MANAGEMENT INFORMATION BASE
AND
OVERVIEW MODELLING

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DISCLAIMER

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Findings and conclusions are those of the authors and do not necessarily reflect the views of the Reference Group or its recommendations to the Commission.

This approach was developed to be applied at the level of the Great Lakes basin and individual lake basins. The use of this information base and methodology on small areas, of the size of an individual river basin, is inadvisable.

1. INTRODUCTION

SCOPE AND PURPOSE

The data management base developed for overview modelling and the modelling process itself have contributed to PLUARG's goal of determining the relative importance of all pollutant sources and in developing plans for pollution abatement from land sources. Overview modelling provides a means of comparing present and future trends in pollutant inputs to the lakes, as well as a methodology for measuring the effectiveness of alternative remedial programs applied to urban nonpoint, rural nonpoint, and municipal point sources.

The overview modelling process was used to examine pollutant inputs to southern Lake Huron, Lake Erie, and Lake Ontario. These waters were considered as a result of the need to implement further phosphorus reductions through international commitments under the Canada-U.S. Agreement on Great Lakes Water Quality. Lake Michigan should be examined further using overview modelling techniques together with better resolution of lake sub-basin environmental quality. Lake Superior should also be considered taking into account atmospheric inputs. While atmospheric inputs are not a major input relative to other sources in the lower lakes, remedial measures affecting atmospheric inputs should be considered in future overview modelling analyses of the upper lakes.

Most attention has been given to total phosphorus and, to a lesser extent at this stage, suspended solids. These are the pollutants of major concern originating from rural lands. However, metals and persistent organics deserve further attention. Although data for suspended solids are not as well developed as for total phosphorus, preliminary overview analysis is warranted at present. The data base should be upgraded in the future to permit a more rigorous analysis for all parameters.

Through the process of overview modelling, remedial programs are described in terms of types of land or point sources treated, tonnes of pollutant(s) removable, unit costs for load reductions and total program costs. Remedial programs have been examined as options which may be combined in various ways and, if necessary, simulated stepwise through time in scenario fashion. Some programs diminish in effectiveness through time as measured against a target load and target reduction. Consequently, simulations through time may feature augmentation of remedial measures in types and/or intensities of programs in order to offset the effects of new growth on target loadings.

In general, the U.S. and Canadian methods are similar and results are comparable and additive. There are differences in detail which are necessitated by differences in data collection systems and definitions. The phosphorus-removal measures[9] have been applied in overview modelling for municipal phosphorus control; descriptions of the technology are found in the Research Advisory Board report[25]. This report includes additional data on rural and urban nonpoint phosphorus and sediment control measures. Further information the pilot watershed studies is contained in the PLUARG technical report series[4]. Information on urban nonpoint unit area loads (UAL's) of pollutants, as well as remedial program costs and effectiveness, are contained in a series of technical notes [31], [32],[33] which will later be consolidated and published as a member of the PLUARG technical report series.

GENERAL FEATURES OF OVERVIEW MODELLING

One of the central concepts basic to the overview modelling methodology is that of "land use" and "land form", and how these two characteristics interact to determine the level of diffuse pollutant load from a given land area. Land use is commonly accepted as a principle factor affecting diffuse loads of total phosphorus, suspended sediment, and other pollutants. However, it is also known that several other factors directly affect diffuse loads; for example, slope, soil texture and fertility, impervious areas, drainage density and vegetative cover in stream valleys, among others. These latter characteristics were combined to arrive at a description of the land form for a given sub-basin, i.e., the interposition of relief factors on soil texture. Thus, land form is considered to be the second dominant attribute determining the level of diffuse pollutant load generated from a specific area. This conclusion is consistent with the findings of technical PLUARG investigations. Task C pilot watershed studies and Task D studies support the hypothesis that slope and soil texture significantly affect diffuse loads and that, in particular, row cropping and fine-textured soils combine to produce the most severe condition, all other factors equal (areas of fine-textured soils are shown for the entire Great Lakes basin in Figure 1). Therefore, for overview modelling purposes, the concept was adopted that a representative UAL could be assigned to a given sub-basin by identification of its predominant land use and land form characteristics; this approach has been applied to both rural and urban areas.

A computer modelling system was designed to accommodate such an approach for estimating diffuse source loadings of pollutants. Estimates of these loadings are generated in overview modelling as indicated from the following sources:

Rural lands: UAL's, as determined from PLUARG pilot basins and related studies, are applied to the Great Lakes basin classified according to land use and land form. Land form types are characterized by soils, physiography, drainage characteristics and natural vegetation. Land use type is based mainly on proportion of rowcrops, with a lesser influence by livestock abundance.

Urban lands: UAL's, as determined from PLUARG and related studies, are applied to all municipalities and proportions of individual municipalities classified according to sanitary waste system (separate sewers, combined sewers, or private waste disposal systems). The UAL's do not include contributions from treatment plant effluents.

Municipal point sources: per capita loads are estimated from literature values and agency data, and classified according to the type of treatment in effect at the municipal plants. Separate industrial point loads are also considered but, in the case of total phosphorus, these are relatively minor inputs.

The outputs from municipal point sources and rural and urban nonpoint sources are either contributed to main stem tributaries or directly to the lakes. In the former case, i.e., upstream inputs, transmission features of the river may be responsible for some proportion of the load being retained in lakes, reservoirs and/or estuaries. This retention is taken into account as data permit.

Changes in land use and consequent changes in the proportion of pollutants generated at different sources are based on population growth and settlement density. The growth or urban areas and loss in rural lands are calculated, and land newly incorporated into urban areas is held in a one-year transient category for the purpose of examining effects of remedial measures applied to developing lands.

Treatment measures are examined in terms of their proportionate reduction to UAL's and costs. The amount of pollutants potentially removable by various measures is of fundamental importance. Costs are examined in various ways – unit (per tonne) costs of reducing the load at its source, unit costs of reducing the load delivered to the lake, as well as annual program cost for a given lake. Costs for scaled intensity of remedial effort are expressed as total program costs and as incremental (or marginal) costs.

One of the main features of the overview model is its ability to facilitate the examination of future trends in the effectiveness and costs of specified pollutant control measures. This is of particular import when evaluating municipal point source measures. For example, the transient increase in population may decrease the reduction obtainable unless the degree of treatment is continually improved to offset greater generation of pollutants.

Much of the modelling effort has been directed toward assembling the large amount of information required to analyze pollutant loads and their variability among sources over time. The utility of simulation as a means of evaluating the effectiveness of various remedial alternatives is dependent on the availability of good information. Further effort is needed in both areas; that is, maintaining currently useful data bases and refining the estimation of effectiveness and costs associated with integrated remedial programs.

MODEL DEVELOPMENT AND OPERATION

The computer algorithm used in this study was written in A Programming Language (APL) and was developed using a cascading system approach to represent a drainage basin [27]. The program is designed to extrapolate demographic trends and corresponding land use shifts in time and space within a given hydrologic region. Its utility as a management strategy assessment tool is accomplished by means of a three step process.

The first step involves building a mathematical description of a river drainage basin. A sub-watershed infrastructure is adopted (Figure 2), and a combination of demographic and geographic statistics for each section is collected which describes the base year conditions. These sections are arranged in cascading sequence in such a way that drainage proceeds from the headwaters, through a series of discrete entry points, to the mouth of the river. This arrangement accommodates urban land area expansions at the expense of adjacent rural land and allows for the application of transmission characteristics exhibited by a particular river. The net result is a two dimensional matrix of numbers which contains information in both an implied and explicit form.

The second component in the process is the construction and utilization of a UAL table for a particular pollutant of concern. The details concerning the development of a UAL table are discussed in full in a following section. This table is a matrix of numbers, each discrete element representing a pollutant load per unit area of land per annum. It is designed to provide UAL's for sections of the river basin matrix, each of which has a pair or numbers associated with it. These represent a land use number coupled with a land form number which intersect at some point in the UAL matrix to yield a discrete UAL value. Essentially, this is the completion of the descriptive activity in the process. The final step and integrative phase of the modelling effort are described below.

The matrices are manipulated by various program functions iteratively in time to produce annual and projected demographic data, land use data, and pollutant load data. The matrices and functions are subjected to a remedial measure implementation scenario (dictated by a management strategy data base) to produce reduced annual loadings of pollutants and associated implementation costs. The aim is to produce an evaluation of (A) the effectiveness of selected remedial programs on reducing loads to the lakes and (B) how the effectiveness of the programs changes through time with shifts in demographic and land use parameters. A more detailed discussion of the computer algorithm is presented in Appendix C along with samples of the model output tables.

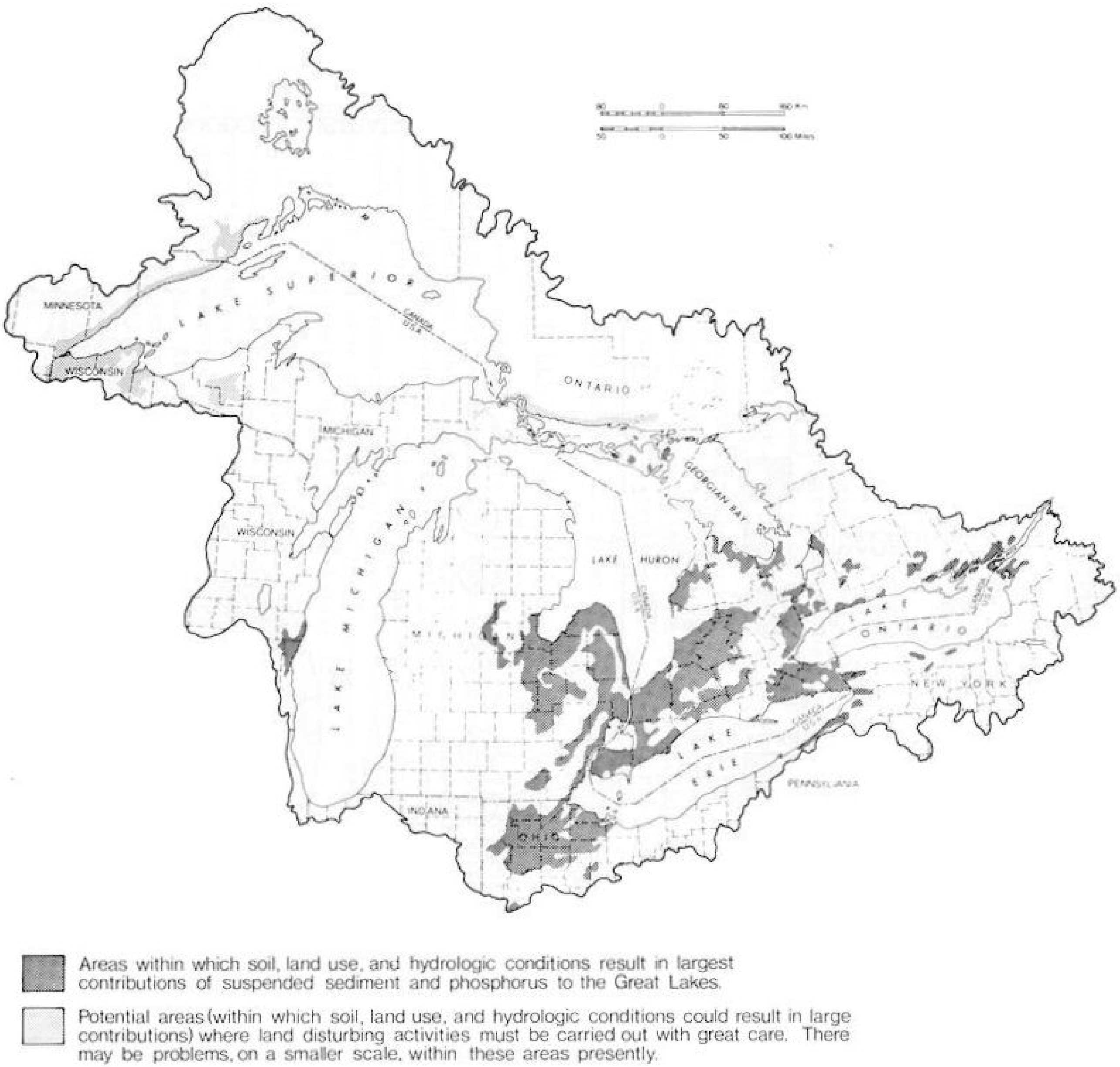


FIGURE 1: Regions Of Fine Textured Soils Requiring, Or Potentially Requiring Treatment For Erosion Control

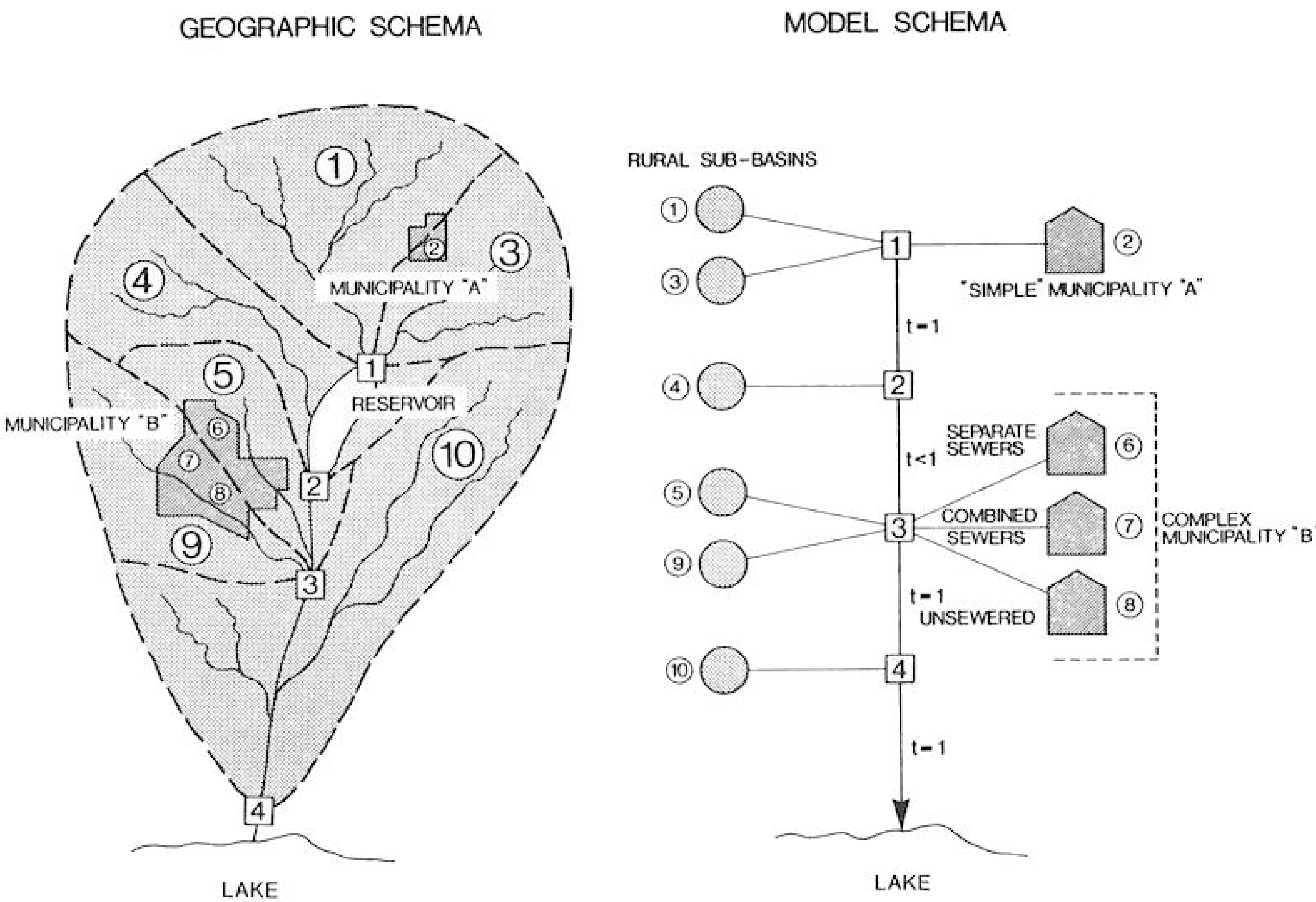


FIGURE 2: Watershed Model Illustration

2. INFORMATION BASE

GENERAL

An extensive information base was required as input to the mathematical algorithm. Demographic and geographic information (sewered populations; growth rates; sub-basin boundaries; river transmission characteristics; urban land-capture rates: separate, combined and unsewered areas; sub-basin land use and land form; areal soil texture distributions; etc.) was derived from a variety of sources in both the Canadian and U.S. efforts. A list of the requisite demographic input data and appropriate information sources has been compiled and presented in Table 1. This represents the body of information necessary for building a matrix representative of each river basin. The river matrix defines how the pollutant load to a lake will respond over time to changes in population, as well as specific point and nonpoint source remedial programs.

DEVELOPMENT OF POLLUTANT UNIT AREA LOAD (UAL) TABLES

Pollutant loading data were collected and assembled from PLUARG pilot watershed investigations, as well as numerous other studies (Table 1) which contained pertinent information on UAL's from specific Great Lakes watersheds. Additional data were obtained from existing water quality records for monitored upstream watersheds. This information was compiled and analyzed for the purpose of deriving UAL estimates representative of long-term average annual pollutant loads. This was done to accommodate the year-to-year meterologic fluctuations and their corresponding effect on total lake loads.

Each of the candidate basins providing an empirical loading measurement was scrutinized for the following characteristics: physiographic and soil textural homogeneity, land use statistics and demographic data. These data were recorded and a master list of candidates compiled presenting the basins in order or descending UAL. Rejections were made at this stage based on two criteria. If a candidate basin contained a population or industrial point source which could have biased the UAL by ten percent or more, it was considered unsuitable for further consideration. Secondly, basins were rejected if insufficiently homogeneous in land use and land form. Clustering of data in relation to use and form was sufficient to create UAL tables for rural diffuse sources. The final Canadian and U.S. rural UAL tables for total phosphorus are presented in Tables 6 and 7, respectively, while Table 8 contains the UAL matrix used in Canada for the analysis of rural suspended solids loads to the Great Lakes.

A single UAL table was applied in both the U.S. and Canadian analyses of total phosphorus loads from diffuse sources (Table 9). This urban UAL table was generated from information contained in a technical note[33] prepared for PLUARG.

Inspection of Table 9 reveals the specific urban diffuse categories defined in the context of overview modelling. The category "Developing Land" refers to those rural areas which shift each year into the urban category to accommodate population growth and urban expansion. It should be noted that the UAL of suspended solids from developing urban areas is estimated to be 225 metric tons per km^2 per year, but the UAL of total phosphorus is assumed to be a function of the urban land use category assigned to these areas after the one year developing or transition period. For example, rural land developing due to the growth of an urban area having separate sewers and high industrial activity will be assigned a UAL of 300 kg of total phosphorus per km^2 per year over the transition period.

Verification of UAL tables was achieved by comparing river mouth loads predicted by the model to monitored river mouth loads for selected watersheds. Some refinement of the rural UAL table for total phosphorus was achieved by this procedure, but only in instances where disagreement of lake loadings at a regional scale dictated an adjustment.

The river mouth loads used in the Canadian verification step were calculated by Ongley [38] from the Ontario Ministry of the Environment water quality records. The watersheds involved were dictated by the Ongley data base, but coverage was adequate. A comparison of predicted and monitored loads of total phosphorus and suspended solids from Canadian watersheds is given in Tables 2 and 5, respectively. In Table 2, the marked difference in loadings between the two multi-year mean columns is due, in part, to the effect of phosphorus detergent legislation which came into effect in Ontario in 1972.

The U.S. predicted loads were compared with calculated loads documented in a Task D PLUARG technical report[50]. Model predictions and monitored loads of total phosphorus from specified hydrologic units in Lakes Erie, Ontario, and Huron are presented in Table 3.

Inspection of the data contained in Tables 2 through 5 reveals that application of the final UAL tables (Tables 6, 7, 8 and 9) resulted in close agreement between model estimates and monitored loads in both the U.S. and Canadian efforts. It should be re-emphasized that the model predictions are designed to approximate expected annual lake loads given meteorological conditions representative of the historical average, e.g., mean annual precipitation. The fact that the model predictions and the 1975 monitored loading data are in good agreement would seem to indicate that 1975 meterological conditions were similar to the historical average. Any comparison of predicted and monitored loads must be carried out with a recognition that the annual load to any given lake is subject to natural variations from year to year. However, loadings from the various diffuse sources may be expected to remain proportional to one another through these fluctuations.

USE / FORM CLASSIFICATION - UNITED STATES BASIN

In the U.S. overview modelling analysis, lands draining to Lake Michigan and Lake Superior were not classified according to the methodology to be discussed in this section. Figures 3b, 4b and 5b delineate the regions considered in the study within the U.S. portion of the Great Lakes Basin.

