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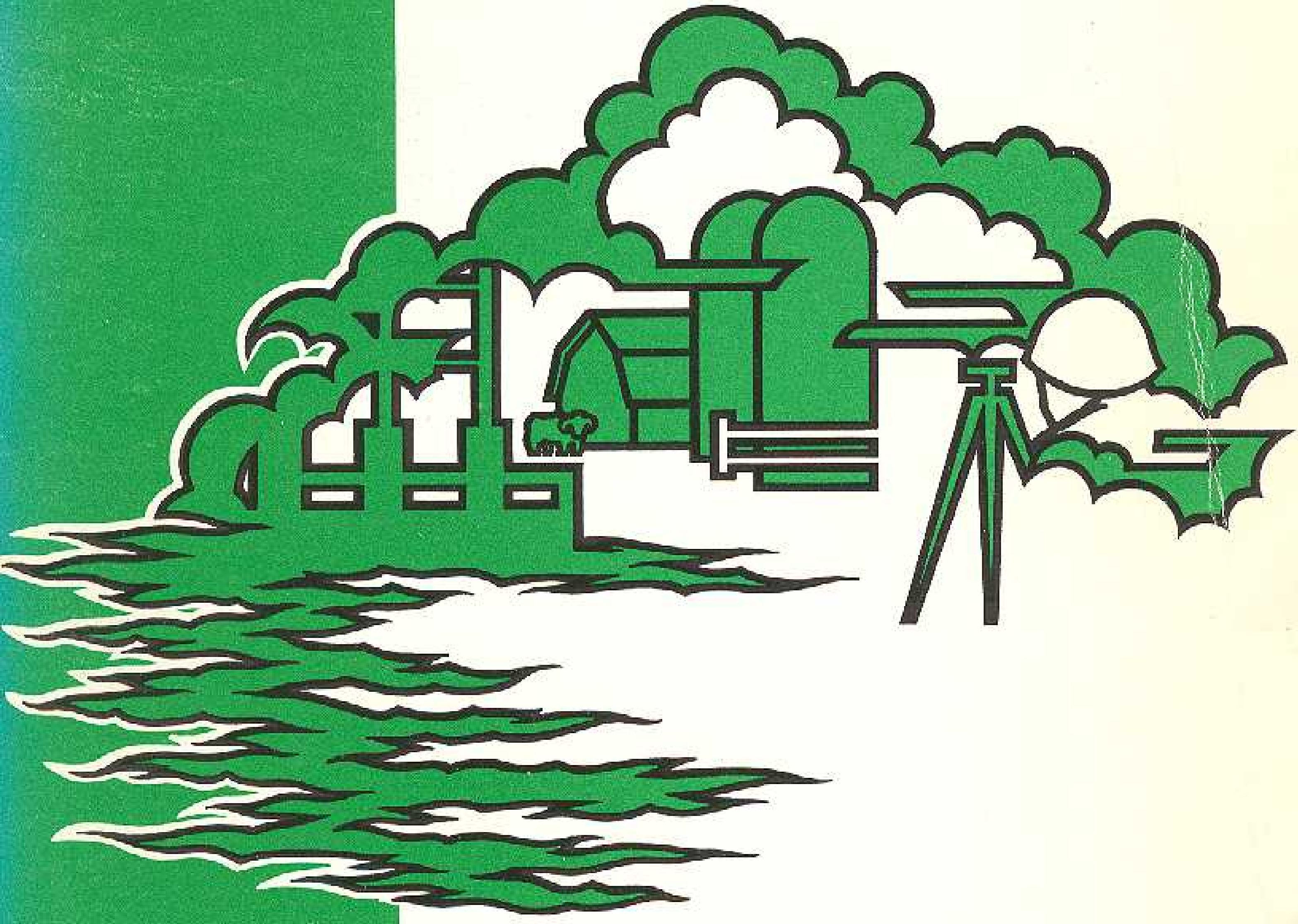

INTERNATIONAL
JOINT
COMMISSION

SOIL EROSION FROM AGRICULTURAL LAND IN THE CANADIAN GREAT LAKES BASIN

COMBINED FINAL REPORT - MARCH 1978

to

AGRICULTURAL WATERSHED STUDIES

(PHASE I AND PHASE II)

