Joint Summary Technical Report

STREAMBANK EROSION IN THE GREAT LAKES BASIN

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DISCLAIMER

The study discussed in this report was carried out as part of the efforts of the Pollution from Land Use Activities Reference Group, an organization of the International Joint Commission, established under the Canada - U.S. Great Lakes Water Quality Agreement of 1972. Funding was provided through the Ontario Ministry of Natural Resources and by the U.S. Environmental Protection Agency through the Ohio Department of Natural Resources and the Great Lakes Basin Commission. 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.

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SUMMARY

Total sediment contributions to the Great Lakes basin from streambank erosion are estimated at 845,000 tonnes per year. This amount is not large when viewed on a global or continental scale or in relationship to other sediment sources.

The average sediment yield rate from banks in the entire basin is less than 20 kg/ha/yr. The predominance of forested areas in the Canadian basin resulted in below average sediment yields.

Total phosphorus is the most significant chemical pollutant associated with streambank erosion with an estimated 426,000 kg per year being added to the lakes from eroding banks.

Downstream bank sections are not seen as causing greater or more serious erosion problems except in localized areas. Loading rates from these areas probably do not vary significantly from other areas of the watershed.

Remedial measures investigations in the U.S. basin suggest that the cost of reducing sediment yield from bank erosion would involve approximately $345 per tonne. It is concluded that this type of program would not be cost beneficial unless land of high value were endangered. It is further suggested that greater benefits would be accrued if these monies were used in reducing sediment yield from sheet erosion. In the Canadian basin it is suggested that the implementation of good management practices in and adjacent to watercourses could reduce the sediment yield in agricultural areas.

INTRODUCTION

Concern over the rapidly depleting water quality of the Great Lakes system spurred the Governments of Canada and the United States to request the International Joint Commission, under the Water Quality Agreement of 1972, to investigate the significance of and recommend solutions to pollution of the boundary waters from land drainage.

Specifically, the Commission was directed to inquire and to report on a series of questions, identifying the nature and extent of pollution from various land use activities and their impact on water quality. Based on these findings, they were further charged to investigate and make recommendations of practical and realistic remedial measures for management and control of pollution from land drainage.

Later in 1972, the Commission appointed a Reference Group on Land Use Activities to plan and direct the study. The Detailed Study Plan developed by this Group defined four basic tasks required to undertake the work. Published in February of 1974, the PLUARG (Pollution from Land Use Activities Reference Group) programme required "Task A" to assess existing problems, management programs and research information in an attempt to set priorities for early action based on the present state of knowledge. "Task B" was requested to inventory present land use in the basin and analyze trends so that projections of future land use could be made. "Task C" has involved the detailed study of selected watersheds to accurately determine the sources and relative significance of various pollutants and to assess their degree of transmission to the boundary waters. "Task D" was asked to assess the degree of impairment of water quality in the Great Lakes system. Under Task C it was recognized that riverbank erosion might contribute a significant amount of sediment to the Great Lakes. Activities were outlined in the 1974 Detailed Study Plan for projects to be initiated in Canada and the United States to examine this potential pollutant source.

The Ontario Ministry of Natural Resources, under the Conservation Authorities Branch, was requested in early 1974 to act as the investigating agency for the Canadian basin due to their prior involvement in water resources and erosion and flood control. Subsequently, in June 1974 a study plan was formalized outlining the research objectives to meet, as best as possible within the limited time frame of the study, the technical requirements of PLUARG. The Reference Group requested that each study determine the relative significance of specific sources and practices which yield pollutants of concern to boundary waters. The degree of transmission of pollutants from the sources and their impact on boundary waters were also to be investigated.

Given these terms of reference, the following goals were established. The main objectives of the Streambank Erosion Study were to gain a better understanding of bank recession mechanisms and to characterize and quantify the material eroded on a representative number of sites such that actual contributions of sediment to study basins might be calculated. An intermediate goal of the research was to determine if, from their characteristics, the amounts of sediment produced from streambank erosion could be predicted. Evaluation and analyses of on-site erosion in the study watersheds also afforded a picture of the seasonality of streambank erosion and land management practices associated with problem areas. Lastly, it was projected that data obtained on the study watersheds could be extended to give rough estimates of the contribution by streambank erosion in the Canadian portion of the Basin to sediment and nutrient pollution in the Great Lakes.

The objectives of the U.S. study were to evaluate the effect of material eroded from riverbanks on water quality of the Great Lakes, to determine measures for riverbank protection and the cost of such a program.

When this study was formulated neither funds nor time was available to accomplish a complete investigation on the U.S. portion of the basin. It was determined that only a small percentage of the basin could be studied and that examining a large number of randomly selected small areas was the best way to acquire accurate information on the various stream- bank conditions.

The Soil Conservation Service had previously done land inventory studies using this technique. The program called Conservation Needs Inventory (CNI) used, in most of the Great Lakes Basin, 160 acre sample areas selected on a random statistical basis that covered two percent of the total area. Soil surveys had been made on each of these sample areas and base maps showing their location were already available. It was decided to use these sample areas for the streambank erosion study.

When the concept for this study was first conceived its feasibility and cost was not known so a trial was conducted on the Maumee River Basin in 1974. After the concept was proved workable and the costs could be estimated more accurately it was decided that the major U.S. watersheds selected for study by Task C would be studied using techniques developed and used in the Maumee River Basin Riverbank Study.

DATA COLLECTION METHODS

Due to slight differences in the original terms of reference and funding agencies involved, the Canadian and United States streambank erosion studies developed separate and different approaches and methodologies. These have been explained in the following discussion. An indication of the location of watersheds for both studies is shown on Figure 1.

CANADIAN STUDY

Following a search of pertinent literature it was determined that limited information exists concerning the streambank erosion contributions to river and lake sediments from streambank erosion. Furthermore it was noted that reliable methods for predicting and estimating streambank erosion rates under various situations are not available because the basic factors affecting erosion are not well defined. As an initial step in the Canadian research then, factors relating to streambanks and their erosional processes were delineated.

The preliminary phase, completed in 1974 involved the mapping of streambanks in sixteen upland watersheds chosen to represent the various physiographic, climatic, land use and hydrologic regions of Southern Ontario. A field coding system was devised by which the characteristics of homogeneous lengths of bank were mapped onto reproductions of aerial photographs. Bank geometry (slope, shape and length), vegetation, evident erosional mechanisms and soil material were noted. These characteristics were summarized into a computer inventory for use in later extrapolation of erosion information.