TABLE 1: Watershed Matrix Information Sources

INFORMATION BASE ITEMS	REFERENCE NUMBER IN BIBLIOGRAPHY	
	UNITED STATES	CANADA
Urban Populations	3, 8, 57, 58	44
Population Growth Rates	8, 57	39, 44, 48, 55, 63
Land Capture Rates	8, 55, 57	48, 55, 63
Sewered Populations	24, 56, 59	37
Per Capita Inputs	3, 5, 7, 13, 15, 17, 23	23, 37
Combined Sewered Areas	2, 3, 59	1
Separate Sewered Areas	2, 3, 58	1
Unit Area Loads	19, 32, 33 50, 51, 60, 61	4, 11, 14, 22, 26 32, 33, 38, 43, 46
Rural Land Uses	16, 20, 21, 36	4, 14, 22, 29, 53
Urban Land Uses	57	29
Land Form Information	51	6, 49, 62
Transmission Values	4, 5	28, 40, 42
Existing Treatment Data	3, 5, 7, 13, 17, 23	37

TABLE 2 . Summary by Major Basin of Monitored and Predicted Total Phosphorus Loads (Tonnes) for Selected Canadian Watersheds

Major Basin	Minor Basin	1975 Model Prediction	1975[1] MOE Data	'68-'76 Mean MOE Data	'72-'76 Mean MOE Data
Lake Erie	St. Clair	292.1	555.7	592.5	814.9
	Western	82.2	43.2	53.8	59.1
	Central	127.5	338.6	108.9	222.0
	Eastern	375.7	296.5	1,284.3	590.4
	TOTAL	1,377.5	1,234.0	2,039.5	1,686.4
Lake Ontario	Western	370.5	293.5	769.1	368.3
	Central	97.4	83.7	160.1	85.2
	Kingston	225.5	221.3	390.7	307.0
	St. Lawrence	25.0	123.9	39.1	110.3
	TOTAL	718.4	722.4	1,359.0	870.8
Georgian Bay	TOTAL	236.1	182.9	171.4	237.1
Lake Huron	TOTAL	382.3	328.0	345.5	334.3
T O T A L		2,714.3	2,467.3	3,915.4	3,127.6

[1] In cases where a 1975 mean was not available, preferably the 1972-76 multi-year mean was substituted, otherwise the 1968-71 multi-year mean was substituted.

TABLE 3: Summary by Major Basin of Monitored and Predicted Total Phosphorus Load (Tonnes) for Selected U.S. River Basin Groups [a]

Major Basin	River Basin Group	1975 Model Prediction	1975 Task D PLUARG Data[b]	'75-'76 Task D PLUARG Data
Lake Erie	4.1	7,207	6,704	*
	4.2	3,972	4,171	*
	4.3	3,085	3,108	*
	4.4	2,170 [c]	2,145 [c]	*
	Total	16,434	16,128	
Lake Huron	3.1	431	268	265
	3.2	1,773	1,496	1,617
	Total	2,204	1,764	1,882
Lake Ontario	5.1	829 [c]	1,162 [c]	1,302
	5.2	870	670	956
	5.3	176 [d]	225 [d]	378 [d]
	Total	1,875	2,057	2,636

[a] Specific watersheds included in each River Basin Group defined in (50)
[b] Total load as given in [50] plus direct point source load.
[c] Load from portion of hydrologic area 4.4.3 (Tonawanda complex) actually discharges to Lake Ontario.
d Does not include load from hydrologic areas 5.3.3 and 5.3.4 which discharges to St. Lawrence River
* 1976 monitoring data not available.

TABLE 4: Summary by Major Basin of Monitored and Predicted Total Phosphorus Load (Tonnes) for Selected Watersheds

(U.S. AND CANADIAN COMBINED DATA)

Major Basin	1975 Model Prediction	1976 Monitored Load
Lake Erie	17812	17362
Lake Huron	2822	2275
Lake Ontario	2593	2779
TOTAL	23227	22416

TABLE 5 : Summary by Major Basin of Monitored and Predicted Suspended Solids Load (Tonnes) For Selected Canadian Watersheds

Major Basin	Minor Basin	1975 Model Prediction	1975 MOE Data [1]	'68-'76 MOE Means
Lake Erie	St. Clair	243,445.4	139,545.3	259,261.6
	Western	32,619.4	13,922.4	16,218.0
	Central	42,401.1	116,508.7	71,896.4
	Eastern	92,218.4	149,599.4	168,930.3
	TOTAL	410,684.3	419,575.8	516,306.3
Lake Ontario	Western	108,815.7	90,559.0	113,650.8
	Central	19,102.2	18,759.0	18,474.5
	Kingston	50,042.2	58,433.4	60,514.3
	St. Lawrence	10,071.3	4,618.5	4,618.5
	TOTAL	188,031.4	172,369.9	197,258.1
Georgian Bay	TOTAL	72,945.1	81,923.1	52,939.3
Lake Huron	TOTAL	124,486.2	133,193.3	109,703.6
TOTAL		796,147.0	807,062.1	876,207.3

[1] In cases where a 1975 mean was not available, the 1968-76 multi-year mean was substituted.

TABLE 6: Total Phosphorus Unit Load By Land Use And Land Form (In Canada)

(Kg/km^2/yr)

FORM USE	FINE TEXTURED		MEDIUM TEXTURED		COARSE TEXTURED		MISC. TYPES
	1. LEVEL	2. SLOPING	3. LEVEL	4. SLOPING	5. LEVEL	6. SLOPING	7.
1. >50% Rowcrops Low Animal Dens.	150	X	63	X	23	X	87 (Sand On Clay)
2. >50% Rowcrops, med. Animal Dens.	X	X	X	X	27	X	X
3. 25-50% Rowcrops med. Animal Dens.	58	69	25	36	15	19	X
4. 25-50% Rowcrops High Animal Dens.	64	79	30	44	20	27	70 (Sand On Clay)
5. <25% Rowcrops Med Animal Dens.	35	42	10	15	10	12	45 (Sand On Clay)
6. <25% Rowcrops High Animal Dens.	40	51	14	20	14	16	X
7. > 60% Forest	20	20	10	10	10	10	9 (Shield)

TABLE 7: Total Phosphorus Unit Load By Land Use And Land Form (In U.S.A.)

($Kg/km^2/yr$)

USE \ FORM	FINE TEXTURED 1. LEVEL	FINE TEXTURED 2. SLOPING	MEDIUM TEXTURED 3. LEVEL	MEDIUM TEXTURED 4. SLOPING	COARSE TEXTURED 5. LEVEL	COARSE TEXTURED 6. SLOPING
1. Plowed Fields	106	125	87	87	23	63
2. Grassland	23	23	10	10	10	10
3. Dairy (Pasture)	40	63	23	23	10	10
4. Brush	23	23	23	23	23	23
5. Orchard/ Truck Crops	125	125	125	125	125	125
6. Forest	10	10	10	10	10	10
7. Wetlands	0	0	0	0	0	0
8. Miscellaneous [a]	250	200	150	100	50	25

[a] Values Do Not Conform To Land Form Heading Descriptions. Rather They Are Used For Special Cases Of Documented Evidence Of Existing Unit Area Loads In Specific Areas.

TABLE 8: Suspended Solids Unit Load By Land Use And Land Form (In Canada)

(Tonnes/km^2/yr)

USE \ FORM	FINE TEXTURED		MEDIUM TEXTURED		COARSE TEXTURED		MISC. TYPES
	1. LEVEL	2. SLOPING	3. LEVEL	4. SLOPING	5. LEVEL	6. SLOPING	7.
1. >50% Rowcrops Low Animal Dens.	60	X	25	X	11	X	41 (Sand On Clay)
2. >50% Rowcrops Med Animal Dens.	X	X	X	X	11	X	X
3. 25-50% Rowcrops Med Animal Dens.	25	30	5	3	5	6	X
4. 25-50% Rowcrops High Animal Dens,	25	30	5	8	5	6	33 (Sand On Clay)
5. <25% Rowcrops Med Animal Dens.	18	23	3.5	4	2.5	3	21 (Sand On Clay)
6. <25% Rowcrops High Animal Dens.	18	23	3.5	4	2.5	3	X
7. >60% Forest	4	4	2	2	2	2	2 (Shield)

TABLE 9: Urban Land Unit Area Loads For Total Phosphorus And Suspended Solids

LAND USE \ PARAMETER		TP ($Kg/km^2/yr$)	SS ($Tonnes/km^2/yr$)
Areas Of Combined	Hi Industry	1100	72.6
Sewer Systems	Med Industry	1000	74.3
	Low Industry	900	75.9
Areas Of Separated	Hi Industry	300	66.0
Sewer Systems	Med Industry	250	52.3
	Low Industry	125	38.5
Unsewered Areas		125	38.5
Areas Of Towns 1000 - 10000 Population		250	52.3

[a] For Developing Urban Land An Aggravated Unit Area Load Applies (For Suspended Solids $225t/km^2/yr$ Was Used For All Land Uses, However For Phosphorus A Simple Multiple Of The Values As They Appear Above Was Employed)

As previously discussed, differences in available information on land use in Canada and the U.S. necessitated a slightly different approach in arriving at a representative UAL of total phosphorus associated with a given sub-basin. The land use information for drainage areas within the U.S. was derived from remote sensing images taken from the NASA LANDSAT satellite. General Electric Co. obtained the raw data from NASA and interpreted the images using a highly interactive computer system. Individual images were subsequently broken down according to sub-basin boundaries and the land use information within each was described according to the following categories:

1. plowed fields
2. pasture
3. grassland (golf courses, prairies, etc.)
4. wetlands
5. urban (residential and commercial)
6. brush
7. orchards
8. forest

Sub-basin boundaries within a given watershed were derived from Conservation Needs Inventory hydrological maps of the U.S. Great Lakes region. Once these sub-basins were defined, their boundaries were transcribed to soil texture maps of the same region in order to arrive at an estimate of the soil texture breakdown within each sub-basin. The land use areas were then pro-rated on the soil textures present, thus providing an estimate of the areas of each land use existing on a specific soil texture. The overall UAL of total phosphorus from the sub-basin was then derived by means of a weighted average of the various land use and land form (soil texture) combinations estimated to be present. Additionally, information on the existing topography was used to grossly categorize the sub-basin area as either (A) generally sloping or (B) generally level. Once an overall UAL was estimated, the loading table was then accessed to identify the appropriate land use/land form intersection which, when input to the model, would most accurately represent the calculated value. This is the major difference between the U.S. and Canadian methodology. Whereas the Canadian sub-basins were of relatively homogeneous soil texture such that an appropriate use/form intersection could be assigned directly, the generally larger grid employed in the U.S. analysis required that the UAL table be used a priori to assigning any sub-basin a specific use/form intersection for entry into the input data base.

It should be noted here that previous studies of diffuse total phosphorus loads from sub-basins in the Maumee River basin 191 revealed that higher UAL's existed in these regions than would be derived from the land use/land form loading table. In such cases the documented loading value was applied in lieu of the table value - a method that was justified in order to improve the estimate of total phosphorus delivered to each lake. Similarly, several tributaries discharging to the southern U.S. portion of Lake Erie east of Sandusky are hydrologically unique due to their geologic and topographic characteristics. Many of these streams have been actively downcutting in highly erodible clay tills since the post-glacial decline in the level of Lake Erie. Consequently, many stream valleys have steep, unstable walls comprised of silts and clays which results in significant slumping of clay till into the channels.

Additionally, some of the medium-textured soils in these regions are underlaid by clay; this condition also leads to actual UAL's in excess of those normally expected through direct application of the UAL tables. Thus, during the process of model calibration, it was necessary to assign higher UAL's to sub-basins within these unique river basins, e.g., the Cuyahoga River, in order to obtain a reasonable fit with measured loads. In view of the previous discussion, this procedure was justified and provided a more realistic representation of these unique conditions.

Finally, because of the high UAL's of total phosphorus associated with areas characterized by plowed fields and fine-textured soils, the distribution of this land use/land form combination in the U.S. portion of the Great Lakes basin was examined. Soil types considered as fine-textured are presented in Appendix B. The regions containing the highest concentration of plowed fields on fine- textured soils are located in the western portion of the Lake Erie basin. The Maumee, Portage and Sandusky river basins each contain large acreages of this land use/land form classification, with over 55 percent of the area comprised of plowed fields and approximately 50 percent of the soils predominantly clay.

The only extensive concentrations of plowed fields on fine-textured soil in the Lake Huron basin are located in the Saginaw Bay region. Up to 50 percent of the land contained within sub-basins draining into Saginaw Bay is classified as plowed field, and this same area contains virtually all of the fine-textured soils present in the U.S. portion of the Lake Huron basin. Lake Ontario, on the other hand, has only a small percentage of its U.S. land drainage categorized as plowed fields, and only the Perch River basin contains a significant percentage of fine-textured soils.

USE/FORM CLASSIFICATION - CANADIAN BASIN

The land use/land form classification of rural land in the Ontario section of the Great Lakes drainage basin excluded land draining to the North Channel, Lake Superior, and Georgian Bay north of the Severn River. The land adjacent and draining into the St. Lawrence River from Kingston to Cornwall was included. Figures 3a, 4a and 5a clearly indicate the region considered within the context of the Canadian overview modelling analysis.

In order to provide some insight into the distribution of various agricultural lands and clay soil within the Canadian portion of the Great Lakes basin, those acreages of agricultural land having a significant amount of row crop production on clay soils were identified. Clays, both lacustrine and till plains, which are heavily row cropped are most abundant in the Lake Erie basin. More than 50 percent of the soils there are fine-textured clays and about half of this area contains 60 to 85 percent row crops, e.g., corn, soybeans, etc. Only a small portion (three percent) of the Lake Huron basin contains agricultural land with greater than 50 percent row crops grown on fine-textured soils. Lake Ontario has no significant acreage at all of this classification.

Clays which are moderately row cropped, i.e., 25 to 50 percent of the land in row crop production, are common in the southern Lake Huron and Lake Erie basins (about 10 percent in each). Less than one percent of the land in the Lake Ontario basin is characterized by moderate row cropping.

Each lake basin has between seven and ten percent of its land area characterized by the combination of clay soils and less than 25 percent row crop production. Of the various levels of row cropping acreage previously specified (>50%; 25 to 50%: <25%), this category is the most predominant in the Ontario basin. Estimates of the combined areas of the aforementioned categories within the Lake Erie, Lake Huron and Lake Ontario basins, respectively, are presented in Appendix A.

Maps were prepared for each major basin (Erie, Ontario, Huron and Georgian Bay) delineating regions of homogenous physiography and soil texture. Production of these maps was achieved by interposing the physiographic relief factors [(2)] upon a soil association map of southern Ontario [(49)]. Areas of the same soil texture were subdivided according to level or sloping topography to demarcate the land form regions for each of the basins.

The next task was to find the intersection between these areas of contiguous land form and the land use distribution within them. Land use statistics, obtained from Statistics Canada[(53)], on a township basis were summarized into more representative agricultural land use categories (based on percentage of: row crops, tree fruits, spring grains, close sown crops, hay and pasture and forest on farms). Animal densities were calculated for beef cows, poultry and pigs within each township. Data for those townships which were completely contained within a land form region were plotted on the maps previously constructed. The resulting maps were divided into a number of land use/land form intersection areas as dictated by differences in land use within a given land form region.

Canadian and United States land use/land form maps are presented in Figures 4, and 5. For purposes of clarity and comparability, both the U.S. and Canadian maps contain land use/land form designations as derived from the Canadian UAL table (Table 6). In order to arrive at this common use/from designation, it was first necessary to study the mix of land uses and soil textures present in each sub-basin. From this analysis, each sub-basin was then assigned the more representative use/form intersection consistent with the categorization scheme used in the Canadian UAL table. Thus, all sub-basin designations in Figures 3, and 5 have been "normalized" to the Canadian information base.

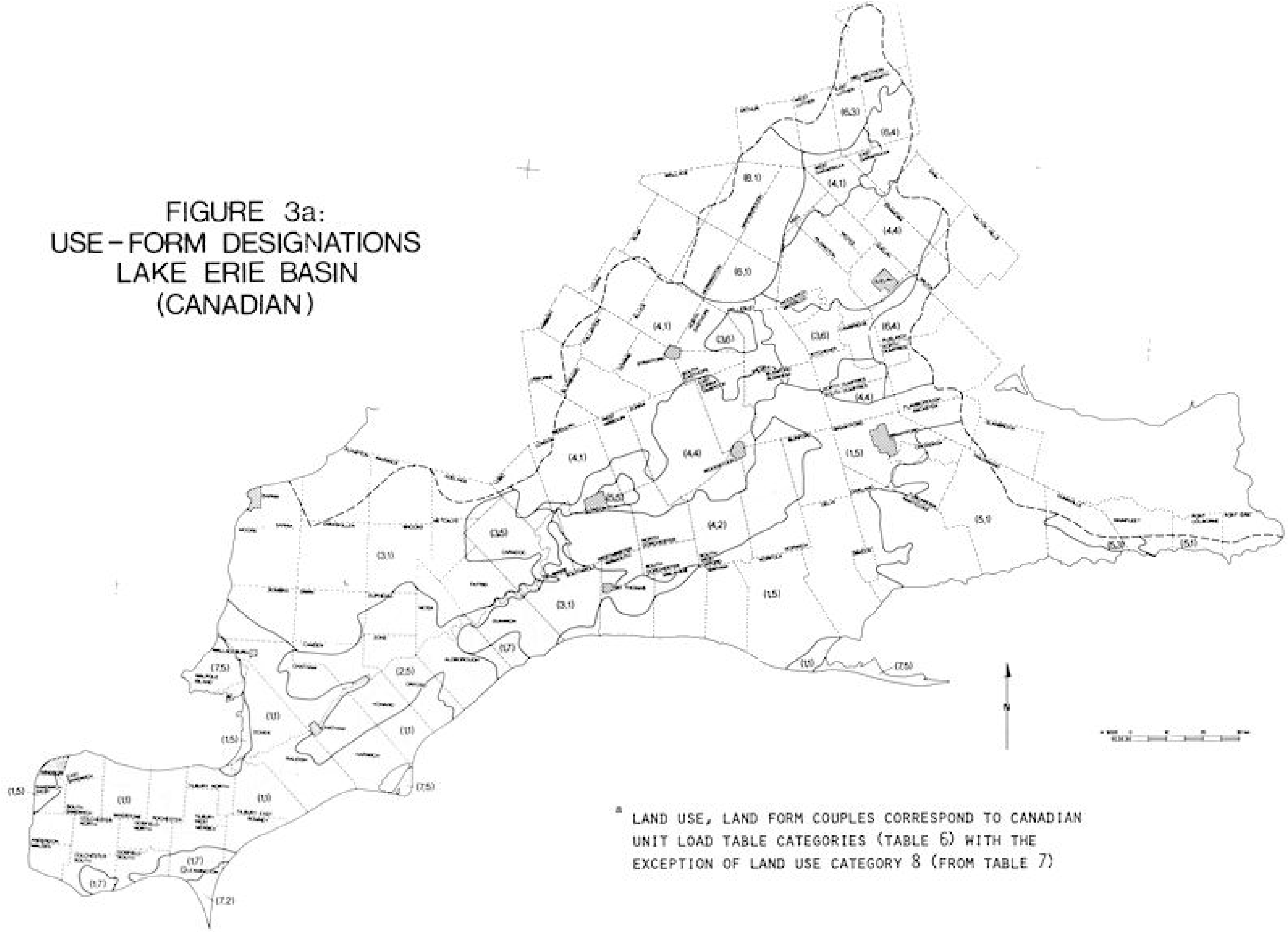
One exception to the above format is the land use category represented by the number 8. This particular land use designation has been used in all cases where either a documented UAL or a unique physiographic condition required the application of a UAL outside the range of values found in Table 7. As previously noted, such special cases existed in the Maumee basin (where documented UAL's exceeded 150 $kg/km^2/yr$), as well as in a few of the eastern Lake Erie U.S. river basins (where coarse- and medium-textured soils are underlaid by clay).

Those soils identified as fine-textured within the overview modelling framework are listed in Appendix B. This classification scheme delineates the various soil associations which are included in the fine-textured soil category presented in the UAL tables.