TASK GROUP C (CANADIAN SECTION) ACTIVITY 1 - PLUARG - IJC

on

PROJECT 16:
EROSIONAL LOSSES FROM AGRICULTURAL LAND;
PROJECT 17:
SEDIMENT DELIVERY RATIOS IN SMALL AGRICULTURAL WATERSHEDS;
AND
SEDIMENT INTEGRATION ASPECTS

by

L.J.P. VAN VLIET[1], G.J. WALL[1], AND W.T. DICKINSON[2]
ONTARIO INSTITUTE OF PEDOLOGY[1] AND SCHOOL OF ENGINEERING[2]
UNIVERSITY OF GUELPH
GUELPH, ONTARIO
N1G-2W1

PROJECT LEADERS: G.J. Wall
W.T. Dickinson

RESEARCH ASSOCIATE: L.J.P. van Vliet

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 describes the results of several integrated projects designed to further our understanding of the sources and magnitude of fluvial sediment derived from agricultural lands and delivered to the Canadian Great Lakes. Agricultural regions with high potential sheet erosion losses were intensively farmed with high percentages of row crops (beans, corn, horticultural crops). Rainfall induced soil erosion losses showed considerable year to year variations and are not equally distributed throughout any given year. Winter soil erosion losses associated with snowmelt events can account for up to 25% of the total annual soil loss.

Suspended sediment yields for agricultural regions in southern Ontario ranged from <100 kg/ha/yr to 1000 kg/ha/yr. In these agricultural regions, cropland is the dominant (70-100%) source of fluvial sediments with streambank and channel erosion representing a minor (0-30%) source. Suspended sediments originating from agricultural land are predominantly (75%) transported in the months of February, March and April.

A suspended sediment delivery ratio curve developed for Canadian agricultural watersheds was lower (≈10%) than a similar curve developed by the Soil Conservation Service in the U.S.A. Delivery ratios were also computed on a monthly basis with delivery ratios in excess of 100% in the spring months and below 5% in the summer months.

Three prediction models have been used (with some success) to estimate stream sediment loads in agricultural watersheds. A regression model ($R^2 = .71$) has been established to predict stream sediment loads in agricultural watersheds where the % row crops and % clay in the soil surface are known.

Active sediment contributing areas in the agricultural watersheds studied have been found to be dynamic and represent <15% of the total watershed area. Maximum sediment contributing areas have been observed in the late winter and spring months.

The use of simulation techniques to assess the utility of several remedial measures to reduce soil erosion have revealed that potential soil loss reductions of up to 75% can be achieved with conservation measures applied to sediment source areas.

Extrapolation of sediment loading rates from the representative agricultural regions of southern Ontario to all agricultural land in southern Ontario gives an average annual agricultural loading rate of 215 kg/ha/yr.

2.0 INTRODUCTION TO REPORT

This final report combines the results of the following study projects undertaken under PLUARG Task Group C (Canadian Section) - Activity 1:

Project 16: Erosional losses from agricultural lands;

Project 17: Sediment delivery ratios in small agricultural watershed;

and Integration of studies dealing with or related to agriculturally derived sediments in the Canadian Great Lakes Drainage Basin (Projects #2A, 6A, 7, 15, 16, 17 and Task C Activity 6).

The aim of the integrated research projects has been to develop a capacity for predicting the source and magnitude of sediment derived from agricultural lands and delivered to the Canadian Great Lakes.

The approach adopted for the broad problem of predicting the surface movement of pollutants from agricultural lands has involved five main stages. These include:

(i) development of conceptual deterministic models of soil erosion and sediment transport from source to stream;

(ii) testing, verification and improvement of the conceptual models with detailed data collected from a limited number of agricultural watersheds;

(iii) testing of the spatial extrapolation capability of the models with monitored data collected from other IJC selected basins;

(iv) testing of the temporal extrapolation capability of the models by comparing the sampled period of record (ie. 2 years) with a longer history of flows and extremal situations; and

(v) integration of results generated from other PLUARG studies relating to erosion and sedimentation.

The data base for the studies has been that established for the agricultural watershed projects regarding the Canadian portion of the Great

Lakes Basin. Eleven representative agricultural watersheds in Southern Ontario were included in the Preliminary Monitoring Programme, Phase I (Agricultural Watershed Study, Task C - Canadian Section, 1974-1975 and 1975-1976). Six of the eleven watersheds were included in the Detailed Studies, Phase II (Agricultural Watershed Studies, Great Lakes Drainage Basin, Canada, Detailed Study Plan, 1975-1976; October 1975).

Frank and Ripley (1977) have described the location and land use activities in these representative agricultural watersheds.