Following the completion of the preliminary phase, twenty-five sites were chosen on nine of the sixteen watersheds for detailed streambank erosion measurement and characterization. In this selection, an attempt was made to choose banks and watersheds representative of the Southern Ontario situation and where water quality monitoring programmes were already established. To facilitate the extrapolation of sediment data in conjunction with the sheet erosion research, the majority of sites were established in the six Task C Agricultural watersheds undergoing detailed study.

Additional sites were chosen from watersheds involved in the preliminary study for reasons related to the morphology of the drainage pattern, the soil type and uniqueness of the banks.

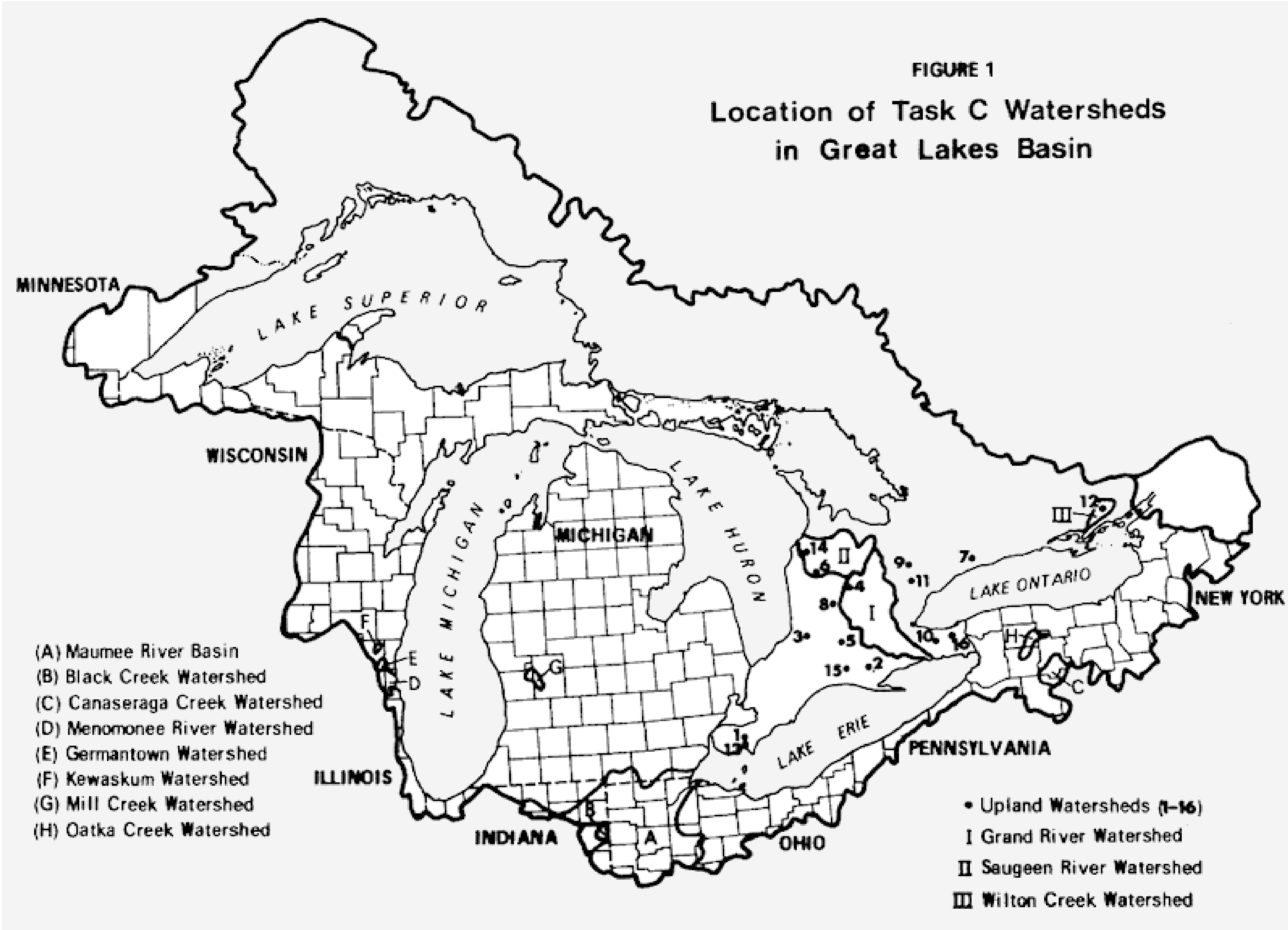


FIGURE 1
Location of Task C Watersheds in Great Lakes Basin
MINNESOTA
WISCONSIN
MICHIGAN
ILLINOIS
INDIANA
OHIO
PENNSYLVANIA
NEW YORK
LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
LAKE ERIE
LAKE ONTARIO
(A) Maumee River Basin
(B) Black Creek Watershed
(C) Canaseraga Creek Watershed
(D) Menomonee River Watershed
(E) Germantown Watershed
(F) Kewaskum Watershed
(G) Mill Creek Watershed
(H) Oatka Creek Watershed
• Upland Watersheds (1-16)
I Grand River Watershed
II Saugeen River Watershed
III Wilton Creek Watershed

The analysis of data collected during the preliminary phase suggested that average erosion rates on streambanks in Southern Ontario involved relatively small quantities, probably in the neighborhood of 1-2 cm. laterally per year. Due to the size of movement to be measured in so short a study and the accuracy required to allow eventual extrapolation of this data to Southern Ontario as a region, a technique involving terrestrial stereo photography was chosen to assess annual bank recession rates.

This method has several distinct advantages over conventional surveying techniques. The study is conducted from a point remote from the bank making the climbing and possible alteration of the bank unnecessary. The most distinct advantage however, is that a set of photographs if taken with some care are a permanent, immensely detailed record of the banks. A variety of information is recorded not only related to bank conformation but also to vegetation, adjacent land use or special features that might not be noticed or deemed important to note in a physical survey. The initial photography is rapid, only requiring an hour or less per site. Once obtained, the photographs may have various levels of detail extracted from them at future dates.

Stereophotographs taken at those twenty-five sites every spring for three years were analyzed and actual recession rates calculated. A detailed description of the methods employed and photogrammetric background is available under the Technical Report Series.