REMEDIAL PROGRAMS

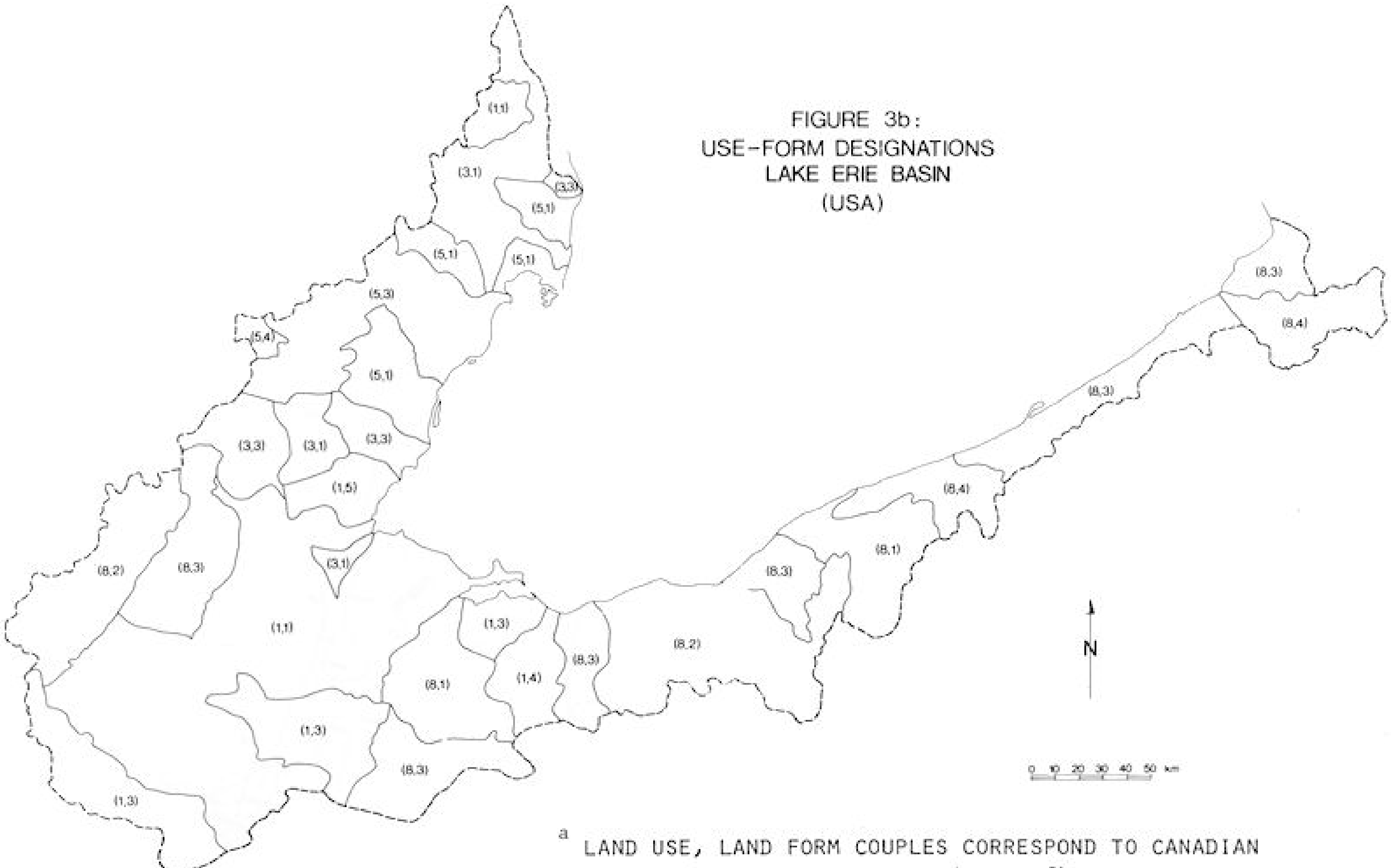
A complementary information base on management options and scenarios for controlling pollutant loads to the lakes was produced from sources listed in Table 10.

FIGURE 3a: USE-FORM DESIGNATIONS LAKE ERIE BASIN (CANADIAN)



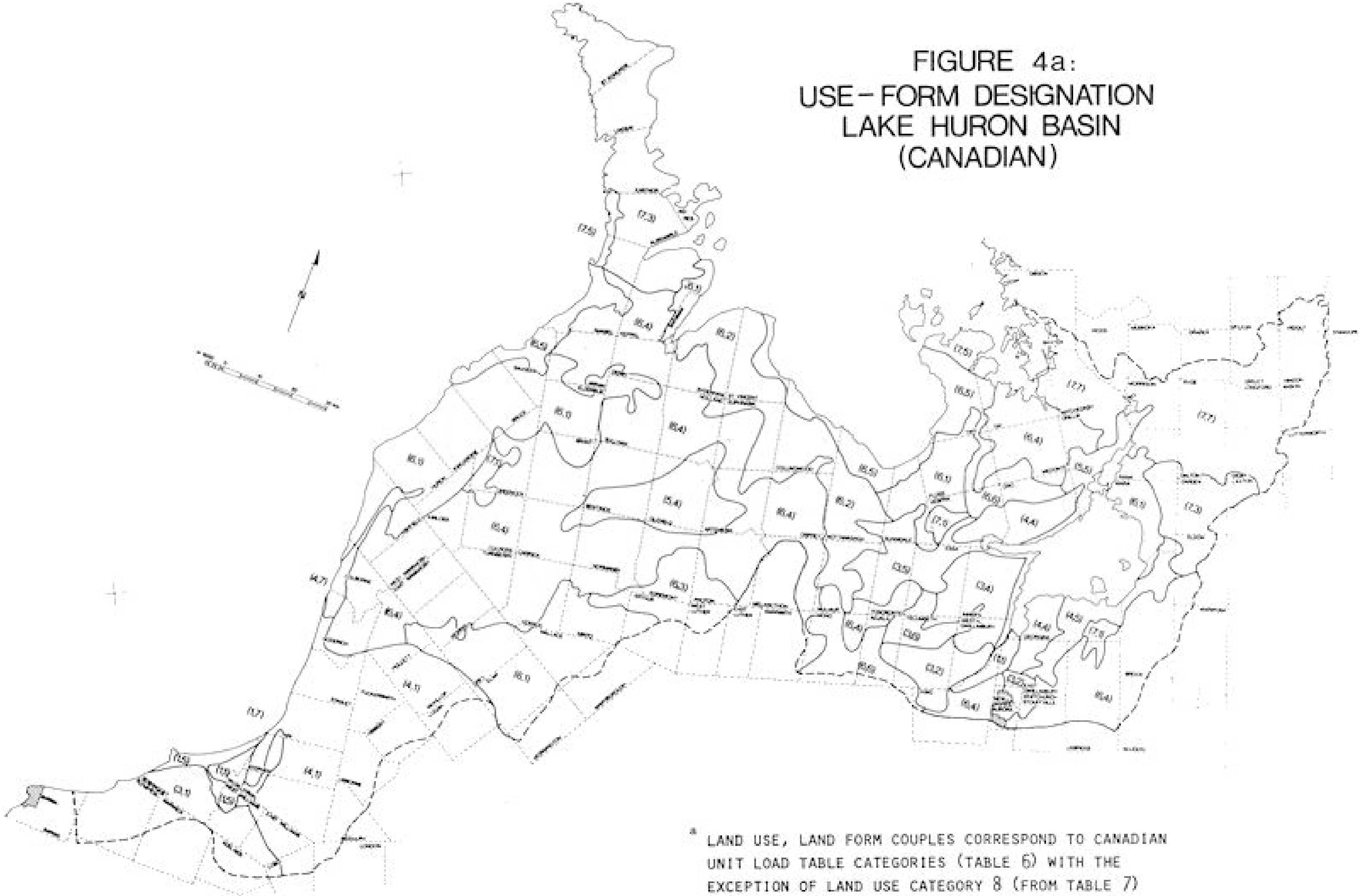
ª LAND USE, LAND FORM COUPLES CORRESPOND TO CANADIAN UNIT LOAD TABLE CATEGORIES (TABLE 6) WITH THE EXCEPTION OF LAND USE CATEGORY 8 (FROM TABLE 7)

FIGURE 3b:
USE-FORM DESIGNATIONS
LAKE ERIE BASIN
(USA)



[a] LAND USE, LAND FORM COUPLES CORRESPOND TO CANADIAN UNIT LOAD TABLE CATEGORIES (TABLE 6) WITH THE EXCEPTION OF LAND USE CATEGORY 8 (FROM TABLE 7)

FIGURE 4a:
USE-FORM DESIGNATION
LAKE HURON BASIN
(CANADIAN)



[a] LAND USE, LAND FORM COUPLES CORRESPOND TO CANADIAN UNIT LOAD TABLE CATEGORIES (TABLE 6) WITH THE EXCEPTION OF LAND USE CATEGORY 8 (FROM TABLE 7)

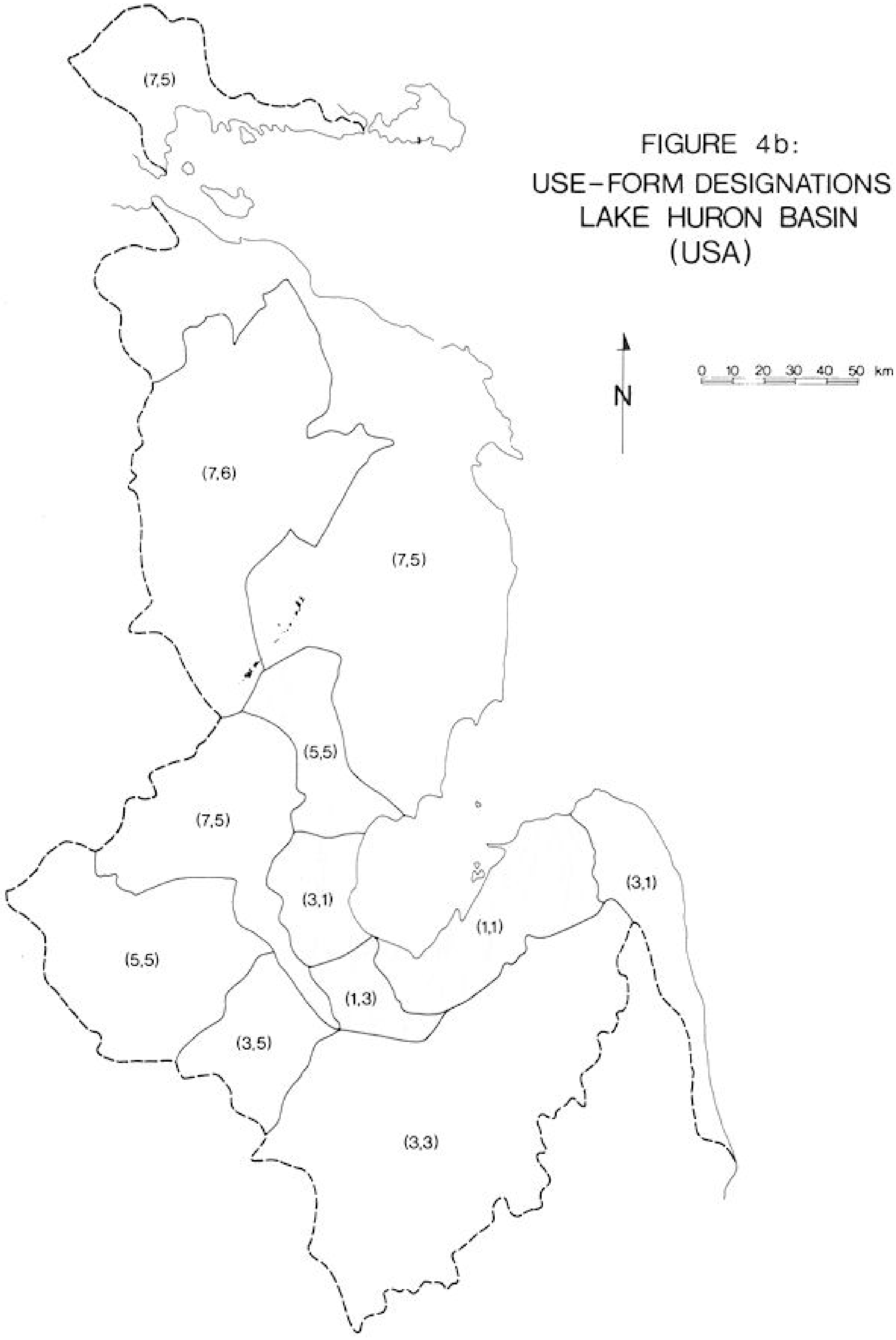


FIGURE 4b:
USE-FORM DESIGNATIONS
LAKE HURON BASIN
(USA)

[a] LAND USE, LAND FORM COUPLES CORRESPOND TO CANADIAN UNIT LOAD TABLE CATEGORIES (TABLE 6) WITH THE EXCEPTION OF LAND USE CATEGORY 8 (FROM TABLE 7)

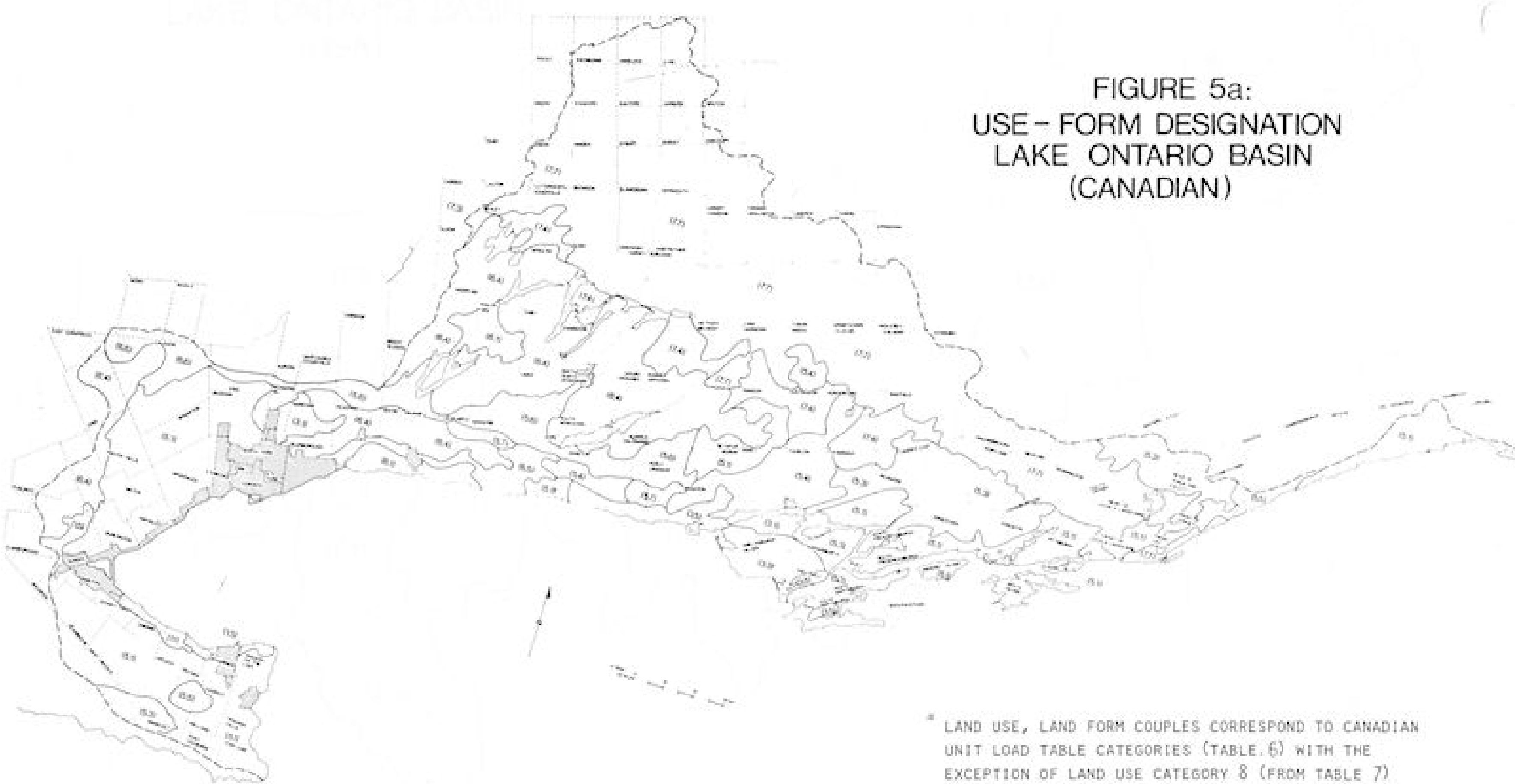
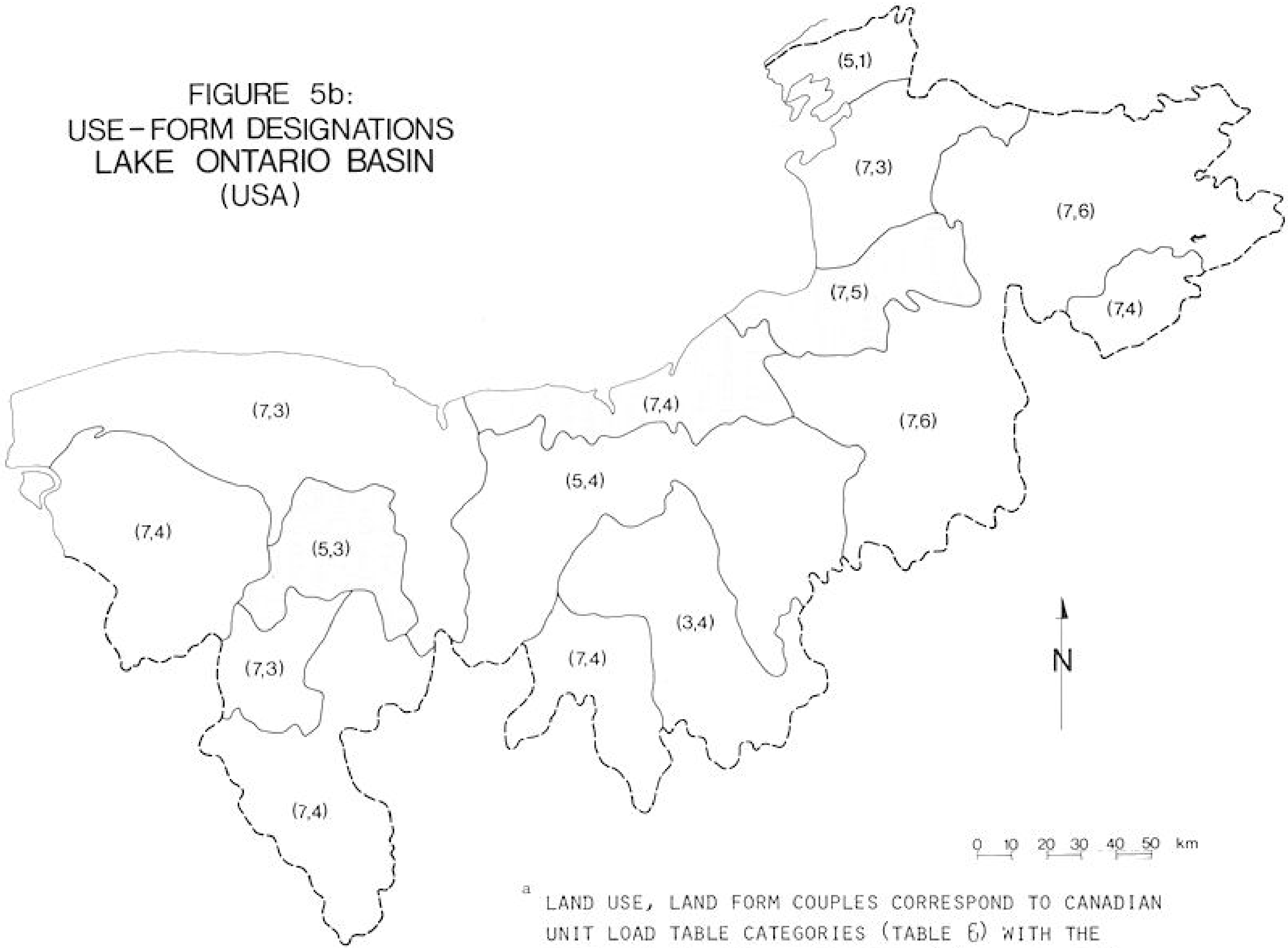


FIGURE 5a:
USE – FORM DESIGNATION
LAKE ONTARIO BASIN
(CANADIAN)

* LAND USE, LAND FORM COUPLES CORRESPOND TO CANADIAN UNIT LOAD TABLE CATEGORIES (TABLE. 6) WITH THE EXCEPTION OF LAND USE CATEGORY 8 (FROM TABLE 7)

FIGURE 5b:
USE-FORM DESIGNATIONS
LAKE ONTARIO BASIN
(USA)



[a] LAND USE, LAND FORM COUPLES CORRESPOND TO CANADIAN UNIT LOAD TABLE CATEGORIES (TABLE 6) WITH THE EXCEPTION OF LAND USE CATEGORY 8 (FROM TABLE 7)

The percent load reductions which could be achieved and the associated costs were determined. Each remedial measure is described by these two variables: (A) the percent reduction in pollutant load generated at the source and (B) annual cost. For remedial programs applied to municipal point sources, the cost is expressed as dollars spent per annum per 1,000 persons served by the treatment plant. In the case of remedial programs applied to both rural and urban diffuse sources, the cost is expressed as dollars spent per annum per km^2 of area within which the treatment is applied.

