with no loss in production.

LONG-TERM WATER QUALITY MONITORING IS REQUIRED TO MEASURE REDUCTIONS IN SEDIMENT AND PHOSPHORUS TRANSPORT RESULTING FROM DIFFUSE SOURCE MANAGEMENT.

The diffuse source total phosphorus load to Lake Erie (excluding atmospheric and Lake Huron outflow) varied between about 6,000 and 11,700 metric tons per year between 1970 and 1977.

The annual variation in diffuse source phosphorus loads is as great as the reductions required and, therefore, long-term monitoring will be required to differentiate between year-to-year variations in load and any reduction which might be achieved by improved management.

AN EDUCATION AND TECHNICAL ASSISTANCE PROGRAM IS NEEDED TO ACCELERATE THE ADOPTION OF CONSERVATION TILLAGE, NO-TILL, AND OTHER COST EFFECTIVE BEST-MANAGEMENT PRACTICES.

Adequate information, knowledge, and technical assistance are the principal ingredients necessary for landowners and farm operators to adapt and apply conservation tillage systems and other Best Management Practices.

Cost shares or other financial and economic incentives, along with demonstrations, may be needed to initiate wide-spread adoption of these BMPs. Some practices may be needed but may not be cost-effective or economically feasible for the individual landowner or farm operator.

A demonstration program in a specific watershed with special emphasis on educational and technical assistance programs is needed. The results of the demonstrational watershed program should be assessed with regard to applicability to other areas in the Lake Erie drainage basin.

CRITERIA FOR SETTING PRIORITIES FOR TREATMENT OF CRITICAL AREAS ARE: POTENTIAL SOIL LOSS, PHOSPHORUS AVAILABILITY OF ERODED SOIL, AND COST EFFECTIVENESS OF REDUCED TILLAGE SYSTEMS AND OTHER APPLICABLE BEST MANAGEMENT PRACTICES.

The Land Resource Information System can be used to set priority problem areas on the county level. However, specific recommendations for BMPs will require assistance of the Soil and Water Conservation District.

THE ENVIRONMENTAL BENEFITS OF EROSION CONTROL EXTEND WELL BEYOND A REDUCTION IN PHOSPHORUS.

Other Lake Erie basin-wide benefits resulting from increased erosion control and sediment reductions include: reduced sedimentation and reduced dredging costs in Lake Erie harbors, lower water treatment costs for sediment removal from domestic water supplies, less movement and transport of other sediment-attached pollutants such as insecticides and herbicides, and reduced instream sedimentation which benefits the fishery resources.

RECOMMENDATION

It is recommended that a demonstration program be implemented in a specific watershed and the results assessed with regard to applicability to other areas in the drainage basin in terms of reducing pollutant loading to the lake. Since economic incentives exist to adopt land management practices which improve water quality, an accelerated education and technical assistance program should be undertaken. The final phase of the study should delineate a recommended wastewater management program which will lead to an improvement of in-lake water quality and the rehabilitation of Lake Erie.

LAKE ERIE WASTEWATER MANAGEMENT STUDY - METHODOLOGY REPORT

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CHAPTER ONE

INTRODUCTION

I. SCOPE OF STUDY

This report summarizes the status of the Lake Erie Wastewater Management Study (LEWMS) particularly work completed since the submission of the 1975 Preliminary Feasibility Report (1). The earlier report described conditions relating to water quality in Lake Erie and presented estimates of pollutant loads to the lake, including a proposed methodology for evaluating the effect of pollutant loads on in-lake water quality. The present report elaborates on the relative importance of nonpoint (diffuse) sources to point sources of pollution as they effect in-lake water quality. The use of land in the Lake Erie drainage basin is described and its role in the generation of pollutants is evaluated, including the availability of nutrient loadings for biological uptake in the lake. The process by which pollutants are removed from the land and transported by the tributary system to the lake has been analyzed. Sediment was found to be an important agent for transport of nutrients. Therefore, land management options designed to reduce sediment export from the drainage basin have been analyzed and evaluated. An economic analysis is presented which demonstrates how land management can lead to reduction in pollutant export from the drainage basin to the lake while at the same time increasing net farm income. The final phase of the study will delineate a recommended wastewater management program which will lead to an improvement of in-lake water quality and the rehabilitation of Lake Erie.

II. STUDY AUTHORIZATION

The authority for the Lake Erie Wastewater Management Study is contained in Sections 108d and e of the Federal Water Pollution Control Act Amendments of 1972 (PL 92-500). Through this act the United States Congress authorized this study to develop a program for restoration of Lake Erie.

The first phase of the Lake Erie Wastewater Management Study was reported in the 1975 Preliminary Feasibility Report. The second phase of the study is summarized in the present methodology report. The third phase of the study, which is scheduled for completion in September of 1981, will deal specifically with the evaluation of the effectiveness of management practices for control of diffuse sources. Phase III of this study calls for the implementation of a demonstration watershed management program designed to reduce the impacts of watershed activities on water quality in Lake Erie. In addition, five other watersheds will be selected for development of technical assistance programs in preparation for demonstration programs. The

Phase III report will establish priorities for management programs in the remaining Lake Erie watersheds and estimate their cost, duration, and expected effectiveness in reducing pollutant loads to Lake Erie with a resulting improvement in Lake Erie water quality.

III. STUDY APPROACH

This study has been planned to develop a wastewater management strategy that will bring about significant improvement in the quality of Lake Erie water. The degradation of Lake Erie water is a result of accelerated cultural eutrophication. The growth of human populations, urbanization and industrialization, and intensive agriculture has developed rapidly in the Lake Erie drainage basin during the past century. Many of the waste byproducts of man's activities in the drainage basin ultimately enter Lake Erie. The addition of nutrients to the lake is of particular importance to the process of eutrophication. These chemical substances are essential to plant growth (e.g., algae) which in turn forms the building block for the aquatic food chain. The over-enrichment of the lake with nutrients stimulates excessive plant growth which leads to taste and odor problems, the appearance of unsightly scum and turbidity, and depletion of oxygen in the bottom waters of the lake where the dead plant material decomposes. Thus, the physical, chemical, and biological equilibria of the lake are affected. Fisheries have been damaged and recreational use has been impaired. The nutrient of primary concern is phosphorus which is believed to be the growth-limiting nutrient in Lake Erie.

Heavy metals (i.e., mercury) and toxic substances (i.e., DDT and PCB) have been and will continue to be of concern in Lake Erie and the other Great Lakes. However, the management approach to them will continue to be the same; either a ban on use of the material or a ban on release of the material to the lake and pathways to the lake (i.e., land, rivers, and air). Therefore, the study has focused on the development of a strategy that would reduce the phosphorus input to Lake Erie.

The development of a practical, cost-effective, and technically sound phosphorus load reduction program involves the following five basic steps.

a. <u>Reliable Estimation of Phosphorus Loads to the Lake</u> - During Phase I of the study, a methodology was developed for estimating phosphorus loads to Lake Erie based on direct measurement of chemical loading from selected tributaries. The measurement program was intensified during storm runoff events. Point source loads were estimated from treatment plant records. The estimation of loading from unmeasured tributaries was based on correlations developed from the measured tributaries which related chemical loading to stream discharge. During Phase II, additional measurements were made which verified the reliability of the estimates based on the methodology developed during Phase I. These point and nonpoint source estimates of phosphorus loading were combined with estimates of atmospheric loading to the lake surface to provide what is considered to be the best estimate of phosphorus loading to Lake Erie now available.

b. Identification of Factors Affecting Nutrient Loads - Estimates have been made of total phosphorus loads and the proportion of point and nonpoint (diffuse) source loads contained in the tributaries at their discharge point into the lake. The importance of hydrologic conditions on diffuse source loading has been established. Average values of diffuse source loading have been developed based on the average of long-term streamflow records.

c. Relationship of Nutrient Loads to Watershed Conditions - The development of a management plan for diffuse sources requires identification of how land type, land use, and hydrology affect the export of nutrients from a watershed. The development of such a methodology was undertaken during Phase II of the study.

d. Relationship of In-Lake Conditions to Nutrient Loading - Data collected by other agencies have been used to characterize in-lake conditions. The three basin phosphorus budget model developed during Phase I as well as USEPA's ecological model for Lake Erie have been used to relate nutrient loads to present Lake Erie water quality and trophic status. These models were then used to determine the reduction in phosphorus loading necessary to achieve the desired improvement in lake water quality and trophic status. This effort was carried out by LEWMS staff representation on an international technical group to review phosphorus loadings. The task group's recommendations have been used in the writing of the Great Lakes Water Quality Agreement of 1978.

e. Development of Alternative Phosphorus Load Reduction Programs - The in-lake effect of implementing various point source load reduction programs was evaluated during Phase I. The present report examines various combinations of point and nonpoint source loading reduction programs which would meet the recommended total loading objective established by the Great Lakes Water Quality Agreement of 1978. The load reductions and associated costs for various land management options that have been developed in the present report are based on extrapolation from existing data and are thought to be the best estimates available. However, the assumptions and cost estimates need to be verified by a demonstration program.

IV. STUDY PROCESS

a. LEWMS Phase I Results - The conclusions of the 1975 Preliminary Feasibility Report are summarized here along with commentary based on new knowledge and findings obtained during Phase II.

(1) During Phase I it was determined that the preponderance of diffuse phosphorus loads to Lake Erie was carried by streamflows resulting from storm runoff events and that for most streams sampled, a significantly high correlation was evident between phosphorus loading and stream discharge. There was also a high correlation between phosphorus loading and suspended solids carried by the streams. The flow interval method developed during Phase I for estimating phosphorus loading from streams has been used with measurements made during Phase II to verify tributary loading estimates. The estimates that have been developed for diffuse source phosphorus loading to Lake Erie are thought to be the most reliable and comprehensive now available.

(2) A mathematical model based on the conservation of mass principle was developed during Phase I for the phosphorus budget of Lake Erie. The model provided a means of relating phosphorus loading to the level of phosphorus concentration in the lake. Phosphorus budget analysis for Lake Erie indicated that reduction of phosphorus loadings to the lake would bring about new and lower equilibrium values of phosphorus concentrations in the lake, a necessary step in improving the trophic status of the lake and in accomplishing the rehabilitation and environmental repair of Lake Erie. This new equilibrium would be established in about one year in the Western Basin, three years for the Central Basin, and four for the Eastern Basin. The phosphorus budget model is used in this report to project the in-lake effects that would result from phosphorus loads to Lake Erie. The model has also served as a framework for understanding the significance of the uncertainty in estimates of phosphorus loads and measurements of in-lake water quality.

(3) During Phase I it was determined that approximately 44 percent of the phosphorus loading to Lake Erie from its drainage basin originated from diffuse sources. It was concluded that management of point sources alone would not achieve the desired improvement in the quality of Lake Erie water and, therefore, management of diffuse sources would also be required. Phase I recommended objectives for total phosphorus concentration for in-lake water. While these concentrations are still desirable, Phase II modifies these objectives by recommending total phosphorus loading to Lake Erie as the objective of the study. This loading objective is designed to reduce the anoxic area in the Central Basin of Lake Erie by 90 percent and will essentially eliminate the release of nutrients from the sediments.

(4) The Phase I conclusion that total phosphorus loading to Lake Erie be reduced to 12,500 metric tons has been revised downward to 11,000 metric tons. Based on the phosphorus budget analysis, the revised total phosphorus loading objective of 11,000 metric tons is projected to achieve the in-lake phosphorus concentrations previously recommended in Phase I, except in the western basin of Lake Erie. The on-going plan to reduce point source loading in the drainage basin greatly reduces phosphorus loadings. However, reducing loadings from point sources alone is not enough to achieve the desired total phosphorus loading objective of 11,000 metric tons; management of diffuse source loading will be required. Inputs from Lake Huron and the atmosphere are assumed to be uncontrollable and constant.

(5) Although wastewater management plans for reduction of point source phosphorus loading are still not complete, the study analysis is based on all municipal point sources with flows greater than one million gallons per day having their effluent total phosphorus concentrations reduced to at least 1 mg/l.

(6) In Phase I it was concluded that a methodology was needed for estimating the effect that control of diffuse sources would have on export of total phosphorus from a watershed and ultimately on the reduction of total phosphorus loading originating from diffuse sources in the drainage basin. Such a methodology has been developed during Phase II. It was also concluded in Phase I that a determination was needed of the proportion of total phosphorus originating from diffuse sources that would be available for biological uptake in the lake. Although this determination has not been completely made, a better estimate is now possible based on work undertaken during Phase II.

(7) The final conclusion in the Preliminary Feasibility Report was that the wastewater management plan eventually recommended for Lake Erie be based on an analysis of the economic, social, and environmental impacts of the proposed plan. This conclusion is still valid. The ramifications of managing diffuse sources of phosphorus in the drainage basin have received special study during Phase II.

b. Direction of LEWMS Phase II - Phase II of the Lake Erie Wastewater Management Study has concentrated on identifying factors affecting rural diffuse sources of phosphorus and the relationship of these phosphorus loads to watershed conditions. Effort has not been spent on management of point sources or urban nonpoint sources since these sources are being dealt with by other programs. The 1972 Canada-United States Great Lakes Water Quality Agreement called for the reduction of the effluent phosphorus concentrations to 1 mg/l for all municipal wastewater treatment plants with an average flow greater than one million gallons per day. Over $900 million has been spent as of August 1977 for municipal waste treatment in the Lake Erie drainage basin in the United States. Programs to control urban diffuse sources have been and are being developed by designated 208 agencies. Over $11.4 million has been spent on Areawide Waste Treatment Management Planning in the Lake Erie drainage basin. Since point source control programs and urban diffuse source management programs are already receiving considerable funding and study, it was decided that Phase II of LEWMS should concentrate on the management of rural diffuse sources of phosphorus.

Phase II of the study has attempted to answer the following questions: How does the use of land affect phosphorus export from a watershed? What percentage of eroded soil ultimately gets to the lake and how long does it take to get there? Where in the Lake Erie drainage basin could erosion control measures be applied? What practices have the most potential for control of phosphorus loss from land? What is the biological availability of phosphorus associated with soil loss once it enters the lake? What would erosion control measures cost agriculture?

To help answer these questions, a Land Resource Information System (LRIS) was developed for the entire U.S. portion of the Lake Erie drainage basin. This data base contains information on soils, land use and cover, slope, and political and watershed boundaries. It serves as an important basis for relating watershed nutrient loads and net farm returns to soil characteristics and land use practices.

An extensive monitoring program was undertaken which characterized pollutant export from 72 watersheds within the drainage basin. These data were used along with the information generated by LRIS to investigate relationships between land use and water quality. A mathematical model was developed to analyze how phosphorus is transported in a river. Phosphorus availability was measured both chemically and biologically. A prototype report was developed for a specific small watershed in the Lake Erie drainage basin describing soil conserving agricultural techniques that could be applied in that watershed. Phase II has resulted in development of methodologies and acquisition of data that answer most of the questions posed above.

Phase III of the study will concentrate on evaluation of a demonstration phosphorus reduction plan using knowledge and methodologies that have been developed during Phases I and II.

c. Public and Agency Coordination - Newsletters, press releases, a special public involvement mailing, conferences, membership on outside work groups, and an Interagency Technical Advisory Group have been used to advise the public of this study.

In place of a public meeting to discuss alternatives, a special mailing of a Public Information Fact Sheet was made in October 1977. Over six thousand people received this special mailing. The purpose of the fact sheet was to inform the public about the Lake Erie Wastewater Management Study and to elicit comment from the public on the status and proposed conduct of LEWMS. The comments received have been compiled and are available for review at the Buffalo District Office.

In addition to presentations to organizations and civic groups, LEWMS staff planned and participated in a series of three research coordination conferences held at Heidelberg College in Tiffin, OH. The purpose of these conferences was to exchange information on nutrient transport in rivers, land use - water quality relationships and Sandusky River basin research in particular. Out of these meetings came a consensus that a research demonstration program was the only way to answer many unresolved questions. The Honey Creek basin in the Sandusky River basin was a logical area because of the excellent data base which existed there. From these meetings Seneca, Crawford, and Huron Counties Soil and Water Conservation Districts formed the Honey Creek Watershed Joint Board of Supervisors. This Joint Board would provide the institutional and legal means of carrying out a demonstration project in Honey Creek.

The staff of LEWMS has served on several work groups concerned with controlling diffuse sources of phosphorus. These groups are: (1) Task Group III, a technical group to review phosphorus loadings for the Fifth Year Review of Canada-United States Great Lakes Water Quality Agrement; (2) Phosphorus Management Strategies Task Force under the Research Advisory Board of the International Joint Commission; (3) Technical Advisory Group for Task III, River Basin Studies; under the Pollution from Land Use Activities Reference Group (PLUARG) of the IJC; (4) Nonpoint Source Work Group for the Fifth Year Review of Canada-United States Great Lakes Water Quality Agreement; (5) Public Consultation Panel for PLUARG; (6) State of Ohio's Undesignated Area 208 Technical Advisory Committee; and (7) the Great Lakes Basin Commission's work group on coordination of Areawide Water Quality Management Planning activities with Great Lakes water quality objectives.

The Interagency Technical Advisory Group (ITAG) was established early in the study effort. This group provides technical advice and coordinates agency effort. Members of ITAG keep the Lake Erie Study staff informed on current policies of Government or agencies they represent.

V. OTHER PROGRAMS

a. Introduction - Two other major programs will have an effect on diffuse sources of phosphorus in the Lake Erie Basin. The Pollution from Land Use Activities Reference Group's (PLUARG) final report, "Environmental Management Strategy for the Great Lakes System" (2) and the Clean Water Act of 1977 Amendments, Section 208; Rural Clean Water Program (3). This section will briefly describe these programs and their interaction with the Lake Erie Wastewater Management Study.

b. PLUARG - The Pollution from Land Use Activities Reference Group was conducted pursuant to Article IV, Section F, of the Great Lakes Water Quality Agreement of 1972. Specifically, this study answered the question posed by the Agreement under the text of reference.

> "Are the boundary waters of the Great Lakes System being polluted by land drainage (including ground and surface runoff and sediment) from agriculture, forestry, urban and industrial land development, recreational and parks land development, utility and transportation systems and natural sources?"

PLUARG's conclusions reaffirmed the LEWMS Phase I conclusion that diffuse sources must be controlled to restore Lake Erie (1) and prioritized Lake Erie as a problem area. PLUARG also concluded that the most important land related factors affecting the magnitude of pollution from land use activities in the Great Lakes Basin were found to be soil type, land use intensity, and materials usage. Areas of high phosphorus loading from intensive agricultural activities such as northwestern Ohio are examples of these areas.

PLUARG pointed out the need to further study the cost-effectiveness and socio-economic tradeoffs of various remedial alternatives available for nonpoint source control as well as the short and long-term effectiveness of various remedial measures or alternatives for controlling erosion and sedimentation of fine-textured soils.

PLUARG recommended a methodology whereby problem areas are defined on a priority basis to which the most practicable control means for a particular source are applied. It also recommended the development and implementation of information, education, and technical assistance programs.

The Land Resource Information System (LRIS) developed during Phase II is the ideal method to carry out PLUARG recommendations. With it, LEWMS can identify problem areas in the Lake Erie drainage basin.

LEWMS has been able to determine the economics of alternative tillage methods and will be able to develop cost-effective programs. LRIS will be used in development and implementation of information, education, and technical assistance programs of Phase III. PLUARG provided a Great Lake-wide perspective. LEWMS can provide the detail and focus needed to develop an effective plan for Lake Erie.

c. Rural Clean Water Act - The Rural Clean Water Act (RCWA) provides cost-sharing funds for implementation of best management practices. It does not identify problems but is based on 208 Water Quality Plans which are not Lake Erie basinwide and are not tied specifically to phosphorus and water quality program needs of Lake Erie. RCWA money goes to designated basins with water quality problems. The Land Resource Information System is one way of choosing these basins. The RCWA requires Soil and Water Conservation Districts, together with the Secretary of Agriculture, to determine priority of assistance to assure the most critical water quality problems are addressed.

Although 208 agencies and Soil and Water Conservation Districts can prioritize problems under their jurisdiction, they cannot prioritize problems basinwide for Lake Erie. LEWMS is the required link between the generalized conclusions of PLUARG and the detailed planning required to prioritize areas for implementation under the RCWA of 1977. Further, LEWMS is specifically aimed at lakewide improvement, in contrast to the RCWA which emphasizes improvement on a small regional scale.

REFERENCES - CHAPTER ONE

1. U. S. Army Corps of Engineers, Buffalo District, "Lake Erie Wastewater Management Study, Preliminary Feasibility Report," Vol. I, Buffalo, New York, December 1975.

2. International Reference Group on Great Lakes Pollution From Land Use Activities," Environmental Management Strategy for the Great Lakes System," Windsor, Ontario, July 1978.

3. Public Law 95-217, the 1977 Amendments to the Clean Water Act.

CHAPTER TWO

LAND USE AND LAND RESOURCES IN THE LAKE ERIE BASIN

I. ORIGIN OF POLLUTANTS

a. Introduction - The manner in which pollutants are introduced into the water environment can be broadly classified into point source and nonpoint (diffuse) sources. A reliable determination of diffuse source loading is difficult because of the complex transport processes involved in moving pollutants from their source to the receiving waterbody. Included in this category of diffuse sources are sediment production from watersheds, urban runoff, and atmospheric fallout. These processes are not easily quantified; however, their importance should not be underestimated.

A common factor in the generation of diffuse source loading is the precipitation-runoff event. The physical transport process begins with the initial material detachment from the earth's crust resulting from the impact of atmospheric precipitation and the erosive transport during runoff. Atmospheric loading is also enhanced by the natural scavenging of precipitation as it falls through the air mass above a waterbody and its drainage basin. It can be imagined that diffuse source pollutants are transported intermittently through a drainage basin by each precipitation-runoff event and that the larger (and rarer) runoff events would be the most significant in terms of moving pollutants ever closer to the receiving waterbody.

The precipitation-runoff event does not discriminate between naturally occurring materials and those introduced by man's activities. Thus, measurements of diffuse source loading will inevitably include a "background" portion that could be attributed to the natural occurrence of some substances. There are, however, unmistakable increases due to the activities of man that depend upon the way he has chosen to use land and the materials that are deliberately or inadvertently placed on the land surface. The application of deicing salts on streets and highways and the application of fertilizers on agricultural land are examples of deliberate spreading. The fallout of lead onto streets and the adjacent lands from automobile exhausts could be classified as inadvertent spreading.

Thus, the determination of the origins of diffuse-source loading is complicated by two factors. The first relates to the complexity of the transport processes that ultimately produces a measurable quantity of pollutant and the second relates to the difficulty in discriminating between the "background" portion of this measured load and that which can be attributed to man's activities.

It is apparent from this discussion why point sources have received the most attention in water quality management. The origins of pollutants contained in point source loadings are more easily determined and are almost always the result of man's activities. Point source wastewater streams frequently are carried by man-made conduits and lead either to specific treatment sites or directly to a receiving waterbody. Most of the resources available for water pollution control that have been expended up to the present time have been devoted to the management of point source loading.

Diffuse source loading is now recognized as a potentially significant contributor to the overall balance of pollutants in the water environment. It has been demonstrated as a result of the findings of this study that diffuse sources account for about one half of the total phosphorus loading to Lake Erie. In the Maumee River basin, approximately 80 percent of the total phosphorus loading discharged to Lake Erie originates from diffuse sources. In some other areas of the U.S. Lake Erie drainage basin, diffuse sources make up only a small fraction of the total loading.

The relationships between land use activities, the physiography of the land resource, and pollutant production will be discussed in this chapter.

b. Land Use and Point Source Loading - The historical development of population centers on navigable waterways is the most important factor relating land use to point source loading. The availability of that same water for domestic and industrial use has resulted in the creation of numerous point sources of pollutant loadings where the degraded water is returned to the waterbody. These point source discharges are generally directly into the lake or near the lake into a river tributary. These direct discharges are of particular concern because pollutants can impact on the Lake Erie ecosystem without opportunity for the action of intermediate processes that tend to mitigate pollutant discharges made in the inland portion of the drainage basin. For instance, soluble phosphorus contained in near-lake point source loadings is immediately available for biological uptake, while inland phosphorus discharges interact with suspended sediments in the stream and are only partially available for direct biological uptake when they enter the lake.

Similarly, biochemically oxidizable pollutants contained in the point source discharges of these inland communities exert a demand for instream dissolved oxygen which is generally satisfied before reaching the lake.

A third tier of communities has developed which frequently do not make direct use of a water course. Most of these communities are without industry and are too small to have installed sewage collection systems and central waste treatment facilities. Many residences in these communities utilize septic systems with leach fields, often where soils are unsuitable for such uses. In many instances, widespread failure of septic systems causes severe local water quality problems. Such pollution may have severe effects on local streams and water bodies, however, it has a relatively small contribution to Lake Erie water quality problems.

c. Land Use and Diffuse Source Loadings - In contrast to the point sources, which originate from a discrete number of locations and contribute a relatively small volume of water, pollutant loading from diffuse sources originates from all parts of the drainage basin and the water volume is very large. Diffuse source pollution is not amenable to treatment in the usual sense of the word. The only practicable approaches to reducing diffuse source loading are reduction in the application of the pollutant to the land surface and/or reduction in the quantity of the pollutants being transported to the lake by the precipitation-runoff process. Although the first approach has merit, the focus of the present study has been on devising control measures which either prevent or reduce the amount of pollutants leaving the initial application site.

To this end, it has been necessary to identify land use and land resource characteristics and to assess areas in terms of potential gross erosion and potential for erosion control. This study concentrated on soil erosion as a source and sediment as a carrier of phosphorus. This identification process reduced the land area to be considered in terms of active contribution of phosphorus to Lake Erie. The portion of the drainage basin that is active in terms of its contribution of phosphorus, although large in extent, can be dealt with much more effectively than the entire drainage basin tributary to Lake Erie.

Diffuse source loading from urban land areas is, in general, not related to soil erosion. The urban landscape is usually dominated by extensive areas of impervious surfaces. Runoff from such surfaces is rapid and the washing of waste residues from streets, parking lots, and roof tops generates the diffuse source pollutant load. The magnitude of this load will depend in large part on the type of land use, the intensity of use (particularly automobiles), and the housekeeping practices of the community.

d. The Erosion Process - Soil erosion can be divided into three categories: gully, rill, and sheet. Gully erosion occurs when concentrated surface runoff is allowed to flow over unprotected areas and cause excessive soil detachment and loss of soil particles. As volumes and rates of flow increase, the resultant erosion scar becomes deeper and wider. Normally, gully erosion is described as those eroded areas which cannot be easily crossed with farm equipment or cannot be eliminated with normal cultural tillage methods.

Although very damaging to farm operations and a cause of sedimentation in streams, the deep horizons in soils removed by gully erosion do not contain significant amounts of biologically available phosphorus, nor is the mass of gully eroded soil large compared to the mass contributed from the other categories. While gully erosion is not considered to be a significant contributor to the Lake Erie phosphorus load, it is a part of the entire erosion-sediment-nutrient loading process that must be addressed.

Sheet and rill erosion are considered together and include the bulk of eroded soil mass and include the soil fraction containing the biologically available phosphorus. Sheet and rill erosion of agricultural lands account for most of the diffuse source loading of total phosphorus to Lake Erie. The factors which affect sheet and rill erosion from agricultural lands involve land use intensity, land form, soil type, and climate. The vegetative cover on a particular parcel of land can easily dominate all other factors in assessing the potential and the rate of sheet and rill erosion. The details of land form, such as slope and length of slope, and soil texture, are important variables determining the rate of erosion and the quantity of sediment produced. The frequency, duration, and intensity of precipitation events are the primary climatic factors that interact with the seasonal soil cover variations on agricultural lands to produce greater or lesser quantities of sheet and rill erosion. Winter rains on uncovered soils can produce erosion and sediment delivery far in excess of that produced during summertime periods when the soil is covered with vegetation and infiltration is greater.

II. STUDY APPROACH

a. Land Resource Information System - In order to analyze diffuse source loading and, in particular, the erosion and phosphorus producing potential of the drainage basin, a Land Resources Information System (LRIS) was developed (1). The LRIS contains data on existing land use and soil type referenced according to geographical and political position in a drainage basin. This information system was computerized for quick and easy use.

The data in the LRIS were obtained and coded during 1976-78. Available data from other studies were incorporated to the extent possible and included 18 counties which had previously compiled computer information systems. Data for the remaining 45 counties in the basin were gathered from many sources. Land use information was obtained by manual photo interpretation of false-color, near-infrared photography. The aerial photography mission was flown by NASA and provided transparency films of some areas of the basin at a 1:70,000 scale and the remainder at 1:120,000. Land use was coded from these photographs on a square grid with four and nine hectare grid areas for intensive study and 16 and 36 hectare grid areas for less intensive study. Sampling density for data obtained from other agencies had four hectare grid areas. (One hectare equals 2.47 acres).

The soils of the basin were coded into the LRIS using the best available data source from each county. Soil surveys used dated back to 1917. In those counties where no soil surveys were available, SCS cooperator maps were used. An interpretative data file containing extensive listings of the properties of the soils in the basin was also compiled. The completed LRIS serves as a data base for use in mapping land use and soil type and for use in the application of simulation models for sediment and phosphorus production.

b. Universal Soil Loss Equation - The erosion potential of each coded area was estimated using the Universal Soil Loss Equation (USLE). Briefly, the USLE is as follows:

$$A = (R) \times (K) \times (LS) \times (C) \times (P)$$

where: A is the estimated soil loss in tons per acre per year, R is a rainfall factor, K expresses the soil erodibility factor, LS denotes the slope length factor and the slope gradient factor, C is the cropping-management factor, and P expresses the erosion control practice factor. Numerical values for each of the factors have been established and coded in the LRIS and are described in a separate technical report (2).

With regards to sheet, rill, and gully erosion, the USLE only predicts an average annual potential gross erosion which results from sheet and rill erosion. Therefore, USLE outputs in total tons of soil loss and tons of soil loss per acre per year specifically excludes gully erosion. Presently, there is no method to predict average annual soil loss attributed solely to gully erosion.

The USLE is used in conjunction with the LRIS to develop estimates of existing potential gross erosion and to explore opportunities for erosion control. The system can also be used to study the relationships between land use, water quality, and tributary loadings to Lake Erie. In the final phase of the study, this system will be used in the development, calibration, and verification of hydrologic response models and chemical transport models.

III. LAND USE AND LAND RESOURCES

a. Land Use - Land use for the subbasins and total United States drainage to Lake Erie is given in Table II-1. This table is derived from an inventory of the LRIS. Map II-1 shows the spatial distribution of land use in the United States drainage to Lake Erie. The Western Basin is dominated by cropland use. None of the other basin areas has any specific land use category greater than 50 percent, although the Central Basin is close with 48 percent of the land in agriculture. Cropland accounts for about 39 percent in both the Detroit River/Lake St. Clair Basin and the Eastern Basin. However, these latter two differ in that the Detroit/St. Clair Basin exhibits urban land uses, principally the city of Detroit, while in the Eastern Basin, forest dominates. In the Western Basin, the most agriculturally oriented area, grassland is least abundant while the Detroit River/Lake St. Clair Basin has the highest percentage of grassland. Transportation and utilities which includes roads, railroads, airports, etc., accounts for from three to six percent in any of the basins. It is interesting to note that the two least urbanized basins have the larger percentages of areas in this use.

b. Soil Texture - Map II-2 portrays the various textures of Lake Erie Basin soils. Because of its large size, the central portion of the Maumee River Basin contains most of the clay and silty clay-textured soils found in the Lake Erie Basin. This area originally drained the lakes which formed as the glaciers of 8,000 to 16,000 years ago receded to the north and before the Niagara River outlet was established. The remainder of the Lake Erie Basin is comprised of clay and silt loam soils in ground and end moraines formed as the glaciers advanced and receded. The Defiance Moraine in the northwest part of the Maumee basin has steep slopes of clay loam and silty loam soils.

Throughout the remainder of the western portion of the basin, there are extensive areas of sands formed in offshore sand bars of the glacial lakes. Southeast of the eastern tip of Lake Erie there are many sandy beach ridges formed at the shorelines of many stages of the glacial lakes. East of Sandusky Bay, the terrain is generally higher than any of the glacial lake stages. Along the eastern shoreline, there is only a narrow band of lake-deposited sands. The remainder of the eastern half of the basin soils are formed of glacial till and outwash and generally silty loam and clay loam soils.

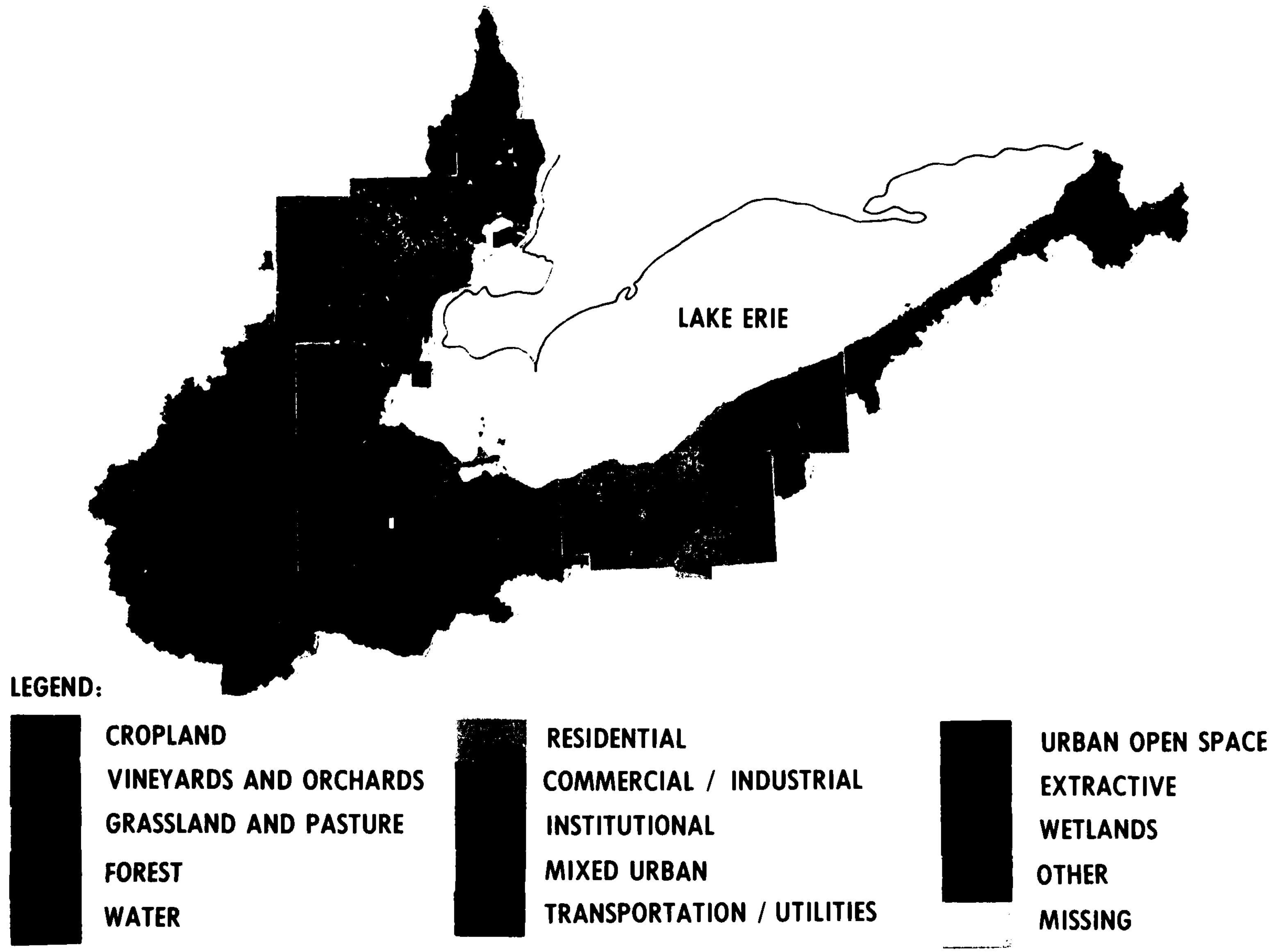
c. Slope - Map II-3 shows the slope of lands in the Lake Erie Basin. The indicated slopes were obtained from the soil phase coded at each location in the LRIS. Each soil phase entry in the LRIS has a slope range. The unique values shown in Map II-3 are the median of the slope range for each soil phase. Additional adjustments were

Table II-1 - Land Use in the United States Drainage to Lake Erie

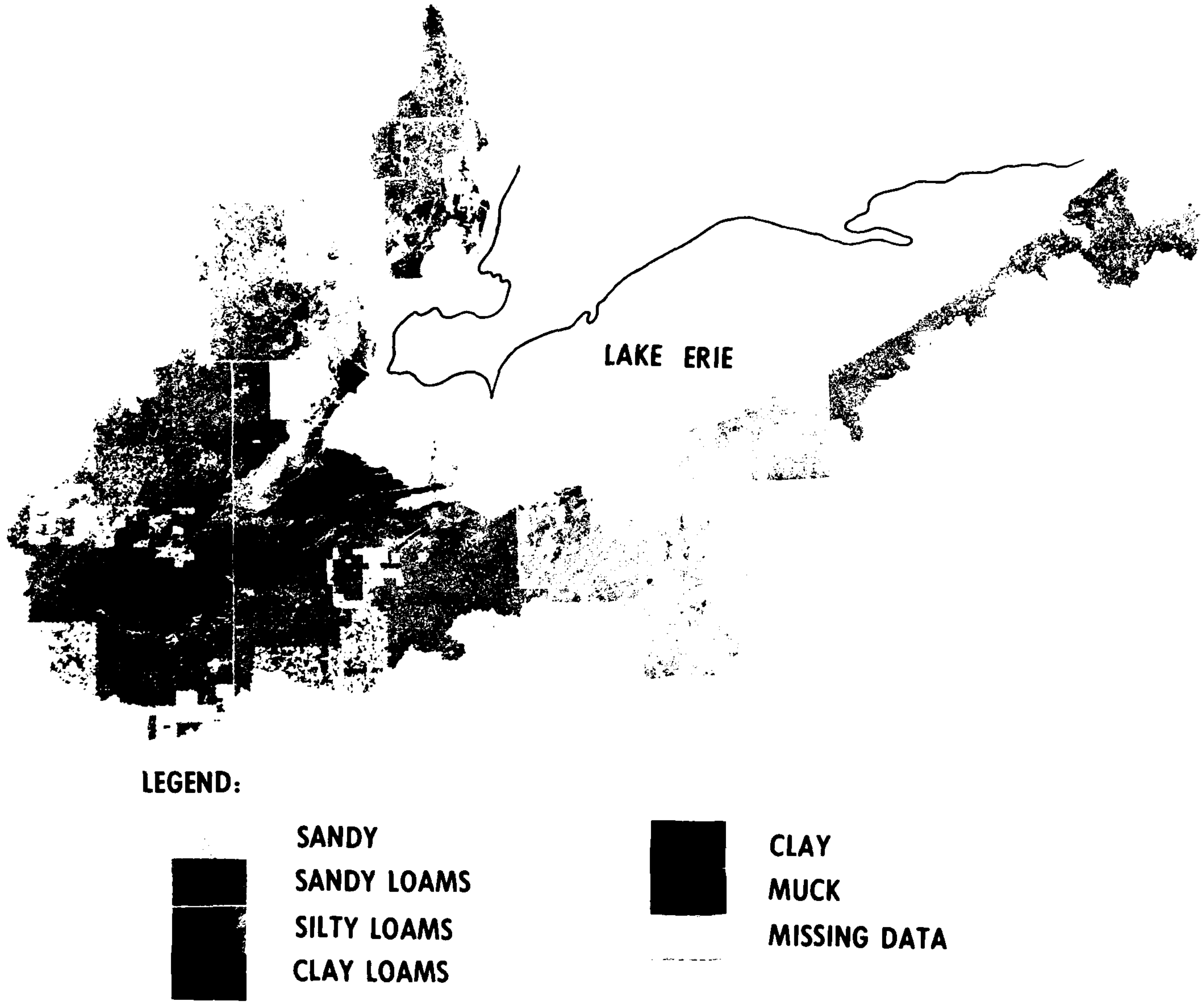
Basin	Detroit River/St. Clair		Western below Detroit River		Central		Eastern		Total	
Land Use	Hectares[1/]	Percent	Hectares	Percent	Hectares	Percent	Hectares	Percent	Hectares	Percent
1. Cropland	272,474	39.2	1,792,096	69.2	694,916	48.1	128,602	38.4	2,888,088	57.0
2. Vineyards/Orchards	1,672	0.2	2,108	0.1	5,768	0.4	2,781	0.8	12,329	0.2
3. Grasslands	94,364	13.6	98,958	3.8	149,366	10.3	18,149	5.4	360,837	7.1
4. Forest	43,480	6.3	220,992	8.5	298,333	20.6	119,529	35.7	682,334	13.5
5. Water	14,960	2.2	87,144	3.4	29,608	2.0	7,596	2.3	139,308	2.8
6. Other	310	0.0	679	0.03	301	0.0	486	0.1	1,776	0.0
7. Residential	121,189	17.5	128,116	4.9	131,327	9.1	19,357	5.8	399,989	7.9
8. Industrial/Comm.	33,748	4.9	21,605	0.8	24,347	1.7	5,382	1.6	85,082	1.7
9. Missing	6,091	0.9	30	0.0	0	0	0	0	6,121	0.1
10. Institutional	104	0.0	5,344	0.2	9,847	0.7	1,341	0.4	16,636	0.3
11. Urban Mixed	36	0.0	671	0.03	6,926	0.5	162	0.0	7,795	0.2
12. Trans/Util	25,170	3.6	129,800	5.0	44,596	3.1	19,679	5.9	219,245	4.3
13. Extr/Mine/Const	12,075	1.7	10,279	0.4	7,349	0.5	1,341	0.4	31,044	0.6
14. Wetlands	54,509	7.9	62,105	2.4	16,576	1.1	6,192	1.8	139,382	2.8
15. Urban Open Space	13,540	2.0	30,360	1.2	25,551	1.8	4,149	1.2	73,600	1.5
Total	693,722	100.0	2,590,287	100.0	1,444,811	100.0	334,746	100.0	5,063,566	100.0

1/ One hectare equals 2.47 acres.