For each detailed site, specific hydraulic information was determined with the intention of investigating the possibility of predictive modelling of streambank erosion. Information regarding the cross-section, channel gradient, and roughness were recorded and the development of stage-discharge rating curves was made. Computer programmes were modified to allow computation of maximum and critical tractive forces at each site as well as other hydraulic variables. At study sites, measured recession rates have been related to a number of variables including soil erodibility, hydraulic factors and management of the stream course. This information is explained fully in the Technical Report Series.

A sampling of soil materials at the twenty-five detailed sites was carried out in 1975 to allow characterization of bank materials for eventual chemical loading calculations. Bank profiles were described as to depth, colour and presence of mottling, roots and stone layers. Estimations were made of soil structure and permeability of each horizon so that soil erodibility factors, K-values (Wischmeier, 1971) could be calculated. Soil samples were analyzed for chemical, physical and mineralogical parameters, with special emphasis on total phosphorus and heavy metals.

U.S. STUDY

The field work on the pilot streambank erosion study began in the fall of 1974 on the Maumee River Basin where a two percent sample of the watershed was examined. Primary Sample Units (PSU's) of 160 acres in size from the CNI were examined for streambank erosion conditions.

The procedure was for an individual of the field crew to walk along every stream on each PSU recording pertinent data on a worksheet. These worksheets were then sent to the Statistical Department, Iowa State University where the data was transferred to punch cards and processed by a computer. The computer then expanded the data to the county, state, sub-basin and basin.

In order to maintain consistency it was necessary to define certain of the terms used in the study. These definitions included natural stream, modified stream, drainage ditch and the various land use and treatment categories. For the purpose of this study natural and modified streams were defined as having a bank height of at least three feet and drainage ditches a bank height of four feet or more.

Each individual of the field crew was given the necessary maps to locate the sample areas and to identify the soil series. They were also given instructions for completing the work sheet, and definitions of the terms used in the study.

The SCS from each state in the basin was asked to furnish an estimated weight for a cubic foot of soil from an eroding streambank. In order to compute the cost of existing treatment or treatment which was needed, the SCS from each state was asked to furnish a cost per mile for each treatment category.

Once the computer printout was available the soil series contributing to streambank erosion could be identified. Samples of the major horizons of the soil series were obtained and analyzed for the parameters selected by the Task C Technical Committee.

After it was determined that the Maumee Study yielded reasonable results and the cost figures were available it was decided that the major U.S. watersheds selected for study by Task C could be examined using similar techniques. In addition, two small watersheds in Wisconsin were included in the study at the request of the Wisconsin Department of Natural Resources.

EXPERIMENTAL RESULTS

CANADIAN STUDY

As previously stated, the Canadian Study involved investigations of sixteen, predominantly agricultural, upland watersheds. A summary of the generalized land use, climatic region and physiographic region represented by each watershed is included in Table 1.

From the mapping of streambanks completed in the preliminary phase, a summary of the physical characteristics of the study watersheds was compiled. Some of the pertinent factors are included in Table 2. The six detailed agricultural study watersheds range in size from approximately 2000 to 6000 hectares and exhibit a wide variation in drainage densities.

Big Creek flows through an intensively cash cropped area of southwestern Ontario and has a drainage density artificially increased by the establishment of municipal and field ditches. Streambank erosion is high because of the large total streambank area susceptible to erosional mechanisms, ditch clearing and the erodible nature of the soil. Spring snow melt and rains, when antecedent moisture is high, produce the greatest potential streambank erosion. Flows respond quickly to rainfall and snow melt due to the dense network of tiling and ditching. As the waters drop in level, slumping occurs on the wet clay banks especially if high water conditions are followed by a rapid drop in level. Once the banks have become dried and hard in late spring, little erosion occurs during the summer except in the form of rilling and minor amounts of scour. A large proportion of the channel area remains dry for the bulk of the year.

Near the opposite end of the streambank erosion scale is the Holiday Creek Watershed. Land use is less intensive with dairy farming, intensive corn and some cash cropping. Streambanks in the watershed are predominantly low in slope and height and have been left in a well vegetated natural state. The *area* of exposed banks is quite small as is the total area of banks showing evidence of erosion.

Recession rates measured on study banks varied depending on the bank type, soil, vegetation and many other factors. The estimated and measured rates on exposed banks ranged from less than 1 cm per annum to 18 cm. Recession rates from the twenty-five detailed study sites were compiled for use in extrapolation purposes.

The results from laboratory analyses of soil materials at the study sites yielded physical and mineralogical data for the range of conditions of Southern Ontario soils. Likewise the chemical analyses showed levels that can be considered to be natural background levels. Since PLUARG has placed emphasis on phosphorus and heavy metal pollution, these are the only chemical data reported here. Other soil analysis data is available through the Technical Report Series.

TABLE 1: General Characteristics Of Sixteen Preliminary Watersheds Canadian Great Lakes Basin

WATERSHED	PHYSIOGRAPHIC REGION	CLIMACTIC REGION	GENERALIZED LAND USE
*1. Big Creek	St. Clair Clay Plains	Kent and Essex	Cash crops on tile drained clay soils
*2. North Creek	Norfolk Sand Plain	Lake Erie Counties	Tobacco production and associated crops on sands
*3. Little Ausable River	Undrumlinized Till Plain	South Slopes	Beef and dairy cattle, feed crops, some cash cropping
*4. Canagagigue Creek	Undrumlinized Till Plain	Huron Slopes	Dairy farming with feed crop production
* 5. Holiday Creek	Fluted Till Plain	South Slopes	Dairy farming, intensive corn production, some cash cropping
6. Teeswater River	Drumlinized Till Plain	Huron Slopes	Beef and hog production, with feed crops
7. Ganaraska River	South Slopes and Oak Ridges Moraine	South Slopes	Forest, hobby farms, tobacco
8. Boyle Drain	Fluted Till Plain	Huron Slopes	Dairy farming, mixed non-intensive farming
9. West Humber River (Above Cedar Mills)	Kame Moraine	Simcoe and Kawartha Lakes	Non-agricultural forest, pasture, hobby farms, horses
10. North Creek (20 Mile Creek)	Haldimand Clay Plain	Lake Erie Counties	Dairy, poultry - depressed
11. West Humber River (above Wildfield)	Fluted Till Plain	South Slopes	Dairy, beef - rapidly urbanizing
12. Wilton Creek	Limestone Plain	Simcoe and Kawartha Lakes	Dairy - non intensive
*13. Hillman Creek	Shallow Sand over Clay Plain	Kent and Essex	Cash crops, fruit, vegetables
14. Little Mill Creek	Huron Slope Clay Plain	Huron Slopes	Beef farming - extensive
*15. Little Jerry Creek	Till Moraine, Till Plain and Sand Plain	Lake Erie Counties	Cash crop corn, marginal tobacco, non-intensive mixed farming
16. Unnamed Creek near Vineland	Lake Iroquois Plain	Niagara Fruit Belt	Fruit growing