Remedial measures were developed for incrementally higher levels of total phosphorus reduction (at increasing total and marginal costs) from the following point and nonpoint sources:

1. effluents from municipal sewage treatment plants, considered at three levels of effort - ambient to 1.0 ppm total phosphorus, 1.0 ppm to 0.5, and 0.5 to 0.3 ppm.

2. urban runoff, considered at two levels of effort - reduction of pollutants and stormwater at source at the first level; the aforementioned plus detention and sedimentation of stormwater at the second level.

3. rural runoff, considered at three levels of effort (which vary in actual measures applied) - approximately 10%, 25% and 40%reduction in total phosphorus lost in runoff of sediment.

Although the specific programs for controlling total phosphorus loads from the above sources are similar for both the United States and Canada, there are some differences in the way the remedial measures data are applied in the U.S. and Canadian analyses. The results, however, are expected to be sufficiently comparable at this stage. Detailed comparisons will be needed at later stages of planning.

A. <u>Municipal Treatment Plants:</u>

Total phosphorus loads to a receiving water from a given treatment plant are a function of the sewered population, the per capita input of total phosphorus (kg/person/yr) and the treatment efficiency of the plant. In evaluating the effectiveness of a remedial program for reducing such loads, input data must be provided as to the percent of the load removed at the plant source and the cost per year to achieve this removal expressed as dollars spent per 1,000 people served. As part of the Water Quality Agreement of 1972, U.S. and Canadian treatment plants greater than 1 MGD capacity are committed to achieving 1 ppm residual total phosphorus concentrations in effluents to Lake Erie and Lake Ontario. For this study an intensified remedial program was evaluated which assumed compliance with a 0.5 ppm effluent standard for residual total phosphorus in effluents to Lakes Erie and Ontario by the year 1980. The reduction obtainable was calculated on the assumption that all treatment plants would have met the 1 ppm effluent "objective". Phosphorus control at treatment plants discharging to Lake Huron and its tributaries, which are not presently committed by Agreement to a 1 ppm effluent standard, was examined with reference to the existing treatment levels for two incremental levels of control: 1.0 ppm and 0.5 ppm residual total phosphorus concentration.

As shown in Table 10, the general information base for assessing the point source management scenarios was derived from several sources in both the U.S. and Canada. However, the primary source of cost information used in the evaluation of point source remedial programs was the 1977 Research Advisory Board report. [25] The consequent cumulative costs associated with each residual effluent concentration are shown in Table 11.

B. Urban Programs:

Remedial programs applied to reduce phosphorus loads from established urban areas are specified by type of services, i.e., unsewered (private systems), sanitary and storm sewers separated, and combined systems for towns of 10,000 people or more. In addition, remedial programs on sewered areas within towns greater than 10,000 population were further delineated on the basis of intensity of industrial development. Thus, a specific urban diffuse pollutant control strategy indicates the effectiveness and costs which may be expected from a specific mix of sewage services and industrial activity. For towns having populations between 1,000 and 10,000, the UAL applied coincides with that of towns characterized by medium industry and separate sewers.

Information on urban diffuse remedial programs was developed for PLUARG which incorporated information from a number of recent studies as indicated in Table 10. Both U.S. and Canadian remedial programs for reducing diffuse total phosphorus loads in established urban areas were evaluated on the basis of this probable cost and load reduction information. The percent load reductions and costs for each level of effort are given in Table 11.

PLUARG recommended that developing land, in most regions and under most circumstances, should have sediment control programs. Using information generated by the previous modelling procedures - namely urban land use projections as presented in Table 12 -- combined with management information specific to developing land sites [31] , a crude estimate was derived of costs associated with remedial measures on developing land in the drainage basins of Lakes Erie and Ontario.

C. Rural Programs:

Remedial programs on agricultural land are defined by a percent reduction in the UAL and an associated annual treatment cost per km^2 of land on which the treatment is applied. Due to minor but necessary differences between U.S. and Canadian methods of applying and evaluating rural remedial measures within the model framework, input data on percent UAL reductions and costs for the rural remedial programs were derived separately.

The same principle of considering remedial programs of varying intensity or levels of effort as was used in the analysis of urban diffuse loads is also used in the case of controlling diffuse loads from rural areas. The first level in the rural remedial program consists of various sound management (or good stewardship) measures to be applied on all agricultural lands. A detailed description of these measures is presented below. It is assumed that approximately a 10 percent reduction in the diffuse total phosphorus load is obtained at minimal cost per km^2.

The second level of treatment of rural diffuse loads consists of sound management on all agricultural land, plus more rigorous programs in areas where row crops are being grown on fine-textured soils (clay and fine loams). The incremental measures over and above sound management applied in these areas producing characteristic high UAL's of total phosphorus are meant to represent alternative combinations of practices which may be expected to produce similar total phosphorus load reductions (25 percent for a second level of effort). Thus, the incremental treatment over and above sound management may consist of butter strips, strip cropping, better drain construction and winter cover crops in one sub-basin, but a slightly different combination of measures to achieve the same load reduction in another sub-basin depending on types of farming, physiography and other factors. The same concept holds true in looking at a third level of treatment (40 percent reduction in total phosphorus load) in areas of row cropping on fine-textured soils.

A PLUARG report [4] provides an indepth description of specific Canadian rural diffuse control measures, including the total phosphorus load reductions achieved with each and the annual cost per unit area treated. The United States remedial programs were derived from information prepared by Stanley Consultants, Inc. for the Northeastern Illinois Planning Commission [52]. The three levels of rural controls applied in the U.S. analysis are discussed below. As a means of comparing rural treatment costs in the U.S. and Canada, the annual cost for treating agricultural land at a second level of effort in the U.S. basins of Lakes Erie, Ontario and Huron is approximately \$690 per km^2 of fine-textured soil, while the complementary figure in the Canadian basins is \$500 per km^2 of fine textured soils.

Level 1 treatment in both the U.S. and Canadian analysis is representative of sound management or good land stewardship. In the U.S., it consists of measures such as properly incorporating fertilizers and manure into the soil, avoiding adding excessive inorganic fertilizers, general conservation plowing techniques, minimizing tillage, mulching, avoiding farming on slopes near streams, etc. Such measures should likely be applied for sound conservation purposes if not for water pollution purposes and are considered to be in the landowner's own self-interest. Level 1 treatment is applied to all rural land which is designated as agricultural (plowed fields) according to the U.S. land classification, plus one-half of that land classified as grassland (pasture, golf courses, etc.). It is assumed that about 10 percent reduction in the diffuse total phosphorus load from these areas is obtained from Level 1 treatment.

The Level 2 program in the U.S. includes Level 1 plus the following measures or combinations of measures:

Conservation Tillage	\$3.80 to \$23.80/ha
Contour Strip Cropping	\$13.75/ha
Cover Crops	\$10.00/ha

Based on the above gross figures, it was estimated that an approximate 25 percent reduction in the diffuse total phosphorus load may be obtained at a cost of approximately \$15/ha. This average cost is to be applied specifically to the U.S. classification of land containing fine loam or clay soils with plowed fields in order to obtain total costs and load reductions. The cost per land area treated would be less if a less specific land classification were considered; i.e., if the total area of those rural sub-basins identified as being appropriate for treatment were considered, the average cost per hectare would be reduced. In other words, the cost for treating a regional area with a mix of land characteristics would be less per unit area than treating only those specific areas thought to require treatment, although the cost per tonne removed would be the same in either case.

Level 2 treatment is believed to be roughly comparable to "best management practices" often considered on the U.S. side. As in all types of nonpoint source treatment, the measures and costs for treatment for any land area can be highly variable and the costs and reductions estimated here can only be considered order of magnitude average estimates.

The U.S. Level 3 program includes Level 1 and Level 2 treatment plus:

Increased Crop Cover, Conservation Tillage and Strip Cropping	$12.50/ha
Spring Instead of Fall Plowing	$ 2.50/ha
Pasture Establishment/Management	$125.00/ha
Critical Area Protection	>$125.00/ha
Improved Drainage	$15.00 to $125.00/ha
Gradient Terracing	$ 2.50 to $ 70.00/ha
Grassed Waterways	$ 2.50 to $ 3.75/ha

Based on the above gross cost figures and information derived from Canadian Level 3 treatment, it was estimated that an additional 15 percent total phosphorus removal can be obtained over Level 2 treatment at an additional cost of roughly $40/ha (total removal 40%; total cost -$55/ha). Again, this average cost is to be applied specifically to the U.S. classification of land containing fine loam or clay soils with plowed fields in order to obtain total costs. Note that the relative increase in costs for Level 3 treatment is significantly higher (about four times) than the resulting increase in total phosphorus reduction obtained. This is consistent with the fact that, as the diffuse load is reduced, it becomes more difficult and expensive to gain additional marginal (incremental) phosphorus removals (analogous to increasing marginal costs associated with more stringent municipal effluent phosphorus controls).

TABLE 10: Remedial Program Information Sources

Remedial Measures Target Source And Information Type	Reference Numbers In Bibliography)	
	UNITED STATES	CANADA
Municipal Treatment Plant Effluents		
A) cost/1000 People of Achieving Residual Concentrations of 1, 0.5, and 0.3 ppm	9, 25	9, 25
Urban Area Diffuse Loading		
A) Annual Costs/km^2 B) % Reduction In UAL	1, 12, 30, 31	1, 12, 30, 31
Rural Area Diffuse Loadings		
A) Annual Costs/km^2 B) % Reduction in UAL	52	4

TABLE 11: Management Strategy Data For Input (Urban Point And Diffuse Sources)

MUNICIPAL PT. SOURCES		URBAN DIFFUSE SOURCES											
Target Residual P-Concentration	Annual Cost $ per 1000 People	Level of Program and Land Type		Combined Sewered Areas		Separated Sewer Areas						Unsewered Areas	
						High Industry		Medium Industry		Low Industry			
				% UAL [b]	$/km^2	% UAL [b]	$/km^2	% UAL [b]	$/km^2	% UAL[b]	$/km^2	% UAL [b]	$/km^2
1.0 ppm	2350	First Level [c]	Existing Urban Land	6	4400	20	4400	25	4400	50	4400	No Measures	
			New Urban Land	No New Combined Areas		20	4400	25	4400	50	4400	No Measures	
0.5 ppm	3340	Second Level [d]	Existing Urban Land	30	25000	40	14400	44	14400	63	14400	No Measures	
0.3 ppm	9370		New Urban Land	No New Combined Areas		44	7200	44	7200	44	7200	44	7200

a Towns of population 1000-10000 are treated the same as medium industry, separated sewered areas.

b These are cumulative remedial percentages applied to unit area loadings of the area type shown.

c First level treatment is an extensive street sweeping program plus measures to reduce flow.

d Second level treatment includes detention/sedimentation of overflows and stormwater from existing waste water treatment facilities and construction of detention/sedimentation systems for the newly developing areas.

TABLE 12: Great Lakes Drainage Basin A Urban Land Growth Projections 1975 To 2000

	Urban Land Area In 1975 (Km^2)			Estimated Urban Land Area In 2000 (Km^2)			Estimated Average Annual Increase In Urban Land (Km^2)		
BASIN	U.S.	CANADA	TOTAL	U.S.	CANADA	TOTAL	U.S.	CANADA	TOTAL
Erie	7706.7	670.0	8376.7	9378.4	1016.1	10394.5	66.9	13.8	80.7
Ontario	1701.7	1498.6	3200.3	1839.1	2494.0	4333.1	5.5	39.8	45.3
Huron & G. Bay	1688.7	127.6	1816.3	1904.3	204.4	2108.7	8.6	3.1	11.7
TOTAL	11097.1	2296.2	13393.3	13121.8	3714.5	16836.3	81.0	56.7	137.7

[a] only urban areas within regions considered (as delineated by Figures 3a through to 5b)

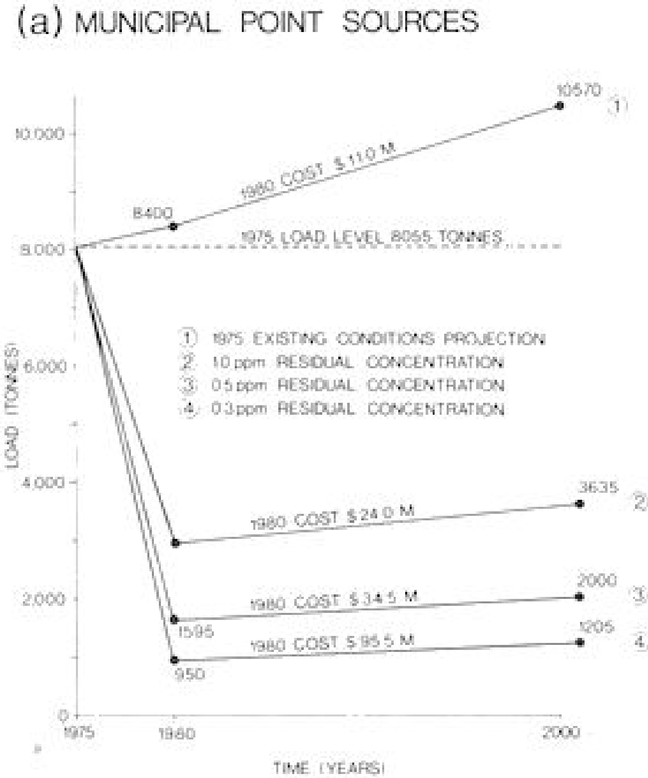
3. OVERVIEW MODELLING OUTPUT

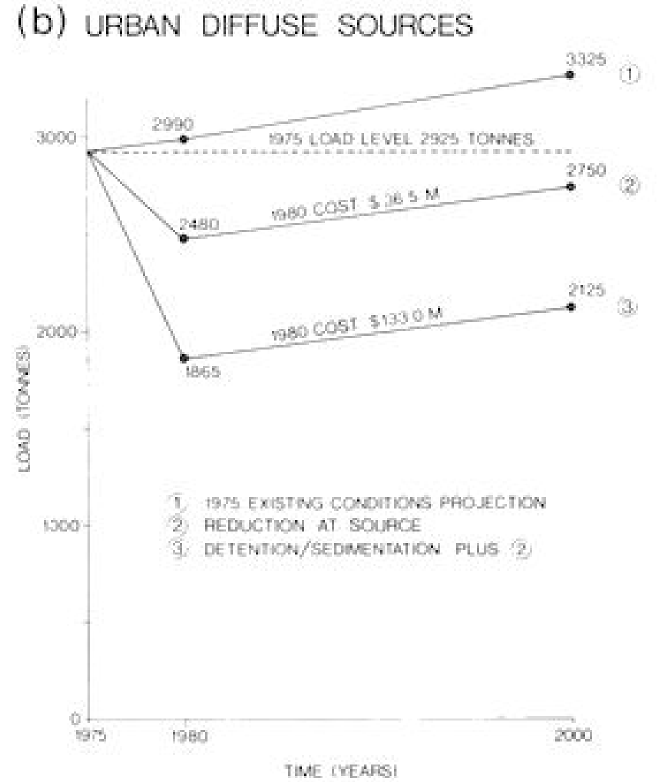
Figures 6, 7 and 8 illustrate the modelling results generated for each lake and pollutant source category. The initial overview modelling data base was representative of 1975 conditions. Hence the figures and discussion in this report use 1975 as the datum year. Although 1976 was used as the base year in the PLUARG final report [(45)], the results are comparable since the difference in loads between years is less than the possible error in estimates.

There are two copies of projections included for each lake-source figure. The first type is a twenty-five year "status quo" projection and is the uppermost solid line on all graphs. These depict the behaviour of the lake load from the source if no treatment measures were implemented under terms of the Agreement between the end of 1975 and the year 2000. The projected status quo curve for municipal point sources has an associated annual cost of $11 million. This cost reflects the amount being spent on 1975 phosphorus control programs adjusted to the 1980 population served by these facilities. No 1980 costs are shown for the status quo curves representing urban and rural diffuse inputs, as it was assumed no control measures were in effect as of 1975.

The second type of projection present in each figure is the curve showing the trend in loads through time arising from the implementation of remedial action programs in 1980 for urban nonpoint and urban point sources, and over the five- year period 1980-1985 (phase-in-period) for rural diffuse sources. The projected 1980 costs for each phosphorus pollution abatement program (outlined in Tables 13a, 13b, and 13c) are shown. Cost-effectiveness, in terms of dollars spent per metric ton reduction of lake load, varies considerably among measures, but only slightly among lakes. Work is being continued on the evaluation of suspended solids reductions which may be realized as a direct result of these phosphorus- sediment reduction programs. Results of preliminary work appear in Tables 14a, 14b, and 14c.

Another issue which was examined using the urban land projections contained in Table 12 was the control of sediment on developing land through erosion control practices. Rough estimates of costs and effectiveness have been made for Lakes Erie and Ontario. Over the period from 1975-2000, approximately 8,000 hectares of land are expected to be developed annually in the Lake Erie basin, and 4,500 hectares in the Lake Ontario basin. Costs for retarding erosion in these areas may amount to $2,000 per hectare for seeding, mulching, and other measures of value. Under the above assumptions, the annual cost of implementing remedial controls on developing land in the Lakes Erie and Ontario basins is $25 million per year.





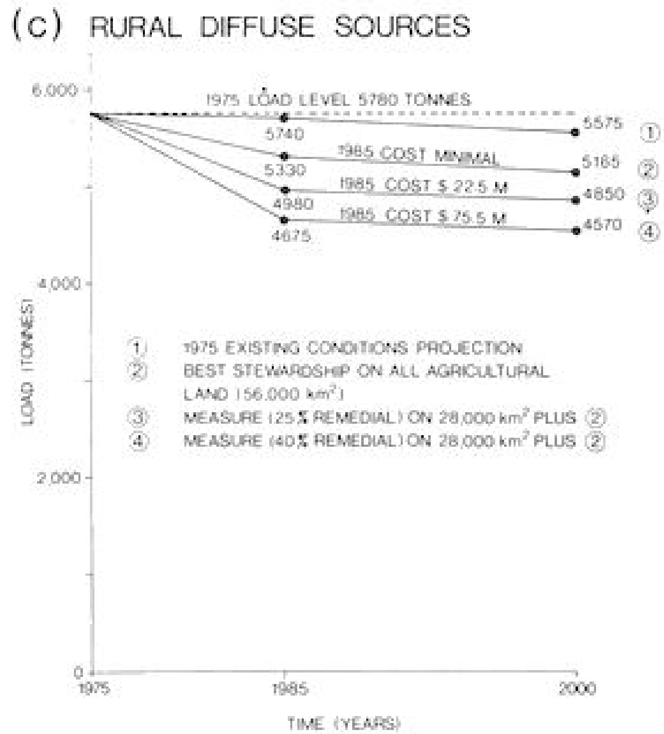
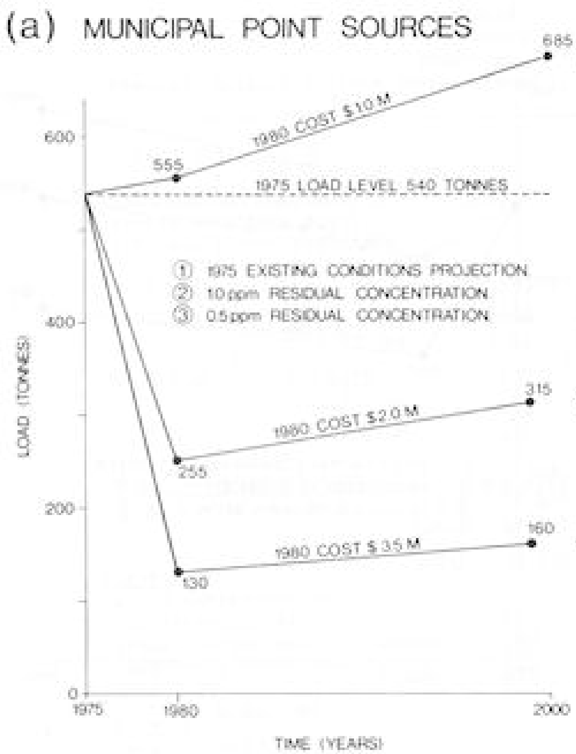
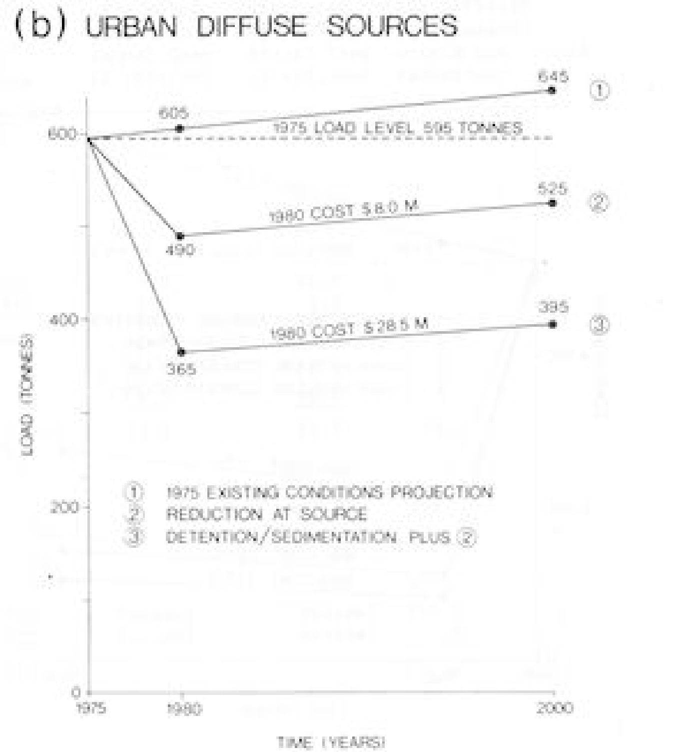