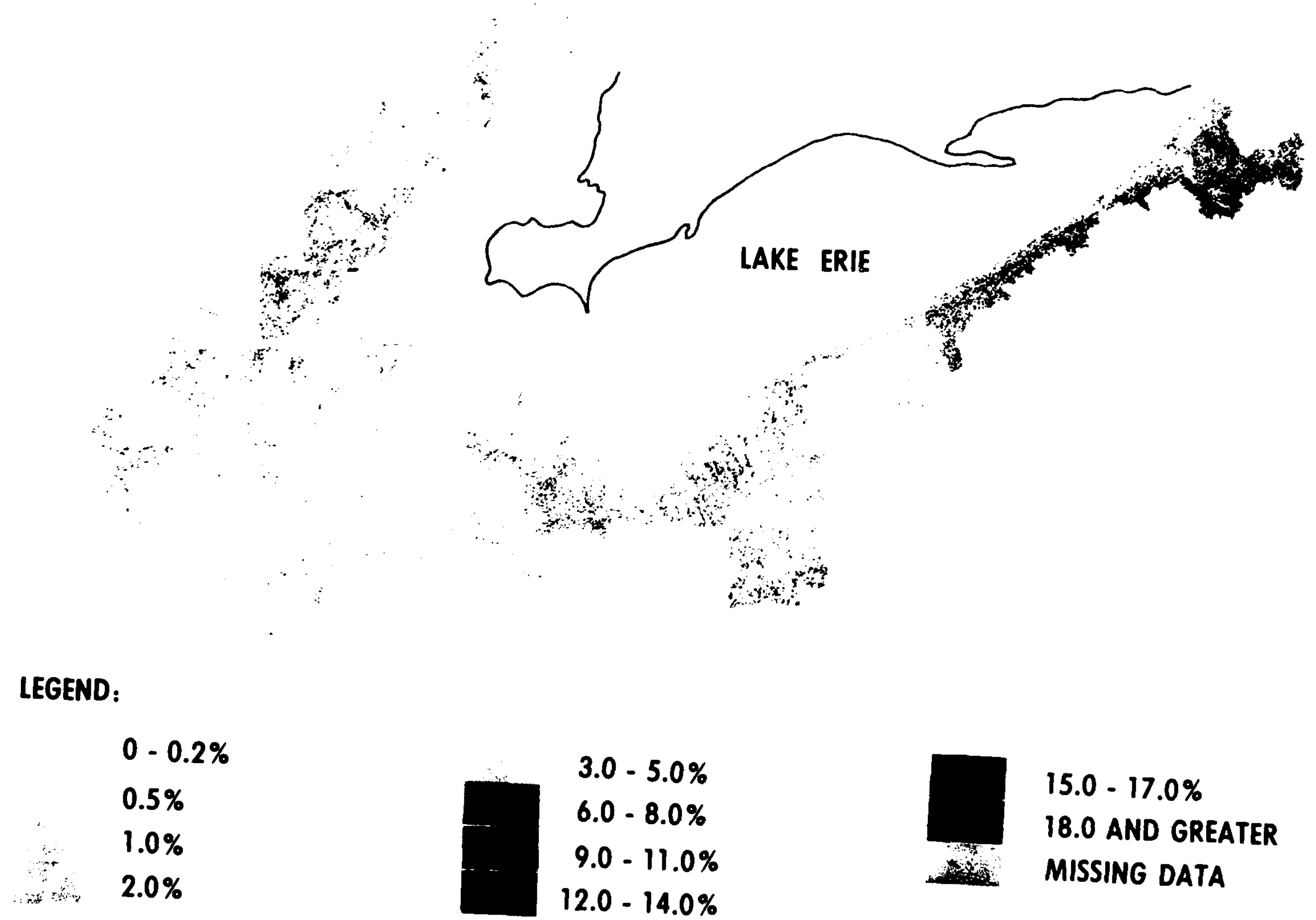
MAP II - 1 LAND USE IN THE UNITED STATES DRAINAGE OF LAKE ERIE



MAP II - 2 SURFACE TEXTURE OF SOILS IN THE UNITED STATES DRAINAGE OF LAKE ERIE



MAP II - 3 SLOPE OF LANDS IN THE UNITED STATES DRAINAGE OF LAKE ERIE



made for poorly drained soils in the zero to two percent range. Depending upon the soil type, a value of either 0.2 or 0.5 percent was used. A value of 0.5 percent was used for flood plain soils. The details of the methodology for determining the slope values can be found in a separate technical report (2).

The steepest sloping areas in the U. S. portion of the Lake Erie basin are concentrated along the eastern end. Sloping areas are on glacial end moraines and glacier-carved valleys. The area south of Buffalo, NY, which includes the area of the greatest slopes in the basin, is a series of parallel moraines extending in a north-south direction. To the west, in northwest Ohio, the land becomes generally flat. The central portions of the Maumee River Basin and the Portage River Basin have slopes that are predominantly less than 0.2 percent. This area was the bottom of the glacial lakes; the soils are clay and silty clay lacustrine deposits over glacial till. Along the northwestern boundary of the Lake Erie Basin, the Defiance and Wabash Moraines give relief to usually gently rolling lands.

IV. COMBINATIONS OF LAND RESOURCE VARIABLES

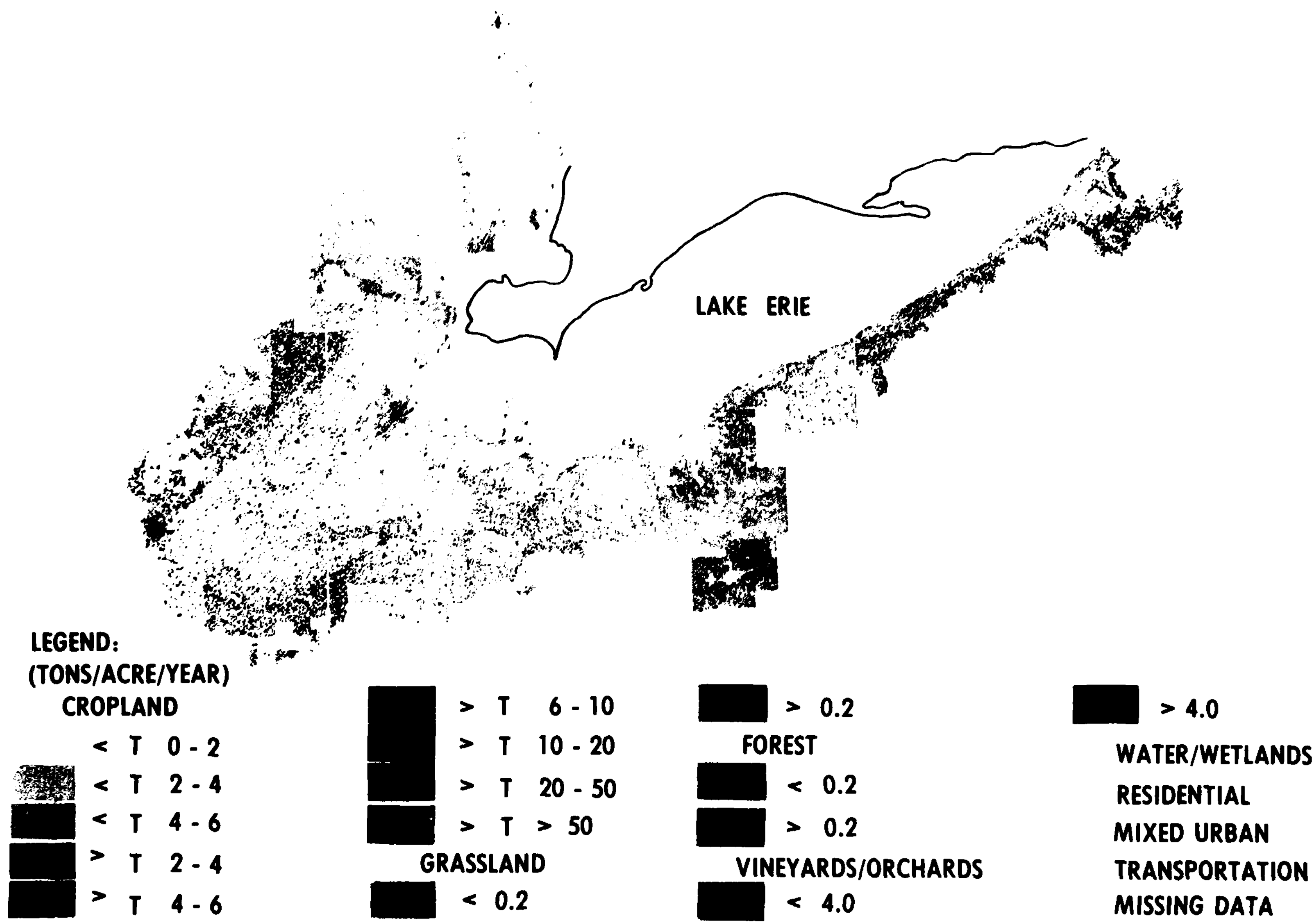
a. Potential Gross Erosion - In the previous section, maps of single properties of the Lake Erie drainage basin were presented. There are, however, combinations of land resource properties which, when taken together, give added information. An example of a combination of land resource properties is Potential Gross Erosion (PGE) calculated by the Universal Soil Loss Equation. The results of the equation represent an estimate of the long-term annual soil loss based on local climatic conditions, soil erodability, topography, land use, and management conditions.

Map II-4 shows PGE for the U.S. drainage to Lake Erie. On the map, soil loss from cropland is expressed as a range (in tons/acre/year) below and above the soil loss tolerance factor, T. Soil loss for grasslands and pasture, forested lands, vineyards, and orchards are expressed in two ranges of soil loss. Land uses other than these are indicated in shades of gray.

A map such as this is more valuable than the tabular reports when considered as a management tool from an erosion control program. It identifies the location of areas where land use and local conditions indicate a high potential for soil loss and, therefore, the areas where attention should be directed in and erosion control program.

It can be seen from Map II-4 that most of the land drainage into Lake St. Clair and the Detroit River has PGE rates less than T. However, land in Michigan, Indiana, and the western Ohio portion of the Western Basin have large areas with PGE rates several times greater

MAP II - 4 POTENTIAL GROSS EROSION IN THE UNITED STATES DRAINAGE OF LAKE ERIE



than T. Land south of Sandusky Bay also has areas where PGE rates exceed T. Most of the land drainage into the remainder of the Central Basin does not exceed T with the exception of some land southwest of Cleveland. There are also some areas of high PGE in the Cattaraugus River drainage into the Eastern Basin. It should be remembered when viewing this map that no estimates for PGE have been made for land uses such as urban, industrial-commercial, residential, and transportation.

b. Tabular Summaries of Combinations of Features - Tabular summaries of combinations of features have also been prepared for all areas in the Lake Erie drainage. The tables are organized according to sampling station drainage basins. Table II-2 lists all of the information summaries which have been prepared. These information summaries will be published as a LEWMS Technical Report.

There are three types of tabular summaries. Single feature summaries present one factor from the land resources information system for each basin; for example, land use as summarized earlier in Table II-1. Figure II-1 is an example of this output format. This report summarizes the area of each of the study watersheds in terms of the texture of the soils of the basin. The table indicates that of the 5,299 square miles of the Maumee River Basin above the sampling station at Waterville, 981 square miles of the basin, or 18.5 percent, has soils with a surface soil texture of clay. The table also indicates that this land area includes 69.8 percent of all the clay soils and 9.7 percent of the total land area of the mainfile database. To determine percentages of the total U. S. Lake Erie watershed the areas must be added to the SEMCOG and OCAP database areas. The table also indicates that there are no soils in the Cattaragus Creek Basin above Gowanda, NY, with surface textures finer than loam, and that the basin is dominated by soils of silty loam texture, 87.3 percent.

Table II-2: Tabular Summaries of Land Resource Features

Single Feature Summaries

Land Use
Soil Texture
Soil Permeability (Surface and Limiting Horizon)
Slope
Soil Drainage Class
Soil Erodability (K Factor)

Dual Feature Summaries

Land Use and Soil Permeability
Soil Permeability and Slope
Land Use and Slope
Land Use and Soil Texture
Soil Texture and Slope
Slope and Soil Erodability
Soil Texture and Erodability
Land Use and Erodability
Land Use and Soil Drainage Class
Land Use and Soil Capability Class

Multiple Feature Analysis

Universal Soil Loss Equation

The dual feature summaries, as illustrated in Figure II-2, take the process of land resource inventory one step further. This table summarizes the combination of intrinsic soil erodability with the slope of land. Problem areas would be indicated by those areas where steeply sloping lands occur on highly erodable soils. There is a great deal of information presented in such a table. Slope increases down the vertical axis, intrinsic soil erodability increases across the horizontal at the right side. Under "row total," the area and percent of area in each slope is summarized, which is the same as a single factor summary. Similarly for soil erodability along the bottom of the table. Note that only 22.2 percent of the watershed has slope less than seven percent. The area enclosed by the heavy line between slopes 6 to 11 percent and soil erodability 0.2 to 0.24 encloses 38.9 percent of the total watershed area. Of the 17.4 percent of the total basin, which has slope greater than 18 percent, 28.3 percent is in the highest (.49) soil erodability group. This combination of high slopes on erodable soil comprises 4.9 percent of the basin area and indicates an obvious problem erosion hazard area.

Multiple feature analyses involve the application of models and evaluative algorithms to select or evaluate combinations of land features such as rates of erosion or suitability for a particular land use such as disposal of municipal sewage and sludges.

Figure II-1 - Example of Single Feature Summary - Inventory of Soil Textures by Major Watersheds

Count (mi²) / Row Pct / Col Pct / Tot Pct	Clay	Silty Clay	Silty Clay Loam	Clay Loam	Sandy Clay Loam	Loam	Silty Loam	VF Sandy Loam	Silt	Sandy Loam	FN Sandy Loam	Fine Sand	Loamy Sand	Loam, Fine Sand	Muck	Row Total
Basin 1	981	240	1259	73	19	797	1389	5	3	225	105	34	19	84	65	5299
Maumee at	18.5	4.5	23.8	1.4	0.4	15.0	26.2	0.1	0.1	4.2	2.0	0.6	0.4	1.6	1.2	52.2
Waterville, OH	69.8	45.7	66.4	39.9	35.5	64.1	36.7	24.7	27.8	75.3	37.5	36.1	53.1	37.3	74.9	
	9.7	2.4	12.4	0.7	0.2	7.8	13.7	0.1	0.0	2.2	1.0	0.3	0.2	0.8	0.6	
Basin 2	179	0	41	9	25	44	48	0	0	4	14	0	0	23	0	386
Portage at	46.3	0.0	10.5	2.3	6.6	11.3	12.4	0.0	0.0	0.9	3.6	0.1	0.0	6.0	0.0	3.8
Woodville, OH	12.7	0.0	2.1	4.8	46.3	3.5	1.3	0.5	0.0	1.2	4.9	0.5	0.0	10.2	0.0	
	1.8	[illegible]	0.4	0.1	0.2	0.4	0.5	0.0	0.0	0.0	0.1	0.0	0.0	0.2	0.0	
Basin 3	11	[illegible]	198	2	0	42	607	2	0	2	10	1	0	4	5	892
Sandusky at	1.3	0.7	22.2	0.2	0.0	4.7	68.0	0.2	0.0	0.3	1.1	0.1	0.0	0.5	0.5	8.8
Fremont, OH	0.8	1.2	10.5	1.0	0.0	3.4	16.0	9.1	0.0	0.8	3.5	1.3	0.5	2.0	5.4	
	0.1	0.1	2.0	0.0	0.0	0.4	6.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	
Basin 31	0	1	58	0	0	40	235	0	0	2	9	0	0	6	7	359
Huron at	0.0	0.4	[illegible]	0.0	0.0	11.1	65.6	0.0	0.0	0.6	2.6	0.1	0.1	1.6	2.0	3.5
Milan, OH	0.0	0.3	[illegible]	0.0	0.0	3.2	6.2	0.0	0.0	0.7	3.3	0.2	1.1	2.5	8.0	
	0.0	0.0	[illegible]	0.0	0.0	0.4	2.3	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.1	
Basin 33	0	0	26	0	0	15	165	0	0	0	1	0	0	1	2	210
Vermilion near	0.0	0.0	12.5	0.0	0.0	7.3	78.4	0.0	0.0	0.1	0.5	0.0	0.0	0.4	0.8	2.1
Vermilion, OH	0.0	0.0	1.4	0.0	0.0	1.2	4.4	0.0	0.0	0.1	0.4	0.0	0.0	0.4	1.9	
	0.0	0.0	0.3	0.0	0.0	0.2	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Basin 34	0	0	0	0	0	39	352	2	0	5	2	0	0	0	2	403
Cattaraugus at	0.0	0.0	0.0	[illegible]	0.0	9.7	87.3	0.5	0.0	1.4	0.5	0.0	0.0	0.0	0.5	4.0
Gowanda, NY	0.0	0.0	0.0	[illegible]	0.0	3.2	9.3	8.7	0.0	1.8	0.7	0.0	0.0	0.0	2.5	
	0.0	0.0	0.0	[illegible]	0.0	0.4	3.5	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	
Basin 36	0	0	0	0	0	0	4	0	0	0	0	0	0	1	0	6
Delaware near	0.0	0.0	0.0	0.0	0.0	7.1	71.4	1.8	0.0	0.0	3.6	0.0	0.0	16.1	0.0	0.1
Angola, NY	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.5	0.0	0.0	0.1	0.0	0.0	0.4	0.0	
	0.0	0.0	0.0	0.0	[illegible]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	

981 Sq. Mi. of clay soils in the Maumee River Watershed
18.5 Percent of the Maumee River Watershed
69.8 Percent of the clay soils in the Mainfile Data File*
9.7 Percent of all land in the Mainfile Data File

* Must be added to SEMCOG and OCAP data files to determine percent of total U. S. Lake Erie Watershed.

Figure II-2 - Example of Dual Feature Summaries - Slope vs. Soil Erodability
for Cattaraugus Creek at Gowanda

Count Row Pct Col Pct Tot Pct	0.10	0.17	0.20	0.24	0.28	0.32	0.37	0.43	0.49	Total Row
Slope Value	1	0	0	1	0	0	0	0	0	2
Less Than 0.2	42.9	0.0	0.0	57.1	0.0	0.0	0.0	0.0	0.0	0.5
	40.9	0.0	0.0	1.2	0.0	0.0	0.0	0.0	0.0	
	0.2	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	
	1	0	0	3	1	4	0	0	0	11
0.5	12.1	0.0	4.7	31.8	5.6	36.4	1.9	3.7	3.7	2.7
	59.1	0.0	0.4	3.4	15.8	14.0	2.5	7.7	0.5	
	0.3	0.0	0.1	0.8	0.1	1.0	0.0	0.1	0.1	
	0	1	2	0	1	5	0	1	5	15
1.0	0.0	9.2	11.8	2.0	5.3	30.9	0.7	4.6	35.5	3.8
	0.0	2.2	1.5	0.3	21.1	16.8	1.3	13.5	7.2	
	0.0	0.3	0.4	0.1	0.2	1.2	0.0	0.2	1.3	
	0	20	3	7	1	3	5	1	16	56
2.0	0.0	36.6	4.8	11.8	1.3	5.7	8.6	1.6	29.4	13.8
	0.0	32.5	2.2	6.7	18.4	11.5	60.8	17.3	22.0	
	0.0	5.1	0.7	1.6	0.2	0.8	1.2	0.2	4.1	
	0	1	1	2	0	0	0	0	1	5
3-5	0.0	25.0	11.5	42.3	0.0	0.0	0.0	0.0	21.2	1.3
	0.0	2.1	0.5	2.2	0.0	0.0	0.0	0.0	1.5	
	0.0	0.3	0.1	0.5	0.0	0.0	0.0	0.0	0.0	
	0	24	37	38	1	10	2	2	22	138
6-8	0.0	17.2	27.0	27.9	1.0	7.3	1.6	1.8	16.1	34.2
	0.0	37.9	31.0	39.0	36.8	36.2	27.8	48.1	29.8	
	0.0	5.9	9.2	9.5	0.3	2.5	0.5	0.6	5.5	
	0	9	42	40	0	5	1	1	9	106
9-11	0.0	8.6	39.6	37.4	0.2	4.4	0.6	0.6	8.7	26.3
	0.0	14.5	35.0	40.3	5.3	16.8	7.6	11.5	12.3	
	0.0	2.3	10.4	9.8	0.0	1.2	0.1	0.1	2.3	
	0	0	0	0	0	0	0	0	0	0
15-17	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	0	7	35	7	0	1	0	0	20	70
18 or Greater	0.0	9.7	50.3	9.5	0.1	1.9	0.0	0.1	28.3	17.4
	0.0	10.8	29.3	6.8	2.6	4.7	0.0	1.9	26.7	
	0.0	1.7	8.8	1.7	0.0	0.3	0.0	0.0	4.9	
Column	2	63	120	99	4	28	8	5	75	403
Total	0.5	15.6	29.8	24.4	0.9	6.9	2.0	1.3	18.5	100.0

1 Sq. mile of basin in class
12.1 percent of basin in class
59.1 percent of this soil erodability in this slope class
0.3 percent of the Watershed in this slope and soil erodability class

11 Sq. mile of the Watershed in this (0.5%) slope class
2.7 percent of the Watershed

75 Sq. mile of the Watershed in this (0.49) soil erodability class
18.5 percent of the Watershed

REFERENCES - CHAPTER TWO

1. Cahill, T. H., "Lake Erie Basin Land Resource Information System," Lake Erie Wastewater Management Study Technical Report, U.S. Army Corps of Engineers, Buffalo, NY, January 1978.

2. Urban, D. R., J. R. Adams, and T. J. Logan, "Application of the Universal Soil Loss Equation in the Lake Erie Drainage Basin," Lake Erie Wastewater Management Study Technical Report, U.S. Army Corps of Engineers, Buffalo, NY, November 1978.

CHAPTER THREE

POLLUTANT EXPORT FROM WATERSHEDS

I. INTRODUCTION

To determine the effect of land and its use on Lake Erie water quality, watershed characteristics must be related to the export of pollutants. The previous chapter described the procedure followed in characterizing land type-land use relationships in tributary sub-basins of Lake Erie and how the relationships affect potential gross erosion. This chapter describes pollutants exported from these sub-basins and how these pollutants move through river systems. Land resource-water quality relationships which were determined by this study are also presented.

The export of pollutants from 64 watersheds was measured in the Lake Erie basin by this study. An additional eight stations monitored by the Cuyahoga Restoration Study of the Buffalo District were also used. The location of these watersheds is shown in Map III-1. It can be seen from this map that the entire U.S. drainage basin was monitored. The heavy concentration of stations in the Sandusky River reflects the special studies carried out there. Table III-1 shows the station identification numbers, locations, areas, and number of samples analyzed.

The strategy used to sample the watersheds was event sampling. A minimum of two high flow events with samples collected on the rising and falling stages of the hydrograph were monitored. The sampling program ran from December 1974 to September 1977. It can be seen from Table III-1 that from 22 to 1,543 samples were used to characterize pollutant export from a watershed. The parameters measured were total phosphorus, dissolved orthophosphate, nitrite-nitrate nitrogen, ammonia nitrogen, total Kjeldahl nitrogen, suspended solids, chlorides, silica, and conductivity. The data from this program are reported in the Lake Erie Wastewater Management Study. Water Quality Data Reports (1, 2, 3). Methods of sample collection and analysis, the quality control program, and data interpretation are reported by Baker (4, 5).

II. CHARACTERIZATION OF POLLUTANT EXPORT

a. Annual Estimates - Annual pollutant loads are not a good representation of pollutant export from a watershed because large variations can occur from year to year. These variations result because rainfall and runoff are causative and vary annually. An example of the annual variation in pollutant loads is shown in Table III-2. This table shows the unit area total phosphorus loads

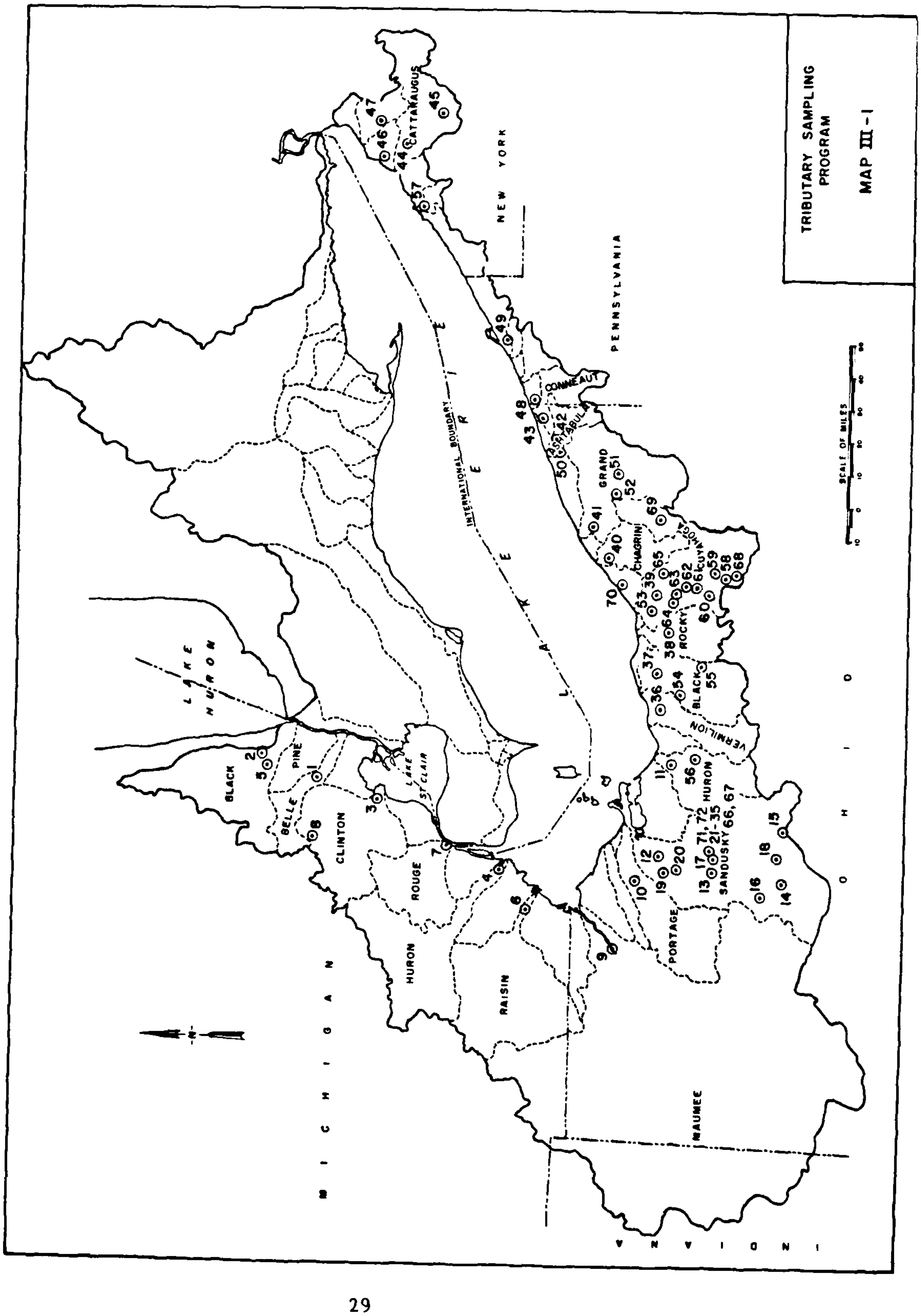

TRIBUTARY SAMPLING PROGRAM
MAP III-I
NEW YORK
PENNSYLVANIA
OHIO
INDIANA
MICHIGAN
LAKE HURON
LAKE ST. CLAIR
LAKE ERIE
INTERNATIONAL BOUNDARY
CATTARAUGUS
CONNEAUT
GRAND
CHAGRIN
ROCKY
BLACK
VERMILION
HURON
SANDUSKY
PORTAGE
MAUMEE
RAISIN
HURON
ROUGE
CLINTON
BELLE
PINE
BLACK
SCALE OF MILES

Table III-1 - Water Quality Monitoring Stations in the Lake Erie Drainage Basin

Stream	Station Number	Sampling Site	Drainage Area (sq. mi.)	Map Code	No. of Samples Analyzed
Belle	04160600 (1)	Memphis, MI	151	1	60
Black	04159500 (1)	Fargo, MI	480	2	61
Clinton	04165500 (1)	Mt. Clemens, MI	734	3	63
Huron	821114 (2)	S. Metropolitan Pkwy., MI	849	4	50
Mill Creek	04159900 (1)	Avoca, MI	169	5	65
Raisin	04176500 (1)	Monroe, MI	1,042	6	61
Rouge	820070 (2)	W. Jefferson Bridge, MI	467	7	57
Sashabaw Creek	04160800 (1)	Drayton Plains, MI	20.9	8	62
Maumee	04193500 (1)	Waterville, OH	6,330	9	1,411
Portage	04195500 (1)	Woodville, OH	428	10	1,292
Huron	04199000 (1)	Milan, OH	371	11	1,543
Sandusky	04198000 (1)	Fremont, OH	1,251	12	1,283
Sandusky	04197000 (1)	Mexico, OH	774	13	908
Sandusky	04196500 (1)	Upper Sandusky, OH	298	14	1,139
Sandusky	04196000 (1)	Bucyrus, OH	88.8	15	1,180
Tymochtee Creek	04196800 (1)	Crawford, OH	229	16	973
Honey Creek	04197100 (1)	Melmore, OH	149	17	1,194
Broken Sword	04196200 (1)	Nevada, OH	83.8	18	988
Wolf Creek West Branch	04197300 (1)	Bettsville, OH	66.2	19	930
Wolf Creek East Branch	04197450 (1)	Bettsville, OH	82.3	20	929
Mohawk Lake	A (3)	Tributary below Mohawk Lake	5.3	21	22
Honey Creek	1 (3)	At Route 231	171	22	43
Buckeye Creek	E (3)	At Route 67	5.6	23	34
Honey Creek	3 (3)	Upstm. from Silver Creek	121.6	24	34
Silver Creek	4 (3)	Confluence with Honey Cr.	24.4	25	35
Silver Creek	M (3)	Downstream from Marsh	16.4	26	43
Silver Creek	N (3)	Upstm. from Marsh	12.1	27	43
Aichholz Ditch	6 (3)	Honey Creek, County Rd. 49	16.3	28	32
Honey Creek	5 (3)	Upstm. from Aichholz Ditch	95.6	29	42
Honey Creek	7 (3)	Attica, Route 4	75.6	30	41
Honey Creek	F (3)	Weis Road	10.1	31	33
Honey Creek	8 (3)	Upstm. from Brokenknife	26.8	32	31
Brokenknife Cr.	D or 9 (3)	County Line Road	20.5	33	35
Trib. Honey Cr.	B (3)	R.R. North at Scott Rd.	3.4	34	29
Honey Creek	10 (3)	Rt. 103	15.7	35	34
Vermilion	04199500 (1)	Vermilion, OH	262	36	106
Black River	04200500 (1)	Elyria, OH	396	37	101
Rocky	04201500 (1)	Berea, OH	267	38	60
Cuyahoga	04208000 (1)	Independence, OH	707	39	441
Chagrin	04209000 (1)	Willoughby, OH	246	40	101
Grand	04212200 (1)	Painesville, OH	701	41	63
Ashtabula River	04212500 (1)	Ashtabula, OH	121	42	23
Conneaut Creek	04213000 (1)	Conneaut, OH	175	43	23
Cattaraugus Creek	04213500 (1)	Gowanda, NY	432	44	142
S. Br. Cattaraugus	04213490 (1)	Otto, NY	25.60	45	77
Delaware Creek	04214040 (1)	Angola, NY	8.15	46	77
18 Mile Creek	04214200 (1)	N. Boston, NY	37.20	47	77
Raccoon Creek	04213040 (1)	W. Springfield, PA	2.53	48	54
Mill Creek	04213200 (1)	Erie, PA	9.16	49	53
Hubbard Run	04212600 (1)	Ashtabula, OH	.88	50	38
Hoskins Creek	04210100 (1)	Hartsgrove, OH	5.42	51	40
Montville Ditch	04210090 (1)	Montville, OH	.29	52	40
Big Creek	04208502 (1)	Cleveland, OH	35.3	53	60
Plum Creek	04200100 (1)	Oberlin, OH	4.83	54	64
Neff Run	04199800 (1)	Litchfield, OH	.76	55	60
Norwalk Creek	04198100 (1)	Norwalk, OH	4.92	56	60
Canadaway		Fredonia, NY	34.9	57	36
Cuyahoga River	04206000 (1)	Old Portage, OH	404	58	197
Mud Brook	04206050 (1)	Akron, OH	29.3	59	162
Yellow Creek	04206220 (1)	Botzum, OH	30.7	60	177
Furnace Run	04206370 (1)	Everett, OH	17.7	61	162
Cuyahoga River	04206400 (1)	Peninsula, OH	494	62	353
Brandywine Creek	04206420 (1)	Jaite, OH	27.2	63	176
Chippewa Creek	04206450 (1)	Brecksville, OH	17.7	64	154
Tinkers Creek	04207200 (1)	Bedford, OH	83.9	65	313
Ackerman Ditch	G (3)	Ackerman Ditch	4.4	66	32
Mohawk Lake	AA (3)	Tributary above Mohawk	3.72	67	34
Little Cuyahoga R.	04205700 (1)	Akron, OH	59.2	68	24
Cuyahoga River	04202000 (1)	Hiram Rapids, OH	151	69	39
Euclid Creek	04208690 (1)	Euclid, OH	22.6	70	189
Rock Creek West	RWW (4)	County Rd 16	13.6	71	34
Rock Creek East	RCE (4)	County Rd 16	7.0	72	33

(1) U.S. Geological Survey Station Code
(2) Michigan Department of Natural Resources Code
(3) Corps of Engineers Honey Creek Watershed Code
(4) Corps of Engineers Code

Table III-2 - Unit Area Total Phosphorus Loads, Water Yields, and Flow Weighted Mean Concentrations for Water Years 1975, 1976 and 1977

Basin	Unit Area Phosphorus Load (1) Kilograms as P/Hectare			Runoff (2) in cm			Weighted Mean Concentration (3) mg/l as P		
Map Code	WY 75	WY 76	WY 77	WY 75	WY 76	WY 77	WY 75	WY 76	WY 77
9	1.58	1.81	1.15	29.3	30.7	18.5	.54	.59	.62
10	1.25	.78	.99	26.7	28.9	22.0	.47	.27	.45
11	1.20	.96	1.15	31.6	29.1	26.1	.38	.33	.44
12	1.61	1.12	.75	31.6	22.9	19.2	.51	.49	.39
13		1.27	1.10		24.0	18.0		.53	.61
14		1.70	1.15		28.3	18.0		.60	.64
15		2.10	1.90		35.6	24.7		.59	.77
16		.63	.34		12.9	11.3		.49	.30
17		1.09	.66		24.9(4)	18.3		.44	.36
18		1.94	1.00		34.6(4)	23.8		.56	.42
19		.80	.49		22.5(4)	16.9		.36	.29
20		1.1	2.04		24.9(4)	55.1		.44	.37
36	1.61		1.03	39.3		32.2	.41		.32
37	1.89		1.65	43.0		38.4	.44		.43
39	3.57		1.57	69.3		38.3	.52		.41
40	1.76		.98	65.2		46.7	.27		.21
44	1.31		2.25	65.5		83.3	.20		.27

(1) Calculated using the flow interval method (Ref 5) with instantaneous fluxes and daily flows measured in the respective water year.
(2) Measured for the respective water year at the U.S.G.S. water level station shown in Table III-1.
(3) mg/l = (kg/hec/cm of runoff) x 10
(4) Approximated for Oct-Jan, WY 76

calculated for watersheds which were monitored more than one year. In many cases, variation in annual loads for a watershed is as great as the variation between basins measured in any water year.