* Watersheds included in detailed phase

TABLE 2: Summary Of Physical Characteristics Of The Canadian Study Watersheds

STUDY WATERSHED	AREA OF WATERSHED (ha)	TOTAL STREAM LENGTH (km)	TOTAL BANK AREA IN WATERSHED	TOTAL BANK SHOWING EVIDENCE OF EROSION (m^2)	TOTAL BANK AREA EXPOSED (NOT VEGETATED) (m^2)	DRAINAGE DENSITY (km/km^2)
Big Creek AG-1	5080	91.35	433,209	192,634	74,758	1.80
Canagagigue Creek AG-4	1860	20.04	45,313	28,085	14,694	1.08
Hillman Creek AG-13 (Northeast Branch)	3594	36.76	192,971	58,857	8,556	1.02
Little Ausable River AG-3	6200	40.30	207,681	129,638	18,773	0.65
20-Mile Creek AG-10	3025	28.87	72,889	16,661	3,693	0.95
Holiday Creek AG-5	3000	21.93	62,271	14,389	3,898	0.73

U.S. STUDY

The U.S. study involved watersheds ranging in size from 1,200 to 1,792,000 hectares. The four largest watersheds, all of which were greater than 35,000 hectares, were studied using a sample technique. The area the samples covered in these watersheds ranged from 2 to 25 percent. The four smaller watersheds, which were less than 5,300 hectares in size, were sampled 100 percent. In other words the entire watershed *was* divided into convenient sample plot sizes and each plot was field checked.

Land use within the watersheds was mostly agricultural. One watershed was mostly urban and urbanizing. This watershed had the highest streambank contribution to the total sediment yield. These watersheds all lie in the southern half of the U.S. portion of the basin and are scattered across the breadth as shown on Figure 1.

All the data shown in Table 3 except the watershed area is a product of the computer program developed for this study. This information was determined either by expansion of the sample plot data or, in the case of the small watersheds, by investigating all the streams.

Only those soil series which were known to be major contributors or sources of streambank erosion were sampled. Never more than eight soil series contributed the majority of eroded material. On one small watershed it was just one soil series. As in the Canadian study chemical analysis showed levels that would be expected of background conditions. Only phosphorus and heavy metals data is included in this report. Other soil analysis data is available through the Technical Report Series.

TABLE 3: Summary Of Physical Characteristics Of The U.. Study Watersheds

STUDY WATERSHED	AREA OF WATERSHED (ha)	STREAM LENGTH (km)	LENGTH OF ERODING BANK (km)	STREAM DENSITY km/km^2
Maumee River Basin	1,792,000	16,396	3,312	0.92
Black Creek	4,900	45.3	7.6	0.97
Canaseraga Creek	86,500	691.8	73.9	0.80
Menomonee River	35,200	224.8	41.8	0.64
Germantown	1,200	10.3	0.3	0.83
Kewaskum	2,800	22.4	4.3	0.80
Mill Creek	5,300	47.6	5.1	0.89
Oatka Creek	55,900	341.0	39.9	0.60

DATA ANALYSIS & INTERPRETATION

CANADIAN STUDY

Expansion of Data to Study Watersheds

To facilitate calculations of sediment loads from bank erosion, sites for measurement of recession rates were chosen to represent actively eroding bank types which were most prevalent in each study watershed. Compilation of the streambank mapping information yielded data on the area of bank in each watershed represented by a specific recession rate.

The method developed for approximating sediment yield involved partitioning of common bank types in each watershed and calculating a volume of eroded material based on a bank area represented and a measured recession rate. A weight of eroded material was obtained from bulk density determinations at each site. The assumption was made that in most cases the silt and clay fractions would be transported, thereby giving a delivery ratio which could be applied to the weight of the eroded material from each major bank type in a watershed. This sediment delivery ratio was used to calculate a sediment yield from bank erosion for each watershed. By dividing by watershed areas, a sediment yield rate in tonnes/ha/year was calculated and this rate was compared to a calculated total sediment yield rate to give the percent contribution from bank erosion. This data is summarized for the six detailed watersheds in Table 4.

A similar process was used for the computation of the yield of total phosphorus and extractable heavy metals. Chemical data was obtained on the soil materials at the study sites and weighted average levels were calculated and combined with sediment yields from bank erosion to give amounts of nutrients produced. For total phosphorus an enrichment ratio of 1.1 was assumed since delivery ratios were based on silt and clay transport. Similar ratios were not available for heavy metals although it is recognized that enrichment would occur from whole soil to transported sediment. The computed weights were converted to a per unit watershed area to facilitate intercomparisons. This summary data is presented in Table 5.

Extrapolation to Canadian Great Lakes Basin

Extrapolation to the Canadian Basin has involved a number of assumptions and necessary estimations and should therefore be treated as the best approximations available at this time.

The general basis for extrapolation has been land use information obtained from the September 1977 Joint Summary Report on Land Use published by Task B. In that report land use categories were broken down as indicated in Table 6.

TABLE 4: Summary Sediment Data Of Canadian Study Watersheds

Study Watershed	Weight Of Eroded Bank Material (tonnes/yr)	Sediment Yield From Bank Erosion (tonnes/yr)	Gross Bank Erosion (tonnes/km of channel/yr)	Sediment Yield Rate From Bank Erosion (tonnes/ha/yr)	Total Load (tonnes/yr)	Total Sediment Yield Rate (tonnes/ha/yr)	Contribution From Bank Erosion %
Big Creek AG-1	1454	1131	15.92	0.223	3888	0.765	29
Canagagigue Creek AG-4	449	255	22.41	0.137	801	0.431	32
Hillman Creek AG-13 (North- East Branch)	201	148	5.47	0.041	587	0.295 [2)]	14
Little Ausable River AG-3	179	151	4.44	0.024	1048	0.169	14
20-mile Creek AG-10	53	51	1.84	0.017	783	0.259	7
Holiday Creek AG-5	32	16	1.46	0.005	776	0.259	2

1) Ontario Ministry of the Environment
2) Measured on West Branch (1990 ha. area)