FIGURE 6:

TOTAL PHOSPHORUS LOADINGS: LEVELS AND TRENDS IN RESPONSE TO REMEDIAL PROGRAMS FOR LAKE ERIE





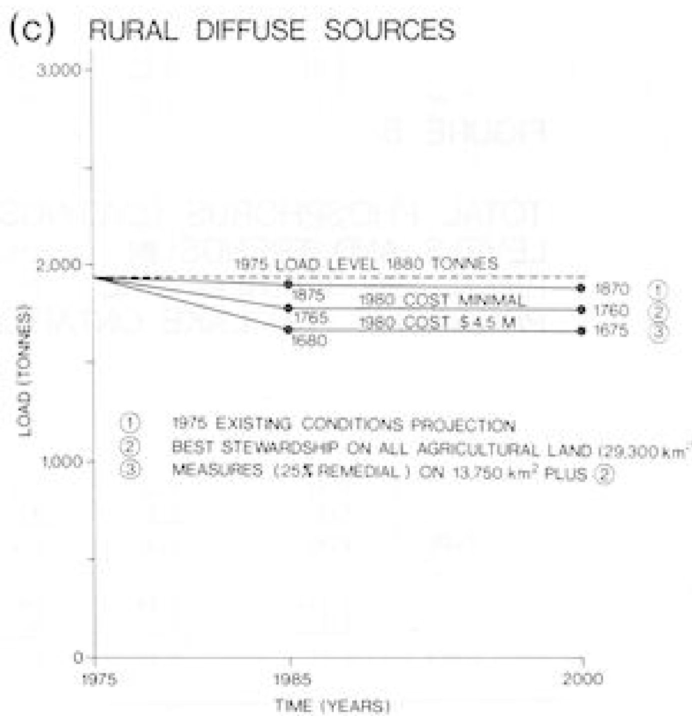
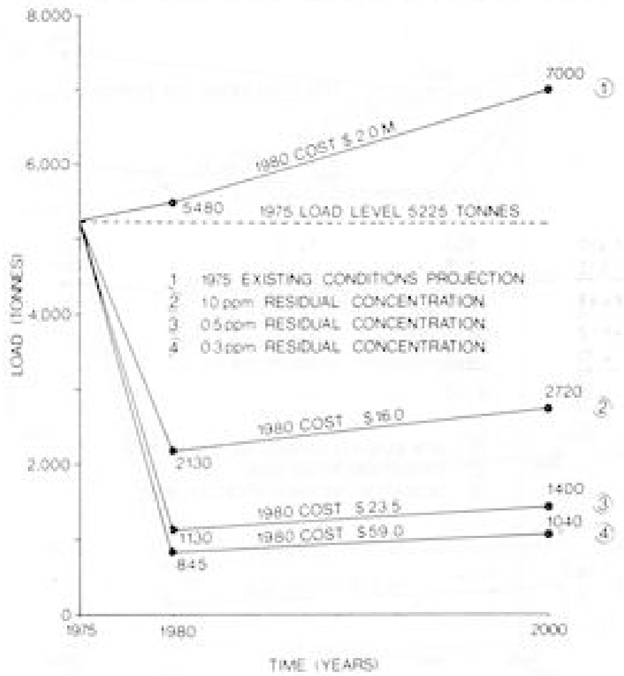


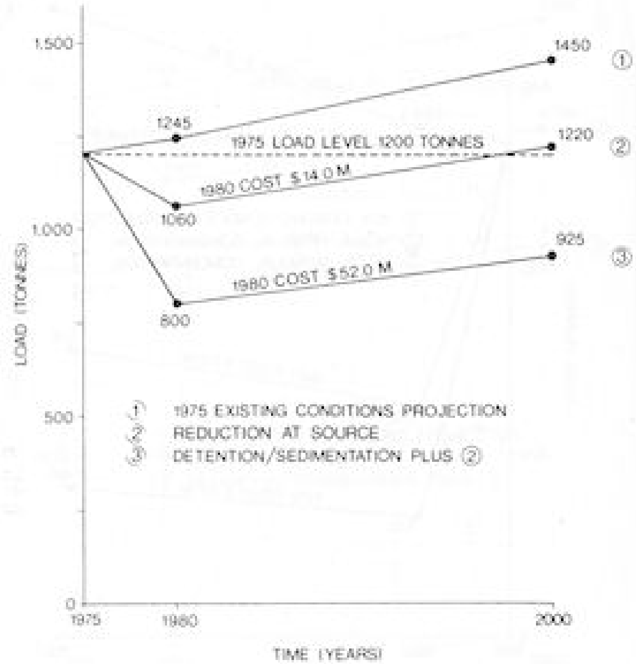
FIGURE 7:

TOTAL PHOSPHORUS LOADINGS: LEVELS AND TRENDS IN RESPONSE TO REMEDIAL PROGRAMS FOR LAKE HURON AND GEORGIAN BAY

(a) MUNICIPAL POINT SOURCES



(b) URBAN DIFFUSE SOURCES



(c) RURAL DIFFUSE SOURCES

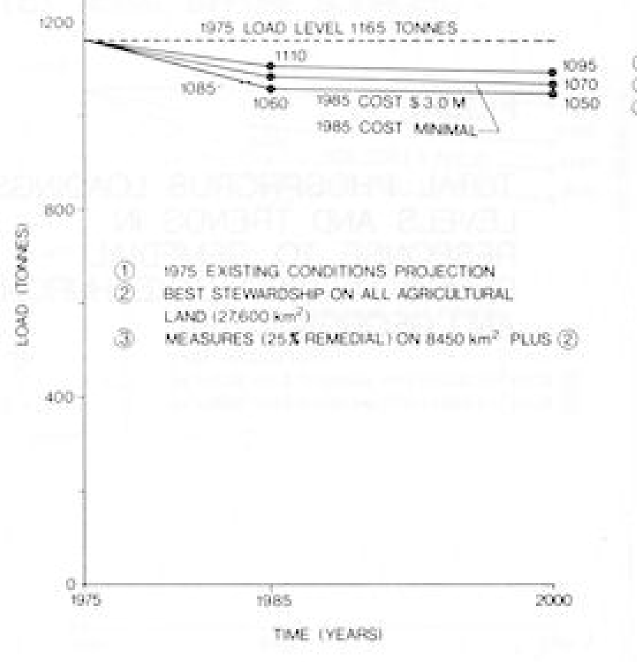


FIGURE 8:

TOTAL PHOSPHORUS LOADINGS: LEVELS AND TRENDS IN RESPONSE TO REMEDIAL PROGRAMS FOR LAKE ONTARIO

TABLE 13a: Phosphorus Reduction Alternatives Applicable To Lake Erie

Remedial Measure Options		Estimated Incremental Phosphorus Reduction (metric tons)	Estimated Cumulative Phosphorus Reduction [b] (metric tons)	Estimated Incremental Annual Cost ($ million)	Estimated Cumulative Annual Cost ($ million)	Estimated Annual Incremental Cost Effectiveness ($ thousand/ metric ton reduction)
URBAN POINT SOURCES:						
Reduction of municipal sewage treatment plant effluent concentrations:						
a) 1.0 mg/L to 0.5 mg/L	U.S.	1180	6330	9.0	31.0	
	Canada	125	355	1.5	3.5	
	TOTAL	1305	6685	10.5	34.5	8.0
b) 0.5 mg/L to 0.3 mg/L	U.S.	580	6910	54.5	85.5	
	Canada	65	420	6.5	10.0	
	TOTAL	645	7330	61.0	95.5	95.5
RURAL NONPOINT SOURCES:	land area					
	U.S.	34,000 km^2				
	Canada	22,000 km^2				
	TOTAL	56,000 km^2				
Level 1 sound management on all agricultural lands (10 % phosphorus reduction)	U.S.	350	350	Minimal	Minimal	0
	Canada	100	100	Minimal	Minimal	0
	TOTAL	450	450			0
Level 2 level 1 measures, plus buffer strips, strip cropping, improved municipal drainage Practices, etc., depending on region (25% reduction in P losses on soils requiring treatment)	U.S.	200	550	12.5	12.5	
	Canada	150	250	10.0	10.0	
	TOTAL	350	800	22.5	22.5	64.3
Level 3 level 2 measures at greater intensity of effort (to achieve 40 % reduction in P losses on soil needing treatment)	U.S.	180	730	32.5	45.0	
	Canada	125	375	20.5	30.5	
	TOTAL	305	1105	53.0	75.5	174.0
URBAN NONPOINT SOURCES:	land area					
	U.S.	6,000 km^2				
	Canada	670 km^2				
	TOTAL	6,670 km^2				
Level 1 program of pollutant reduction at source	U.S.	425	425	34.0	34.0	
	Canada	20	20	2.5	2.5	
	TOTAL	445	445	36.5	36.5	82.0
Level 2 level 1 measures, plus detention	U.S.	575	1000	89.5	123.5	
	Canada	40	60	7.0	9.5	
SEDIMENTATION	TOTAL	615	1060	96.5	133.0	156.9

[a] based on 1976 datum, a reduction of 2400 metric tons/yr has been recommended. Costs are current dollars to nearest 0.5 million dollars and reductions to nearest 5 metric tons. All reductions refer to the parameter total phosphorus.

[b] reduction in 1980 from 1976 existing load; values cumulative only within each specific urban and rural category.

TABLE 13b: Phosphorus Reduction Alternatives Applicable To Lake Huron[a]

Remedial Measures Options		Estimated Incremental Phosphorus Reduction (metric tons)	Estimated Cumulative Phosphorus, Reduction (metric tons)	Estimated Incremental Annual Cost ($ million)	Estimated Cumulative Annual Cost ($ million)	Estimated Annual Incremental Cost Effectiveness ($ thousand/ metric ton reduction)
URBAN POINT SOURCES: Reduction of municipal sewage treatment plant effluent concentrations						
a) present concentration to 1.0 mg/L	U.S.	260	260	0.5	1.5	
	Canada	25	25	0.5	0.5	
	TOTAL	285	285	1.0	2.0	3.5
b) 1.0 mg/L to 0.5 mg/L	U.S.	40	350	1.0	2.5	
	Canada	35	60	0.5	1.0	
	TOTAL	125	410	1.5	3.5	12.0
RURAL NONPOINT SOURCES	land area					
	U.S.	9,500 km^2				
	Canada	11,240 km^2				
Level 1	TOTAL	20,740 km^2				
Sound management on all agricultural lands (10 % P reduction) southern Lake Huron and Saginaw Bay	U.S.	50	50	Minimal	Minimal	0
	Canada	40	40	Minimal	Minimal	0
	TOTAL	90	90			0
Level 2						
Level 1 measures, plus buffer strips, stripcropping, improved municipal drainage, practices, etc., depending on region (25% reduction in P losses on soils requiring treatment southern Lake Huron and Saginaw Bay)	U.S.	40	90	2.5	2.5	
	Canada	35	75	1.5	1.5	
	TOTAL	75	165	4.0	4.0	53.3
URBAN NONPOINT SOURCES:	land area					
	U.S.	1,500 km^2				
	Canada	125 km^2				
Level 1	TOTAL	1,625 km^2				
Program of pollutant reduction at source	U.S.	100	100	7.5	7.5	
	Canada	5	5	0.5	0.5	
	TOTAL	105	105	8.0	8.0	76.2
Level 2						
Level 1 measures, plus detention/ sedimentation	U.S.	120	220	19.0	26.5	
	Canada	5	10	1.5	2.0	
	TOTAL	125	230	20.5	28.5	164.0

[a] based on 1976 datum, a reduction of 100 metric tons/yr. to southern Lake Huron and 580 metric tons/yr to Saginaw Bay have been recommended. Most of the total urban point and nonpoint programs listed above would occur in the Saginaw Bay basin. Costs are current dollars to nearest 0.5 million dollars and reductions to nearest 5 metric tons. All reductions refer to the parameter total phosphorus.

[b] Reduction in 1980 from 1976 existing load; values cumulative only within each specific urban and rural category.

TABLE 13c: Phosphorus Reduction Alternatives Applicable To Lake Ontario[a]

Remedial Measure Options		Estimated Incremental Phosphorus Reduction (metric tons)	Estimated Cumulative Phosphorus Reduction (metric tons)	Estimated Incremental Annual Cost ($ million)	Estimated Cumulative Annual Cost ($ million)	Estimated Annual Incremental Cost Effectiveness ($ thousand/metric ton reduction)
URBAN POINT SOURCES: Reduction of municipal sewage treatment plant effluent concentrations						
a) 1.0 mg/L to 0.5 mg/L	U.S.	300	1650	2.5	8.5	
	Canada	700	1740	5.0	15.0	
	TOTAL	1300	3390	7.5	23.5	7.5
b) 0.5 mg/L to 0.3 mg/L	U.S.	160	1810	15.5	24.0	
	Canada	125	1865	20.0	35.0	
	TOTAL	285	3675	35.5	59.0	124.6
RURAL NONPOINT SOURCES:		land area				
	U.S.	9,600 km^2				
	Canada	18,000 km^2				
Level 1	TOTAL	27,600 km^2				
Sound management on all agricultural lands (10 % phosphorus reduction)	U.S.	25	25	Minimal	Minimal	0
	Canada	55	55	Minimal	Minimal	0
	TOTAL	80	80			0
URBAN NONPOINT SOURCES:	land	area				
	U.S.	1,400 km^2				
	Canada	1,500 km^2				
	TOTAL	2,900 km^2				
Level 1						
Program of pollutant reduction at source	U.S.	90	90	7.5	7.5	
	Canada	50	50	6.5	6.5	
	TOTAL	140	140	14.0	14.0	100.0
Level 2						
Level 1 measures, plus detention/sedimentation	U.S.	110	200	19.5	27.0	
	Canada	150	200	18.5	25.0	
	TOTAL	260	400	38.0	52.0	146.0
Reduction From Lake Erie (At 11,000 Metric Ton Recommended Target Load)			1200 (See	Lake Erie program on Table 13a)		

[a] based on 1976 datum, a reduction of 2400 metric tons/yr has been recommended. Costs are current dollars to nearest 0.5 million dollars and reductions to nearest 5 metric tons. All reductions refer to the parameter total phosphorus.

[B] reduction in 1980 from 1976 existing load; values cumulative only within each specific urban and rural category.

TABLE 14a: Suspended Solids Reduction From Phosphorus Control Programs In Lake Erie Basin[a]

Remedial Measures Options		Estimated Incremental Suspended Solids Reduction (tonnes)	Estimated Cumulative Suspended Solids[b] Reduction (metric tons)	Estimated Incremental Annual Cost ($ million)	Estimated Cumulative Annual Cost ($ million)	Estimated Annual Incremental Cost Effectiveness ($ thousand/ metric ton reduction)
URBAN POINT SOURCES						
Reduction of municipal sewage treatment plan effluent concentrations						
a) 1.0 mg/L to 0.5 mg/L	U.S.	19305	103560	9.0	31.0	
	Canada	2045	5810	1.5	3.5	
	TOTAL	21350	104370	10.5	34.5	0.49
b) 0.5 mg/L to 0.3 mg/L	U.S.	10885	114445	54.5	85.5	
	Canada	1215	7025	6.5	10.0	
	TOTAL	12100	121470	61.0	95.5	5.04
RURAL NONPOINT SOURCES		land area				
	U.S.	34,000 km^2				
	Canada	22,000 km^2				
Level 1	TOTAL	56,000 km^2				
sound management on all	U.S.	132030	132030	minimal	minimal	0
agricultural lands (10 %	Canada	37725	37725	minimal	minimal	0
Phosphorus reduction)	TOTAL	169755	169755			0
Level 2 level 1 measures, plus buffer strips, strip cropping, improved municipal	U.S.	232145	364175	12.5	12.5	
drainage practices, etc., depending on region (25 percent reduction in	Canada	127810	165535	10.0	10.0	
phosphorus losses on soils requiring treatment.	TOTAL	359955	529710	22.5	22.5	0.06
Level 3 level 2 measures at greater intensity of effort (to achieve 40	U.S.	27840	392015	32.5	45.0	
percent reduction in phosphorus	Canada	35845	201380	20.5	30.5	
losses on soil needing treatment)	TOTAL	63685	593395	53.0	75.5	0.83
URBAN NONPOINT SOURCES		land area				
	U.S.	6,000 km^2				
	Canada	670 km^2				
Level 1	TOTAL	6,670 km^2				
program of pollutant reduction at source	U.S.	129345	129345	34.0	34.0	
	Canada	6085	6085	2.5	2.5	
	TOTAL	135430	135430	36.5	36.5	0.27
Level 2 level 1 measures, plus detention/ sedimentation	U.S.	20140	149485	89.5	123.5	
	Canada	2885	8970	7.0	9.5	
	TOTAL	23025	158455	96.5	133.0	4.19

[a] based on 1976 datum. Costs are current dollars to nearest 0.5 million dollars and reductions to nearest 5 metric tons. All U.S.A. reductions shown here are based on phosphorus reductions as per table 13A.

[b] Reductions in 1980 from 1976 existing load; values are cumulative only within each specific urban and rural category.

TABLE 14b : Suspended Solids Reduction From Phosphorus Control Programs In Lake Huron Basin [a]

Remedial Measures Options		Estimated Incremental Suspended Solids Reduction (tonnes)	Estimated Cumulative Suspended Solids [b] Reduction (tonnes)	Estimated Incremental Annual Cost ($ million)	Estimated Cumulative Annual Cost ($ million)	Estimated Annual Incremental Cost Effectiveness ($ thousand/ metric ton reduction)
URBAN POINT SOURCES:						
Reduction of municipal sewage treatment plant effluent concentrations						
a) present concentration to 1.0 mg/L	U.S.	21695	21695	0.5	1.5	
	Canada	2095	2095	0.5	0.5	
	TOTAL	23790	23790	1.0	2.0	0.04
b) 1.0 mg/L to 0.5 ppm	U.S.	7510	29205	1.0	2.5	
	Canada	565	2660	0.5	1.0	
	TOTAL	8075	31865	1.5	3.5	0.19
RURAL NONPOINT SOURCES	land area					
	U.S.	9,500 km²				
	Canada	11,240 km²				
Level 1	TOTAL	20,740 km²				
Sound management on all agricultural lands (10 % phosphorus reduction) southern Lake Huron and Saginaw Bay).	U.S.	19313	19315	Minimal	Minimal	0
	Canada	15455	15455	Minimal	Minimal	0
	TOTAL	34770	34770			0
Level 2						
Level 1 measures, plus buffer strips, stripcropping, improved municipal drainage, practices, etc., depending on region (25 % reduction in phosphorus losses on soils requiring treatment southern Lake Huron and Saginaw Bay).	U.S.	28420	47735	2.5	2.5	
	Canada	24325	39780	1.5	1.5	
	TOTAL	52745	87515	4.0	4.0	0.08
URBAN NONPOINT SOURCES	land area					
	U.S.	1,500 km²				
	Canada	125 km²				
	TOTAL	1,625 km²				
Level 1						
Program of pollutant reduction at source	U.S.	26760	26760	7.5	7.5	
	Canada	1335	1335	0.5	0.5	
	TOTAL	28095	28095	8.0	8.0	0.28
Level 2						
Level 1 measures, plus detention/ sedimentation	U.S.	14005	40765	19.0	26.5	
	Canada	520	1855	1.5	2.0	
	TOTAL	14525	42620	20.5	28.5	1.41

[a] based on 1976 datum. Costs are current dollars to nearest 0.5 million dollars and reductions to nearest 5 metric tons. All U.S.A. reductions shown here are based on phosphorus reductions as per table 13B.

[b] Reductions in 1980 from 1976 existing load; values are cumulative only within each specific urban and rural category.