Annual loads were estimated with the flow interval method which uses instantaneous flow-concentration measurements and daily flow measurements. This method was developed during Phase I and is described in a separate technical report (6). The instantaneous flow-concentration measurements are used to calculate loadings for a specific flow event. The daily flows are used to determine the duration of these flow events. The loads from all these flow events are summed up for the annual estimate. The load estimates shown in Table III-2 are based on instantaneous flow-concentrations and daily flows measured in the water year.

The annual runoff for these basins is also shown in Table III-2. It can be seen that annual runoff varies by almost 100 percent in some basins. The effect of variations in total runoff can be reduced by dividing the unit area loads by the runoff measured in a basin to calculate an annual flow weighted mean concentration.

The annual flow weighted mean concentrations are a better representation of pollutant export than annual loads. It can be seen from Table III-2 that annual concentrations do not vary as much as annual loads. However, variations in annual concentrations exist and result from differences in flow characteristics, i.e., the magnitude, duration, frequency, and season of high flow events. Therefore, if pollutant export from a basin is to be adequately characterized, these differences in annual flow characteristics must be eliminated.

b. Mean Annual Estimates - Differences in pollutant estimates caused by annual flow characteristics can be partially eliminated if mean annual estimates are made. The difference between mean annual estimates and the annual estimates made in the previous section is that daily flows measured in the water year are no longer used to determine the duration of a pollutant loading event. Instead, all the daily flows that were ever measured at the station for as many as 50 years are used to estimate the probability that a loading event will occur.

Table III-3 shows the unit area loads which were calculated using the daily flows measured for the period of record at each station monitored more than one year. It can be seen from this table that the annual variation in the estimates has been reduced when compared with the annual estimates shown in Table III-2. The variations between

Table III-3 - Mean Annual Total Phosphorus Unit Area Loads for Water Years 1975, 1976, and 1977 (Kilograms of P/Hectare) Period of Record Flow Statistics Used

Basin No.	WY 75	WY 76	WY 77
9	1.23	1.12	1.26
10	.93	.66	.79
11	.88	.66	.86
12	.95	.94	.96
13	-	.99	1.13
14	-	1.28	1.55
15	-	1.51	1.86
16	-	.87	.55
17	-	.88	.79
18	-	1.62	1.02
19	-	.65	.56
20	-	2.06	1.43
36	.77	-	.75
37	1.61	-	1.24
39	2.55	-	1.67
40	.99	-	.76
44	1.00	-	1.02

years seen in Table III-3 are caused by annual variations in the measured flow-concentration relationships which are used to estimate loads for the flow events. The flow-concentration relationship measured each year for a river depends on the condition of the basin and type and season of rainfall events. This basin response can only be determined through the use of a deterministic model which will be applied during Phase III of this study.

The unit area loadings presented in Table III-3 are good estimates of the mean annual phosphorus loads which are exported from these basins. However, analysis of land resource and water quality relationships requires one estimate for mean annual export. Therefore, the flow-concentration data measured for the entire monitoring period of water years 1975, 1976, and 1977 were used with daily flows measured during the period of record at the water level station. These data were used in the flow interval method to estimate mean annual loads for all parameters.

Any analysis of land resource and water quality relationships must also consider rainfall and/or runoff. Mean annual runoff in the Lake Erie drainage basin varies from 0.633 to 1.765 cfs/mi^2 between basins (7). Since the amount of pollutant exported from a watershed depends upon flow, this difference in runoff must be considered in the representation of pollutant export. Division of mean annual loads by the mean annual water yield gives an average annual concentration. These concentrations are presented in Table III-4.

The limitations of the data presented in Table III-4 should be noted. Stations 9 to 16 are considered as excellent data sets. The water quality data were collected every six hours, excluding malfunctions, for two to three years at USGS water level stations. The flow records at these stations contain 13 to 53 years of data. Stations 17 to 20 have similar chemical records but only two years of flow data exist. At stations 21 to 35, 66, 67, 71 and 72, flows were measured only when samples were collected. Daily flow information at these stations is not available. Daily flows at station 17, prorated by area, were used to make loading estimates at these stations.

III. IN-RIVER TRANSPORT

a. Introduction - This section presents results of studies carried out to determine how total phosphorus is transported in a river system. In-river transport of phosphorus has been studied to determine the effect of river processing on delivery of phosphorus from inland point sources to Lake Erie. The program was designed to answer questions regarding modifications in phosphorus forms, percent delivery, and the time required for material in transport to reach Lake Erie. These same questions also pertain to diffuse sources.

Table III-4 - Mean Annual Flow Weighted Mean Concentrations (mg/l)

Basin No.	Total Phosphorus as P	Ortho phosphate as P	Nitrite-Nitrate Nitrogen as N	Ammonia Nitrogen as N	TKN as N	Suspended Solids	Chloride as C	Silica as SiO_2	Mean Annual Flow
1	0.022	0.009	0.194	0.021	0.15	4.9	8.2	0.51	523.0
2	0.222	0.071	1.040	0.287	0.82	65.5	25.1	2.52	277.0
3	0.231	0.133	2.250	0.187	1.03	53.1	89.1	5.03	523.0
4	0.086	0.033	0.688	1.250	1.96	20.9	70.0	6.36	563.0
5	0.123	0.044	0.849	0.153	0.91	27.9	23.7	2.63	95.9
6	0.322	0.145	3.000	0.263	1.03	84.2	27.5	4.64	693.0
7	0.255	0.097	0.876	0.413	1.10	79.0	80.9	4.36	947.0
8	0.036	0.005	0.228	0.046	0.67	8.4	22.6	5.99	12.2
9	0.430	0.089	4.440	0.163	1.70	217.0	30.6	6.29	4,786.0
10	0.318	0.103	5.070	0.169	1.54	144.0	36.8	6.31	307.0
11	0.298	0.081	3.100	0.154	1.07	176.0	28.0	6.34	295.0
12	0.350	0.068	3.970	0.147	1.38	173.0	29.1	6.00	944.0
13	0.433	0.070	3.990	0.215	1.83	256.0	24.1	4.76	572.0
14	0.481	0.112	3.340	0.191	1.66	251.0	24.1	4.85	240.0
15	0.515	0.213	2.940	0.543	1.74	142.0	34.8	5.70	84.2
16	0.268	0.050	3.980	0.156	1.17	142.0	20.4	4.56	166.0
17	0.410	0.091	5.850	0.234	2.78	154.0	28.2	7.65	94.4
18	0.458	0.058	4.780	0.317	1.71	328.0	26.6	6.51	70.7
19	0.332	0.096	6.640	0.191	2.39	131.0	39.8	7.90	37.4
20	0.387	0.132	5.650	0.262	2.12	136.0	40.7	7.44	94.0
21	0.346	0.043	3.818	0.280	2.64	52.7	57.7	10.16	3.4
22	0.260	0.091	3.310	0.264	2.12	66.0	25.6	4.77	108.4
23	0.312	0.079	4.730	0.176	1.88	53.8	24.8	5.71	3.6
24	0.291	0.090	3.960	0.323	2.48	61.7	29.5	5.19	77.1

Table III-4 - Mean Annual Flow Weighted Mean Concentrations (mg/l) (Cont'd)

Basin No.	Total Phosphorus as P	Ortho phosphate as P	Nitrite-Nitrate Nitrogen as N	Ammonia Nitrogen as N	TKN as N	Suspended Solids	Chloride as C	Silica as SiO_2	Mean Annual Flow
25	0.241	0.049	5.290	0.158	1.960	35.5	26.00	8.00	15.46
26	0.178	0.051	3.720	0.231	1.820	18.7	37.10	7.17	10.52
27	0.232	0.080	5.040	0.284	2.010	43.8	34.70	6.36	7.73
28	0.345	0.094	7.245	0.551	2.923	71.8	32.74	8.28	10.33
29	0.253	0.016	4.510	0.407	1.960	41.2	28.10	5.22	60.60
30	0.338	0.117	5.030	0.429	2.610	64.7	32.10	5.77	47.90
31	0.253	0.075	4.890	0.282	2.120	27.3	46.60	5.36	6.40
32	0.272	0.069	5.140	0.229	2.020	107.0	28.90	5.81	17.00
33	0.390	0.154	8.000	0.480	3.300	77.5	37.13	8.49	12.99
34	0.193	0.052	6.730	0.224	2.090	34.1	26.40	5.98	2.15
35	0.259	0.080	4.950	0.218	2.042	86.4	33.40	5.73	9.95
36	0.225	0.056	2.530	0.062	0.611	220.0	18.80	3.79	240.00
37	0.457	0.204	3.000	0.715	4.120	285.0	34.40	4.65	318.00
38	0.418	0.215	1.284	0.168	0.821	135.0	58.80	4.29	259.00
39	0.429	0.204	1.845	0.375	1.390	152.0	92.50	6.50	789.00
40	0.219	0.050	0.786	0.072	1.113	308.0	42.00	5.20	325.00
41	0.074	0.022	0.301	0.021	-	53.0	15.89	2.55	782.00
42	0.051	0.004	0.172	0.016	-	34.0	10.53	1.49	150.00
43	0.057	0.002	0.283	0.013	-	50.0	10.98	2.16	260.00
44	0.182	0.007	1.140	0.136	0.706	430.0	10.45	4.11	731.00
45	0.116	0.006	0.932	0.048	-	119.6	7.73	2.82	43.32
46	0.059	0.012	1.371	0.101	-	25.9	17.66	4.02	13.80

Table III-4 - Mean Annual Flow Weighted Mean Concentrations (mg/l) (Cont'd)

Basin No.	Total Phosphorus as P	Ortho phosphate as P	Nitrite-Nitrate Nitrogen as N	Ammonia Nitrogen as N	TKN as N	Suspended Solids	Chloride as C	Silica as SiO_2	Mean Annual Flow
47	0.119	0.013	0.814	0.016	-	123.8	8.6	2.91	62.9
48	0.063	0.008	0.273	0.008	-	55.4	47.0	3.77	4.1
49	0.076	0.043	1.821	0.018	-	35.8	110.9	9.87	14.8
50	0.175	0.062	0.421	0.164	-	101.4	51.6	8.10	1.1
51	0.090	0.011	0.315	0.025	-	26.1	38.6	2.79	6.2
52	0.044	0.014	0.102	0.044	-	13.8	49.9	3.05	0.3
53	0.305	0.107	1.122	0.590	-	103.0	146.4	7.20	51.4
54	0.144	0.075	4.980	0.081	-	35.1	42.4	5.20	3.9
55	0.110	0.018	1.119	0.055	-	46.8	37.5	7.36	0.6
56	0.163	0.026	13.490	0.106	-	95.9	24.8	7.85	3.9
57	0.129	0.015	1.372	0.386	0.434	263.2	19.1	6.73	59.1
58	0.149	0.065	1.360	0.233	1.160	36.8	78.9	5.63	416.0
59	0.279	0.090	1.035	0.116	1.094	123.2	62.6	7.25	45.3
60	0.100	0.021	0.729	0.073	0.703	86.8	63.4	6.96	47.5
61	0.211	0.041	0.854	0.057	1.162	328.5	109.1	6.84	27.4
62	0.405	0.220	2.091	0.378	1.148	142.2	90.6	7.00	551.3
63	0.683	0.278	1.251	0.274	1.700	181.1	71.8	6.41	39.9
64	0.403	0.138	1.252	0.123	1.556	450.2	84.6	6.27	26.0
65	0.637	0.298	1.279	0.326	1.467	163.7	91.7	6.26	123.0
66	0.349	0.185	5.049	0.285	2.520	45.4	30.2	6.36	2.8
67	0.579	0.133	8.980	0.436	3.286	115.3	38.0	9.61	2.4
68	0.368	0.153	0.855	0.344	1.770	46.4	97.8	3.60	91.5
69	0.108	0.020	0.269	0.082	0.362	19.5	12.8	-	202.0
70	0.260	0.035	1.184	0.383	1.335	131.1	82.6	6.62	25.8
71	0.358	0.091	5.820	0.209	2.380	97.0	29.3	7.18	8.6
72	0.116	0.031	2.100	0.109	1.042	20.7	16.1	4.53	4.4

The program was also designed to answer questions about what periods of the year were important in controlling erosion and if controlling sheet erosion would lead to an increased streambed erosion.

To answer these questions, special methods were developed to calculate travel distances of total phosphorus during storm events (8) and rates of phosphorus loss downstream from an outfall during steady state conditions (9). A dynamic material transport model (10) was developed to study deposition and resuspension of total phosphorus and suspended sediment during high flow events.

A network of nine monitoring stations was established in the Sandusky River. These stations were located at USGS water level stations and equipped with automatic samplers. Samples were collected every six hours from January 1976 to September 1977 (1). In addition, a special study to measure phosphorus deposition was carried out during steady state flow conditions (3). A network of five stations was established below the Bucyrus sewage treatment plant. Samples were collected every two hours on two different occasions for two days.

b. Delivery of Point Sources - The steady state deposition studies showed orthophosphate and total phosphorus discharged from a sewage treatment plant are rapidly removed from the water column (9). As this material moves downstream from the outfall it is adsorbed to river sediments by clay minerals and/or micro-organisms. Figure III-1 shows orthophosphate concentrations as a function of time at stations downstream of the Bucyrus, Ohio, treatment plant. The diurnal variation of the point source can be seen. Calculations show that about 75 percent of the total phosphorus is lost after traveling 16 kilometers during low flow conditions which occur 35 percent of the time (9). At these periods, Lake Erie or stations located 16 or more kilometers downstream do not experience increased phosphorus concentrations resulting from point sources.

The phosphorus deposited in the river bottom sediments during steady state conditions is resuspended during high flow events. This phenomenon can be seen in Figure III-2 which shows deposition and resuspension of total phosphorus and orthophosphate between Bucyrus and Upper Sandusky on the Sandusky River. Deposition and resuspension were calculated utilizing a dynamic phosphorus transport model (10). This model routes all upstream inputs between Bucyrus and Upper Sandusky to Upper Sandusky. If the routed sum is larger than what was actually measured, deposition is assumed. If the measured is larger, resuspension is assumed. It can be seen from Figure III-2 that both total phosphorus and orthophosphate are lost from the water during low flow. However, during high flow, only total phosphorus is resuspended. Orthophosphate is neither deposited to nor released from

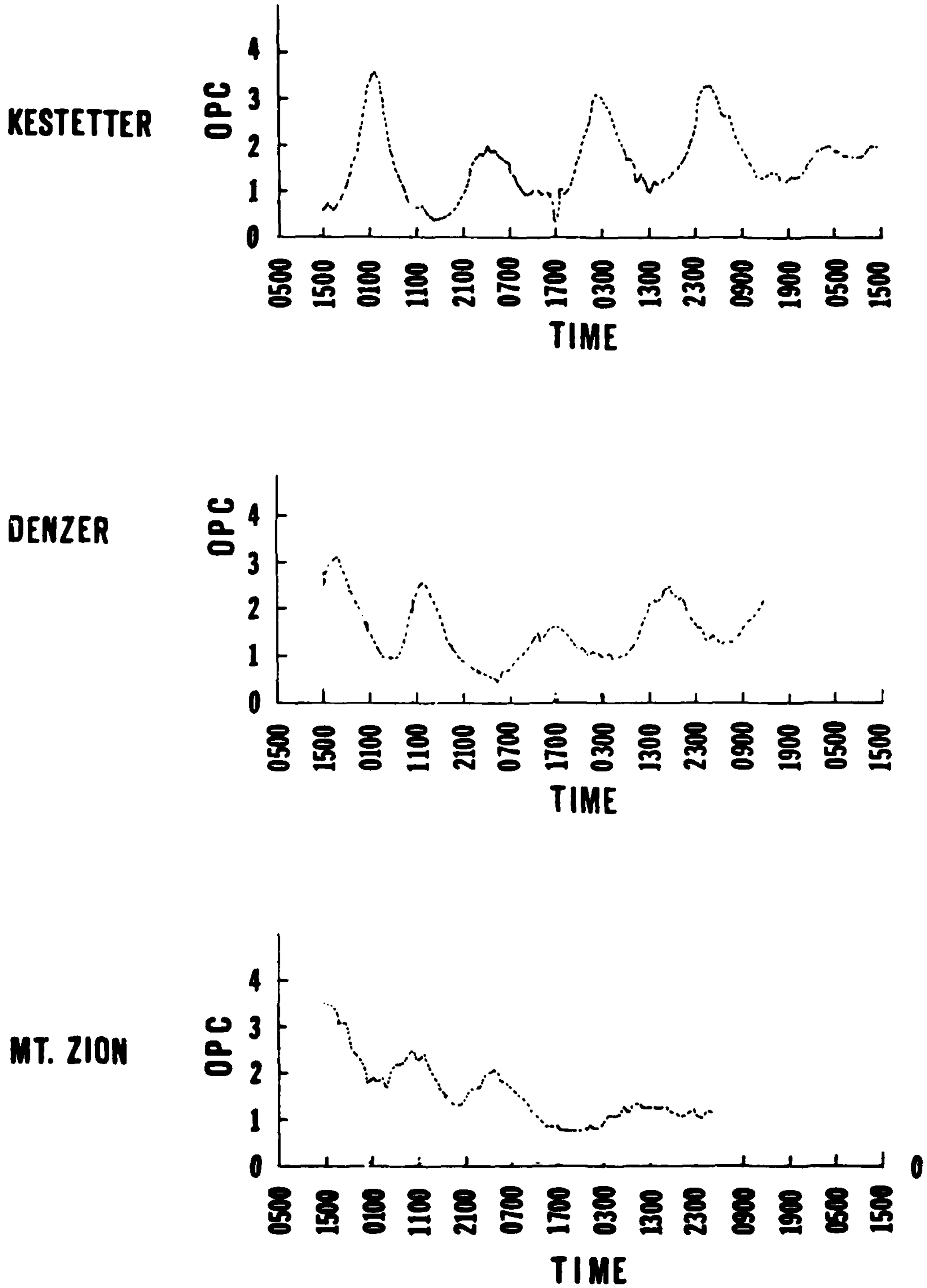


Figure III-1 - Orthophosphate Concentrations (mg/l as P) Kestetter (0.9 km), Denzer (4.25 km) and Mt. Zion (6.53 km) are downstream of Bucyrus, Ohio

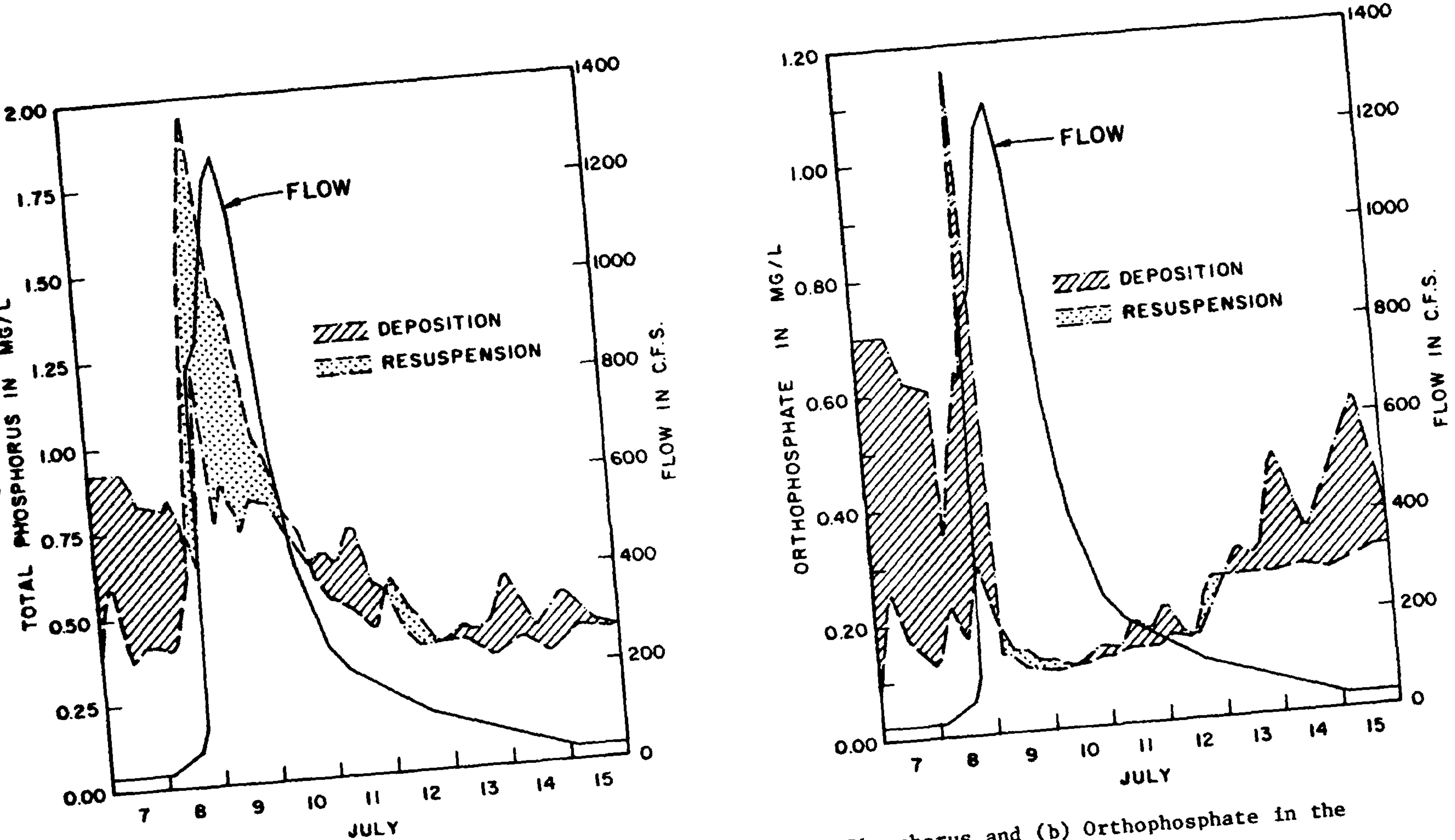


Figure III-2 - Deposition and Resuspension of (a) Total Phosphorus and (b) Orthophosphate in the Sandusky River near Upper Sandusky - Storm beginning 7 July 1976 the sediments during high flow. It moves right through the system. This figure very clearly illustrates the instream processing of nutrients. Immediately available orthophosphorus is converted to potentially available sediment phosphorus during steady state flow conditions. The phosphorus is later transported as potentially available sediment phosphorus during high flow. It also should be noted that during high flow, phosphorus from point sources is transported directly through the river with no instream processing.

Material transport data have been collected at the USGS gaging station at Fremont on the Sandusky River since 1969. Reduction of point source phosphorus to 1 mg/l at the wastewater treatment plants at Tiffin and Upper Sandusky began in January 1976. As a result of this program, point source phosphorus inputs to the Sandusky River decreased about 20 metric tons from 1975 to 1976. Table III-5 shows the total phosphorus and orthophosphate loading from the Sandusky River to Lake Erie measured at Fremont. It can be seen from this table that total phosphorus loadings decreased 113 metric tons or 25 percent from 1975 to 1976. However, annual flow also decreased 25 percent during this period. If the flow weighted mean concentrations are examined, it is seen that they have not changed. If annual loads are calculated, no decrease is seen. Measured phosphorus loads increased 351 metric tons between 1976 and 1977. However, the calculated mean annual loads remained the same. Therefore, although there was a decrease in total phosphorus loading to the Sandusky River between 1975 and 1977, it has not been possible to measure a decrease in phosphorus delivered by the Sandusky because of large variations in the average annual flow.

Since a decrease in phosphorus loading as a result of point source removal of phosphorus has not been measured, the question arises as to how long point source phosphorus remains in the river. It has been shown that point source phosphorus which is deposited at low flow becomes resuspended at high flow. Figure III-3 shows the cumulative probability that total phosphorus will either move a given distance downstream or settle out in the Sandusky River (8). It can be seen from this figure that 50 percent of the phosphorus from Bucyrus which was resuspended and measured at Upper Sandusky will move at least 52 miles, which is the distance to Lake Erie. The rest of this material will be deposited before it reaches the lake. Flows at least as great as the flow event for which these calculations were made occur on the average of nine times a year. Therefore, the point source phosphorus which is deposited in-stream and resuspended has an average residence time of about one year in the Sandusky River.

Table III-5 - Phosphorus Loads from the Sandusky River to Lake Erie

Parameter	1969[2]	1974[2]	1975	1976	1977
Annual Loads					
TP MT/yr as P	407	506	446	333	684
	±161	±128	±24	±16	±153
OP MT/yr as P	96	96	65	64	136
	±9	±7	±2	±5	±27
Annual Flow cfs	1,221	1,247	1,025	769	1,326
Flow weighted mean concentration					
TP mg/l as P	.373	.454	.487	.485	.578
	±.148	±.115	±.026	±.023	±.129
OP mg/l as P	.088	.086	.071	.093	.103
	±.008	±.006	±.002	±.007	±.023
Mean Annual Loads[1]					
TP MT/yr	329	279	317	298	312
	±110	±31	±18	±33	±13
OP MT/yr	77	67	47	61	80
	±4	±5	±2	±4	±12

Calendar Year applies to columns 1969–1977.

1/ Calculated using the flow-concentration relationship for that year and flow probabilities from the 50 year record.
2/ Data provided by the River Studies Laboratory, Heidelberg College, Tiffin, Ohio.

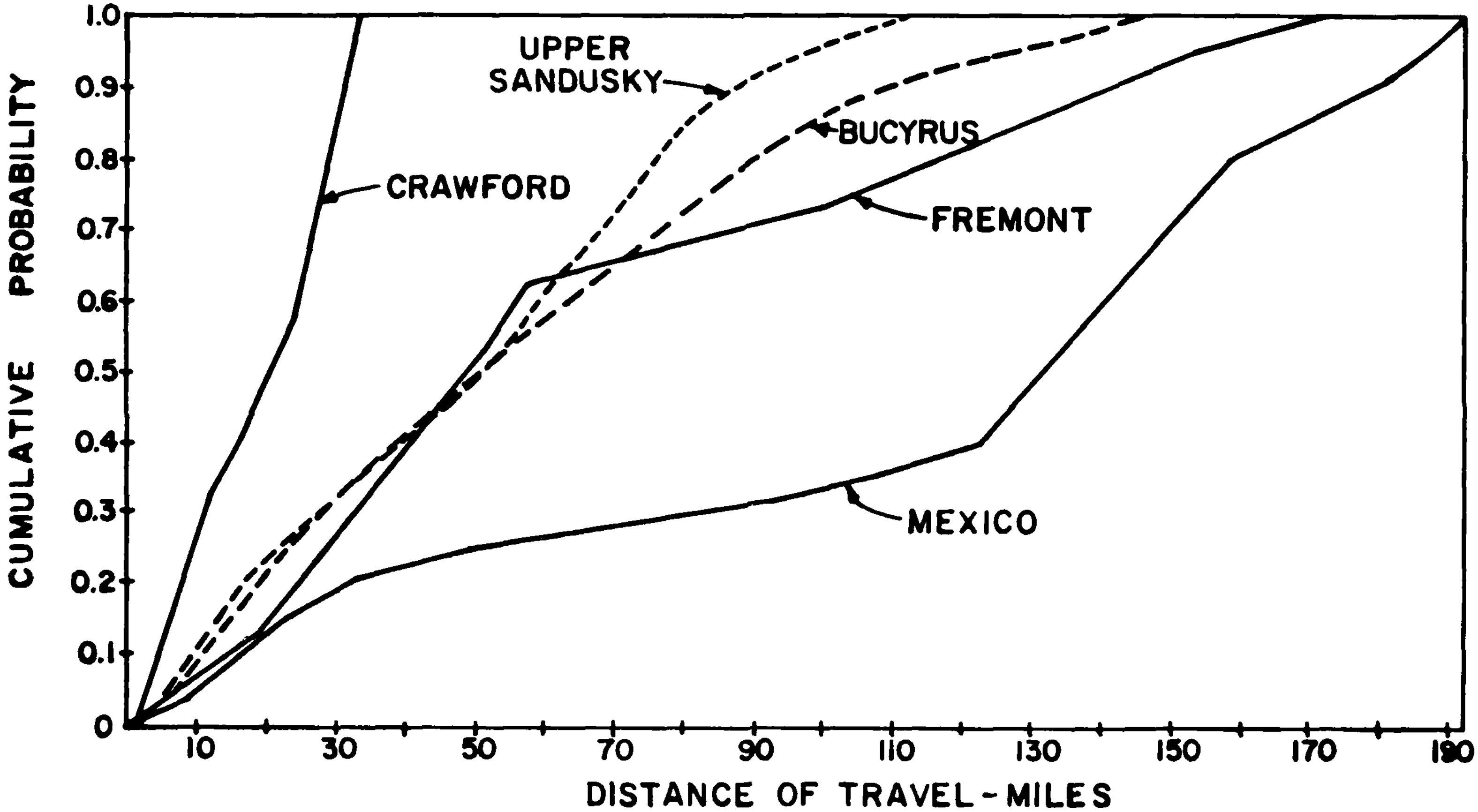


Figure III-3 - Cumulative probability that total phosphorus will be deposited in-stream before traveling the stated distance. Sandusky River Basin, 12 July 1974

Based on the river transport studies described in this section, the following conclusions have been made:

1. Delivery of point source phosphorus is a question of delivery of sediment through the river system. The average residence time of this material is estimated to be about one year in the Sandusky River.

2. Immediately available orthophosphate is converted to potentially available particulate phosphate.

3. Through analysis of individual events, it is possible to document deposition and resuspension of point source phosphorus. However, changes in annual load resulting from removal of point source phosphorus cannot be discerned from the measurements.

c. Delivery of Diffuse Sources - The previous section has shown that point source phosphorus enters a river primarily as orthophosphate and is quickly lost from the water column to the river sediments. During high flows, these sediments are resuspended and move downstream through a series of deposition and resuspension episodes. Most phosphorus originating from diffuse sources leaves the land attached to particulates. However, the fraction of soluble phosphorus to particulate phosphorus originating from diffuse sources varies widely in the Lake Erie basin. In the heavily fertilized river basins of northwest Ohio with high available phosphorus levels in the soil, the fraction is about 0.20. In the less fertile basins of New York with low available phosphorus levels in the soil, this fraction is about 0.05. High phosphorus fertilizer application rates have increased available phosphorus levels in the soil by about 500 percent (11). It is likely that these increased levels will increase soluble phosphorus concentrations in runoff.

Soluble phosphorus from diffuse sources enters the river primarily during high flow events and, as previously shown, is not lost from the water column but moves through the river and is delivered directly to Lake Erie. For the Maumee River, 66 percent of the dissolved phosphorus load was delivered in January through April in 1975 and 1976. Of this 66 percent, diffuse sources contributed 84 percent of the total (12). This orthophosphate loading is utilized by the diatom community in Lake Erie and is available throughout the spring and summer growing season through subsequent nutrient recycling.

Movement of particulate phosphorus from diffuse sources through a river is controlled by soil moisture in the drainage basin and rainfall. Soil moisture affects both the base flow in the stream and the amount of runoff. When soil moisture is high, as is the case in late winter and early spring, and rainfall is basin-wide, the entire basin is a contributing area. Dislodged soil particles move off the fields, through the drainage ditches, through the tributaries, and through the river to Lake Erie. During this time, delivery of eroded material is high due to high flows and the high percentage of rainfall which appears as runoff. In addition, sediment which has been deposited in streambeds is resuspended.

The distance this resuspended material travels increases with river flow and the storm duration (8). Small tributaries and upstream reaches of the basin have hydrographs which rise and fall sharply. Material resuspended from these reaches does not on the average travel as far as material which is picked up in the downstream reaches of the mainstream. This observation is verified by examining Figure III-3. The distance of travel for upstream stations of Crawford, Upper Sandusky, and Bucyrus is less than downstream stations of Mexico and Fremont.

Resuspended material was deposited during other times of the year; when soil moisture was low, streamflow down, and the infiltration capacity of the soil high. A basin-wide rainfall will not produce the same response under these conditions as when soil moisture is high. Less runoff will occur and material which moves off the field will be deposited in drainage ditches and will stay there until the ditches are cleaned. When rainfall is greater and material reaches tributaries, there will not be as high a base flow to move it through the tributary and it will be deposited there. In cases of higher rainfall summer thunderstorms, there may be enough runoff to produce transport through a tributary. However, since the storm is not basin-wide, flows are not high in the mainstem and the material is deposited there. Therefore, when soil moisture is low, the entire basin is not a contributing area, the immediate delivery of eroded material is not high, and material which is trapped in ditches has a low probability of reaching the lake.

The time required for material deposited in streams draining small watersheds to reach Lake Erie will be greater than for material deposited in larger tributaries. However, the travel distance during events which occur several times a year is great enough to move most material deposited in the small tributaries out of the river to Lake Erie in about five years.

However, there is material which is deposited in long term storage which will not move out of river until a certain frequency storm occurs. A 14 February 1977 high flow event in the Maumee River was a snowmelt. Lower sediment concentrations are usually observed during these events because there is very little raindrop impact for sheet erosion. However, a storm of this magnitude had not occurred in the Maumee River for 12 months. Although sheet erosion was minimal during this event, velocities were sufficient to remove material that had been deposited but could not be moved by previous storms which were smaller.

Snowmelt events also illustrate that rivers do not always carry the maximum amount of sediment possible. Suspended sediment data has been collected for snowmelt and rainfall events of similar magnitude. However, suspended sediment concentrations are lower during snowmelt because of decreased sheet erosion. Since events of similar magnitude have similar potential to carry sediment, concentrations would be the same at similar flows if streams always carried this maximum potential. But concentrations are not the same. Therefore, rivers do not always carry the maximum amount of sediment possible, and controlling sheet erosion will not result in streambed erosion. They only carry what can be resuspended at the flow which occurs. The large snowmelt resulted in high concentration because flows had not occurred in 12 months which could move that material. Those concentrations which were measured were nowhere near the maximum carrying capacity and would have been greater if rainfall had occurred.

