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Sediment Integration Report

Contribution of Sediments to the Great Lakes from Agricultural Activities in Ontario

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DISCLAIMER

The information presented in this report is an integration of the data from several projects conducted as a part of the efforts of the International Reference Group on Great Lakes Pollution from Land Use Activities (PLUARG), an organization of the International Joint Commission, established under the Canada-U.S. Great Lakes Water Quality Agreement of 1972. The conclusions are the responsibility of the authors and not of those responsible for the individual projects. The results and conclusions do not necessarily reflect the views of the Reference Group or its recommendations to the Commission.

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1.0 SUMMARY

This report summarizes the results of a three year study conducted in the Canadian Great Lakes Basin to ascertain the nature and extent to which agricultural land use contributes to the sediment load of the Great Lakes. Two years of stream water monitoring data in representative agricultural watersheds indicated a loading rates of <100 to 900 kg/ha/yr for the dominant agricultural regions of Southern Ontario. Highest sediment loads were observed in intensively farmed regions characterized by a high percentage of row crops, fine textured soils and an efficient transport system that delivers eroded sediments to the stream.

The predominant sources of sediments to streams within agricultural areas are sheet and rill erosion from cropland (70 to 100%) and stream-bank erosion (0 to 30%). While soil erosion occurs throughout the year, the delivery of eroded sediments to streams is maximum in the Spring months of February, March and April. It is during this period of time that 75 to 85% of the annual fluvial sediment load is delivered to the Canadian Great Lakes.

Within an agricultural watershed, the percentage of land area that was actively contributing sediments to the streams ranged from a high of 25% when the ground was saturated to <5% with dry soil conditions. The sediment contributing areas in the agricultural watersheds studied were usually in close proximity to natural and man-made drainage ways or ephemeral drainage routes.

Two methods of predicting sediment loading rates from agricultural land have been evaluated in the Grand and Saugeen River Watersheds. In the Grand River Watershed, the predicted agricultural sediment contribution to the Great Lakes ranged from 68 to 90% of total fluvial inputs when computed in four different manners. Similarly the predicted agricultural sediment contribution to the Great Lakes from the Saugeen River ranged from 12 to 66% of total fluvial inputs.

A regression equation $R^2 = 64$ has been used to compute the relative agricultural contribution of sediments to the Canadian Great Lakes. The total predicted annual agricultural sediment load of 1,084,000 tonnes delivered to the Great Lakes from Canadian sources was partitioned as follows: Georgian Bay (4%), Lake Huron (18%), Lake Erie (64%) and Lake Ontario (14%).

Localized variations in pollutant sources, soil properties and landscapes, sediment contributing areas and cropping systems make generalizations about remedial sediment control programs impossible. Erosion and transport of sediments from agricultural land is a site-specific problem requiring the implementation of site-specific remedial measures on the active contributing areas.

All estimates and observations in this report are based on one to two years of field data. The limited time base of the study should be considered in any application of the data contained herein.

2.0 INTRODUCTION

This report summarizes the information from all the PLUARG, Task C, Activity 1 projects dealing with or related to agriculturally derived sediments in the Canadian Great Lakes Basin. These projects have been described in the Detailed Study Plan 1975-76, Agricultural Watershed Studies (D.R. Coote, 1975) and will subsequently be published in Technical Reports by the International Joint Commission. Frank and Ripley (1977) have described in some detail both the location and the land use activities in the 11 agricultural watersheds employed in these studies.

Many of the above noted technical reports deal with individual components or phases of the erosional process and/or the impact of the erosion/sedimentation on Great Lakes water quality. It is the purpose of this summary report to draw together the results of these studies in order to assess the significance of erosional processes in rural landscapes as a source of pollution to the Canadian Great Lakes Basin.

The generalized objectives of this report may be summarized as follows:

- to identify the sources of erosion and sediment production in rural landscapes and assess the relative significance of each source;
- to establish the magnitude of soil erosion and stream sediment loads from rural land;
- to establish a method of predicting soil erosion and stream sediment loads in rural landscapes where no measured data exists;
- to assess remedial measures that have potential to reduce soil erosion and stream sediment loads.

3.0 SOURCES OF EROSION IN THE RURAL LANDSCAPE

The principle sources of sediments to streams in rural areas are generally considered to be sheet and rill erosion from uplands and streambank erosion from natural and man-made drainage courses. However, the nature of these erosion processes as well as spatial characteristics of these sediment sources are not well understood and have been the subject of investigation in several of the recent PLUARG studies.

3.1 Sheet and Rill Erosion

Sheet and rill erosion have been defined as soil movement resulting from raindrop splash and surface runoff from the land. Average annual potential sheet and rill erosion losses for agricultural watersheds representative of the predominant soils, climates and cropping systems in Southern Ontario have been computed with the universal soil loss equation. The following factors were considered: longterm rainfall data (>22 years of record), soil erodibility, slope length, slope gradient, cropping management and erosion control practices. Figure 1 indicates the average annual potential sheet and rill erosion losses from the representative agricultural watersheds.

If the effect of land use on soil is considered, the summary results in Figure 1 reveal that agricultural watersheds with the highest sheet and rill erosion potential (eg. AG-1, AG-13) are characterized by high rainfall erosion values and a high percentage of row crops (eg. horticultural crops, soybeans, corn) affording slight canopy protection to the erosive energy or raindrop impact. On the other hand, agricultural watersheds with low sheet and rill erosion potential are located in less intensively farmed regions where grass and legume crops have been grown in greater abundance.

Mean annual sheet and rill erosion soil losses for the major crops grown in Southern Ontario are also shown in Figure 1. The sheet and rill erosion losses range from a low of <1 ton/ha/yr for permanent grass cover to a high of >9 ton/ha/yr for some horticultural row crops. The wide range of average crop soil losses observed gives credence to the fact that sudden changes in cropping practices in any given region can result in significantly higher levels of soil erosion.

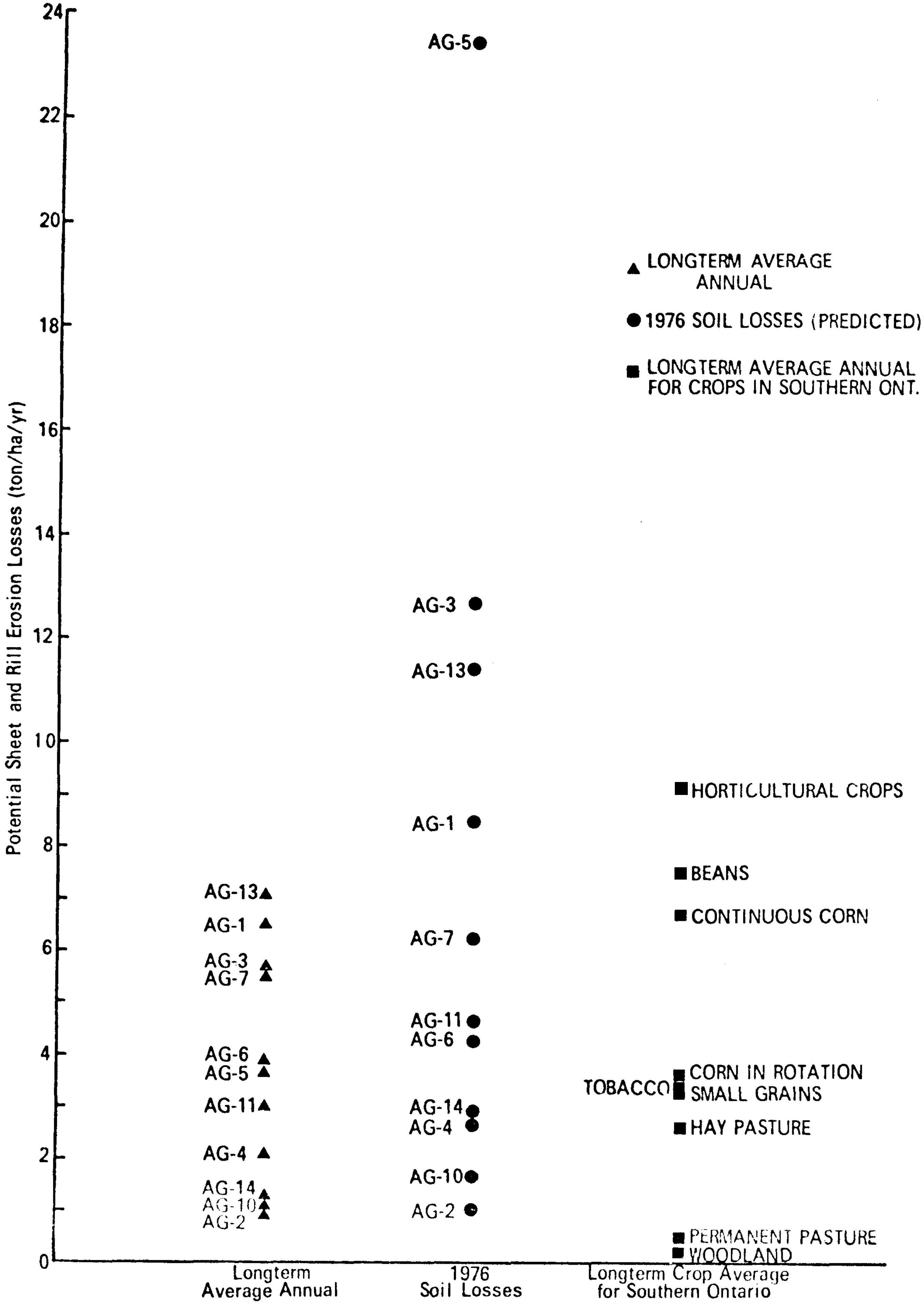

Figure 1: Predicted Sheet and Rill Erosion Losses for Agricultural Watersheds

The sheet and rill erosion values noted above are predicted longterm averages with no allowances made for the effect of year to year rainfall variations or the effect of snowmelt events on soil loss. For comparative soil erosion predictions in the representative agricultural watersheds, sheet and rill erosion soil losses were computed with 1976 rainfall data. For snowmelt effects, soil loss predictions were adjusted upward by values of 10 to 15% of the annual soil loss, on the basis of 3 years of unpublished plot studies at Guelph (van Vliet et al, 1978).

