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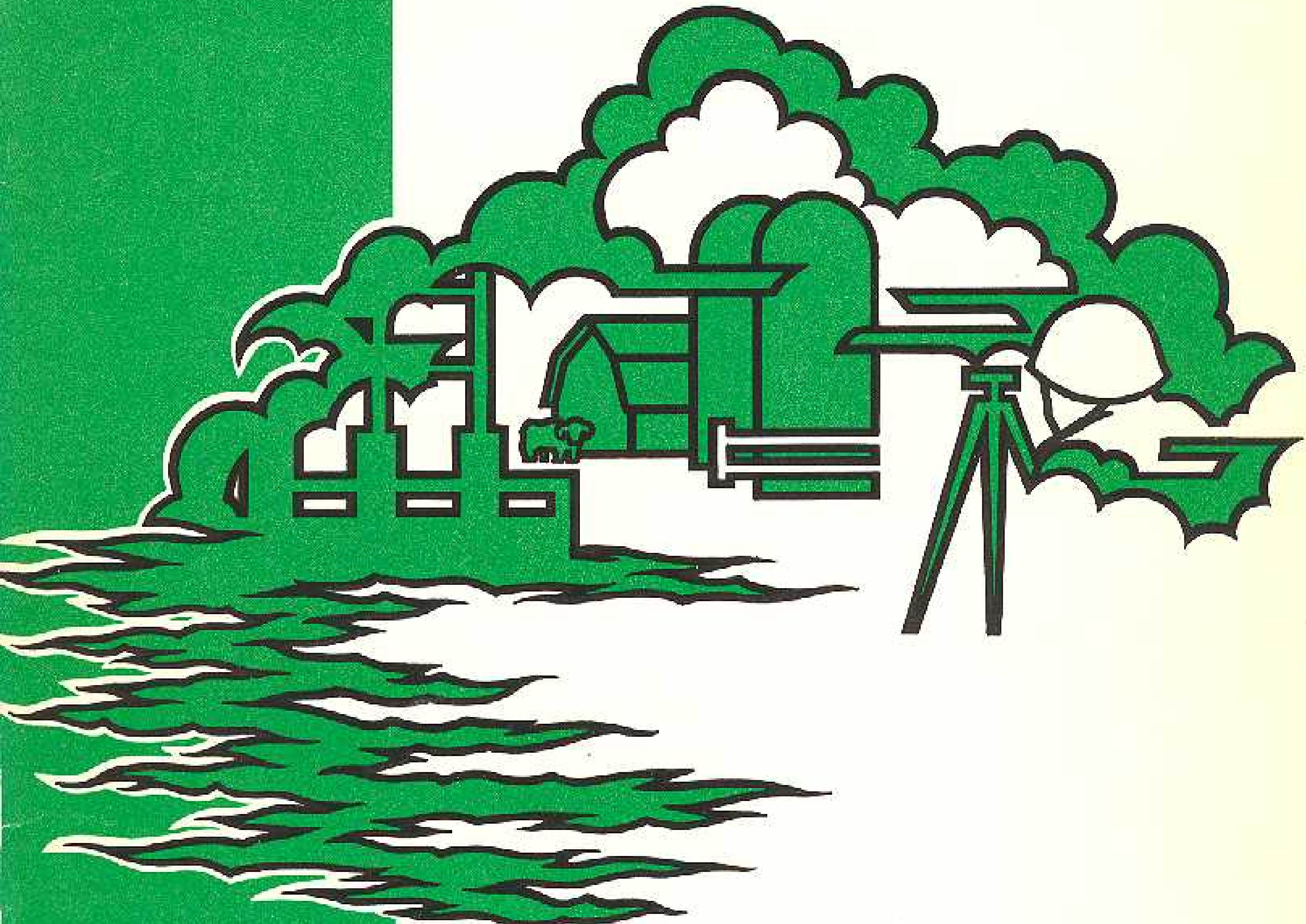
INTERNATIONAL REFERENCE GROUP ON GREAT LAKES POLLUTION FROM LAND USE ACTIVITIES



INTERNATIONAL
JOINT
COMMISSION

PILOT WATERSHED STUDIES SUMMARY REPORT

JUNE 1978

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SUMMARY REPORT

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DISCLAIMER

This report was prepared utilizing the Summary Pilot Watershed Reports for the Genesee (New York-Pennsylvania), Menomonee (Wisconsin), Maumee (Ohio-Indiana), Grand (Ontario) and Saugeen (Ontario) River Basins; the Summary Reports for the Agricultural Watersheds (Ontario) and Forested Watershed (Ontario); and the Streambank Erosion Study Reports (Canada and United States). Findings and conclusions are those of the authors and do not necessarily reflect the views of the Reference Group or its recommendations to the International Joint Commission.

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FOREWORD

In investigating the effects of land use activities on the boundary waters of the Great Lakes system for the International Joint Commission, the International Reference Group on Great Lakes Pollution from Land Use Activities (PLUARG) undertook intensive studies of land uses, characteristics and management practices in several representative watersheds in Canada and the United States. The objective was to relate inputs of contaminants to the Great Lakes to specific sources and management practices and to contribute to identifying practicable remedial measures, principles and factors which would aid in reducing pollution of the lakes.

The pilot watershed studies program, designated Task C, was one of four major tasks comprising the PLUARG investigative program. The results were combined with information on water and environmental conditions in the Great Lakes and tributary mouths, land uses and characteristics, and remedial measures in the preparation of the PLUARG Final Report. The watershed studies also provided much of the input for overview modelling, which was used to evaluate findings in relation to existing and projected land uses and integrate cost estimates for remedial measures.

Pilot watershed studies were undertaken in six major drainage basins in the Great Lakes basin, in eleven smaller agricultural watersheds in southern Ontario, in one forested watershed area in northern Ontario, west of the Lake Superior basin, and at a few other locations where specific sources of contaminants were evaluated. The pilot watersheds were selected to represent major land use activities, geology, and climatic conditions. Studies were undertaken to determine contaminants being produced from urban, agricultural, and forested land uses and special land-use activities such as orchards, private waste disposal systems, and spray irrigation of municipal sewage effluents. In addition, investigations into the effects of streambank erosion on water quality were conducted in each country.

Individual studies were undertaken by members of government agencies, universities and consulting firms, and guidance and co-ordination were arranged within the framework of the Task C Technical Committee. Field investigations commenced in 1974 and were intensified in 1975 and 1976, with many continuing into the spring of 1977. With strong co-operation from the analysts of participating laboratories and field staff, a quality control program was run to ensure that suitable data were produced from the different studies for comparison and extrapolation purposes.

The results of studies of particular land uses and management practices, and pollutant generation, transport and reaction processes are contained in detailed reports by individual investigators or groups of investigators. They are published in either the PLUARG technical report series or as reports of the funding agencies. Combined, they provide a wealth of information on diffuse sources of pollutants and the processes affecting them.

To strengthen co-ordination and provide a means for reviewing the major results from the watershed studies, Task C established a Synthesis and Extrapolation Work Group (SEWG) in 1976. In June, SEWG held its first meeting and then, in concert with the River Basin Studies Co-ordinator, set out on a series of meetings with pilot watershed investigators. Through their efforts, agreement was reached on the general format for the summary pilot watershed reports published by PLUARG.

The members of the Synthesis and Extrapolation Work Group, supported by the efforts of several investigators who accepted the task of integrating results on agricultural sources of pollutants, prepared this Task C Summary Report. It highlights the findings, shows the range of effects and causes of variations in pollutant loadings, and provides maps showing the results of extrapolation of loading information for suspended sediment, total phosphorus, and total nitrogen contributed by agricultural and urban land uses. In the report, they describe other contaminants such as organic toxicants, metals, and micro-organisms and go on to present principles, factors and practices needed in considering and implementing remedial and preventative measures to reduce diffuse sources of pollutants. Unit area loadings derived for the major land uses and an evaluation of the factors which influence these loads were used in developing the priority management concept discussed in the PLUARG Final Report.

We express our appreciation to all of the investigators, analysts, and field staff, the members of the Task C Technical Committee and Ad Hoc groups, and to the members of SEWG and the River Basin Studies Co-ordinator, the joint authors of this report, for the important contributions made by them to PLUARG results from the pilot watershed studies.

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SUMMARY

One of the four principal tasks of PLUARG, Task C was to determine the characteristics and locations of diffuse sources of pollutants in the Great Lakes Basin, and to assess their relative significance. A further objective was to quantify the processes involved in transmission of pollutants from these sources to the boundary waters. The Technical Committee appointed by PLUARG to meet Task C objectives planned and supervised eight "pilot watershed" programs each of which included intensive water quality monitoring and a great variety of source evaluation and process studies. The Task C report incorporates major findings of these studies and is structured to provide: a) a description of land uses in the pilot watersheds and in the Great Lakes Basin, b) a rationale for the choice of parameters receiving greatest emphasis, c) an evaluation of unit area loadings for individual land uses in the pilot watersheds, d) an extrapolation of unit area loads to the watersheds of each lake, e) a ranking of hazardous land uses for different parameters, f) a discussion of information and factors useful in designing alternative remedial strategies and g) future research, monitoring and demonstration needs.

The pilot watersheds were selected to represent the variety of physiographic features and land uses represented in the Basin. Urban areas were intensively studied in the Grand River watershed of southwestern Ontario and the Menomonee watershed in Wisconsin. These watersheds along with the Genesee (New York), Maumee (Ohio), Felton-Herron and Mill Creeks (Michigan) and the Saugeen (Ontario) provided results from a variety of agricultural soils and management practices. Additional detailed information on agricultural sources was obtained from 11 small agricultural subwatersheds selected to represent major agricultural regions in southwestern Ontario. Forestry practices and forested land were assessed in small watersheds in the Kenora district of Ontario.

Additional special studies were carried out by Task C investigators and provided information on private waste disposal systems, sanitary landfills, stream-bank erosion and other diffuse sources of pollutants.

A wide range of potential pollutants was monitored in various Task C studies but not all of these are reported on here. Lake scientists (Task D) developed a list of significant pollutants from diffuse sources which included organic toxicants, metals and microorganisms among those of public health significance, and phosphorus which contributes to algal growth and therefore has aesthetic significance to the lakes. The transmission of each of these to the lakes was examined in Task C projects and many (especially phosphorus, metals and some pesticides) were found to be carried by or largely associated with suspended sediments. For this reason but also because of its deleterious effects on near-shore water quality, suspended sediment received considerable attention from Task C.

A general observation made throughout this work was that physiographic factors were in many cases as significant as land use in determining the quantity of pollutants in runoff. For example, a major determinant of sediment loadings (and the loadings of sediment-related pollutants) in any tributary is the percentage of clay in the soils of the watershed. Coarse-textured (sandy) soils yield very low loadings of sediment regardless of land use while fine-textured (clay) soils yield appreciable levels of sediment even under low-yielding land uses such as pasture or forest. For this reason, there are very wide ranges in the "unit-area-load" (the calculated amount of pollutant entering the lakes from each hectare) for the various land uses. However, it was found that the unit-area-loads of intensive agricultural activities and urban land uses are approximately equal (i.e. of the same order of magnitude) for suspended sediment, phosphorus and copper. The unit-area loads from both land-use categories are one or two orders of magnitude greater than forested and/or idle land. These latter loads can be considered to be the minimum to which pollutant-level reduction can be realistically lowered with the application of remedial measures. Urban inputs of chloride and lead are an order of magnitude greater than the upper range for general agriculture and cropland. Livestock were found to contribute phosphorus to the Great Lakes but inputs from this source probably total less than 20% of agricultural land use inputs.

Almost all tributary samples contained PCB which presumably was derived from atmospheric fall-out. DDT and some of its derivatives were recorded frequently in tributary samples draining areas where these insecticides were intensively used in the past. Other pesticides were only found infrequently and in low concentration except when careless handling resulted in spills. An exception was atrazine, a herbicide used extensively in corn cultivation. This chemical was detected in a large proportion of samples from tributaries draining corn-growing areas throughout the basin.

Task C data were combined with physiographic data from the pilot watersheds to develop correlations for extrapolation to unmonitored areas of the basin. The objective was to locate areas of land use or land use/land form combination with the greatest hazard potential for each pollutant of interest to PLUARG. A series of basin maps appear in the Task C report and show, for pollutants such as phosphorus, sediment and lead, the areas expected to yield high, medium or low unit area loads. For example, the northwestern Ohio region making up most of the Maumee River basin and the southwestern Ontario region draining directly into Lake St. Clair are the primary high loading areas for sediments and phosphorus of agricultural origin. Predominantly urban areas such as Chicago, Cleveland, Detroit and Toronto and their suburbs are high loading areas for sediment of urban origin. Certain agricultural areas of medium hazard when combined with local urban development produce areas of high hazard. Examples are the area around Toledo, Ohio and the Hamilton-St. Catharines area of Ontario.

Task C has made some specific recommendations for reducing pollutant loadings to the Lakes; details will be found in the report. However, several important considerations have arisen from findings and subsequent discussions within Task C that relate to how remedial measures should be approached. These considerations are as follows:

1. Dispersed pollution does not arise uniformly from watersheds in the Great Lakes Basin. Close examination of pilot watershed information on forms, amounts and concentrations of pollutants demonstrates, in some cases, definable source areas. The source areas may represent only a small portion of the total land area of the pilot watersheds and the same is probably true for the Great Lakes Basin as a whole. This finding, supported by unit area loading data, points to two principles that relate to implementing remedial measures when constrained by finite financial resources:

   A. Installation or implementation of remedial or preventative measures to control diffuse pollutional sources should be aimed at those source areas in which the pollutant is generally at its highest concentration.

   B Remedial measures may not be required for large areas of land.

2. Deterioration of the Great Lakes through additions of persistent contaminants, although reversible in the long term, may be more serious than the aesthetic or eutrophication impacts because: (a) the lakes will require longer periods of time to clean themselves and (b) small amounts of some toxic agents introduced infrequently can create long-term problems. Thus, the nature of the pollutant should be an important factor in ranking hazardous areas and dictating the degree of treatment required for remedial measures.

3. An implementation program of remedial measures must be tailored to meet the unique features of the watershed in which they are placed to ensure long-term public acceptance.

1. INTRODUCTION

Concern for the effects of various land use activities on Great Lakes water quality prompted the governments of the United States and Canada -under the Great Lakes Water Quality Agreement of April 15, 1972 - to direct the International Joint Commission (IJC) to conduct studies of the impact of land use activities on the water quality of the Great Lakes and to recommend remedial measures for maintaining or improving Great Lakes water quality.

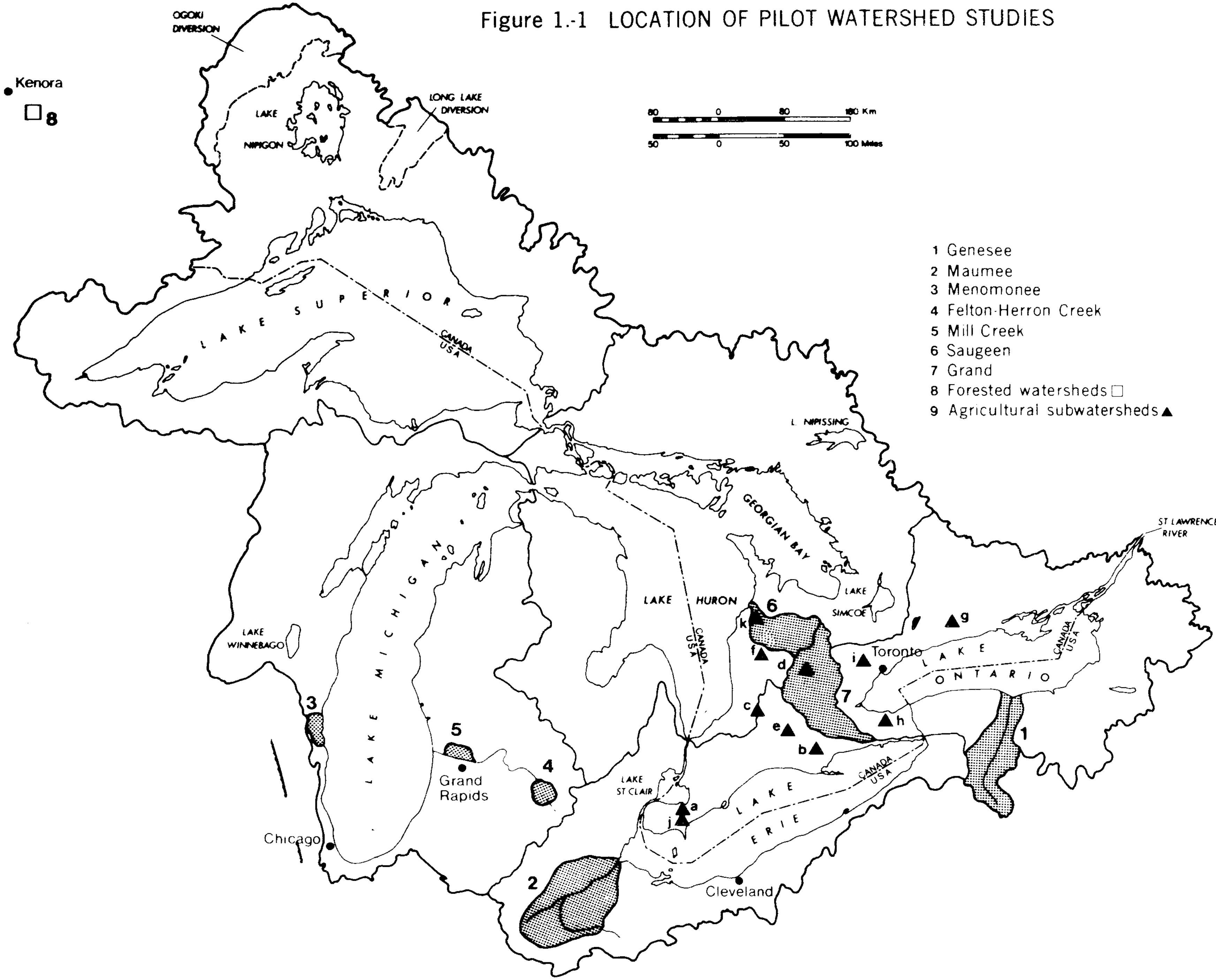
To effect this undertaking, the IJC established the International Reference Group on Great Lakes Pollution from Land Use Activities (PLUARG). The Reference Group developed a program which consisted of four major tasks. Task A was devoted to the collection and evaluation of management and research information and in its later stages to an assessment of the implications of remedial management strategies. Task B prepared a land use inventory largely from existing data, and, also, an analysis of trends in land use patterns and practices. Task C studied selected watersheds to determine the sources of pollutants, their relative significance and an assessment of the degree of transmission of pollutants to boundary waters. Task D was devoted to obtaining supplementary information on the impacts of pollutants reaching the boundary waters, their effect on water quality and their significance in the future.

The Task C portion of the PLUARG "Detailed Study Plan" prepared in 1974 included an intensive investigation of watersheds in Canada and the United States (see Figure 1.-1 for locations) which are representative of a full range of urban and rural land uses found in the Great Lakes Basin. A Task C Technical Committee was established by PLUARG and assigned primary responsibility for developing and conducting the pilot watershed studies. A Synthesis and Extrapolation Work Group was established by Task C to develop this summary report, using the reports covering the pilot watershed studies.

1.1 REPORT FORMAT

The Task C Summary Report is structured to provide: a) a description of land uses in the Pilot Watersheds and in the Great Lakes Basin, b) a rationale for the choice of parameters receiving greatest emphasis in the studies, c) an evaluation of unit area loadings for individual land uses in the pilot watersheds, d) an extrapolation of unit area loads to the watersheds of each lake, e) a ranking of hazardous land uses for different parameters, f) a discussion of informational needs to design alternative remedial strategies and g) future research, monitoring and demonstration needs.

Figure 1.-1 LOCATION OF PILOT WATERSHED STUDIES



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1.2 DESCRIPTION OF PILOT WATERSHEDS

The eight pilot watershed studies (Summary Reports for each watershed are available as part of the PLUARG Technical Report Series) and the rationale for their choice are listed briefly below.

1.2.1 Genesee River Watershed

The Genesee River watershed encompasses an area of 617,456 hectares in central New York and 24,864 hectares in north-central Pennsylvania. The Genesee River rises in Pennsylvania and flows north to Rochester, New York, where it discharges to Lake Ontario. The current watershed population of about 485,000 is concentrated along the main stem of the river and near Lake Ontario at the City of Rochester. The watershed south of suburban Rochester is, for the most part, sparsely populated and consists primarily of agricultural lands with some forested areas. Although the agriculture is predominantly dairy farming, extensive areas of truck and row crops exist. Corn is the major crop while oats, wheat and barley combined occupy about the same acreage as corn. Physiographically, the watershed consists of three terraces separated by northward facing escarpments. Glacial till predominates except in the narrow lake plain within the City of Rochester which consists of lacustrine silt and clay deposits. The watershed soils range from well to moderately well drained to poorly drained. The average discharge from the watershed is 76 m^3/sec and the river flow is carefully regulated by a series of dams in and near the City of Rochester. The watershed has a humid climate with mild summers and cold winters; average annual temperature is 10°C in the lower portion of the watershed and 7°C in the higher elevations. Average annual precipitation is 86 cm, decreasing from a high of 107 cm in the upper reaches of the watershed to 71 cm in the lower portion of the basin. The Genesee River watershed served as the focus of investigations on the impact of diverse land uses on water quality.