TABLE 5: Summary Chemical Data Of Canadian Study Watersheds

YIELD RATE FROM BANK EROSION

STUDY WATERSHED	TOTAL PHOSPHORUS[1] $kg/km^2/yr$	EXTRACTABLE HEAVY METALS[2] $kg/km^2/yr$					
		Cu	Pb	Zn	Cr	Ni	Cd
Big Creek AG-1	10.30	0.46	0.10	0.85	0.04	0.10	0.01
Canagagigue Creek AG-4	10.16	0.21	0.09	0.42	0.04	0.03	0.01
Hillman Creek AG-13 (Northeast Branch)	1.56	0.10	0.01	0.14	0.01	0.02	TR
Little Ausable River AG-3	1.87	0.07	0.02	0.12	0.01	0.01	TR
20-Mile Creek AG-10	1.36	0.03	0.01	0.03	0.01	0.01	TR
Holiday Creek AG-5	0.33	0.01	0.01	0.01	TR	TR	TR

1 $HClO_4$ method
2 1N. HNO_3 extractant

TABLE 6: Major Land Uses In The Canadian Great Lakes Basin

Land Use	Area (km^2)	of Total Area
Agriculture	51,657	22.15
Forest	173,834	74.54
Urban	3,544	1.52
Outdoor Recreation	2,282	0.98
Wetland	1,497	0.64
Barren	384	0.17
Total Area of Canadian Basin	233,198	

When the agricultural watersheds were selected in 1974, they were chosen to each represent an area of Southern Ontario where similar soils, climate and land use occur. These areas cover the majority of the 51,657 km of agricultural land in the basin.

The actual extrapolation involved the construction of an equation summing the products of the percent area represented by each agricultural region or land use group and the loading estimate for each area. Loading estimates were extended from the sixteen watersheds included in the preliminary phase to the twenty agricultural regions delineated. This calculation showed that 38 kg/ha/yr of sediment could be attributed to streambank erosion in agricultural areas.

Two other land use categories were forested areas, which includes Outdoor Recreation lands, Wetlands and Barren lands, and a second category of urban areas including Residential, Commercial and Industrial. While the six agricultural regions chosen for detailed study contained few forested areas, there were several watersheds with a high proportion of forest in the sixteen preliminary watersheds. Sediment loads calculated from streambank erosion on these watersheds ranged from 0.4 to 2.0 kg/ha with an average of 1 kg/ha. This was the loading rate assumed for forested areas.

Residential, Commercial and Industrial land accounted for only 1.5% of the land in the basin and this situation was not represented by study watersheds. The United States study suggests on the basis of studies in the basically urban Menomonee Basin that bank erosion would probably be 40 kg/ha/yr in these areas.

Based on the unit loading estimates for the above three major land use categories, the total sediment contributions to the Great Lakes from streambanks in the Canadian basin were estimated at 228,270 tonnes. Over the 23,319,800 ha area of the basin, this represented an average sediment yield rate of 10 kg/ha/yr.

Similar equations were constructed to estimate bank erosion contributions for the Task C basins; The Grand River, Saugeen River and Wilton Creek. Estimates of sediment yields were 40, 17, and 5 kg/ha/yr respectively.

For extrapolation of chemical data to the Canadian basin, it was felt that information was too limited to predict heavy metal loadings given the widely varying levels that can occur in soils. Total phosphorus was approached on a basin equation approach much like the sediment load calculations and a total amount of phosphorus for the Canadian basin from bank erosion was estimated at 81,900 kg/yr.

A summary statement of the basin phosphorus and sediment is contained in Table 12 following the discussion of data analysis from the U.S. study.

U.S. STUDY

Sediment yield from material eroded from streambanks was obtained by determining the amount of sand, silt and clay that was furnished by streambank erosion. Then a delivery ratio was selected for each size fraction. This delivery ratio was based on judgement and experience, comparison with the amount of that size material passing a gauge and comparison with the computed sheet erosion. The delivery ratio for each size fraction was multiplied by the amount of that material and the product of the three sizes totaled for the yield. The delivery ratio for material from streambank erosion from the watershed was determined by dividing the yield from that source by the erosion. Sediment data from streambank erosion is shown in Table 7.

Examination of the computer data shows that much streambank treatment has already been installed and that frequently the most expensive is yet to be accomplished. It is also recognized that in general streambank treatment is expensive and frequently not cost beneficial. It is to be expected that much of the streambank treatment still needed will not be cost beneficial. Table 8 shows summary data on existing streambank treatment, needs and cost.

Total phosphorus and heavy metals delivered to the Great Lakes were calculated by applying the known amount of these elements in the bank material to the estimated yield from that source. All calculations are based on yearly averages, with no attempt to correct for seasonal variations. The computed weights were converted to rate per area to facilitate comparisons and are shown on Table 9.

Expansion of Data to the U.S. Portion of the Great Lakes Basin

It is obvious that examination of 1,377 sample plots in watersheds totaling 19,035 square kilometers provided meager data from which to expand to a basin of 305,900 square kilometers less water areas, particularly when the samples did not include all vegetative types, geologic, physiographic and soils conditions.

A decision was made to use the Land Resource Regions (LRR) and Land Resource Areas (LRA) as a basis for expansion. There are four Land Resource Regions and 20 Land Resource Areas in the U.S. portion of the Great Lakes Basin. Figure 2 shows the location of the Land Resource Regions and Areas.

Land Resource Areas consist of geographically associated land resource units which are areas of land that are characterized by particular patterns of soil (including slope and erosion), climate, water resources, land use, and type of farming. Land Resource Regions consist of geographically associated major land resource areas.