The 1976 predicted soil losses are all higher than the longterm average values because of the 10 to 15% snowmelt adjustment and because the 1976 rainfall erosion index of 130 was twice as high as the longterm average annual value of 66. The very high 1976 predicted soil loss value for Holiday Creek (AG-5) can be attributed to localized extremal summer rainfall events (eg. 121 mm rainfall fell in one 27 hour period). These observations reveal the difficulty in employing single year or short duration data for the purpose of obtaining relative rankings of the severity or magnitude of the problem.

Although rainfall-induced erosion occurs over the entire landscape at varying rates, the studies have confirmed that only a small percent of the agricultural landscape contributes eroded soil materials to stream channels. During the transport phase of the soil erosion process, deposition of eroded materials (all or in part) can take place in depressional areas, at fence rows, or in grassed bufferstrips before reaching the stream system.

A two year field study (1975, 1976) on areas that contribute sediments into streams has indicated that about 10% of the watershed area of AG-4 and 15% of AG-5 were actively contributing eroded soil to stream sediment loads during the year. Under high soil moisture conditions (such as the spring months) the sediment-producing areas were highest (eg. 15-20% of the watershed area). Under low soil moisture conditions (such as in summer) the sediment-contributing areas were much smaller than the average annual values, varying between 0-5%. In these latter cases, most of the surface runoff water appears to infiltrate into the soil and very little or no sediment from the land system reaches the stream system. For large storms, observed sediment-contributing areas have been found to be in close agreement with overland runoff areas predicted with Hydrologic Model (Whiteley and Ghate, 1978).

At what time of the year are rainfall-induced sheet and rill erosion losses most severe? The studies have shown that these soil losses are not equally distributed over the year. Rainfall erosion potential is low in the spring, maximizes in June, July and August and declines in the autumn. Approximately one half of the annual rainfall erosion potential is associated with the short duration, high intensity convective storms of June, July and August.

Aforementioned observations on temporal and spatial patterns of soil erosion and sediment-contributing areas have a significant influence on the selection of remedial measures for the reduction of soil loss.

3.2 Streambank Erosion

A preliminary survey of the streambanks in 16 agricultural watersheds in Southern Ontario indicated that the most common form of active erosion was sloughing and rotational slumping, often in combination with scour. About 2/3 of the banks were concave shaped. Of the total bank area observed, 13% (range: 0-43%) were found to be totally exposed, the remainder (87%) was partly or completely vegetated (Knap, 1978).

Active streambank erosion occurred on 37% (range: 0-62%) of the total streambank area observed, the remainder (63%) had no active erosion or no erosion at all. Over 70% of the bank area had slopes of between 20° to 45° (44-100%) and slope lengths from 120 to 365 cm. The streambank information obtained in this preliminary survey was used for the interpretation and extrapolation of measured streambank erosion rates in the agricultural watersheds.

4.0 NATURE AND MAGNITUDE OF FLUVIAL SUSPENDED SEDIMENT LOADS IN RURAL LANDSCAPES

4.1 Magnitude of Fluvial Sediment Loads

Two years of measured stream discharge and sediment concentration were available from the monitoring program of the 11 agricultural watersheds. From these raw data, sediment loads were computed by four different methods. Figure 2 illustrates the variability of annual loading rates obtained with the four methods of computation. This variability reveals that interpretations, extrapolation of results and subsequent conclusions about sediment loads from the agricultural watersheds are highly dependent on the data base used. The sediment integrators determined that the integration and the Naquadat methods reflected the observed load conditions most accurately and hence provide the most reliable relative ranking of watersheds. Also, both of these methods provide the sediment loads by month as required for computing monthly sediment delivery ratios.

Sediment loads computed by the integration method were only available for the 6 watersheds studied in detail. Consequently, a combination of the integration and Naquadat methods of load computations were used for the sediment integration aspect of the Canadian PLUARG Task C studies.

The agricultural watersheds have been placed into sediment load categories on the basis of measured unit area loadings as follows:

AVERAGE WATERSHED UNIT AREA LOADING (kg/ha/yr)	WATERSHED IDENTIFICATION*
900	1
350	3, 4, 5, 10, 13
80	2, 6, 7, 11, 14

* See Frank and Ripley (1977) for description and location of watersheds.

The temporal distribution of sediment loads for the 11 agricultural watersheds is one for which most of the total annual loads (mean of 75%,

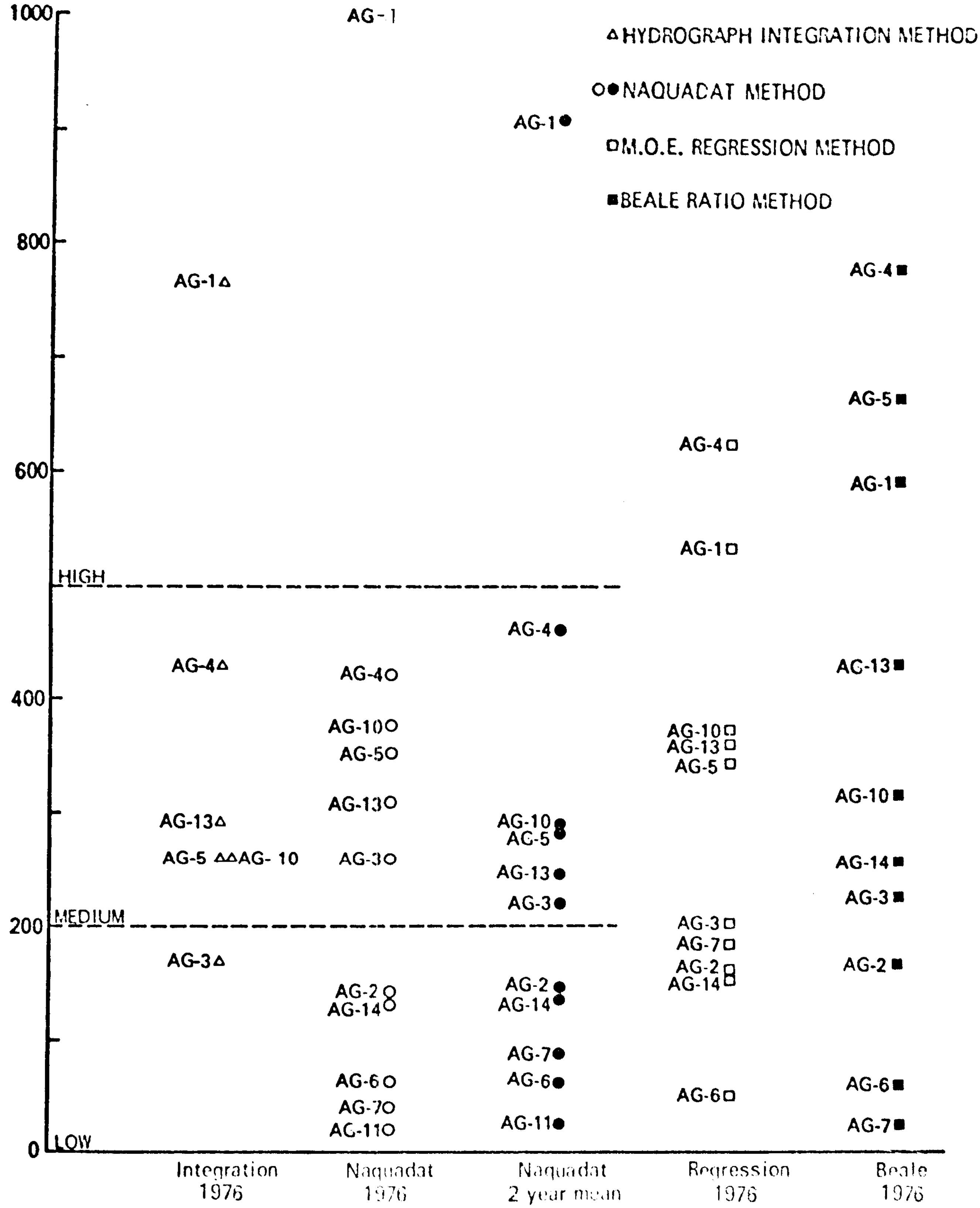

Figure 2: Measured Suspended Sediment Loads for the 11 Agricultural Watersheds as Computed by Different Methods

range of 41-93%) are transported to the mouth of the watersheds during the months of February and March. These 2 critical months are characterized by snow melt events, low rainfall intensities and high antecedent soil moisture conditions. During the remainder of the year, sediment loads in the stream system are generally very low. This same pattern has been observed for rivers in much larger drainage basins (100-1759 km^2) in Ontario by the authors.

It should be noted that the average unit area loadings reported above are representative of rural land and may include both cropland and stream-bank components.

4.2 Nature of Fluvial Sediment Loads

The physical and chemical properties of fluvial sediments transported from agricultural watersheds are quite different from the soil materials from which they were derived (Wall, 1978). This observation reflects the selective nature of the soil erosion process towards the finest, most erodible, soil particles. The texture of the fluvial suspended sediments in all agricultural regions was usually a heavy clay (>60% clay) with clay contents ranging from 59 to 98%. This represents an enrichment of clay from one to four times that found in watershed soil materials. Organic matter levels of suspended sediments were analogous to surficial soil material (<5%) while the cation exchange capacity of the suspended sediments was two to three times greater than soil materials.

Sediments that settle out on stream beds during transport are often resuspended and transported at a later date, under a high stream energy regime. The texture of these bottom sediments in the agricultural watersheds was usually a sandy loam with clay contents ranging from 10% to 35% and sand contents from 25% to 90%. Enrichment of sand in bottom sediments over soil materials of from >1 to 4 times reflects the selectivity of the transport process to the fine soil particles. The organic matter content of the bottom sediments was usually <3%, while cation exchange capacities ranged from 10 to 25 meq/100g. The clay mineralogy of the watershed soils, fluvial suspended sediments and bottom sediments were analogous with mica, quartz and vermiculite predominant.