1.2.2 Menomonee River Watershed

The Menomonee River watershed comprises an area of 35,483 hectares in the southeast corner of Wisconsin. The Menomonee River and its tributaries flow in an easterly direction and the river discharges to Lake Michigan at the City of Milwaukee. This highly urbanized watershed encompasses all or parts of four counties, 17 cities, villages and towns and currently contains a population of about 336,800, with 97 percent concentrated in the lower three quarters of the watershed. Existing land uses range from an intensely developed commercial-industrial complex in the lower quarter of the watershed to low to medium density residential areas in the center half, while the upper quarter is in the process of conversion from rural to urban land uses. The irregular topography of the watershed was determined largely by the underlying bedrock and the overlying heterogeneous glacial deposits. Dominant soil types tend to be of silt loam texture and are poorly drained. The long term average discharge from the watershed is 2.3 m^3/sec but flood flows as high as 380 m^3/sec have been recorded. The watershed has a humid climate with mild summers and cold winters. The average annual temperature is 10°C with monthly means ranging from -7°C in January to 22°C in July. Average annual precipitation is 74 cm (107 cm snow). The Menomonee River watershed served as the focus of investigations on the impact of urban land uses on water quality.

1.2.3 Felton-Herron and Mill Creek Subwatersheds

The Felton-Herron subwatershed is a small drainage area (less than 100 hectares) that lies almost entirely within the boundaries of the campus of Michigan State University in southcentral Michigan. The subwatershed is tributary to the Red Cedar River which flows into the Grand River a few miles downstream from the City of East Lansing. The Grand River flows in a westerly direction and discharges to Lake Michigan at Grand Haven. Topographically, the subwatershed is moderately rolling and the area includes a complex variety of soil types ranging from sand and gravel to heavy clays and muck soils. The land was partially under cultivation until approximately 10 years ago. Since that time, much of the land has reverted to old-field succession with the exception of 12 hectares of cultivated plots presently serving as a hydrological evaluation of spray irrigation of sewage effluent. The subwatershed has a humid climate with mild summers and cold winters. The annual average temperature is 9°C with monthly means ranging from -5°C in January to 22°C in July. Average annual precipitation is 77 cm (130 cm snow). In many ways, the area that was developed for spray irrigation is a microcosm of the drainage basin of the Great Lakes and as such served aptly as a representative environment for prediction and extrapolation for the short and long term.

The Mill Creek subwatershed is located within the well-known "Peach Ridge" fruit farming area in Kent County of southwest lower Michigan. The subwatershed encompasses an area of approximately 5,570 hectares of which the upper 3,058 hectares are under investigation. About 50% of the subwatershed is in corn, 30% in fruit orchards, 10% in pasture or alfalfa, and the remaining 10% in woodlots or wetlands. Mill Creek flows through approximately 20 orchards for 16 km before its confluence with the Grand River. The orchards are of various sizes and employ a variety of cultural practices for production of crops such as apples, peaches, pears, cherries and grapes. The subwatershed has a rolling topography of low relief which has been determined largely by the underlying bedrock and the overlying heterogeneous glacial deposits. Dominant soil types tend to be of sandy loam texture and are moderately to well-drained. The subwatershed has a humid climate with mild summers and cold winters. The average annual temperature is 9°C with monthly means ranging from -5°C in January to 22°C in July. Average annual precipitation is 81 cm (157 cm snow). The Mill Creek subwatershed served as the focus of investigations on the impact of intensive use of insecticides, herbicides and fertilizers under different practices within a single land use.

1.2.4 Maumee River Watershed

The Maumee River watershed contains approximately 1,639,500 hectares, of which 19.1% are in northeastern Indiana, 73.7% are in northwestern Ohio, and 7.2% are in southern Michigan. The Maumee River is formed at

Fort Wayne, Indiana, by the confluence of the St. Joseph and St. Marys Rivers. The Maumee River flows in a northeastward direction to Toledo, Ohio, where it discharges to the Maumee Bay of Lake Erie. The population of the watershed is approximately 1,400,000 with the majority residing in Toledo, Ohio, and Fort Wayne, Indiana. The watershed is primarily agricultural, with more than 90 percent of the land in agricultural use. The principal crops grown are corn, soybeans, wheat and oats, with some sugar beets. There are also significant acreages of vegetable crops and nursery stock. Sales from livestock and livestock products account for about one-fourth of the farm income. Physiographically, the Maumee River watershed is almost a level plain that represents a portion of the abandoned floor of glacial Lake Maumee which occupied the Lake Erie Basin in late Pleistocene Time. The soils, which have predominantly silty clay loam texture in the surface horizon with clay sub-soils are very poorly to moderately well drained. These soils have been brought into production through one of the most intensive farm drainage systems in the nation. The watershed has a humid climate with mild summers and cold winters; average annual temperature is about 10°C with monthly means ranging from -3°C in January to 22°C in July. The average annual precipitation is 84 cm (61 cm snow). The average discharge from the watershed is about 142 m^3/sec but flood flows as high as 2,630 m^3/sec have been recorded. The Maumee River watershed served as the focus of investigations on the impact of agricultural land uses on water quality.

1.2.5 Grand River Watershed

The Grand River watershed is the largest watershed in southwestern Ontario, draining an area of approximately 667,200 hectares. The Grand River rises in a massive swampy upland south of Georgian Bay and runs a southerly course of 290 km to Lake Erie at Port Maitland. The Nith, Conestogo and Speed Rivers are the three major tributaries which join the main stem in the middle portion of the watershed. The Conestogo River drains the northwestern portion of the watershed with the Nith and Speed Rivers draining the western and eastern portion, respectively. The watershed can be divided into an upper part where the Grand River and its three main branches flow, for the most part, in previously formed glacial spillway channels. In the lower part, below the City of Brantford, the river has scoured its own channel across glacial lake deposits of silt and clay. The Grand River watershed has been developed extensively for urban and agricultural uses which, respectively, comprise three and 75 percent of the total watershed area. The principal crops are corn and small grains with additional land used for forage and pasture. Approximately, 19 percent of the watershed area is wooded and/or idle and the remaining three percent is in other uses. The watershed population of 514,000 is primarily concentrated in the central portion of the watershed in the Kitchener-Cambridge area and within the cities of Guelph and Brantford. The topography of the watershed is primarily determined by the underlying bedrock and overlying heterogeneous glacial deposits and ranges from an irregular surface of till plains and moraines in the upper part to a near-level lake plain in the lower part. Dominant soil types range from sandy soils in the upper part to silty clay loams in the lower region of the watershed. Climatically, the average annual temperatures vary from 6°C in the headwaters to 9°C at Lake Erie. Long term average annual precipitation varies from 84 cm (178 cm snow) in the lower reaches to 88 cm (127 cm snow) in the upper reaches of the watershed. Average annual flow at the outlet of the river is estimated to be 64 m^3/sec with peak discharges ranging from 500 to 1,400 m^3/sec. The Grand River watershed served as the focus of investigations on the impact of agricultural and urban land uses on water quality.

1.2.6 Saugeen River Watershed

The Saugeen River originates in a swampy upland south of Georgian Bay and runs a northwesterly course of 184 km to Lake Huron at Southampton, Ontario. Four major tributaries - the North Saugeen, the Rocky Saugeen, the South Saugeen and the Teeswater Rivers and numerous smaller streams - feed the main channel. The total drainage area of the watershed is approximately 397,900 hectares. The headwater areas of the Saugeen River are shared with the Grand River, the divide between them being somewhat indistinct, often consisting of a sprawling swamp from which drainage occurs in two directions. The upper stream reaches consist of rough and rocky land with large areas of swamp and non-productive woodlands. Cleared areas in the headwaters are primarily used for permanent pasture. The soil is loamy or gravelly. The topography of the watershed is primarily due to glaciation and ranges from an irregular rolling surface of terraces and moraines in the upper and middle parts to a near level plain in the lower section. Land use in the Saugeen River watershed is predominantly agricultural (64 percent) with large areas of the basin in permanent pasture. Intensive livestock and poultry operations and a wide variety of crops are also found in the area. Much of the land, particularly in the headwater areas, is swamp or unproductive woodland (33 percent). Urban development is restricted to a few small communities. The total population of the watershed is about 57,280 of which 28,880 are concentrated in towns and villages. The average annual temperature is approximately 6°C. Average annual precipitation varies from 84 cm to 101 cm across the watershed. Average annual flow of the Saugeen River is approximately 56 m^3/sec with peak discharges ranging from 300 to 850 m^3/sec. The Saugeen River watershed served as the focus of investigations on the impact of agricultural uses on water quality.

1.2.7 Forested Watersheds

The Forested Watershed studies were undertaken in twelve small watersheds of 35 to 1,250 hectares within the headwaters of the English and Winnipeg Rivers systems about 55 km southeast of Kenora, Ontario. Although this study was not conducted within the Great Lakes Basin, it is the only study available in Ontario dealing with any aspect of forest management practices and their effect on water quality and quantity. The study concentrated on the impact of clearcutting and scarification. The topography of the study area is aligned in an approximately east-west direction in conformity with the major fracture system of the bedrock. The magnitude of relief is about 76 meters. Glacial-fluvial deposits occur occasionally in some valleys, and are found locally on hill flanks and crests. The soil parent material appears to be derived entirely from granitic rock. Its texture is dominantly sandy loam, but it contains highly variable components of gravel and cobbles. Some outwash and deltaic deposits of fine sand are present. The soils are generally thin and subject to rapid leaching. The average annual temperature is 2°C ranging from -17°C in January to 19°C in July. Average annual precipitation is 67 cm (200 cm snow).

1.2.8 Agricultural Watersheds

The Agricultural Watersheds studies consisted of monitoring 11 small (1,860 - 7,913 ha) agricultural subwatersheds selected to represent major agricultural regions in southern Ontario. In six of the subwatersheds, a number of detailed studies were conducted. Table 1.1-1 contains information about each area. For all subwatersheds, the study program consisted of monitoring precipitation, stream flow quantity and quality and preparing an inventory of land use practices. As part of the detailed study, precipitation quality was determined and a detailed soil survey was made of the six subwatersheds. In addition, these sites were the focus of investigations on the sources, nature and enrichment of sediments, and on the effects of soils, crops, livestock, surface hydrology and groundwater movement on concentrations, loading rates and delivery of selected pollutants from agricultural areas.

Table 1.1-1 CANADIAN REPRESENTATIVE AGRICULTURAL SUBWATERSHEDS

Watershed	River Basin	Area, ha	Surficial Geology	Average Annual Precipitation, cm	Average Temperature, °C January	July	Growing Degree Days Above 6°C	Major Crops	Major Livestock
1(a)*	Thames River	5,080	Lacustrine clay over till plain over limestone bedrock	76	-4	23	4,200	Corn, soybeans	None
2(b)	Big Creek	7,913	Deep level deltaic sands	89	-4	21	3,600	Tobacco, rye	None
3(c)*	Ausable River	5,645	Level clay till plain over shale	94	-6	20	3,500	Corn, small grains	Dairy, beef
4(d)*	Grand River	1,860	Silty clay ground moraine	91	-7	19	3,000	Corn, small grains	Dairy
5(e)*	Middle Thames River	3,000	Clacareous loamy till	86	-6	21	3,400	Corn, small grains	Dairy
6(f)	Maitland River	5,472	Drumlinized loam till	99	-7	19	2,900	Mixed grains, corn	Dairy, beef, hogs
7(g)	Shelter Valley Creek	6,200	Wind blown sand and silt on sloping sandy calcareous till	79	-7	21	3,500	Pasture, corn	Beef, beef feeders
10(h)*	Twenty Mile Creek	3,025	Lacustrine and reworked clay over dolomite	79	-4	22	3,750	Hay, pasture	Hogs, poultry
11(i)	Humber River	2,383	Stratified clay over shale and limestone till	79	-7	20	3,300	Hay, mixed grain	Dairy, beef
13(j)*	Hillman Creek	1,990	Shallow moraine sand over clay till plain over limestone bedrock	76	-3	23	4,300	Vegetables, orchard, corn, soybeans	None
14(k)	Saugeen River	4,504	Reworked lacustrine clay over clay till	89	-6	19	3,100	Pasture, hay	Beef feeders, dairy

*Subwatersheds in which detailed studies were conducted. (a-k) Map locations of subwatershed on Figure 1.-1.

2. SOURCES, FORMS AND AMOUNTS OF POLLUTANTS REACHING THE GREAT LAKES FROM PILOT WATERSHEDS

The data in this section were obtained in the pilot watershed studies. Annual total loads and annual unit area loads for rural and urban land uses are compared between pilot watershed areas and the relative importance of particular land uses as contributors to Great Lakes pollution are evaluated.

2.1 LAND USE CATEGORIES

This section of the report indicates the land use activities included in the Task C pilot watershed studies, defines the broad land use categories considered in this Report, and summarizes under these categories the land use activities in the Great Lakes Basin.

2.1.1 Land Use Activities In Pilot Watersheds

The sites for the eight pilot watershed studies conducted under Task C were selected because collectively they represented the range of land use activities found in the Great Lakes Basin. Each study defined the predominant land uses to be considered in a watershed, but the descriptors used by the several investigators were not always identical or directly comparable. Table 2.1-1 indicates the land use activities included in each of the pilot watershed studies and shows the area of that land use and its percentage of the watershed area.

The results of the Task C studies indicate that the contributions of pollution from land uses in the Great Lakes Basin are generally related to the intensity of the activities that are taking place on the land. For the purposes of this report, the land use activities included in the pilot watershed studies were collected under broader land use categories to reflect this intensity. These land use categories are defined as follows:

RURAL LAND USE CATEGORIES

AGRICULTURAL LAND

GENERAL AGRICULTURE--a broad land use category that encompasses all of the rural land use categories including agricultural and non-agricultural rural land uses.

CROPLAND--land used for the production of annual crops and for orchards and vineyards. It includes row crops such as corn, tobacco and vegetables, and close grown crops such as wheat, oats and other grains.

TABLE 2.1-1 LAND USE ACTIVITIES IN PILOT WATERSHED STUDIES
Land Use Areas in 1000 ha Units and Percentages of Each Watershed

	Genesee		Menomonee		Felton-Herron*		Mill Creek		Maumee		Grand		Saugeen		Forest**		Agriculture***	
Land use activities	area	%	area	%	area	%	area	%	area	%	area	%	area	%	area	%	area	range (%)
Rural																		
Agricultural																		
General Agricultural											504.0	75.0	228.0	64.0				53-98
Cropland	284.5	44.7			+													22-91
Row crops			4.8	13.6			1.3	45.0	923.0	56.3								10-60
Close grown crops			4.3	12.1					146.8	9.0								9-29
Orchards							1.3	45.0										0-4
Improved pasture	26.7	4.2	5.7	16.1	+				265.5	16.2								0-67
Spray irrigation					+						0.1	<1.0	<.1	<1.0				
Sludge disposal											5.1	<1.0	0.1	<1.0				
Forest/Woodland	215.1	33.8	2.0	5.6	+		0.2	5.0	166.8	10.2	127.0	19.0	131.0	33.0	**	100.0		4-37
Other																		
Water	4.5	0.7	0.2	0.5					13.1	0.8								
Wetlands	26.1	4.1	1.1	3.0			0.2	5.0	2.0	0.1								
Recreation	9.6	1.5																
Transportation											11.3	1.7	6.8	1.7				
Sanitary landfills			0.1	0.3							0.5	<1.0	0.2	<1.0				
Extractive											0.1	<1.0	<.1	<1.0				
Feedlots			<.1	<.1													+	
Private Waste Disposal											+		+					
Misc.	15.3	2.4																
Urban																		
General Urban											20.0	3.0	4.0	1.0				
Developed																		
Residential	38.2	6.0							112.9	6.9								
High			0.4	1.2														
Medium			4.5	12.7														
Low			4.2	11.8														
Commercial	} 16.5	2.6	6.5	18.5					9.4	0.6								
Industrial			0.6	1.7														
Undeveloped																		
Developing			0.7	2.0														
Total	636.4	100	35.3	100			3.1	100	1,639.5	100	668.0	100	400.0	100				

*wastewater irrigation study - 7 plots between 1.2 and 4.0 ha
**forested watershed study - 12 plots between 35 and 1250 ha
***11 agricultural watersheds (1860 to 7913 ha)
+identifies plot experiments

IMPROVED PASTURE--land used to grow forage and other close grown crops and managed for pasturing livestock or making hay by techniques such as fertilization, re-seeding and/or overseeding.

SPRAY IRRIGATION AND SEWAGE SLUDGE DISPOSAL LAND--agricultural land used for these purposes and separately studied by Task C investigators.

NON-AGRICULTURAL LAND

FOREST/WOODLAND--land bearing forests, short trees or brush.

OTHER RURAL LAND--a category included to reflect those activities that do not lend themselves to the unit area loading concepts. It includes transportation, extraction, recreation land, livestock feedlots, and private waste disposal systems.

IDLE LAND--land not used for active agricultural purposes. It includes open water such as lakes, ponds and rivers; wetlands such as swamps and marshes; barren land; and perennial grasslands not used for pasture.

URBAN LAND USE CATEGORIES

URBAN LAND

GENERAL URBAN LAND--a broad land use category that encompasses all urban land uses including developed and developing urban land uses.

DEVELOPED URBAN LAND

RESIDENTIAL LAND--land used for residential purposes. It includes single and multiple dwelling units in built up portions of cities, towns and villages; and areas of urban sprawl such as strip residential development.

COMMERCIAL LAND--land used for commercial purposes including office buildings, shopping centers, principal transportation corridors, etc.

INDUSTRIAL LAND--land used for industrial purposes.

UNDEVELOPED URBAN LAND

DEVELOPING URBAN LAND--land that is actively being developed for residential, commercial or industrial purposes.

2.1.2 Land Use Activities In The Great Lakes Basins

Table 2.1-2, prepared from the most recent data available on land use in the Great Lakes Basin, shows the broad categorization of land uses in the Basin. These broad categories are groupings of the narrower categories of land use included in this report.

2.2 POLLUTANTS AND THEIR TRANSMISSION TO THE GREAT LAKES

The pollutants selected for study in the various pilot watersheds differed in each case, partly because of differences in land uses in the watersheds, and partly because of differences in analytical capabilities of the investigators. During the course of the study priorities were established by scientists (Task D) indicating which parameters were most important to lake quality. This priority ranking and the fact that extremely low loadings were measured for some of the pollutants monitored in some watershed studies, dictated the reporting procedure used by watershed investigators. The result is that not all parameters monitored have been reported on so that more attention could be devoted to the more important pollutants detected.

Listed below are the pollutants for which information is available in the pilot watershed reports, along with the reasons for their inclusion.

2.2.1 Pollutants Having Public Health Significance

2.2.1.1 Organic toxicants: A very large number of organic chemicals are in commercial and/or industrial use in the basin-- some authorities put the number at 500,000. Of these, many undoubtedly are potentially hazardous and many find their way into the receiving waters but few are used in land-based activities. In any case, toxicological information on many of these chemicals is inadequate and, hence, the significance, if any, of the presence of these compounds would be impossible to interpret. Nevertheless, certain chemicals with well defined biological effects are so widely used in land-based activities (e.g. the herbicide, atrazine) or are so common as aerial contaminants (e.g. PCBs) that their presence in land drainage can be expected and can be related to land use activities and to mechanisms governing movement of pollutants. Where possible, pilot watershed investigators monitored stream loadings of organic compounds. Pesticides received special consideration in a fruit-growing area of Michigan (Mill Creek) and in the Canadian agricultural watershed studies.

2.2.1.2 Metals: The discovery that methylation of metals occurs readily in natural systems (e.g. mercury in sediment) alerted scientists to the potential public health threat of methylated metals as compared to the elemental forms of metals. The toxicity of methylated metals are of concern not only for mercury but also lead and perhaps other metals and metalloids as well. Inputs of metals to land occur in sanitary land fills and other waste disposal sites and during the recycling of sewage sludge on cropped land. Aerial fallout is also a source of metals to all land surfaces; e.g. lead from automobile exhausts. These may become mobilized along with metals resulting from natural weathering processes,

TABLE 2.1-2 **MAJOR LAND USES IN THE GREAT LAKES BASIN***

	1,000 ha						
	URBAN LAND USE		RURAL LAND USE				
	DEVELOPED LAND		AGRICULTURAL LAND		NON-AGRICULTURAL LAND		
LAKE BASIN	RESIDENTIAL	COMMERCIAL/ INDUSTRIAL	CROPLAND	PASTURE	FOREST/ WOODLAND	BARREN/BRUSH/ WETLAND	TOTAL LAND
LAKE SUPERIOR							
U.S.	7.1	1.5	25.3	114.5	3,753.6	497.9	4,399.9
Canada	6.0	3.7	2.2	51.1	9,342.6	53.1	9,458.7
TOTAL	13.1	5.2	27.5	165.6	13,096.2	551.0	13,858.6
LAKE MICHIGAN							
U.S.	379.4	28.1	1,453.7	1,295.6	5,842.8	2,741.2	11,740.8
Canada	0	0	0	0	0	0	0
TOTAL	379.4	28.1	1,453.7	1,295.6	5,842.8	2,741.2	11,740.8
LAKE HURON							
U.S.	140.4	5.0	690.1	387.1	2,026.9	942.3	4,191.8
Canada	79.2	9.7	511.9	1,303.9	6,444.0	345.8	8,694.5
TOTAL	219.6	14.7	1,202.0	1,691.0	8,470.9	1,288.1	12,886.3
LAKE ERIE							
U.S.	553.1	79.7	1,923.3	882.3	1,005.7	1,114.8	5,558.9
Canada	65.9	23.3	1,182.2	670.0	342.2	34.4	2,318.0
TOTAL	619.0	103.0	3,105.5	1,552.3	1,347.9	1,149.2	7,876.9
LAKE ONTARIO							
U.S.	155.3	6.7	407.9	526.2	2,942.2	538.7	4,577.0
Canada	110.2	56.4	387.7	1,056.5	1,254.6	84.8	2,950.2
TOTAL	265.5	63.1	795.6	1,582.7	4,196.8	623.5	7,527.2
GREAT LAKES BASIN							
United States	1,235.4	121.0	4,500.3	3,205.7	15,571.2	5,834.9	30,468.5
Canada	261.3	93.1	2,084.0	3,081.5	17,383.4	518.1	23,421.4
TOTAL	1,496.7	214.1	6,584.3	6,287.2	32,954.6	6,353.0	53,889.9

*Prepared from the most recent data available on land use in the Great Lakes Basin. The U.S. data differ from those in earlier PLUARG reports on land use and reflect a reevaluation of the U.S. data base. There are some differences in definition of specific land uses between Canada and the U.S.

and the extent to which some of these metals are transported in streams was measured in several Task C investigations.