TABLE 14c : Suspended Solids Reduction From Phosphorus Control Programs In Lake Ontario Basin

Remedial Measures Options		Estimated Incremental Suspended Solids Reduction (tonnes)	Estimated Cumulative Suspended Solids Reduction (tonnes)	Estimated Incremental Annual Cost ($ million)	Estimated Cumulative Annual Cost ($ million)	Estimated Annual Incremental Cost Effectiveness ($ thousand/ metric ton reduction)
URBAN POINT SOURCES:						
Reduction of municipal sewage treatment plant effluent concentrations						
a) 1.0 mg/L to 0.5 mg/L	U.S.	3990	21945	2.5	8.5	
	Canada	10350	23155	5.0	15.0	
	TOTAL	14340	45100	7.5	23.5	0.52
	U.S.	3880	25825	15.5	24.0	
b) 0.5 mg/L to.3 mg/L	Canada	5200	28355	20.0	35.0	
	TOTAL	9080	54180	35.5	59.0	3.91
RURAL NONPOINT SOURCES:	land area					
	U.S.	9,600 km^2				
	Canada	18,000 km^2				
	TOTAL	27,600 km^2				
Level 1						
Sound management on all agricultural lands (10 percent phosphorus reduction)	U.S.	9645	9645	minimal	minimal	0
	Canada	21220	21220	minimal	minimal	0
	TOTAL	30865	30865			0
URBAN NONPOINT SOURCES:	land area					
	U.S.	1,400 km^2				
	Canada	1,500 km^2				
	TOTAL	2,900 km^2				
Level 1						
Program of pollutant reduction at source	U.S.	28210	28210	7.5	7.5	
	Canada	17085	17085	6.5	6.5	
	TOTAL	45295	45295	14.0	14.0	0.31
Level 2						
Level 1 measures, plus detention/sedimentation	U.S.	4355	32565	19.5	27.0	
	Canada	4320	21405	18.5	25.0	
	TOTAL	8675	53970	38.0	52.0	4.38

[a] based on 1976 datum. Costs are current dollars to nearest 0.5 million dollars and reductions to nearest 5 metric tons. All U.S.A. reductions shown here are based on phosphorus reductions as per table 13C.

[b] Reductions in 1980 from 1976 existing load; values are cumulative only within each specific urban and rural category.

4. DISCUSSION

GENERAL CONSIDERATION

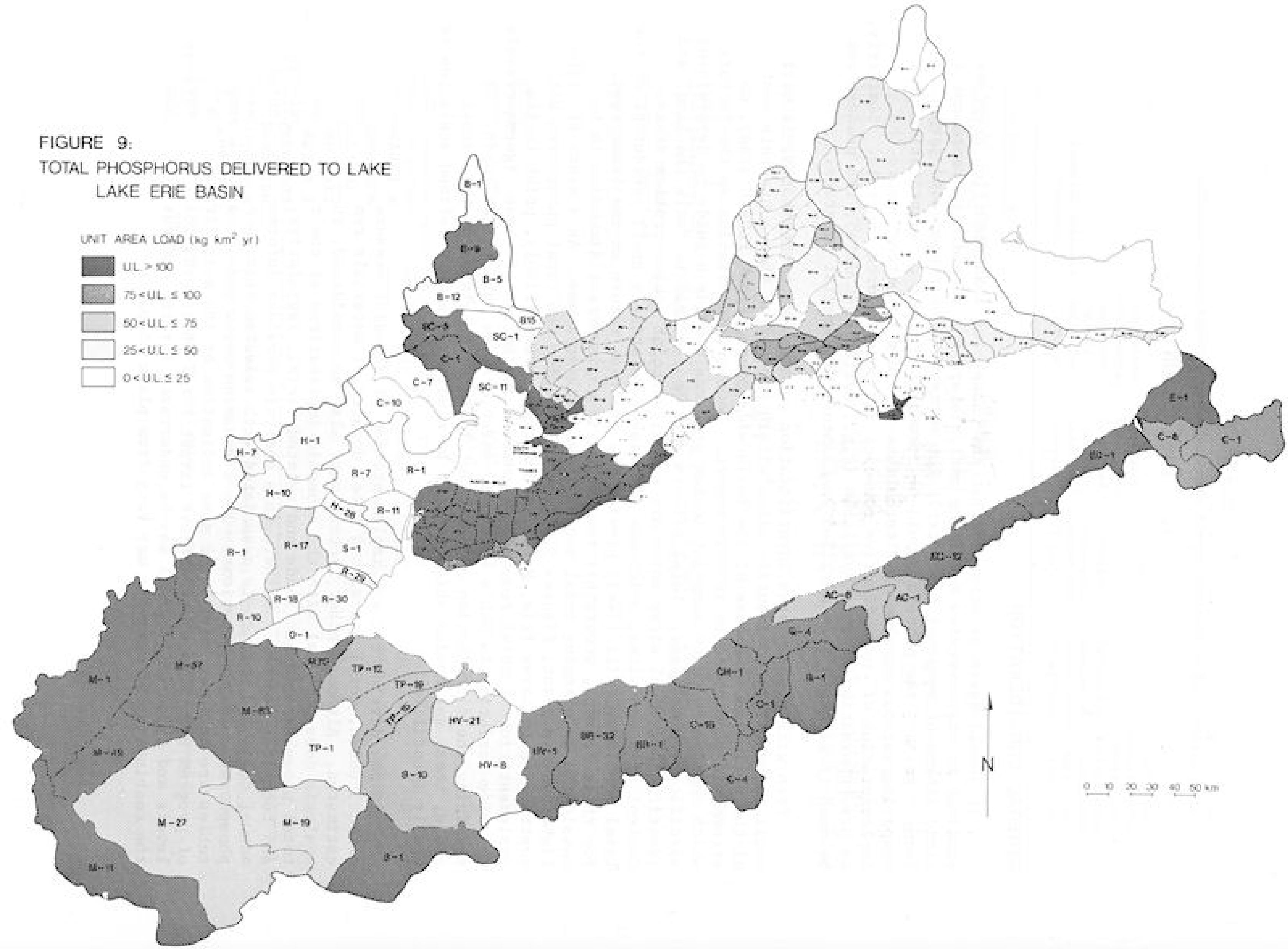
It should again be stressed that the phosphorus load reduction programs examined in this overview modelling analysis are not intended to represent a rigid scheme or sequence of controls for achieving the recommended target loads. Rather, the process should be viewed as a means of quantitatively comparing various management alternatives in order to better insure the implementation of cost-effective nonpoint and point source controls. Similarly, as new information becomes available (e.g., better cost data), the process can be used to generate more detailed assessments of remedial programs.

Even with problem area identification on a sub-watershed basis, it will still be necessary to identify sites within sub-basins that contribute most of the pollution. Because of the basin-wide scope of the PLUARG study, no attempt is made to do so in this report. However, information on the factors which combine to cause nonpoint source problems provide a guide to determining specific problem areas. Local efforts will be required to "walk the land" and identify individual sites which are actual nonpoint source problem areas. Control of these sites, which may comprise a relatively small percentage of the total land area, will likely provide the greatest return at the least cost.

For these reasons, geographic resolution is an important dimension to be considered in planning rural nonpoint remedial programs. As a means of highlighting this point, Figures 9, 10, and 11 depict the total phosphorus UAL contributed to Lakes Erie, Huron, and Ontario, respectively, prior to the implementation of rural remedial measures. Inspection of these figures reveals the wide variation in UAL's which may exist over an entire lake basin. By examining the distribution of pollutant loads to the lakes on this gross scale, those sub-basins which need to be studied on a more refined scale can be easily identified.

In the development and implementation of remedial measures, cost- effectiveness, total costs, and total amounts of materials removable are estimated. Although other factors must also be considered, the PLUARG analysis does not deal with the economic implications of the recommended total phosphorus target loads and related social, legislative, institutional and technical factors. Rather, this analysis provides information on total annual costs and unit costs associated with selected degrees of total phosphorus loading reductions. The discussion below and the accompanying tables are designed to provide some indication of the most direct costs of program alternatives to achieve target total phosphorus loadings. Various levels and types of programs may be undertaken for the various lakes, and the combination of measures may vary from place to place.

FIGURE 9:
TOTAL PHOSPHORUS DELIVERED TO LAKE
LAKE ERIE BASIN



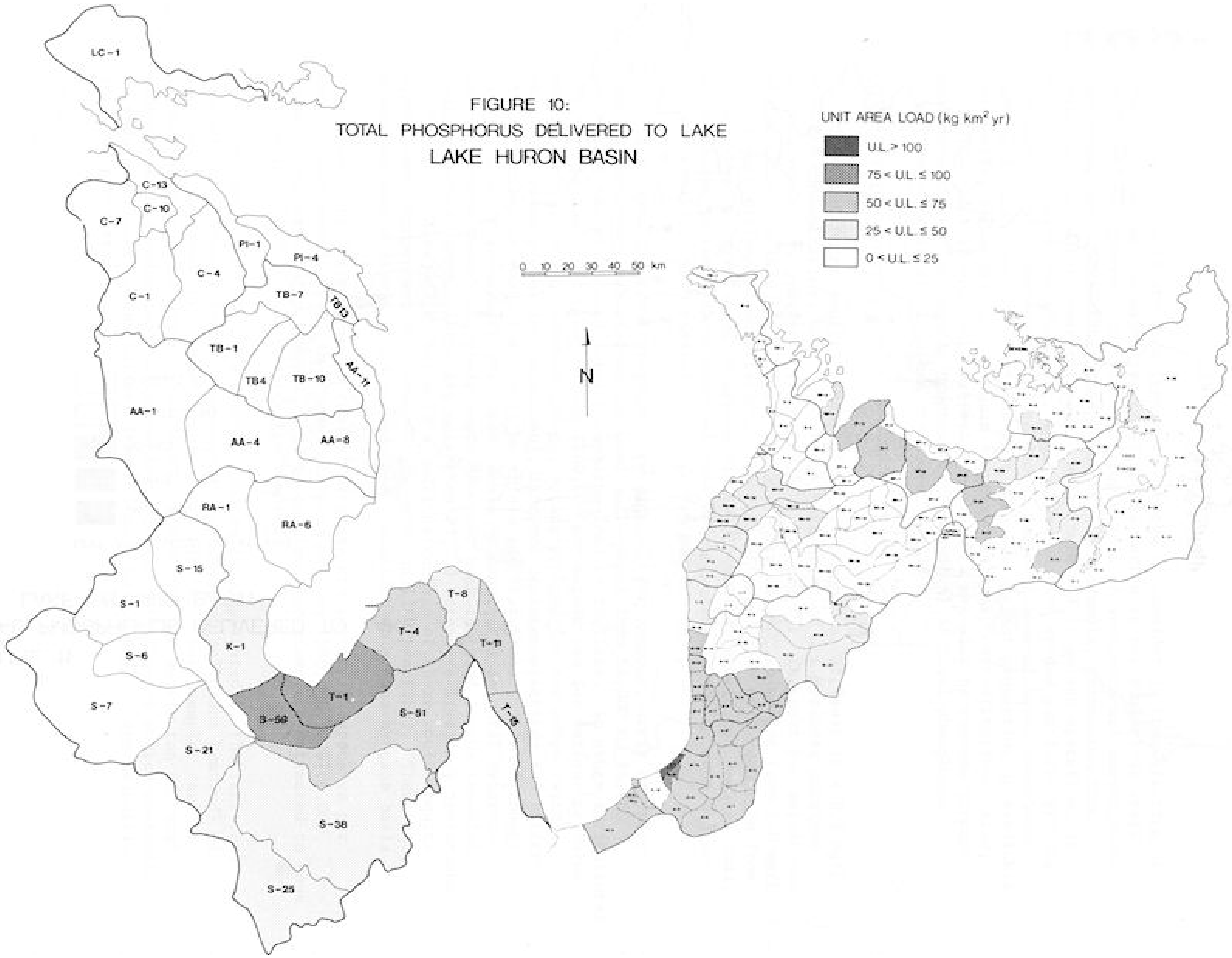


FIGURE 10:
TOTAL PHOSPHORUS DELIVERED TO LAKE
LAKE HURON BASIN
UNIT AREA LOAD (kg km² yr)
U.L. > 100
75 < U.L. ≤ 100
50 < U.L. ≤ 75
25 < U.L. ≤ 50
0 < U.L. ≤ 25
0 10 20 30 40 50 km
N
LC-1
C-13
C-10
C-7
PI-1
PI-4
C-4
C-1
TB-7
TB13
TB-1
TB4
TB-10
AA-11
AA-1
AA-4
AA-8
RA-1
RA-6
S-15
S-1
T-8
K-1
T-4
T-11
S-6
T-1
S-51
S-7
S-50
T-15
S-21
S-38
S-25

FIGURE 11:
TOTAL PHOSPHORUS DELIVERED TO LAKE
LAKE ONTARIO BASIN

Other criteria are also important factors to consider in the selection of remedial programs. A major technical consideration is the biological availability of phosphorus. The relative proportions of available and unavailable phosphorus vary considerably among sources. For example, phosphorus from municipal wastewater treatment plants and manure and livestock operations is more biologically available than that associated with eroded particles arising from agricultural sources. In some cases, the unit cost of total phosphorus removal is also lower for those sources with the highest proportion of available phosphorus, making control of these sources relatively cost-effective. Also, it is important to consider what other pollutants may also be removed through implementation of a specific program for the removal of total phosphorus (e.g., removing metals in urban stormwater).

COST-EFFECTIVENESS

Municipal point source removal of total phosphorus, at least to a 0.5 mg/L effluent concentration, was the most cost-effective of all measures examined in this study. As presented in Tables 13a, 13b and 13c, the cost per metric ton of reductions in lake loads range from $7,500 to $12,000 in moving from 1.0 mg/L to 0.5 mg/L effluent concentration. The cost-effectiveness of a reduction from 1.0 mg/L to 0.3 mg/L would be approximately $35,000 per metric ton reduced load, although the incremental or marginal cost-effectiveness in moving from 0.5 to 0.3 mg/L would be approximately $100,000 per metric ton.

Unit costs for rural programs vary widely. For example, strip cropping programs in some areas of fine-textured soils range from $5,000 to $6,000 per metric ton of reduced total phosphorus load to the lake. In other agricultural regions the annual cost may exceed $100,000 per metric ton for various measures and/or combinations of measures, e.g., spring plowing for row crops (with attendant large losses in production), improved drainage practices and buffer strips (including costs for labor, materials and lost production). Although livestock waste management practices should be considered in rural programs for phosphorus reduction, their costs have not been included in the remedial costs presented here. There are more than 25,000 intensive livestock operations in the Great Lakes basin, but only a small percentage of these would require significant improvement (for Great Lakes water quality benefits). Therefore, a more refined analysis would necessitate evaluation on a case-by-case basis.

Urban nonpoint phosphorus removal programs are extremely expensive per metric ton removed. The first-level programs may cost $80,000 to $100,000 annually per metric ton removed, while second-level programs are estimated to have unit costs of $150,000 per metric ton removed.

The final selection of a control program is complicated by the fact that the unit cost (cost-effectiveness or cost per tonne of pollutant removed) of some point and nonpoint control programs are similar. For example, various agricultural programs might cost $50,000 to $100,000 per metric ton of total phosphorus load reduction, while the incremental cost of point source controls to reduce effluent concentrations from 0.5 mg/L to 0.3 mg/L is approximately $100,000 per metric ton.

PROGRAM COSTS AND RESULTS

The overview modelling analysis provides a process for evaluating the amounts of pollutant removable through various management scenarios, as well as the associated costs. In doing so, those combinations of control programs which achieve recommended pollutant load reductions at least cost are clearly identified, thereby reducing the number of feasible alternatives which are to be considered in greater detail as candidates for implementation. In view of the further reductions in total phosphorus loads recommended by PLUARG to improve and/or maintain existing water quality conditions in the Great Lakes, it is essential that a cost-effective sequence of measures be adopted for meeting these targets. Table 15 shows (A) the 1975 total phosphorus loads to Lake Erie, Lake Huron and Lake Ontario, (B) the recommended target load values, and (C) the necessary load reductions to achieve the targets.

Because these three lakes represent unique problems in terms of load reduction targets, a separate discussion of the overview modelling results will be provided for each. However, it is necessary to first discuss some basic concepts and procedures adopted in the analysis.

As previously described, the study concentrated on pollutant loads from three distinct sources: (A) municipal point sources, (B) urban diffuse sources, and (C) rural diffuse sources. Each was considered first from the perspective of pollutant load transmitted to the lake over a 25-year period assuming no remedial programs are implemented, and then from the perspective of specified remedial programs being initiated after the fifth year of the 25-year planning period (1975-2000).The former pollutant load scenario was generated by starting the model from the initial 1975 conditions and running a 25-year simulation directly. The latter profile was generated by starting from the same initial conditions, but interrupting the simulation after the fifth year to incorporate the implementation of remedial measures.

In evaluating the overall reduction in total phosphorus required to meet a specific target load for any lake, it is necessary to modify the reduction to account for natural or "status quo" increases (or decreases) in the load which occur over time due to population increases, urban land expansion, and rural land reductions. For example, in 1975 the total phosphorus reduction necessary to achieve the 11,000 metric ton/yr. target for Lake Erie was approximately 2,400 metric tons. However, by the year 1980 the required reduction would exceed 2,500 metric tons in order to meet the same 11,000 metric ton target load. Thus, temporal increases in phosphorus loads to sewage treatment plants, urban expansion and development, as well as decreases in rural areas to accommodate urban growth, combine to produce an upward trend in the pollutant load. This trend must be evaluated in any ongoing assessment of future program requirements. The overview modelling results are based upon 1975 conditions; the pollutant load reductions are evaluated with respect to the 1975 datum. For example, a recommended remedial program achieving a load reduction of 1,000 metric tons (from the 1975 datum) from diffuse urban sources in 1980 actually produces a total reduction of these 1,000 metric tons plus the status quo increase in the load from the urban areas between 1975 and 1980. The

TABLE 15: Derivation Of Recommended Reductions In Total Phosphorus Loading To Lakes Erie, Huron And Ontario

	Estimated 1975 Load (Metric Tons/yr.)	Target Load (Metric Tons/yr.)	Recommended Reduction (Metric Tons/yr.)
Lake Erie[a]	13,400	11,000	2,400
Lake Ontario[a]	9,400	7,000	2,400
Lake Huron			
A) Whole Lake	4,500	4,400	100
B) Saginaw Bay	1,200	620	580

[a] 1975 Load Shown Assumes Compliance With 1 Mg/L Residual Effluent Concentration of Total Phosphorus

following discussion will concentrate on these results as they apply to Lake Erie, Lake Huron, and Lake Ontario.

A. Lake Erie:

PLUARG has recommended that the load of total phosphorus to Lake Erie be reduced to 11,000 metric tons/yr.; this would require a net reduction of approximately 2,400 metric tons/yr. from the estimated 1975 load level. Overview modelling examines what sources can be controlled such that the desired load reduction is attained at least cost. The potential load reductions and annual costs associated with the three categories of pollutant sources are compared below.

1. Municipal Point Sources - Figure 6a provides a graphical representation of existing total phosphorus loads to Lake Erie from municipal sewage treatment plants, as well as the potential reductions which may be expected by lowering effluent concentrations to specified levels (0.5 ppm and 0.3 ppm) by the year 1980. The top curve in Figure 6a delineates the load to the lake as projected from existing 1975 conditions. If no remedial measures were applied, the load would be expected to increase by approximately 325 tonnes (≈4%) in the first five years, and by roughly 2,400 (≈0.31%) over the total 25-year period. Therefore, by the year 2000 the total phosphorus load to Lake Erie from municipal plants would exceed 10,000 tonnes/yr. if no further control programs were instituted. However, as part of the 1972 Water Quality Agreement, all municipal treatment plant effluents greater than 1 MGD are to comply with a 1 ppm residual total phosphorus constraint. For this reason any remedial measure to further reduce the municipal point source total phosphorus load is evaluated with respect to the curve representing projections from a 1 ppm initial condition at all plants in 1975.

The bottom two curves in Figure 6a represent the total phosphorus load transmitted to Lake Erie if the required residual effluent concentration is lowered to 0.5 and 0.3 ppm, respectively. If all load reductions are evaluated with respect to the 1975 datum on the assumption that all plants are meeting a 1 ppm effluent concentration (2,900 metric tons), it can be seen that a 0.5 ppm requirement instituted in 1980 will result in a total reduction of 1,305 metric tons from U.S. and Canadian municipal treatment plant sources (1,180 from the U.S. and 125 from Canada). However, due to the effects of population growth, as previously discussed, this reduction decreases to approximately 900 metric tons by the year 2000 (820 from the U.S. and 80 from Canada). The total annual cost of operating the phosphorus control program to 0.5 ppm at all plants is estimated at $34.5 million ($3,340/1,000 people served/yr), while the marginal annual costs of achieving a 0.5 ppm residual total phosphorus concentration from a 1.0 ppm initial condition is approximately $10.5 million ($990/1,000 people served/yr).