TABLE 7: Summary Sediment Data Of U.S. Study Watersheds

Study Watershed	Weight Of Eroded Bank Material (tonnes/yr)	Sediment Yield From Bank Erosion (tonnes/yr)	Gross Bank Erosion (tonnes/km Of Stream/yr)	Sediment Yield Rate From Bank Erosion (tonnes/ha/yr)	Total Sediment Load (tonnes)	Total Sediment Yield Rate (tonnes/ha/yr)	Contribution From Bank Erosion (%)
Maumee	97,912	68,540	5.9	0.038	973,426	0.54	7
Black Creek	362	210	6.7	0.043	3,500 [1)]	0.71	6
Canaseraga	3,568	2,210	0.5	0.026	190,512	2.20	1
Menomonee	1,628	1,400	7.2	0.040	13,872	0.39	10
Germantown	8.2	5	8.0	0.004	600 [1)]	0.50	1
Kewaskum	50.8	35	2.3	0.013	1,200 [1)]	0.43	3
Mill Creek	259	150	5.4	0.028	3,000 [1)]	0.57	5
Oatka Creek	1,008	580	3.0	0.010	11,967	0.21	4

1) Estimated

TABLE 8: Summary Of Existing Streambank Treatment, Needs And Cost - U.S. Study Watersheds

STUDY WATERSHED	EXISTING STREAMBANK TREATMENT		STREAMBANK TREATMENT NEEDS	
	km	cost [1)]	km	cost [1)]
Maumee River	25,091.0	121,339,799	3,291.0	26,605,612
Black Creek	68.1	265,151	11.7	72,420
Canaseraga Creek	308.2	2,111,591	74.9	1,407,728
Menomonee River	140.0	14,908,402	41.8	1,585,917
Germantown	1.4	6,218	0.3	1,591
Kewashkum	3.4	23,292	4.3	22,750
Mill Creek	22.5	99,865	5.3	20,678
Oatka Creek	73.3	447,455	40.0	551,727

1) 1975 dollars

TABLE 9: Summary Chemical Data of U.S. Study Watersheds

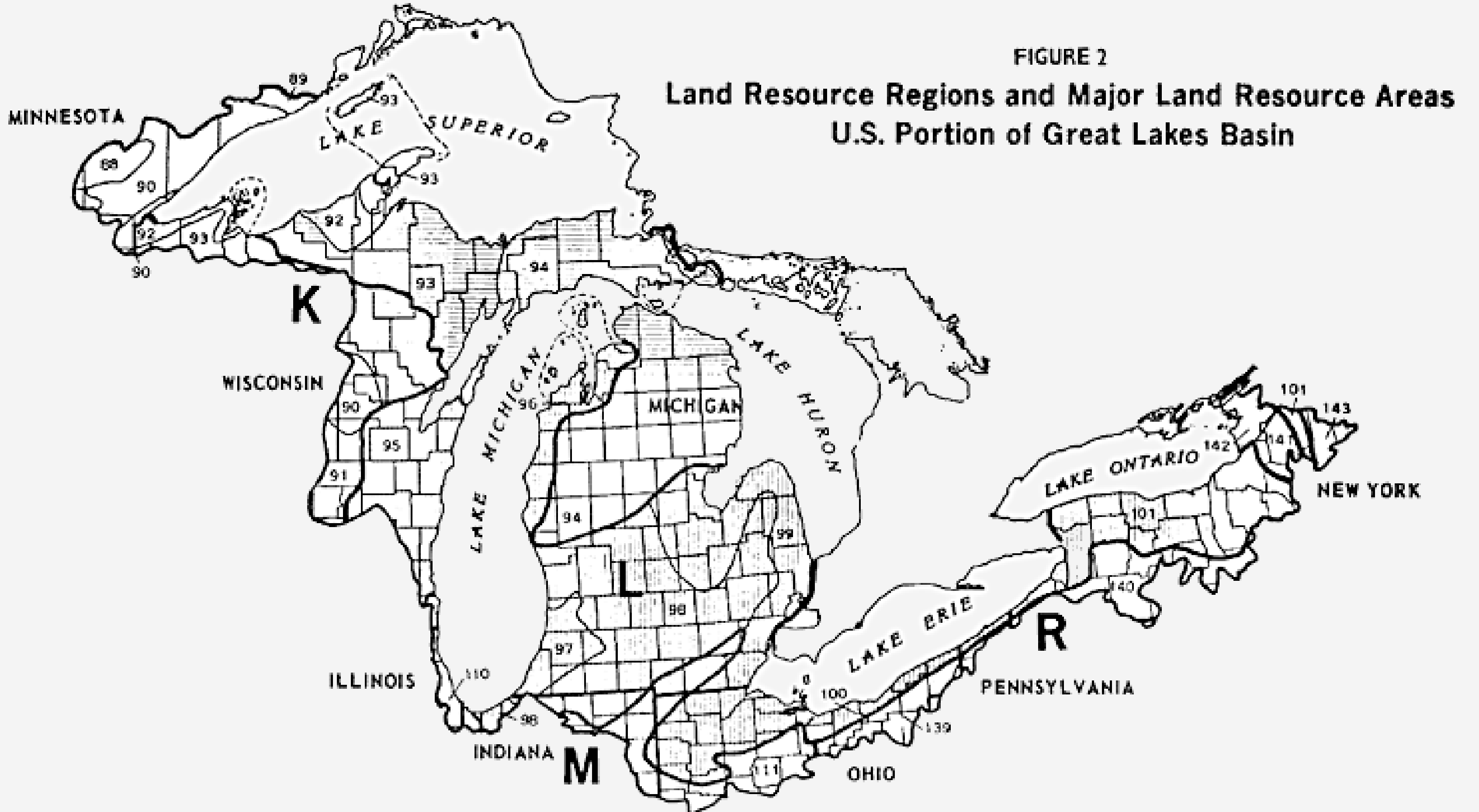
YIELD RATE FROM BANK EROSION

STUDY WATERSHED	TOTAL PHOSPHORUS[1] $kg/km^2/yr$	EXTRACTABLE HEAVY METALS[2] $kg/km^2/yr$					
		Cu	Pb	Zn	Cr	Ni	Cd
Maumee	3.24	0.67[3]	0.05[3]	0.10[3]	0.10[3]	0.03[3]	TR[3]
Black Creek	NA	NA	NA	NA	NA	NA	NA
Canaseraga	1.73	0.04	0.19	0.15	0.14	0.09	0.02
Menomonee	3.41	0.11	0.45	0.45	0.17	0.23	0.05
Germantown	NA	NA	NA	NA	NA	NA	NA
Kewaskum	NA	NA	NA	NA	NA	NA	NA
Mill Creek	1.23	0.02	0.49	0.15	0.07	0.25	0.05
Oatka Creek	0.70	0.02	0.12	0.10	0.03	0.06	0.01

1 Perchloric acid digestion
2 6N. HCl extract unless otherwise noted
3 1N. HNO_3 extractant
NA not available

FIGURE 2

Land Resource Regions and Major Land Resource Areas
U.S. Portion of Great Lakes Basin