2.2.1.3 Microorganisms: Surface waters may act as a vector for a variety of pathogenic microorganisms and viruses. Among water-borne bacteria of public health significance are salmonellas, pseudomonads and staphylococci. These, along with coliform and other indicator bacteria are deposited on land in the droppings of wild and domestic birds and animals. Bacteria were monitored in the Grand and Saugeen Rivers and were also the subject of special study in projects carried out in the Grand River Basin and as part of the Agricultural Watershed studies in Ontario.

2.2.2 Pollutants Having Aesthetic Significance

2.2.2.1 Plant nutrients: The elements which are agreed to be most significant in the increase in productivity and the consequent decline in aesthetic quality of surface waters are nitrogen and phosphorus. In addition, a large number of trace nutrient elements such as molybdenum and silica are found in land drainage. Since plants have a very small requirement for the latter elements it seems unlikely that land management could reduce the concentrations of these nutrients in drainage water to growth-limiting levels. Task C investigations, therefore, concentrated on nitrogen and phosphorus and of these, phosphorus received the most attention since it is generally conceded to be the major nutrient with the best potential for management. Nitrogen and phosphorus are major components of fertilizers used on farms, gardens and recreation areas, of animal manure and a variety of waste organic materials, crop residues and septic tank effluents. A number of forms of nitrogen and phosphorus were monitored and the significance of these is discussed below. While not strictly speaking a plant nutrient, the anion, chloride was a subject for investigations in most Task C pilot watershed studies. Chloride is a very mobile ion and, as a major component of deicing salt, has a large input to the basin.

2.2.2.2 Sediment: Soil and other solid particles are picked up by water moving across the land surface and, as suspended solids or sediment, move to water courses. In the lakes, suspended material in itself may not be a serious pollutant, except as it affects the appearance of the water in nearshore areas; but, as indicated below, a number of other pollutants are associated with or are influenced by sediment. For these reasons all of the Task C pilot watershed studies included extensive monitoring of sediment.

2.2.3 Transmission of Pollutants from Source to the Great Lakes

2.2.3.1 Pollutants transported to streams by groundwater: Surface soil characteristics determine the proportion of precipitation which infiltrates to groundwater. In areas where rapid infiltration occurs (when soil moisture conditions permit), certain pollutants are carried into the groundwater system while others are retained by sorption in the soil profile. In cases where discharge to the groundwater system is direct, as is the case in poorly designed sanitary landfills, the less mobile pollutants are attenuated rapidly as water moves through porous strata. In general, the pollutants which move into the groundwater system are anions - those of concern in Task C studies are chloride and nitrate. In agricultural areas, movement of these ions may be facilitated by drainage tiles. During low flow stream conditions, the discharge of anionic pollutants from land-based activities may continue when the concentration of other parameters is very low. Generally speaking, the groundwater concentration of all other pollutants is below the levels of concern to Great Lakes water quality.

It is usually accepted that the transport of the principal soluble anionic pollutants (nitrate and chloride and possibly borate) in groundwater is very conservative, i.e. no sinks exist for these pollutants in the groundwater system. However, it was shown in a PLUARG study that some denitrification of nitrate occurs if discharge is through sediment containing organic carbon; and from another PLUARG study denitrification is suspected of occuring in the groundwater itself.

2.2.3.2 Pollutants transported to streams by surface drainage: Water moving across cultivated land or paved areas, indeed any surface, suspends particulate material or dissolves soluble material. Soil particles move in this way as do materials like manure or fertilizer lying on the soil surface. Atmospheric fallout also may serve as a source for a significant portion of this solids load. As these dissolved or suspended solids are transported over land they may be redeposited by a variety of mechanisms. Suspended solids, particularly the coarser ones, are deposited as water velocity is reduced temporarily by irregularities in the surface or by vegetation. In addition, retention of dissolved cations, e.g. ammonium (NH_4^+) at negatively charged sites on stationary soil particles occurs and soluble inorganic phosphorus may react with metallic complexes at the soil particle surface to produce highly insoluble, immobile metal phosphates. Thus, a significant reduction in pollutant load of overland drainage water may occur before the water reaches a channel.

2.2.3.3 Transport of pollutants in streams: Many water pollutants are associated with sediment particles. Examples are metals, some insoluble organic toxicants and phosphorus. Thus, sinks for sediment also act as sinks for these sediment-related pollutants, at least to the extent that they are not solubilized by physical or biological processes. Conversely, reduction of sediment load by deposition in streams or reservoirs may not reduce sediment-related pollutants as much as expected because the pollutants tend to be associated with the smaller particles which tend to remain in suspension. Generally, Task C investigators have assumed that all of the sediment and sediment-related pollutants are transported to the lake once these have entered a stream channel. It is likely, however, that this stream delivery ratio of 1

$$(SDR = \frac{\text{pollutants reaching lake}}{\text{pollutants discharged to channel}} = 1)$$

is only achieved in the very long term, probably decades. Exceptions to the SDR = 1 rule occur where large lakes or reservoirs are present upstream of the Great Lakes e.g., the Kawartha Lakes of S. Ontario.

Pollutants associated with sediments, including phosphorus, may become solubilized, but the extent to which this occurs during stream transport is unknown. Certain pesticides which are relatively insoluble and associated with sediment may decompose while residing in temporary sinks in streams.

The fate of soluble ions in transport in a stream depends largely on their biological activity although soluble phosphate is subject to physical processes which affect its transport. Phosphate reacts with fine particulate solids in suspension or on the streambed to produce insoluble P complexes which may precipitate. Aquatic plants retain phosphorus as a result of biological uptake and may serve as a significant sink during late spring and early summer. This would be a temporary sink because dead plant material is transported downstream and the contained phosphorus is mineralized.

Nitrogen (N) transformations occur in streams, particularly at the sediment/water interface. Organic N may be mineralized, nitrate produced and denitrified, resulting in losses of N during transport. Temporary sinks also occur in plant uptake and in immobilization during decomposition of nitrogen-poor organic residues.

Unlike phosphorus and nitrogen, chloride is relatively non-reactive and biologically inert. Its transport in streams is conservative (i.e. no losses or uptake during transport).

2.3 POLLUTANT LOADS FROM PILOT WATERSHEDS

2.3.1 Lake Loadings from Pilot Watersheds

The unit area loads shown in Table 2.3-1 are based on river-mouth monitoring and include point and diffuse sources. They also reflect the stream transmission characteristics described above. Thus, the unit area loads for sediment and sediment-related parameters may not be representative of long-term unit loads depending on whether storage of sediment or removal of stored sediment occurred during the two years of record. For example, there is evidence that in both 1975 and 1976 deposition of sediment occurred in the lower reach of the Grand River as shown by monitoring data at a station 65 km upstream of the river mouth where the sediment loadings in both years were about 4 times higher than the load at the mouth. Table 2.3-1 provides an overview summary of the pilot watershed studies and permits comparison of unit loads for selected parameters at the mouths of watersheds having very different land-use and transmission characteristics.

It is clear from the data in Table 2.3-1 that the year has a major influence on unit area loads and that the effects may be quite local. For example, suspended sediment unit loads in the Genesee in 1976 were less than half the loads in 1975 but in the Maumee the reverse was true. The range of annual unit area loads observed was from 300 kg/ha in the Menomonee to 1590 kg/ha in the Genesee. A slightly narrower range of annual unit area loads of total phosphorus (P) was observed, from about 0.4 kg/ha in the Saugeen in 1976 to 2.1 kg/ha in the Maumee. Within

TABLE 2.3-1

LAKE LOADS FROM PILOT WATERSHEDS AND TOTAL ESTIMATED TRIBUTARY LOADS TO EACH OF THE GREAT LAKES

Sources of Great Lakes data are Sonzogni et al (1978) and Unpublished Ontario Ministry of the Environment Tributary Monitoring Data

Watershed and Area	Year of Record	Stream Flow	Runoff	Land Uses				ANNUAL LOADS[k] Sediment		Total P		Total N		Cl		Pb	
				Agr	I-F*	Urban	Other	Tot**	UAL**	Tot	UAL	Tot	UAL	Tot	UAL	Tot	UAL
ha		m³/sec	cm	----	----	%	----	kT†	kg/ha	kT	kg/ha	kT	kg/ha	kT	kg/ha	T†	kg/ha
Genesee	1976/77			49	34	9	8	544	860	0.52	0.82	3.86	6.1	112	180		
636,400	1975/76	81	40					1,010	1,590	0.81	1.28	7.57	12.0	127	200		
U.S. L. Ontario 4,577,000	1976							1,545	340	3.51	0.77	35.0	7.7	1,600	350		
Cdn. L. Ontario 2,950,000 (2,157,000+)	1976							416	193	1.06	0.49	18.3	8.5	311	144	124	0.057
Grand	1976	87	41	75	19	3	3	305	460	0.62	0.90	9.3	14	70	110	15	0.022
667,000	1975	69	33					220	330	0.44	0.60	7.7	11	65	100		
Maumee	1976	159	31	82	10	7	1	1,509	920	2.51	1.53	20.4	12††	126	77		
1,639,500	1975	151	29					1,610	982	3.44	2.10	52.9	32††	209	127		
Portage	1976	10	29	85	8	3	4	41	367	0.09	0.83	1.2	18††	11	100		
110,900	1975	9	24					105	949	0.16	1.45	3.6	34††	15	138		
U.S. L. Erie 5,559,000	1975							6,055	1,090	8.64	1.55	112	20	856	154		
Cdn. L. Erie 2,318,000 (1,847,000+)	1976							456	247	1.60	0.85	34	19	188	102	40	0.022
Saugeen	1976	69	55	64	33	1	2	208	520	0.16	0.40	3.4	8.6	15	37	7	0.019
400,000	1975	61	48					181	460	0.21	0.51	3.2	7.9	14	36		
U.S. L. Huron 4,192,000	1976							765	183	1.95	0.47	27	6.4	422	100		
Cdn. L. Huron 8,695,000 (7,091,000+)	1976							256	36	0.11	0.10	22	3.1	171	24		
Menomonee	1976	2.7	27	26	25	49	0	9.6	300	0.028	0.90	0.20	6.2	12	380	4	0.14
35,500	1975	3.0	30					11.5	370	0.036	1.10						
L. Michigan 11,741,000	1976							742	63	3.6	0.31	55	4.7	712	61		
U.S. L. Superior 4,400,000	1976							721	163	0.96	0.22	10.9	2.5	81.6	19		
Cdn. L. Superior 9,459,000 (7,148,000+)	1976							1,778	249	1.28	0.18	12.0	1.7	47.5	7		

k Includes diffuse and tributary point source inputs

* I-F is idle/forested land.

**Tot is total annual load and UAL is unit area load.

†kT is thousand tonnes and T is tonnes

††Estimated from (nitrate + nitrite)as nitrogen x 1.67.

+Area drained by tributaries deemed to be significant by IJC -- Loads and unit area loads based on significant tributary data only.

watersheds the total P loads in the 2 years reflected differences in suspended sediment loads. However, between watersheds, total P unit loads did not rank the same as suspended sediment. This is to be expected since soils, and sediments derived from them, differ markedly in phosphorus content. Also the percentage of total load attributable to point sources varies from basin to basin and from year to year (e.g. in the Menomonee, P input from point sources varied from 40 percent of total P in 1975 to 27 percent in 1976).

Nitrogen unit area loads did not vary much between watersheds - the somewhat higher values observed in the Maumee and Grand watersheds probably reflect the high natural fertility and the large fertilizer inputs characteristic of these intensive cropping areas. On the other hand, chloride showed very small unit area loadings in the rural Saugeen watershed and the higher loads observed in the Grand, the Menomonee and the Genesee may be related to the larger areas of urban development in these three watersheds. Similarly, lead loadings might be expected to reflect the larger number of automobiles in urban areas - the very high unit area load of the Menomonee is, therefore, not surprising.

When unit area loads for the smaller areas are compared with the basin-wide loadings (Table 2.3-1), the watersheds chosen for Task C studies appear reasonably representative of the lake basin in which they are located. An exception is the Menomonee Basin which, because of its intensely urban land use, generates much higher unit loads of most pollutants than is characteristic of the Lake Michigan Basin.

2.3.2 Land Use Unit Area Loads from Pilot Watersheds

As part of the Task C program, data were compiled to provide a range of unit-area loads for those areas in a dominant single land use (Tables 2.3-2 to 2.3-5). These data were used to provide the information needed to predict loads to the Great Lakes basin which in turn can be used for development of management alternatives. The parameters of principle concern are:

a) suspended sediment (Table 2.3-2)
b) total phosphorus (Table 2.3-2)
c) filtered reactive phosphorus (Table 2.3-3)
d) dissolved phosphorus (Table 2.3-3)
e) total nitrogen (Table 2.3-4)
f) (nitrate + nitrite) as nitrogen (Table 2.3-4)
g) lead (Table 2.3-5)
h) copper (Table 2.3-5)
i) zinc (Table 2.3-5)
j) chloride (Table 2.3-5)

The wide ranges reported herein for the unit-area loads for each of the land-use categories result from variations and differences in soil types, physiography, watershed area and land-use categorization amongst the pilot watersheds. In a few instances, climatic extremes encountered in the watersheds during the period of record caused large variability. For example, a one-in-a-hundred year frequency storm in the Black Creek

TABLE 2.3-2

UNIT AREA LOADS OF SUSPENDED SEDIMENT AND TOTAL PHOSPHORUS BY LAND USE (Point sources excluded)

Land Uses	ANNUAL UNIT AREA LOADS															
	Genesee		Menomonee		Felton-Herron		Mill Creek		Maumee		Grand/Saugeen		Forested		Agricultural	
	SS*	TP*	SS	TP	SS	TP	SS	TP	SS	TP	SS	TP	SS	TP	SS	TP
	kg/ha/yr															
RURAL																
General agriculture	30-900	0.1--1.1	230-410	0.3-0.6					500-5,600	1.4-9.1	3-2,200	0.1-2.3			30-800	0.1-1.5
Cropland							20-70	0.2-0.6	80-5,100	0.8-4.6					400-800	0.9-1.5
Improved Pasture															30-80	0.1-0.5
Forested/wooded	7-820	0.02-0.67									30-50	0.1	1-5	0.04-0.2		
Idle/perennial	7-820	0.02-0.67			10-30	0.1-0.2					30-50	0.1				
Sewage sludge												0.2				
Spray irrigation						0.4-1.4						0.2				
URBAN																
General urban			210-280	0.3-0.9							400-1,750	0.7-2.1				
Residential			830-2,300	0.9-1.3							620**	0.4**				
Commercial			50-660	0.1-0.4							830**	0.9**				
Industrial			400-1,700	1.1-4.1							1,080**	0.9**				
Developing***			27,500	23												

*SS is suspended sediment, TP is total phosphorus.
**Data obtained from Canada/Ontario Agreement studies.
***one site one year

TABLE 2.3-3

UNIT AREA LOADS OF FILTERED REACTIVE PHOSPHORUS BY LAND USE (Point sources excluded)

	ANNUAL UNIT AREA LOADS							
	Genesee	Menomonee	Felton-Herron	Mill Creek	Maumee	Grand/Saugeen	Forested	Agricultural
Land Uses	FRP*	FRP*	FRP	FRP	FRP	FRP	TDP**	FRP
	kg/ha/yr							
Rural								
General agriculture	0.01-0.16	0.2			0.2-0.5	0.01-0.5		0.02-0.6
Cropland				0.1-0.3	0.05-0.3			0.3 -0.4
Improved Pasture								0.02-0.2
Forested/wooded	0.01-0.03					0.01	0.03-0.1	
Idle/perennial	0.01-0.03		0.02-0.07			0.01		
Sewage sludge						0.01		
Spray irrigation			0.1-1.3					
URBAN								
General urban		0.3				0.05-0.12		
Residential		0.2						
Commercial		0.02-0.08						
Industrial		0.3						
Developing		0.1						

*FRP is filtered reactive phosphorus
**Total dissolved phosphorus (only data available)

TABLE 2.3-4

UNIT AREA LOADS OF TOTAL NITROGEN AND (NITRATE + NITRITE) - NITROGEN BY LAND USE (Point sources excluded)

	ANNUAL UNIT AREA LOADS													
	Genesee	Menomonee		Felton-Herron		Mill Creek		Maumee	Grand/Saugeen		Forested		Agricultural	
Land Uses	TN*	TN	Inorg. N*	TN	Inorg.N	TN	Inorg.N	Inorg.N	TN	Inorg.N	TN	Inorg.N	TN	Inorg.N
	kg/ha/yr													
RURAL														
General agriculture	4-22	14	10					2.4-16	0.6-24	0.2-17			3.2-42	2.1-37
Cropland						4.3-10	3.5-6.7	2.2-22					16-31	11-24
Improved Pasture													3.2-14	2.1-11
Forested/wooded	1-6								4.8-5.6	0.3-3.5	1.7-6.3	0.1-2.0		
Idle/perennial	1-6			0.5-1.5	0.1-0.2				4.8-5.6	0.3-3.5				
Sewage sludge									11	11				
Spray irrigation				2.2-5.6	1.3-3.2				370	17				
URBAN														
General urban		6.2	3.2						6.7-10	3.0-3.1				
Residential		7.3	3.1						5.0**					
Commercial		1.9-2.2	0.6-1.2						11**					
Industrial		1.9	0.6						14**					
Developing		63	3.0											

*TN is total nitrogen and Inorg.N is (nitrate + nitrite) - nitrogen.
**Data obtained from Canada/Ontario Agreement studies.

TABLE 2.3-5

UNIT AREA LOADS OF CHLORIDE, LEAD, ZINC AND COPPER BY LAND USE (Point sources excluded)

	ANNUAL UNIT AREA LOADS													
	MENOMONEE				FELTON-HERRON	MILL CREEK	GRAND/SAUGEEN			FORESTED		AGRICULTURAL		
Land Uses	Cl	Pb	Zn	Cu	Cl	Cl	Cl	Pb	Zn	Cu	Cl	Pb	Zn	Cu
	kg/ha/yr													
RURAL														
General agriculture	90	0.01	0.1	0.06			10-120	0.002-0.08	0.005-0.3	0.002-0.09		0.004-0.015	0.019-0.189	0.013-0.064
Cropland						10-50						0.005-0.006	0.026-0.083	0.014-0.064
Improved pasture												0.004-0.015	0.019-0.172	0.021-0.038
Forested/wooded							20	0.01-0.03	0.01-0.03	0.02-0.03	2-10			
Idle/perennial					35		20	0.01-0.03	0.01-0.03	0.02-0.03				
Sewage sludge							10	0.01	0.2	0.005				
Spray irrigation					40-160									
URBAN														
General urban	380	0.14	0.3	0.07			130-270	0.3-0.5	0.3-0.6	0.05-0.13				
Residential	1,050	0.06	0.02	0.03										
Commercial	10-150	0.17-1.1	0.25-0.43	0.07-0.13										
Industrial														
Developing	75-160	2.2-7.0	3.5-12	0.29 1.3										

portion of the Maumee basin in 1975 caused as much as two orders of magnitude greater yield of sediment in 1975 compared with 1976. These types of data illustrate the difficulty in deriving representative values for general extrapolation purposes and for the development of a hazard ranking scale for land uses. Greater details of on-site characteristics are to be found in the Task C Summary Pilot Watershed Reports and the supporting technical documents.

2.3.3 Land Practices, Usages and Parameters not Suited to the Unit-Area Load Concept

Some land uses and practices such as small-scale waste disposal, transportation, streambank erosion, livestock and parameters such as microorganisms, pesticides and toxic organic compounds, which were monitored in the Task C studies, do not lend themselves to a strict unit-area load calculation. Major regional differences, management, density and the probability that some of the land uses act more like point than diffuse sources, suggest that unit loadings independent of area would provide a more suitable method of reporting the loads from these sources.

2.3.3.1 Small-scale waste disposal: Studies of private waste-disposal systems (septic systems) and sanitary landfills were undertaken as part of the Canadian Task C program. These studies suggest that the only pollutants of concern from private waste-disposal systems are phosphorus and, to a lesser extent, nitrogen. Bacterial contamination may also occur as a result of runoff from faulty private waste-disposal systems. In areas where large urban and rural populations use private waste-disposal systems (i.e. unsewered areas), an impact on the water quality of the receiving streams and ultimately on the quality of the Great Lakes can occur. Estimates of average contributions of nutrients from septic systems, assuming a 30% failure rate and a nominal distance from the receiving waters of each septic system, are 0.74 kg of filtered reactive phosphorus and 8.2 kg of (nitrate + nitrite) - nitrogen for each system. Although nitrogen inputs are initially in the organic form, nitrification to nitrate occurs in a short distance from the waste-disposal system. This form of nitrogen is highly soluble and mobile, thereby posing a threat to groundwater systems.

Increased levels of chloride, metals and toxic organic compounds can occur in the receiving streams from poorly designed or mismanaged sanitary landfills. Properly designed and well-managed sanitary landfill sites using the natural attenuation capacity of the soil column accompanied by leachate treatment, where necessary, provide no threat to Great Lakes water quality.