5.0 RELATIVE SIGNIFICANCE OF DIFFERENT FLUVIAL SEDIMENT SOURCES

As stated earlier, the primary sources of sediments to streams in rural landscapes are cropland and streambanks. While other sources of fluvial sediment are recognized (e.g. roadside erosion), the contribution from such sources have been judged to be minimal in the agricultural watersheds investigated. The purpose of this discussion is to report data that can be used to partition the total sediment load of the agricultural study watersheds into relative streambank and cropland component sources.

Streambank erosion studies on the agricultural study watersheds provided measures of the quantity of fluvial sediments contributed to streams from this source. For computational purposes, the amount of streambank material that is transported by streams as suspended sediments to the Great Lakes was assumed to be only the silt and clay fraction of the eroded material. The sand-sized material eroded from the streambanks was assumed to have become deposited during transport (the many dams and impoundments on rivers in Ontario would entrap much of this coarse sediment load) and not to have contributed significantly to Great Lakes loadings. Table 1 shows streambank erosion rates in 11 of the agricultural study watersheds. The streambank erosion rates range from 223 kg/ha/yr to less than 10 kg/ha/yr for the 11 agricultural watersheds.

The sediments derived from streambank erosion have been expressed as a percentage of the measured 1976 fluvial suspended sediment load (Table 1). The percentage of the total suspended sediment load contributed by streambank erosion ranges from a high of 33% in AG-4 to a low of 2% in AG-5. Since no independent estimate of erosion from cropland was available, the cropland contribution to suspended sediment loadings has been calculated by the difference. On this basis, it is concluded that erosion from cropland is the largest source (ranging from 70 to 100%) of suspended sediments to streams in agricultural watersheds (Table 1).

Table 1: Partitioning of 1976 measured suspended sediment loads in streambank and cropland erosion components

WATERSHED	1976 STREAM SEDIMENT LOADS[1] (kg/ha/yr)	1976 STREAMBANK EROSION ESTIMATES[2] (kg/ha/yr)	STREAMBANK AS PROPORTION OF TOTAL SEDIMENT LOAD (%)	CROPLAND AS PROPORTION OF TOTAL SEDIMENT LOAD (100 - % STREAMBANK)
AG-1	998	223	22	78
AG-2	140	10 [4]	7	93
AG-3	258	24	9	91
AG-4	419	137	33	67
AG-5	351	5	2	98
AG-6	64[3]	10 [4]	16	84
AG-7	43	7 [4]	16	84
AG-10	375	17	5	95
AG-11	19 [3]	65	--	--
AG-13	310	41 [4]	13	87
AG-14	135	75 [4]	--	--

[1] Using NAQUADAT method of sediment load computation.
[2] Knap, (1978) PLUARG, TASK C, ACTIVITY 6.
[3] Problems with streamflow measurements account for the very low sediment load.
[4] Estimates for original selected watersheds, before relocation.

6.0 PREDICTION OF FLUVIAL SEDIMENT LOADS

Since many of the tributaries to the Great Lakes are not monitored for suspended sediments, it was desirable for the studies to obtain a methodology whereby suspended sediment loads could be predicted. This prediction capacity would assist in locating areas with excessive sediment loading rates without the expense of a monitoring program. The Universal Soil Loss Equation provided a method whereby potential soil erosion losses could be computed from readily available soil and land use data. By the application of a delivery ratio factor (defined as the proportion of the gross soil erosion delivered to the stream), the Universal Soil Loss Equation has been used to predict stream suspended sediment loads. The Soil Conservation Service, United States Department of Agriculture, has published a delivery ratio curve from which the delivery ratio of drainage basins can be computed. Suspended sediment loads for the agricultural study watersheds were predicted in this manner, and with a delivery ratio based on drainage size but modified for predominent soil textures. These predicted sediment loadings, along with measured suspended sediment values have been included in Table 2.

The predicted sediment loadings for the 11 agricultural watersheds appear to overestimate measured suspended sediment loads. The delivery ratio (A) based on drainage area appears to provide a more accurate estimate of the sediment loads than does delivery ratio B based on drainage area and soil texture (Table 2). Given the limitations of both prediction procedures and the short term (2 yrs) of record available for actual load measurement, the estimates of sediment load in the agricultural watersheds seem reasonable and merit future consideration for soil erosion prediction studies.

A computerized version (SEDEL Model, S.C.S. Washington) of the above methodology has been employed with satisfactory results to predict suspended sediment loads in AG-4 and AG-5. This method is well suited for use in large drainage basins.

A sediment transport computer model (STCM, Kling and Olsen) has been employed in two of the agricultural watersheds, AG-4 and AG-5. This model applies a transport factor (based on slope changes) to gross soil erosion losses as computed by the Universal Soil Loss Equation to predict suspended sediment loads. Predicted suspended sediment loadings have been found to be approximately 2.5 times greater than the 1976 measured

Table 2: Predicted stream sediment loads for the 11 agricultural study watersheds

WATERSHED	POTENTIAL[1] SHEET EROSION LOSSES (kg/ha/yr)	POTENTIAL STREAMBANK EROSION LOSSES (kg/ha/yr)	GROSS[2] EROSION (kg/ha/yr)	DRAINAGE AREA (sq miles)	DELIVERY RATIO (D.R.) % A[3]	B[4]	SEDIMENT LOADINGS (kg/ha/yr) PREDICTED (Gross Erosion x D.R.) A[1]	B	MEASURED
AG-1	6574	286	6860	19.6	15	30	1029	2058	906
AG-2	984	20	1004	30.5	14	7	141	70	146
AG-3	5752	29	5781	23.9	15	21	867	1214	219
AG-4	2086	241	2327	7.2	19	25	442	582	475
AG-5	3739	10	3749	11.6	17	22	637	825	279
AG-6	3980	14	3994	21.1	15	18	599	719	63
AG-7	5676	18	5694	21.8	15	10	854	569	87
AG-10	1055	18	1073	11.7	17	30	182	322	282
AG-11	2997	93	3090	9.2	18	26	556	803	158
AG-13	7252	56	7308	7.7	19	10	1389	731	245
AG-14	1244	94	1338	17.4	16	25	214	335	134

[1]As computed by the universal soil loss equation.
[2]Gross erosion is the sum of potential sheet erosion losses and potential streambank erosion losses.
[3]Delivery ratios based on drainage basin zone (S.C.S., 1973)
[4]Delivery ratios based on drainage basin zone but modified for predominant soil textural materials in watersheds (S.C.S., 1973 b).
[5]"Naquadat" method, mean of 2 years data (May 1, 1975 - April 30, 1977)

suspended sediment loads.

Since the STCM Model considers individual 4 ha grids within a watershed, it becomes a useful method to identify the location of erosion-sensitive lands within a watershed. This aspect of the model has been employed to assess the utility of different remedial measures in reducing soil erosion. The results of these studies are reported elsewhere in this summary.

A regression analysis for the 11 agricultural watersheds, with 14 measured watershed characteristics and the 1976 unit area loads (Naquadat Methodology) as the dependent variable has indicated that sediment load is a function of % row crops and % clay, explaining 71% of the total variation in sediment yield with the equation,

Sediment load (KG/HA) = -281.2 + (% row crops x 8.3) + (% clay x 13.6).

This regression equation could be used to predict sediment loads for other areas where % row crops and % clay are known (van Vliet et al, 1978).

Delivery ratios have been used for the prediction of fluvial suspended sediment loads in Canadian as well as United States Great Lakes Basin studies. Published delivery ratios that have been available for use in these studies have often not been developed from Great Lakes Basin data. Since measures of fluvial suspended load as well as potential gross erosion were available for the 11 agricultural study watersheds in the Canadian Great Lakes Basin, it has been possible to compute a delivery ratio for these watersheds. Table 3 shows computed delivery ratios for the 11 study watersheds as well as published delivery ratios based on drainage basin area.

In many cases, the computed and published delivery ratios compare favourably (e.g. AG-1, 2, 4, 5, 10, 14) while in other watersheds the delivery ratios differ significantly (AG-3, 6, 7, 11, 13). There is no apparent reason for this discrepancy in delivery ratio values. Analysis of the data suggests that extreme care should be used in the selection of delivery ratios for use in the prediction of fluvial suspended sediment loads.

Sediment delivery ratios have been computed from 1976 data on a monthly basis for the Canadian agricultural study watersheds in order to investigate seasonal variation in sediment delivery. The general seasonal picture that has evolved reveals a high delivery of eroded sediments in the cool wet spring months and a low delivery of eroded sediments in the hot dry summer months which increases slightly during the autumn prior to freeze up. While soil erosion may be active throughout the year, there appears to be only a rather short time period in the spring of the year when the transport of eroding sediments to streams is significant. This data gives credence to the suggestion that effective soil erosion remedial measures must take into account both temporal and spatial aspects of the erosion process.

Table 3: Delivery ratios for the agricultural study watersheds

WATERSHED	DELIVERY RATIO (D.R.) % A[1]	B[2]	C[3]
AG-1	13	16	30
AG-2	15	14	7
AG-3	4	15	20
AG-4	21	19	23
AG-5	7	18	21
AG-6	2	15	19
AG-7	2	15	9
AG-10	26	18	37
AG-11	5	18	38
AG-13	3	19	10
AG-14	10	16	30

[1]Computed for the agricultural study watersheds as follows:

$$\text{D.R.} = \frac{\text{Suspended Sediment Load (2 yr mean, Naquadat)}}{\text{Average Annual Sheet and Rill Erosion + Gross Streambank Erosion}}$$

[2]Based on drainage basin area (S.C.S., 1973)

[3]Based on drainage basin area with modification for drainage basin texture. (S.C.S., 1973 b).

7.0 EXTRAPOLATION OF SEDIMENT LOADING RATES TO AGRICULTURAL LAND IN THE CANADIAN GREAT LAKES BASIN

During the course of the PLUARG study, sediment loading rates were determined for small (<6000 ha) agricultural watersheds representative of the predominant agricultural cropping practices, soils and climates in the Canadian Lower Great Lakes Basin. This data base was used to first, extrapolate agricultural loading rates to the PLUARG watersheds of the Grand and Saugeen Rivers and subsequently extrapolate to the entire lower Great Lakes Basin.