3.0 POTENTIAL SOIL EROSION LOSSES FROM AGRICULTURAL LAND

3.1 Introduction

The study objectives of this chapter regard soil erosion in agricultural watersheds in Southern Ontario and are as follows:

- to describe spatial and temporal aspects of soil erosion processes for agricultural lands in Southern Ontario, and
- to identify the effects of agricultural land use on erosion losses.

The study approach has involved the use of the Universal Soil Loss Equation to compute:

- average annual potential soil erosion losses for the 11 agricultural watersheds that represent the major agricultural regions of Southern Ontario;
- monthly, seasonal and annual soil losses for the year 1976 for 6 detailed studied watersheds (AG-1, AG-3, AG-4, AG-5, AG-10, AG-13); and
- monthly distribution of 1976 rainfall "R" values for comparison to long-term average annual erosion values.

Soil erosion information presented in this Chapter has also been used in Chapter 5 for delivery ratio computations, in Chapter 6 for sediment load predictions and in Chapter 7 for extrapolation purposes.

3.2 Data Collection Methods

On the basis of soil material, physiography, climate and predominant livestock and cropping-management systems, Coote *et al*. (1974) identified major agricultural regions within the Canadian Great Lakes Basin (Southern Ontario) and selected watersheds (19-54 km^2) representative of each region. The agricultural regions and representative watersheds are identified on Figure 1. Data for the soil erosion study were obtained from all 11 watersheds selected initially for the monitoring study. Frank and Ripley (1977) have described the land use activities in these study watersheds.