Pollution of the groundwater system is usually of localized significance and occurs most commonly with small-scale waste disposal practices. Ultimate discharge of the polluted groundwater into the receiving streams, particularly during low-flow conditions in perennial streams, places an increased burden on the assimilative capacity of the stream. Direct overland runoff from small-scale waste disposal sites located near receiving streams also may require remedial attention. The natural attenuation capacity of soils through sorption processes for some parameters, e.g. metals, toxic organic compounds and phosphorus, minimizes the potential pollutant impact of these disposal practices.

2.3.3.2 Transportation corridors: The major pollutant produced as a result of maintenance operations on transportation corridors is chloride from highway deicing operations. Levels of chloride in groundwater adjacent to highways have been increasing as the use of salt as a deicing agent has increased. Salt usage on provincial highways in Ontario doubled between 1960 and 1975. Highway salting ranges from 20 tonnes of salt (13 tonnes of chloride) per kilometre of two-lane highway to 67 tonnes of salt (40 tonnes of chloride) per kilometre of four-lane highway. Task C monitoring data from a 1.3 km length of a four-lane highway in the Grand River basin confirms increased chloride loads as a result of deicing operations.

The literature indicates that other pollutants such as grease and oil, pesticides and heavy metals may be produced as a result of routine maintenance operations on roads. Airborne lead has been reported as accumulating in the soil downwind of the highway study site that was monitored in the Grand River basin. No other water quality parameters that were monitored in the small stream draining the area along the highway exhibited increased concentrations (with the exception of chloride) downstream of the highway. Similarly, levels of metals and pesticides were unchanged downstream of the highway in suspended and bed-sediment samples.

2.3.3.3 Streambank erosion: Task C studies on streambank erosion were conducted to estimate the amount of sediment eroded. This information was utilized to determine whether predictions of streambank erosion were feasible. By this means, the effect of material eroded from river banks on the quality of the Great Lakes could be determined so that remedial measures could be designed and costs ascertained. Data on bank geometry (slope, shape, length), vegetation, erosional mechanisms, soil materials, drainage-pattern morphology, stream cross-section, channel gradient, roughness and streamflow were collected. Recession rates and the areas of recession were determined to provide an average recession rate per kilometre of streambank. These data were subsequently converted to provide general estimates of yields/unit area. Sampling of soil materials was also undertaken to estimate chemical loadings resulting from streambank erosion. The estimated yields of sediment, phosphorus and metals from streambank erosion are as follows:

Study	Parameter				
	Sediment*	Phosphorus*	Lead**	Copper**	Zinc**
Forested Watersheds (Cdn)	0.4 - 2.0				
Agricultural Watersheds (Cdn)	38				
Menomonee Basin	40				
Canada (average)	9	0.016			
United States (Average)	4 - 43	0.007-0.034	0.5-5.0	0.2-7	1-5

*kg/ha/yr
**g/ha/yr

The best estimate of the relative contribution of streambank erosion to Great Lakes tributary sediment loads is 10%, with a range for individual major tributaries of near zero to 30%.

2.3.3.4 Livestock: A model of livestock inputs of total phosphorus was developed for use in the Canadian basin. This was possible because comparable data were available for the whole of the basin and included a survey of livestock enterprise locations in relation to stream channels. The information in the U.S. was not so amenable to integration because data were available in different forms in different States and surveys of livestock enterprise locations were limited to small areas. For these reasons, the PLUARG modelling of livestock inputs in the U.S. basin was restricted to the State of Wisconsin. Estimates of loadings on an animal unit basis were not very different in the two studies. For Ontario the range was 0.08 kg to 0.22 kg of total phosphorus per animal unit per year. The equivalent figures for Wisconsin were 0.11 to 0.35 kg. Ranges are given because the model assumes that manure phosphorus may be fully attenuated by overland travel to a channel, and the distance estimated for complete attenuation ranges from about 30 metres to about 120 metres.

Part of the difference observed in results of the two studies may be attributed to differences in the animal unit used in the two countries; that in the Wisconsin study was based on live weight while the Ontario animal unit is based on nitrogen excreted. Furthermore, channel density is an important variable in the model used and the method of estimating channel density was different in the two studies. Nevertheless, the animal unit base and the unit inputs calculated in the two studies were sufficiently similar to encourage the development of a representative input for extrapolation purposes. The middle of the range of total phosphorus animal unit loads in the Canadian study was 0.15 kg while in the Wisconsin study it was 0.23 kg. The mean of these two figures is close to 0.20 kg and this figure was taken to be the animal unit input for extrapolation to the Great Lakes Basin.

When sources within the livestock industry as modelled in the two studies are compared, differences are much more obvious, as might be expected. Table 2.3-6 shows such a comparison. The differences result not only from the disparities noted above but largely from differences in the livestock industry in Ontario and Wisconsin--the latter is a major dairy area while Ontario has experienced a decline in dairying and growth in the beef industry over the past few years.

2.3.3.5 Pesticides and other toxic organic substances: Monitoring of a variety of herbicides and insecticides and some fungicides was carried out routinely in samples from Mill Creek, the Grand and Saugeen Rivers and the Agricultural Watersheds. These samples were also analyzed for PCBs and mirex. A series of bottom-sediment samples from the Maumee River were also analyzed for similar chemicals. A number of chemicals were occasionally detected at levels so low as to preclude calculation of precise loading rates. Included among these were lindane, endrin and

TABLE 2.3-6
PROPORTION OF TOTAL PHOSPHORUS LOADING FROM LIVESTOCK ENTERPRISES ATTRIBUTABLE
TO SPECIFIC LIVESTOCK CLASSES

Wisconsin portion of the Great Lakes drainage basin			Ontario portion of the Great Lakes drainage basin		
	Critical distance assumed			Critical distance assumed	
	30.5 m	121.9 m		30.5 m	121.9 m
Dairy Cattle	50%	44%	Beef Cattle Lots[1]	49%	44%
Winter Spread Manure	30	38	Dairy Cattle Lots[1]	26	24
Beef Cattle	18	16	Winter Spread Manure	13	19
Hogs	1	1	Poultry/Hog Manure Storages	5	5
			Hogs[1]	2	2

[1]direct input from feed lots/loafing areas

heptachlor in urban stations of the Grand River, certain derivatives of DDT, dieldrin and endosulfan in the Agricultural Watersheds and DDT derivatives in the Maumee River. Frequent occurrences were recorded for atrazine and DDT and some of its derivatives in all the Canadian agricultural watersheds examined and in Mill Creek. Mill Creek samples also erratically showed low levels of guthion.

DDT and dieldrin residues in water are derived from past uses of DDT and aldrin, and little can be done to change the slow release to water. The extent of atrazine use may have reached a peak since there is currently some shift to the use of other herbicides. The pattern of atrazine occurrence in the basin is discussed in Section 3. Guthion is rapidly degraded and has not been detected in the lakes.

Mirex was not detected in any of the monitored watersheds but PCBs were detected in all Agricultural Watersheds and in over 90% of all water samples from these watersheds. PCBs were found consistently in the samples for urban reaches of the Grand River. Crude calculations of unit loads of PCBs for urban areas based on results from the Grand River study show a range of 0.003 to 0.26 g/ha/yr. For the Agricultural Watersheds, the range was 0.08 to 0.22 g/ha/yr. These data suggest that atmospheric inputs may be the dominant source of PCBs in receiving streams.

In summary, it appears that DDT and its derivatives and dieldrin will continue to enter the lake from land areas where past use was substantial. Atrazine occurs at appreciable loadings in corn-producing areas. Other pesticides may be detected infrequently as a result of careless handling or accidental introduction to streams. PCBs are common contaminants of streams in the basin as a result of aerial deposition on land as well as from point sources.

2.3.3.6 Microorganisms: Frequent monitoring of the Grand and Saugeen Rivers established that microbiological quality of these waters is often very poor and did not always meet Ontario standards for recreational quality at some sampling sites. Urban and agricultural areas were shown to contribute fecal indicator bacteria and, in special studies, pathogenic *Salmonella* spp. The source of these organisms in urban areas is thought to be fecal material from domestic animals and wildlife, and, in some instances, from combined sewers.

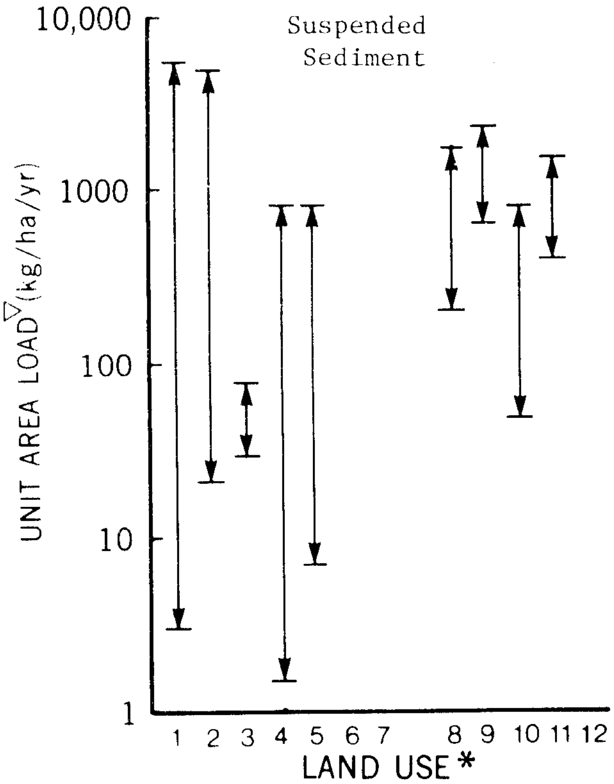
In agricultural areas, livestock are believed to make a significant contribution to microorganism content in water, although it was not possible to show a direct relationship between livestock numbers and the microbiological quality of water. No estimates could be made of the transmission of pathogenic microorganisms to the lakes, although previous work suggests that die-off is likely to be rapid, particularly during summer when microbial contamination appears to be most serious. It is likely that bacterial contamination may be locally hazardous where surface waters are used for contact recreational purposes and/or as a water-supply source.

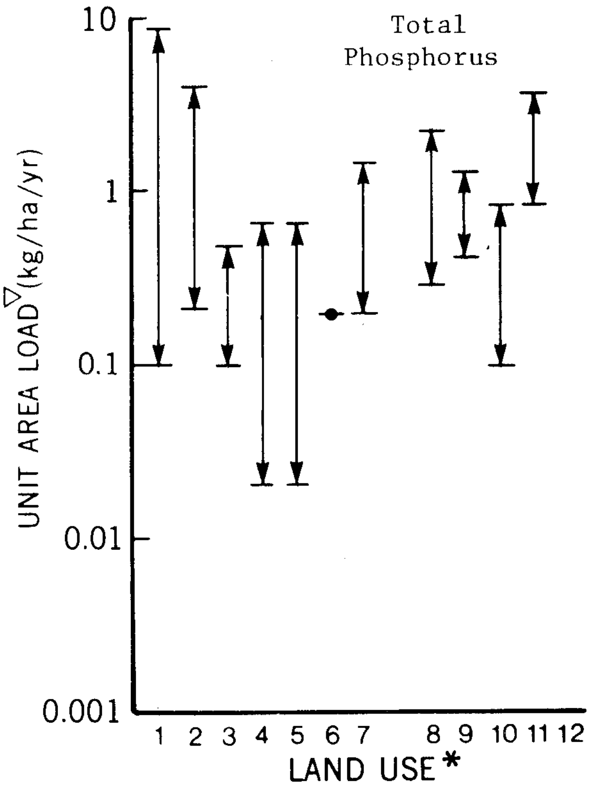
2.3.4 Hazard Ranking of Land Uses

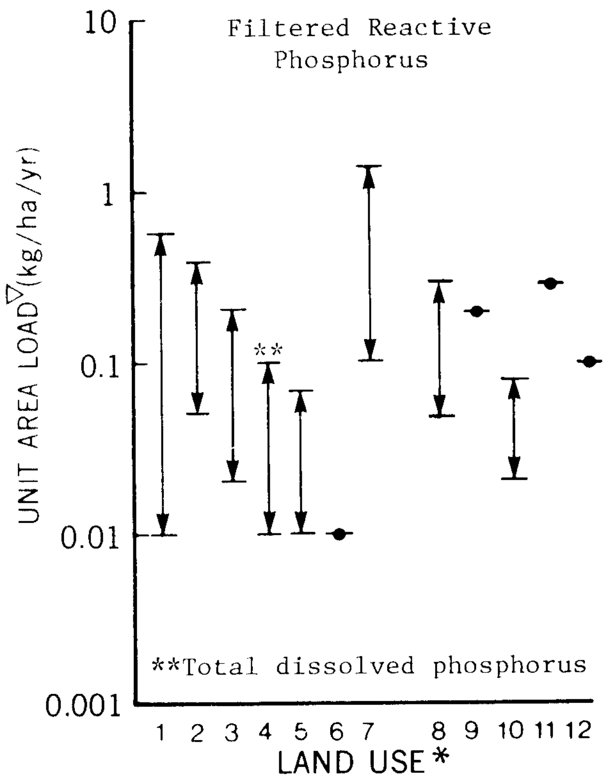
The ranking of land uses has been attempted using data presented in Tables 2.3-2 to 2.3-5 inclusive, for each of the parameters listed in Section 2.3.3 with the exception of copper and zinc. The ranking factors consist of the unit area loads that were estimated for the rural and urban land uses described in Section 2.1.1. Outputs from these land uses were monitored by Task C investigators at dominantly single land-use sites. Monitoring of all permutations and combinations of land use, soil, physiography, climate, etc. was not possible; however, the most representative land uses and practices in the Great Lakes basin were sought. As reported earlier, large variations in the unit-area load ranges are attributed to differences in soil, physiography, area, land-use categorization and climatic differences amongst the watersheds. These data are presented in graphical form in Figures 2.3-1 and 2.3-2.

Although dominantly single land-use areas are shown for specific categories of both rural and urban land use, more general combinations of rural and urban categories are also presented ("general agriculture" and "general urban") for comparative purposes and to further substantiate the unit-area load ranges reported for the dominantly single land-use studies. However, some caution should be exercised in making comparisons of loadings under these general land use categories, since land characteristics, climate and distribution of component land uses within the general categories will have a major bearing on unit loads. Thus, the "general agriculture" category of land use includes the whole gamut of agricultural land-uses and its range of unit-area loads is expected to be greater than the range of unit-area loads for any single agricultural land use. A similar situation occurs for the "general urban" land-use category.

The unit area load comparisons presented in Figures 2.3-1 and 2.3-2 indicate that the relative hazard of intensive agricultural activities (i.e. cropland category) and urban land uses are approximately equal (i.e. of the same order of magnitude) for suspended sediment, phosphorus, nitrogen and copper. The unit area loads from both land-use categories are one or two orders of magnitude greater than forested and/or idle land. The loads from forested and/or idle land can be considered to be the minimum to which pollutant-level reduction can be realistically lowered with the application of remedial measures; unit area loads for improved pasture overlap with the upper range of the forested and/or idle land categories and the lower range of the cropland category. Developing urban land was an order of magnitude higher for sediment and total phosphorus than the general agricultural or general urban categories. Urban inputs of chloride and lead are an order of magnitude greater than the upper range shown for general agriculture and cropland. Unit-area loads for spray irrigation practices are shown to be approximately equal to the loads obtained from general agriculture, cropland and urban categories for phosphorus and up to an order of magnitude greater for nitrogen. The high loading values should be utilized to delineate alternative control strategies and to set priorities on the parameters of concern in Great Lakes water quality assessments.







*Definition of land use found on Figures 2.3-1 and 2.3-2

1 General agriculture
2 Cropland
3 Improved pasture
4 Forested/wooded
5 Idle/perennial
6 Sewage sludge
7 Spray irrigation
8 General urban
9 Residential
10 Commercial
11 Industrial
12 Developing urban

NOTE: Different scales were used for different parameters

No data presented indicates data not available

● only one value available

∇ Unit Area Loads are plotted on a log scale

Figure 2.3-1 Hazard rankings of suspended sediment, total phosphorus and filtered reactive phosphorus by land use from pilot watershed studies

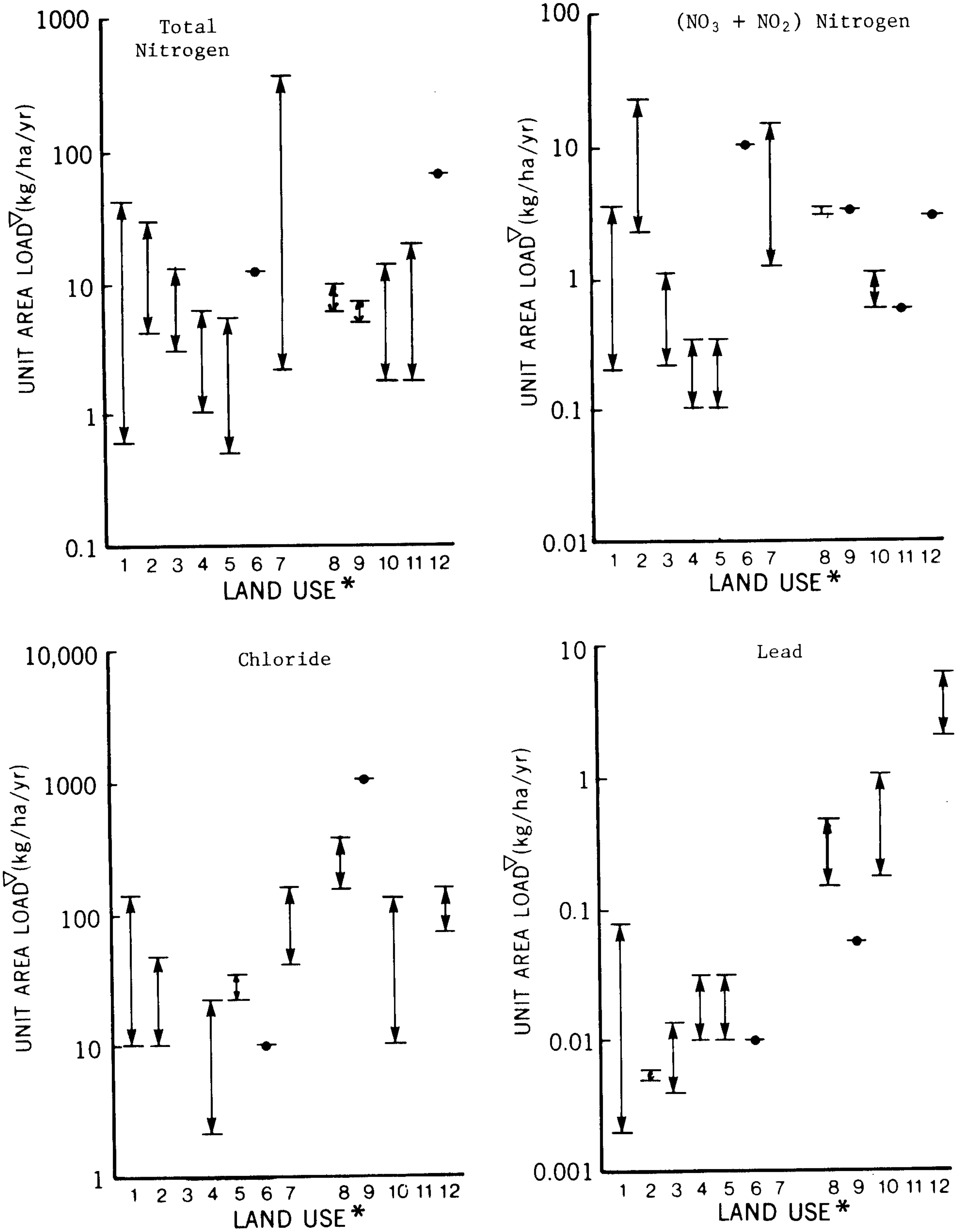


Figure 2.3-2 Hazard rankings of total nitrogen, (nitrate + nitrite) - N, chloride and lead by land use from pilot watershed studies

3. BASINWIDE LOADINGS BY EXTRAPOLATION

The Task C effort provided loading information at different points in the Great Lakes Basin from which predictions of land use diffuse loadings can be made for unmonitored areas. Two distinct problems were encountered which become critical when this type of extrapolation is attempted: i) many water quality loading data have been collected in watersheds for which upstream land uses and physiographic conditions could not be identified in detail: ii) climatic variability during the 1975 to 1977 monitoring period resulted in incompatibility of data between the western and eastern sectors of the basin. These problems combine to make verification of the consistency of loading data difficult. Nonetheless, verification was attempted since extrapolations based on the major land use and physiographic factors which affect each water quality parameter are otherwise of questionable validity.

The extrapolation process was necessarily limited to those land uses for which sufficient information was collected over a range of basin conditions, and to those parameters which were monitored and amenable to the unit area load concept.

3.1 EXTRAPOLATION PROCEDURES

3.1.1. Loads from Agricultural land

The results of the Canadian Agricultural Watershed Studies have been used to develop regression-type prediction equations for various parameters. These watersheds had wide ranges in most agricultural and physical characteristics. Independent variables used in the prediction equations were watershed characteristics which accounted for the greatest amount of the variability in loadings at the 11 watersheds when entered in regression equations. Such characteristics as soil clay content, percent watershed area in row crops, mean fertilizer application rates, etc., were measured in each watershed. Over 30 such variables were tested in the regression approach. The results were generally capable of accounting for greater than 80% of the variability in loads and concentrations of most parameters. Other extrapolation techniques were considered for such pollutants as pesticides and sources such as livestock. Representative loadings under specified source conditions were developed where possible.