Since the Grand and Saugeen Rivers were monitored for sediment loads during the PLUARG study period, these watersheds provided a good starting point to check extrapolation procedures. Measured suspended sediment loadings for the Grand and Saugeen Rivers were 332 and 488 kg/ha/yr respectively (Table 4). These values represent both the rural and urban input sources to the Great Lakes.

Prediction of the rural (agricultural) contribution to the total suspended sediment load in each of these watersheds was made by two methods (Table 4). First, an estimate of agricultural sediment loading for the Grand and Saugeen River watersheds was obtained by extrapolating unit area loadings obtained from the PLUARG agricultural watersheds to like areas in the Grand and Saugeen watersheds. Predicted agricultural unit area loadings for the Grand and Saugeen watersheds were 300 and 76 kg/ha/yr respectively. When compared to the measured loading rates, the agricultural contribution to the total sediment input is 90% for the Grand and 16% for the Saugeen (Table 4).

A second prediction of the rural (agricultural) contribution to sediment loadings was made with a regression equation (R^2 = .71) that was developed from measured sediment loading rates and watershed characteristics in the 11 PLUARG agricultural study watersheds. Agricultural unit area loadings predicted with the regression equation method for the Grand and Saugeen watersheds were 227 and 57 kg/ha/yr. The estimated agricultural sediment load for the Grand and Saugeen watersheds ranged from 68 to 90% and 12 to 66% respectively when expressed as percentages of measured loads and percentages of all other estimated sources (Table 5). The low (12 to 16%) estimated agricultural load in the Saugeen river may reflect an erroneous measured suspended sediment load.

Table 4: Measured and Predicted Suspended Sediment Loadings for Agricultural Land in the Canadian Great Lakes Basin

Method of Load Estimation	Watershed			Source of Sediment
	Grand River	Saugeen River (kg/ha/yr)	Canadian Great Lakes	
Measured (Rural and Urban Sources)	332[1]	448[2]	ND[3]	All Rural and Urban Sources
Predicted (Rural Sources) (a) Extrapolation of measured agricultural watershed unit area loadings	300	76	215	Rural Sheet and Bank Erosion
(b) Extrapolation by regression equations	227[4]	57[4]	209[5]	Rural Sheet and Bank Erosion

[1](Hore and Ostry, 1978). O.M.E., regression computations, 2 yr mean 1975-76

[2](Hore and Ostry, 1978). Water Survey of Canada, integration computation, 2 yr mean, 1975-76.

[3]Measured data not available for all Canadian tributaries

[4](van Vliet et al., 1978). Regression equation based on two years data from 11 agricultural watersheds as follows: Sediment Load (kg/ha/yr) = -281 + 8.3 (% Row Crop) + 13.6 (% Clay) [R^2 = .71]

[5](van Vliet et al., 1978). Regression equation based on two years data from 11 agricultural watersheds as follows: Sediment Load (kg/ha/yr) = -204 + 7.9 (% Row Crops) + 11.0 (% Clay) [R^2 = .64] (Appendix 1 and 2)

Table 5: Estimated agricultural contribution to the sediment load of the Grand and Saugeen Watersheds

WATERSHED	ESTIMATED UNIT AREA LOADINGS: EXTRAPOLATION BY REGRESSION[2] (kg/ha/yr)	ESTIMATED UNIT AREA LOADINGS: EXTRAPOLATION OF UNIT AREA LOADS[3] (kg/ha/yr)	ESTIMATED LOAD AS A PERCENTAGE OF MEASURED LOAD (%)	ESTIMATED LOAD AS A PERCENTAGE OF ALL ESTIMATED SOURCES[1] (%)
Grand	227	300	68[2] to 90[3]	73[2] to 78[3]
Saugeen	57	76	12[2] to 16[3]	59[2] to 66[3]

[1] Hore and Ostry, 1978

[2] Estimated land computed by the regression method (van Vliet et al., 1978)

[3] Estimated load computed by extrapolation of unit area loadings (van Vliet et al., 1978)

Extrapolation of sediment loadings for the total agricultural land area in the lower Canadian Great Lakes Basin was made by methods as described for the Grand and Saugeen watersheds. The agricultural land area considered was 5,165,733 ha. The representative agricultural watersheds that were used in the PLUARG study to derive sediment loading rates were considered analagous to 83% of the total agricultural land area. The remaining 17% agricultural land was not intensively farmed and judged to have low erosion potential.

The sediment loading rates for agricultural land in the lower Canadian Great Lakes Basin were essentially analogous (215 vs 209 kg/ha/yr) when computed by the two different methods (Table 4). The rural streambank erosion contribution to the agriculturally derived sediment load was computed to be approximately 20%. Data used in the regression equation and computed sediment loads for each subbasin in the southern Ontario portion of the Great Lakes Basin are presented in the Appendix. Since no total (rural and urban sources) sediment loadings were available for the Canadian Great Lakes Basin, it was not possible to report the relative contributions of the agricultural and urban contributions. Figure 3 shows the spatial distribution of agriculturally derived sediment loads in part of the Canadian Great Lakes Basin. The following table shows the relative agricultural contribution of suspended sediments to the Canadian Great Lakes (Appendix 1 and 2).

	Agricultural Sediment Load (Tons)[1]	% of Total Agricultural Load
Georgian Bay	45,120	4
Lake Huron	198,627	18
Lake Erie	685,250	64
Lake Ontario	155,205	14

As computed by the regression equation:

$$\text{Sediment load (kg/ha/yr)} = -204 + 7.9\ (\%\ \text{Row Crops}) + 11.0\ (\%\ \text{Clay})$$

$$[R^2 = .64]$$

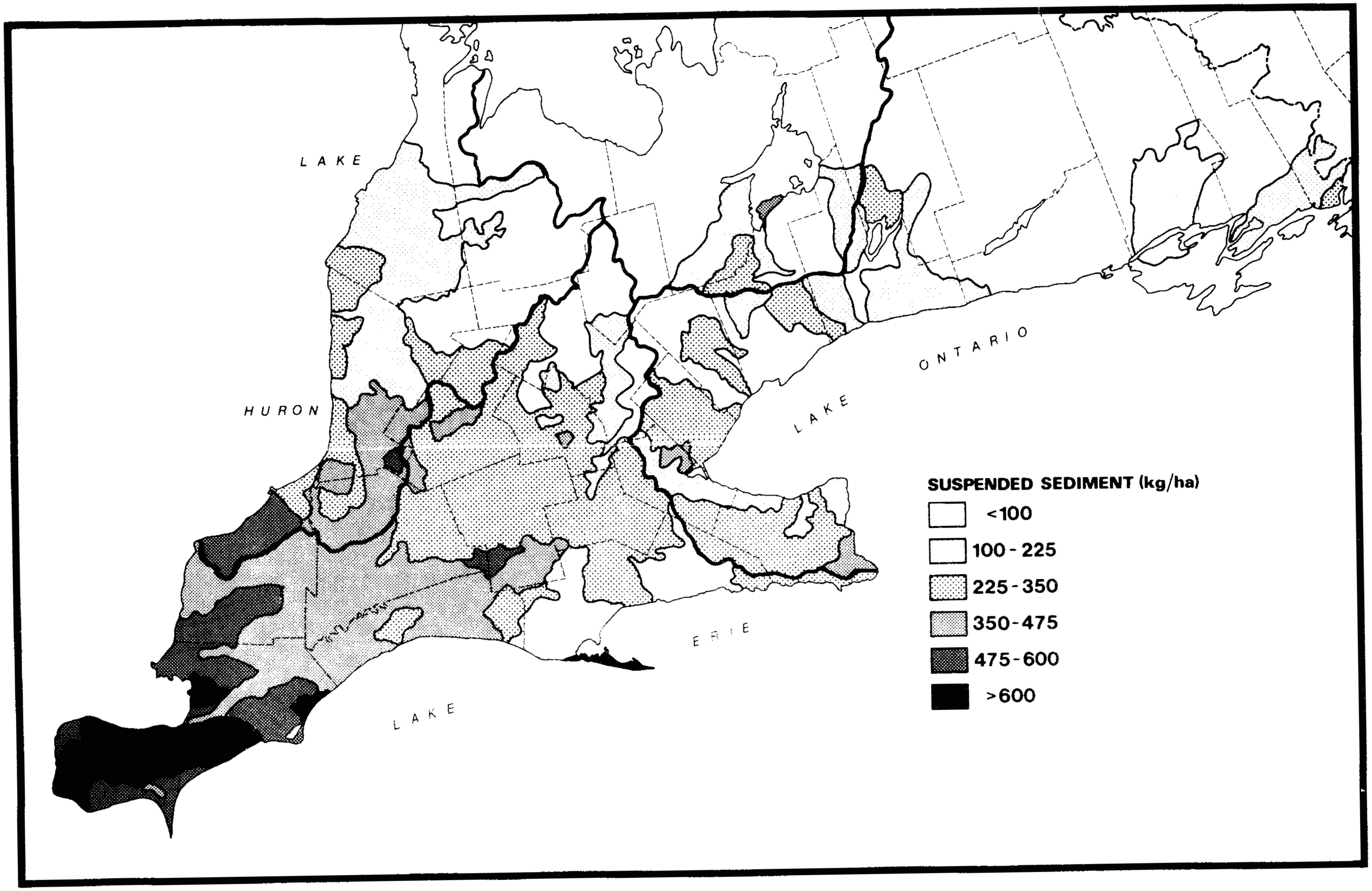

Figure 3: Spatial Distribution of Agriculturally Derived Fluvial Sediment Load in Part of the Canadian Great Lakes Basin

8.0 REMEDIAL MEASURES TO REDUCE SOIL EROSION AND SEDIMENT DELIVERY

The results of several PLUARG studies concerned with temporal and spatial aspects of soil erosion and sediment delivery have important implications in the establishment of cost effective remedial programs designed to lower sediment and associated contaminant inputs to the Great Lakes. While soil erosion was observed to occur throughout the year, the delivery of fluvial sediments to the Great Lakes was maximum in the late winter and spring months. The two years of monitoring data collected for PLUARG studies revealed that greater than 70% of the annual sediment load was transported in the months of February, March and April. It is apparent from these observations that any remedial programs advocated for the reduction of sediment loads must be effective for the soil, climatic and hydrologic conditions that exist in the months of February, March and April.