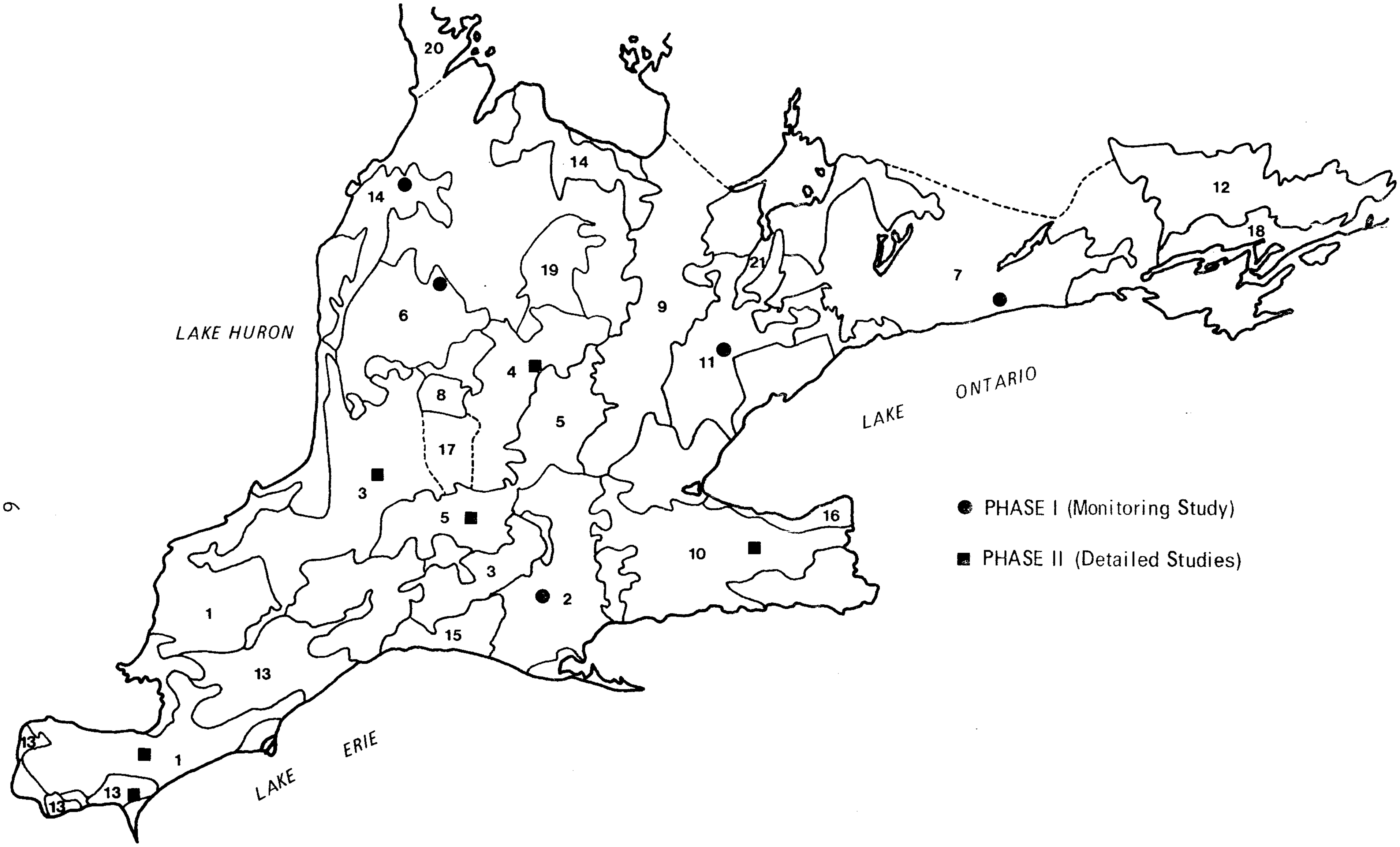

Figure 1: Agricultural Regions and Representative Watershed Locations

The Universal Soil Loss Equation (Wischmeier and Smith, 1965) has been used for estimating rainfall and runoff-induced soil erosion losses for the various crops grown in each watershed. Losses estimated by this method are meant to include both sheet and rill erosion, as defined by the original authors.

The Universal Soil Loss Equation (U.S.L.E.) is:

$$A = RKLSCP, \text{ where}$$

A = the predicted average soil loss, expressed in ton/acre/yr,

R = the rainfall factor, expressed as a rainfall-erosion index,

K = the soil erodibility factor, expressed as tons of soil loss per acre per unit of rainfall-erosion index on a plot (9% slope, 22.1 m long, in continuous fallow, tilled up-down slope),

L = the length-of-slope factor, expressed as the ratio of soil loss from a specified length of slope to that defined for the K factor,

S = the slope-gradient factor, expressed as the ratio of soil loss from a specified percent slope to that of the K factor,

C = the cropping management factor, expressed as the ratio of soil loss under a specified cropping management system to the loss under fallow conditions,

P = the erosion control practice factor, expressed as the ratio of soil loss with a specific conservation practice (e.g. contouring, strip-cropping, or terracing) to that with up-down slope cultivation.

The rainfall erosion "R" values were derived from long-term rainfall records and calculated for 11 climatic stations in Southern Ontario (Ateshian, 1974). A map showing the average annual values of the rainfall factor R in Southern Ontario was produced by employing computed R values and published R values for the United States bordering Southern Ontario (van Vliet et al. 1976) (Figure 2). Measured rainfall data in the watersheds (PLUARG Project 6A - Sanderson, 1978) were the basis for the determination of "R" values for the year 1976 by the same method (Ateshian, 1974).

Detailed information concerning land use, cultivation practices, crop rotation systems, soil properties and land slopes required for the application of the soil loss equation were obtained by a combination of on-site evaluation, laboratory analyses and aerial photographic interpretation.