3.1.2 Loadings from Urban Land

Urban runoff appears to be more influenced by factors such as the degree of impervious cover, degree of industrialization and frequency of street sweeping than by the physical location of the urban land. Therefore, it seems reasonable to compare loadings from different types of urban land to see if extrapolation is possible. The most extensive urban monitoring has been done in the Menomonee basin, with additional information from urban sites in the Grand River basin. Unit area loads developed in these studies were not entirely consistent. For example, total phosphorus loads were higher for commercial and residential areas in the Menomonee than they were for the Canada/Ontario Agreement studies reported in the Grand River report. The "general urban" values for the Grand basin include an upper range which was higher than any of the urban loads in the Menomonee, except for developing and industrial land. Suspended sediment loads were more consistent between these studies. The Menomonee values for residential land were somewhat higher than those values reported in the Grand River studies. Insufficient data were available to compare nitrogen or heavy metal loads for different urban land uses, but industrial land in the Menomonee had the highest loads of lead, zinc and copper of any area studied.

Simulation modelling has been tested in the Menomonee study. However, unit area loads used in the model were not measured in the PLUARG Study. They represent literature values and some are inconsistent with the monitored loads shown in Table 2.3-1.

It must be concluded, at this time, that extrapolation of urban land unit area loads must be done on the basis of "best estimate" values for "general urban" land use.

3.1.3 Loadings from Forested Land

Only one study has measured the loadings from forest land directly. This study was located in the Laurentian Shield outside the Great Lakes Basin, but is fairly representative of most of the Lake Superior Basin and the northern shore of Lake Huron which are predominantly forested areas. Indications of forest land loadings can also be obtained from sub-basins of other pilot watersheds, and these loadings may provide better estimates of forest land loadings in the Lower Lakes than those obtained in the Forest studies. However, the range in loadings for the predominantly forested basins is narrow and a single "best estimate" can probably be used for all parameters except suspended sediment, where a higher "best estimate" of about 30 kg/ha/yr is probably more representative for the Lower Lakes loadings than the value of 2 kg/ha/yr obtained for the sandy Upper Lakes drainage basins. Any error involved in extrapolating the "best" values is likely to be small, except in basins where forestry makes up the dominant land use. Since little, if anything, can be done to reduce the loadings from forest land, it is apparent that the extrapolation of these loadings is a low priority concern. For most other parameters (i.e. heavy metals, pesticides, toxic organics) loadings will likely be very low and as close to "background" levels as will be found anywhere in the basin. Extrapolation of values at this level is probably not very meaningful.

3.2 VERIFICATION OF EXTRAPOLATION PROCEDURES

For agricultural land in the basin, the results of the Canadian Agricultural Watershed Studies have provided extrapolation values. For urban and forested land, representative values have been estimated from the data presented in the preceding section of the report.

In the following discussion, data from primarily rural sub-basins of the Pilot Watersheds are compared with the loading values for these sub-basins predicted by applying the extrapolation procedures and representative loads. These sub-basins are independent (loadings do not have to be found by difference) tributary catchments of the Pilot Watersheds. No such watersheds could be found which were entirely agricultural, urban or forested, so a combined extrapolation approach has been used in this verification section.

3.2.1 Suspended Sediment from Rural Watersheds

Suspended sediment data were highly variable throughout the watershed studies. An attempt at extrapolation for agricultural land based on simple linear regression on soil texture and row-crop density has been examined. This extrapolation is based on the relatively uniform size and stream characteristics of the 11 Canadian agricultural watersheds. Table 3.2-1 shows these results together with estimates of loads from urban and forested land.

The extrapolation based on soil and row crop data may be reasonable for estimating inputs from agricultural fields where stream border conditions are similar to those found in the Agricultural Watersheds. It should be noted that management of land bordering a stream is critical to the sediment yields and may, in part, account for the unexplainable variations found in Table 3.2-1. Furthermore, since the prediction method does not include a flow variable, the discrepancies found between predicted and measured loads in the Black Creek Watershed in 1975 can be partly explained by the occurrence of a 100 year frequency storm in 1975, and the unusually low runoff which occurred in 1976.

It must be concluded that this approach to extrapolation of sediment loadings requires refinement. Only the sites with highest predicted loadings agreed with the sites with highest monitored loads, and there was poor agreement in terms of magnitude of these loads.

The Modelling Task Force of PLUARG has also developed extrapolation procedures for suspended sediment based on the Universal Soil Loss Equation and estimated delivery ratios.

3.2.2. Phosphorus from Rural Watersheds

One of the findings in the Agricultural Watershed studies was that about 85% of the variability in unit area loadings of total P in small agricultural basins can be accounted for by 2 variables, namely clay content of soils and proportion of land area in wide-spaced row crops. Using this correlation to estimate loadings from agricultural land and loadings of 2.0 kg/ha/yr and 0.1 kg/ha/yr respectively in urban and forested land areas, total P loadings were predicted for the sub-basins of the pilot watersheds.

The predicted and measured values from the unit area load extrapolation are shown in Table 3.2-2.

TABLE 3.2-1 COMPARISON OF MEASURED AND PREDICTED ANNUAL LOADS OF SUSPENDED SEDIMENTS

Site[1]	Year	Predicted load (tonnes/yr)[2]			Net Unit Area Loads (Kg/ha/yr)		Stream Discharge
		Agr.	Urban	Forest	Measured	Predicted	(cm/yr)
GR-6	1976	6358	384	166	145	180	48
GR-13	1976	1196	795	668	69	33	42
GR-14	1976	14110	775	304	409	196	53
SR-4	1976	4129	333	379	138	73	61
SR-5	1976	0	249	240	191	20	59
G-1	1975-76	392	25	101	65	104	42
G-2	1975-76	701	108	82	162	165	43
G-3	1975-76	1329	1367	82	655	299	43
G-4	1975-76	511	58	20	232	305	36
G-5	1975-76	224	701	165	457	129	36
G-6	1975-76	587	37	64	189	166	63
G-7	1975-76	698	0	30	399	258	63
G-8	1975-76	6426	6886	1224	27	194	45
B-2[3]	1975	668	0	0	3376	709	29
B-6[3]	1975	464	36	1	5599	702	26
B-2[3]	1976	668	0	0	528	709	12
B-6[3]	1976	464	36	1	641	702	10
MR	1976	623	279	1	486	421	25
M-5[3]	1975-76	1773	0	11	44	350	38
M-5[3]	1976-77	1773	0	11	51	350	11

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[1] GR is Grand River; SR is Saugeen River; G is Genessee River; B is Black Creek; MR is Menomonee River station 463001; M is Mill Creek.

[2] Predicted loads for small, primarily rural, sub-basins using regression of 1976 Canadian Agricultural Watershed unit-area loads on soil clay content and row crops as follows:

$$\text{Total suspended sediments (kg/ha/yr)} = -281 + 13.6(\%\text{Clay}) + 8.3(\%\text{ Row Crops})$$

and a representative "best estimate" of 1000 kg/ha/yr and 30 kg/ha/yr for urban and forested land respectively.

[3] The loads for 1975 and 1976 in Black Creek and 75-76 and 76-77 in Mill Creek have been separated as both years had unusual runoff conditions.

TABLE 3.2-2 COMPARISON OF MEASURED WITH PREDICTED ANNUAL LOADS OF TOTAL PHOSPHORUS

Site[1]	Year	Predicted load (tonnes/yr)[2]			Net Unit Area Loads (Kg/ha/yr)		Stream Discharge
		Agr.	Urban	Forest	Measured	Predicted	(cm/yr)
GR-6	1976	10.6	0.77	0.55	0.37	0.31	48
GR-13	1976	12.28	1.59	2.23	0.25	0.20	42
GR-14	1976	41.39	1.55	1.01	0.77	0.57	53
SR-4	1976	10.17	0.67	1.26	0.20	0.18	61
SR-5	1976	2.84	0.5	0.80	0.28	0.17	59
G-1	1975-76	0.76	0.05	0.34	0.10	0.23	42
G-2	1975-76	1.15	0.22	0.27	0.11	0.30	43
G-3	1975-76	2.35	2.73	0.27	0.44	0.58	43
G-4	1975-76	0.99	0.12	0.07	0.35	0.61	36
G-5	1975-76	0.51	1.40	0.55	0.38	0.29	36
G-6	1975-76	1.04	0.08	0.21	0.30	0.32	63
G-7	1975-76	1.32	0	0.1	0.60	0.51	63
G-8	1975-76	11.03	13.77	4.08	0.15	0.39	45
B-2[3]	1975	1.67	0	0	9.07	1.77	29
B-6[3]	1975	1.28	0.08	0	6.9	1.9	26
B-2[3]	1976	1.67	0	0	1.6	1.77	12
B-6[3]	1976	1.28	0.08	0	1.42	1.9	10
MR	1976	1.25	0.56	0	0.72	0.84	25
M-5[3]	1975-76	3.31	0	0.04	0.58	0.66	38
M-5[3]	1976-77	3.31	0	0.04	0.33	0.66	11

[1] GR is Grand River; SR is Saugeen River; G is Genessee River; B is Black Creek; MR is Menomonee River station 463001; M is Mill Creek.

[2] Predicted loads for small, primarily rural, sub-basins using regression of 1976 Canadian Agricultural Watershed unit-area loads on soil clay content and row crops as follows:

$$\text{Total phosphorus (kg/ha/yr)} = -0.094 + 0.00085(\%\ \text{Clay})^2 + 0.00021(\%\ \text{Row Crops})^2$$

and a representative "best estimate" of 2 kg/ha/yr and 0.1 kg/ha/yr for urban and forested land respectively.

[3] The loads for 1975 and 1976 in Black Creek and for 75-76 and 76-77 in Mill Creek have been separated as both years had unusual runoff conditions.

In some cases, the extrapolation model does not predict the variability in the measured loads exactly because of the higher clay content of many of the U.S. Lake Erie Basin soils compared to the soils in the Canadian part of the basin, thereby necessitating extrapolations outside the range of the original agricultural data set (Table 3.2-2). The extreme variability in flow conditions observed in the two years of data at some of the U.S. Task C Study sites created added difficulties. Nevertheless, the unit area load extrapolation procedure does appear to give an effective separation of "high" (>1.5 kg/ha/yr), "medium" (0.5-1.5 kg/ha/yr) and "low" (<0.5 kg/ha/yr) yielding rural areas, despite the lack of a flow variable in the equation.

The extrapolation of total phosphorus from agricultural land takes into account an average effect from livestock. By modelling procedures in both U.S. and Canadian studies, livestock have been found to contribute phosphorus to streams at a rate of approximately 0.20 kg P/animal unit/yr (see Section 2.3.3.4.). Since livestock density was not a statistically significant determinant of total P loadings to the stream in the agricultural watersheds studied, extrapolation of livestock effects must be handled as a separate procedure in order to estimate their probable impact. However, livestock units and phosphorus production in manure were statistically significant in explaining variability in total dissolved phosphorus measured by flow-weighted mean concentrations and unit area loads respectively. Nevertheless, since concentrations of dissolved P are known to change markedly during stream transport, and since the extent of these changes cannot be predicted, estimation of lake loadings from upstream inputs is impossible. Extrapolation of dissolved P loadings was therefore not attempted.

3.2.3 Nitrogen from Rural Watersheds

Not all studies have included nitrogen since this has been deemed a parameter of secondary significance to PLUARG. Nitrogen is subject to losses during transport to the lakes, and therefore extrapolation of lake loadings based on upstream inputs is not possible. Extrapolations are nevertheless included to provide information on stream concentrations which may be of local significance, and may also indicate locations where high nitrogen inputs to the Great Lakes may be expected.

Extrapolation from the Agricultural studies has been reasonably good based on the fertilizer and manure inputs of nitrogen and on the land area planted to corn. Representative urban and forested land inputs of nitrogen were 10 kg/ha/yr and 2 kg/ha/yr, respectively, in this extrapolation.

Comparisons of monitored loadings with predicted loadings of nitrogen based on this extrapolation are seen in Table 3.2-3. There appears to be a general, but not consistent, tendency for predicted values to exceed measured values by 20% or more. This over-prediction was noticeable at most of the U.S. sites. At this time, no further explanation exists for the lower loadings of total nitrogen measured at most sites compared to those which might be expected from the extrapolation procedure, other than the potential stream transport losses discussed above.

TABLE 3.2-3 COMPARISON OF MEASURED AND PREDICTED ANNUAL LOADS OF TOTAL NITROGEN

Site[1]	Year	Predicted load (tonnes/yr.)[2]			Net Unit Area Load (Kg/ha/yr)		Stream Discharge
		Agr.	Urban	Forest	Measured	Predicted	(cm/yr)
GR-6	1976	835.7	3.3	11.1	19.2	22.1	48
GR-13	1976	474.2	8.0	44.5	5.6	6.6	42
GR-14	1976	1284.2	7.8	20.3	13.1	16.9	53
SR-4	1976	717.4	3.3	25.3	9.5	11.2	61
SR-5	1976	88.0	2.5	16.0	6.1	4.2	59
B-2[3]	1975	11.9	0	0	16.3	12.6	29
B-2[3]	1976	11.9	0	0	7.1	12.6	12
B-6[3]	1975	9.6	0.4	0	9.1	14.0	26
B-6[3]	1976	9.6	0.4	0	2.4	14.0	10
MC-5[3]	1975-76	61.1	0	0	9.7	12.0	38
MC-5[3]	1976-77	61.1	0	0	5.0	12.0	11

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[1] GR is Grand River; SR is Saugeen River; B is Black Creek; MC is Mill Creek.

[2] Predicted loads from small, primarily rural, sub-basins using estimates based on 1976 Canadian Agricultural Watershed data as follows:

Total N (kg/ha/yr) = 0.117(Manure N) + 0.0016(Manure N^2 + (Fertilizer N x Manure N))
26.0(% corn + potatoes) + 3.6(% cereals + soybeans + vegetables)
0.1(% pasture + hay)

where manure and fertilizer nitrogen are in kg/ha/yr,
and a representative "best estimate" of 10 kg/ha/yr and 2 kg/ha/yr for urban and forested land respectively.

[3] The loads for 1975 and 1976 in Black Creek and 75-76 and 76-77 in Mill Creek have been separated as both years had unusual runoff conditions.

3.3 BASIN-WIDE EXTRAPOLATION

The intent of the extrapolation procedure was to locate, within the Great Lakes Basin, those land uses or land use/land form combinations which were found in the Task C Studies to be associated with the highest loadings of each pollutant. This is not to suggest that these are the only high loading areas, or that the presence of a high loading area necessarily indicates that a high load will be delivered to the lake in any particular year. Rather, it is an extension of Task C Studies to unmonitored areas so that some explanations of observed loading rates might be attempted.

In addition to the problems indicated in the verification process discussed above, there remains the problem of availability of data with which to extrapolate. This is a potential constraint in that a particular extrapolation procedure may appear satisfactory, but requires the use of characteristics which may be unavailable on an extensive basis.

The maps shown in the following section are simplified summaries. In many cases, they are based on more detailed maps at a scale which makes them too large for incorporation into this report. Because of delays in the availability of some of the most recent land use data, some of these maps are based on provisional data only.

The unit on which the extrapolation has been mapped is generally the county in the U.S., and the drainage basin in Canada. Averaging over county or drainage basin areas was carried out using a weighting procedure in order that a single value could be mapped for each mapping unit.

3.3.1 Suspended Sediment

Figure 3.3-1 shows the result of extrapolating the loadings of suspended sediment which are predicted to arise from combinations of row crops and high clay soils. The agricultural loadings for each area have been estimated and mapped in detail after overlaying county or watershed sub-basin crop data on soil association maps for which estimates of the mean clay content of the soils in each soil association have been made. Weighting was based on variations of the density of agricultural land in each area (county or sub-basin), and the results are shown in Figure 3.3-2. Urban inputs are mapped as a summary in Figure 3.3-3 and it should be noted that suspended sediment loads from urban land are relatively high compared to agricultural land. Unfortunately, it has not been possible to identify land which is undergoing rapid urbanization, where far higher loadings might be expected.

3.3.2 Phosphorus

Figure 3.3-4 shows the extrapolated loadings of total phosphorus in the Great Lakes Basin from agriculture based on areas where soils with high clay content and predominantly row crop culture occur together. The load values were weighted according to the percentage of each county or sub-basin which is in active agriculture, and have been plotted in Figure 3.3-5. Livestock contributions to the load values have been

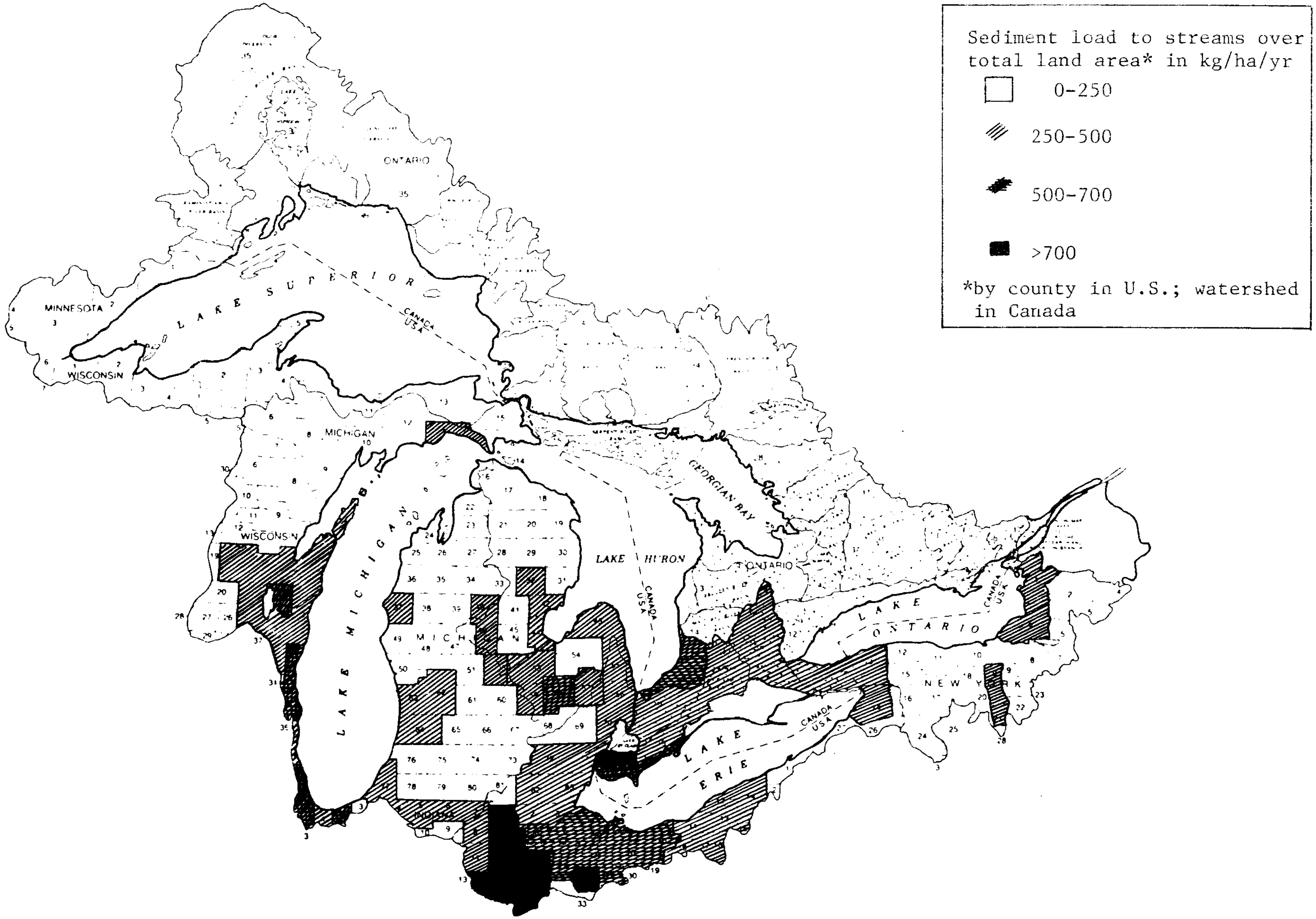


Figure 3.3-1 Locations of agricultural land having unit area loads as indicated of suspended sediment (by extrapolation of 1976 loads to provisional land use data).