From the preceeding discussion it can be concluded that in addition to high intensity summer storms, late winter and early spring are critical periods to control sheet erosion. However, control of sheet erosion will not stop all phosphorus losses from diffuse sources since the soluble portion may not be controlled. Finally, control of sheet erosion will not cause increased streambed erosion.

IV. ANALYSIS OF LAND RESOURCE AND WATER QUALITY RELATIONSHIPS

a. Introduction - The preceding sections have analyzed the variations in river transport with respect to annual changes in the duration and frequency of high flow events. Mean annual loadings for measured water quality parameters are calculated to characterize export and average annual concentrations are also calculated for comparison between basins. This section will analyze the effect of natural land forms and man's use of land on differences in nutrient export and water quality in river basins.

Omernik (13) analyzed the influence of land use on nutrient export. He found that both concentrations and export of total phosphorus, dissolved orthophosphate, and organic and inorganic nitrogen increased as the sum of the percentage of urban and agricultural land increased in a basin. Dillon and Kirchner (14) also found single variables, agriculture and urbanization, greatly increased the total phosphorus exported. They also analyzed the combination of two variables, geology and land use, on total phosphorus export from watersheds. They found phosphorus export was signigicantly lower from forested watersheds on igneous rock than from pasture and forest on sedimentary rock.

The use of two or more variables in combination to describe a watershed can easily be accomplished by the Land Resource Information System (LRIS). LRIS has the capacity to quantify selected combinations of land resource factors or "co-occurrences" as descriptive statistics of any land area in the data base. An example of the use of co-occurrences is the calculation of potential gross erosion (PGE) by use of the Universal Soil Loss Equation. This calculation quantifies the co-occurrence of a specific soil type, land use, slope, slope length, management practice, cover, and rainfall for a point. The comparison of sediment yield to potential gross erosion (delivery ratio) between basins is one example of a land resource and water quality analysis which uses co-occurrence statistics.

The purpose of this section is to examine the chemical variability between rivers and determine what relationships exist with respect to river basin characteristics; those natural and man-made variables which characterize a river basin and its water quality. For the purpose of this analysis, the parameters contained in the Land Resource Information System (LRIS) will be used both separately and in combination with each other.

b. <u>Sediment Yield and Potential Gross Erosion</u> - The Universal Soil Loss Equation has been used in this study to evaluate the expected results of land management programs by comparing relative differences between programs and not absolute results such as sediment yields. However, it is interesting to compare PGE to sediment yield. Table III-6 presents the results of this analysis. It can be seen from this table that the sediment yield does not have a high correlation to PGE (Equation 1.) The correlation is improved slightly if sediment yield is corrected for basin areas where no estimate is made for PGE (Equation 2.) The influence of land resource variables on the delivery ratio and the ratio of adjusted sediment yield to PGE is shown by Equations 3 to 13. The ratio of basin runoff to rainfall (Equation 9) is the most significant variable. Multivariate analysis of the parameters RORF, TEXT 123 (TEXT 345), TEXT 45 (TEXT 12), A, ABS, and PERM with DR explained 48 percent of the variance. RORF accounted for 42 percent, TEXT 123 (TEXT 345) accounted for an additional three (four) percent of the cumulative variance.

From the above analysis it is obvious that PGE and a single value delivery ratio should not be used to predict sediment yield. In addition, basin area, slope, drainage, permeability, and soil do not sufficiently explain the variance in delivery ratio. The only parameter which satisfactorily explains the observed delivery ratios is the ratio of basin runoff to rainfall as shown in Figure III-4.

Table III-6 - Relationship of Sediment Yield to Potential Gross Erosion for Lake Erie Watersheds

Equation[1/]	Dependent Variable (y)[2/]	Independent Variable (x)[2/]	a	b	Explained Variance R^2	Degrees of Freedom	F-Test[3/]
1	UASY	PGER	.556 E-2	.252	.006	49	.29
2	AUASY	PGER	.170 E-1	.138	.056	49	2.89
3	DR	A	.214 E-7	.066	.004	49	.19
4	DR	ABS	.452 E-2	.563	.005	49	.25
5	DR	TEXT 1	-.146 E-3	.074	.000	54	.01
6	DR	TEXT 2	-.206 E-2	.100	.102	54	6.12*
7	DR	TEXT 3	-.105 E-2	.149	.062	54	3.55
8	DR	TEXT 45	.130 E-2	.068	.013	54	.68
9	DR	RORF	.404	.072	.416	54	38.47**
10	DR	DRNG	-.147 E-2	.109	.077	54	4.50
11	DR	PERM	-.126 E-2	.139	.142	54	8.91**
12	DR	TEXT 12	-.147 E-2	.094	.074	54	4.31
13	DR	TEXT 123	-.199 E-2	.244	.217	54	14.95**

1/ y = a x +b

2/ UASY = Mean annual unit area sediment yield (metric tons per hectare).
PGER = Potential gross erosion rate (metric tons per hectare).
AUASY = Adjusted unit area sediment yield (metric tons per hectare).
= UASY -0.5 percent other land.
DR = Delivery ratio = AUASY/PGER.
A = Area (hectares).
ABS = Absolute basin slope (percent).
TEXT 1 = Percent of basin area with very fine testure soils.
TEXT 2 = Percent of basin area with fine texture soils.
TEXT 3 = Percent of basin area with medium testure soils.
TEXT 12 = TEXT 1 + TEXT 2.
TEXT 123 = TEXT 12 + TEXT 3.
TEXT 45 = Percent of basin area with coarse texture soils.
RORF = Ratio of basin runoff to rainfall.
DRNG = Percent of basin poorly drained or very poorly drained.
PERM = Percent of basin, a permeability of .01 to .09 inches per hour in the surface or subsurface level.

3/ A "*" is significant at the 95 percent level of the F-Test and "**" is significant at the 99 percent level of the F-Test.

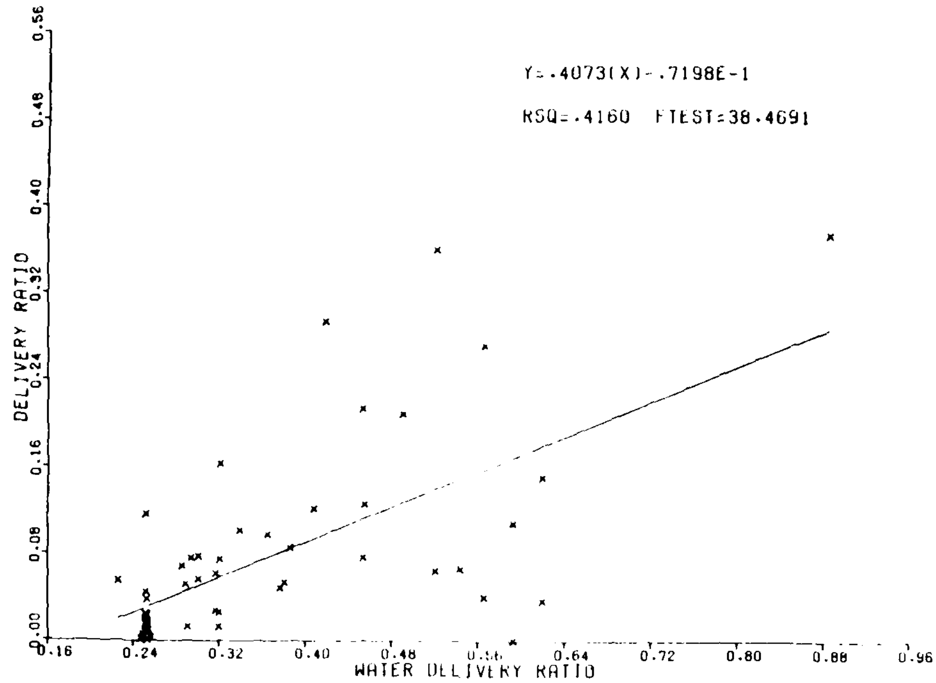


Figure III-4 - Relationship of Delivery Ratio vs the Runoff Rainfall Ratio for Lake Erie Watersheds.

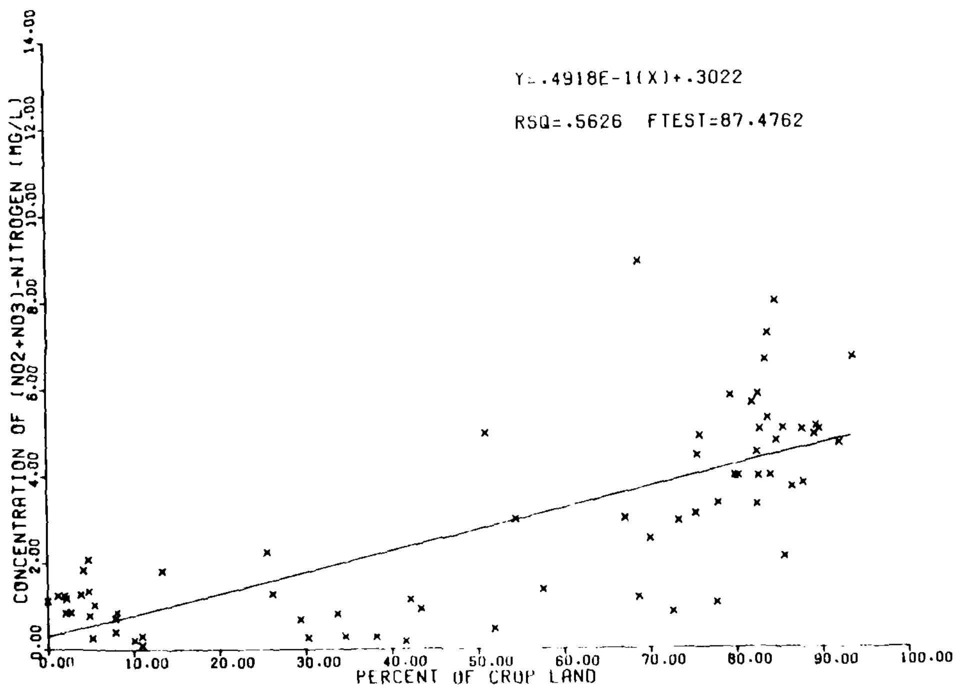


Figure III-5 - Relationship of Nitrite-nitrate Nitrogen to Agricultural Land for Lake Erie Watersheds.

c. Nutrients and Land Use - Table III-7 shows the results of the land use water quality analysis. It can be seen from this table that basin total phosphorus concentration or unit area load are not dependent upon percent of basin area that is in cropland or in cropland and other land (Equations 14 to 17.) In contrast, concentration of nitrite-nitrate nitrogen is well correlated with the percent of basin area that is cropland. Including the percent of basin area in other land does not improve the correlation (Equation 19.) Using the unit area load of nitrite-nitrate nitrogen instead of concentration does not produce as good as a correlation (Equations 20 and 21.)

In summary, nitrite-nitrate nitrogen concentrations are well correlated with percent of basin area in cropland, while phosphorus is not, as shown in Figures III-5 and III-6, respectively.

d. Phosphorus-Sediment Ratios - The relationship of phosphorus-sediment ratios to land resources was examined since a reasonable estimate of sediment yield could be made using a potential gross erosion estimate and a delivery ratio adjusted for the basin rainfall runoff ratio. If a basin's phosphorus-sediment ratio could be related to a basin's land resources, an estimate of phosphorus yield would also be made from potential gross erosion estimates.

Thirty-nine of the watersheds monitored showed an excellent correlation for individual water quality samples, between sediment phosphorus, and suspended sediment with an explained variance, R^2, greater than 60 percent. Another 21 basins showed a good correlation between these variables with the explained variances between 30 and 60 percent.

Use of the mean annual total phosphorus and suspended sediment concentrations for all watersheds indicated a significant but not strong relationship (Equation 22 of Table III-8.) Use of sediment phosphorus instead of total phosphorus improved the correlation (Equation 23 and Figure III-7.) This relationship was not improved by including land resource variables (Equations 24 to 31.) In fact, multivariate analysis with the variables used in Equations 24 to 31 did not produce an explained variance greater than four percent.

In summary, although the relationship between mean annual sediment phosphorus concentrations and suspended sediment concentrations is significant basinwide, it cannot be improved by including land resource variables.

Table III-7 - Relationship of Nutrient Concentrations and Loads to Land Use for Lake Erie Watersheds

Equation[1/]	Dependent Variable (y)[2/]	Independent Variable (x)[2/]	a	b	Explained Variance R^2	Degrees of Freedom	F-Test[3/]
14	CTP	PAL	.653 E-3	.227	.024	68	1.63
15	CTP	PAL + POL	.120 E-2	.182	.048	68	3.44
16	UATP	PAL	-.631 E-2	1.17	.115	68	8.83**
17	UATP	PAL + POL	-.537 E-2	1.20	.051	68	3.62
18	CNO23	PAL	.491 E-1	.302	.563	68	87.48**
19	CNO23	PAL + POL	.608 E-1	-1.16	.525	68	75.12**
20	UANO23	PAL	.872 E-1	3.24	.351	68	37.79**
21	UANO23	PAL + POL	.113	.335	.358	68	37.89**

1/ y - a x +b

2/ CTP = Mean annual flow weighted mean total phosphorus concentration (mg/l as P).
UATP = Unit area total phosphorus load (kg/hectare).
CNO23 = Mean annual flow weighted mean nitrite-nitrate nitrogen concentration (mg/l as N).
UANO23 = Mean annual unit area nitrite-nitrate nitrogen load (kg of N/hectare).
PAL = Percent of basin area that is cropland.
POL = Percent of basin area that is land other than cropland, woodland, grassland, vineyards or orchards, and water.

3/ A "*" is significant at the 95 percent level of the F-Test and "**" is significant at the 99 percent level of the F-Test.

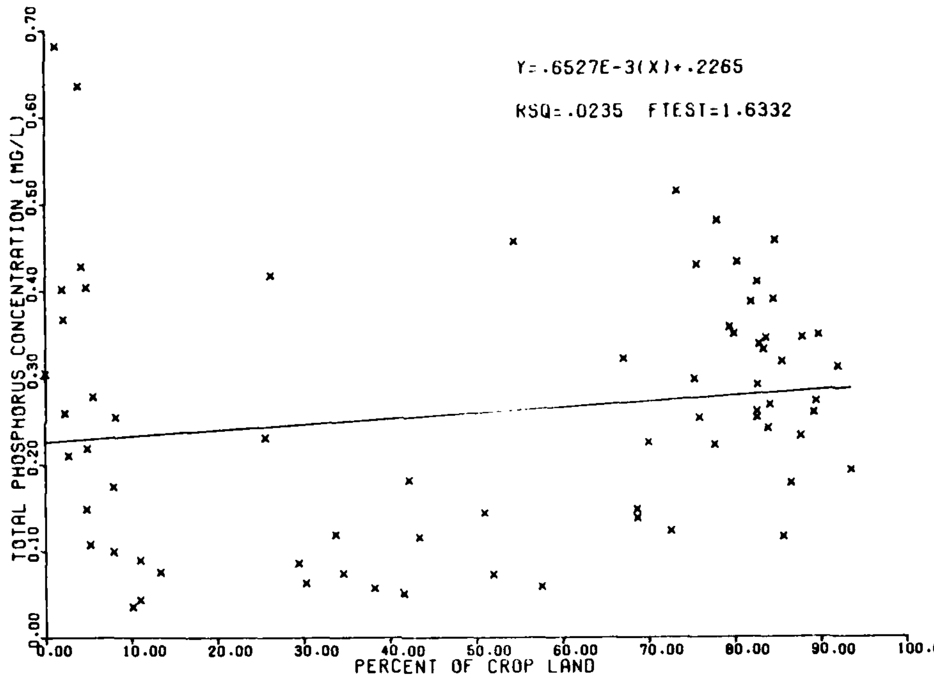


Figure III-6 - Relationship of Total Phosphorus to Agricultural Land for Lake Erie Watersheds.

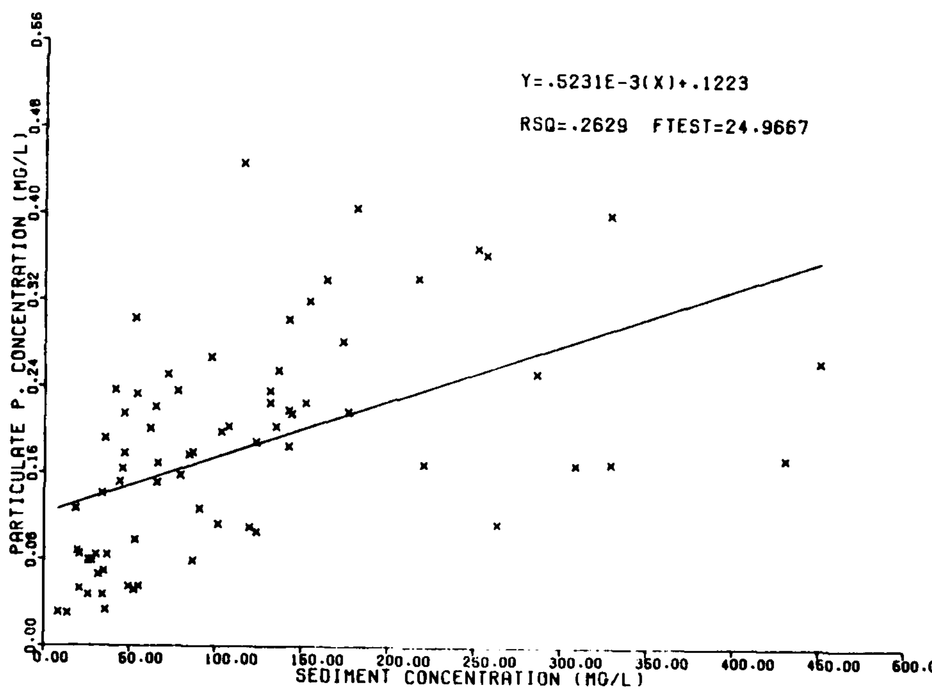


Figure III-7 - Relationship of Mean Annual Sediment Phosphorus Concentrations to Suspended Sediment Concentrations for Lake Erie Watersheds.

Table III-8 - Relationship of Phosphorus Sediment Ratios to Land Resources for Lake Erie Watersheds

Equation 1/	Dependent Variable (y) 2/	Independent Variable (x) 2/	a	b	Explained Variance R^2	Degrees of Freedom	F-Test 3/
22	CTP	CS	.670 E-3	.187	.194	70	16.82**
23	PP	CS	.523 E-3	.122	.263	70	24.97**
24	PF	TEXT 1	-.293 E-1	2.50	.022	49	1.11
25	PF	TEXT 2	.104 E-1	2.30	.010	49	.49
26	PF	TEXT 3	.736 E-2	1.93	.011	49	.55
27	PF	TEXT 45	-.428 E-1	2.63	.052	49	2.66
28	PF	TEXT 12	.899 E-3	.245	.000	49	.00
29	PF	TEXT 123	.869 E-2	1.72	.015	49	.76
30	PF	AGCL	.440 E-1	2.65	.053	49	2.76
31	PF	PAP	.209 E-2	2.54	.000	49	.02

1/ y = a x +b

2/ CTP = Mean annual flow weighted mean total phosphorus concentration (mg/l as P).
PP = Sediment phosphorus mean annual flow weighted mean total phosphorus concentration minus soluble orthophosphate concentration (mg/l as P).
CS = Mean annual flow weighted mean suspended sediment concentration (mg/l).
PF = PP/CS.
PAP = Plant available phosphorus (lb/acre).
AGCL = Percent of the basin area on very fine soil textures which is agricultural land.

3/ A "*" is significant at the 95 percent level of the F-Test and "**" is significant at the 99 percent level of the F-Test.

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CHAPTER FOUR

IN-LAKE EFFECTS OF PHOSPHORUS LOADS

I. INTRODUCTION

This chapter summarizes the estimates of phosphorus loadings and in-lake phosphorus concentrations for Lake Erie during the period 1970-1977. The phosphorus loadings have been separated into contributions from point and nonpoint sources. Using these available data and assuming equilibrium between historical loadings and in-lake concentrations for selected periods, a long-term phosphorus model has been calibrated and used to project future in-lake phosphorus concentrations for various reduced loading scenarios. The results of this model application are summarized in this chapter and a discussion of the significance of the model results is presented. The model output enables a projection of the possible improvement in the trophic status of Lake Erie as a result of reducing phosphorus loadings. The scenarios are also evaluated using results from models developed by others for the projected effect on chlorophyll *a* concentrations and dissolved oxygen in the hypolimnion of the Central basin. Finally, a discussion is presented of the biological availability of the phosphorus loads to Lake Erie.

II. IN-LAKE CONDITIONS

Lake Erie's water quality has undergone considerable degradation during the past half century as a result of increasing pollutant loads to the lake. Normally, the time scales associated with the trophic evolution of a waterbody are very long. However, high intensity agricultural development, growth of human populations, urbanization, and industrialization have proceeded very rapidly in the Lake Erie drainage basin. As a result, the time scale for trophic evolution has been greatly shortened. This phenomenon is often referred to as cultural eutrophication. Eutrophic lakes are characterized by their excessive plant (or algae) growth that is stimulated by the over enrichment of nutrients such as phosphorus. Dead and dying plant matter settles to the sediments where decay takes place through bacterial decomposition. Oxygen is consumed by this aerobic decay process and, in stratified lakes such as the central basin of Lake Erie, depletion of dissolved oxygen can stress other aquatic life that inhabits the bottom waters.

The oxygen depletion rate in the hypolimnion waters of the Central Basin of Lake Erie has been measured and the findings are summarized in Figure IV-1.

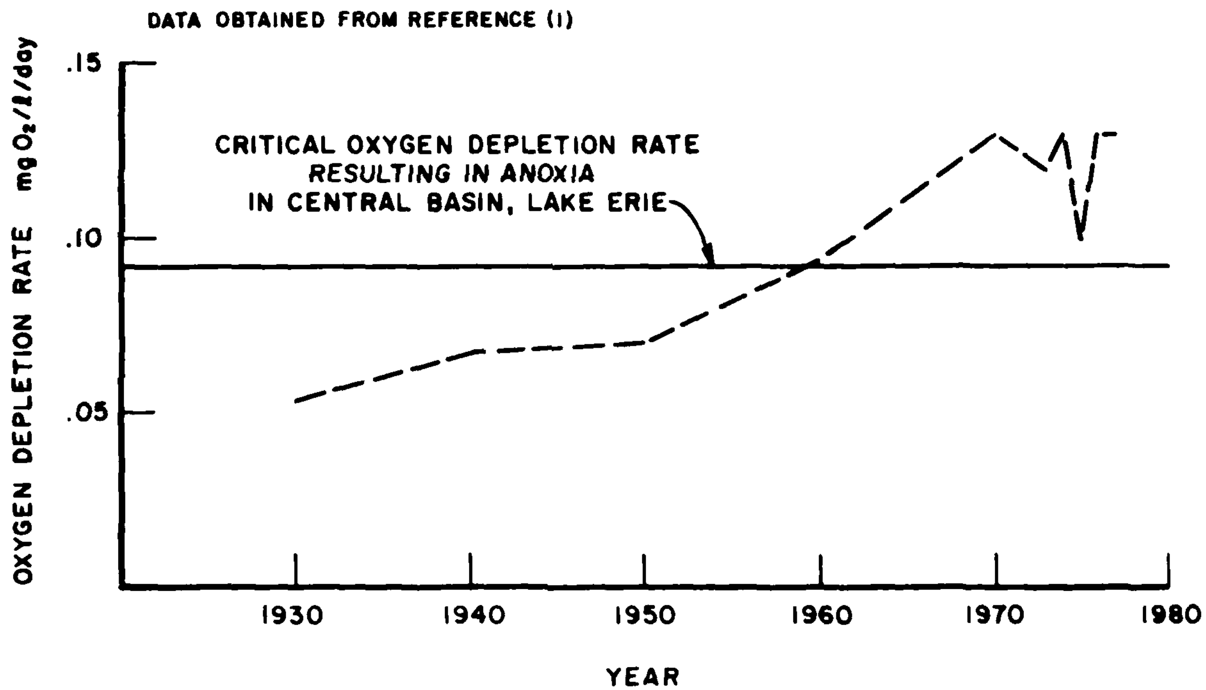

FIGURE IV-1
OBSERVED OXYGEN DEPLETION RATES IN THE HYPOLIMNION WATERS OF THE CENTRAL BASIN, LAKE ERIE

The critical oxygen depletion rate which brings about anoxia in the Central Basin bottom waters has been estimated as .093 mg O_2/l/day (2). This critical rate has been exceeded in Lake Erie since 1960.

The oxygen depletion rate in the Eastern basin is about .060 mg O_2/l/day(1). Although the oxygen demand in the Western basin is high, the basin does not stratify or become anoxic except in rare cases.

Figure IV-2 shows the variation of the mean annual concentration of total phosphorus in the Western, Central, and Eastern Basins of Lake Erie for the period 1970-1977. The primary reasons for the variation from year to year are the variations in hydrology and the timing of the sampling from which the averages are determined. In Figure IV-3, the seasonal variation of total phosphorus concentration is shown for the Western Basin of Lake Erie. It can be seen from this figure that the concentrations are higher in early spring and in the fall. Spring values reflect increases due to increased phosphorus loading during the spring runoff period. Higher fall concentrations are partly due to resuspension of phosphorus bearing lake sediments during fall storms. If sampling cruises are not made during these periods, as was the case in 1973 and 1974, reported annual phosphorus concentrations could be expected to be lower. Since no definite trend can be seen in the annual phosphorus concentrations and since they vary considerably, two sets of annual average in-lake phosphorus concentrations have been utilized in the calibration of the long-term phosphorus model. They are summarized in Table IV-1.

Table IV-1 - Estimated Annual Average Total Phosphorus Concentrations in Lake Erie (in milligrams per liter)

	Western Basin	Central Basin	Eastern Basin
1976	.045	.023	.024
1970-1976 Average	.039	.019	.020

III. NUTRIENT LOADINGS

Phosphorus enters the surface of Lake Erie from the atmosphere, at the lake boundaries from shoreline erosion of phosphorus-bearing sediments, in the tributary inflows that drain the watershed, and in direct discharges from wastewater outfalls. Data obtained from the sampling program described in Chapter Three were used to estimate tributary loadings for the period 1970 to 1977. Municipal and

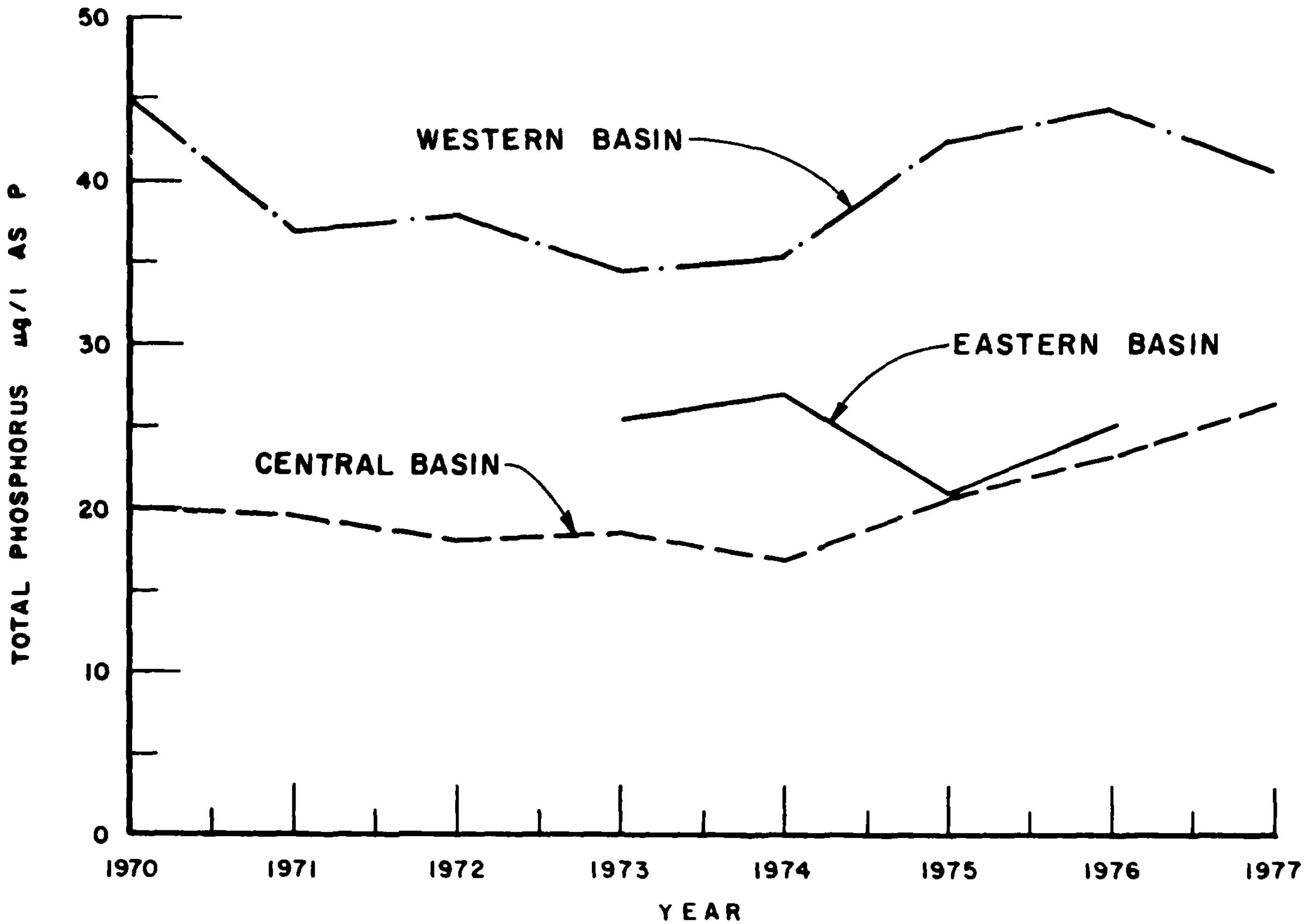

FIGURE IV-2 LAKE ERIE TOTAL PHOSPHORUS CONCENTRATIONS

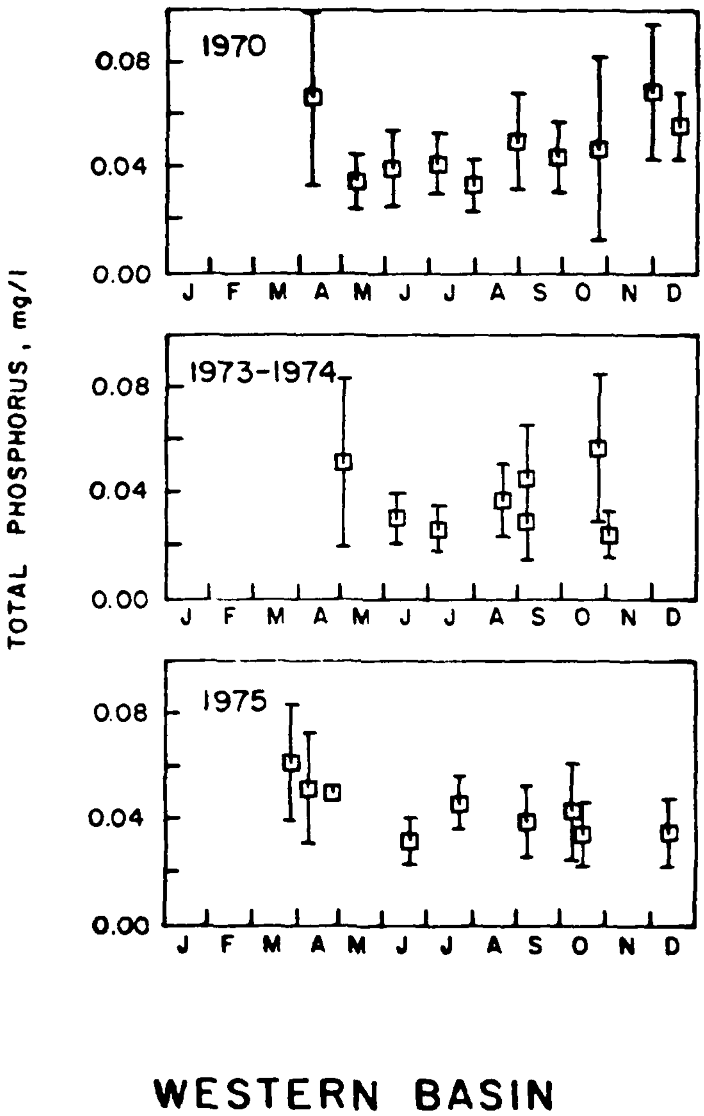

Figure IV-3 - Seasonal Variation in Total Phosphorus Concentrations in the Western Basin of Lake Erie

Source: Reference 3

industrial loadings were obtained from surveillance data obtained by the states and the province of Ontario. Atmospheric loadings were estimated from data extrapolated from measurements taken within the Great Lakes Basin. Phosphorus contained in shoreline eroded materials has been estimated to be 14,800 MT/yr; however, it has been excluded from the analysis because it is not considered available for biological uptake. A detailed discussion of the methods used to calculate nutrient loadings to Lake Erie is contained in a separate technical report of this study entitled, "Nutrient Loadings to Lake Erie"(4).

Estimated total phosphorus loads to Lake Erie for the period 1970 to 1977 are presented in Figure IV-4. It can be seen in the figure that the estimated total phosphorus loading decreased slightly from 1970 to 1977. During this same period, the contribution from point sources decreased from 12,600 to 7,400 MT/yr. The annual variation is a result of variations in hydrologic conditions. For example, the increase in loads from 1976 to 1977 results from a 20 percent increase in stream flows during this period. Table IV-2 lists the estimated total phosphorus loads by basin for these two years.

Table IV-2 - Differentiation of Total Phosphorus Sources to Lake Erie 1976, 1977 (metric tons per year)

Basin	Upper Lakes	Point	Diffuse	Atmospheric	Total
Western	1,080[1/]	6,840	4,635	134	12,689
	(1,080)[2/]	(5,273)	(7,208)	(134)	(13,695)
Central		1,557	2,109	716	4,382
		(1,740)	(2,595)	(716)	(5,051)
Eastern		368	1,968	269	2,605
		(389)	(1,920)	(269)	(2,578)
Totals	1,080	8,765	8,712	1,119	19,676
	(1,080)	(7,402)	(11,723)	(1,119)	(21,324)

1/ 1976
2/ 1977

The annual variation in tributary loads, which reflect the contribution from diffuse sources, makes it important to determine if hydrologic conditions are unusual in the year in which loadings are estimated. In an effort to "smooth out" the hydrologic variations, "base year" loads were developed using historical average data for

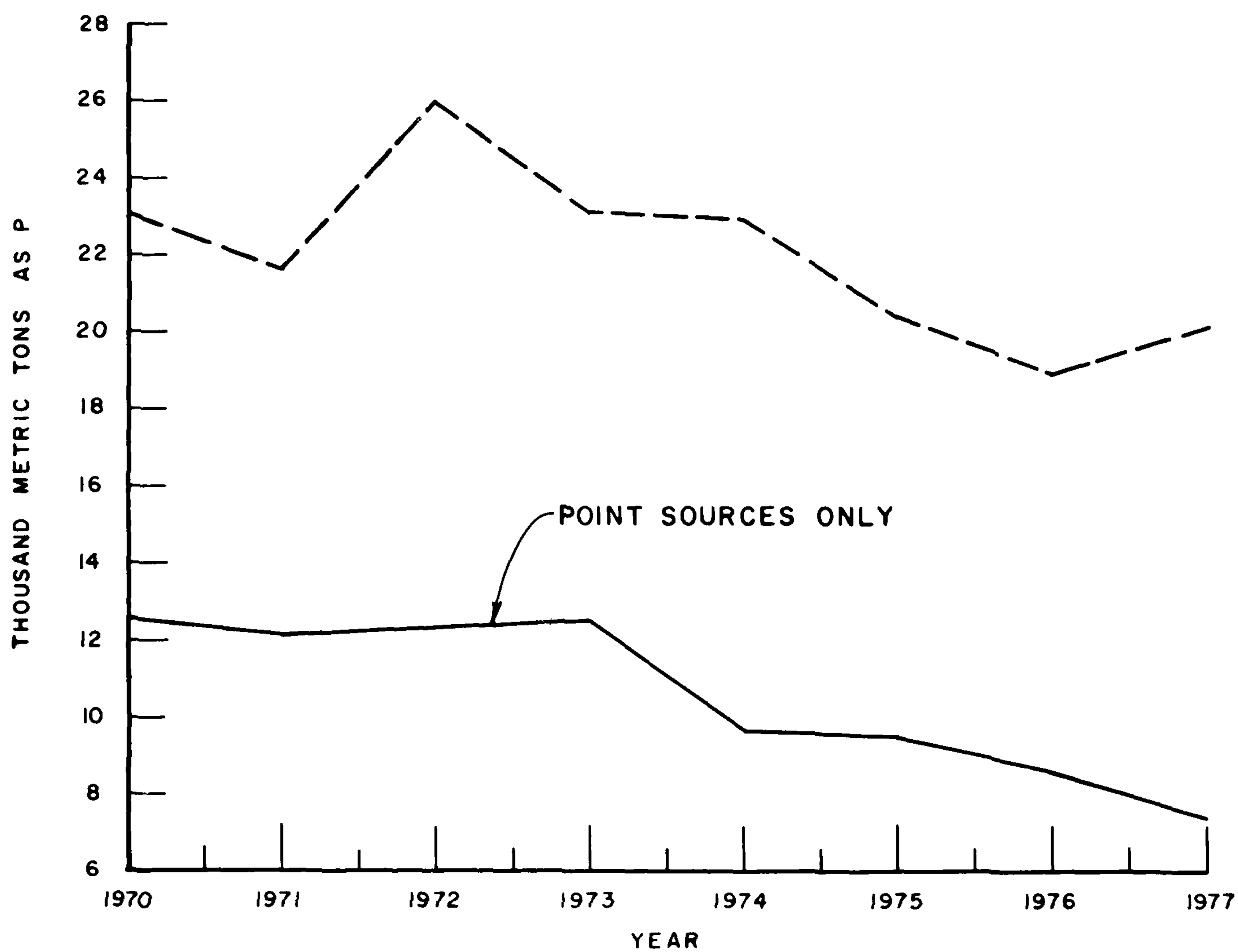

FIGURE IV-4 LAKE ERIE TOTAL PHOSPHORUS LOADINGS.
ATMOSPHERIC INPUT AND SHORELINE EROSION ARE NOT INCLUDED.

the tributary flows and inter-lake exchange flows. The tributary loadings computed in this manner were combined with the 1975 estimates for point source loadings and atmospheric loadings to give the estimated total loadings for the so-called "base year." The 1974-1975 estimate from the Preliminary Feasibility Report and the average of the estimated loads for 1976-1978 are presented in Table IV-3 along with the "base year" estimates.