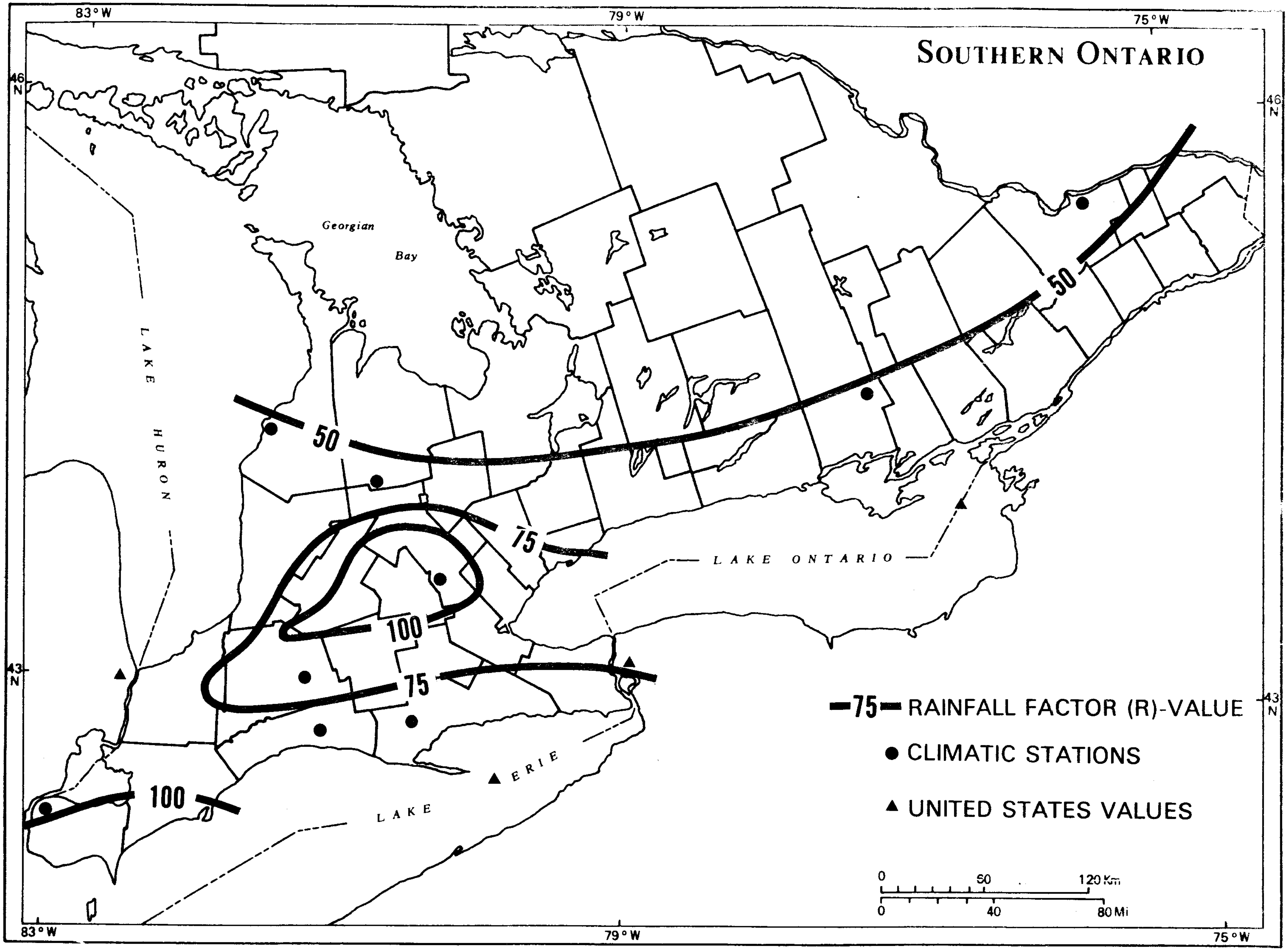

Figure 2: Average Annual Rainfall Factor "R" Values for Southern Ontario

Soil erodibility "K" values for surficial soil materials (Ap or Ah + Ae horizons) were determined by the soil erodibility nomograph (Wischmeier et al. 1971).

The topographic factors, slope length "L" and slope gradient "S", were determined on-site and LS values were derived from the LS chart (Wischmeier and Smith, 1965).

During the 1974 and 1975 growing seasons, agricultural land use on the individual fields in each watershed was mapped on aerial photographic base maps and the percent of the watershed in different crops was calculated. If a grass cover was part of a crop rotation, it was mapped as meadow. Areas with permanent grass or mixed shrubs and grass vegetation were classified as permanent pasture. Tree vegetation, including marshes, woodlots and forests were classified as woodlands. The regional soils and crop specialists of the Ontario Ministry of Agriculture and Food were contacted to establish the most common crop rotations for each watershed. This source was also very helpful for establishing plowing, seeding (planting) and harvesting dates, as well as residue management and yield levels that were required for the computation of "C" factors (Wischmeier and Smith, 1965).

Erosion control practices "P" such as terracing, strip-cropping or contour ploughing, were not present in the watersheds studied. Therefore, the erosion control practice factor P in the U.S.L.E. was given a value of 1 (Wischmeier and Smith, 1965).

The predicted average annual soil loss "A" is the long-term average annual soil loss in tons/acre/yr. It should be recognized that any soil loss estimate based on only a single year of data may deviate considerably from this long-term average value. Since this study was conducted for only a 1 to 3 year period, an attempt was made to determine how soil loss during this short time period varied both by month and annually in comparison with long-term average annual soil loss values.

The rainfall factor "R" and cropping-management factor "C" (Wischmeier and Smith, 1965) are the only factors that change temporally and hence require consideration in determining either monthly or yearly values. For the computation of monthly predicted erosion losses, monthly "R' and "C" values were calculated and the U.S.L.E. was solved in the normal way. The method of calculation is demonstrated below by an example for Watershed AG-1 (Table 1).

Monthly rainfall "R" values for 1976 (column 2) were computed by the Ateshian method (1974), with data from PLUARG Project 6A (Sanderson, 1978). Long-term monthly "R" values have also been included in Table 1 (column 3). For the derivation of an average monthly soil loss ratio (column 4), the growing season was divided into the following 5 crop stage periods, as defined by Wischmeier and Smith (1965).