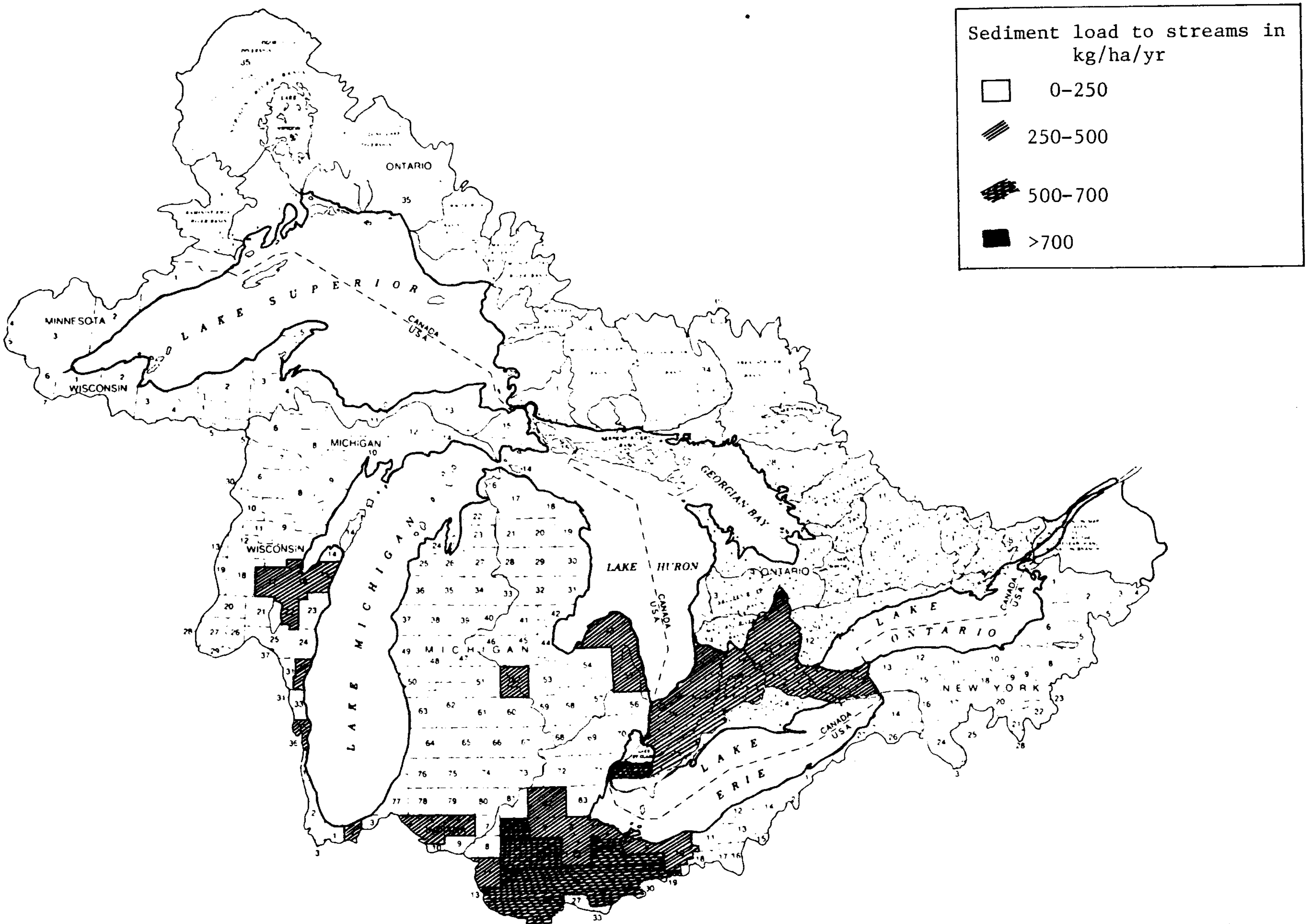
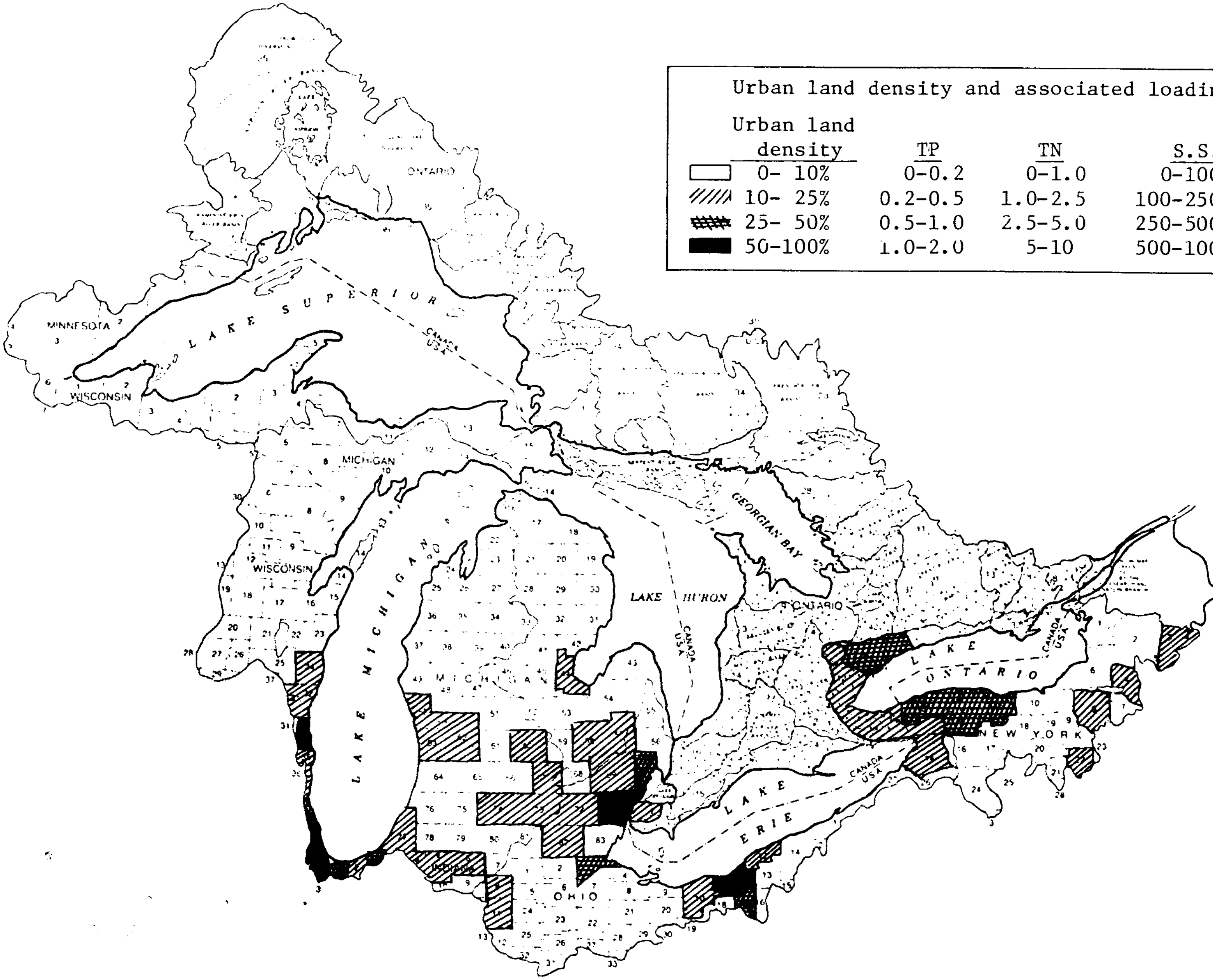


Figure 3.3-2 Suspended sediment loads from agricultural land, adjusted for farm land density (i.e. per unit area of all land) (by extrapolation of 1976 loads to provisional land use data).



Urban land density and associated loadings in kg/ha/yr

Urban land density	TP	TN	S.S.	Pb
0- 10%	0-0.2	0-1.0	0-100	0- .1
10- 25%	0.2-0.5	1.0-2.5	100-250	0.1- .25
25- 50%	0.5-1.0	2.5-5.0	250-500	.25- .5
50-100%	1.0-2.0	5-10	500-1000	.5-1.0

Figure 3.3-3 Distribution of urban land and estimates of associated loadings for total phosphorus, total nitrogen, sediment and lead, per unit area of all land (excludes developing land) (by extrapolation of 1976 loads to provisional land use data).

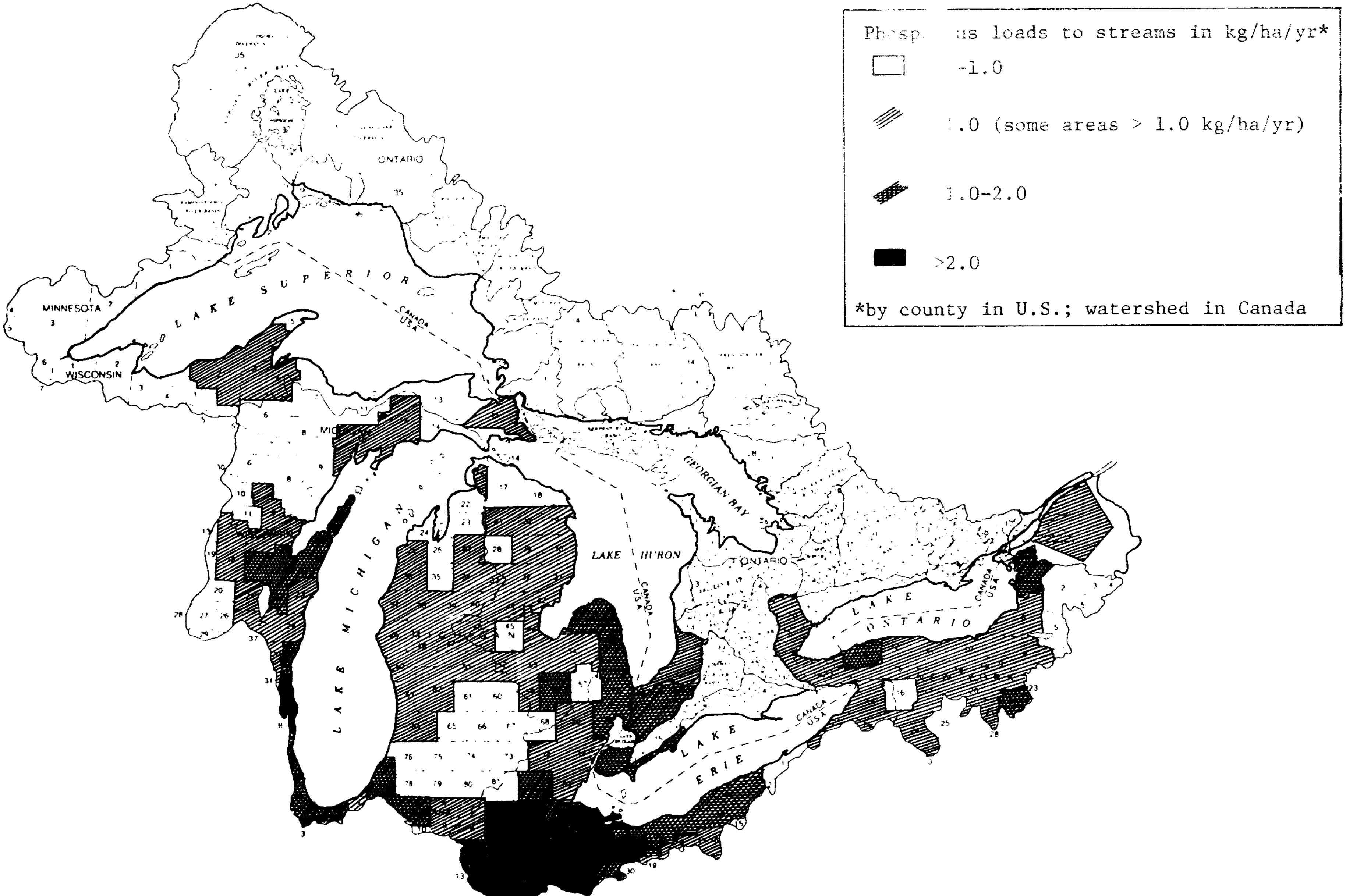


Figure 3.3-4 Locations of agricultural land having unit area loads as indicated of total phosphorus (by extrapolation of 1976 loads to provisional land use data).

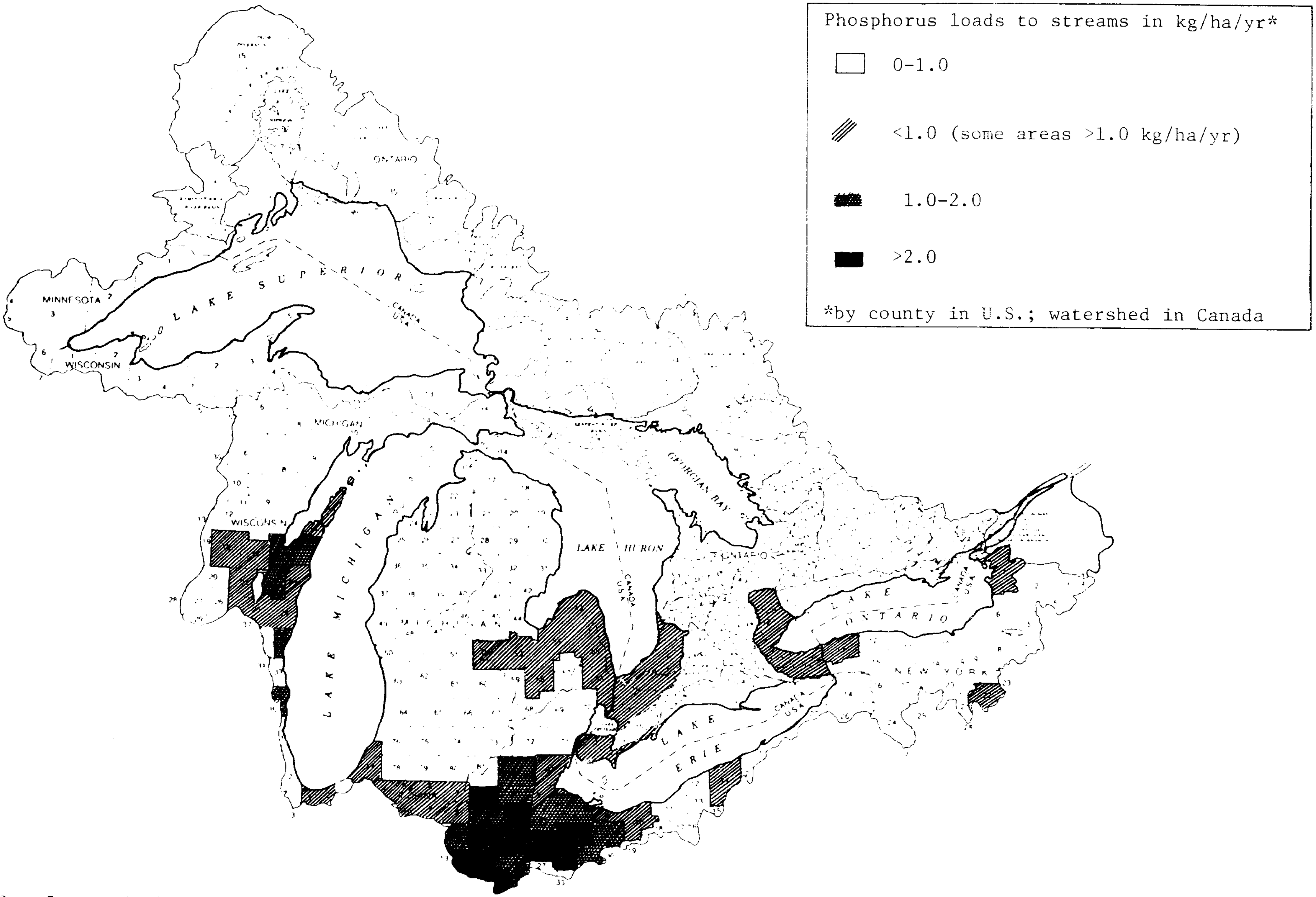


Figure 3.3-5 Total phosphorus loads from agricultural land, adjusted for farm land density (i.e. per unit area of all land) (by extrapolation of 1976 loads to provisional land use data).

estimated by direct extrapolation of the animal unit load. The relative magnitude of these estimated loads are shown in Figure 3.3-6. These load values should not be added to the loads shown on the previous map, as a variety of livestock densities were present in the base sites on which the first extrapolation of total phosphorus was made. Rather, the livestock loads should be used to indicate where actual loads are probably higher or lower than those shown by the first extrapolation. However, the livestock loadings are small enough that they bring about few changes to the expected average agricultural loadings.

An urban unit-area load of 2 kg/ha/yr has been extrapolated and is shown in Figure 3.3-3. These loadings can be added to the loading pattern for total phosphorus from agricultural land. In those areas such as Wayne County, Michigan, and the area around Cleveland, Ohio, this added load becomes a major factor in overall source area identification (i.e. "hot spots").

3.3.3 Nitrogen

The regression model discussed earlier has been used to extrapolate the effect of cropping and livestock activities on total nitrogen loadings from agricultural land in the basin. The predicted loads are shown in Figure 3.3-7.

The tabulated loadings from earlier sections of this report indicate that urban lands may contribute fairly high levels of total nitrogen in runoff water, and Figure 3.3-3 includes nitrogen estimates to indicate the possible distribution of nitrogen from diffuse urban sources.

3.3.4 Pesticides

Atrazine loadings are statistically related to corn hectarage and the texture of the soil. Figure 3.3-8 shows the distribution of corn - which is the only crop on which this herbicide is used. Thus the pattern seen should closely resemble that expected for the atrazine extrapolation, although it has not been possible to predict unit area loads reliably.

The other pesticides are not extrapolatable by the unit area load approach. However, Figure 3.3-9 has been compiled to show the distribution of orchard and vegetable production areas in which useage is likely to be highest. It can be assumed that spills, accidents, misuse, etc. are more likely to occur in areas where useage is greatest.

Although pesticide use in urban areas is likely to be appreciable, few data are available to assess this source. The limited information available for DDT indicates that the range of values observed in urban runoff is lower than those seen at agricultural sites. No attempt has been made to extrapolate this information, but the agricultural loadings are likely to be highest in those areas shown on Figure 3.3-9 where past use was probably most frequent.

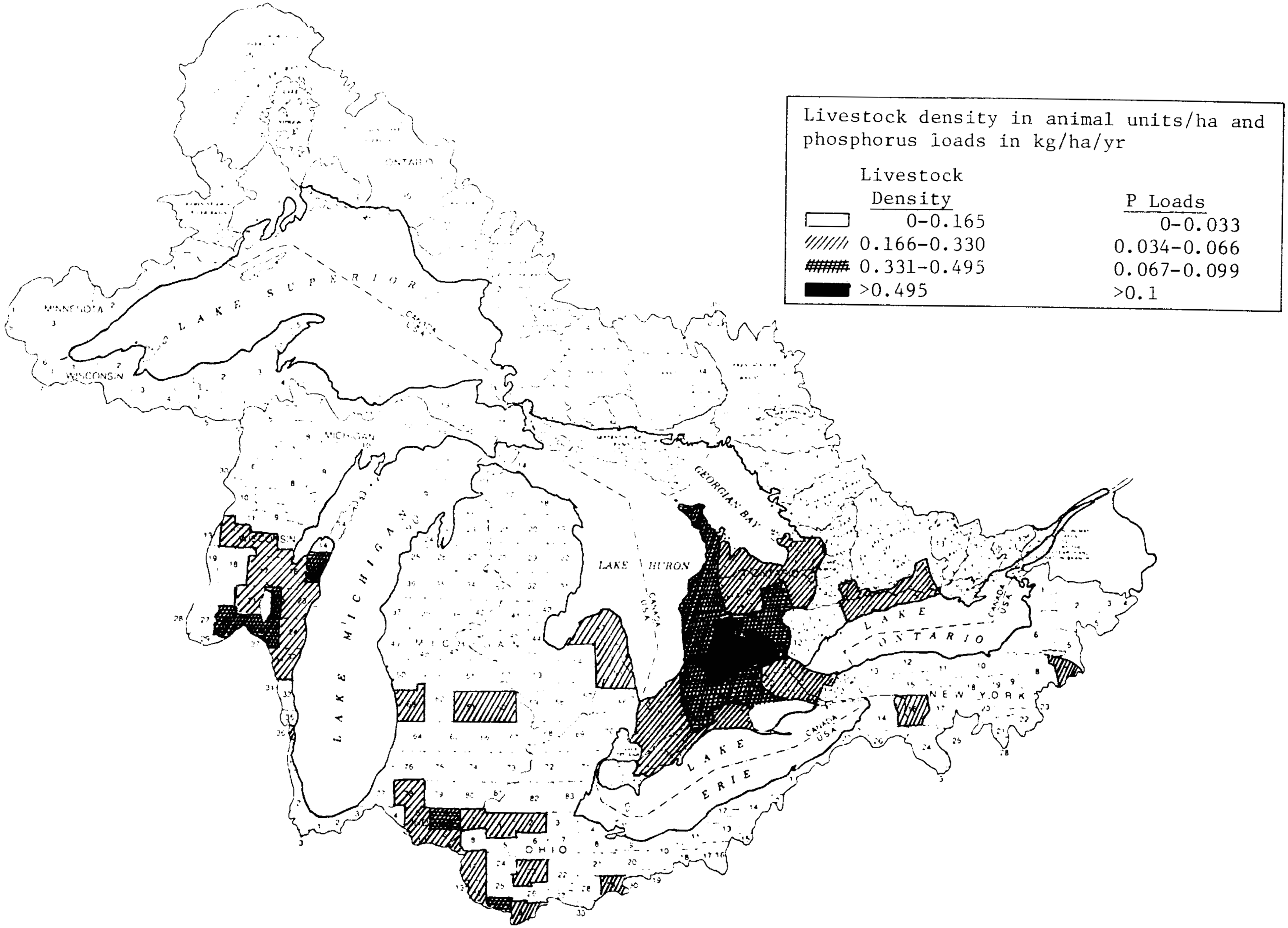


Figure 3.3-6 Livestock density and estimated total phosphorus loads from livestock per unit area of all land (by extrapolation to provisional land use data).