Soil erosion from cropland sources was found to range from 70 to 100% of the total agricultural contribution to stream sediment loads. While soil erosion does occur on all agricultural land, PLUARG studies found that the actual percentage of the agricultural land that yield sediments to streams is much less than 100%. In two detailed agricultural watershed studies, the fluvial sediment source areas ranged from a maximum of 20% of the total watershed area in the wet spring months to a minimum of less than 5% of the total watershed area in the dry summer months. For remedial programs designed to improve water quality, it is most important that corrective measures be applied specifically to the active sediment-producing areas of the agricultural landscape.

Many erosion control practices have been used in agriculture over a wide range of soil, slope, hydrologic and climatic conditions with varying success levels. Crop rotations, cross-slope and contour farming, winter cover crops, residue management, minimum tillage, grassed waterways and stream channel buffer strips are among practices employed both directly and indirectly to minimize soil erosion losses.

However, it should be emphasized that localized variations in pollutant sources, soil properties and landscapes, cropping systems and active pollutant-contributing areas make generalizations about satisfactory remedial programs impossible. Therefore, the erosion and transport of pollutants from any point on the agricultural landscape must be considered as a site-specific problem requiring the implementation of site-specific remedial measures on the active contributing areas. In order to illustrate an approach to remedial measure recommendations, sets of practices were developed for four agricultural watersheds to demonstrate (a) the selection of remedial measures commensurate with an existing viable agricultural industry and (b) the probable cost-effectiveness of the implemented remedial program (Tables 6-9).

The relative magnitude of a pollutant source is a site-specific factor governing the implementation of remedial programs. For example, the streambank erosion component of the total sediment load varies from greater than 30% as in watershed #1 (Table 6) to less than 5% as in watershed #5 (Table 9). In remedial programs, the greater streambank erosion component in watershed #1 as opposed to that in watershed #5 is reflected in the extensive and costly drainage engineering measures implemented (Tables 6 and 8).

Soil properties such as texture can also affect the suitability of a remedial practice at a given location. Clay soils such as located in watershed #1 are not suited to spring plowing or zero tillage remedial practices since the corresponding yield reductions would make corn or soybeans production uneconomical. However, spring plowing or zero tillage are viable remedial programs in areas with medium to coarse-textured soils such as illustrated in watersheds #4 and #5 (Tables 7 and 8). The shape of the landscape can also affect the selection of remedial measures. For example, strip or contour cropping as employed in watersheds #4 and #5 are most applicable on simple, uniform slopes rather than hummocky, complex topography.

The existing range of crops grown in a region can also affect the selection of feasible remedial programs. Crop rotation is presently a common practice in watershed #4 so was not included as a remedial measure (Table 7). On the other hand, the use of hay crops in rotations which are recommended as remedial measures in watershed #1 has a very high cost because there is no local market for the hay (Table 6).

The active pollutant-contributing area can also vary in magnitude on a regional basis. Watershed #1, for example has a contributing area of 50% while the remaining watersheds used in the examples (#3, 4, 5) have contributing areas of 25% (Tables 5-8). A large contributing area such as observed in watershed #1 necessitates the implementation of remedial measures on a larger area with associated greater costs (Tables 6-8).

Tables 6-9 have been used as examples of an approach to remedial measures based upon the understanding of erosion and pollutant transport processes and data generated during the PLUARG program. However, it should be reinterated that the recommendations made for the 4 watersheds are examples of remedial programs rather than final solutions in these areas.

Table 6: Application of Some Feasible Remedial Measure Alternatives in Agricultural Watershed AG-1; estimated costs and effectiveness

Watershed Ag-1 - Big Creek

Watershed description: Area - 5080 ha; soil - 35% to 40% clay; relief - level; stream length - 91 km; hydrologically active contribution area - 50%; land use - 62% row crops, 23% corn, 37% soybeans, 27% wheat, 1% hay; livestock - 0.08 animal units per ha.

Pollutant loads:	Sediment (suspended solids)	Total phosphorus
Measured loading rates	900 (kg/ha/yr)	1.8 (kg/ha/yr)
Potential minimum - zero row crops[1]	260	0.8
Potential maximum reduction	640	1.0

Remedial Measure[2]	Effectiveness[2] Sediment % Reduction	Sediment Residual	Phosphorus % Reduction	Phosphorus Residual	Cost ($) Annual	Cost ($) Capital	Explanatory Note
1. Good management practices	5	850	5	1.70	0	0	3
2. Crop rotations (Corn-soybeans - wheat - hay)	10	765	10	1.50	130,000	0	4
3. Winter cover (oats) - shorter season corn	10	690	10	1.35	57,500	0	5
4. Stream channel buffer strips	15	590	10	1.25	61,820	0	6
5. Drainage engineering:	40	350	15	1.00			
a. Grading channel banks to 3:1 slopes					31,000	57,000	7, 8
b. Drop inlet structures						100,000	9
c. Amortization of capital costs					17,900		10
Total annual costs - $58/watershed ha.					298,200	157,000	

Explanatory Notes:

1. As computed by the following regression equations (row crops = 0) Sediment (kg/ha/yr) = -281 + 8.3 (% row crops) + 13.6 (% clay); Total phosphorus (kg/ha/yr) = $-0.0939 + 0.000846\ (\%\ \text{clay})^2 + 0.000212\ (\%\ \text{row crops})^2$.
2. Relative benefits obtained by each remedial measure (i.e. cost effectiveness) depends on the order in which they are implemented.
3. Good management practices include the following no cost items that are applicable to all agricultural land: - a. fertilize by soil test; b. retain surface residues over winter; c. minimum tillage for optimum yield; d. manure incorporation and restricted use near streams; e. residue management for soil organic matter maintenance; f. cross slope farming.
4. Assumed costs and returns for cropping practices:

	Corn and Soybeans	Cereal Grains	Hay	Revenue Lost by Crop Conversions
Returns	300 bu/ha @ $2.50/bu = $750/ha	150 bu/ha @ $2.0/bu = $300/ha	25 bu/ha increase in subsequent corn yield = $60/ha. Nitrogen added @ 114 kg/ha @ 44¢ = $50/ha $80/ha (assumed equal to costs since no market)	Corn or soybeans to hay - $340/ha Corn or soybeans to grains - $250/ha Grains to hay - $90/ha
Costs	$300/ha	$100/ha	$80/ha	
Net	$450/ha	$200/ha	$110/ha	

2500 ha in contributing area (currently 500 ha corn, 1000 ha soybenas, 750 ha wheat, 50 ha hay, 200 ha other improved) is changed to meet rotation requirements (575 ha corn, 575 ha soybeans, 575 ha wheat, 575 ha hay) requiring 350 ha of corn or soybeans and 125 ha of wheat to be converted to hay.

5. 575 ha corn with 25 bu/ha yield reduction ($60/ha) and cost of $40/ha for oats establishment.
6. 182 ha in contributing area lost from production (110 ha corn and soybeans and 55 ha wheat to uncut hay) for $60,000; buffer strip maintenance @ $10/ha.
7. Lost from production by grading channels to 3:1 bank slopes - 10 m X 91 km = 91 ha (55 ha corn or soybeans and 30 ha wheat)
8. Grading costs @ $600/km for 91 km of channel
9. Drop inlet structures @ 4/km^2 @ $500/structure
10. Amortization over 20 years @ 10%

Table 7: Application of Some Feasible Remedial Measure Alternatives in Agricultural Watershed AG-3; estimated costs and effectiveness

Watershed Ag-3 - Little Ausable River

Watershed description: Area - 6200 ha; soil - 25% to 30% clay; relief - gently sloping; stream length - 40 km; hydrologically active contributing area - 25%; land use - 45% row crops, 32% corn, 12% beans, 22% small grains, 5% wheat, 10% hay; livestock - 0.48 animal units per ha.	Pollutant loads:	Sediment (suspended solids)	Total phosphorus
	Measured loading rates	260 (kg/ha/yr)	1.1 (kg/ha/yr)
	Potential minimum - zero row crops[1]	60	0.4
	Potential maximum reduction	200	0.7

Remedial Measure[2]	Effectiveness[2] Sediment % Reduction	Sediment Residual	Phosphorus % Reduction	Phosphorus Residual	Cost ($) Annual	Cost ($) Capital	Explanatory Note
1. Good management practices	10	230	10	1.00	0	0	3
2. Strip cropping	5	220	5	0.95	2,900	1,000	4
3. Crop rotations (corn - corn - grain - hay - hay)	10	200	10	0.85	25,000	0	5
4. Winter cover (oats) - shorter season corn	10	180	10	0.75	42,000	0	6
5. Stream channel buffer strips (20 m width)	15	150	10	0.70	18,000	0	7
6. Drainage engineering:	10	135	0	0.70			
a. Tile outlet stabilization						15,000	8
b. Bank stabilization on 13 ha						5,200	9
c. Amortization of capital costs					2,500		10
Total annual costs - $15/watershed ha.					90,400	21,200	

Explanatory notes:

1, 2, and 3 - see notes for Watershed Ag-1 (Note 1 includes 0.1 kg P/ha/yr livestock reduction estimate for applying remedial measures)

4. Strip cropping on 75% of the "C" slopes in the contributing area (290 ha) @ $10/ha plus a capital cost of $1,000 for some tree and fence-row removal.

5. Assumed costs and returns for cropping practices:

	Corn (net same for soybeans)	Cereal grains	Hay	Revenue Lost by Crop Conversions
Returns	250 bu/ha @ $2.50/bu = $600/ha	150 bu/ha @ $2.00/bu = $300/ha	25 bu/ha increase in subsequent corn yield = $60/ha/2 yrs 114 kg/ha N added @ 44¢ = $50/ha/2 yrs 7.5 tonnes/ha hay @ $30/t = $225/ha	Corn or soybeans to hay - $100/ha Corn or soybeans to grains - $100/ha Grains to hay - nil
Costs	$300/ha	$100/ha	$80/ha	
Net	$300/ha	$200/ha	$200/ha	

1550 ha in contributing area (currently 700 ha corn/beans, 340 ha grain, 280 ha hay) is changed to meet rotation requirements (525 ha corn/beans, 265 ha grains, 525 ha hay) requiring 175 ha of corn/beans and 75 ha small grains to be converted to hay.