K NORTHERN LAKE STATES FOREST AND FORAGE REGION

- 88 *Northern Minnesota Swamps and Lakes*
- 89 *Minnesota Rockland Hills*
- 90 *Central Wisconsin and Minnesota Thin Loess and Till*
- 91 *Wisconsin and Minnesota Sandy Outwash*
- 92 *Superior Lake Plain*
- 93 *Northern Michigan and Wisconsin Stony, Sandy and Rocky Plains and Hills*
- 94 *Northern Michigan Sandy Drift*

L LAKE STATES FRUIT, TRUCK, AND DAIRY REGION

- 95 *Southeastern Wisconsin Drift Plain*
- 96 *Western Michigan Fruit Belt*
- 97 *Southwestern Michigan Fruit and Truck Belt*
- 98 *Southern Michigan Drift Plain*
- 99 *Erie - Huron Lake Plain*
- 100 *Erie Fruit and Truck Area*
- 101 *Ontario - Mohawk Plain*

M CENTRAL FEED GRAINS AND LIVESTOCK REGION

- 110 *Northern Illinois and Indiana Heavy Till Plain*
- 111 *Indiana and Ohio Till Plain*

R NORTHEASTERN FORAGE AND FOREST REGION

- 139 *Eastern Ohio Till Plain*
- 140 *Glaciated Allegheny Plateau and Catskill Mountains*
- 141 *Tughill Plateau*
- 142 *St. Lawrence - Champlain Plain*
- 143 *Northeastern Mountains*

Each LRA was compared to each watershed studied and the watershed with the most factors in common was selected as the representative watershed for the LRA. Then parameters from the watershed such as streambank erosion rate, delivery ratio, stream density, percent of streambank kilometers needing treatment and average cost of treatment were used to develop tables which show sediment yield from bank erosion and the cost of needed treatment.

Table 10 shows that the annual sediment yield from streambanks to the Great Lakes is 617,110 tonnes. Table 11 indicates the cost of streambank treatment needed is slightly less than 213 million 1975 dollars.

The estimated annual sediment yield from sheet and gully erosion to the Great Lakes is 4,316,200 tonnes. The estimated sediment yield from streambank erosion as shown on Table 12 is 617,110 tonnes for a total sediment yield from the U.S. portion of the Great Lakes of 4,933,310 tonnes annually. This makes the contribution from streambank erosion about 12.5 percent of the total. This percentage is larger than for any watershed studied but it can probably be explained by noting that LRA 93 and 94 which are 31 percent of the basin are 80 percent forest. Forested lands were not well represented by the watersheds studied but it can be assumed that sheet and rill erosion in these areas is low. Most of these areas are sandy which would tend to increase streambank erosion, at least in relation to that from sheet and rill.

The confidence level for an expansion of chemical data from streambank erosion to the basin is less than for the procedure for determining sediment yield from streambank erosion or the cost of streambank treatment. This is because only five of the eight watersheds studied had chemical data of the stream discharge to compare with data from the eroding banks. Also, information on every parameter on each watershed was not available.

Total phosphorus eroded from streambanks compared to that element in the stream, is the most important and largest chemical contributor. Using phosphorus as a "worst case" example of the chemical parameters and expanding to the basin with the constraints listed above shows that slightly more than 344,000 kg/yr are delivered to the Great Lakes from streambank erosion (Table 12). This represents less than four percent of that contributed by shoreline erosion on the U.S. side of the Great Lakes.

TABLE 10: Estimated Annual Sediment Yield From Streambank Erosion, U.S. Portion Of Great Lakes Basin

Land Resource Region and Area	Area (km^2)	Representative Watershed	Streambank Erosion Rate (tonnes/km^2)	Streambank Erosion (tonnes)	Streambank Delivery Ratio %	Sediment Yield From Bank Erosion (tonnes)
K 88	3,800	Germantown	0.64	2,430	62	1,510
K 89	1,500	Germantown	0.64	960	62	600
K 90	4,200	Germantown	0.64	2,690	62	1,670
K 91	2,600	Kewaskum	1.83	4,760	68	3,240
K 92	7,800	Black Creek	7.43	57,950	58	33,610
K 93	38,300	Germantown	0.64	24,510	62	15,200
K 94	52,800	Germantown	0.64	33,790	62	20,950
Subtotal	111,000			127,090		76,780
L 95	23,400	Kewaskum	1.83	42,820	68	29,120
L 96	6,500	Kewaskum	1.83	11,900	68	8,090
L 97	4,400	Mill Creek	4.88	21,470	57	12,240
L 98	41,100	Mill Creek	4.88	200,570	57	114,320
L 99	36,100	Maumee	5.46	197,110	70	137,980
L 100	7,000	Maumee	5.46	38,220	70	26,750
L 101	20,900	Oatka	1.80	37,620	57	21,440
Subtotal	139,400			549,710		349,940
M 110	3,100	Menomonee	4.62	14,320	86	12,320
M 111	18,900	Black Creek	7.43	140,430	58	81,450
Subtotal	22,000			154,750		93,770
R 139	8,300	Black Creek	7.43	61,670	58	35,770
R 140	15,900	Canaseraga	4.12	65,510	62	40,610
R 141	3,900	Canaseraga	4.12	16,070	62	9,960
R 142	2,300	Oatka	1.80	4,140	57	2,360
R 143	3,100	Canaseraga	4.12	12,770	62	7,920
Subtotal	33,500			160,160		96,620
Total	305,900			991,710		617,110

TABLE 11: Cost Of Needed Streambank Protection U.S. Portion Of Great Lakes Basin

Land Resource Region and Area	Area (km^2)	Representative Watershed	Stream Density (km/km^2)	Percent of Stream Needing Treatment	Treatment Cost Per Bank Kilometer	Cost (Dollars)
K 88	3,800	Germantown	0.29	1.5	4,940	163,300
K 89	1,500	Germantown	0.29	1.5	4,940	64,500
K 90	4,200	Germantown	0.29	1.5	4,940	180,500
K 91	2,600	Kewaskum	0.55	9.6	5,290	1,452,400
K 92	7,800	Black Creek	0.97	8.4	6,250	7,944,300
K 93	38,300	Germantown	0.29	1.5	4,940	1,646,100
K 94	52,800	Germantown	0.29	1.5	4,940	2,269,200
Subtotal	111,000					13,558,300
L 95	23,400	Kewaskum	0.55	9.6	5,290	13,071,800
L 96	6,500	Kewaskum	0.55	9.6	5,290	3,631,100
L 97	4,400	Mill Creek	0.89	5.4	4,020	1,700,200
L 98	41,100	Mill Creek	0.89	5.4	4,020	15,997,100
L 99	36,100	Maumee	0.92	10.1	7,770	52,127,600
L 100	7,000	Maumee	0.92	10.1	7,770	10,107,800
L 101	20,900	Oatka	0.61	5.9	15,820	23,799,300
Subtotal	139,400					120,434,900
M 110	3,100	Menomonee	0.64	9.3	37,900	13,986,100
M 111	18,900	Black Creek	0.97	8.4	6,250	19,249,700
Subtotal	22,000					33,235,800
R 139	8,300	Black Creek	0.97	8.4	6,250	8,453,600
R 140	15,900	Canaseraga	0.80	5.3	19,060	25,699,000
R 141	3,900	Canaseraga	0.80	5.3	19,060	6,303,500
R 142	2,300	Oatka	0.61	5.9	13,820	2,288,000
R 143	3,100	Canaseraga	0.80	5.3	19,060	4,010,500
Subtotal	33,500					45,754,600
Total	305,900					212,983,600