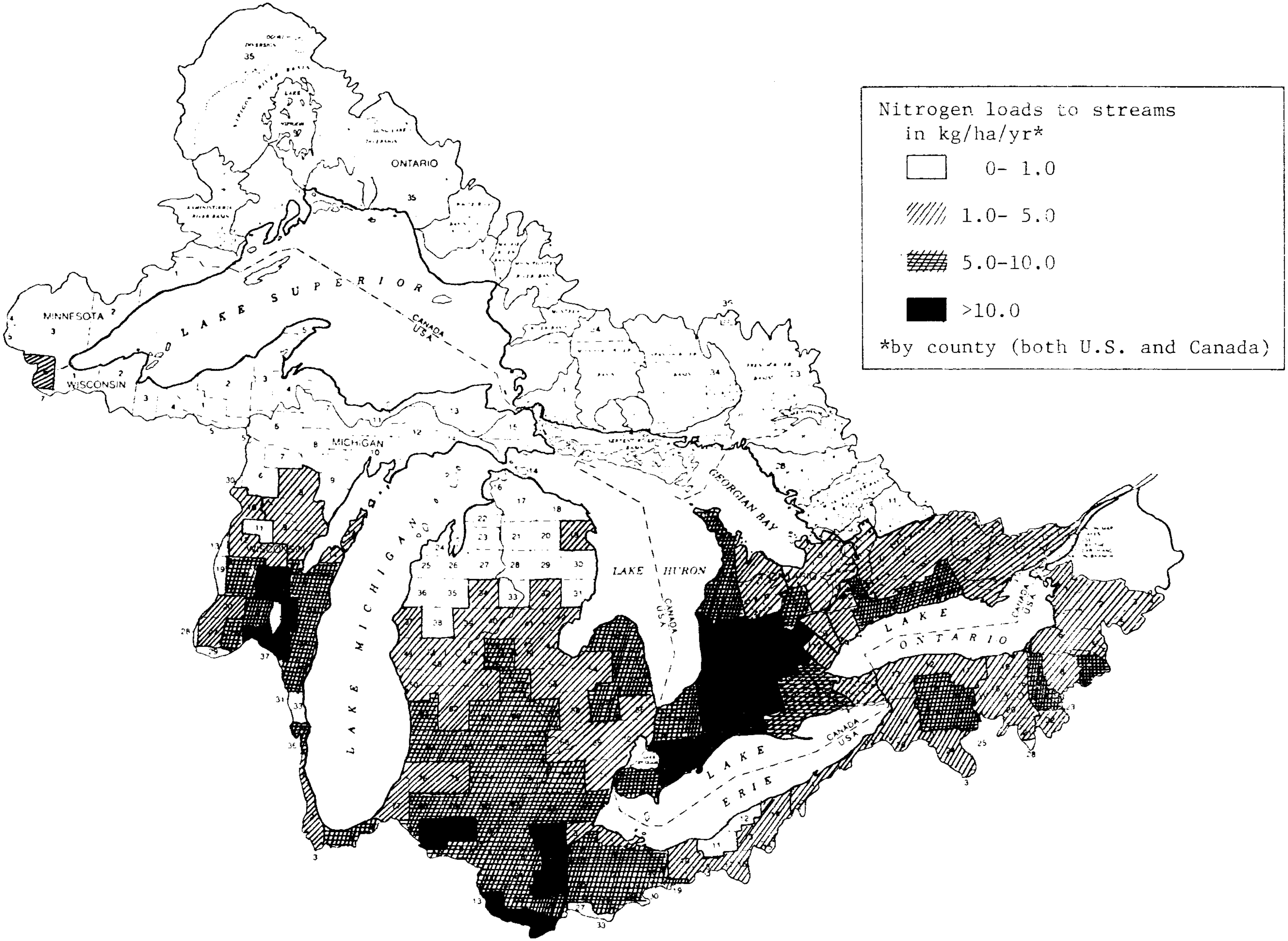


Figure 3.3-7 Total nitrogen loads from agricultural land, adjusted for farm land density (i.e. per unit area of all land) (by extrapolation of 1976 loads to provisional land use data).

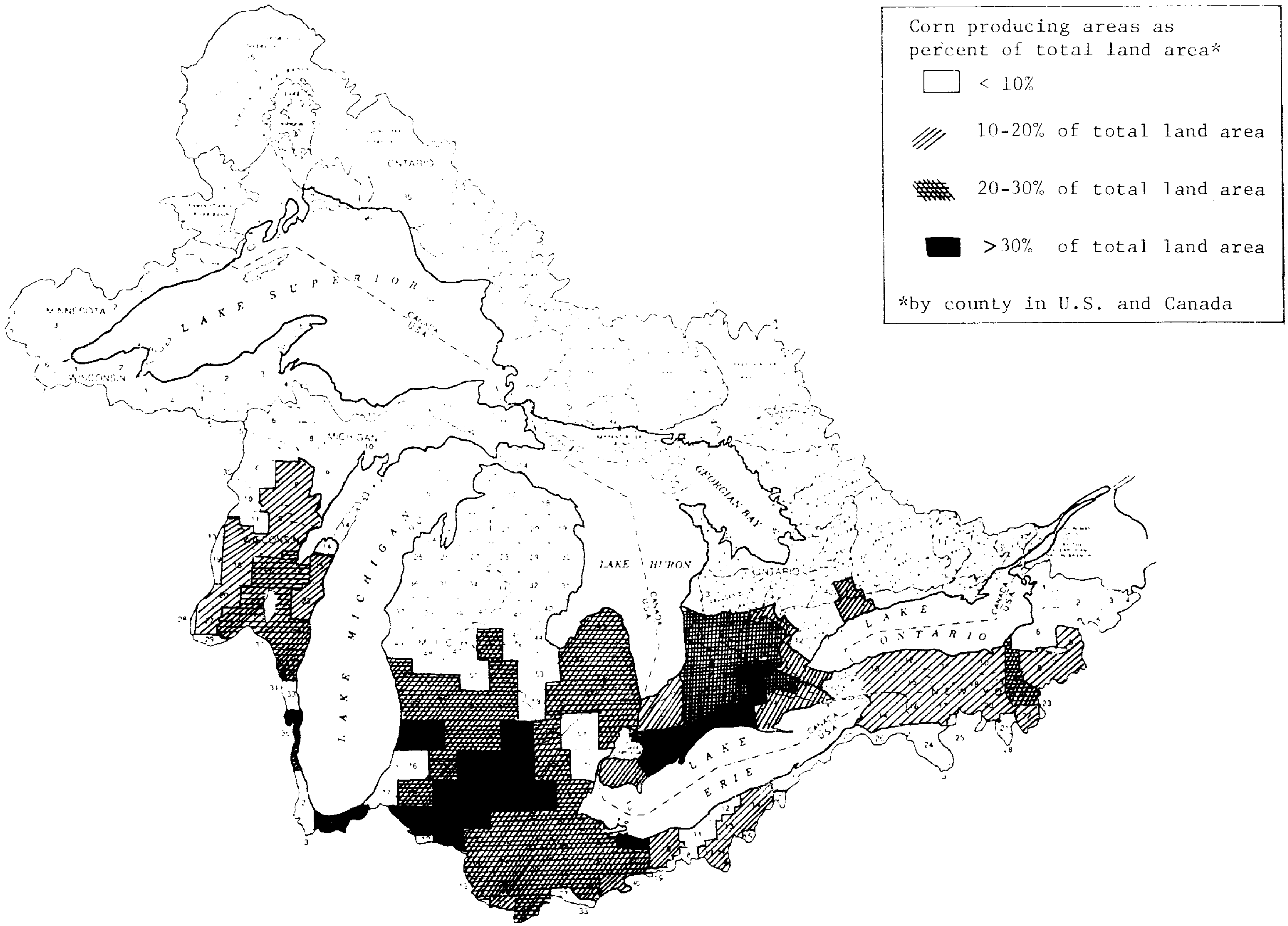


Figure 3.3-8: Distribution of corn production areas (provisional land use data).

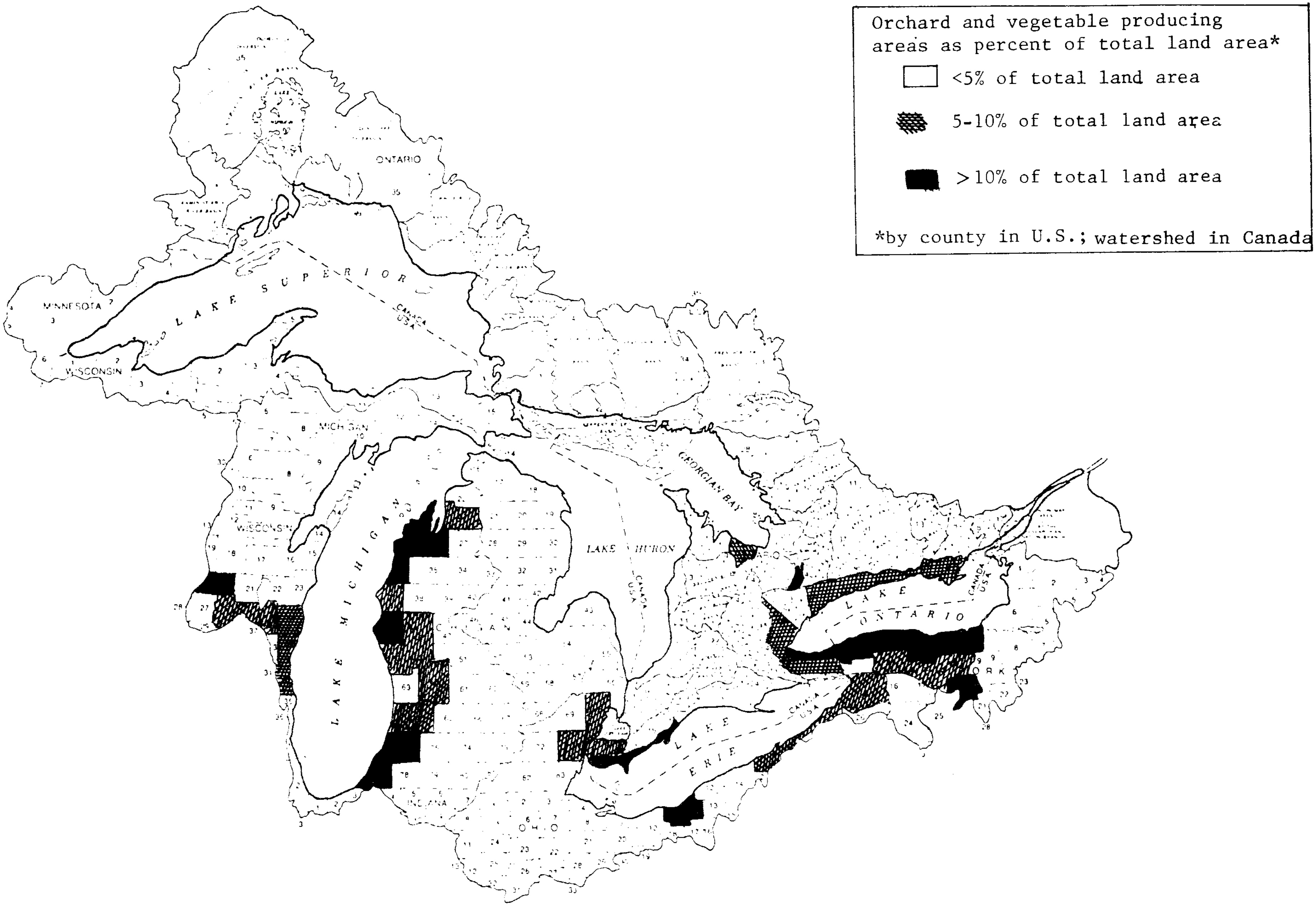


Figure 3.3-9: Distribution of orchards and vegetable production areas (provisional land use data).

3.3.5 Metals

The agricultural loadings of metals are highly dependent on sediment movement, and concentrations in sediment are almost entirely of natural origin and may be considered as background levels. Reference to Figure 3.3-2 showing agricultural sediment loadings suggests the relative distribution of agricultural inputs of metals. Urban loadings, however, are far higher, and the urban land distribution shown in Figure 3.3-3 gives an indication of unit area load distribution.

3.4 MAJOR CONTRIBUTING AREAS FOR DIFFUSE SOURCES OF POLLUTANTS

There has been considerable concern as to the feasibility of using extrapolation techniques to identify areas of high potential loadings (sometimes referred to as "hot spots") arising from one or more land use activity. Using suspended sediment as an example, it can be seen from Figure 3.2-2 in the previous section that the northwestern Ohio region making up most of the Maumee River basin, and the southwestern Ontario region draining directly into Lake St. Clair are the primary high source areas for sediments of agricultural origin. If other sources are included, those predominantly urban areas such as Chicago, Detroit, Cleveland, Buffalo and Toronto and their surrounding suburban areas, can be added to the agricultural "hot spots". Furthermore, some areas with moderate agricultural loadings which have significant urban land may become "hot spots" when these two sources are combined. For example, the area around Toledo, Ohio, and the Hamilton-St. Catharines strip along the Niagara Peninsula are regions which probably contribute high sediment loads as a consequence of having more than one major contributing land use.

In general, the same picture will be seen for major contributing areas of phosphorus. Livestock sources of phosphorus can also be considered, but cannot be ranked on the same basis as other loadings because they are small by comparison, even in areas with large numbers of livestock. Livestock do not appear to add significantly to the locations of the phosphorus "hot spots" on a basin wide scale, but they are, nevertheless, quite noticeable in the southeastern Wisconsin and central Southwestern Ontario areas.

Major contributing areas of nitrogen are distributed somewhat differently from those of sediment and phosphorus. The Wisconsin, northwestern Indiana and southwestern Ontario regions are as high in nitrogen contributions as northwestern Ohio. Highly urbanized areas show up as "hot spots" for nitrogen as they did for suspended sediment and phosphorus and the effect of adding urban to agricultural loads in this case appears to make southern Michigan into an additional "hot spot" for nitrogen contributions.

For most other parameters, major contributing areas can be identified based on a single land use. For example, lead "hot spots" will correspond to areas of dense urban and transportation land use. Pesticides will generally be associated with the crops on which they are used, and so "hot spots" for atrazine, for example, will be seen to occur in southern

Michigan and northeastern Indiana where the corn density is high while those for the major fruit and vegetable insecticides will be in eastern Michigan, and along the U.S. and Canadian southwestern shore of Lake Ontario. The nature of these latter insecticides, however, is such that those in use today will not generally persist long enough to reach the Great Lakes waters.

4. REMEDIAL AND PREVENTATIVE STRATEGIES

4.1 GOALS

Task C recognized that the overriding goal in PLUARG activities resulting from the 1972 U.S.-Canada Great Lakes Water Quality Agreement was that of maintaining and enhancing the water quality of Great Lakes boundary waters. To achieve this goal will, of necessity, require management of many elements of the environment which directly or indirectly impact on the Great Lakes. It should be recognized, however, that the implementation of any water management practice designed to achieve that goal has the potential of creating secondary problems, some of which could conceivably be as serious as those being solved by the remedial measure. The primary theme of this section is that water management is inseparable from environmental management in its broadest context.

Approaches to environmental management historically have been simplified through artificial compartmentalization into component parts (Land, Air, Water). However, it is important to recognize that sound management requires consideration of the environment as a whole. Thus, it is inappropriate to advance a recommendation, management practice or remedial measure which has been structured singly to meet the goal of Great Lakes water quality if it has known or suspected deleterious consequences on some other aspect of the environment or on the social fabric of the basin, without considering the net result of the proposal. In all likelihood, optimal overall environmental management will require compromise in the degree to which many societal goals are met.

4.2 ROLE AND IMPORTANCE OF TASK C INPUT

Encompassed within the combined experience of Task C investigators was a broad base of technical expertise. There were also disciplinary biases related to the importance of different water and land use issues. Yet there were common threads linking components of the Task C effort which are perhaps unique. One of these threads was data -- data obtained from a Study Plan designed to provide input to meeting PLUARG's objectives. Another thread was that of familiarity with the watersheds under study. Still another thread was the development and operation of a data quality control program for all investigators. These, coupled with the broad disciplinary diversity of Task C's composition assigns special importance to the output of this group.

4.3 FACTORS FOR CONSIDERATION IN DEVELOPING AN APPROACH TO REMEDIAL MEASURES

Several important considerations have arisen from findings and subsequent discussions within Task C that relate to how remedial measures should be approached. These considerations are as follows:

1. Diffuse pollution does not arise uniformly from watersheds in the Great Lakes Basin. Close examination of pilot watershed information on forms, amounts and concentrations of pollutants demonstrates, in some cases, definable source areas. The source areas may represent

only a small portion of the total land area of the pilot watersheds and the same is probably true for the Great Lakes Basin as a whole. This finding, supported by unit area loading data, points to two principles that relate to implementing remedial measures when constrained by finite financial resources:

A. Installation or implementation of remedial or preventative measures to control diffuse pollutional sources should be aimed at those source areas in which the pollutant is generally at its highest concentration.

B. Remedial measures may not be required for large areas of land.

2. Deterioration of the Great Lakes through additions of persistent contaminants, although reversible in the long term, may be more serious than the aesthetic or eutrophication impacts because: (a) the lakes will require longer periods of time to clean themselves, and (b) small amounts of some toxic agents introduced infrequently can create long-term problems. Thus, the nature of the pollutant should be an important factor in ranking hazardous areas and dictating the degree of treatment required for a remedial measure.

3. An implementation program of remedial measures must be tailored to meet the unique features of the watershed in which they are placed to ensure long-term public acceptance.

4.4 OTHER CONSIDERATIONS

A series of remedial measure options should be developed indicating the disbenefits as well as the benefits which accrue for each measure in an attempt to clarify the following:

- How much will the measure reduce pollutant loadings?
- Are there local water quality benefits (i.e. upstream) to be recognized?
- What problems might arise in implementing the measure?
- Can the measure be maintained?
- Are there known or suspected adverse effects of the measure (environmental and/or resource use inefficiency).

4.5 SPECIFIC REMEDIAL MEASURE RECOMMENDATIONS

The following measures are those which appear, from the perspective of the Task C results, to be most likely to be technically feasible. Comments are made on the public acceptability, costs, indirect benefits or disbenefits, etc., of a remedial measure only where Task C activities led investigators into situations where these could be appraised realistically without excessive individual bias.

Since no Task C studies were formulated with the specific objective of demonstrating reductions in pollutant loadings from remedial measures, any such information contained in this section will be by way of estimates based on incidental or literature documented field observations.

4.5.1 Sediment

Sediment is contributed from urban and agricultural land at similar unit area loads. Although load reductions from each of these sources will have approximately the same impact in terms of total sediment, there may well be important qualitative and quantitative differences in the contaminants transported by this sediment. Also, sediments generated from forested land or through streambank erosion may carry less contaminants than sediments arising from urban or agricultural activities. The justification for sediment control is contained in Section 2.2.

4.5.1.1. Sediment from agricultural land use: Agricultural land contributes sediment to streams by a combination of sheet, rill, gully and bank erosion. The spatial loading pattern from these sources shows wide differences within individual farms, in extensive agricultural areas, and within the Great Lakes Basin. Of the agricultural sediment load, 60% may be generated from about 30% of the agricultural area of the basin because of the major differences in soil characteristics and cropping practices across the Great Lakes Basin. In an area consisting of a small number of farms, 80 to 90% of the sediment is generally contributed by only 15 to 20% of the land area i.e. the most hydrologically active area concept. It is clear that wide-spread remedial measures are neither feasible nor desirable. Measures need only be applied to those areas which are most hydrologically active, which normally occupy the land bordering drainage ways and natural stream courses.

In this "sensitive" area, modificiations to cultural practices are recommended to: i) reduce soil erosion rates; and ii) reduce the transport of eroded soil into the stream or drainage channel.

i) Reducing soil erosion rates can be accomplished by a number of well-tested techniques which either reduce the impact energy of rain drops (e.g. mulch or cover crops) or alter the soil or other conditions so as to lessen erodibility (e.g. maintaining soil structure by increasing organic matter content or by minimum tillage).

ii) Reducing transport of eroded soil to stream channels can be partly accomplished by application of established measures such as contour cropping, diversion terraces, etc. Of greater value will be the separation of cropping and cultivation activities from streams and drainage channels by vegetated "buffer strips" or "field borders" thereby reducing the velocity of runoff water and increasing infiltration leading to increased settling of sediments before reaching the stream. Dense vegetation will also act partially as a filter. Sediment thus precipitated is unlikely to be remobilized if the soil remains undisturbed. Grassed waterways will perform a similar function in areas where surface drainage is controlled and diverted away from stream banks and into artificial channels or conduits. These artificial channels should be designed for maximum stability by using bank slopes suitable for maintaining soil stability and vigorous vegetative cover. Maintenance practices should be designed to create as little disturbance as possible from cleaning and regrading operations. If soil is kept on the field, there will be less need for ditch cleaning operations.

Some aspects of agricultural land management directly influence the stability of stream banks and should be considered a part of any overall agricultural remedial strategy. Tillage operations close to stream banks can increase the susceptibility of the banks to slumping, and is an additional justification for maintaining vegetated buffer or border strips. Restricting the access of livestock to stream banks during periods of high soil moisture, such as in the spring months, also will reduce the incidence of bank instability and slumping. Subsurface drainage outlets into streams and ditches should be designed to give stability in terms of their resistance to disintegration or misalignment (e.g. use adequate length of rigid pipe) and in terms of minimizing scouring and undercutting of the stream or ditch bank (e.g. by providing erosion resistant protective material where necessary).

It should be emphasized that, in the northern sector of the Great Lakes Basin, 70 to 80% of the annual agricultural sediment load is delivered to streams between February and April during snowmelt and spring runoff events. To be effective, remedial measures must reduce erosion and sediment transport to streams during this critical period.

As a gross approximation, the treatment of the most active areas of the 30% of the agricultural part of the basin which is presently contributing 60% of the sediment load from agricultural land may have the potential to reduce this input by about 50%. Thus, an overall reduction of about 30% of the agricultural sediment load may be achieved by treating only 4.5 to 6% of the total agricultural land surface.

4.5.1.2 Sediment from urban land: Urban unit loadings of suspended sediment are relatively high, and probably do not vary greatly from one location to another within the Great Lakes Basin. Highest loads are generated from areas under construction. Remedial measures can be applied to these areas in the form of prevention or retention. Preventative measures include minimizing the disturbance of existing vegetation, revegetation or mulching of all exposed soil material and minimizing the gradients of cut or filled slopes. Retentive measures include the construction of settling basins for runoff or the establishment of vegetated borders or filter strips.

Within established urban areas, measures which will reduce sediment loads include storage and infiltration systems such as settling basins for storm runoff, and vegetated channels and infiltration areas. Mechanical removal of dust particles by street cleaning will further decrease sediment loads in storm runoff.

No determination has been made as to the degree of reduction in sediment loads which may be possible from urban lands. It may be reasonable to expect considerable reductions of sediment from construction sites if adequate control measures are established at the initiation of each development. This is an obvious remedial measure and locating the areas is simple because of permit requirements.