Table IV-3 - Estimates of Total Phosphorus Loadings to Lake Erie 1/ (metric tons per year)

	Base Year	1974-1975 2/	1976-1977 Average
Western Basin	14,499	13,389	13,192
Central Basin	4,007	5,096	4,717
Eastern Basin	1,463	2,022	2,591
Whole Lake Total	19,969	20,507	20,500

1/ Shoreline erosion loadings excluded.
2/ Preliminary Feasibility Report

The "base year" loading estimates were used to estimate the total phosphorus loads remaining after municipal point sources with flows greater than one million gallons per day reached effluent concentration of one and 0.5 mg/l as P. These estimates are shown in Table IV-4. It can be seen from this table that the total phosphorus loads will be reduced to 15,500 and 14,200 MT/yr for each scenario. Scenario 1 will require an additional reduction of 4,500 MT/yr if the phosphorus loading objective for Lake Erie of 11,000 MT/yr is to be reached. Scenario 2 will require an additional 3,200 MT/yr reduction. Therefore, the phosphorus loading objective can be reached by a uniform reduction in diffuse sources of 47 and 33 percent in addition to reductions reached in Scenario 1 and 2, respectively.

The "base year" loadings were used as a basis for calibrating the long-term phosphorus model along with the in-lake total phosphorus concentrations given in Table IV-1.

Table IV-4 - Total Phosphorus Loads to Lake Erie
After Control of Municipal Point Sources
(metric tons per year)

Basin	Upper Lake	Point	Diffuse	Atmospheric	Total
Western	1,080	2,514 1/	7,071	134	10,799
		(1,500) 2/			(9,785)
Central		913	1,723	716	3,352
		(657)			(3,096)
Eastern		182	919	269	1,370
		(93)			(1,281)
Total	1,080	3,609	9,713	1,119	15,521
		(2,250)			(14,162)

Only point sources with flows greater than one million gallons per day are controlled.

1/ Scenario 1 is based on point sources at one mg/l.
2/ Scenario 2 is based on point sources at 0.5 mg/l.

IV. PHOSPHORUS BUDGET MODEL

The long-term phosphorus model adopted in this study is basically the application of a material balance on total phosphorus incorporating the exchange of phosphorus at the sediment-water interface and the retention of phosphorus in the sediments. Phosphorus loading to the lake basin and phosphorus discharge (or export) from the basin are also accounted for. The lake basin is assumed to be continuously stirred and the effect of varying internal lake circulation is presumably integrated out by considering a time step of one year in model application. Lake Erie was simulated using this model by treating the lake as three separate basins arranged in series. Model output provides phosphorus concentrations in the lake basin water and in the sediment interstitial water as a function of time measured in years. A detailed description of the long-term phosphorus model and comparison with other modeling approaches is contained in a separate technical report to this study (5).

The application of the model requires the estimation of rate constants and knowledge of the physical characteristics of the lake basin. One basic assumption made in arriving at the above estimates of rate constants is that the in-lake phosphorus concentrations were at equilibrium with the estimated phosphorus loadings for the period selected for calibration. The model constants were determined for two cases: Case A - "base year" estimated loadings with 1976 in-lake total phosphorus concentrations; Case B - "base year" loadings with the 1970-1976 average in-lake total phosphorus concentrations (see Table IV-1 and Table IV-3).

V. PROJECTED FUTURE LAKE CONDITIONS

The projected in-lake total phosphorus concentrations for the various whole lake loadings given by scenarios 1 and 2 and the 11,000 MT/yr loading objective are summarized in Figure IV-5. It can be seen from this figure that even at the 11,000 MT/yr loading objective, the Western basin will have total phosphorus concentrations between .021 and .024 mg/l as P. The Central basin will be between .011 and .012 mg/l and the Eastern basin will be between .012 and .013 mg/l when the loading objective is reached.

Other Lake Erie modeling efforts have been summarized in the Report of Task Group III (6) and those results are displayed here in Figures IV-6 through IV-8. The various model projections all indicate that in-lake chlorophyll a concentrations will be reduced as annual loading of total phosphorus to the lake is decreased. According to these model projections, the levels of chlorophyll a concentrations in the Western, Central, and Eastern basins will decrease as shown in Figure IV-6. The prediction of chlorophyll a concentrations, although uncertain as to specific magnitude, clearly has a downward trend as phosphorus loading is reduced.

According to analysis of oxygen levels in the Central basin of Lake Erie, the recommended objective whole lake loading of 11,000 MT/yr is estimated to result in a mean hypolimnetic dissolved oxygen level during the summertime stratification period of no less than one mg/l. These results are shown in Figure IV-7, which shows the projected recovery of the dissolved oxygen level in the Central basin as phosphorus loading is reduced. The model projections indicate that if a phosphorus loading of 11,000 metric tons is achieved, the level of hypolimnetic dissolved oxygen in the Central basin would remain above one mg/l and could be as high as four mg/l.

It was also estimated that this objective loading would lead to a reduction in the area of anoxia in the central basin by 90 percent in the short-term (say within five years after the objective loading has been achieved and maintained) and ultimately lead to elimination of anoxia completely. (See Figure IV-8). The application of the presently constituted long-term phosphorus model does not permit estimates of oxygen levels based on computed in-lake concentrations of total phosphorus.

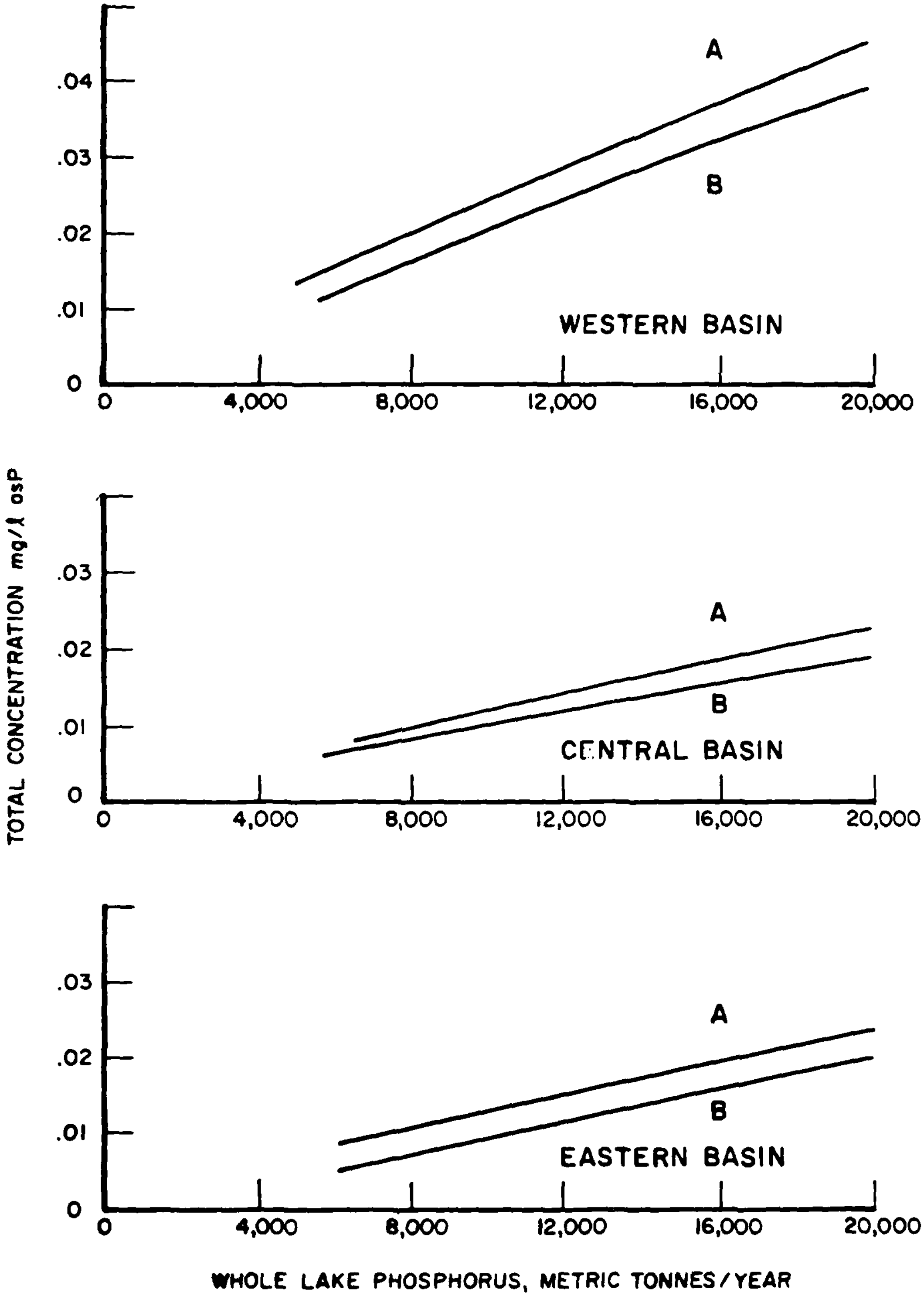

Figure IV-5. Projected In-Lake Total Phosphorus Concentrations for Indicated Whole-lake Loading Using Base Year Data

Case A = Model results using base year loads and 1976 concentrations
Case B = Model results using base year loading data and 1970-76 average concentration data

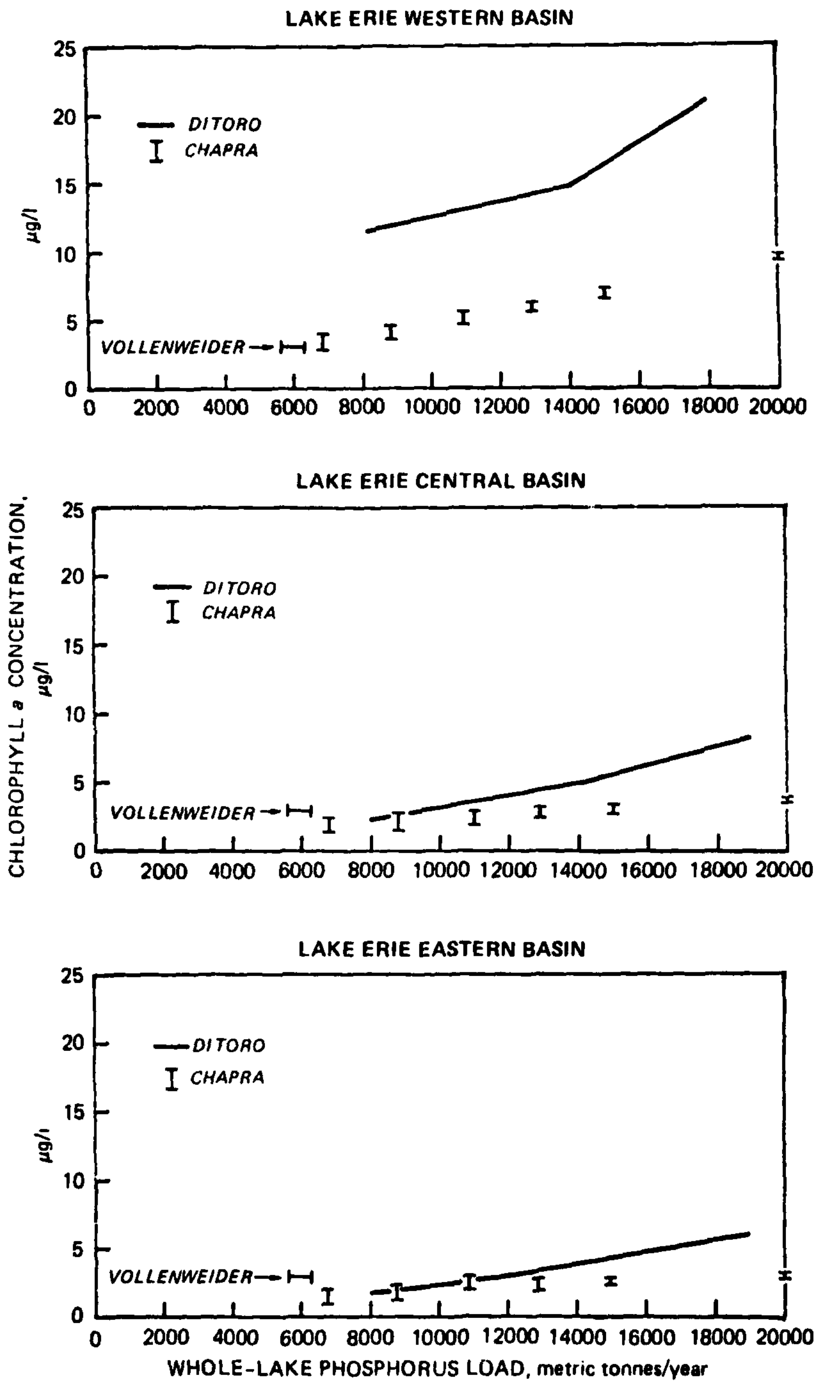

Figure IV-6 - Relationship Between Chlorophyll A Concentration and Whole-lake Phosphorus Load in Lake Erie for the Vollenweider, DiToro, and Chapra models.

Source: Reference 6

LAKE ERIE CENTRAL BASIN

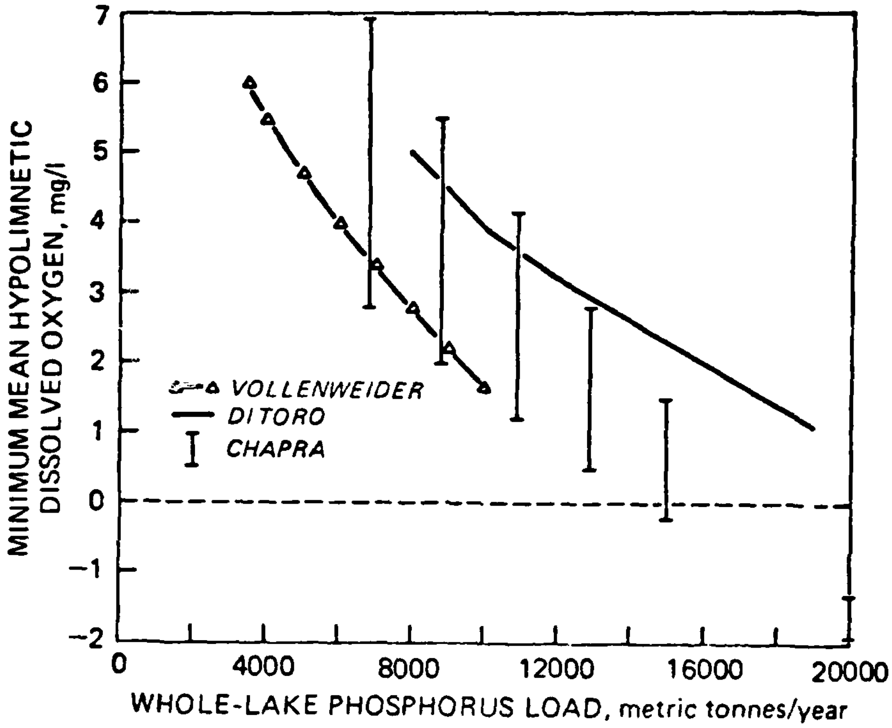

Figure IV-7 - Relationship Between Minimum Mean Hypolimnetic Dissolved Oxygen Concentration and Whole-lake Phosphorus Load in the Central Basin of Lake Erie for the Vollenweider, DiToro, and Chapra models.

Source: Reference 6

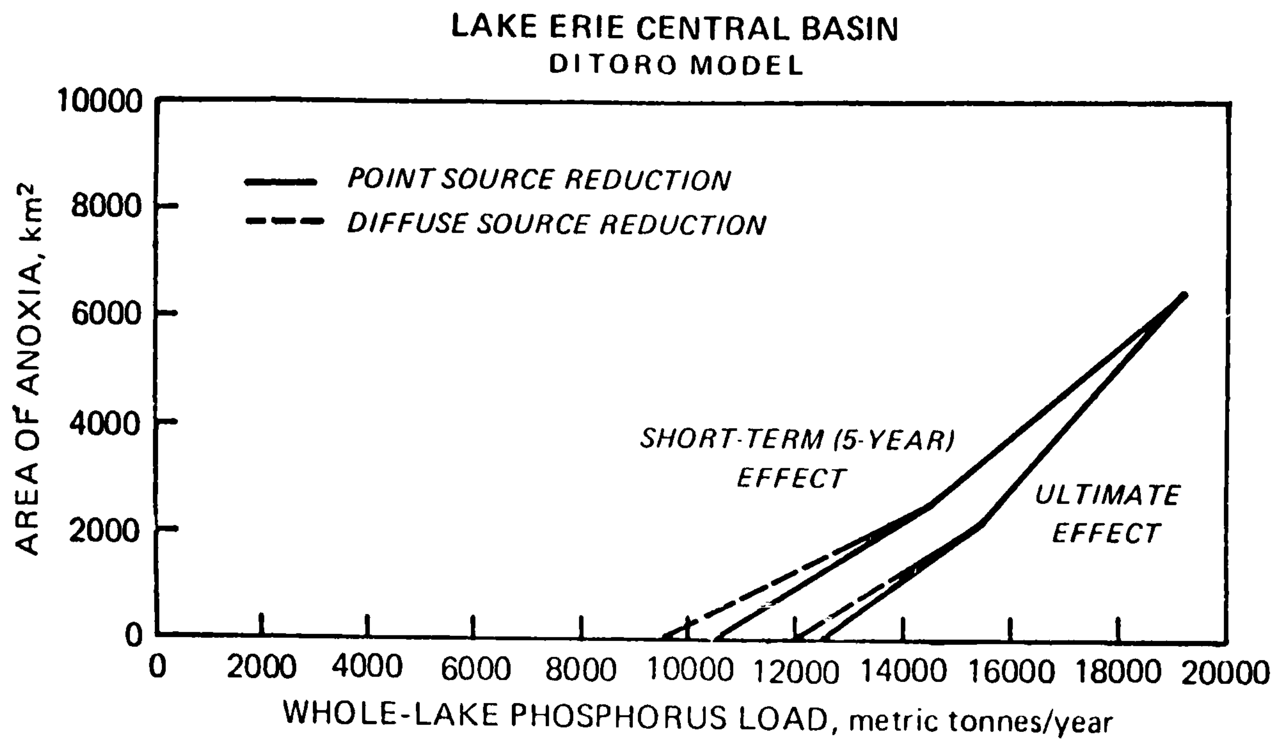

Figure IV-8 - Relationship Between Area of Anoxia and Whole-lake Phosphorus Load in the Central Basin of Lake Erie for the DiToro Model.

Source: Reference 6

These reductions in chlorophyll a concentrations and summertime oxygen deficits in the Central basin are the desired effects of a phosphorus reduction program and should lead to improvement in the trophic status of Lake Erie as indicated in Figure IV-9.

A projection of the possible improvement in trophic status for the new equilibrium situations portrayed in Figures IV-5 to IV-8 is shown in Figure IV-9. It can be seen that the projection indicates significant improvement in the Central and Eastern basins. However, the Western basin status is projected to remain eutrophic, even though the loading to the Western basin has been reduced by some 47 percent. Assuming the point source phosphorus levels were reduced to one mg/l, it would require an 80 percent reduction in nonpoint source loading to the Western basin in order to bring the trophic status to just between mesotrophic and eutrophic according to the categorization shown in Figure IV-9. This amount of reduction in total phosphorus loading would be very difficult to achieve and probably unrealistic when considering the small volume of the Western basin compared to the large drainage basin tributary to it, population pressure, and industrial development.

VI. AVAILABILITY OF PHOSPHORUS FOR BIOLOGICAL UPTAKE

The Canada-United States Water Quality Agreement of 1972 set target loadings of total phosphorus to Lake Erie. However, not all the total phosphorus entering the lake is immediately available to algae. The percent availability of the different sources of phosphorus and the rate they become available must be known if cost effective phosphorus programs are to be developed.

Phosphorus biological availability has been defined in various ways. For the dissolved fraction, soluble reactive phosphorus is usually considered immediately available. The remaining dissolved fraction is considered potentially available. Phosphorus forms in suspended solids are determined by chemical fractionation. The forms often measured are sodium hydroxide extractable phosphorus, (NaOH-P) and citrate-dithionite-bicarbonate extractable phosphorus (CDB-P) the sum of which is nonapatite inorganic phosphorus (NAIP). Apatite phosphorus and organic phosphorus are also measured. The pollution from Land Use Activities, Reference Group (PLUARG) defined NAIP as immediately available and some portion of organic phosphorus as potentially available (7). Logan (8) considers NaOH-P to be short-term bioavailable and the CDB-P to be potentially available. The ecological model of Lake Erie (3) defined soluble reactive phosphorus as available and the remaining total phosphorus as potentially available.

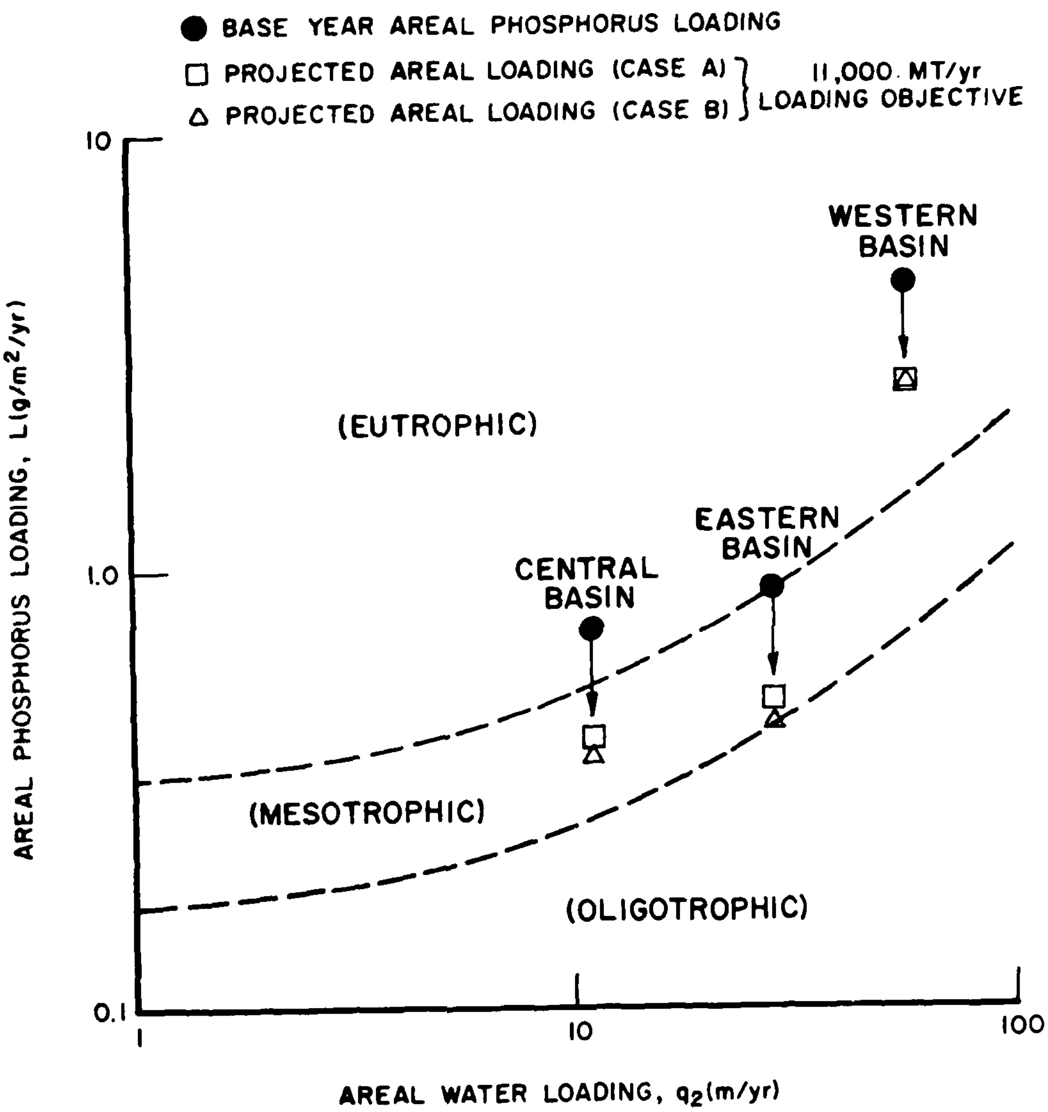

FIGURE IV-9 TROPHIC STATUS GRAPH

Ideally, availability would be measured biologically and then related to a chemically extractable form of phosphorus. Verhoff, et al. (9) measured the rate at which total phosphorus in water of tributaries to Lake Erie was utilized by algae. They found this utilization rate to be about 0.4 percent per day. They also determined the extractable phosphorus forms of the phosphorus after utilization by algae and found that NaOH-P was preferentially used although all chemical extraction fractions were removed.

Logan et al. (10) have reviewed the biological availability question for Lake Erie. From their work, it may be concluded that:

a. The sediment phosphorus forms vary considerably by river basin. Sediment phosphorus bioavailability as measured by chemical extraction reflects native soil phosphorus levels in basin soils and its chemical and biological reactivity, fertilizer phosphorus additions, the degree to which sediment is enriched in phosphorus because of preferential clay transport, and the adsorption of point source soluble inorganic phosphate by stream sediments. Based on these considerations, sediments from the more urbanized tributary areas in Michigan and eastern Ohio and those from the high clay agricultural basins in western Ohio have the highest percentage NAIP. Suspended sediments from New York tributaries were lowest in NAIP but highest in unavailable phosphorus (Apatite-P and Residual-P). (See Table IV-5.)

b. Fractions of extractable phosphorus forms vary with river flow. At higher river flows, large sized, suspended sediment particles are carried. These larger particles are more likely to have phosphorus in the unavailable form.

c. Phosphorus in the NaOH-P form can be considered immediately available. CDB-P is potentially available after the material has seen anaerobic conditions as in the case of sediments in the Western basin which later become resuspended during minor lake storms and sediments in the Central basin which release nutrients to the overlying water when it is anoxic. Both Central and Eastern sediments are anoxic and are resuspended during major lake storms.

d. The experimentally determined algae utilization rate of 0.4 percent per day is similar to rates which must be used to calibrate mathematical models. It is speculated that this rate is controlled by factors which include mineralization of organic matter and kinetics of phosphate desorption from sediment.

e. The kinetic rate at which phosphorus becomes available appears to be more of a limiting factor in supply of phosphorus to algae than the total amount potentially available sediment phosphorus.

f. Phosphorus extracted by algae from sediment resulted in a removal from all chemical extraction fractions (NaOH-P, CDB-P, and Apatite-P), but greatest reduction was in the NaOH-P fraction.

g. Bioassay procedures to estimate bioavailable sediment P should measure the rate of phosphorus uptake and the phosphorus associated with the algal bioamass rather than just biomass production and they should consider the effect of phosphorus uptake by indigenous phytoplankton.

h. Phosphorus attached to sediments carried by Lake Erie tributaries is utilized by algae in Lake Erie and a program to reduce erosion of sediment will decrease the amount of phosphorus available to algae in Lake Erie.

Table IV-5 - Percent Bioavailability of Sediment-P in Lake Erie Tributaries (1)

	NaOH-P	CDB-P	NaOH-P + CDB-P	Apatite-P + Residual - P
Michigan (2)	30.0	45.0	75.0	25
Western Ohio (3)	41.9	35.9	77.8	22.2
Eastern Ohio (4)	32.8	55.8	88.6	11.4
New York (5)	14.0	28.5	42.5	57.5

(1) Expressed as percent of total sediment inorganic phosphorus
(2) Stations 1-8 on Map III-1
(3) Stations 9-20 and, 56
(4) Stations 38-41, 50-53 and 55
(5) Stations 44-47

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CHAPTER FIVE

LAND MANAGEMENT OPTIONS TO REDUCE GROSS EROSION

I. INTRODUCTION

a. Role of Land Management - This chapter presents alternative land management practices which can reduce the amount of land-generated pollution. It discusses these practices in the context of their economic and technical suitability for inclusion in the list of Best Management Practices (BMPs) for the Lake Erie Basin as well as their relative effectiveness in reducing sediment and phosphorous loadings to the lake.

Implementation of the listed BMPs is not a simple matter of stating that they should be used, or, in the extreme, mandating their use. The success of a diffuse source control program will depend on proving to the land managers that the desired practices are not only effective in reducing pollution but that in some way, through increased profits, reduced work time, energy savings or preservation of the soil resource, they will also be beneficial to the farming community. The results of the programs may not be known for many years and this will reduce the incentive for implementation.

b. Intervention Points - In planning for BMP application, it is useful to understand how the various practices intervene with the erosion process to reduce overland transport and ultimate delivery to the lake. BMPs can generally be classified into one of three categories, depending on the point of intervention in the erosion or transport process:

(1) Reduction of Raindrop Impact - Raindrop impact is the principal force in sheet erosion. More soil is moved by the impact of falling raindrops than by any other erosion process. How far particles move after being detached is a function of soil particle size and the presence of an adequate surface runoff flow to transport them. Cultural land management practices which effectively minimize the effect of raindrop impact include no tillage, reduced tillage, crop rotation (during meadow or winter cover phases), and winter cover crops. With these practices, soil detachment is reduced while sediment and nutrients adsorbed to the sediment are prevented from leaving the field surface. This is the most desirable form of erosion control.

(2) Reduction of Surface Runoff Volume - Practices which reduce surface runoff volume are also very effective in reducing the removal of sediment and nutrients from the land surface. There are several mechanisms which reduce runoff volume. Minimum tillage techniques,

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such as chisel plowing, produce a very rough field surface. The rough surface reduces surface runoff volume by trapping runoff water in many unconnected microcatchments on the field surface. There is no runoff unless rainfall excess exceeds the catchment capacity. Although this roughness is greatly reduced over the course of the winter by freezing and thawing and local erosion, sediment delivery is greatly reduced. Subsurface tile drainage can be a very important BMP on fine textured soils which have a seasonal high water table near the surface. Tile continually lowers the water table and maintains the water infiltration capacity of the soil. Very little sediment is lost in tile drainage water. Crop rotations which include meadow phases and less intensive row cropping serve to reduce runoff volume by improving soil tilth, the natural soil aggregate status, and therefore restore more natural infiltration capacity.

(3) Reduction of Surface Runoff Velocity - Almost all of the above conservation practices affect runoff velocity to some degree; however, some of the BMPs are designed explicitly for this purpose. Contour farming or contour strip cropping systems, diversions, terraces, and parallel terraces with tile outlets are such practices. Grassed waterways also retard runoff velocity. These practices are principally designed for more steeply sloping land, and act to reduce gross erosion by altering the slope length and direction of overland flow. The slope length is altered, as with terraces and diversions, by physically breaking the slope into shorter segments. The direction and velocity of flow is directed along the contour of the slope by using cross slope tillage rather than up and down slope. Rill and gully erosion are greatly reduced. However, all fields which stand without surface cover remain subject to raindrop impact sheet erosion, and the fine-grained sediment which carries most of the phosphorus continues to be transported from the field.

(4) Sediment Retention - Sediment retention beyond the field area after runoff has reached confined drainage channels is very difficult. The Black Creek Study[1] has demonstrated that instream impoundments are good for reducing total sediment transport, but relatively inefficient in reducing transport of phosphorus. Fine-grained sediment is preferentially transported through impoundments when flow detention time is short. However, specially designed sediment basins, ponds, and other types of impoundments have proven to be effective sediment-retention measures.

c. Best Management Practices - Table V-1 lists those conservation practices which will be considered BMPs for the reduction of sediment and phosphorus transport in the Lake Erie Basin. The BMP list (Table V-1) includes only those practices which will reduce gross erosion and sediment/phosphorus delivery to the greatest degree at the least cost to the public and the agricultural community.

Table V-1 - Best Management Practices: Their Effect on Erosion, Sedimentation, and Phosphorus Transport [1/]

	Practices Which Affect			Sediment Retention Point			Effect (H,M,L) [2/]		
	Raindrop Impact	Reduced Runoff Volume	Reduced Runoff Velocity	On Field	Swale	Stream	Gross Erosion Reduction	Sediment Delivery	Phosphorus Delivery
Cultural & Land Management									
Conservation Tillage									
.No-till									
.Minimum or Mulch Tillage	X	X	X	X			M	H	H
.Ridge, Strip Tillage	X	X	X	X			M	M	M
Winter Cover Crop - Crop Residue Use	X	X	X	X			M	M	M
Conservation Cropping System	X	X	X	X			H-L	H-L	H-L
Critical Area Planting	X	X	X	X			H	H	L
Runoff Collection and Disposal									
Contour Farming		X	X	X			M	M	L
Contour Strip Cropping	X	X	X	X	X		H	M	M
Terrace		X	X		X		M	M	L
Diversion		X	X		X		M	M	L
Parallel Tile Outlet Terrace		X	X	X	X		M	H	M
Grassed Waterways			X		X		H	L	L
Outlet Protection Structure					X		L	L	L
Subsurface Tile Drainage		X	X	X			L	H	H
Sediment Retention and Trapping									
Sediment Detention Basins			X			X	-	H	L
Ponds and Impoundments			X			X		H	L
Filter Strip - Vegetative			X	X	X		M	L	L
Other Practices									
Waste Management Systems									
.Storage Pond									H
.Storage Structure									H
.Treatment Lagoon									H
Wind Breaks									
.Field				X			M	L	L
.Farmstead				X			L	L	L
Stream Bank Protection			X			X	L	L	L

1/ Details on the best managment practices presented in this table are given in Appendix IV.
2/ H = High, M = Medium, L = Low

Table V-1 also depicts the mode and relative effectiveness of each practice in reducing gross erosion, sediment delivery, and phosphorus delivery. Each individual BMP and its range of applicability is discussed in Appendix IV.

In the application of the USLE for assessment of present potential gross erosion conditions, soil loss attributable to gully and wind erosion is not estimated. The USLE is a predictive tool for average annual soil loss via water erosion. This potential gross erosion deals only with sheet and rill erosion. There is no credit given to gully erosion soil losses nor is there any method to predict average annual gully erosion without doing a detailed field inventory. Therefore, the USLE potential gross erosion outputs specifically exclude the soil loss from gully erosion. With regard to wind erosion, no calculations or values have been developed for this problem. Where appropriate, measures to control gully and wind erosion must be applied.

Gully erosion, along with other diffuse source problems such as urban construction sites and animal feed lot wastes, may be classified as identifiable nonpoint sources. While they cannot be classified specifically as point source discharges, they are oftentimes readily visible and easily identified. Control of these highly eroded sediment sources and waste disposal problems cannot be accomplished with cultural land management practices. These problems and numerous other problems will require the unique blending and application of other BMPs. These practices have been partially identified in the discussions above on volume and velocity of runoff control.

II. ALTERNATIVE SCENARIOS

a. Scenario Development - The scenarios developed in this section are designed to evaluate reductions in gross erosion which can be achieved by application of cultural and land management practices to cropland. The baseline against which the scenarios are compared is the estimated potential gross erosion for existing conditions. The methodology for the use of the Universal Soil Loss Equation with the Land Resources Information System was presented briefly in Chapter Two. Complete documentation of the methodology is presented in two separate Technical Reports (2, 3).

For these scenarios, only those practices which will not adversely impact on crop yields have been considered. The tillage systems considered and the methodology for their application are described briefly below. An excellent discussion of tillage systems is given in (4). The methodology for assignment to Soil Management Groups is given in (5).

The following tillage systems were used to develop the scenarios:

Conventional Tillage - utilizes the moldboard plow (fall or spring) plus preplanting cultivation for soil smoothing. Planting is in a smooth bare soil surface.

Conservation Tillage - is any tillage system which is not based on the use of the moldboard plow. For the purpose of the scenarios, conservation tillage is defined as the use of a noninversion chisel plow-based system in the fall or spring plus spring leveling operations. The chisel plow tills and mixes the soil to a depth of eight to 12 inches, but retains a considerable amount of crop residue cover on the surface.