6. 420 ha corn with a 25 bu/ha yield reduction ($60/ha) and cost of $40/ha for oats established.

7. 80 ha in contributing area lost from production (36 ha corn/beans @ $300/ha, 18 ha grains @ $200/ha, 14 ha hay @ $200/ha): buffer strip maintenance @ $10/ha.

8. 150 drain outlets @ $100/outlet.

9. 13 ha of eroding banks stabilized @ $400/ha.

10. Amortization over 20 years @ 10%.

Table 8: Application of Some Feasible Remedial Measure Alternatives in Agricultural Watershed AG-4; estimated costs and effectiveness

Watershed Ag-4 - Canagagigue Creek

Watershed description: Area - 1860 ha; soil - 25% clay; relief - gently sloping; stream length - 20 km; hydrologically contributing area - 25%; land use - 20% row crop (all corn), 32% small grains, 38% hay/pasture; livestock - 0.75 animal units per ha.

Pollutant loads:	Sediment (suspended solids)	Total phosphorus
Measured loading rates	425 (kg/ha/yr)	0.75 (kg/ha/yr)
Potential minimum - zero row crops[1]	75	0.30
Potential maximum reduction	350	0.45

Remedial Measure[2]	Effectiveness[2] Sediment % Reduction	Sediment Residual	Phosphorus % Reduction	Phosphorus Residual	Costs ($) Annual	Costs ($) Capital	Explanatory Note
1. Good management practices	10	380	10	0.67	0	0	3
2. Strip cropping	15	325	10	0.60	1,400	500	4
3. Crop rotation (corn - grain - grain - hay - hay)	-	-	-	-	-	-	5
4. Spring plowing (corn and hay)	5	310	5	0.57	12,000	0	6
5. Stream channel buffer strips (20 m); grassed waterways	40	185	25	0.43	18,400	0	7
6. Drainage engineering:	10	165	0	0.43			
a. Tile outlet stabilization						5,000	8
b. Stream bank stabilization						1,200	9
c. Amortization of capital costs					800		10
Total annual cost - $18/watershed ha.					32,600	6,700	

Explanatory notes:

1, 2, and 3 - see notes for Watershed Ag-1 (Addition to Note 1. - includes subjective 0.1 kg/ha/yr livestock input reduction assumed to result from the implementation of the remedial measures listed.)

4. Strip cropping on 75% of the "C" slopes in the contributing area (140 ha) @ $10/ha, plus $500 capital costs for fence row removal.

5. Crop rotation is not applicable as a new remedial measure, since, in this watershed, they are already generally practiced.

6. To avoid fields in the contributing area being left bare over the winter period, either plow in the spring, or use cover crop over winter; - 100 ha corn with expected yield loss of 25 bu/ha @ $2.50/bu = $6,000 and 200 ha grain @ a loss of $30/ha = 6,000 - total $12,000/yr.

7. 40 ha to buffer strips and lost from production (8 ha corn @ $300/ha, 16 ha grain @ $200/ha, 16 ha hay @ $200/ha = $8,800); grassed waterways established on an equal land area with the same costs. Assumed that the buffer strips and waterways are clipped and not harvested for hay - maintenance costs @ $10/ha = $800. Total cost $18,400.

8. 50 tile outlets stabilized @$100/outlet.

9. 3 ha of eroding streambanks stabilized @ $400/ha.

10. Amortization of capital costs at 10% for 20 years.

Table 9: Application of Some Feasible Remedial Measure Alternatives in Agricultural Watershed AG-5; estimated costs and effectiveness

Watershed Ag-5 - Holiday Creek

Watershed description: Area - 3000 ha; soil - 20% clay; relief - gently sloping; stream length - 22 km; hydrologically active contribution area - 25%; land use - 48% row crops (all corn), 13% small grains, 25% hay; livestock - 0.61 animal units/ha.

Pollutant loads:	Sediment (suspended solids)	Total phosphorus
Measured loading rates	250 (kg/ha/yr)	1.00 (kg/ha/yr)
Potential minimum - zero row crops[1]	25	0.15
Potential maximum reduction	225	0.85

Remedial Measure[2]	Effectiveness[2]				Cost ($)		Explanatory Note
	Sediment		Phosphorus		Annual	Capital	
	% Reduction	Residual	% Reduction	Residual			
1. Good management practices	10	225	10	0.90	0	0	3
2. Strip cropping	15	190	10	0.80	2,000	500	4
3. Crop rotations (Corn - corn - grain - hay - hay)	20	150	15	0.67	10,000	0	5
4. Spring plowing (corn)	10	135	10	0.60	15,600	0	6
or - no-till corn					(24,700)	0	7
5. Stream channel buffer strips (20 m) and grassed waterways	40	70	15	0.50	20,800	0	8
6. Drainage engineering:	10	60	0	0.50			
a. Tile outlet stabilization					5,000	5,000	9
b. Stream bank stabilization					800	800	10
c. Amortization of capital costs					750		11
Total annual cost - $16/watershed ha.					49,150	6,300	

Explanatory notes:

1, 2 and 3 - see notes for Watershed Ag-1 (Note 1 includes 0.05 kg P/ha/yr livestock reduction estimate for applying remedial measures)

4. Strip cropping on 75% of the "C" slopes in the contributing area (200 ha) @ $10/ha plus a capital cost of $500 for fence-row removal.

5. Assumed costs and returns for cropping practices - see note 5 to Watershed Ag-3.

6. 260 ha corn with 25 bu/ha yield reduction ($60/ha) = $15,600.

7. No-till corn with 35 bu/ha yield reduction ($95/ha) = $24,700 for 260 ha.

8. 40 ha in contributing area lost to production (16 ha corn @ $300/ha, 8 ha grain @ $200/ha, 16 ha hay @ $200/ha = $10,000; grassed waterways established on an equal land area with the same costs. Assumed that the buffer strips and waterways are clipped and not harvested for hay - maintenance costs @ $10/ha = $800. Total cost = $20,800.

9. 50 tile outlets stablized at $100/outlet.

10. 2 ha of eroding stream banks stabilized @ $400/ha.

11. Amortization of capital costs @ 10% over 20 years.

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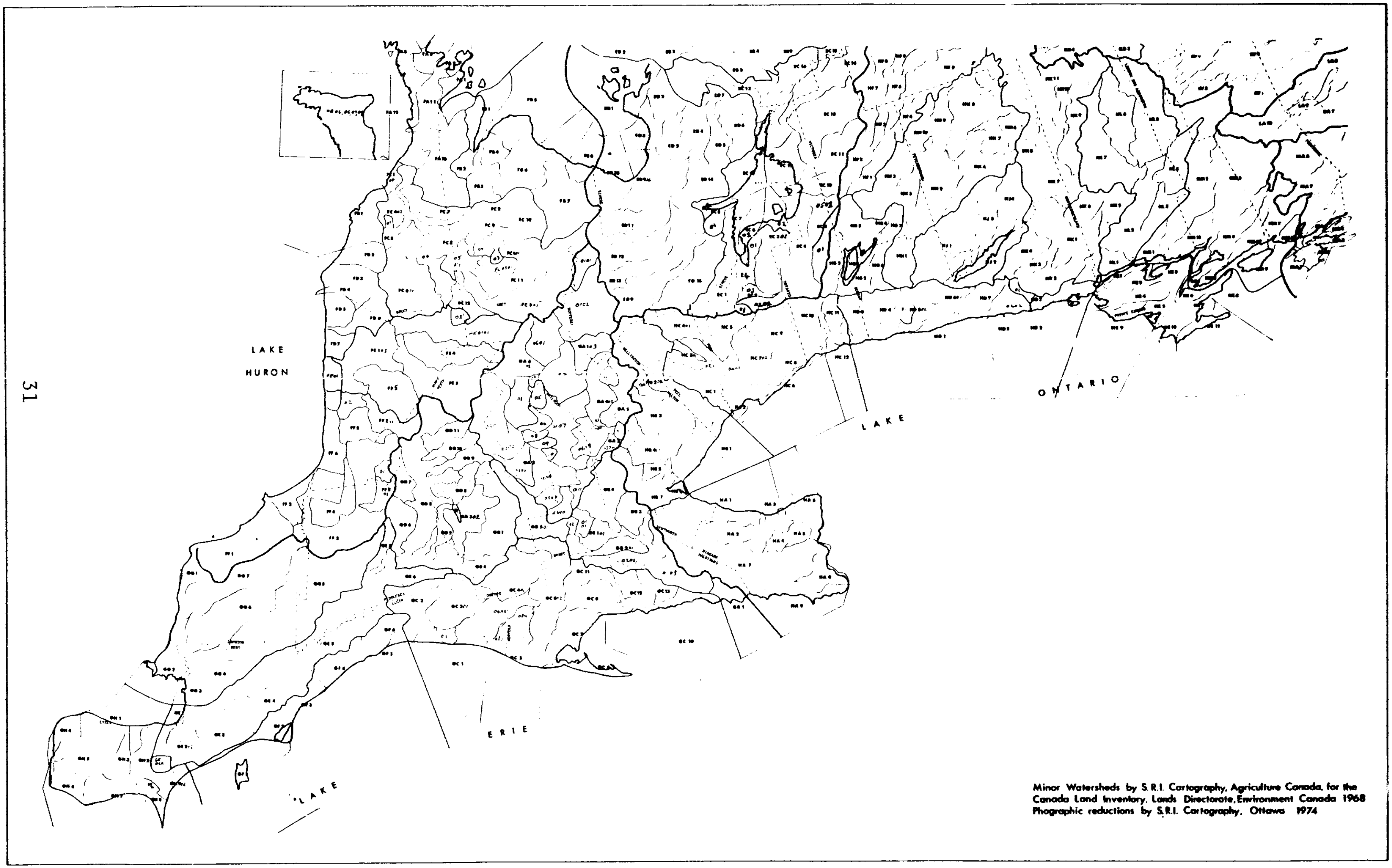
APPENDIX 1

Location of watersheds in the Ontario portion of the Lower Great Lakes Basin.