In existing urban environments, 50% reductions in sediment loads may be feasible, but this estimate is entirely speculative. With urban land occupying 3% of the land in the Great Lakes Basin (7% of the Lake Erie Basin), 50% reductions in current loads of about 1,000 kg/ha/yr would have a marked effect. It is suggested that this urban sediment be particularly subject to control for, while its phosphorus content may be relatively low, it is likely to contain higher levels of toxic contaminants such as trace metals and other deleterious substances such as hydrocarbons originating with motor vehicles, compared with sediments arising in the rural environment. Remedial strategies should take into account that the control of fine particles is most important because they have a much greater capacity for the transport of adsorbed pollutants.

4.5.1.3. <u>Sediments from forest land, streambanks and other land use activities:</u> Sediments are generated in forested areas at low levels which are probably difficult to control. Although some increases in these low levels accompany harvesting activities, simple application of good management (e.g. minimizing skidding routes; working in fine textured soil areas when frozen or snow covered) will be adequate to maintain the present low levels of sediment contribution. Protecting streams from damage by road construction, and leaving undisturbed buffer or border strips along streams will further ensure the success of good management practices.

Streambanks are influenced considerably by agricultural practices where streams flow through farming areas, and remedial measures for sediments from these were discussed under the section on agricultural sediments. Streambanks in urban and recreation areas are often subject to a variety of abuses. Management, protection, stabilization and vegetation will contribute to reduced streambank erosion in these areas. Streambanks elsewhere in the basin are eroding primarily through natural processes. The natural geologic movement of material is accelerated by poor design and construction of bridges, dams, utility corridors, etc. Nevertheless, the processes are largely uncontrollable and probably unimportant from a remedial standpoint because the sediments involved almost invariably contain low levels of pollutants. Thus, remedial activity has little potential benefit and is largely unwarranted.

The low levels of sediment loads from other land uses (e.g. sanitary land fills, transportation corridors) do not appear to be in need of remedial action, though it must be recognized that mismanagement may lead to hazardous inputs of sediment to streams.

4.5.2 Phosphorus

In general, the tendency of phosphorus to be sorbed by mineral soil particles and to be precipitated as metal hydrous oxides leads to a very close relationship between sediment and total phosphorus. Thus, the measures described above for the control of sediment yields from diffuse sources will serve to reduce phosphorus loads. Nevertheless, the two contaminants are not entirely interrelated and in some cases must be controlled by different remedial measures.

4.5.2.1. Phosphorus from agricultural land use: In some cases, agricultural land yields phosphorus at relatively high rates due to a variety of factors. The high natural soil fertility of some areas may be contributory as it leads to the eroded sediments from these soils having a high phosphorus content. In such areas, sediment control measures will be especially effective in reducing phosphorus. The natural phosphorus content of some soils can be enriched from repeated fertilizer and manure applications. In the zones which are most hydrologically active and which yield eroded soils as sediment to streams, measures designed to minimize the enrichment of these soils with phosphorus will serve to decrease phosphorus loads, but only to a limited degree. Education should be intensified to encourage farmers to utilize phosphatic fertilizers only at levels required for "optimum" crop production. However, measures which restrict phosphorus inputs as fertilizer or manure to those recommended from a soil phosphorus plant availability test may have very limited impact in improving water quality because of the relatively high natural phosphorus content of most soils used for intensive agriculture.

Soluble phosphorus in runoff water from the most hydrologically active areas may be increased by poor management of phosphorus fertilizer or manures. Specifically, failure to incorporate these materials into the soil can lead to high concentrations of soluble phosphorus in runoff water. Remedial measures should encourage the incorporation of manure into the soil as soon as possible after application. Most phosphatic fertilizers are applied in bands because of the decreased availability of broadcast materials. Broadcasting of fertilizers without immediate plowdown should be discouraged in areas where water quality may be affected.

Direct manure inputs from runoff or seepage from manure storage or livestock feeding areas add phosphorus to streams primarily in soluble forms. Remedial measures are recommended which will separate livestock facilities from streams unless runoff and seepage is contained within the operation. The degree of separation necessary to protect water quality depends on soil type, slope, climate and other features of each site. Guidelines should be prepared which will result in the siting of future operations in non-hazardous areas. Furthermore, existing operations need runoff control measures if stream contamination is evident. Runoff should be contained and then pumped or transported to non-hazardous areas for disposal or use for crop production. Livestock defecating directly into streams while watering is an unquantified, but probably minor, source of phosphorus. It can be controlled by restricting access to streams which cross pastures, but management and costs of such a measure may be unacceptable.

Other agricultural sources of phosphorus can be considered for control by site specific measures. Examples are those farm silos from which drainage liquor is allowed to flow into a stream or into a farm drainage system leading to a stream. Farm yard and milk-house drainage has also been found to contaminate sub-surface drain systems. Connections from these sources to field drainage systems should be traced and eliminated, with contaminated water being diverted instead into seepage disposal beds, or stored and pumped for land disposal.

Organic soils which have been drained may yield large quantities of phosphorus to drainage water because of high soil decomposition rates, and because of fertilizer applications for crop production. In some instances, these fertilizer applications are excessive, although management recommendations are available which will keep application rates to levels which meet crop needs. Following these recommendations will reduce phosphorus loadings from these areas. The area to which this remedial measure might apply is, however, very small, consisting mainly of two locations in Ontario, an area in New York near the south shore of Lake Ontario, and some sites scattered throughout Michigan.

In terms of priorities based on technical effectiveness (including the extent of controllable sources), it is suggested that the remedial measures which can be utilized for phosphorus reduction from agricultural land should be applied in the most hydrologically active areas as follows: i) reduction of sediment from soil erosion: ii) control of runoff from manure storage and livestock feeding areas and the incorporation of manure into the soil immediately after spreading; iii) restriction of applications of fertilizer phosphorus to "soil test" rates; and iv) control of drainage from silos and barn yards which are connected to subsurface field drains.

4.5.2.2. Phosphorus from urban land: As discussed previously, phosphorus levels in urban runoff are not excessively high. If sediment loads are controlled as indicated in Section 4.5.1.2, the bulk of the phosphorus will also be controlled.

Additional measures may further reduce phosphorus in urban runoff: control of wastes from pets, especially those deliberately deposited in runoff channels along the edge of pavements; control of leaves in the fall, especially the burning of leaves in road side gutters where ash is washed away in the next rain; more care in the spreading of phosphorus fertilizer on park and grassed land along streets and highways, some of which falls on paved surfaces is washed by rain into nearby streams.

A further problem specific to certain urban areas is that of the combined sewer system. When overflows occur, untreated wastes containing phosphorus are discharged to streams with runoff water. Combined systems have the advantage, however, that street and storm sewer flushing is possible, and if overflows seldom occur, most runoff is treated before discharge.

4.5.2.3. Phosphorus from other land uses: Phosphorus is present in all sediments discharged to streams and the control of this sediment will suffice to control this phosphorus.

Sewage sludge disposal on land is a source of phosphorus similar to the spreading of farmyard manure. Plowdown requirements should be similar to those suggested for manure.

Private waste disposal systems (septic tanks) are a controllable source of soluble phosphorus in many rural watersheds. Septic tanks may fail and lead to discharges of phosphorus by being located near streams or ditches in either soils which are too permeable (sands and gravels) for adequate phosphorus fixation, or soils which are of such low permeability that effluent rises to the surface and flows into surface channels. These situations can often be corrected by setting back seepage beds away from streams or ditches, and replacing unsuitable soil with fill of appropriate characteristics prior to seepage bed installation. In uncorrectable situations such as shallow soils over bedrock or sands where separation from the stream and/or soil replacement by fill is impracticable, holding tanks are necessary, which must be periodically pumped out. Where septic tank effluent pipes are connected directly to subsurface drainage systems, (e.g. field tile) correction should be simple and immediate, with installation of approved seepage beds. Inspection of private waste disposal systems installed prior to the tightening of local health department regulations in the last 5 to 10 years appears warranted to try to locate faulty or illegally by-passed systems.

4.5.3. Nitrogen

While not a parameter of major significance to lake water quality at this time, the high levels of nitrogen found in many upstream areas in both surface and ground water suggest that remedial measures are desirable where practicable. While some nitrogen is associated with sediments, and will therefore be controlled by remedial measures implemented for sediment, the most abundant form of nitrogen is the highly soluble nitrate ion which moves freely through soils and into drainage systems and groundwater. Unfortunately, many remedial measures designed to control phosphorus or sediment result in additional flow of contaminated water through the soil to drainage systems or groundwater. While achieving their objective of retaining phosphorus, they may result in additional loads of nitrate entering groundwaters.

4.5.3.1. Nitrogen from agricultural land: Evidence suggests that much nitrogen originates from either soil organic matter undergoing mineralization with successive years of cultivation, or as fertilizer or manure nitrogen which is added to promote crop growth. Improved efficiency in the use of the added sources would reduce leaching losses. Optimum timing of applications, matching rates of application to crop needs and planting cover crops after harvest of the main crop to take up excess available nitrogen will reduce these losses. An adequate soil test for determining soil available nitrogen is currently needed.

Many of the suggested measures for control of soluble phosphorus from manure storage and livestock operations also reduce concentrations of nitrogen in runoff, but will do little to reduce leaching to groundwater or to tile drains. Tile drains should not be placed under unpaved manure storage or livestock feeding areas if nitrogen is to be kept out of streams. Best remedial measure for these sites is probably the roofing over of areas where manure is deposited so that the manure will dry out and the nitrogen will not be leached into groundwater or drainage systems by rainfall and snow-melt.

Once water of high nitrate content enters a stream or groundwater the potential exists for denitrification, resulting in the return of nitrogen to the atmosphere. PLUARG studies suggest that stream renovation measures which include the revegetation of stream banks with trees and shrubs may create conditions conducive to denitrification.

4.5.3.2. Nitrogen from urban land: Since most runoff from urban lands originates from paved areas, the measures suggested previously for control of sediment and phosphorus will have a similar effect in reducing runoff nitrogen from this land use, but may increase the amounts reaching groundwater. Heavy fertilization of lawns and gardens in urban areas also will enrich groundwater in these areas. Education to encourage the reduced usage of lawn fertilizer is urged.

4.5.3.3. Nitrogen from other land uses: From most other land uses (e.g. forest, recreation, transportation), nitrogen is discharged to streams at low levels which are essentially uncontrollable and generally represent natural background levels and precipitation inputs.

Private waste, sewage sludge and refuse disposal present a potential for mineralization and nitrification of organic nitrogen and consequent leaching of nitrate to groundwater or drainage systems. Little appears feasible by way of control of these situations, since nitrogen losses are to be expected. For example, when nitrogen is leaching from a septic tank effluent disposal area, the system is probably working as it was designed to do.

Sewage sludge applications can be controlled, as suggested for manure, by matching nitrogen applications with crop requirements, and applying at times appropriate for optimum crop uptake.

4.5.4 Chloride

The major diffuse source of chloride in the Great Lakes Basin arises from the use of salt for highway de-icing. Remedial measures must rely on minimizing usage, and protecting storage areas from leaching by rainwater or snow-melt, i.e., covered storage. The dumping of salt-laden snow and ice removed from streets into ditches, rivers or directly to the lakes should be discouraged. New innovative methods of highway de-icing are urgently needed.

Chlorides also are leached from manure storage and livestock feeding areas, and from private and public waste disposal sites (septic tanks and sanitary land fills). No technically-feasible methods of control are available at this time and, in view of the overwhelming influence of the highway source, the development of technology to control chlorides from these waste disposal sources has a low priority.

4.5.5. Pesticides

Pesticides are best dividided into their two main broad groups, namely, insecticides and herbicides:

4.5.5.1. Insecticides: Most insecticides in use today are non-persistent soluble compounds of short-term high toxicity. When properly applied little danger is presented by these materials as far as can be ascertained from present toxicological information. Careless handling, misuse and spillage have been found to lead to stream contamination. Strict enforcement of regulations, adequate training of users and general education on ways to minimize usage will contribute to lowering incidences of environmental contamination.

Usage is not restricted to the agricultural sector, but is common in urban household and garden use, semi-industrial operations such as mushroom houses and greenhouses, and, to some degree, in forestry. Industrial waste disposal sites are also a potential source if these materials are deposited in them. For all of these sources, the same requirements should apply, i.e., recognize the hazard, minimize usage, and eliminate pathways by which the material may enter water systems.

4.5.5.2. Herbicides: Today's herbicides are used widely for weed control in agriculture and on utility corridors. They are generally soluble materials of low toxicity, with relative persistence greater than the currently used insecticides, but less than the older and no longer used insecticide materials.

Although no evidence exists of environmental damage, the rates at which atrazine (a herbicide used for corn culture) is showing up in monitoring may be cause for concern. This soluble material is present in runoff and tile drainage water from fields on which it is used, and may persist in soils upwards of 2 years after use. Other materials can be substituted for atrazine under appropriate weed conditions, and may not persist long enough to appear in drainage water. To reduce atrazine levels to guard against future problems (should this material eventually be linked with environmental health concerns), it is suggested that education and extension programs be aimed at reducing excessive usage where this occurs, especially in the most hydrologically-active areas and encouraging the use of less persistent materials.

Herbicides used in crops other than corn have not appeared at other than trace levels in agricultural drainage. However, these same materials are used quite widely for control of weeds on roadsides, ditches, utility corridors, etc. While application personnel are generally aware of the dangers of sprays damaging crops and garden plants, additional education is needed to keep sprays from contaminating water in ditches and streams around which weeds are being controlled.

4.5.6. Organic Toxicants

The problems associated with organic toxicants in Great Lakes waters appear to be severe and growing. Few land uses are contributing these toxicants except by way of atmospheric fallout. Industrial air and water discharges; industrial wastes illegally dumped into streams, rivers or lakes; and wastes buried in land fills and wastes from discarded equipment all need to be strictly controlled and eliminated where necessary. The effects of organic toxicants on Great Lakes water are far from clear; thus, rigorous enforcement of strong legislative measures appears to be the most feasible way of dealing with the matter. Better monitoring and toxicological examination of new chemicals is essential, coupled with constant surveillance of the environment for evidence of contamination.

4.5.7. Trace Elements

Trace elements are contributed by all land uses. In the rural area, the levels are generally related to the natural content of geologic materials, and loading rates are directly proportional to sediment yields. Little can be done in these areas to reduce the loadings other than controlling sediment (already discussed) and avoiding contamination from manmade inputs to the rural environment such as industrial or municipal waste disposal (e.g. sewage sludge disposal).

In urban areas, trace metals are associated particularly with highway traffic. A variety of elements are lost from vehicles such as from wear of metallic parts, tires and brake linings. The lead contamination from gasoline consumption is an especially serious problem with a readily available solution, namely, eliminate leaded fuels as soon as possible.

The diversion of runoff from streets and parking lots into settling basins or infiltration areas would retain most of these trace elements in the soil rather than continuing their discharge to water. This, however, creates a new problem--contaminated soil. The problem is widespread, being associated with soils downwind of industrial areas, soils in sewage or industrial sludge disposal areas, and some soils which have been used in the past for orchards and vegetable growing in which metallic pesticides were used. All of these areas share the problem of identification. Once identified, measures to minimize soil loss to streams can be applied. This is especially important where massive disturbance, such as construction activities, takes place on these soils.

The use of metal-containing pesticides has been virtually eliminated, but the discharge of contaminated airborne wastes from industrial sources continues, and the disposal of industrial and municipal wastes in the rural environment is accelerating. Plans for disposal of industrial and urban wastes should emphasize recovery of toxic materials rather than land or atmospheric disposal, which may eventually lead to contamination of surface and groundwater resources.

4.5.8. Summary of Remedial Recommendations

The foregoing discussion indicates a number of overlapping measures which suggests there are some particularly effective approaches which might be taken to control diffuse sources of pollution in the Great Lakes:

Stream renovation, which includes streambank stabilization, revegetation, and the separation of all land use activities (agricultural, urban, industrial, recreation, etc.) from streams by vegetated "natural" buffer strips would take care of much of the sediment, phosphorus, and toxic materials problem throughout the basin.

Education and enforcement (where necessary) programs to reduce soil and sediment movement to streams from erosion of agricultural soils and construction sites are necessary. Reductions in soil erosion would also benefit farmers and developers to some extent which will help offset costs of remedial measures.

The degree of hydrologic activity of an area is an important concept, which will reduce the need for arbitrary application of control measures, and will make compliance more acceptable to the public if the most active areas can be easily identified.

Education programs to encourage optimum usage of chemicals (fertilizers, road salt, pesticides) in the environment by all land users would have some water quality benefits while being sound long-term policy for reducing wastes, reducing costs, and generally slowing resource depletion.

The bypassing of sewage treatment plants by overflow of combined sewer systems is environmentally and socially unacceptable, and this situation should be corrected by physical installation modifications as soon as possible.

Waste materials from urban and industrial sources cannot continue to be dispersed indefinitely into the air and land components of the environment as a response to reducing discharges to water. Environmental plans for the removal of particulates from smokestacks, nutrients from sewage treatment plants, toxic materials from industrial outfalls, etc., must consider the ultimate disposal of these materials, and emphasis should be placed on reducing the need for this disposal (e.g. reduced nutrient content in detergents; resource recovery internalized by industry).

The presence of toxic organic and inorganic materials in the total environment is a threat to the entire ecologic system (human as well as non-human), not just the Great Lakes. The problem of compounds being produced without knowledge of their persistence, toxicology or synergistic effects, and in many instances without methodology for their detection and monitoring, must be brought to the attention of the public and measures enacted to correct this situation. The public must be made aware of the potential costs of continuing to accept ever more sophisticated and chemically-oriented lifestyles. Ultimately, corrective measures, which should fall primarily on industry, will result in far greater costs for existing and new materials and products, and may lower perceived standards of living.

5. SIGNIFICANT GAPS AND FUTURE ACTIONS

5.1 RETROSPECTIVE VIEW OF PILOT WATERSHED STUDIES

Delays encountered in obtaining and installing monitoring equipment shortened the data collection period in several instances. A collection period of five years would have provided a more reliable data base so that climatic and other differences between years of record could have been more fully evaluated.

Study of a greater number of watersheds would have provided additional information on the geologic, soil, and vegetation factors for use in modeling activities and for extrapolation of data to the entire Great Lakes Basin.

Installation of adequate atmospheric input monitoring facilities would have added materially to the value of the pilot watershed studies. As of now, it is not known what proportion of the parameters collected in atmospheric collectors came from areas far-removed from the collectors and from resuspensions near the collectors.

Sufficient information was available at the start of PLUARG studies to name the main pollutant parameters of concern to the Great Lakes, but a larger list of parameters was selected for monitoring. That selection provided information applicable to some local water quality issues. However, it also resulted in the expenditure of resources that could have been concentrated on a more limited number of parameters of concern, which would have provided a better basis for answering the questions posed in the reference.

5.2 FUTURE NEEDS AND ACTIONS

5.2.1 Accelerated Public Education Program

Implementation of proposed remedial strategies will require that elected officials view the maintenance or improvement in water quality of the Great Lakes as significant national goals. Convincing decision makers of this requires public support and an accelerated public education program on nonpoint sources of pollution. In large measure, this program can be installed using the present extension and education programs in the U.S. and Canada. However, it is essential that this information be presented in a form to which the public can relate. An early aim should be to repackage information generated by PLUARG in forms acceptable to a diversity of publics. Technical information, economic and financial evaluations, benefits accruing from expenditures, and the implication of remedial measures on the overall well-being of the citizens of the geographic region need to be assessed and forcefully presented.

5.2.2. Development of Early Warning System for Pollutant Entry to the Great Lakes

Development of an early warning system should be undertaken as quickly as possible as a preventative measure against further pollution of the Great Lakes by toxic and hazardous chemicals. The warning system should be developed for known environmentally hazardous chemicals, and also for compounds still to be synthesized. Phosphorus has been emphasized in the PLUARG investigations, but is is likely that the effects of this pollutant can be reversed by lowering the loadings to the lakes. However, the effects of such materials as the polychlorinated biphenyls may take decades to reverse and no remedial practice will reverse such an effect. These are the materials which are exceedingly dangerous to the lakes and their inhabitants as well as to public health. An early warning system supported by strong cease-and-desist regulations is the only mechanism by which some environmental catastrophies can be avoided.

5.2.3 Monitoring in Pilot Watersheds

This activity should be continued for collection of flow data and for determination of concentrations of important parameters. Furthermore, if demonstrations of remedial practices (Item 5.2.4) are to be made in the pilot watershed areas, this monitoring capability (already in place) would allow an evaluation of the effectiveness of the remedial measures. A complete inventory of tributary and other loadings to the Great Lakes is essential.

5.2.4 Demonstration of Remedial Practices

A diversity of proposed remedial practice demonstrations should be established at three or four locations in the Great Lakes Basin. Capital and maintenance costs should be assessed and the effectiveness of the practices should be evaluated to determine not only the extent of control achieved but any secondary impacts the practice may have. As of now, only generalized costs can be associated with the benefits to be derived from the application of remedial measures; and, for those land uses that pose the greatest threats to the environment, more adequate information is needed on the "costs" of implementing or not implementing remedial practices.

5.2.5 Atmospheric Pollutants

Further research is required to develop methods for determining the sources of airborne pollutants. Methods for identifying locally generated pollutants and those generated external to the land area of concern need to be developed in order that recommendations for remedial control can be made at the point of origin.

5.2.6 Lake Response Models

The relationship between nutrient loadings -- both spatially and temporally -- and the eutrophication process is in need of new data. The questions of phosphorus availability, delivery ratios, and changes during transport are as yet unresolved and their resolution will require further research. Of particular concern is the development of a more complete understanding of the physical, biological and chemical processes in stream mouth areas and the nearshore zones of the lakes.

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