Following the same analysis for a 0.3 ppm residual control program, a total load reduction of 7,330 metric tons can be expected in the year 1980 at an annual cost of $95.5 million. With respect to the 0.5 ppm control, the 0.3 ppm program results in a marginal reduction of 645 metric tons at a marginal cost of $61 million. Thus, the 0.3 ppm program removes an additional 50 percent more total phosphorus than the 0.5 ppm program, but at almost a 500 percent increase in the incremental annual cost.

2. Urban Nonpoint Sources - Figure 6b provides a visual description of the effectiveness achieved through implementation of the first two levels of urban nonpoint programs. The specific input data describing each program is given in Table 11.

The top curve in Figure 6b represents the projected total phosphorus load transmitted to Lake Erie from urban runoff in the U.S. and Canada over the 25-year period from 1975 to 2000. The 1975 datum of 2,925 metric tons increases to 2,990 metric tons by 1980, and ultimately to 3,325 metric tons by the year 2000 without additional controls. However, if a Level 1 remedial program is initiated, by 1980 the total annual load is expected to decrease by approximately 445 metric tons from the 1975 datum at an annual cost of $36.5 million. The second level of effort in controlling urban runoff would result in a load reduction of 1,060 metric tons from the 1975 datum by the year 1980 (2.4 times greater than the Level 1 reduction) at an annual cost of $133 million (3.6 times greater than the Level 1 annual cost). Table 13a shows that the U.S. total phosphorus input to Lake Erie from urban runoff far outweighs the Canadian contribution, and therefore the load reductions and costs associated with the U.S. remedial program comprise a high percentage of the Lake Erie totals.

3. Rural Sources - Three levels of effort were evaluated for reducing total phosphorus loads to Lake Erie from rural sources. The first level is defined as voluntary "sound management" of all agricultural land, while the second and third levels incorporate further measures (in addition to sound management practices) on agricultural land in regions of fine-textured soils. It is important to note that the U.S. and Canadian analyses differed somewhat in this particular case. Whereas in the Canadian analysis a remedial measure was assumed to apply uniformly over a given sub-basin, in the U.S. study the measure was only applied to that area within a given sub-basin which was estimated as having cropland on fine-textured soils. This difference was necessitated by the fact that the Canadian grid was finer scaled, and therefore each sub-basin had a dominant soil texture. The coarser U.S. grid, on the other hand, resulted in certain cases where a sub-basin contained equal areas of two or more different soil textures. Because the second and third levels of effort were applied only to areas having fine-textured soils, it was necessary to adjust the remedial load reduction and cost per unit area treated to the percentage of fine-textured soil present in each sub-basin. This approach seemed to represent a consistent and more realistic method of evaluating and comparing rural control programs in the U.S. and Canada.

Figure 6c provides a composite of the rural source results for Lake Erie. The top curve delineates the projections of the total phosphorus load transmitted to the lake from rural nonpoint sources under the assumption that no remedial measures are applied during the 25-year planning period. As opposed to the existing condition (or status quo) curves for municipal point source and urban runoff loads, the top curve representing the load from rural runoff has a negative slope. This characteristic is attributable to the gradual decline in rural land to accommodate population growth and urban expansion.

Inspection of Figure 6c reveals that the first level of effort -- the voluntary sound management program -- results in a 450 metric ton reduction in the load to Lake Erie in 1980. Although augmented extension programs would be an integral part of this measure, the total cost of voluntary sound management is considered minimal. In 1980, the second and third levels of effort reduce the load by 800 and 1,105 metric tons, respectively, at associated annual costs of $22.5 million and $75.5 million.

Having estimated the potential total phosphorus load reductions which can be achieved by applying remedial measures to municipal point sources, urban and rural nonpoint sources, a sequence of controls then can be selected which will reduce the lake load to specified target levels. The criterion used here for choosing among alternative controls is cost-effectiveness -- the annual cost of removing a metric tone of total phosphorus delivered to the lake. As previously mentioned, phosphorus availability should also be considered. Table 13a contains the reductions, costs and cost-effectiveness values for each remedial program applied to sources of total phosphorus loads to Lake Erie. If a 2,400 metric ton reduction will be required in order to meet the 11,000 metric ton target for Lake Erie, inspection of Table 13a reveals that the most cost- effective means of achieving part of this reduction is by initiating voluntary sound management practices on all agricultural lands in the basin.

This will result in a 450 metric ton reduction by the year 1980. The second most cost-effective means of achieving total phosphorus load reductions is the implementation of a 0.5 ppm effluent standard at all municipal sewage treatment plants. This measure results in a 1,300 metric ton reduction (assuming all plants are already in compliance with a 1 ppm effluent standard), still leaving approximately 650 tonnes to be removed by additional controls. Of this remaining load, the first 350 tonnes are most cost-effectively removed through a second level of effort program applied to selected rural nonpoint sources, i.e., specifically to areas of cropland on fine-textured soils (potential contributing areas). The final measure to be implemented in meeting the 2,400 tonne objective would be a Level 1 program to control urban runoff. This program would result in an additional 445 tonne reduction, bringing the total removal to roughly 2,550 metric tons.

The scenario of measures to achieve the target loading is summarized in Table 16.

B. Lake Huron:

Figures 7a, 7b and 7c provide a visual description of the total phosphorus load projections from existing conditions and the potential reductions from remedial programs applied to municipal point sources, urban diffuse and rural diffuse sources, respectively, in the Lake Huron basin. Following the same procedure as was used in the Lake Erie analysis, each remedial program is rated on the basis of the cost-effectiveness criterion in selecting an optimum combination of controls for reducing the total phosphorus load to the specified target load of 4,400 metric tonnes per year for the main lake and the 620 tonne target load for Saginaw Bay. A reduction of 580 tonnes to Saginaw Bay is required in the interests of southern Lake Huron and Saginaw Bay. The data for Lake Huron have been compiled and presented in Table 13b.

Implementation of a voluntary sound management program on all agricultural land will result in a reduction of approximately 90 metric tons at minimal cost. If the second most cost-effective measure -- lowering all municipal treatment plant effluents to a 1.0 ppm total phosphorus residual -- is also instituted, another 285 metric ton reduction is achieved, bringing the total load reduction to 375 metric tons. Almost all of the 285 tonne reduction from point sources and roughly one-half of the 90 tonne rural nonpoint reduction would occur in the Saginaw Bay sub-basin.

It would appear to be advisable to proceed with a second level of effort rural program in the southern Lake Huron drainage areas, most of which would take place in the Saginaw Bay basin. This would result in an additional 55 metric ton load reduction at an annual cost of $4 million. Similarly, a Level 1 urban nonpoint phosphorus control program would be expected to further reduce the load by 105 tonnes. A summary of this sequence of measures to be applied to Lake Huron sources is presented in Table 17.

C. Lake Ontario:

The total phosphorus load projections and the potential reductions which may be expected through various remedial measures in Lake Ontario are presented in Figures 8a, 8b and 8c. This information has been compiled, along with corresponding cost-effectiveness values for each measure, in Table 13c. Again, following the same procedure used to derive the sequence of measures to be implemented in Lake Erie and Lake Huron, a series of controls is selected to achieve a 2,400 metric ton per year reduction in the total phosphorus load to Lake Ontario, as recommended by PLUARG. It is critical to note that the load reduction to Lake Ontario resulting from the Lake Erie remedial program has been estimated to be approximately 1,200 metric tons. This is based on the assumption that roughly 50 percent of the Lake Erie total phosphorus load is transported by bulk flow into Lake Ontario (Vollenweider, personal communication). Thus, a successful Lake Erie remedial program is expected to decrease the required total phosphorus load reduction in Lake Ontario from 2,400 metric tons per year to 1,200 metric tons per year.

Given that this latter condition holds, inspection of the cost-effectiveness values contained in Table 13c reveals the least-cost sequence of measures for reaching the 7,000 metric ton/yr. target load for Lake Ontario is that presented in Table 18.

Total program costs to meet target loads in the southern Lake Huron, Lake Erie and Lake Ontario basins are expected to be about $106 to $137 million per year [(45)]. Probable rural costs are estimated to be between $26.5 and $57.0 million annually, depending upon the levels of treatment selected. The average annual cost per hectare of agricultural land treated is estimated to be $3.50, ranging from a minimal additional cost for a Level 1 program up to approximately $60 per hectare in certain areas receiving Level 3 treatment. About 112,000 km (27,400,000 acres) of agricultural land should receive at least Level 1 treatment. Close to 40 percent of this land will require additional treatment beyond Level 1 in order to meet target loads. The annual cost of the urban Level 1 nonpoint program is $58.5 million; urban point source "0.5 ppm" programs would likely cost $21.5 million per year in addition to the costs of total phosphorus removal obligated by the 1972 Agreement.

Based upon available information, it is reiterated that a whole lake phosphorus loading reduction program is not required for Lakes Superior and Michigan. Special attention, however, is required for segments of both lakes to protect nearshore water quality. In Lake Superior, this includes reduction of point source loads to restricted embayments (e.g., Thunder Bay, Duluth- Superior Harbor), as well as minimizing activities on the highly erodible red clay area long the southwestern part of the lake. The southern portion of Lake Michigan should be treated as a sub-system similar to Saginaw Bay by agencies developing management plans for phosphorus load reductions.

Sufficient information is available to permit the estimation of other pollutant reductions which are a direct result of phosphorus control programs. Estimates of the suspended solids load reductions which may be expected as a direct result of phosphorus control measures have been compiled for Lakes Erie, Huron and Ontario; the information is presented in Tables 14a, 14b, and 14c, respectively. For example, the load of suspended solids entering Lake Erie from rural sources in the Canadian portion of the basin can be expected to decrease by about 40,000 metric tons per year (from 450,000 to 410,000 metric tons per year) with implementation of a Level 1 remedial program for reducing total phosphorus loads from rural diffuse sources. Similarly, Level 2 and Level 3 rural remedial programs for reducing total phosphorus loads could reduce annual suspended solids loads by approximately 170,000 metric tons and 200,000 metric tons, respectively.

PLUARG has recommended that developing land, in most regions and under most circumstances, should have sediment control programs; in fact, agencies promoting erosion control from rural lands should require a practicable level of effort on developing urban lands, notwithstanding that these lands contribute a low percentage of the total sediment load. As mentioned in Section 3, the annual costs of controlling pollutant loadings from these lands may amount to $2,000 per hectare and would result in a total annual expenditure of approximately $25 million for the Lake Erie and Lake Ontario programs.

This cost appears large, but it translates to an average of less than $200 per single family residential lot. The control program on developing land could reduce suspended solids losses by 10,000 to 15,000 metric tons/yr. This is not a large proportion of the total suspended solids input to the lakes from all sources, but it is significant, especially in terms of local effects near urban areas. A considerable improvement in data on sediment losses and program costs, collected under Great Lakes region conditions, will be necessary before more refined cost estimates can be derived. Also, actual sediment sampling measurements by approved procedures would be necessary in lieu of the suspended solids data which are now commonly available.

TABLE 16: Scenario Example For Lake Erie

		REMOVAL (METRIC TONS)	ANNUAL COST
1.	Voluntary Sound Management On All Agricultural Land	450	Minimal
2.	0.5 ppm Total Phosphorus Effluent Residual At All Municipal Sewage Treatment Plants	1,305	($34.5 Million) $10.5 Million New Program Costs
3.	Second Level Of Effort On All Cropland In Fine-textured Soil Areas	350	$22.5 Million
4.	First Level Of Effort On Non-Point Inputs From Urban Areas	445	$36.5 Million
	Totals	2,550	$69.5 Million

TABLE 17: Scenario Example For Lake Huron

		REMOVAL (METRIC TONS)	ANNUAL COST
1.	Voluntary Sound Management On All Agricultural Land	90	Minimal
2.	1.0 ppm Total Phosphorus Effluent Conc. from All Municipal Sewage Treatment Plants	285	($2.0 Million) $1.0 Million New Program Costs
3.	Further Reduce Effluent Conc. From 1.0 Ppm To.5 Ppm	125	$1.5 Million
4.	Second Level Of Effort On All Cropland In Fine–textured Soil Areas	75	$4.0 Million
5.	First Level Of Effort On Non-Point Inputs From Urban Areas	105	$8.0 Million
		TOTAL 680	$14.5 Million

TABLE 18: Scenario Example For Lake Ontario

	(METRIC REDUCTION TONS/YR.)	ANNUAL COST
Voluntary Sound Management On All Agricultural Land	80	Minimal
0.5 Ppm Residual Concentration Of Total Phosphorus in All Sewage Treatment Plant Effluents	1,000	$7.5 Million Program Costs ($23.5 Million)
First Level Of Effort On Nonpoint inputs From Urban Areas	140	$14.0 Million
TOTAL	1,220 Metric Tons	$21.5 Million
Reduction From Lake Erie Program	1,220 Metric Tons	
Total Reduction To Lake Ontario	2,420 Metric Tons	

REFERENCES

1. American Public Works Association Paper. Evaluation of the Magnitude and Significance of Pollution Loading From Urban Stormwater Runoff - Ontario, American Public Works Association and University of Florida, Chicago, Illinois, 1977.

2. Chapman, L.J. and D.F. Putman. Physiography of Southern Ontario, Ontario Department of Mines and Northern Affairs, Ontario Research Foundation, 1972.

3. Chester Engineers, Inc., Areawide Waste Treatment Management Plan, Appendices 14 and 15, Base Line Facilities, Waste Load and Residual Projections, East Central Michigan Planning and Development Region, Bay City, Michigan, 1977.

4. Coote, D.R., E.M. MacDonald and W.T. Dickenson. 1978. Agricultural Watershed Studies - Great Lakes Drainage Basin. PLUARG Technical Report Series. 78 pp.

5. Department of Environmental Conservation, Office of Program Development, Planning and Research, Division of Pure Waters, New York State. Water Quality Management Plan for Planning Area 03-01 Lake Ontario West, Albany, New York, 1975.

6. Department of Land Resource Science, University of Guelph. Ontario Soils: Physical, Chemical, and Biological Properties and Soil Management Practices, Ontario Ministry of Agriculture and Food, Publication No. 492.

7. Division of Land Resources and Forest Management and Division of Pure Waters, Draft, Water Quality Management Plan for the Lake Ontario Basin, Central (03-02), Eastern (03-03), Albany, New York, 1977.

8. Division of Research, Graduate School of Business Administration, Michigan State University, Michigan Statistical Abstract, Tenth Edition, East Lansing, Michigan, 1974.

9. Drynan, W.R., Relative Costs of Achieving Various Levels of Phosphorus Control at Municipal Wastewater Treatment Plants in the Great Lakes Basin, IJC Great Lakes Regional Office, Windsor, Ontario, 1978.

10. Dwyer, L.A. and R.B. Williams. Canadian Detergent Phosphorus Contributions to the Great Lakes, Water Pollution Control Directorate, 1977.

11. Environment Canada. Surface Water Data - Ontario, Water Survey of Canada, Inland Waters Directorate, 1968-1976.

12. Evaluation of Remedial Measures to Control Non-point Sources of Water Pollution in the Great Lakes Basin, prepared by Marshall, Macklin, Monaghan, Ltd. for the Pollution From Land Use Activities Reference Group, International Joint Commission, Windsor, Ontario, 1977.

13. Federal Water Quality Administration Technical Advisory Committee, Black and Veatch Consulting Engineers, Environmental Protection Agency. Water Quality Management Study, Final Report, Erie and Niagara Counties Regional Planning Board, Grand Island, New York, 1973.

14. Frank, R. and B.D. Ripley, Land Use Activities in Eleven Agricultural Watersheds in Southern Ontario, Canada, 1975-76, Ontario Ministry of Agriculture and Food, 1977.

15. Gakstatter, J.H., M.O. Allum, S.E. Dominguez and M.R. Crouse, "A Survey of Phosphorus and Nitrogen Levels in Treated Municipal Wastewater," Jour. Water Poll. Control Fed., 44, 1352 (1972).

16. General Electric Space Systems. United States Great Lakes Basin Land Cover Classification, Beltsville, Maryland, 1978.

17. Genesee-Lapeer-Shiawasee Region V Planning and Development Commission. 208 Areawide Waste Treatment Management Plan, Interim Output Report, Flint, Michigan, 1977.

18. Great Lakes Basin Commission. Existing River Mouth Loading Data in the U.S. Great Lakes Basin, Ann Arbor, Michigan, 1976.

19. Great Lakes Basin Commission. Maumee River Basin Level B Study, Erosion and Sedimentation Technical Paper, Public Information Office, Great Lakes Basin Commission, Ann Arbor, Michigan, 1976.

20. Great Lakes Basin Commission. Maumee River Basin Level B Study, Land Use Technical Paper, Public Information Office, Great Lakes Basin Commission, Ann Arbor, Michgian, 1976.

21. Great Lakes Basin Commission. Maumee River Basin Water and Related Land Resources, Public Information Office, Great Lakes Basin Commission, Ann Arbor, Michigan, 1977.

22. Hoffman, D.W. and H.F. Noble. Acreages of Soil Capability Classes for Agriculture in Ontario, Ontario Ministry of Agriculture and Food, 1975.

23. International Joint Commission. Great Lakes Water Quality Appendix C, Great Lakes Water Quality Board, Windsor, Ontario, 1977.

24. International Joint Commission. Computerized List of Municipal Facilities with Design Flows and Type of Treatment, Great Lakes Regional Office (unpublished).

25. James F. MacLaren, Ltd. Capital and Operating Cost Analysis of Municipal Phosphorus Control Strategies, London, Ontario, 1977.

26. Johnson, M.G. and G.E. Owen. Nutrient Budgets in the Bay of Quinte, Lake Ontario, Water Pollution Control Federation, May 1971.

27. Johnson, M.G. and B.W. Stahlbaum. PLUARG Model: A Computer Model to Assess Land Planning and Management Strategies As They Affect Pollutant Output to a Lake, Canada Centre for Inland Waters, Staff Report, December 1977 (unpublished).

28. Kirchner, W.B. and P.J. Dillon. "An Empirical Method of Estimating the Retention of Phosphorus in Lakes," Water Resources Research, Vol. II, No. 1, 1975.

29. Lands Directorate, Environment Canada. Land Information for the Great Lakes Basin, Report to the Technical Committee B, Great Lakes Pollution from Land Use Activities Reference Group, International Joint Commission, Appendix B, Parts 2 and 3, 1975.

30. Marsalek, J. Abatement Measures for Pollution Due to Urban Runoff, Hydraulics Research Division, Canada Centre for Inland Waters, Burlington, Ontario, 1978.

31. Marsalek, J. Memorandum for M.G. Johnson, Regional Director, Fisheries & Marine Service, Ontario Region, Erosion Control in Urbanizing Watersheds, Environment Canada, May 1978.

32. Marsalek, J. Overview of Annual Pollutant Loads for Urban Runoff and Combined Sewer Overflows, Hydraulics Research Division, Canada Centre for Inland Waters, Burlington, Ontario, 1978.

33. Marsalek, J. Annual Unit Pollutant Loads for Urban Runoff and Combined Sewer Overflows (Addendum), Hydraulics Research Division, Canada Centre for Inland Waters, Burlington, Ontario, 1978.

34. Metcalf and Eddy, Wastewater Engineering, McGraw-Hill Book Company, 1972.

35. Michigan United Conservation Clubs. Michigan County Maps and Recreation Guide, Lansing, Michigan, 1977.

36. Monteith, T.J. and E.A. Jarecki. Land Cover Analysis for the United States Great Lakes Watersheds, prepared by the Great Lakes Basin Commission staff for the Pollution From Land Use Activities Reference Group, International Joint Commission, Windsor, Ontario (in print), 1978.

37. Municipal and Private Section, Pollution Control Branch, Water and Sewage Treatment Plants in Ontario. Ontario Ministry of the Environment, 1975.

38. Ongley, E.D. Appendix 7: Water Quality Tables for Period of Record to 1974, Volume 1, Interconnecting Waterways, Lake Ontario, Queen's University, Kingston, Ontario, 1977.

39. Ontario Department of Municipal Affairs. Municipal Directory, 1969.

40. Ontario Ministry of the Environment. The Kawartha Lakes Water Management Study - Water Quality Assessment (1972-1976), 1976.

41. Ontario Ministry of the Environment. Muskoka Lakes Water Quality Evaluation: Report No. 3, 1973.

42. Ontario Ministry of the Environment. Water Management Study: Thames River Basin, 1975.

43. Ontario Ministry of the Environment. Water Quality Data for Ontario Lakes and Streams, Volumes 6, 7, 9, Water Resources Branch, 1971, 1972, 1974.

44. Ontario Ministry of Treasury, Economics, and Intergovernmental Affairs. Municipal Directory, 1974 and 1976.

45. PLUARG 1978. Environmental Management Strategy for the Great Lakes System, International Joint Commission Regional Office, July 1978.

46. Pollution From Land Use Activities Reference Group. Reference Tributary Loadings: PLUARG Task D: For the 1975 Water Year. Also PLUARG Task D for the 1976 Water Year, International Joint Commission.