Location of watersheds in the Ontario portion of the Lower Great Lakes Basin



APPENDIX 2

APPENDIX 2

Annual unit area loads and total loads of total sediment from agricultural activities in subbasins of the Canadian Great Lakes as estimated by the following regression equation:

Sediment Load = -204 + 7.9 (% Row Crops) + 11.0 (% Clay) kg/ha/yr

GEORGIAN BAY

Watershed	Clay In Surf Soil	% Of Farm Area In Row Crop	% Of Total Area In Farms***	Total Sediment Unit Area Load	Total Sediment Total Loading
	%	%	%	Kg ha	Tonnes
EC01	23.7	30.8	70.7	302	7303.5
EC0201	30.3	4.0	37.1	162	206.4
EC020	16.0	14.2	39.8	85	345.8
EC0203	20.5	19.0	30.5	173	224.8
EC0204	17.8	19.9	59.8	150	645.2
EC0205	17.3	13.8	60.5	136	339.1
EC0301	11.9	20.5	54.4	90	1638.2
EC0302*	17.4	4.8	40.1	26	314.6
EC04	11.1	15.3	61.1	40	1149.3
EC0501	18.9	16.9	73.2	139	1861.5
EC0502	18.2	14.0	77.8	108	1694.0
EC0601	18.1	25.0	76.2	194	966.7
EC0602*	30.6	34.0	51.5	404	2232.6
EC07	16.2	24.8	37.7	172	863.4
EC0801	13.4	33.2	65.8	207	891.3
EC0802	11.2	20.6	52.0	83	491.0
EC09	16.3	12.9	53.3	78	1391.0
EC10	14.6	8.2	51.2	22	144.7
EC11	5.0	3.6	49.2	0	0
EC12	19.3	3.2	51.5	34	428.5
EC13	4.0	1.1	36.6	0	0
EC14*	---	0	14.5	0	0
EC16*	---	0	10.1	0	0
EC17*	6.0	0.9	25.5	0	0
ED02*	5.8	6.2	37.7	0	0
ED03	11.0	9.2	54.5	0	0
ED04	8.1	7.8	41.7	0	0
ED05	16.1	6.9	42.1	28	244.0
ED06	20.2	3.1	46.8	44	639.3
ED07	19.2	0.8	16.4	14	32.1
ED08	5.8	10.0	34.7	0	0
ED09	13.4	19.1	64.4	96	6814.00
ED10	18.3	6.9	65.7	53	999.5
ED11	15.3	11.1	66.1	53	1623.7
ED12	12.2	21.5	62.2	101	2035.9
ED13	12.6	18.5	77.9	82	1599.9
ED14	11.8	18.7	47.7	75	1105.4
ED15	19.1	24.7	71.3	203	6887.9
ED16*	5.8	14.4	18.9	0	0
Total for Georgian Bay					45120.6

LAKE HURON

Watershed	Clay In Surf Soil	% Of Farm Area In Row Crop	% Of Total Area In Farms***	Total Sediment Unit Area Load	Total Sediment Total Loading
	%	%	%	Kg ha	Tonnes
FA01	9.0	1.5	39.7	0	0
FA02*	0	0.6	43.8	0	0
FA03	0	0.4	40.0	0	0
FA04*	0	0.6	6.7	0	0
FA07	0	0.5	6.7	0	0
FA08	0	0.4	10.2	0	0
FA09	13.3	5.2	49.2	0	0
FA10	19.6	7.3	76.5	70	3570.4
FA11	0	2.5	30.7	0	0
FA12	0	1.2	24.7	0	0
FB01	20.8	1.7	40.7	39	334.2
FB02	18.4	4.9	79.2	38	274.1
FB0301	19.9	6.0	74.0	63	1034.5
FB04	18.2	3.0	55.2	21	141.3
FB05	24.5	2.5	35.8	86	880.0
FB06	23.2	4.6	73.1	89	2578.6
FB07	15.5	3.1	60.5	0	0
FB0701	21.8	3.9	62.3	68	2515.5
FB0702	21.6	5.4	58.4	77	185.6
FB08	22.9	4.9	56.1	88	431.9
FC0101	16.2	4.9	64.3	14	345.9
FC0102	16.9	12.1	76.6	79	50.7
FC0103	9.2	17.8	37.6	39	207.8
FC0104	10.7	7.3	66.5	0	0
FC0105	10.7	13.7	75.7	23	209.4
FC0106	18.6	16.4	85.0	131	3432.7
FC0201	17.5	5.2	69.6	30	517.1
FC0203	27.3	8.7	89.2	166	116.0
FC0301	17.3	6.9	80.9	42	2194.5
FC0302	10.6	16.6	83.4	45	44.8
FC0401	29.7	8.9	79.0	194	645.0
FC0402	27.2	8.8	55.2	166	886.5
FC05	28.1	7.4	78.8	165	858.6
FC0601	16.3	16.0	82.4	103	5836.7
FC07	25.5	9.0	93.0	149	2608.1
FC08	12.4	5.6	85.7	0	0
FC09	12.4	5.8	60.0	0	0
FC10	11.7	5.8	61.2	0	0
FC11	14.0	7.3	77.0	8	154.2
FC12	16.3	13.0	87.2	79	1100.7
FC1301	10.5	7.1	68.1	0	0
FD01	20.8	12.8	49.9	127	2505.5
FD02	24.5	19.7	74.2	223	3657.7
FD03	29.6	24.4	73.8	316	5505.3
FD04	26.3	21.3	78.1	255	2098.2

Lake Huron - cont'd

Watershed	Clay In Surf Soil	% Of Farm Area In Row Crop	% Of Total Area In Farms***	Total Sediment Unit Area Load	Total Sediment Total Loading
	%	%	%	Kg ha	Tonnes
FD05	24.9	26.2	70.9	279	3872.8
FD06	14.6	20.1	87.7	117	2548.1
FD07	20.0	33.6	58.6	283	2535.6
FE01	21.1	29.0	75.9	259	3024.9
FE0101	16.2	13.1	91.7	79	3868.5
FE0102	10.2	10.0	83.0	0	0
FE0103	16.5	24.7	84.4	174	7290.3
FE02	17.5	16.7	93.1	122	10331.3
FE03	24.0	28.5	91.5	287	10744.0
FE04	23.2	1.7	91.9	66	3906.5
FE05	18.8	15.7	93.6	128	4633.1
FF01	30.0	44.4	53.6	480	26256.1
FF02	20.4	38.2	66.5	324	4358.4
FF03	27.2	33.3	87.5	361	35154.5
FF04	23.3	26.0	86.8	260	5618.2
FF0501	30.6	43.5	97.3	479	2719.8
FF0502	30.3	32.9	96.1	392	4251.4
FF06	23.4	32.6	74.6	313	5911.5
FF0701	27.3	33.6	90.9	364	7343.9
FF0702	22.1	26.3	84.6	249	1960.3
FF08	27.1	34.4	96.2	368	7376.5
Total for Lake Huron					286,666.9

LAKE ERIE

Watershed	Clay In Surf Soil	% Of Farm Area In Row Crop	% Of Total Area In Farms***	Total Sediment Unit Area Load	Total Sediment Total Loading
	%	%	%	Kg ha	Tonnes
GA0101	20.2	3.7	72.8	48	432.6
GA0102	19.9	5.9	73.9	62	2581.5
GA0103	20.6	14.2	82.1	136	1497.9
GA0104	15.0	16.0	83.7	0	0
GA0105	12.6	27.9	96.5	157	1344.9
GA0107	15.9	41.0	85.2	297	9669.6
GA0108	16.1	29.3	67.3	206	908.4
GA0109	17.2	32.0	73.9	240	700.9
GA0110	15.7	56.2	70.1	415	638.3
GA0111	3.7	41.1	85.2	163	1339.4
GA0201	30.1	13.3	90.8	234	6874.2
GA0202	25.2	21.0	88.6	241	4677.7
GA0205	23.0	38.4	84.7	315	3022.2
GA0206	12.3	46.4	79.4	300	6382.8
GA0209	15.7	37.4	74.1	266	1889.7
GA0210	5.8	54.3	100.0	291	2998.3
GA0301	5.8	8.9	51.7	0	0
GA0302	5.8	20.6	64.7	24	3.9
GA0303	5.8	17.1	63.8	0	0
GA0304	5.8	12.7	56.1	0	0
GA0401	13.1	19.1	70.9	92	370.5
GA0402	14.3	29.4	78.8	187	3272.5
GA0406	8.0	27.6	67.3	103	290.3
GA0407	12.8	33.3	66.1	202	162.5
GA0408	9.6	40.4	78.9	223	2402.9
GA05	9.2	14.8	64.0	15	254.5
GA0601	24.0	5.0	79.9	0	0
GA0602	28.4	14.9	87.2	228	5723.3
GA0603	28.0	13.1	92.9	0	0
GA0604	19.4	32.3	94.9	267	1404.9
GB0101	11.4	48.2	63.3	305	1400.3
GB0102	27.2	18.3	78.2	241	8771.8
GB0103	28.5	13.7	44.2	219	2413.0
GB0201	18.0	35.6	77.1	277	4335.0
GB0202	26.0	27.8	91.2	304	6394.5
GB03	24.0	28.3	80.2	286	3952.7
GB04	20.8	30.4	76.8	267	8373.9
GB0501	15.3	37.7	85.6	264	8619.8
GB0502	6.3	51.0	94.2	270	671.4
GC01	8.4	59.0	80.1	357	3612.5
GC02	23.7	45.6	92.3	420	18235.3
GC0301	23.9	45.8	78.9	423	11564.3
GC0302	7.2	52.8	73.6	295	1723.0
GC0401	18.6	54.7	91.4	436	15221.4
GC0402	10.1	43.4	87.5	252	6560.3
GC0403	6.5	45.1	83.3	226	480.2