Table 1: 1976 Sheet and rill erosion losses for AG-1 (Big Creek Watershed)

1	2	3	4	5	6	7	8	9	10
						Soil Loss			
	"R" Value		Average Soil Ratios	RxC	RxC		Adjusted For Snow		
Month	1976	Longterm	(C)		(%)	(metric tons)	(%)	(metric tons)	(ton/ha)
JANUARY	6.7	0.53	0.51	3.417	7.5	2942.5	8.5	3334.9	0.656
FEBRUARY	6.7	1.03	0.51	3.417	7.5	2942.5	9.5	3727.2	0.734
MARCH	18.38	1.81	0.51	9.374	20.5	8042.9	27.5	10789.3	2.124
APRIL	14.36	4.71	0.51	7.324	16.1	6316.6	16.1	6316.6	1.243
MAY	6.03	6.32	0.67	4.040	8.9	3491.8	8.9	3491.8	0.687
JUNE	6.91	16.69	0.50	3.455	7.6	2981.8	7.6	2981.8	0.587
JULY	35.28	26.27	0.26	9.173	20.1	7885.9	20.1	7885.9	1.552
AUGUST	0	20.72	0.26	0	0	0	0	0	0
SEPTEMBER	11.38	7.59	0.26	2.959	6.5	2550.2	6.5	2550.2	0.502
OCTOBER	5.90	4.48	0.41	2.419	5.3	2079.4	5.3	2079.4	0.409
NOVEMBER	0	1.65	0.51	0	0	0	0	0	0
DECEMBER	0	3.20	0.51	0	0	0	0	0	0
YEAR	111.6	95.00		45.578	100.0	39233.8	110.0	43157.2	8.496

Crop Stage Period	Month
F - Rough fallow	November - April
1 - Seedling	May
2 - Establishment	June
3 - Growing and maturing of crop	July, August, September
4 - Residue or stubble period	October

Months corresponding to the crop stage periods reflect average cropping-management conditions for the crops grown in the watershed (AG-1) as follows:

- average planting date for all crops :	May 1;
- average harvest date for all crops:	October 1;
- average plowing date for all crops:	November 1.

(These average dates and consequently the months in each crop stage period vary slightly from one watershed to the other).

Average soil loss ratio values were derived from soil loss ratio tables (Wischmeier and Smith, 1965) for the crops for each of the 5 crop stage periods and corresponding months. Column 5 which is the product of column 2 and column 4, has dimensionless numbers. Column 6 is the monthly proportion of column 5, expressed as a percentage. The total long-term predicted sheet erosion loss for AG-1 was adjusted for the 1976 annual rainfall "R" value (Table 1), resulting in a value of 39,234 metric tons of soil loss (column 7). On the basis of the percentage values in column 6, the yearly soil loss value was proportioned by months (column 7).

Since snowmelt has been observed to affect erosion and since the effect of snowmelt is not included in the universal soil loss equation, soil erosion losses were adjusted in accordance with local observations. Recent unpublished research has indicated that the contribution from snowmelt in Southern Ontario varies between 10-15% of the total annual soil loss value (van Vliet and Wall, 1978). Consequently, in areas with relatively low snowfall accumulations (AG-1, AG-10, AG-13), 10% of the annual soil loss value was added to the yearly value as follows: January 1%, February 2% and March 7% (column 7). In areas with relatively high snowfall accumulations (AG-3, AG-4, AG-5) 15% of the annual soil loss value was added to the yearly value as follows: January 2%, February 3%, March 10%. Column 9 shows the snowmelt-adjusted soil loss values for the months of January, February, March. Monthly unit area losses were computed in column 10.

These computations, demonstrated for AG-1, were also performed for the other 5 watersheds (AG-3, AG-4, AG-10, AG-13) and may be found in Appendix 1.

3.3 Experimental Results

The locations of the 11 representative agricultural watersheds for which potential sheet erosion losses were computed are shown in Figure 1. The predominant soil material and land use encountered in the watersheds are summarized in Table 2. Results of the application of the U.S.L.E. to the 11 watershed areas are presented in histograms (Appendix 2) and data for watershed #1 are discussed below to illustrate how the information in the histograms can be interpreted.