47. Rand McNally Company. Road Atlas, United States, Canada, Mexico, Chicago, Illinois, 1976.

48. Regional Planning Branch. Ontario's Future: Trends and Options, Ministry of Treasury, Economics, and Intergovernmental Affairs, Ontario, 1976.

49. Soil Research Institute, Research Branch. Soil Associations of Southern Ontario, Canada Department of Agriculture and Ontario Department of Agriculture, Guelph, Ontario, 1964.

50. Sonzogni, W.C., T.J. Monteith, W.N. Bach, V.G. Hughes. United States Great Lakes Tributary Loadings, Great Lakes Basin Commission, Ann Arbor, Michigan, 1978.

51. Sonzogni, W.C., T.J. Monteith, W.N. Bach, C.H. Pringle. Critical Assessment of U.S. Land Derived Pollutant Loadings to the Great Lakes - A Summary of U.S. Task D PLUARG, prepared by the Great Lakes Basin Commission staff for the Pollution from Land Use Activities Reference Group, International Joint Commission, Windsor, Ontario (in draft), 1978.

52. Stanley Consultants. Preventative and Corrective Measures for Controlling Agricultural Pollution, Northeastern Illinois Planning Commission, Chicago, Illinois, 1977.

53. Statistics Canada. Agriculture: Census - Farms by Size, Area, and Use of Land, 1977.

54. Statistics Canada. Population: Census Subdivisions (Historical), Volume I, part 1, 1973.

55. Sudar, A. Urban Land Use Forecasts, PLUARG Task B - 5 Report, Inland Waters Directorate - Ontario Region, Burlington, Ontario, May 1976.

56. United States Army Corps of Engineers. Lake Erie Wastewater Management Study, Volume 2, Appendix A, Lake Erie Water Quality Inventory, Buffalo, New York, 1975.

57. U.S. Department of Commerce, Bureau of the Census, "1970 Census of Populations: Characteristics of the Population: United States Summary," June 1973.

58. U.S. Environmental Protection Agency. Estimating Nutrient Loadings of Lakes from Nonpoint Sources, EPA Report No. 660/3-74-020, 1974.

59. U.S. Environmental Protection Agency. Nationwide Evaluation of Combined Sewer Overflows and Urban Stormwater Discharges Volume II: Cost Assessment and Impacts, EPA Report No. 600/2-77-064, 1977.

60. U.S. Environmental Protection Agency. Nonpoint Source - Stream Nutrient Level Relationships: A Nationwide Survey, EPA Report No. 600/2-77-105, 1977.

61. U.S. Soil Conservation Service. State Soils and Water Conservation Needs Inventory (1968), Unpublished data for hydrologic units in U.S. drainage areas of the Great Lakes.

62. Webber, L.R. and D.W. Hoffman. Origin, Classification and Use of Ontario Soils, Ontario Department of Agriculture and Food.

63. Yeates, M. Main Street: Windsor to Quebec City, MacMillan Co. of Canada Ltd. and Ministry of State for Urban Affairs and Information Canada, Toronto and Ottawa, Ontario 3975.

APPENDIX A

RURAL LAND USE AND LAND FORM AREA SUMMARIES

Rural Land Use And Land Form Area Summary For Lake Ontario Drainage Basin[a] (Km^2)

Land Use \ Land Form		Fine Textured Level	Fine Textured Sloping	Medium Textured Level	Medium Textured Sloping	Coarse Level	Coarse Sloping	Misc. Types	Use Sub-total
> 50% Row Crops	Canada	0	0	0	0	147	0	0	147
	U.S.A.	0	0	0	0	0	0	0	0
25 - 50% Row Crops	Canada	383	0	414	0	420	0	0	1,217
	U.S.A.	0	0	0	2,846	0	0	0	2,846
<25% Row Crops	Canada	6,110	0	2,222	6,050	693	1,286	48	16,409
	U.S.A.	717	0	1,379	4,951	0	0	0	7,047
> 60% Forest	Canada	0	0	0	1,170	0	0	10,917	12,087
	U.S.A.	0	0	8,011	9,948	1,504	7,978	0	27,441
Miscellaneous	Canada	0	0	0	0	0	0	0	0
	U.S.A.	0	0	0	0	0	0	0	0
Form Subtotal		7,210	0	12,026	24,965	2,764	9,264	10,965	67,194

[a] The U.S.A. land was classified using the Canadian land use categories for purposes of this table. The U.S.A. area figures, as they appear above, are planimetered measurements from a map of figure 56.

Rural Land Use And Land Form Area Summary For Lake Huron And Georgian Bay [a] (Km²)

Land Use \ Land Form		Fine Textured Level	Fine Textured Sloping	Medium Textured Level	Medium Textured Sloping	Coarse Level	Coarse Sloping	Misc. Types	Use Sub-total
> 50% Row Crops	Canada	0	0	0	0	94	0	61	155
	U.S.A.	2,191	0	699	0	0	0	0	2,890
25 - 50% Row Crops	Canada	2,941	586	0	918	840	67	126	5,478
	U.S.A.	2,688	0	8,078	0	1,483	0	0	12,249
< 25% Row Crops	Canada	3,450	1,347	473	6,886	1,232	603	0	13,991
	U.S.A.	0	0	0	0	5,086	0	0	5,086
> 60% Forest	Canada	416	0	4,093	0	306	0	2,409	7,224
	U.S.A.	0	0	0	0	16,037	6,248	0	22,285
Miscellaneous	Canada	0	0	0	0	0	0	0	0
	U.S.A.	0	0	0	0	0	0	O	0
Form Subtotal		11,686	1,933	13,343	7,804	25,078	6,918	2,596	69,358

[a] The U.S.A. land was classified using the Canadian land use categories for purposes of this table. The U.S.A. area figures, as they appear above, are planimetered measurements from a map of figure 4b.

Rural Land Use And Land Form Area Summary For Lake Erie Drainage[a] (Km^2)

Land Use \ Land Form		Fine Textured Level	Fine Textured Sloping	Medium Textured Level	Medium Textured Sloping	Coarse Level	Coarse Sloping	Misc. Types	Use Sub-total
> 50% Row Crops	Canada	3,123	0	22	0	4,706	0	284	8,135
	U.S.A.	12,731	0	4,985	1,105	906	0	0	19,727
25 - 50% Row Crops	Canada	5,871	1,570	0	2,101	466	567	0	10,575
	U.S.A.	3,597	0	2,035	0	0	0	0	5,632
< 25% Row Crops	Canada	2,265	0	593	460	0	0	0	3,318
	U.S.A.	2,959	0	3,661	223	0	0	0	6,843
> 60% Forest	Canada	0	0	0	0	201	0	0	201
	U.S.A.	0	0	0	0	0	0	0	0
Miscellaneous	Canada	0	0	0	0	0	0	0	0
	U.S.A.	4,100	7,346	8,585	2,743	0	0	0	22,774
Form Subtotal		34,646	8,916	19,881	6,632	6,279	567	284	77,205

[a] The U.S.A. land was classified using the Canadian land use categories for purposes of this table. The U.S.A. area figures, as they appear above, are planimetered measurements from a map of figure 3b.

APPENDIX B

FINE-TEXTURED SOIL CLASSIFICATION

Fine Textured Soils Found In Significant Amounts In The Ontario Basin Of The Great Lakes

FINE TEXTURED SOILS FORMED ON TILL OR LACUSTRINE SEDIMENTS

	Good Drainage	Imperfect Drainage	Poor Drainage
Lacustrine, silty clay	Saugeen	Elderslie	Chesley
Till on red shale, clay	Dunedin	Craigleith	Morley
Till on limestone, clay loam	Vincent	Kemble	Brookston
Till on shale and sandstone, clay loam	Walford	Morrisburg	Osnabruk
Till on limestone, clay and clay loam	Huron	Perth	Brookston
Till on red shale, clay	Nelson	Tansley	
Lacustrine, clay	Cashel	Peel	Halton
Lacustrine, clay	Schomberg	Smithfield	Simcoe
Lacustrine, clay loam	Waupoos	Solmesville	Lindsay
Till on shale, clay loam	King	Monaghan	Brookston
Lacustrine, silty clay	Brantford	Beverly	Toledo
Lacustrine, silt loam over clay	Smithville	Binbrook	
Lacustrine, clay and silt loam	Gananoque	Lansdowne	Napanee

VERY FINE TEXTURED SOILS FORMED ON TILL OR LACUSTRINE SEDIMENTS

	Good Drainage	Imperfect Drainage	Poor Drainage
Till on red shale, clay	Lockport	Trafalgar	
Till on grey shale, clay	Brockport	Cooksville	Mississauga
Till on brown shale, clay	Oneida	Chinguacousy	Jeddo
Till on grey shale, clay		Caistor	
Lacustrine, clay	South Bay	Elmbrook	Sidney
Lacustrine, clay		Haldimand	Lincoln
Lacustrine, clay	Medonte	Lovering	Atherly
Lacustrine, clay		Niagara	Welland

Fine Textured Soils Found In Significant Amounts In The United States Basin Of The Great Lakes

Alexandria	silty clay loam
Andres	silty clay
Ashkum	silty clay loam
Beecher	silty clay loam
Bennington	silty clay loam
Bergland	clay
Blount	silty clay
Bono	silty clay loam
Brookston	silty clay loam
Bryce	silty clay
Candice	silty clay loam
Caneadea	silty clay loam
Cazenovia	silty clay loam
Clarence	silty clay loam
Condit silty	clay loam
Danley	silty clay loam
Derinda	silty clay loam
Dolph	clay
Drummer	silty clay loam
Elliott	silty clay loam
Ellsworth	silty clay
Flanagan	silty clay loam
Fonda	silty clay
Fries	silty clay loam
Fulton	silty clay loam
Hoytville	clay
Hudson	silty clay
Hulberton	silty clay loam
Hurst	silty clay
Ilion	silty clay loam
Indus	clay
Kewaumee	clay
Kokomo	silty clay loam
Latty	clay

Lenawee	silty clay loam
Lockport	silty clay loam
Livingston	clay
Lorain	silty clay loam
Luray	silty clay loam
Mahoning	silty clay
Manawa	silty clay loam
Markhem	silty clay loam
Milton	silty clay loam
Millsdale	silty clay loam
Miner	silty clay loam
Monroeville	silty clay loam
Morley	silty clay loam
Mappanee	clay
Odessa	silty clay
Ontonagon	silty clay
Oshkosh	clay
Ovid	silty clay loam
Panton	clay
Papakating	silty clay loam
Paulding	clay
Pella	silty clay loam
Pewamo	clay loam
Pickford	silty clay loam
Poygan	silty clay loam
Remsen	silty clay loam
Rhinebeck	silty clay
Romulus	silty clay loam
Roselms	silty clay loam
Rowe	silty clay
Schoharie	silty clay loam
Selkirk	clay
Sidell	silty clay loam
Sims	clay loam
St. Clair	clay loam

Swygert	silty clay
Taylor	clay
Toledo	silty clay
Trumbull	silty clay loam
Vergannes	Clay
Wadsworth	silty clay loam
Ward	silty clay loam
Weinbach	silty clay loam
Westland	clay loam
Wickliffe	silty clay

APPENDIX C

MODEL DESCRIPTION AND SAMPLE OUTPUT

This appendix is intended to provide a stepping stone for a more in depth study of the computer model used in the overview modelling exercise for PLUARG. The complete documentation manual for the simulation system programs is on file in the Department of Academic Computer Services, Institute of Computer Science, University of Guelph.

The APL simulation system is composed of three groups of programs. First is the group enabling the creation of a pollutant unit area load matrix. Second are those programs which are used to construct the watershed matrix and finally are the modelling functions and associated reporting facilities. Below are some excerpts from the documentation manual chosen to elucidate somewhat on the three groups and their respective results.

<u>Pg. 104 - C.2 - Pollutant Matrix Description</u>

The pollutant matrix is a table of unit loads (ie. kg. of pollutants per sq. km.). The rows of the table represent land USE and the columns are land FORM. A watershed is composed of identifiable units of land whose use and form are specified by two numbers which refer to the row (use) and column (form) of the pollutant matrix to yield the unit load for this section of land. Newly urbanizing land is assigned an urban use unit load times a multiplication factor (which is referenced by the name AGGRAVATION FACTOR) which is applied for one year for land passing through the "developing" category.

<u>Pg. 107 - D.2 - Watershed Matrix Description</u>

The river matrix is a table of information related to the watershed. It is composed of both information for the physical characteristics of the watershed as well as data required as a "starting point" for a scenario.

The rows of the matrix represent "sections" along the watershed, where the first section (row) starts at the "source" of the river. The sequence of the sections represents the order in which they appear along the river itself. The columns of the matrix are summarized below:

COLUMN # DESCRIPTION:

1. Transmission Entry Point
2. Land Area (sq. km.)
3. Land Use Number
4. Land Form Number
5. Population (no. of people)
6. Population Density (no. of people per sq. km.)
7. Growth Rate (%) of population

SCENARIO STARTING VALUES:

8. Intensification % (for any section)
9. Aggravation Factor (for newly urbanized)

   Remedial Measures (for established urban & rural land)

10. percent
11. $ capital (per sq. km.)
12. $ operating (per sq. km.)

Development Measures (for urbanizing land)
13. percent
14. $ capital (per sq. km.)
15. $ operating (per sq. km.)

Treatment Measures (for populated areas)
16. percent
17. $ capital (per 1000 people)
18. $ operating (per 1000 people)
19. Transmission Coefficients
20. Name of Watershed

Pg. 111 - E.2 - Model Overview

Before running the model, one must first acquire copies of the watershed and pollutant matrices that are to be used.

Once the model begins, it tells how many sections there are in the watershed, then it shows both the transmission coefficients and the modified transmission coefficients. Since it is possible to run any pollutant against any river, it becomes necessary to enter, at the start of each run of the model, the per capita input (PCI) of the pollutant being used for each populated area. Thus the program automatically prompts for the PCI values which are required for calculating population-related pollutant figures.

From this point, the program prompts with the question "WHAT NOW" to which one can reply with a keyword, as summarized in the following section.

Pg. 112 - E.3 - Keywords Available

Elements of data are manipulated, changed, reported and modified by responding with one of the keywords listed below. After typing the keyword and pressing RETURN, the programs will prompt for the information required to complete the request.

AGGravate: to change the aggravation factor being applied to unit loads for developing areas
CONtinue: to continue the model process for another N years as specified by PAUSE (or 25 by default)
COSts: to view, by year, the costs calculated for the overall cycle to date
DENsity: to change population densities
DEVelopment measures: to change the development % and $ capital and operating for populated areas
EFFectiveness: to view the effectiveness report
GROwth: to change the growth rate % for populated areas
HELP: to produce a condensed list of keywords available
INFlation: to change the inflation rate % (default = 0%)
INTensify: to change the unit load intensification % for rural or urban areas
MEAsures: to view the measures currently being used
NOT transmitted: to view the report of pollutants either removed by some treatment measure or stored in the river

PAUse: to specify the duration in years after which the program will next pause (default = 25 years)
PCI: to change the per capita input values of pollutant
PERiod: to respecify the interestperiod over which capital costs will be amortized (default = 15 years)
POLLutants: to view the pollutants generated report
POPulation: to change population figures
RATe of interest: to change the interest rate % that is used in amortizing capital costs (default = 0%)
REMedial measures: to respecify remedial measures (%, and $ capital and operating per sq. km.)
STOP: to discontinue this model process
SUMmary: to view the watershed summary report
TREatment measures: to respecify the treatment measures (%, and $ capital and operating)

The reporting facilities of the modelling programs are briefly illustrated on the following pages and are indicative of the information derived from the modelling procedure.

The Watershed Summary Report along with the Measures Report provide a means to obtain an annual snapshot of the watershed matrix. The former describes the matrix under the two major categories of Land and Population.

The header symbols for the land, from left to right are: Transmission Entry Point; Land Use; Land Form; Intensification Factor; Remedial Percentage; Aggravation Factor; Developing Land Remedial Percentage; Cascading Sequence Position. For the Population category the header reads as follows: Population; New Growth Settlement Density; Population Growth Percentage; Remedial Treatment Percentage from Municipal Point Inputs; Per Capita Input as kg/ person/yr.

The next two reports have to do with the pollutant load from various viewpoints. First of all it should be pointed out that the pollutant input type is always kept separate. Referring to those reports, it is seen that the header information in both reports are the input types considered. These are rural diffuse, established urban diffuse, developing urban diffuse and municipal points inputs. The reports express the pollutant load in two distinct categories. First the amount of pollutant generated at the source of generation for each type of input and secondly the amount eventually getting to the lake. Of the amount that does not get to the lake, the bottom pollutant report shows how much was removed by remedial measures and the amount of pollutant that transmission features have capturedthroughout the drainage basin.

The third group of reports are comprised of the costs report and the cost effectiveness report. The former is a compilation of costs accrued through remedial programs, input type integrity again being maintained. That is, remedial costs incurred from measures on rural land, urban land, developing urban land and municipal sewage treatment plants are kept separated. The effectiveness report shows, for each type of pollutant input, the cost per tonne of removing pollutant. This report presents the cost effectiveness in two ways. One, as a cost per tonne at the source of pollutant generation; and two, as a cost per tonne removed from the lake load (i.e., taking into account transmission effects of reducing the lake load).

WATERSHED
SUMMARY REPORT

SUMMARY AT YEAR 5

LAND									POPULATION				
T	AREA	U	F	INT	REM	AGG	DEV	POS	POP	DEN	GRO	TRE	PCI
1	76.93	4	2	0	0	0	0	1	0	1	0.00	0	0.000
2	113.47	4	2	0	0	0	0	2	0	1	0.00	0	0.000
3	16.82	4	2	0	0	0	0	3	0	1	0.00	0	0.000
3	5.16	12	1	0	0	10	0	4	27232	1290	0.93	63	0.800
3	1.14	14	1	0	0	10	0	5	893	645	0.93	0	0.000
3	151.69	3	1	0	0	0	0	6	0	1	0.00	0	0.000
3	12.65	9	1	0	0	10	0	7	1	1	0.00	0	0.000
4	27.63	3	1	0	0	0	0	8	0	1	0.00	0	0.000
5	82.50	1	5	0	0	0	0	9	0	1	0.00	0	0.000
5	0.90	15	1	0	0	10	0	10	1500	1000	0.00	40	0.650

MEASURES REPORT

MEASURES AT YEAR 5

	REMEDIAL			TREATMENT			DEVELOP		
POS	%	$CA	$OP	%	$CA	$OP	%	$CA	$OP
4	0.00	0	0	63.00	0	2350	0.00	0	0
10	0.00	0	0	40.00	0	2350	0.00	0	0

POLLUTANTS GENERATED AND TRANSMITTED REPORT

POLLUTANTS:

	GENERATED					TRANSMITTED TO L A K E				
YR	RURAL	ESTAB	DEVEL	POPUL	TOTAL	RURAL	ESTAB	DEVEL	POPUL	TOTAL
1	28725	14111	0	21969	64804	28725	14111	0	8353	51188
2	28711	14160	0	22164	65034	28711	14160	0	8425	51295
3	28697	14209	0	22361	65267	28697	14209	0	8498	51404
4	28683	14259	0	22560	65501	28683	14259	0	8571	51513
5	28669	14309	0	22761	65738	28669	14309	0	8646	51623

POLLUTANTS REMOVED BY TREATMENT AND STORED IN RIVER

POLLUTANTS :

	REMOVED BY TREATMENT					STORED IN RIVER				
YR	RURAL	ESTAB	DEVEL	POPUL	TOTAL	RURAL	ESTAB	DEVEL	POPUL	TOTAL
1	0	0	0	13616	13616	0	0	0	0	0
2	0	0	0	13739	13739	0	0	0	0	0
3	0	0	0	13863	13863	0	0	0	0	0
4	0	0	0	13988	13988	0	0	0	0	0
5	0	0	0	14115	14115	0	0	0	0	0

COSTS REPORT

REMEDIAL MEASURES

	RURAL		ESTABLISHED		DEVELOPING		TREATMENT	
YR	$CA	$OP	$CA	$OP	$CA	$OP	$CA	$OP
1	0	0	0	0	0	0	0	65194
2	0	0	0	0	0	0	0	65767
3	0	0	0	0	0	0	0	66345
4	0	0	0	0	0	0	0	66930
5	0	0	0	0	0	0	0	67520
	0	0	0	0	0	0	0	331757

COST EFFECTIVENESS REPORT

COST EFFECTIVENESS: $ PER TONNE

	-------------- AT SOURCE -----------------				------------- AT LAKE ------------------			
YR	RURAL	ESTAB	DEVEL	POPUL	RURAL	ESTAB	DEVEL	POPUL
1	0	0	0	4788	0	0	0	4788
2	0	0	0	4787	0	0	0	4787
3	0	0	0	4786	0	0	0	4786
4	0	0	0	4785	0	0	0	4785
5	0	0	0	4784	0	0	0	4784