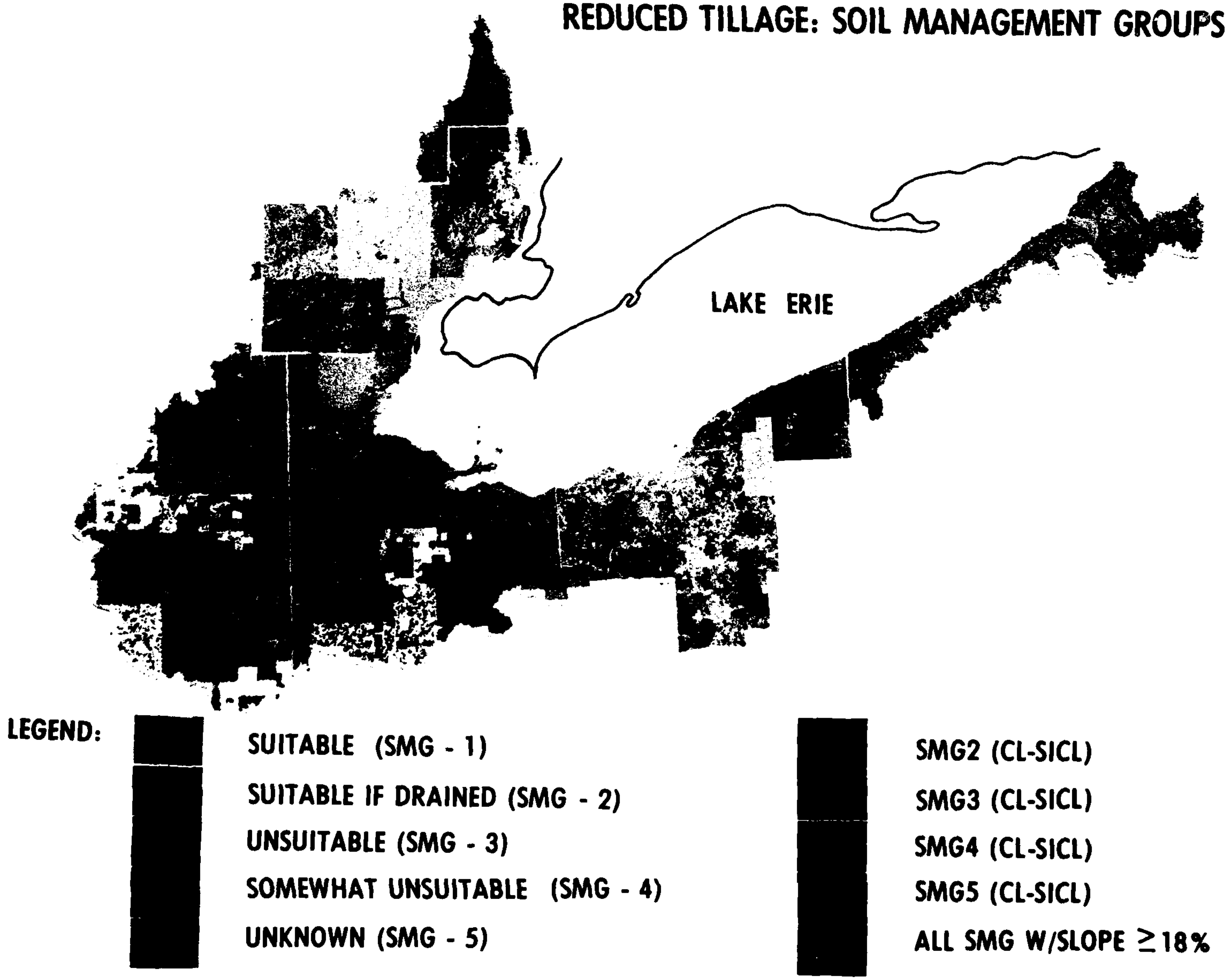
No-tillage - requires planting directly in the residue of the previous year's crop. There is minimal disruption of the soil. Planting is accomplished with a planter which is specially equipped for planting in trashy rough surfaces. Weed and turf control is achieved strictly with herbicides.

Cropland soils have been grouped according to their crop response to the above tillage systems. These soil management groups are briefly described in Table V-2 and their distribution is shown in Map V-1.

Table V-2 - Soil Management Group Codes and Descriptions

Group	Description
1	Excessive, well and moderately well drained soils.
2	Somewhat poorly and poorly drained soils which have good response to surface or subsurface drainage.
3	Somewhat poorly and very poorly drained soils with slow permeability that show little or no response to reduced tillage even with subsurface drainage.
4	Very poorly drained soils with fine textured surfaces and relatively high amounts of organic matter, response to subsurface drainage is good.
5	Organic soils, alluvial soils and other soils with slow permeability and relatively high clay contents.
6	Group 2 soils with clay or silty clay surface textures.
7	Group 3 soils with clay or silty clay surface textures.
8	Group 4 soils with clay or silty clay surface textures.
9	Group 5 soils with clay or silty clay surface textures.
0	All soil types with slopes in excess of 18 percent.

MAP V - 1 SUITABILITY OF SOILS IN THE UNITED STATES DRAINAGE OF LAKE ERIE FOR REDUCED TILLAGE: SOIL MANAGEMENT GROUPS



The soil groups as described by Triplett (5) are:

Soil Management Group 1

With good management, soils included in this group should have yield response to no-tillage equal to or greater than conventional tillage. Soils in this group are moderately well, well, and excessively well drained or shallow. They have a silt loam, loam, sandy loam, or loamy fine sand surface texture. These soils are relatively low in organic matter and include glaciated, residual, and terrace soils. No recent alluvial soils are included.

Group 1 soils must have mulch cover for satisfactory no-tillage crop production. Mulch should cover 70 percent to 80 percent of the soil surface at planting time. This can be old crop residue, killed sod, dead weeds, or manure. If the site has less than 35 percent mulch cover, it should be tilled (disking and postplanting cultivation are satisfactory).

Soil Management Group 2

With good management, soils in this group should have yield response to no-tillage nearly equal to conventional tillage, provided soil drainage has been improved by surface or subsurface drainage. These soils are somewhat poorly to poorly drained in the natural state. They have a silt loam, loam, sandy loam, or loamy fine sand surface texture. Soil permeability is equal or greater than 0.2 inches per hour within the top two feet of the profile. Soils in this group are relatively low in organic matter and include glaciated, residual, and terrace soils. No recent alluvial soils are included.

Mulch cover is important to proper performance of no-tillage on the lower organic matter soils (1.5 to 2.5 percent organic matter) in this grouping, as is the case with group 1. No-tillage corn following sod, or delaying planting with no-tillage until the latter part of the optimum planting period in areas where continuous row cropping is practiced, are excellent choices on these soils.

Soil Management Group 3

Soils in this group may yield less with no-tillage in comparison to conventional tillage and should not be considered for no-tillage under most circumstances. These soils are somewhat poorly to very poorly drained. Internal water movement is so slow that even tile does not provide adequate drainage. Surface texture is primarily loam, silt loam, or silty clay loam. These soils are derived from glacial till or residual parent material. No recent alluvial soils are included. Most of these soils are relatively low in organic matter content.

Soil Management Group 4

Soils in this group may yield less with a no-tillage system in comparison to conventional tillage. These soils are very poorly drained and have surface textures of silty clay loam, clay loam, silty clay, or clay. They contain relatively high amounts of organic matter in the surface. Soils developed in glacial till and residuum are included in this group, but alluvial soils are not. Corn on these soils does not respond to mulch cover where no-tillage is used, except perhaps for slower growth in cool, wet springs where mulch is present.

Soil Management Group 5

This group includes organic soils, recent alluvial soils, strip mine land, and certain fine-textured soils that are not recommended for no-tillage. There has been little or no experience with no-tillage on organic soil. Corn grown on well-drained, recent alluvial soils should respond satisfactorily to no-tillage, but in a small number of tests, this has not been observed. No reason is known for this poor response at this time.

Yields on poorly drained clays, such as Paulding, have not been satisfactory with no-tillage. Well-drained soils where erosion has exposed a high clay subsoil probably should not be planted to row crops. No-tillage may do as well on these soils as any other system, but planter function with no-tillage has been a problem. Strip mine land is so variable that decisions for crop production must be made on an individual site basis.

Soil Management Groups 6-9

These groupings correspond directly to Groups 2 through 5. Group 6 responds to no-tillage cropping as does Group 2, Group 7 responds as does Group 3, etc. The division of each group is by surface texture classification. Groups 6-9 include all soils which might have been included in Groups 2-5, except that they have clay or silty clay surface horizon textures. The purpose for breaking out these fine-textured surface horizon soils involves the sediment phosphorus delivery characteristics of fine clays. Since such soils have been identified as having a more significant effect on water quality, it is useful to know the degree to which a reduced tillage conservation program will be applied to them.

Soil Management Group 10

Group 10 includes all cropland on soils with slopes greater than 18 percent. This grouping is made because it is not recommended that lands with slopes of this magnitude should be in cropland. However, if these lands are presently in cropland, they would experience the lowest achievable level of soil loss if a no-tillage management system were employed.

Since the soil management groups are formed around the potential crop yield response of each group, they are also useful for economic impact analysis for the scenarios. Forster (6), has evaluated the costs and benefits of a range of cropping management schemes for soils representative of each of the groups. The same approach has been used in this study. The results of the economic impact analysis are discussed in Chapter Six and in a separate technical report (7).

b. Scenarios for Potential Gross Erosion Control - The scenarios which have been evaluated for potential gross erosion reduction are illustrated in Table V-3. In the scenarios, tillage and cover conditions for cropland SMGs are evaluated. Vineyards, orchards, pastureland, and woodlands essentially remain the same in all scenarios.

Scenario 1 is the present conditions scenario. PGE is calculated for each of the 62 counties in the Lake Erie drainage for the best estimate of prevailing conditions in each. The methodology for determining current C, cropping management practice factors and R, *rainfall erosion intensity factors*, is described in Chapter Two and a separate technical report (2).

Scenario 2 evaluates the effect of limiting PGE across the basin to T, the soil loss tolerance factor. The T factor is the upper limit of PGE which a soil in crop production can withstand over the long-term without reduction in crop yield. For any given soil resource unit, it is the standard or goal to reach in the development of conservation plans for farm units. Thus, in Scenario 2, the assumption is made that all farms in the Lake Erie Basin have fully implemented conservation plans in effect. For any cell in which the present PGE is less than T, the present condition is unaltered.

Scenario 3 alters the present condition by eliminating the practice of fall plowing.

Scenario 4 is the inverse of Scenario 3 in that the soil loss equation is evaluated for fall plowing only. Although this is a scenario which increases PGE, it was necessary to assess the range of soil loss which might be expected from an increase in fall plowing and a decrease of the spring plowing.

Scenario 5 requires the introduction of a winter cover crop planted in the residue of the previous crop. Spring tillage precedes the next crop.

Table V-3 - Potential Gross Erosion Scenarios for the Lake Erie Drainage Basin Cropland

Scenario	Soil Management Group Code									
	1	2	3	4	5	6	7	8	9	10
1. Present Condition	PC	PC	PC	PC	PC	PC	PC	PC	PC	PC
2. Reduce Soil Loss to T and Existing	T=PC T=T	T=PC T=T	T=PC T=T	T=PC T=T	T=PC T=T	T=PC T=T	T=PC T=T	T=PC T=T	T=PC T=T	T=PC T=T
3. Spring Plow Only	SP	SP	SP	SP	SP	SP	SP	SP	SP	SP
4. Fall Plowing Only	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP
5. Winter Cover Crop	WC	WC	WC	WC	WC	WC	WC	WC	WC	WC
6. Maximum Reduction: Tillage	NT	NT	PC	CP	PC	NT	PC	CP	PC	NT
7. Reduced Tillage: Chisel Plow	CP	CP	PC	CP	PC	CP	PC	CP	PC	CP

PC: Present Condition

T=PC: If the existing potential gross erosion (PGE) calculated for a cell is less than the soil loss tolerance factor, PGE remains as the present condition.

T=T: If the existing PGE calculated for a cell is greater than the soil loss tolerance factor for the soil, PGE is set equal to T.

SP: Implies the use of spring moldboard plow tillage only as an alternative to present conditions.

FP: Implies the use of fall moldboard plow tillage as an alternative to present conditions. This will usually imply an increase in PGE.

WC: Requires the introduction of a winter cover crop planted in the residue of the previous crop. Spring tillage precedes the next crop.

NT: No-tillage. Crop is planted directly in the residue of the previous crop.

CP: Chisel plow. Applied as spring or fall reduced tillage as an alternative to present use of moldboard plow tillage systems.

Scenario 6 is the most extreme of the scenarios. It requires the maximum PGE reduction practically achievable through the use of tillage modification. Before tillage modification is allowed on a particular soil in this scenario, that soil must be identified as "suitable" or not having significant adverse impacts on net farm income. The no-till crop production system is applied on SMGs 1, 2, 6, and 10; chisel plowing (fall or spring, depending on current timing) is utilized on SMGs 4 and 8; and present practices (predominantly fall moldboard plowing) are continued on SMGs 3, 5, 7, and 9.

Scenario 7 is an intermediate reduced tillage scenario which requires the use of the chisel plow (again, in fall or spring as presently used) on SMGs 1, 2, 4, 6, 8, and 10, while continuing the allowance of present practices on SMGs 3, 5, 7, and 9.

In addition to the cropland, vineyards and orchards, pastureland, and woodland soil loss values, there are soil loss values developed for those areas which appear as missing data. Missing data represents those cells for which no soils information is available due to lack of available published soil survey maps.

For areas missing soil data, the assumption was made that land use distribution for missing data was the same as the land use distribution for which soils information was available. The average soil loss values in tons per acre per year for the particular land use with soils data was assigned to those assumed land uses with missing soil data.

Excluded from the soil loss totals for the various scenarios are soil losses from water areas which have no soil loss and soil losses from other land use areas. These other areas include such land uses as: commercial, industrial, residential, public utilities, developing areas, extractive, and transportation lands. While it is known that these areas do indeed have soil loss problems, there was no methodology established to estimate the extent of soil loss. In many cases, these land uses have more gully erosion problems which can be considered "identifiable non-point sources." Where other land use categories represent a high percentage of the land area, for example, in the river basins draining the Detroit or Cleveland metropolitan areas, this problem is significant. However, on a lakewide basis it is not important.

When evaluating the results of the following scenarios, keep in mind these points: Each data point represents a landscape cell of between 10 and 90 acres, each scenario option is assumed to be adapted totally for those Soil Management Groups where it is suitable. Scenario 6 assumes that adequate subsurface drainage has been installed in all Group 2 and 6 soils.

The object was to determine the total possible reduction in PGE that would be accomplished under ideal conditions using only tillage and cover modifications. Ideal conditions will not be achieved for a number of reasons. The normal intermingling of both adaptable and unadapted soils for a given scenario within a field precludes total adaption. All Group 2 and 6 soils do not have adequate subsurface drainage. None of the scenarios tested will achieve the allowable soil loss limits for Group 10 soils. A land use change, rotation change or structural means will be required for Group 10 soils.

III. POTENTIAL GROSS EROSION REDUCTIONS

a. Introduction - This section presents potentia gross erosion and potential achievable reductions estimated for ach of the scenarios. The results are summarized by river basin and direct drainage areas as well as by the Western, Central and Eastern Basins and total Lake Erie.

A much more detailed breakdown of PGE calculations exists for each major river basin, sub-basins, and county portions of the river basins. This information is contained in a separate technical report (8) and will be used selecting five basins for more intense study during Phase III.

b. Western Basin - The Western Basin of Lake Erie has the largest drainage area, as well as the highest sediment and phosphorus loadings. Table V-4 shows the PGE in the Western Basin for the scenarios. It can be seen from this table that existing Potential Gross Erosion (PGE) averages about 2.3 Tons per Acre per Year (T/A/Y). It must be recognized that the average PGE figure actually camouflages the extremely high PGE areas and the low PGE areas. With the average PGE figures, it is impossible to identify specific problem areas and critical erosion areas.

Looking at the individual river basins and direct drainage areas of the Western Basin, the Maumee River Basin and the Raisin River Basin are immediately obvious as having high average annual PGE. The PGE rates are also equally high at 3.0 and 4.3 T/A/Y for the Maumee and Raisin Rivers, respectively.

In order to provide adequate protection against soil erosion for purposes of maintaining productivity and the soil resource base, a 43 percent reduction in PGE would be needed on those soils where PGE exceeds the tolerable soil loss limits. These values are reflected in Scenario 2.

Potential achievable reductions under the various scenarios show that the spring plow, fall plow, and winter cover crop scenarios yield essentially the same PGE ranging from 2.1 to 2.4 T/A/Y. While the

Table V-4 - Western Basin Potential Gross Erosion: Existing and Potential Achievable Reductions

	Existing Pot. Gross Erosion (Tons) 1	Reduce Soil Loss to T and Existing (Tons) 2	Spring Plowing Only (Tons) 3	Fall Plowing Only (Tons) 4	Winter Cover Crop (Tons) 5	Maximum Reduction Tillage (Tons) 6	Reduced Tillage Chisel Plow (Tons) 7	Cropland Grassland and Forest (Acres)	Other Land Use (Acres)
River Basins									
Belle River	62,964	55,286	62,101	71,833	62,958	21,761	50,690	86,226	10,223
Black River	86,272	84,766	85,004	96,985	86,272	36,684	75,967	267,705	30,948
Clinton River	263,196	253,588	259,784	299,111	260,429	85,835	168,697	426,135	61,600
Mill Creek	59,331	57,718	58,502	67,914	59,331	20,584	47,707	94,608	-
Rouge River	230,038	162,549	227,075	255,286	227,822	63,924	131,532	262,456	44,190
River Raisin	2,462,627	1,024,031	2,356,470	2,616,390	2,378,991	425,544	1,106,973	566,571	71,224
Maumee River	11,081,131	6,179,702	10,498,421	11,631,026	10,554,470	2,969,085	5,418,653	3,634,019	323,877
Portage River	547,152	369,691	515,085	568,659	517,252	125,705	232,256	245,180	10,247
Huron River	552,648	466,785	543,857	625,109	540,403	138,881	319,453	376,676	104,207
Direct Drainage	1,213,329	998,107	1,156,006	1,279,440	1,171,429	631,201	771,766	1,380,428	252,812
Total Soil Loss	16,558,689	9,652,224	15,762,305	17,511,751	15,859,357	4,519,203	8,323,693	7,340,003	909,368
PGE Rate (T/A/YR)	2.3	1.3	2.1	2.4	2.2	0.6	1.1		
Percent Reduction	-	42.	5.	(-6)*	4.	73.	50.		

*Denotes negative impacts where soil loss is increased instead of decreased.

differences in PGE appear to be rather insignificant, it is important to recognize that winter cover crops (Scenario 5) and crop residue protection (spring plow, Scenario 3) afford surface protection against soil detachment from raindrop impact during winter and early spring months. Infiltration is likely to be improved under these conditions also. Another consideration is that delivery of sediment eroded in the winter and early spring months is high.

There are large reductions in PGE realized from using reduced tillage systems as applied in Scenarios 6 and 7. By applying no-till and reduced tillage (chisel plow) on those soils suited to these tillage techniques, PGE is reduced 73 percent (Scenario 6). A 50 percent reduction is realized under the "chisel plow" reduced tillage scenario.

c. Central Basin - Table V-5 shows potential gross erosion in the Central Basin for the scenarios. The PGE rate of 2.0 T/A/Y of the Central Basin is less than the Western Basin. However the PGE rate of the Sandusky (3.7 T/A/Y), Huron (3.3 T/A/Y), and Vermilion (3.1 T/A/Y) river basins are high.

In Scenario 2, a 35 percent reduction in PGE would be needed on those soils exceeding the tolerable soil loss to adequately protect the soil resource base. This type of soil loss reduction cannot be achieved under the spring plow, fall plow, or winter cover scenarios. Here again, the range in PGE from 1.9 to 2.1 T/A/Y is essentially negligible. Major PGE reductions are also potentially achievable under reduced tillage, Scenarios 6 and 7. Scenario 6 reductions of 65 percent and Scenario 7 reductions of 42 percent are both significant, yet slightly lower than the same scenarios for the Western Basin.

d. Eastern Basin - Table V-6 shows potential gross erosion in the Eastern Basin for the scenarios. The Eastern Basin has a PGE rate of 2.2 T/A/Y, which is similar to the Western Basin. In Scenario 2, a 39 percent reduction in PGE is needed on those soils exceeding tolerable soil loss limits to adequately protect the resource base. As in the other basins, this reduction cannot be achieved under conventional tillage system unless there is a rotation change. Some type of reduced tillage system will be needed for these areas.

The PGE rates of 2.2 to 2.5 T/A/Y for spring plow, fall plow, and winter cover crops are not significantly different from the present condition.

Scenarios 6 and 7 show reasonable reductions in PGE (49 percent and 29 percent, respectively), but not nearly as significant as in the Western and Central Basins. Reduced tillage systems are, however,

Table V-5 - Central Basin Potential Gross Erosion: Existing and Potential Achievable Reductions

	Existing Pot. Gross Erosion (Tons) 1	Reduce Soil Loss to T and Existing (Tons) 2	Spring Plowing Only (Tons) 3	Fall Plowing Only (Tons) 4	Winter Cover Crop (Tons) 5	Maximum Reduction Tillage (Tons) 6	Reduced Tillage Chisel Plow (Tons) 7	Cropland Grassland and Forest (Acres)	Other Land Use (Acres)
River Basins									
Sandusky River	2,789,267	1,655,505	2,674,484	2,980,948	2,734,208	577,262	1,302,277	758,725	35,074
Huron River	737,802	492,884	704,523	777,761	710,753	220,097	387,982	220,400	15,886
Vermilion River	412,190	284,902	397,056	445,271	400,587	180,474	274,473	132,172	8,580
Black River	486,112	343,435	463,419	525,169	476,969	277,301	363,695	248,453	12,690
Rocky River	285,306	159,127	271,541	306,830	278,496	131,668	191,949	149,423	20,529
Cuyahoga River	159,619	127,148	157,739	170,096	159,097	99,218	127,115	397,520	47,557
Euclid Creek	6,315	5,891	6,283	6,660	6,210	5,912	6,055	11,711	3,031
Big Creek	8,004	8,004	8,004	8,004	8,004	8,004	8,004	21,907	2,113
Chagrin River	85,686	55,176	85,086	91,946	83,984	52,176	64,759	126,795	29,600
Grand River	298,073	243,013	294,408	340,822	293,775	144,643	228,254	433,452	18,646
Ashtabula River	49,610	45,119	48,816	58,377	49,542	27,694	44,685	80,345	6,592
Conneaut Creek	158,062	115,110	154,712	180,884	157,416	79,508	120,765	108,958	10,205
Direct Drainage	1,254,533	861,683	1,202,262	1,337,898	1,210,477	564,500	772,362	716,748	
Total Soil Loss	6,730,579	4,396,989	6,468,333	7,230,668	6,569,516	2,368,456	3,892,375	3,406,608	313,209
PGE Rate (T/A/YR)	2.0	1.3	1.9	2.1	1.9	.7	1.1		
Percent Reduction	0.	35.	4.	(-7.)*	2.	65.	42.		

*Denotes negative impacts where soil loss is increased instead of decreased.

Table V-6 - Eastern Basin Potential Gross Erosion: Existing and Potential Achievable Reductions

	Existing Pot. Gross Erosion (Tons) 1	Reduce Soil Loss to T and Existing (Tons) 2	Spring Plowing Only (Tons) 3	Fall Plowing Only (Tons) 4	Winter Cover Crop (Tons) 5	Maximum Reduction Tillage (Tons) 6	Reduced Tillage Chisel Plow (Tons) 7	Cropland Grassland and Forest (Acres)	Other Land Use (Acres)
River Basins									
Mill Creek	6,417	3,826	6,318	7,060	6,367	3,927	5,086	3,736	2,135
Raccoon Creek	1,751	1,675	1,719	1,957	1,735	593	1,132	1,661	158
Cattaraugus Creek	785,562	373,050	774,967	882,073	785,562	361,637	507,902	248,926	23,952
Delaware Creek	5,960	4,932	5,828	6,754	5,960	3,720	5,235	4,670	623
Eighteenmile Creek	42,589	27,120	41,747	47,640	42,589	21,241	35,681	21,105	2,357
Direct Drainage	966,673	688,193	950,633	1,088,044	963,690	535,157	720,919	530,440	99,991
Total Soil Loss	1,808,952	1,098,794	1,781,211	2,033,528	1,805,904	926,274	1,275,956	810,538	129,216
PGE Rate (T/A/YR)	2.2	1.4	2.2	2.5	2.2	1.1	1.6		
Percent Reduction	0.	39.	2.	(-12.)*	0.	49.	29.	-	-

*Denotes negative impacts where soil loss is increased instead of decreased.

viable erosion control measures for the Eastern Basin and should be further developed.

e. Lake Erie Summary - Table V-7 summarizes potential gross erosion for the scenarios for the entire Lake Erie drainage area. Basically, the same holds true for the Lake Erie basin-wide summary as applies in the individual basins. Average PGE of 2.2 T/A/Y still distorts the true picture because of the averaging. There are many areas where soil loss is well below the tolerable limits. In fact, in many cases, existing PGE is less than 1.0 T/A/Y or where soil loss is well over "T." It is not uncommon to find some soil losses in certain areas ranging from six to 12 T/A/Y or higher. It is these high PGE areas which must be identified and treated if sediment and nutrient loading reduction objectives are to be achieved.

Throughout the Lake Erie Basin, it holds true that on the average where soil loss exceeds tolerable limits, merely a change to conventional spring plow or winter cover crops will not bring soil loss to within tolerable limits. The reduced tillage Scenarios (6 and 7) indicate that throughout the Lake Erie Basin significant reductions in PGE can be achieved. It should be stressed that scenarios 6 and 7 use no-till and chisel plow tillage systems only where practical. It is recognized that a voluntary approach to reducing cropland nonpoint pollution is only feasible if incomes remain nearly the same or enhanced by the pollution reducing technologies. Thus, these scenarios depict the potential practical reduction in PGE with the adoption of reduced tillage practices.

It should also be remembered that the estimates of PGE in Table V-7 do not include any values for soil losses attributable to streambank and shoreline erosion, gully erosion, or other land use areas previously identified. Control measures and conservation treatments to reduce erosion and sediment problems from these areas must be appropriately applied where needed.

IV CONTROL OF IDENTIFIABLE DIFFUSE SOURCES

a. Introduction - While diffuse sources represent an accumulation of nutrients and sediments from large areas, there are identifiable diffuse sources which include areas that are highly visible, easy to identify, and obviously contribute to the overall erosion problems of the Lake Erie basin. Areas of extreme gully erosion; streambank, ditchbank, and roadside erosion; erosion from construction sites, and other areas of disturbed land are considered to be identifiable diffuse sources of pollution. These areas contribute a portion of the total diffuse source loading in a river basin. In LEWMS Phase II activities, there was no special effort to identify and quantify sediment and nutrient loads from such identifiable diffuse sources. Because of the wide range of identifiable diffuse

Table V-7 - United States Drainage to Lake Erie. Potential Gross Erosion: Existing and Potential Achievable Reduction

	Existing PGE (Tons) Scenario 1	Reduce Soil Loss to T and Existing (Tons) Scenario 2	Spring Plowing Only (Tons) Scenario 3	Fall Plowing Only (Tons) Scenario 4	Winter Cover (Tons) Scenario 5	Maximum Reduction Tillage (Tons) Scenario 6	Reduced Tillage (Chisel) (Tons) Scenario 7	Cropland Grassland and Forest (Acres)	Other Land Use (Acres)
Western	16,558,689	9,652,224	15,762,305	17,511,751	15,859,357	4,519,203	8,323,693	7,340,043	909,328
Average PGE (T/A/YR)	2.3	1.3	2.1	2.4	2.2	0.6	1.1		
Percent Reduction		42.	5.	(-6.)*	4.	73.	50.		
Central	6,730,579	4,396,989	6,468,333	7,230,668	6,569,516	2,368,456	3,892,375	3,406,608	
Average PGE (T/A/YR)	2.0	1.3	1.9	2.1	1.9	0.7	1.1		
Percent Reduction		35	4.	(-7.)*	2.	65.	42.		
Eastern	1,808,952	1,098,794	1,781,211	2,033,528	1,805,904	926,274	1,275,956	810,538	
Average PGE (T/A/YR)	2.2	1.4	2.2	2.5	2.2	1.1	1.6		
Percent Reduction		39.	2.	(-12.)*	0.	49.	29.		
Lake Erie Total	25,048,220	15,148,007	24,011,849	26,775,947	24,234,777	7,813,933	13,492,024	11,557,189	
Average PGE (T/A/YR)	2.2	1.3	2.1	2.3	2.1	0.7	1.2		
Percent Reduction		40.	4.	(-7.)*	3.	69.	46.		

*Denotes negative impacts where soil loss is actually increased instead of reduced.

source problems and because of the level of detailed field inventory that would be required, these sources are only addressed in a general nature. However, these specific problems are recognized as components of the overall lake basin water quality problem which can and should be treated.

b. Rural Areas - In rural areas of the Lake Erie basin, there are numerous types of identifiable diffuse source problems. These are problems which do not relate directly to urban areas.

(1) Roadsides and Streambanks - Roadsides and streambanks present erosion and sediment problems throughout the Lake Erie basin. These nutrient, and more specifically phosphorus loading contributions, are normally much less than cropland areas. Roadside and streambank erosion problems are easily identified by observation. The extent of erosion and sediment yields from these areas can also be quantified. Roadside and streambank erosion problems vary locally throughout the basin. In some places, these problems should be treated purely from a safety standpoint. Examples would be roadbank or streambank erosion that threatens roads, bridges, homesites, or other types of areas which could be harmful to human safety. In other areas, streambank erosion is more of a natural geologic process which has always existed.

Various studies, both completed and ongoing, have shown that streambank erosion is rather insignificant when compared to erosion from the total watershed areas. The International Joint Commission (PLUARG) conducted a study of streambank erosion in the U. S. portion of the Great Lakes basin. This study estimated that transport of phosphorus and sediment from streambank erosion in the Maumee River Basin was 58 MT/YR and 97,900 MT/YR, respectively. These loads are 2.2 percent of the total phosphorus load and seven percent of the sediment loads as estimated for the Maumee River (9).

Specific site-by-site treatment in the form of stream protection and roadside seeding is necessary to correct these problems. Frequently a combination of mechanical and vegetative treatments will be needed to solve a particular problem.

(2) Gully Erosion - Gully erosion occurs when concentrated flows of storm runoff have severely eroded the soil and formed deeply eroded channels in the landscape. These eroded scars are not considered sheet or rill erosion as calculated in the Universal Soil Loss Equation. Eroded gullies cannot normally be crossed easily with farm equipment, and cannot normally be eliminated using conventional tillage methods.

Gully erosion is usually found in agricultural areas where runoff collection and disposal systems are inadequate. It is often found in pastureland and woodland areas as well as along drainage ditches and roadsides where excessive concentrated surface runoff flows across bare slopes.

Most eroded material (sediment) from gullies is low in available phosphorus. There is a certain natural soil-phosphorus content, but this is normally of the mineral apatite form and unavailable for algal growth.

The existence of gully erosion in may cases aggravates soil loss problems as they make it difficult to effectively treat sheet and rill erosion problems on a field-by-field basis.

The use of runoff collections and disposal practices such as waterways, diversions, and water control structure are generally needed to solve gully erosion problems. Sometimes these practices are used separately, while in other situations it may be necessary to employ a combination of practices. (See Table V-1)

(3) <u>Livestock Waste</u> - Livestock waste disposal problems are another form of identifiable diffuse source of pollution. This problem seldom involves an erosion and sediment component per se, although occassionally livestock waste disposal problem areas do have an associated erosion and sediment problem. However, in most cases, livestock waste disposal involves principally the loss of organic livestock wastes and associate nutrients to surface runoff and eventual delivery to a downstream receiving stream.

Any form of livestock enterprise (beef, dairy, swine, poultry, etc.) will have animal wastes to dispose. Some already have existing facilities and capabilities to handle this with little to no effect on water quality. Other agricultural operations, because of their size, location, management capabilities, equipment limitations, or some other reason, may have problems in properly handling and disposing livestock wastes. The degree, magnitude, and significance of each agricultural operation again depends upon the individual site-by-site circumstances.

The degree and magnitude of this problem Lake Erie basin-wide, is another case where it was not practical to perform an inventory and to quantify the livestock waste disposal problem. This could be handled on a subwatershed basis or a county-level basis by local agricultural agencies.

Because of the high organic content and soluble nutrient concentrations (phosphorus and nitrogen) in livestock wastes, this problem should receive priority consideration for treatment where the likelihood of water quality pollution is high. Again this situation needs to be approached on a site-by-site basis.

(4) Other Rural Identifiable Diffuse Source Problems - These problems include quarries, land fills, failing on-lot septic systems, and others. Here again, it is impractical to do a detail inventory and quantification of these sources. Nonetheless, these are contributing problem areas in the Lake Erie basin. Although their effect on Lake Erie is negligible they can be significant locally. These problem areas can also be better identified at the local level on either a watershed or county basis.

c. Urban Areas - Developed urban and urbanizing areas have their own unique set of water quality related problems. Erosion and sediment with urban runoff and sewage treatment are the most significant problems. Within these areas, there is a complex intermixing of land use patterns and related water quality problems. Urban area problems also include a very diverse and more sophisticated institutional structure. There are both governmental and political jurisdictional boundaries to deal with. Urban areas also involve a wide range of governmental agencies and complex permit-requiring programs. Sociological influences become more evident in urban areas. Society today has become more and more public-involvement oriented than traditionally found in rural areas.

(1) Construction Sites and Developing Areas - These problems exist within all urbanizing areas of Lake Erie basin. As land use shifts from rural agriculture to intensive residential, industrial, and commercial land uses, there are extensive earth-moving and land disturbing activities generally involving complete removal of existing vegetative cover and an extended period of construction activity. Many developments take in excess of two years from start to finish and final cover. In most cases, there are no voluntary or mandatory erosion and sediment control measures applied during this period.

Few sediment control programs or ordinance exist within the basin. Where they do exist, lack of enforcement because of inadequate manpower, regulatory control, or enforcement authority render many programs ineffective.

A host of urban area erosion and sediment control practices exist to abate the adverse effects of construction activities. Through the elected officals (State, county, and municipal), enabling authorities and legislative actions are needed to place effective urban area erosion control programs into operation. The involvement of engineers, developers, planners, agency personnel, and elected officials are needed to develop and effectively implement programs to address these problems. Institutional arrangements, operating procedures, and technical criteria or standards must be developed on a jurisdictional basis. Hopefully, as many jurisdictions as possible, would utilize the same or similar programs.

No attempt has been made to inventory or quantify the developing construction site problems in the Lake Erie basin. However, estimates have been made for the phosphorus load resulting from these problems.

(2) Developed Urban Areas - Runoff problems become much more significant in highly congested, highly developed metropolitan areas. As new areas develop, runoff problems increase. Peak rates and volumes of runoff often increase as rural area residuals are picked up and flushed from impervious surfaces such as streets, parking lots, and buildings. Urban runoff may include oils, petroleum wastes, nutrients, and many other surface collected debris.

The first flush of the impervious area storm runoff is heavily polluted with high concentrations of oils, residues, and other debris. The increased peak rates and volumes of runoff also tend to cause severe instream channel erosion, sedimentation, and pollution. There may also be downstream flood damages associated with increased urban area runoff.

Combined sanitary storm sewer overflows contribute to pollution problems in Lake Erie. Ongoing wastewater treatment plant programs are targeted towards these problems.

More attention is needed for the collection, controlled release, and distribution of increased urban area runoff. In already developed areas, this is often times impractical. Downstream and developing areas can often be protected with retention ponds and runoff disposal systems that control increased urban storm runoff. These runoff control facilities should be planned, designed, and incorporated into the public storm drainage system. Operation and maintenance should also be under the jurisdiction of the public storm drainage system authorities.

Development of the urban areas storm water runoff and management system should be a component of urban erosion and sediment control programs. Some municipal jurisdictions have initiated such programs in the basin.

The extent of the urban area storm runoff problem again is generally associated with the major metropolitan areas in the basin. However, urban development activities in rural communities may create drainage and flood-related problems.

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CHAPTER SIX

REMEDIAL PREVENTIVE STRATEGIES

I. INTRODUCTION

This chapter presents alternative strategies for the reduction of phosphorus loads into Lake Erie. The possibility of achieving the diffuse source reductions required after control of municipal point sources of phosphorus is examined. The economics of promising scenarios developed in Chapter Five are examined. In addition, institutional operations for carrying out the diffuse source control program are examined.

The goal of this study is to rehabilitate and environmentally repair Lake Erie. This goal will be achieved when the anoxic area in Lake Erie is reduced by 90 percent. It has been shown in Chapter 4 that this goal will require annual total phosphorus loads to Lake Erie to be reduced to 11,000 metric tons. This goal and loading objective are part of the 1978 Canada-United States Water Quality Agreement.

II. PROBLEM REVIEW

In 1975, the Lake Erie Wastewater Management Study Preliminary Feasibility Report (1) indicated the following:

a. The present total phosphorus load to Lake Erie is about 20,000 metric tons per year.

b. Control of diffuse sources is required to restore and rehabilitate Lake Erie.

c. The diffuse source phosphorus load depends upon annual runoff volume and seasonal distribution and can vary greatly from year to year.