TABLE 12: Joint Canada - U.S. Summary Of Sediment Yields To The Great Lakes From Bank Erosion

	CANADA	U.S.	BASIN TOTAL
Total Sediment Yield from Banks (tonnes/yr)	228,270	617,110	845,380
Total Sediment from all Sources (tonnes/yr)	NA	4,933,310	---
Contribution from Bank Erosion (%)	NA	12.5	---
Sediment Yield Rate from Bank Erosion (tonnes/ha/yr)	0.010	0.020	---
Total Phosphorus Contribution to Lakes from Bank Erosion (kg/yr)	81,900	344,000	425,900

NA - Not Available

CONCLUSIONS & RECOMMENDATIONS

Due to differences in the approaches to streambank erosion investigations on both sides of the border, study objectives varied and conclusions and recommendations reflect these differences. There are also statements that can be made common to both studies.

CONCLUSIONS

Joint Statements

1. The amount of sediment produced from streambank erosion can vary from basin to basin, season to season and year to year. It is also noted that the total amount of material eroded is not large when viewed on a global or continental scale. For the entire basin it is estimated that sediment yield to the Great Lakes from streambank erosion is 845,000 tonnes per annum.

2. When viewed relative to other sources of sediment, bank erosion does not appear to be a major contributor., accounting for one to ten percent of the load in the U.S. study watersheds and two to thirty-two percent in the Canadian Basins.

3. Total Phosphorus is the most important chemical contributed from bank erosion. An estimated 426,000 kg. of phosphorus are added to the Great Lakes each year from eroding banks.

4. While downstream sections of rivers were not specifically included in the Canadian study watersheds they were in U.S. study basins. There seem to be no reasons why loading rates on these areas should be higher or lower than other areas. If downstream banks were receding faster than study banks, this would be evident on aerial photography. Canadian tests indicated that this was not the case.

In addition to the above conclusions there are several comments particular to each study. Under the U.S. project it was felt that the cost of treatment per assumed tonne of sediment yield controlled varies widely. This can be explained simply by noting the highest cost is in an urban area with high land values and with expensive treatment required. The low value is because the treatment required was "simple" and not very expensive. The total cost of treatment to reduce annual sediment yield from streambank erosion is $345 per tonne.

In the Canadian basins several other conclusions have been reached and are listed below.

1. The source areas of bank erosion within each watershed can be highly variable and both point and non-point in nature. Banks most actively contributing to sediment can often *be* identified as small sections with specific problems both natural and man influenced. Remedial measures thus become site specific requiring planning on an individual basis geared to solving the problems at each site.

2. From observations in the field a list of natural and cultural factors contributing to bank erosion has been compiled. Some of the main physical causes are sheet and rill erosion by overland flow and scouring by the stream followed often by slumping of the upper bank under gravity. These processes depend on moisture conditions in the bank, the erodibility of the soil material, vegetative cover and hydraulic characteristics of the stream. Man's influence can often be a main contributing factor especially in relation to his use of the area Immediately adjacent to the stream. Cropping right to the bank edge and allowing cattle to graze on banks in the spring can add to bank instability. More directly, man can alter the drainage pattern and erodibility of the banks through the construction and maintenance of municipal ditches and channel alterations. A more complete description of this subject is contained in the technical report series.

3. These above factors vary from area to area with some regions of the province having a combination of factors that would suggest higher or lower sediment yields from bank erosion. While the exact manner in which these factors combine to produce high and low source areas is uncertain, a qualitative picture emerges. Areas that have a low intensity land use (e.g. forestry, permanent grassland) and low or moderately erodible soils appear to have low sediment loads attributable to bank erosion (10 kg./ha./yr.). Areas with a high intensity land use (e.g. cash cropping) and a highly erodible soil will tend to have bank erosion rates possibly in excess of 200 kg/ha/yr. unless the banks are protected or well managed.

RECOMMENDATIONS

U.S. Study

From the study of remedial measures in the U.S. basins it was determined that the cost of treatment of the annual sediment yield from streambank erosion is $345 per tonne. This figure is very high for the benefits which could accrue. If the total cost needed for streambank treatment were instead spent for land treatment to prevent sheet and rill erosion the resulting sediment decrease would be much larger. The benefits from a reduction of sheet and rill erosion would be greater still when it is considered that most contaminants from agricultural land are attached to the fine particles removed by sheet and rill erosion.

Canadian Study

The investigation of remedial measures was not included in the original study objectives and was therefore approached on a different level than in the U.S. Also it was noticed that good soil conservation practices are not as readily accepted and implemented in Canadian basin as they are in the U.S. Most of the Canadian recommendations therefore deal with the prevention of bank erosion through proper management of stream courses. It is recognized that localized cases or encroachment on high value land by bank erosion may warrant the expense of protective measures.

1. Agricultural cropping should be kept back from the bank edge leaving a buffer strip as a catchment for sediments carried in overland flow and as an aid in stabilizing the upper bank areas.

2. Pastured animals need to be restricted from bank areas in the spring when banks are wet and vulnerable.

3. Hydraulically vulnerable spots, such as tile outlets, drain inlets and sharp bends are localized point sources of sediment and should be properly protected.

4. Municipal and field ditches require better construction and maintenance than at present. Establishment of bank slopes should be related to the properties of the soil materials. Ditch slopes should be revegetated and maintained.

5. A final recommendation deals with future research needs. This study has established a base of information on bank erosion and there is a need to continue study to accertain quantitative relationships between factors causing bank erosion.