Figure 3 shows the percentage of watershed #1 occupied by the different crops versus the average annual potential sheet erosion losses. In addition, the range of soil loss for each cropping system that results from different soil factors and topographic factors is indicated for each crop by a range line. For example, the average annual potential sheet erosion losses from corn, soybeans and small grains in rotation are approximately 7 metric ton/ha/yr, but soil losses may range from 3.5 - 9.6 ton/ha/yr depending upon the soil erodibility and slope factors. Both permanent pasture and woodland are estimated to have low soil losses (<0.5 ton/ha/yr) as compared with rotational crops (>6 ton/ha/yr) in this watershed. Soil erosion losses for the other 10 watersheds are presented in the same manner in Appendix 2.

A soil erosion index was developed in order to provide a method for comparing the long-term potential erosion hazards of the different agricultural watersheds. The sheet and rill erosion index for each watershed studied was derived by integrating the average sheet erosion losses (i.e. the total area under the histograms depicted in Figure 3 and Appendix 2). On the basis of this watershed erosion index, each watershed was placed into a high, medium, or low erosion category as indicated in Table 3. Based on the results for the representative watersheds the agricultural regions in southern Ontario were also classified into a high, medium or low erosion potential category. The spatial distribution of potential soil erosion in southern Ontario is depicted in Figure 4.

Another way of presenting the erosion data of Figure 3 and Appendix 2 is to summarize the potential sheet erosion values for several of the predominent agricultural crops grown in southern Ontario. The mean values of the estimated soil losses for the crops grown in different watersheds were calculated and are summarized in Table 4. The range values express the effects of variations in soil erodibility "K", topography "LS" and rainfall "R" over the different areas. Potential sheet erosion losses for southern Ontario on a long-term (22 years) basis, on a single year (1976) basis and on a crop basis are shown in Figure 5. Soil losses (1976) were higher than longterm average annual losses reflecting greater than average rainfall in 1976.

Table 2: Predominant soil materials, topography and land uses for 11 agricultural watersheds.

WATERSHED			
AG-Number	Name and County	SOIL MATERIALS AND TOPOGRAPHY	LAND USE
1	Big Creek (Essex Co.)	Clay to clay loams over clay to silty clay tills; nearly level to undulating terrain.	Cash crops, corn, soy beans, small grains.
2	Venison Creek (Norfolk Co.)	Sands, sandy loams and loamy sands; undulating to gently rolling terrain.	Tobacco and dairy.
3	Upper Little Ausable River (Huron Co.)	Silty clay loams and silt loams over silty clay loam tills; undulating terrain.	Cash crops, corn, white beans, small grains, dairy.
4	Canagagigue Creek, West Br. (Wellington-Peel Co.)	Silt loams, silty clay loams and clay loams over silty clay loam and clay loam tills; undulating terrain.	Dairy, small grains and corn in meadow rotations.
5	Holiday Creek, Trib. of Middle Thames (Oxford Co.)	Silt loams over loam and silt loam tills, undulating terrain.	Dairy, hogs, corn, small grains.
6	Tributary of Maitland Riv. (Huron & Wellington Co.)	Silt loam and loam tills; undulating terrain.	Beef, hogs, meadow in rotation with small grains.
7	Shelter Valley Creek (Northumberland Co.)	Sandy loam tills; stony; moderately to strongly rolling terrain.	Forest, hobby farms, tobacco, permanent pasture.
10	North Creek Br. of Twenty Mile Creek (Lincoln Co.)	Silty clay loams over clay and silty clay till. Undulating terrain.	Dairy, hogs, poultry, permmanent pasture, meadow in rotation.
11	Salt Creek (Peel Co.)	Loam to clay loam to clay; nearly level to undulating terrain.	Beef, dairy, rapidly urbanizing, permanent pasture, corn.
13	Hillman Creek, West Br. (Essex County)	Fine sands, loamy fine sands and very fine sandy loams; level to very gently sloping terrain.	Cash crops, fruits, vegetables, corn, soybeans, tomatoes, etc.
14	Wilmot Creek (Bruce Co.)	Clay and silty clays; gently rolling terrain.	Beef (extensive), permanent pasture, meadow.