The results of that 1975 report have since been verified by this report, the Report of Task Group III "A Technical Group to Review Phosphorus Loads" (2), the Pollution from Land Use Activities Reference Group (PLUARG) of the International Joint Commission (3) and the Great Lakes Water Quality Agreement of 1978 (4). Although these reports agree that diffuse sources of phosphorus must be controlled if Lake Erie is to be restored, they disagree upon the exact reductions. Table VI-1 summarizes the diffuse source reductions recommended by these studies to reach the 11,000 metric ton per year phosphorus loading objective for Lake Erie. The reasons these

Table VI-1 - Diffuse Source Reductions Required to Reach an 11,000 Metric Ton Per Year Objective for Lake Erie

Study	Percent Reduction in Diffuse Sources Required after Control of Point Sources to 1.0 mg/l	0.5 mg/l
LEWMS Phase I	42 (1)	
LEWMS Phase II	42 (2)	26 (2)
	47 (1)	33 (1)
Task Group III	50 (1)	30 (1)
Great Lakes Water Quality Agreement of 1978		30 (1)
PLUARG		
1980 Conditions	28 (1)	12 (1)
2000 Conditions	44 (1)	19 (1)

(1) Only municipal wastewater treatment plants with flows greater than 1,000,000 gallons per day

(2) All municipal wastewater treatment plants

numbers differ is not important. What is important is that diffuse source phosphorus loads to Lake Erie must be reduced. The exact percentage reduction cannot be stated with certainty. The reasons for this are:

a. The large annual variations in diffuse source phosphorus loading.

b. Our inability to predict with certainty the improvements that will result from specific phosphorus control measures.

The diffuse source total phosphorus load to Lake Erie has varied between about 6,000 and 11,700 metric tons per year between 1970 and 1977. In fact, the diffuse source phosphorus loading varied from 6,800 metric tons for water year 1977 (October 1976 to September

1977) to 11,700 metric tons for calendar year 1977. The main reason for this huge variation was a total phosphorus load of 4,600 metric tons for December 1977, as compared to 126 metric tons for December 1976. Obviously, requiring an exact reduction in diffuse source loading of phosphorus is not meaningful when the annual variation is so great.

The other problem in requiring an exact reduction in diffuse source loading is our inability to predict with certainty the results of a diffuse source management program. The only method which is available for lakewide analysis of diffuse source programs is the Universal Soil Loss Equation (USLE). The USLE calculates potential gross erosion (PGE). This study has calculated PGE for present conditions and the management scenarios shown in Table V-3. While the relative reductions in PGE calculated for the scenarios are reasonable, we cannot predict with certainty the reductions in diffuse source phosphorus loading which will take place. Although a substantial reduction in potential gross erosion, for example 60 percent, will produce a large reduction in delivered phosphorus, the reduction in delivered phosphorus will likely be in the range of 35 to 55 percent or 60 to 90 percent of the reduction in gross erosion.

Quite realistically, it is not reasonable to expect development of an applicable method other than the USLE in the foreseeable future. Since diffuse source loads are extremely variable on a year-to-year basis, and since we cannot predict exactly the effects of any diffuse source reduction plan, it is meaningless to argue about the exact reductions in diffuse sources required.

III. ASSUMPTIONS

In order to make an estimate of the reductions in diffuse sources of phosphorus which will be achieved by any management plan, the following assumptions are made:

a. The base year diffuse source annual phosphorus load to Lake Erie is 9,710 metric tons, of which 83 percent is sediment phosphorus.

b. Urban diffuse sources annually account for 1,570 metric tons of phosphorus.

c. A 4,520 metric ton per year reduction of diffuse sources of phosphorus will be required if all municipal point sources with flows greater than one million gallons per day reach an effluent phosphorus concentration of one mg/l.

d. A 3,160 metric ton per year reduction of diffuse sources of phosphorus will be required if all municipal point sources with flows greater than one million gallons per day reach an effluent phosphorus concentration of 0.5 mg/l.

e. Reduction of potential gross erosion could be 60 to 90 percent effective in reducing phosphorus.

f. Reduction of potential gross erosion by application of Best Management Practices calculated for the United States portion of the Lake Erie basin are also achievable on the Canadian side.

IV. POSSIBLE PHOSPHORUS REDUCTIONS

a. Relative Effectiveness of Best Management Practice Scenarios - Reductions in potential gross erosion will not produce equivalent reductions in phosphorus yield. Research in diffuse source runoff (5)(6) has shown that instream sediment is enriched with small (clay and silt) sized particles relative to the particle size distribution of the soils in the drainage basin. This work has also shown that most of the phosphorus transported in rivers is adsorbed to the clay fraction particles of the sediment load.

Other research has shown that reduced tillage land management practices cause a further increase in the proportion of clay sized particles carried by runoff and an accompanying increase in the phosphorus sediment ratio (7)(8)(9). Even though these studies indicate that it is possible for the ratio of phosphorus to sediment in runoff to increase by use of reduced tillage practice, significant reductions in phosphorus transport would still be achievable. The "relative effectiveness" (RE) of management practices in reducing phosphorus relative to soil loss derived from the above research is given in Table VI-2.

Table VI-2 - Relative Effectiveness of Reduced Tillage Practices on Phosphorus in Runoff Water

Practice	Percent Sediment Reduction	Percent Sediment Phosphorus Reduction	Relative Effectiveness	Reference
(1) Fall Plow	-	-		
(2) No-Till	80	43	54	(7)
(3) Fall Plow	-	-		
(4) No-Till	92	69	75	(8)
(5) Chisel Plow	98	98	100	
(6) Double Disk	87	86	99	
(7) Till Plant	67	46	69	
(8) Fall Plow	-	-		
(9) Chisel Plow	52	41	79	(9)
(10) Disk	83	68	82	
(11) No-Till	81	73	90	

Based on the results obtained in these studies it will be assumed that application of best management practice technology will be from 60 percent to 90 percent effective in reducing phosphorus transport relative to reduction of potential gross erosion. This estimate of "relative effectiveness" will be applied to the estimated potential gross erosion reductions to determine the reductions in total phosphorus transport achievable in the BMP scenarios.

Another question which is unanswered at this time is the effect a reduction in potential gross erosion will have on the dissolved fraction of diffuse source phosphorus. Therefore, in determining total phosphorus loading reductions achievable, two cases have been considered, a minimum reduction case where the dissolved fraction is unaltered by reductions in potential gross erosion and a maximum reduction case where the dissolved fraction is reduced by the same percentage the sediment fraction is reduced.

b. Distribution of Diffuse Source Phosphorus Inputs - The distribution of urban and rural diffuse phosphorus sources and the dissolved and sediment fractions of the rural diffuse source loading are shown in Table VI-3. The urban diffuse phosphorus load is estimated by applying a unit area load factor of 2.0 kg/ha for all lands not included in the remainder of the scenario land use categories. Rural diffuse source phosphorus is divided into rural dissolved and rural sediment bound phosphorus on the basis of measured sediment/total phosphorus ratios in each of the three major lake drainages, i.e., Western, 0.81, Central, 0.71, and Eastern, 0.89.

c. Annual Reductions Achievable - The annual reduction of total phosphorus loading achievable through the application of BMPs is determined by applying the relative effectiveness values of 0.6 and 0.9 against the percentage reductions in potential gross erosion given for promising scenarios evaluated in Table V-7. The resultant phosphorus reduction percentages are then applied to both the rural sediment and rural total phosphorus loading to give the range of achievable annual rural diffuse source. Table VI-4 gives the total rural diffuse source phosphorus reduction achievable if only sediment phosphorus is controlled. Table VI-5 shows the results if the reductions can be applied against dissolved and sediment phosphorus. It can be seen from these tables that reducing soil loss to soil tolerance levels will result in projected total phosphorus reductions of 1,610 to 2,980 metric tons per year (mta). This projected reduction is less than the 3,160 mta reduction of diffuse sources required if all municipal point sources with flows greater than one million gallons per day (MGD) reach an effluent phosphorus concentration of 0.5 mg/l. Clearly, this scenario alone cannot meet the phosphorus loading objective from Lake Erie.

Table VI-3 - Distribution of Diffuse Sources of Total Phosphorus in Lake Erie (Metric Tons Per Year)

Basin	Urban(1)	Rural Dissolved(2)	Rural Sediment	Total
Western	1,020	1,150	4,900	7,070
Central	450	290	980	1,720
Eastern	100	90	730	920
Total	1,570	1,530	6,610	9,710

(1) Two Kg/hec assumed for all urban and other land uses
(2) Sediment fraction of diffuse load calculated to be 0.81, 0.77, and 0.89 for Western, Central, and Eastern Basins, based on tributary monitoring for 1976 and 1977

Scenario 6, "maximum reduction tillage," will result in a projected total phosphorus loading reduction of 2,740 to 5,080 mta. If the 5,080 mta projection is achieved, tillage modification alone will achieve the 4,520 mta reduction of diffuse sources required if all municipal point sources with flows greater than 1 MGD reach an effluent phosphorus concentration of one mg/l. If the projected reduction is only 2,740 mta, additional control of point and diffuse sources will be required.

Scenario 7, "reduced tillage chisel plow," is projected to result in a total phosphorus loading reduction of 1,850 to 3,420 mta. If phosphorus loading objective is to be met, additional control of point and diffuse sources will be required.

V. ECONOMIC IMPACTS OF REDUCED TILLAGE SYSTEMS

a. Introduction - The previous section has shown that reduced tillage systems have the potential of reducing total phosphorus loadings to Lake Erie by 1,850 to 5,080 mta. This range of phosphorus loading reductions has the potential of achieving the diffuse source phosphorus loading reductions required to meet the phosphorus loading objective for Lake Erie.

Scenario 6, "maximum reduction tillage," identifies the maximum PGE practically achievable through the use of tillage modification. It assumes no tillage is used on soil management groups 1, 2, 6, and 10; chisel plowing is utilized on soil management groups 4 and 8; and present practices are continued on soil management groups 3, 5, 7, and 9. Scenario 7, "reduced tillage chisel plow," assumes chisel

Table VI-4 - Rural Diffuse Source Sediment Phosphorus Reductions

Basin	Scenario 2: Reduce to T and Existing			Scenario 6: Maximum Reduction: Tillage			Scenario 7: Reduced Tillage: Chisel Plow			Present Rural Diffuse Source Sediment Phosphorus Load
	Percent PGE Reduction	Reduction @ .6 RE*	Reduction @ .9 RE	Percent PGE Reduction	Reduction @ .6 RE	Reduction @ .9 RE	Percent PGE Reduction	Rediction @ .6 RE	Rediction @ .9 RE	
Western	42	1,235	1,852	73	2,146	3,219	50	1,470	2,205	4,900
Central	35	206	309	65	382	573	42	247	370	980
Eastern	39	171	256	49	215	322	30	131	197	730
Total		1,612	2,417		2,743	4,114		1,848	2,772	6,610
Percent Reduction Relative to Rural Diffuse Source Total Phosphorus		20	30		34	51		23	34	

* Relative Effectiveness

Table VI-5 - Rural Diffuse Source Total Phosphorus Reductions

Basin	Scenario 2: Reduce to T and Existing — Percent PGE Reduction	Scenario 2: Reduction @ .6 RE*	Scenario 2: Reduction @ .9 RE	Scenario 6: Maximum Reduction: Tillage — Percent PGE Reduction	Scenario 6: Reduction @ .6 RE	Scenario 6: Reduction @ .9 RE	Scenario 7: Reduced Tillage: Chisel Plow — Percent PGE Reduction	Scenario 7: Rediction @ .6 RE	Scenario 7: Rediction @ .9 RE	Present Rural Diffuse Source Total Phosphorus Load
Western	42	1,525	2,287	73	2,650	3,975	50	1,815	2,723	6,050
Central	35	267	400	65	495	743	42	320	480	1,270
Eastern	39	192	288	49	241	362	30	148	221	820
Total	-	1,984	2,975	-	3,386	5,080	-	2,283	3,424	8,140
Percent Reduction Relative to Rural Diffuse Source Total Phosphorus		24	37		42	62		28	42	

* Relative Effectiveness

plowing on soil management groups 1, 2, 4, 6, 8, and 10 while continuing moldboard plowing on soil management groups 3, 5, 7, and 9.

The purpose of this section is to discuss the selection of these scenarios and to estimate the impacts of these scenarios on net farm incomes. These scenarios have the potential for achieving significant total phosphorus reductions, hence it is important to consider the criteria used in formulating these strategies and the economic impacts of these strategies on the agricultural community.

Results of an economic analysis of reducing soil loss in the Honey Creek watershed indicated that initial reductions in soil loss are inexpensive to the farmer and society (10). Soil loss could be reduced by nearly one-half with little or no reduction in net farm income. These reductions were accomplished by shifts toward reduced tillage systems on selected soils.

Another general method of reducing soil loss was through changing rotations and/or shifting away from row crops. While effective in reducing soil loss, this strategy caused severe reductions in net farm income and disruptions to the agricultural community.

Since results from the Honey Creek analysis indicated that adoption of reduced tillage systems (minimum tillage or no tillage technologies) on selected soil types could substantially reduce soil loss at little or no cost to the farmer, the decision was made to examine the impacts of reduced tillage systems across the entire Lake Erie Basin. The questions of primary concern were:

1. What is the potential reduction in gross erosion if reduced tillage practices are adopted only on those soils which are conducive to these practices?

2. What is the likely change in net farm income if these practices are adopted?

3. What areas appear to offer the most potential for reducing soil loss at a low cost to society with the adoption of reduced tillage technology?

Thus, the attempt was made to view the results of changes in technology (tillage systems) which promise to sharply reduce soil loss. It should be stressed that other management practices (see Table V-I) are available to reduce diffuse source pollution. Some of these practices may be cost effective methods of reducing soil loss and diffuse source pollution; however, their omission from this analysis was necessitated by the site specific nature of their adoption.

b. Method Used for Economic Analysis - A computerized simulation model was developed to enable the economic impacts of alternative tillage practices to be traced (11). The model used each county's soil series as the basic units of analysis. An inventory of each county's soils was obtained from the LRIS data base. Soils were aggregated to the soils series level.

Over 300 soil series were identified in counties across the basin. Yields for major crops were assigned to each soil series. Costs of production and prices were developed for each crop by using research data from each State's Land Grant University and the U.S. Department of Agriculture. In short, an attempt was made to simulate the net farm income across the Basin resulting from present cropping and tillage practices.

The impact of tillage systems was estimated by first estimating the effect that conservation tillage (i.e., chisel plowing) would have on yields and costs of production for corn and soybeans. Agronomy research and extension personnel were contacted in Ohio, Michigan, and New York in order to develop corn and soybean yield responses. Soil management groups 1 and 2 were the most conducive to conservation tillage and no-till. In all States the yields under reduced tillage systems were nearly the same as those under conventional tillage on soil management group 1 soils. Yields for reduced tillage systems were slightly higher than the conventional tillage yields on soil management group 2 soils in Indiana and Ohio. Here the assumption was made that improved drainage systems are in place. Reduced tillage yields on group 2 soils may be nearly the same as conventional tillage yields if improved drainage is not provided. Thus, the yield indices may be biased upward for reduced tillage on group 2 soils. Other yield indices are shown in Table VI-6.

Several costs were omitted from the analysis. One of these costs is the reduction in future productivity associated with soil loss. Due to a number of factors, the assignment of a value to lost productivity is somewhat arbitrary. Thus, this cost was omitted from the analysis. Since conventional tillage systems produce more soil loss than reduced tillage systems, conventional tillage net returns tend to be biased upward from a societal perspective. Another cost omitted from the analysis was the cost of soil loss to the downstream user. Ditch clearing costs, harbor dredging costs, water treatment costs, damage to recreational sites, etc. would be higher with the conventional tillage systems than with the reduced tillage systems.

In short, the analysis considers only the annual returns and costs of the farmers. It is a most conservative estimate of the economic impacts to society of changing to reduced tillage systems. In reality, society's net returns from reduced tillage systems should be higher than those shown here.

Table VI-6: Yield Indices Assumed for Alternative Tillage Systems

Soil Management Groups	Corn: Minimum Tillage	Corn: No Tillage	Soybeans: Minimum Tillage	Soybeans: No Tillage	Corn and Soybeans Conventional Tillage
		Ohio and Indiana			
1	100	102	100	100	100
2 and 6	105	104	103	103	100
3 and 7	90	85	90	85	100
4 and 8	96	87	95	91	100
5 and 9	NA	NA	NA	NA	100
		Michigan			
1	100	100	100	100	100
2 and 6	100	100	100	100	100
3 and 7	90	85	90	85	100
4 and 8	96	87	95	91	100
5 and 9	NA	NA	NA	NA	100
		New York and Pennsylvania			
1	100	100	100	100	100
2 and 6	90	90	90	90	100
3 and 7	NA	NA	NA	NA	100
4 and 8	NA	NA	NA	NA	100
5 and 9	NA	NA	NA	NA	100

c. <u>Results</u> - Results indicate that the Basin's net farm income from crops is approximately $338.2 million under conventional tillage. The distribution of this income is noteworthy. While western counties enjoy large net incomes, eastern counties have relative small and sometimes negative net incomes. With the implementation of minimum and no tillage technologies, Basin net incomes change as follows:

Soil Management Group	Conservation	No Tillage
1	+1.3%	+2.2%
2 and 6	+4.9%	+5.9%
3 and 7	-3.7%	NA
4 and 8	-1.2%	NA
5 and 9	NA	NA

Those situations where "NA" is shown resulted in sharply reduced Basin incomes, thus they were excluded from consideration.

Scenario 6, "maximum reduction tillage" is developed from this set of results. It assumes that no till is used on soil management groups 1, 2, 6, and 10 while chisel plowing is used on groups 4 and 8. Conventional tillage is used on other soils. Net farm income in the Basin increases by 6.9 percent under this scenario.

Scenario 7, "reduced tillage chisel plow" replaces no till systems with chisel plowing. Conventional tillage remains on soil management groups 3, 5, 7, and 9. Net farm income in the Basin increases by 5.0 percent under this scenario.

The simple conclusion from this analysis is that Scenarios 6 and 7 do not disrupt the Basin's agricultural economy. In fact, they slightly improve society's net benefits since they (a) make the farmer no worse off, (b) reduce downstream user costs, and (c) reduce the loss of soil products.

Maps VI-1 and VI-2 provide some perspective on the spatial impacts of the "maximum reduction strategy." The farmers experiencing the most economic gain are in the western portion of the Basin. Those counties surrounding the area formed by glacial lake bed sediments are the areas most adaptable to reduced tillage. These areas have a predominance of soils in management groups 1 and 2. Also, several counties in Michigan, eastern Ohio, and western New York appear to be suitable for widespread adoption of reduced tillage systems.

The greatest reduction in soil loss is achievable from reduced tillage in many of those counties where incomes are improved by adopting reduced tillage. Comparing Maps VI-1 and VI-2 it is apparent that the largest reductions in soil loss from the "maximum reduction strategy" are encountered in counties surrounding the area formed by glacial lake bed sediments in the western portion of the basin. In addition, counties in western New York experience substantial reductions in gross erosion.

VI. INSTITUTIONAL OPTIONS

a. Introduction - The management options for control of point source pollutants are well established. The water quality standards are given. These standards can change or be negotiated, but the methods and responsible management agencies are set. The mechanism for issuing permits and for monitoring of performance is likewise established.

The management options for control of diffuse sources of pollution are less clear. One of the major problems regarding diffuse source pollution is that little work has been done in the area of monitoring. Any attempt at enforcement of a standard becomes purely arbitrary since there is no direct knowledge of baseline conditions.

Map VI-1: Change in County Net Farm Income with the Adoption of "Maximum Reduction Strategy"

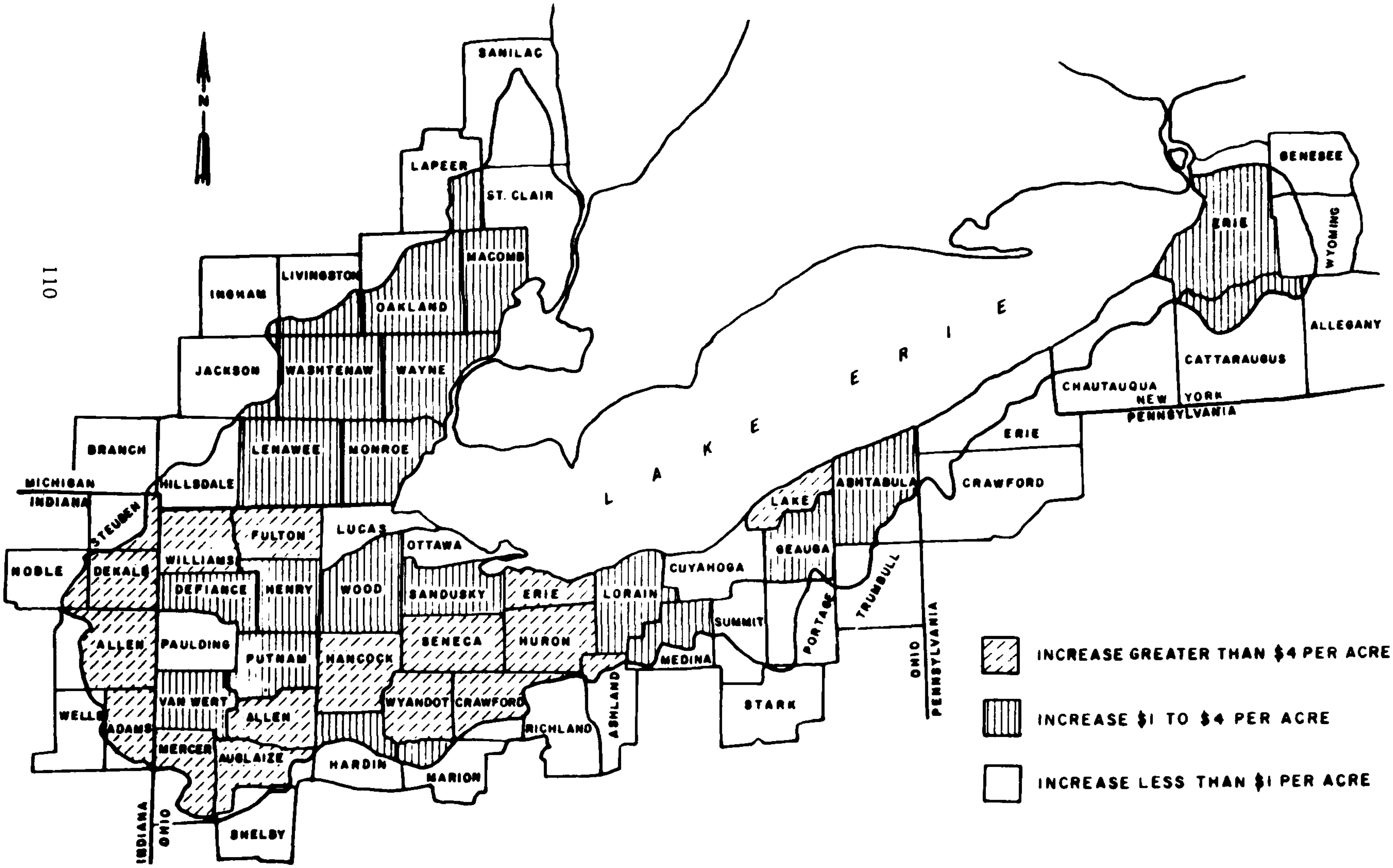
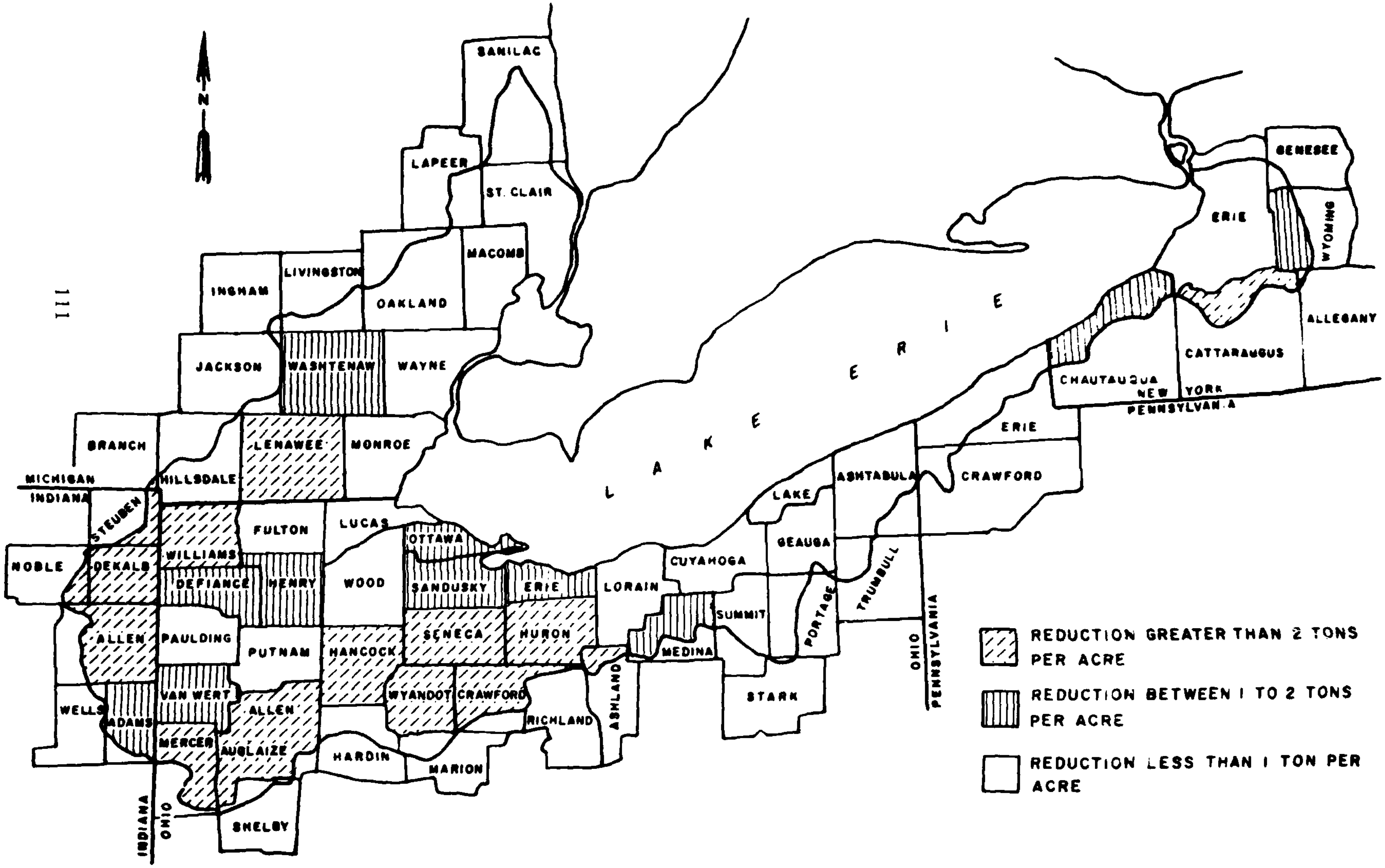


Figure VI-2: Change in County Gross Erosion with the Adoption of "Maximum Reduction Strategy"



There is general acknowledgment that the diffuse source pollution problem does result in impaired water quality. The issue really is how stringent should any control program be and what goals should be established. A rigid permit system with hard limits enforced by national or State law does not seem to apply to the diffuse source pollution problem.

Pollution from diffuse sources occurs in two forms. That which is soluble in water and that which is attached to the soil complex. A control program, therefore, must be designed that will address the particular form that the pollutant is in. The transport agent for both is running water. The common element then in the control of pollution from diffuse sources is the management of water runoff from the land's surface.

Another aspect of diffuse source pollution is that a program that responds to a water quality problem is less effective and probably more expensive than one that is directed toward prevention. There obviously are numbers of identifiable nonpoint sources that must be dealt with even if their contribution of pollution is small. The design of a program must deal with these types of problems while at the same time looking toward means of prevention. This suggests that a program that addresses the management of water runoff from the land would be the cheapest and most effective.

b. Options Considered - Consideration of the institutional options were divided into three broad categories:

(1) Create new agencies.

(2) New authorities for existing agencies.

(3) Present authorities (and capabilities) of existing agencies.

The creation of new agencies is the least desirable option. The cost of creation, possible duplication of efforts in some areas, lack of trained technicians, and the timeframe for a new agency to become operational are some major reasons for discarding this option. Adverse political and citizen reaction to this option would also be overwhelming. Creating a new agency will only be a viable option if existing agencies cannot accomplish the job.

The second option of providing new authorities to existing agencies is only viable if existing agencies cannot accomplish the necessary tasks under their present authorities. In order to assess the viability of this option, it is appropriate to analyze the authority and capabilities of existing agencies with respect to the documented diffuse source problems.

It is clearly documented that the major nonpoint diffuse source phosphorus loading problem in the Lake Erie basin comes from rural diffuse agricultural lands, especially cropland. Water quality monitoring data also document that high runoff events from rural watersheds carry the finer-grained clay particles with attached phosphorus through our streams and rivers to Lake Erie. Therefore, it is only logical to look to the agencies, organizations, and institutions with authority, experience, and capabilities in agricultural runoff and erosion control.

Looking at existing agencies with the necessary authorities and capabilities, local Soil and Water Conservation Districts (SWCD) surface immediately as the most likely institution to address the diffuse source problems. Each State within the Lake Erie basin has passed enabling State legislation which provides for the voluntary creation of SWCDs in each county. These special purpose districts exist within each county in the basin. They presently have responsibilities for the development and implementation of soil and water conservation programs within their respective counties. Each district within the basin presently establishes their own priorities of work for their counties. Many of the SWCD's present priorities are directed towards erosion control and water management needs for maintaining soil productivity.

In many cases, districts have joined forces on a multi-county basis to address soil, water, and other natural resource problems which cross county boundaries. In much of the Lake Erie basin, many of the diffuse source problems from various watersheds or subwatersheds cross the district/county jurisdictional boundaries.

The soil and water conservation districts basin-wide also have an excellent connection with available agricultural and natural resources expertise of Federal, State, and local Governments, as well as the agricultural land grant colleges in each State. Most SWCDs have executed memorandum of understandings with USDA agencies such as Soil Conservation Service, Agricultural Stabilization and Conservation Service, and the Cooperative Extension Service. Memoranda of understanding or working agreements also exist with many State natural resources agencies in the fields of forestry, fish and wildlife, conservation, and environmental services.

Over the past 30 to 40 years, SWCDs have demonstrated that local level initiative through local people provides an excellent arrangement for the necessary delivery of educational, technical, and financial assistance to the agricultural needs in each county. It is the strength of this local level agricultural delivery system and capability which a Lake Erie diffuse source phosphorus reduction program must be built upon.

In summary, the soil and water conservation district is an existing institution which incorporates within its total program certain elements which also are elements of a water quality program. However, it should be kept in mind that present district programs are not specifically water quality programs. Any additional shift to water quality emphasis will require an SWCD agreement to shift in priorities and goals. Additional educational assistance, financial support, and increased technical staffing will be necessary for SWCDs to take on these added responsibilities. These additional services may come from existing agencies such as the Cooperative Extension Service (educational) or the Soil Conservation Service (technical). Adequate funding and staff must also be provided to these and other cooperating agencies.

Therefore, the logical existing institution to be assigned additional responsibilities for water quality in the area of diffuse source pollution is the Soil and Water Conservation District. Within the rural area they might logically operate the entire program. Within a totally urban setting or an urbanizing area which already has home rule powers, their role may well shift to that of providing advice and council to that official who within that jurisdiction is responsible for the control of water runoff. This may be the city engineer, the building department, service director, or a multi-jurisdictional watershed district or any other agreed to division of responsibility.

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CHAPTER SEVEN

PROPOSED PHASE III ACTIVITIES

I. INTRODUCTION

This chapter outlines the proposed activities that will be accomplished during the third phase of the Lake Erie Wastewater Management Study effort. Phase II results indicate that widespread adoption of best management practices (BMP's), particularly conservation tillage and no-till methods will achieve the phosphorus loading reductions from diffuse sources required in Lake Erie. A major objective of Phase III will be to develop methods to achieve this change.

Another major objective of Phase III will be to develop the necessary methods to measure progress. Progress may be measured in two ways: adoption of BMP's and reduction of phosphorus loadings. Adoption rates of BMP's can be measured by statistical sampling methods. However, measuring reduction in phosphorus loadings from diffuse sources is not straightforward. Phase II has shown that annual variation in nutrient and sediment yields are greater than the changes we hope to measure. Although we have been able to explain some of this variation, the amount and distribution of the rainfall and the condition of basin must also be considered.

In order to accomplish these two objectives, four major tasks are necessary. These tasks are the following:

a. Honey Creek Watershed Management Project

b. Five basin studies

c. Measurement of change

d. A Lake Erie drainage basin wide educational program.

The ultimate objective of the detailed feasibility study will be to develop a recommended management program to repair and rehabilitate Lake Erie water quality.

II. HONEY CREEK WATERSHED MANAGEMENT PROGRAM

The Honey Creek Watershed has been the focal point of a pilot study by LEWMS. The findings of this study are explained in the Honey Creek Report. Basically, the report, as an education tool, relates agricultural activities to water quality and describes opportunities to improve water quality by changing farm management practices and applying soil conservation/water management practices. This task will further develop these concepts and lead towards a total watershed management work plan for the entire Honey Creek Watershed.

The Land Resource Information System (LRIS) developed for the Lake Erie drainage basin contains generalized information on conservation practices and slope lengths. While this information is sufficient to point out regions which are problem areas, it is not detailed enough to develop a management program for Honey Creek. Therefore this task will collect and record actual field data regarding land use/cover conditions, slope, and other factors related to sheet erosion and nonpoint sources. An inventory of current conservation practices and tillage methods in the basin will also be made.

Identifiable nonpoint sources will be mapped and quantified and conservation practices and needs will be estimated. Major problem areas will be prioritized and applicable conservation practices on farm management will be recommended for these areas. Demonstration of these practices will be implemented and evaluated.

Conservation tillage and no-till demonstration plots will be established on a wide range of soils and management systems. The purpose of this program will be to demonstrate the crop production potential, economics and reliability of a wide variety of tillage combinations. These demonstration plots will be designed so results can be extended to other farms in the watershed.

Publicity will be a continuing effort. Progress of the demonstration plots will be reported frequently in the local press over the period of the demonstration. Field days will be held at different stages of crop production on the demonstration plots and will be conducted as working sessions to inform farmers in the actual techniques of conservation tillage and no-till farming.

An inventory of attitudes in the basin will be made concerning the need for agricultural pollution control, needed programs, and agencies to administer the program. In addition the respondents would be questioned about their knowledge of conservation tillage and no-till methods and the information they would need to apply these methods.

The Honey Creek Watershed lies within the jurisdiction boundaries of Huron, Crawford, and Seneca Soil and Water Conservation Districts (SWCD's) of Ohio. These three SWCD's comprise the Honey Creek Watershed Joint Board of Supervisors. Since SWCD's are the unit of Government which have the institutional capabilities to carry out a land management program directed at water quality, the Joint Board will carry out this project.

III. FIVE BASIN STUDIES

The Honey Creek Watershed Management Project will answer many questions about the implementation of BMP's in the Lake Erie drainage basin. However there are many land forms and soil types that are not found in Honey Creek. Therefore different BMP's will be necessary in other parts of the basin. In this task five additional basins will be selected on the basis of their representing the land forms, land use and soil types found in five critical regions of the Lake Erie drainage basin. The Land Resource Information System will be used to make this selection as well as economic information from earlier studies. LRIS will be used to summarize in tabular form and display with maps, present basin conditions, potential erosion sources, and opportunities for implementing BMP's. Economic information will be used to select those basins which provide the potential for reducing soil loss at little or no expense to the farmer.

Model management programs will be developed for each basin. Reports which relate agricultural activities to water quality and describe opportunities to improve water quality by changing farm management practices and applying soil conservation practices will be prepared as educational tools.

Baseline water quality and quantity information will be collected as well as necessary hydrologic data. The diffuse source model will be calibrated and verified for the watershed. At the conclusion of Phase III the information about the basin will be sufficient so that watershed management projects can be started and the water quality effects documented.

IV. MEASUREMENT OF CHANGE

Progress may be measured in two ways: adoption of BMP's and reduction of phosphorus loadings. To measure adoption rates of BMP's, the extent of present practices must be known. Statistical sampling methods will be used to measure present conditions. This data will be used as a baseline when future surveys are made.

Measurement of reductions in phosphorus loadings is more difficult. Annual variations in the frequency and duration of high-flow events, make any simple evaluation of changes in sediment and phosphorus export caused by implementation of BMP's impossible. Basin input (rainfall) must be related to basin sediment and phosphorus output by basin conditions such as soil type, land use and cover, and slopes contained in the LRIS system. Phase II used LRIS to calculate potential gross erosion under present conditions and a number of possible management scenarios. However, as shown in Chapter 3, potential gross erosion is not sediment yield measured at the monitoring stations. A delivery ratio must be used to relate the two. This task will use LRIS to explain sediment and phosphorus yield from a rainfall event.

This task will begin with a thorough evaluation of available models, their data requirements and shortcomings. Data collected during Phase II will be used to calibrate and verify the model. Additional data for the selected five subbasins will be collected where necessary.