Lake Erie - cont'd

Watershed	Clay In Surf Soil	% Of Farm Area In Row Crop	% Of Total Area In Farms***	Total Sediment Unit Area Load	Total Sediment Total Loading
	%	%	%	Kg ha	Tonnes
GC05	8.1	39.5	73.5	199	3376.9
GC06	19.4	87.8	3.8	707	581.9
GC07	10.9	36.4	57.1	205	3920.1
GC08	9.9	42.5	80.2	243	2866.4
GC0801	7.6	33.6	88.9	147	1010.6
GC0802	7.4	38.7	87.9	185	7815.9
GC09	14.8	39.5	84.7	273	6460.5
GC10	30.3	13.7	45.0	239	2164.9
GC11	20.8	36.9	76.3	319	4757.0
GC12	30.0	12.0	72.3	222	3505.4
GC13	27.9	7.9	76.5	167	1715.8
GD01	18.8	40.8	86.7	327	22124.8
GD02	19.6	36.1	83.6	299	2642.0
GD0301	18.6	42.2	82.2	336	794.8
GD0302	19.4	38.9	85.5	319	7930.9
GD04	25.2	47.1	86.4	448	5982.0
GD05	26.3	33.2	91.7	350	24126.2
GD06	22.9	35.8	86.3	333	5745.7
GD07	27.5	40.4	88.8	420	5516.1
GD08	27.4	28.5	81.6	325	4587.6
GD09	27.8	25.2	92.6	303	4156.9
GD10	26.3	18.3	86.0	232	2637.7
GD11	31.3	28.0	92.2	364	4636.6
GE01	21.6	64.4	82.0	546	17050.1
GE0201	33.7	65.5	98.1	688	3906.0
GE0202	33.8	68.6	87.9	714	17089.8
GE03	32.5	70.7	85.5	716	19402.7
GE04	19.7	64.9	88.9	519	17687.6
GE05	16.7	47.3	81.0	306	32548.9
GE06	23.8	42.3	77.6	394	5023.0
GE07	20.7	36.3	83.9	313	2549.8
GF01	25.6	68.6	68.3	623	5739.7
GF02	18.0	68.0	61.1	535	6088.6
GF03	25.5	67.5	70.3	613	4284.6
GF04	9.1	60.3	74.1	375	7164.9
GF05	14.8	53.7	77.7	386	2324.7
GF06	10.4	51.8	79.7	322	5624.9
GG01*	32.4	38.7	76.2	461	7869.0
GG02*	20.7	67.7	73.1	562	21409.8
GG03	26.9	77.2	84.4	706	11493.5
GG04	17.5	71.9	98.6	560	13261.7
GG05	22.6	47.0	87.2	419	55463.7
GG06	34.1	42.4	84.6	509	26345.3
GG07	32.2	35.6	87.6	434	24731.7

Lake Erie - cont'd

Watershed	Clay In Surf Soil	% Of Farm Area In Row Crop	% Of Total Area In Farms***	Total Sediment Unit Area Load	Total Sediment Total Loading
	%	%	%	Kg ha	Tonnes
GH01*	32.1	63.0	56.1	650	26118.6
GH02	30.0	63.4	82.3	630	11904.1
GH03	33.1	59.5	79.5	634	7883.0
GH04*	19.4	63.5	33.9	514	2506.9
GH05	32.8	59.1	83.3	627	15117.0
GH06	31.1	62.2	39.8	633	7946.9
GH07	21.5	58.9	36.2	501	9992.3
GH08	20.2	68.8	23.3	565	2131.4
GH0901	9.2	66.1	86.7	422	955.4
GH0902	19.9	71.9	73.4	586	6881.7
GH10	34.4	66.2	3.6	701	1743.6
GH11*	14.0	65.8	35.8	473	802.2
Total for Lake Erie					293,858.

LAKE ONTARIO

Watershed	Clay In Surf Soil	% Of Farm Area In Row Crop	% Of Total Area In Farms***	Total Sediment Unit Area Load	Total Sediment Total Loading
	%	%	%	Kg ha	Tonnes
HA01	28.7	7.2	68.0	170	3633.7
HA0201	36.8	14.9	78.3	320	693.1
HA0202	34.7	20.6	79.1	342	7729.4
HA03	32.2	13.6	68.9	259	2362.7
HA04	28.2	11.1	45.9	195	1060.7
HA05*	30.3	12.6	23.9	230	710.1
HA06	25.0	3.7	46.0	101	911.3
HA07	32.1	16.5	66.9	281	1977.1
HA08*	33.8	27.4	14.8	387	1172.0
HA09*	27.8	23.0	25.8	285	2592.7
HB0201	10.9	9.1	60.5	0	0
HB0202	18.4	10.9	54.6	86	3587.5
HB03*	25.2	15.1	54.2	194	5069.5
HB0401	21.8	24.6	51.3	232	3686.9
HB05	21.3	50.8	64.5	434	2424.5
HB07	19.3	25.8	56.6	214	3386.3
HC01	36.6	16.3	83.2	329	6762.9
HC02**	13.0	5.3	42.2	0	0
HC0301	29.8	22.3	78.0	302	642.9
HC0302	34.8	13.8	76.1	290	3552.4
HC0401	18.2	11.5	51.8	88	1538.3
HC0402*	7.0	19.1	67.3	25	280.4
HC05	30.1	9.5	61.5	204	2594.5
HC0702	11.0	22.9	40.1	99	1363.6
HC09	25.8	30.7	48.4	324	6114.7
HC10*	18.9	14.5	46.7	120	1589.7
HC11**	21.7	4.3	52.4	0	0
HD01	17.8	18.2	63.6	137	650.4
HD0201	5.0	26.7	66.7	63	252.7
HD0202	6.0	22.6	50.7	42	248.6
HD0203	3.0	26.3	47.3	38	21.0
HD03	18.9	16.8	80.3	138	2969.9
HD0401	15.7	22.7	63.3	149	2165.7
HD0501	16.1	19.0	61.4	125	713.1
HD0502	14.8	24.2	54.5	151	2006.6
HD0601	13.8	17.0	63.1	83	1341.1
HD07	11.0	14.9	68.9	36	318.9
HE01	19.8	19.1	57.1	166	513.1
HE02	19.3	17.1	64.4	145	1318.0
HE03	17.1	9.6	60.4	61	538.5
HE04	8.0	15.2	75.9	51	87.3
HE05	0	13.0	61.1	0	0
HE06	17.4	8.3	49.2	54	211.2
HE07	0	10.7	45.1	0	0
HE08	20.0	13.0	22.8	120	517.2

Lake Ontario - cont'd

Watershed	Clay In Surf Soil	% Of Farm Area In Row Crop	% Of Total Area In Farms***	Total Sediment Unit Area Load	Total Sediment Total Loading
	%	%	%	Kg ha	Tonnes
HE09	0	26.7	15.4	8	68.0
HE10	0	19.4	27.1	0	0
HE11	0	5.7	10.7	0	0
HF01	11.0	4.0	73.0	0	0
HF02	5.0	4.5	68.2	0	0
HF03**	0	1.3	56.8	0	0
HF04**	0	1.0	56.8	0	0
HF05	0	0	5.9	0	0
HF06	0	1.0	31.9	0	0
HF08	0	0	9.1	0	0
HF09	0	0	7.5	0	0
HG02	17.0	14.3	59.1	97	986.4
HG03	17.8	14.4	65.4	107	1213.0
HG04	29.7	10.6	71.2	208	538.6
HG05	30.7	13.9	84.5	245	4540.5
HG06	18.2	16.4	66.7	127	1104.9
HG07	29.8	9.2	81.3	198	1539.8
HH01	17.6	13.2	59.8	95	1738.4
HH02	12.0	9.3	61.0	2	65.3
HH03	16.0	5.3	69.6	15	390.6
HH04	21.4	7.7	44.8	93	1689.3
HH05	21.6	7.2	61.5	92	890.2
HH06**	0	0	8.6	0	0
HH07**	0	0	7.2	0	0
HH08**	0	0	5.6	0	0
HH10**	0	0	56.9	0	0
HJ01	20.0	10.1	69.1	97	4977.8
HJ02	17.7	11.6	62.4	83	2040.9
HJ03	21.2	8.2	67.4	95	1315.5
HJ04	19.1	9.5	60.0	82	1458.3
HK01	16.0	11.4	71.5	63	2791.6
HK02	6.0	20.5	63.6	25	447.1
HK03	13.9	17.1	72.5	85	579.1
HK04	10.7	10.4	62.5	0	0
HK05	23.5	6.2	76.8	105	1499.7
HK06	19.6	6.0	76.9	60	827.0
HK07	12.0	2.2	28.6	0	0
HK08	11.0	0.6	16.9	0	0
HK09	11.0	2.4	13.7	0	0
HK10	4.0	2.6	13.4	0	0
HL01	20.3	20.3	73.1	181	1625.2
HL02	27.3	8.6	74.9	166	5752.0
HL03	26.6	2.1	57.6	106	1178.0
HL04	17.3	0.7	52.2	0	0
HL05	14.2	0.7	17.5	0	0
HL06	17.4	2.3	51.3	6	67.4
HL07	19.7	3.2	52.9	39	1208.7

Lake Ontario - cont'd

Watershed	Clay In Surf Soil	% Of Farm Area In Row Crop	% Of Total Area In Farms***	Total Sediment Unit Area Load	Total Sediment Total Loading
	%	%	%	Kg ha	Tonnes
HM01	24.1	5.6	69.9	106	908.5
HM02	21.3	2.7	56.3	52	2282.2
HM03	20.9	2.9	55.3	50	2352.3
HM04	28.2	11.0	65.3	195	4390.9
HM05	19.8	12.9	50.3	117	601.8
HM06	28.7	7.1	53.2	169	2411.4
HM07	34.2	3.7	62.1	203	2311.1
HM08**	36.3	10.9	39.7	283	0
HM09	0	7.5	10.1	0	0
HM10	23.4	4.7	63.3	92	1310.4
Total for Lake Ontario					27,226.9

* 50-70% of enumeration areas suppressed

** More than 70% of enumeration areas suppressed

*** Since corrections could not be made accurately for urban land area in these subbasins, these values of percent of total area in farmland may be high (by average of less than 3%). Data for individual watershed subbasins should be used with care if urban land is significant.

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