V. LAKE ERIE DRAINAGE BASIN-WIDE EDUCATIONAL PROGRAM

The objective of this task will be to develop and implement a basin-wide educational program. This program will relate agricultural activities to water quality and describe opportunities to improve water quality by applying BMP's. It will be developed with the assistance of Federal, State, and local agricultural agencies.

Information packages on diffuse source pollution and diffuse source pollution control for most counties in the Lake Erie drainage will be prepared. Tabular information relating the relative significance of the diffuse source loading derived from each county to the total loading to Lake Erie will be prepared. A variety of mapped products will be prepared to assist the county Soil and Water Conservation Districts and others in the long term implementation of diffuse source controls. The material provided will not require or suggest any short term mandatory control programs.

LEWMS, in cooperation with the Cooperative Extension Service, will undertake an education program throughout the basin, to include presentation of technical reports and documentation of the above mentioned information packages. In addition, seminars will be held with District conservationists, county extension agents, and others at the area level. These meetings are intended to inform the working level conservationists of the LRIS products available. The progress of the Honey Creek Demonstration Project will be reported to soil conservation professionals throughout the basin on a regular basis.

The Educational Program will distribute the Honey Creek Watershed Report and prepare technical assistance packages which may include the following types of information:

a. Maps indicating gross erosion rates

b. Maps which indicate the suitability for reduced tillage crop production systems throughout the county

c. Information on economic aspects of reduced tillage cropping management systems

d. Information on performance and execution of reduced tillage cropping management systems

In addition, LEWMS will work with county agents and local soil conservation agents to develop educational programs at the county level. This program might include demonstration plots, field days, educational meetings, individual farm visits, and development of information for local media.

VI. RECOMMENDED PROGRAM

After the above activities have been completed, their results will be integrated into a final recommended phosphorus load reduction program which will meet the phosphorus load objective for Lake Erie of 11,000 metric tons per year, required by the Great Lakes Water Quality Agreement of 1978. This program along with specific recommendations of the Chief of Engineers and recommendations for its financing, shall be submitted to the Congress for statutory approval.

CHAPTER EIGHT

CONCLUSIONS

This chapter presents conclusions reached by the Lake Erie Wastewater Management Study, based on activities conducted during Phase II of the study. Phase II of LEWMS has verified the estimates of pollutant loads made in Phase I. These loads have been used in mathematical models to estimate the effect of phosphorus load reductions on lake water quality. The effect of land type, land use, and hydrology on the export of nutrients from a watershed and their subsequent movement through the river system has been studied. Finally, land management options designed to reduce sediment export from the drainage basin have been analyzed and the costs evaluated.

The following conclusions, based on LEWMS Phase II activities, have been made.

PHASE I CONCLUSION THAT DIFFUSE SOURCE CONTROL IS NECESSARY IS STILL VALID.

If only municipal point sources with a flow greater than one million gallons per day are required to reach effluent phosphorus concentrations of one mg/l or 0.5 mg/l, it is estimated that diffuse sources of phosphorus must be reduced accordingly to 47 and 33 percent (4,500 and 3,200 MT/YR) respectively, to reach the loading objective of 11,000 metric tons per year. Inclusion of all point sources will change these reductions to 42 and 26 percent (4,100 and 2,500 MT/YR).

These diffuse source reductions are calculated for an average hydrologic year.

For the scenarios considered above, the anoxic area of the Central basin will be reduced by 90 percent but the western basin would still remain eutrophic.

THE BULK OF THE PHOSPHORUS FROM DIFFUSE SOURCES AND INLAND POINT SOURCES REACHES LAKE ERIE IN ASSOCIATION WITH SUSPENDED SEDIMENT TRANSPORTED DURING STORM EVENTS.

Tributary monitoring has shown that an average of 83 percent of the total phosphorus load from diffuse sources was sediment phosphorus for 1976 and 1977.

Soluble phosphorus from point sources is rapidly removed from the water column and subsequently transported as sediment phosphorus during high flow events.

The bulk of phosphorus from diffuse sources is attached to eroded soil particles, especially the clay fraction.

Most nonpoint source phosphorus is delivered to the lake during runoff events, particularly during the major late winter-early spring periods.

Dissolved orthophosphate derived from nonpoint sources and delivered to the lake during storm flows form a significant component of the orthophosphate loading to the open water of the lake. This fraction of the nonpoint phosphorus loading to the lake may not be significantly affected by farm management practices.

Through analysis of individual events, deposition and resuspension of point source phosphorus has been documented. However, changes in annual load resulting from removal of point source phosphorus have not been measured in agricultural river basins.

While some of the sediment phosphorus is directly delivered to the lake, a substantial portion reaches the lake through a series of deposition and resuspension events.

Delivery losses, i.e. long-term losses of sediment and associated phosphorus, occur along the main stem channels of the river. These losses occur when sediments settle behind dams and on flood plains.

Hydrologic modifications resulting from agricultural practices such as tile drainage, parallel tile outlet terraces, and reduced tillage will reduce peak flows which will reduce the transport of phosphorus to Lake Erie.

Analysis of individual storms indicate that control of sheet erosion will not increase channel erosion.

THE BIOLOGICAL AVAILABILITY OF SEDIMENT BOUND PHOSPHORUS VARIES CONSIDERABLY WITH FLOW AND BETWEEN RIVER BASINS.

Suspended sediments from the more urbanized tributary areas in Michigan and eastern Ohio and those from the high clay agricultural basins in western Ohio have the highest percentage of immediately and potentially available phosphorus.

Suspended sediments from New York tributaries were lowest in immediately and potentially available phosphorus.

The rate at which phosphorus becomes available appears to be more of a limiting factor in supply of phosphorus to algae than the total amount of potentially available sediment P.

Phosphorus control at inland point sources is much less effective in reducing bioavailable phosphorus loading into Lake Erie than phosphorus removal at point sources emptying into the lake.

The high total annual sediment load in Western basin rivers together with high bioavailable sediment phosphorus point to these rivers as large contributors of bioavailable sediment phosphorus. In addition, the discharge of these sediments into the shallow western basin of Lake Erie make their impact on algal production even more significant. In the Central and Eastern basins the contribution of sediment phosphorus to algal growth is diminished for two reasons: lower sediment loads and lower bioavailable sediment phosphorus, and shorter contact time between algae and sediment because of settling.

REDUCING GROSS EROSION WILL REDUCE PHOSPHORUS LOADS TO LAKE ERIE.

The actual phosphorus load reduction will depend upon the soils, phosphorus enrichment ratio, sediment delivery, and type of erosion occurring.

The reduction in delivered phosphorus resulting from a given decrease in potential gross erosion, although substantial, can only be estimated and appears to be between 60 and 90 percent.

NONPOINT SOURCE PHOSPHORUS IS DERIVED PRINCIPALLY FROM AGRICULTURAL LAND USE, PARTICULARLY CROP PRODUCTION.

A program to reduce the delivery of sediment phosphorus to the lake should be based on erosion reduction programs for agricultural lands.

Sheet erosion is the major source of the bioavailable sediment phosphorus delivered to Lake Erie. Consequently, erosion reduction programs must center on sheet erosion even though gully and stream bank erosion create severe land problems and are also deserving of attention.

ADOPTION OF CONSERVATION TILLAGE AND NO-TILL PRACTICES APPEARS TO BE AN ECONOMICALLY FEASIBLE METHOD OF REDUCING POTENTIAL EROSION IN THE LAKE ERIE BASIN.

Adoption of conservation tillage and no-till practices as estimated by the Universal Soil Loss Equation can potentially reduce gross erosion in the basin by 47 to 69 percent.

Conservation tillage and no tillage practices are feasible for the soils which generally have the highest erosion rates in the basin.

Conservation and no-till practices have the greatest potential for reducing phosphorus loadings from diffuse sources to Lake Erie and will be more easily accomplished and accepted than basin-wide attempts to change cover, land use, or crop rotations.

Conservation tillage and no-till practices, with their surface residue protection, provide erosion control during: (1) the high hazard erosion (soil detachment) season of May through September; and (2) during the high runoff periods of January to May.

A MAXIMUM RURAL DIFFUSE SOURCE TOTAL PHOSPHORUS LOADING REDUCTION OF 4,100 TO 5,100 MT/YR WILL RESULT IF THE MAXIMUM REDUCED TILLAGE SCENARIO IS ACHIEVED AND IF POTENTIAL GROSS EROSION REDUCTION IS 90 PERCENT EFFECTIVE IN REDUCING TOTAL PHOSPHORUS.

If this reduction is achieved, the phosphorus loading objective will be met if municipal point sources with flows greater than one million gallons per day reach an effluent phosphorus concentration of one mg/l.

A MAXIMUM RURAL DIFFUSE SOURCE TOTAL PHOSPHORUS LOADING REDUCTION OF 2,800 TO 3,400 MT/YR WILL RESULT IF THE CHISEL PLOW REDUCED TILLAGE SCENARIO IS ACHIEVED AND IF POTENTIAL GROSS EROSION IS 90 PERCENT EFFECTIVE IN REDUCING TOTAL PHOSPHORUS.

If this reduction is achieved, the phosphorus loading objective will be met if municipal point sources with flows greater than one million gallons per day reach an effluent phosphorus concentration of 0.5 mg/l.

TILLAGE PRACTICES OTHER THAN CONSERVATION TILLAGE AND NO-TILL WERE SHOWN BY UNIVERSAL SOIL LOSS EQUATION ANALYSIS TO BE UNABLE TO ACHIEVE SIGNIFICANT REDUCTIONS IN POTENTIAL GROSS EROSION.

There is no significant difference in potential gross erosion between existing conditions and the adoption of all plow, spring plow, or winter cover practices.

Although fall plow, spring plow, and winter cover appear to have little effect on potential gross erosion rates, the lack of winter cover due to fall plowing exposes soil during the high winter-spring sediment transport periods.

THE U.S.L.E. ANALYSIS SHOWS DIFFUSE SOURCE PHOSPHORUS LOAD OBJECTIVES WILL NOT BE MET EVEN IF ALL SOILS MEET SOIL LOSS TOLERANCE LEVELS.

Reducing all existing conditions soil losses presently exceeding tolerance soil loss limits to tolerable soil losses, reduces potential gross erosion 40 percent. If potential gross erosion reductions are 90 percent effective in reducing total phosphorus, the phosphorus loading reductions would only be 2,400 to 3,000 mt/yr.

IN ADDITION TO CONSERVATION TILLAGE AND NO-TILL PRACTICES, OTHER CONTROLS OF SEDIMENTS AND PHOSPHORUS MUST BE APPROPRIATELY APPLIED:

These controls may include animal waste runoff and disposal systems, gully erosion control via waterways and structures, and use of total farm conservation plans where needed.

Increased storm water infiltration and reduction of surface runoff through improved subsurface drainage system effectively reduce erosion and soil loss via storm runoff.

In many Lake Erie basin soils, plant available phosphorus is adequate to achieve maximum production. Therefore, phosphorus application rates could be reduced accordingly with no loss in production.

LONG-TERM WATER QUALITY MONITORING IS REQUIRED TO MEASURE REDUCTIONS IN SEDIMENT AND PHOSPHORUS TRANSPORT RESULTING FROM DIFFUSE SOURCE MANAGEMENT.

The diffuse source total phosphorus load to Lake Erie (excluding atmospheric and Lake Huron outflow) varied between about 6,000 and 11,700 metric tons per year between 1970 and 1977.

The annual variation in diffuse source phosphorus loads is as great as the reductions required and, therefore, long-term monitoring will be required to differentiate between year-to-year variations in load and any reduction which might be achieved by improvement management.

AN EDUCATION AND TECHNICAL ASSISTANCE PROGRAM IS NEEDED TO ACCELERATE THE ADOPTION OF CONSERVATION TILLAGE, NO-TILL, AND OTHER COST EFFECTIVE BEST-MANAGEMENT PRACTICES.

Adequate information, knowledge and technical assistance are the principal ingredients necessary for landowners and farm operators to adopt and apply conservation tillage systems and other Best Management Practices.

Cost shares or other financial and economic incentives along with demonstrations, may be needed to initiate wide-spread adoption of these BMPs. Some practices may be needed, but may not be cost-effective or economically feasible for the individual landowner or farm operator.

A demonstration program should be implemented in a specific watershed with special emphasis on educational and technical assistance programs. The results of the demonstrational watershed program should be assessed with regard to applicability to other areas in the Lake Erie drainage basin.

CRITERIA FOR SETTING PRIORITIES FOR TREATMENT OF CRITICAL AREAS ARE: POTENTIAL SOIL LOSS, PHOSPHORUS AVAILABILITY OF ERODED SOIL, AND COST EFFECTIVENESS OF REDUCED SYSTEMS AND OTHER APPLICABLE BEST MANAGEMENT TILLAGE PRACTICES.

The Land Resource Information System can be used to set priority problem areas on the county level. However, specific recommendations for BMPs will require assistance of the Soil and Water Conservation District.

THE ENVIRONMENTAL BENEFITS OF EROSION CONTROL EXTEND WELL BEYOND A REDUCTION IN PHOSPHORUS.

Other Lake Erie basin-wide benefits resulting from increased erosion control and sediment reductions include: reduced sedimentation and reduced dredging costs in Lake Erie harbors, lower water treatment costs for sediment removal from domestic water supplies, less movement and transport of other sediment-attached pollutants such as insecticides and herbicides, and reduced in-stream sedimentation which benefits the fishery resources.

CHAPTER NINE

RECOMMENDATIONS

I recommend that:

a. The LEWMS be continued into Phase III, the demonstrational phase.

b. A demonstrational watershed program be developed and implemented with primary emphasis on education and technical assistance being provided by the existing agricultural agencies.

c. A basin-wide education program, which stresses economics of conservation tillage systems, be developed and implemented in conjunction with the Cooperative Extension Service of each State. Necessary assistance to farmers interested in conservation tillage systems should be provided.

d. The Land Resource Information System (LRIS) be used, in conjunction with other supporting data, to identify and select priority basins within Lake Erie drainage area for specific problem identification and for development of special educational and technical assistance programs.

e. The Land Resource Information System be used to produce maps showing critical erosion areas and opportunities for implementing conservation tillage systems. Maps and other supporting data should be made available to the counties for use at the local level.

f. Best management practices be implemented in priority problem areas; that they be tailored to the local watershed conditions and needs, and that best management practices, which control erosion and reduce delivery of runoff water, be preferred over others.

g. Monitoring of water quality be continued to establish a long-term data base and that monitoring of land treatment activities and conservation tillage systems be initiated for at least cropland areas in problem watersheds.

Daniel D. Ludwig

DANIEL D. LUDWIG
Colonel, Corps of Engineers
District Engineer

GLOSSARY OF TERMS

adsorption - The taking up of one substance on the surface of another.

algae - Thallophytes, or rootless plant bodies, possessing chlorophyll, and so capable of photosynthesis.

anaerobic - Containing no dissolved oxygen.

anoxic - Anaerobic; depleted of oxygen.

baseflow - That part of streamflow contributed by groundwater seeping into surface streams.

best management practices - A practice, or combination of practices, that is determined by a State (or designated areawide planning agency) after problem assessment, examination of alternative practices, and appropriate public participation to be the most effective, practicable (including technological, economic, and institutional considerations) means of preventing or reducing the amount of pollution generated by nonpoint sources to a level compatible with water quality goals.

benthos - Organisms that live on or in the bottom of a body of water.

critical areas - Within a watershed, those areas contributing the largest amounts of sediment and nutrients to streamflow.

delivery ratio - A measure of the sediment actually reaching a stream or lake; equal to the quantity of material reaching a point in a stream divided by the quantity of material eroded above that point.

diffuse source - Any source which is not a point source. A nonpoint source.

drainage basin - An area delineated by a boundary within which runoff drains to a common outlet. A watershed. When used with reference to a lake, the area includes the surface area of tributary streams and lakes and their drainage basins, but not that of the receiving lake.

eutrophic - Richly supplied with plant nutrients and supporting heavy plant growth. Having high biological production and turbid waters with deeper waters depleted of oxygen at times during the year.

eutrophication - The enrichment of natural waters by nutrients, resulting in systematic changes in the quality of the waters.

event - A distinct period of high rainfall over a watershed or high streamflow during a storm.

flux - Mass per unit of time.

hypolimnion - The deep, cold, and relatively undisturbed region of a summer stratified lake.

institution - A process or organization which is structured, systematized, and stable. It may be a formalized practice such as a water rights law or a water use ordinance, or it may be a group such as a sanitary district, a Government, or a council of Governments.

interstitial water - Water occupying intervening space or crevices between soil or sediment particles.

lake basin - The entire area within the drainage boundaries of a lake, including tributaries and the lake itself. (e.g., the Lake Erie Basin.) Also, the depression which holds the lake water body. (e.g., Lake Erie's Central Basin.)

load - Flux. Mass per unit time.

mathematical model - A systematic, logical representation of physical, chemical, or other phenomena by mathematical expressions, which simulate the response of a real system to inputs or changes. Often programmed for computer analysis, hence the term "computer model."

mesotrophic - Intermediate in characteristics between oligotrophic and eutrophic; that is, having a moderate supply of plant nutrients, and moderate plant growth and biological production.

nonpoint source - Diffuse source.

nutrient - Organic or inorganic chemical necessary for the growth and reproduction of organisms.

oligotrophic - Poorly supplied with plant nutrients and supporting little plant growth; as a result, biological production is generally low, waters are clear and the deeper waters are well supplied with oxygen throughout the year.

phosphorus - Phosphorus in all its forms; total phosphorus reported as phosphorus.

point source - Effluent from a municipal or industrial outfall.

potential gross erosion - A measure of the potential for soil to be dislodged and moved from its place of origin; it is not necessarily the amount of soil which actually reaches a stream or lake.

Report - The Lake Erie Wastewater Management Study Preliminary Feasibility Study Main Report.

river basin - The drainage basin of a given river.

runoff - That portion of precipitation which drains overland to a receiving body of water with a free surface.

sediment phosphorus - The difference between total phosphorus and soluble orthophosphate concentrations measured in a sample of water.

Study - The Lake Erie Wastewater Management Study (Lake Erie Study). The current study, authorized by Section 108 of Public Law 92-500.

trophic level - Level of nutrient enrichment of a body of water.

watershed - Drainage basin.

water quality standard - A regulation or law specifying mandatory quantitative measures of the physical, chemical, bacteriological and sensible qualities of water.

wastewater - Water which carries the wastes of cultural processes or activities.

APPENDIX I

STUDY AUTHORIZATION

The Authority for the Lake Erie Wastewater Management Study is contained in Sections 108d and e of the Federal Water Pollution Control Act Amendments of 1972 (PL 92-500), which read as follows:

> "Sec. 108(d) (1) In recognition of the serious conditions which exist in Lake Erie, the Secretary of the Army, acting through the Chief of Engineers, is directed to design and develop a demonstration waste water management program for the rehabilitation and environmental repair of Lake Erie. Prior to the initiation of detailed engineering and design, the program, along with the specific recommendations of the Chief of Engineers, and recommendations for its financing, shall be submitted to the Congress for statutory approval. This authority is in addition to, and not in lieu of, other waste water studies aimed at eliminating pollution emanating from select sources around Lake Erie.
>
> "(2) This program is to be developed in cooperation with the Environmental Protection Agency, other interested departments, agencies, and instrumentalities of the Federal Government, and the States and their political subdivisions. This program shall set forth alternative systems for managing waste water on a regional basis and shall provide local and State governments with a range of choice as to the type of system to be used for the treatment of waste water. These alternative systems shall include both advanced waste treatment technology and land disposal systems including aerated treatment-spray irrigation technology and will also include provisions for the disposal of solid wastes, including sludge. Such a program should include measures to control point sources of pollution, area sources of pollution, including acid-mine drainage, urban runoff and rural runoff, and in place sources of pollution, including bottom lands, sludge banks, and polluted harbor dredgings.
>
> "(e) There is authorized to be appropriated $5,000,000 to carry out the provisions of subsection (d) of this section, which sum shall be available until expended."

APPENDIX II

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APPENDIX IV

BEST MANAGEMENT PRACTICES

I. GENERAL

Best Management Practices are those soil and water conservation practices or combination of practices, both cultural land management and structural measures, which provide for the best production and conservation protection on a particular parcel of land while also effectively serving to reduce sediment and phosphorus transport from diffuse sources of pollution. R. M. Davis, the Administrator of the USDA, Soil Conservation Service has said "What farmers and conservationists need are new, integrated farming systems, including recommendations for: capital requirements; machinery; fertilizer needs; weed, insect and disease control; suitable plant varieties; soil and water management; fuel needs; and tillage systems." In effect, Best Management Practices, when used in association with other crop management factors, are equivalent to "integrated farming systems." BMPs are an effective and practicable (including technological, economic, and institutional considerations) means of preventing and reducing the amount of pollution generated by nonpoint sources to a level compatible with water quality goals.

For purposes of the LEWMS, the list of BMPs are categorized according to their effect in the erosion process and in relation to the treatment of the land surface, erosion control, runoff collection and disposal, sediment retention, and other related nonpoint source control practices. The categories are:

a. Cultural and Land Management Practices

b. Runoff Collection and Disposal Practices

c. Sediment Retention and Trapping Practices

d. Other Related Practices

The following explanations and description of BMPs provides an insight to those practices which are known to be effective in diffuse control. The list of BMPs is not intended to be all inclusive nor is intended to exclude any specific BMP. Rather, the following categories and listed BMPs provides a perspective of those practices which are preferred and most likely to be accepted as effective practices for control of diffuse source loadings in the Lake Erie Basin.

II. CULTURAL AND LAND MANAGEMENT PRACTICES

The practices in this category deal principally with cultural and land management decisions made by the land owner, operator, or user. These decisions effect primarily the soil surface and its protection from the impact of falling raindrops. Included are decisions related to crop planning, crop planting, harvest and the management of crop residues.

a. Conservation Tillage - A form of noninversion tillage that retains protective amounts of residue mulch on the surface throughout the year (minimum of 1,000 pounds surface residue at planting time). Conservation tillage methods vary greatly. A few accepted methods are as follows:

(1) No Till - Planting the crop with a minimum of seedbed disturbance in the remaining residue of the previous crop. Seedbed is normally prepared by a coulter, single chisel, disk-opener or similar tool with the seed placement occurring at the same time.

(2) Minimum or Mulch Tillage - Maintaining a majority of the crop residues on the soil surface. Minimum tillage is accomplished by chisel, disk, rotary tillage, or other similar implement tools which maintain high percentage of residue on the surface. Seedbed preparation and planting may be either single or separate operations.

(3) Ridge Planting, Strip Tillage - Creating a ridge for seedbed preparation and planting with special equipment, however, residue surface protection is maintained. Special ridge planters and ridgers are available for these planting methods.

(4) Combinations of the above systems may also be utilized (e.g. - no till planting on ridges).

Suitability - Conservation tillage applies to those lands where crop residues or annual vegetation is available. Soil must be adequately drained either naturally or artificially to permit planting, crop growth, and harvesting.

Relative Water Quality Impact - Major benefits result from surface cover and protection against erosion caused by impact of falling raindrops. Reduced volume and velocity of runoff water due to increased infiltration and improved soil structure.

b. Winter Cover Crops (Crop Residue Use) - The growing of grasses, legumes, or small grains for seasonal soil surface protection and soil improvements, usually grown for one year or less. Existing plant residues (crop residue use) may also be maintained and used to provide this seasonal erosion protection. Cover crops are normally used for winter protection and crop residues are normally used for protection on cultivated fields during the erosion seasons, both may be used for summer and winter protection.

Suitability - Cover crops are suited primarily for cropland, however other land uses are applicable. Crop residue use is suited wherever adequate surface residue cover is produced.

Relative Water Quality Impacts - Controls erosion during periods of inadequate crop protection against raindrop impact. There are also benefits of moisture conservation, increased infiltration, less soil loss, improved soil structure, and reduced nutrient transport.

c. Conservation Cropping Systems (Rotations) - The growing of crops, or combination of crops, with needed cultural and management practices, in a system or rotation which provides adequate protection against soil erosion to maintain soil productivity. Small grains, grasses, and legumes may be included in these cropping systems or it may be a continuous cropping sequence such as continuous corn.

Suitability - Cropping systems and rotation all suited on all cropland. They help improve and maintain soil conditions and provide cultural control for weed, insect and disease problems. Other factors such as livestock demands, equipment limitations, market prices or other economic influences may dictate the crop(s) to be grown in rotation.

Relative Water Quality Impacts - Erosion is decreased and infiltration is increased during periods when row crops are not present.

d. Critical Area Planting - The planting of adequate vegetative cover such as grasses and legumes or other cover such as trees, shrubs and vines on high-sediment, critical erosion areas. Included are adequate seed bed preparation, proper species selection, necessary lime and fertilizer, and mulch cover protection to insure erosion control, seed germination, and plant growth.

Suitability - This practice applies to all highly eroding, sediment producing areas. Normally these are smaller isolated areas such as roadsides, cut and fill slopes, spoil areas and other eroding areas outside of cropland areas. Steep, highly eroded escarpments in cropland fields are also considered critical areas.

Relative Water Quality Benefits - Reduced erosion, sediment yield, and runoff to downstream areas are major benefits of this practice.

III. RUNOFF COLLECTION AND DISPOSAL PRACTICES

Runoff collection and disposal practices are those which collect and dispose of excessive runoff water at nonerosive velocities. Any time high amounts of water are allowed to accumulate and concentrate, the rate of flow increases tremendously and excessive soil erosion occurs unless adequate erosion protection is provided. Normally these concentrated flows result in deep hazardous gully erosion as opposed to sheet and rill erosion caused by the raindrop impact and diffuse overland surface flows. Practices in this category disperse and control surface runoff; collect and concentrate flows for safe, nonerosive runoff disposal; and provide protection against gully erosion where runoff flows concentrate.

a. Contour Farming (Stripcropping) - The conducting of all farming operations and tillage of sloping lands across slope and on the contour. Normally contour guidelines are established by contour strip boundaries, diversions, or terraces. Contour stripcropping incorporates the use of rotational strip fields on the contour. In stripcropping, there are alternate strips of row-crops with small grain or grasses/legumes hays. One hay or meadow strip must be present in every four contour strips.

Suitability - Contour farming is generally suited to sloping land where slope directions are uniform and degree of slope range from two to six percent. If slopes are too flat or irregular, contour farming and stripcropping are not normally feasible.

Relative Water Quality Impact - The practice of contour farming and stripcropping is highly effective in reducing soil erosion and water losses. Sediment runoff and nutrient transport are reduced. There is better control and utilization of water for all crops.

b. Terraces - A terrace is an earth embankment ridge and combination channel constructed across slope. They normally have a uniform spacing and planned grade. They are not vegetated and are normally cropped concurrently with the adjoining field.

Suitability - Terraces are normally limited to cropland with water erosion problems. Topography must be rather gentle and uniform. With excessive slopes, terraces cannot be cropped. Adequate outlets for disposal of excess water must be provided.

Relative Water Quality Impact - Terraces reduce runoff, erosion, and intercept excess surface runoff for diversion to adequately protected outlets. Sediment transport and delivery is reduced.

c. Diversions - Diversions are constructed across slope, vegetative channels with a supporting ridge on the downslope side.

Suitability - Diversions are applicable wherever excessive water can be diverted to protect downstream areas from erosion, excessive runoff, or wetness. They cannot be constructed on excessively steep slopes. Suitability of vegetation established on the ridge and channel is important.

Relative Water Quality Benefits - This practice helps reduce and control excessive runoff. It has an indirect benefit on erosion, sediment, and nutrient transport.

d. Parallel Tile Outlet Terraces - Parallel tile outlet terraces are a combination of practices where parallel terraces or across slope ridge-channel structures are used to intercept and divert excess runoff. A combination overflow/inlet structure to a subsurface tile outlet drainage system is used for controlled discharge of excess runoff.

Suitability - These structures are suited primarily to uniform cropland with excessive runoff disposal and erosion problems. Many times the tile outlet is used in conjunction with subsurface drainage systems.

Relative Water Quality Benefits - Control of runoff, temporary ponding, and detention of sediment-laiden runoff, and adequate disposal of excessive runoff are major benefits of parallel terrace outlets.

e. Grassed Waterways (or Outlet) - Grassed waterways are natural or constructed vegetative channels with uniform grade and channel cross section used to collect and dispose excess runoff at nonerosive velocities.

Suitability - Waterways are suitable to all land uses where excess runoff occurs or where gully erosion has occurred. They are often used as adequate outlets for terraces, diversions, and other natural concentrations of runoff. Suitability for the establishment of adequate vegetative channel protection is extremely critical.

Relative Water Quality Benefits - While waterways protect the channel bottom from erosion, their principal function is runoff disposal. There are some beneficial results from safe disposal of excess runoff and from the partial sediment trapping efficiency in the vegetative channel.

f. Outlet Protection Structures - Outlet protection structures are structures such as pipe drops, rock chutes, and other similar devices installed to control erosion, reduce head cutting, and to control excessive runoff.

Suitability - This practice applies to those situations where runoff surface flows concentrate such as overbank flows into ditches, tile outlets, small ditches flowing into larger streams, etc.

Relative Water Quality Impacts - Structures are essential water management practices in disposal of surface runoff. They make only a small contribution to improved water quality but have significant benefits relating to adequate and safe disposal of surface runoff. They reduce erosion and sediment where head cutting and gully erosion is a problem.

g. Subsurface Tile Drainage - Drainage through subsurface tile includes the subsurface installation of tile, pipes, or other types of tubing for the collection and disposal of drainage water within the upper soil profile. Tile drainage may include a random tile system for a specific problem area or a complete systematic tile system covering entire fields.

Suitability - Tile drainage is suited to all land uses and those soils with sufficient permeability and drainage characteristics to permit the removal of excessive high water tables from the soil profile.

Relative Water Quality Impact - Subsurface drainage has a positive effect where high water tables can be lowered and infiltration capacity of the surface soils improved. With greater infiltration, there is less runoff and rates of runoff can be decreased. Tile drainage may also improve soil suitability for other practices such as no till planting which is not feasible unless the soil has good drainage.

IV. SEDIMENT RETENTION AND TRAPPING PRACTICES

When the combination of land management and runoff disposal practices are inadequate, sediment and attached particulate phosphorus might be prevented from entering streams, rivers, and lakes through sediment retention and trapping practices. From an erosion and sediment transport standpoint, the use of sediment trapping practices is probably the last resort. Sediment retention and trapping practices function under the principle of slowing runoff waters (including ponding) to increase sediment deposition.

With controlled sediment deposition and trapping, phosphorus and other attached pollutants are prevented from entering streams, rivers, and lakes.

Sediment basins, ponds, impoundments, and vegetative filter strips are each effective in slowing runoff, and trapping sediment.

a. Sediment Basins - A sediment basin is a temporary barrier or dam constructed across a watercourse or at other suitable locations to trap and pond runoff, to retain sediment, and to catch other waterborne debris. The earthen embankment is normally well constructed to adequate design specification.

Suitability - Sediment basin applies to those site conditions which permit the location and construction of the practice. Normally it is used to trap sediments which are not or cannot be controlled by other practices. It is generally used most often in urban construction areas, but also has applicability in agricultural and surface mining areas.

Relative Water Quality Benefits - Control of finer grained sediment in storm runoff is a significant benefit. Often sediment basins trap sediments which would otherwise be flushed into streams and rivers. The greater the detention period of surface runoff waters within the ponded area, the higher the trap efficiency. In fact, trap efficiency is considered in design, shape, depth, and internal water movement through the sediment basin.

b. Ponds and Impoundments - Ponds or impoundments are water holding areas. An earthen embankment is constructed across a stream or natural drainage area. These are "embankment" ponds as opposed to "dugout" ponds which are created by excavation alone with no embankment. For the purpose of this discussion, only embankment ponds which detain or retain surface runoff waters are considered.

Suitability - Ponds are normally constructed for many purposes in many different places. However, in all cases, soil suitability for pond construction is very important. Likewise, the site condition and location in relation to the intended use is important. Adequate water supply, design and control of contributing drainage area is extremely crucial for a safe design.

Relative Water Quality Benefits - Major benefits to water quality are generally secondary benefits to the intended use. Depending on size, shape, depth, and detention time, ponds are also good sediment traps. Ponds also control volumes of runoff and reduce peak discharges.

c. Filter Strip (Vegetated) - A filter strip is a planned vegetative strip or area of plant growth. The primary purpose is to slow runoff and filter sediments, organic matter and other pollutants from surface flows.

Suitability - This practice is not restricted to one land use, but is applicable instead to any area where surface runoff water enters directly into a stream or watercourse. Normally, filter strips are used in cropland areas or animal waste disposal areas to filter flows before they enter a defined watercourse.

Relative Water Quality Impacts - Filter strips are quite effective in reducing pollutant loads from smaller diffuse source flows. They reduce sediment and other pollutants by filtration, infiltration, absorption, adsorption, decomposition and volatization. However, if the surface flow volumes and concentrations are too high for the width of the filter strip and the type of vegetation, the effectiveness is decreased tremendously.

V. OTHER PRACTICES

In addition to those practices discussed above, there are certain other practices which have a beneficial effect on water quality. These other practices must be considered essential BMPs to effectively control the broad cross section of difffuse source water quality problems. These practices relate to other types of problems and controls which cannot be reasonably classified in the other categories.

a. Waste Management Systems (WMS) - Waste Management Systems are planned systems to manage liquid and solid waste, including runoff from concentrated waste areas, with ultimate disposal in a manner which does not degrade air, soil and water resources, and which protects public health and safety. Generally applicable in rural agricultural areas, the systems are planned to preclude discharge of pollutants to surface or ground water, and where possible to recycle waste through soil and plants. There are many BMP component practices which may go into a complete WMS. Likewise, there are several other major considerations such as design, installation, operation, and maintenance of the component practices. The following are principle waste management structures used in WMS:

(1) Waste Storage Pond - A waste storage pond is an impoundment made by excavation or earth fill for temporary storage of animal or other agricultural waste. It is simply a holding area, eventual disposal of the waste is a part of the waste management system.

(2) Waste Storage Structure - This facility is a fabricated structure designed to temporarily hold animal or other agricultural waste. Like the waste storage pond, eventual waste disposal is part of the waste management system.

(3) Waste Treatment Lagoon - A waste treatment lagoon is an impoundment made by excavation or earth fill which depends upon biological treatment of animal or other agricultural waste.

Suitability - Waste management systems are suited for any situation where livestock animal wastes and other agricultural wastes are generated. The selection of components and practices of the WMS depends on site condition, soils, nature and source of wastes generated, preferred methods of waste handling, and eventual disposal techniques to be used.

Relative Water Quality Benefits - Water quality benefits are generally high for waste management systems. Collection, control, and disposition of livestock animal or other agricultural wastes have positive effects in reducing organic wastes, nutrient pollution, and other biological impacts on receiving streams, rivers, and lakes.

b. Windbreaks (Field or Farmstead and Feedlot) - Windbreaks are belts of trees and/or shrubs established in specific locations for the primary purpose of reducing the adverse effects of high winds. They may be used to protect fields from soil erosion by winds or to protect farmsteads and feedlots from wind damage.

Suitability - Windbreak protection and establishment of windbreaks is feasible any place where high prevailing winds are likely to cause damage either to fields or farmsteads. Selection of species, soil types, and specific location of windbreaks to prevailing winds are important considerations.

Relative Water Quality Benefits - The benefits of windbreaks may not be as high as some other BMP's, however, they do have significant benefits to control of wind erosion. In some areas of the Lake Erie Basin, soils have high susceptibility to wind erosion. Often times these wind erosion particles end up in the drainage ditches or road-side ditches. Control of wind erosion and subsequent transport of wind-eroded material is beneficial to water quality.

c. Streambank Protection - This practice is the protection of streambanks, lakes, estuaries, or excavated channels from the scour and erosion of soil particles caused by flowing waters or wave action. Methods of protection may include either vegetative or structural techniques, or a combination of both.

Suitability - Use of streambank protection practices is acceptable at any place where excessive bank or shore erosion is causing adverse effects relative to sedimentation, loss of lands, channel obstruction and meandering, or damage to structures or utilities such as roads, bridges, and homes.

Relative Water Quality Benefits - Streambank protection is another practice which is not generally considered to have high water quality benefits. This practice is however, a key element in the control of localized problems and assists in the safe managing and disposition of flowing waters.

VI. OTHER BMP CONSIDERATIONS

In addition to benefits and protection provided by BMPs as discussed above, it should be noted that these BMPs may offer many secondary benefits. Many of the practices discussed earlier, when used in conjunction with other practices, provide opportunities for wildlife enhancement. For example, vegetative filters and diversions may provide wildlife habitat cover. Used in conjunction with conservation cropping systems, adequate food would also be available. This type of example is true in numerous other combinations of practices.

Energy conservation is another significant secondary benefit. With reduced and no tillage systems, there are less horsepower and fuel requirements. Also, with windbreak protection around farmsteads, there could be considerable energy savings in domestic heating requirements.

Economic feasibilities and benefits are also hidden secondary benefits. All landowners and operators prefer to have the flexibility and option to select the cropping system or tillage methods which are demanded by market prices and soil conditions. Studies have proven that conservation tillage systems when used properly on suitable soils provides a net increase in farm income.

The flexibility to mix and match the many possible combinations of practices and still achieve the desired result is most likely the most significant hidden secondary benefit. No one set of practices is necessary if other combinations of practices can achieve the desired gross erosion reduction and eventual phosphorus load reductions in the Lake Erie Basin.