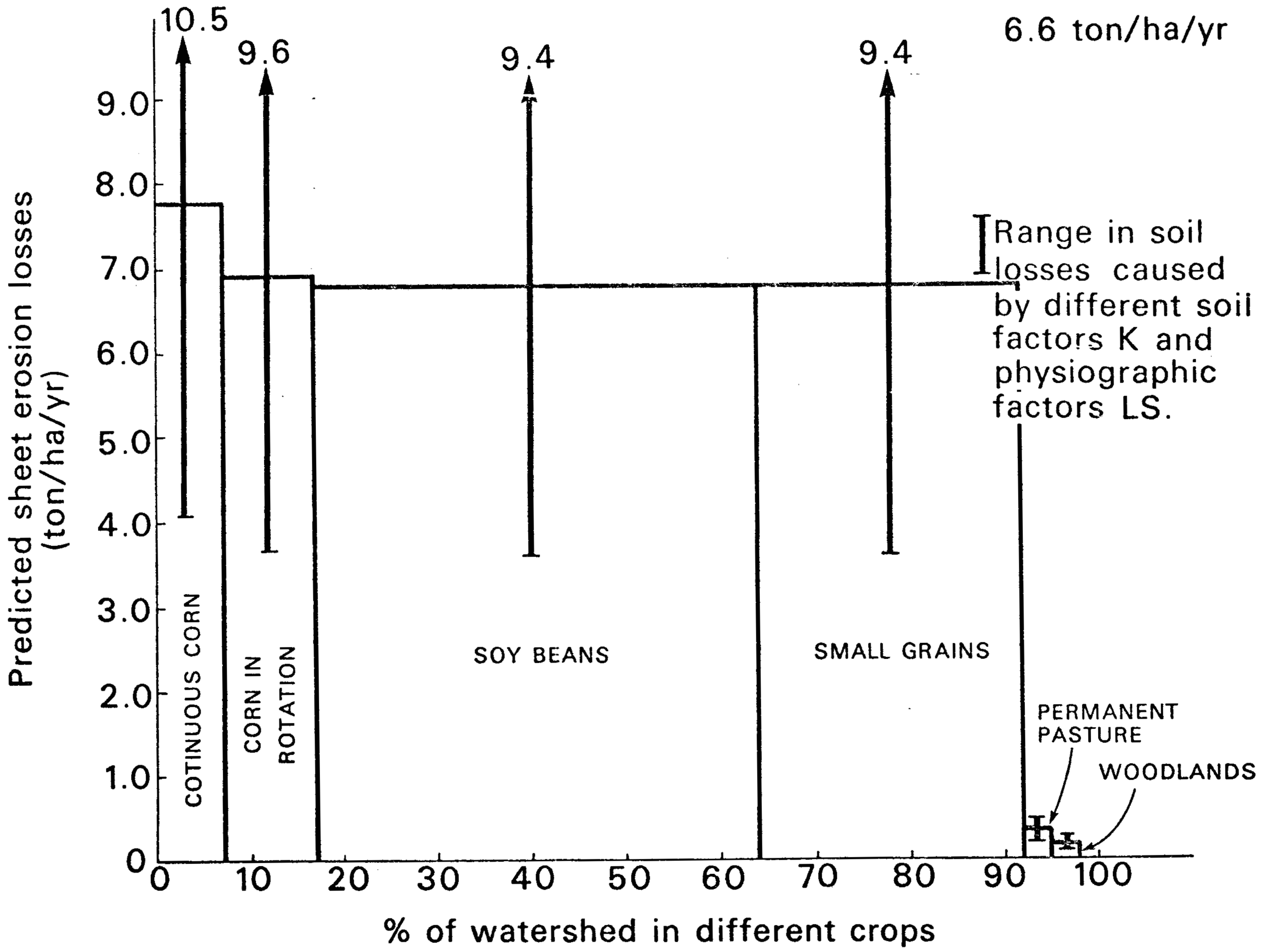

Figure 3: Longterm Average Annual Soil Erosion Losses by Crop for AG-1 (Big Creek Watershed)

Table 3: Soil erosion indices for 11 agricultural watersheds

WATERSHED NO[1]	WATERSHED NAME	WATERSHED AREA (ha)	WATERSHED EROSION INDEX (ton/ha/yr)	WATERSHED EROSION INDEX (ton/acre/yr)	EROSION POTENTIAL CATEGORY
13	Hillman Creek (West Branch)	1990	7.3	3.2	High
1	Big Creek Trib. to Thames River	5080	6.6	2.9	
7	Shelter Valley Creek	5645	5.7	2.5	
3	Upper Little Ausable River	6200	4.3	1.9	Medium
6	Tributary of Maitland River	5472	4.0	1.8	
5	Holiday Creek (Trib. of Middle Thames River)	3000	3.7	1.7	
11	Salt Creek	2383	3.0	1.3	
4	Canagagigue Creek (West Branch)	1860	2.1	0.9	Low
14	Wilmot Creek	4504	1.2	0.6	
10	North Creek Branch of Twenty Mile Creek	3025	1.1	0.5	
2	Venison Creek	7913	1.0	0.4	

[1] See Figure 1 for location of watersheds and Table 2 for a brief watershed description.

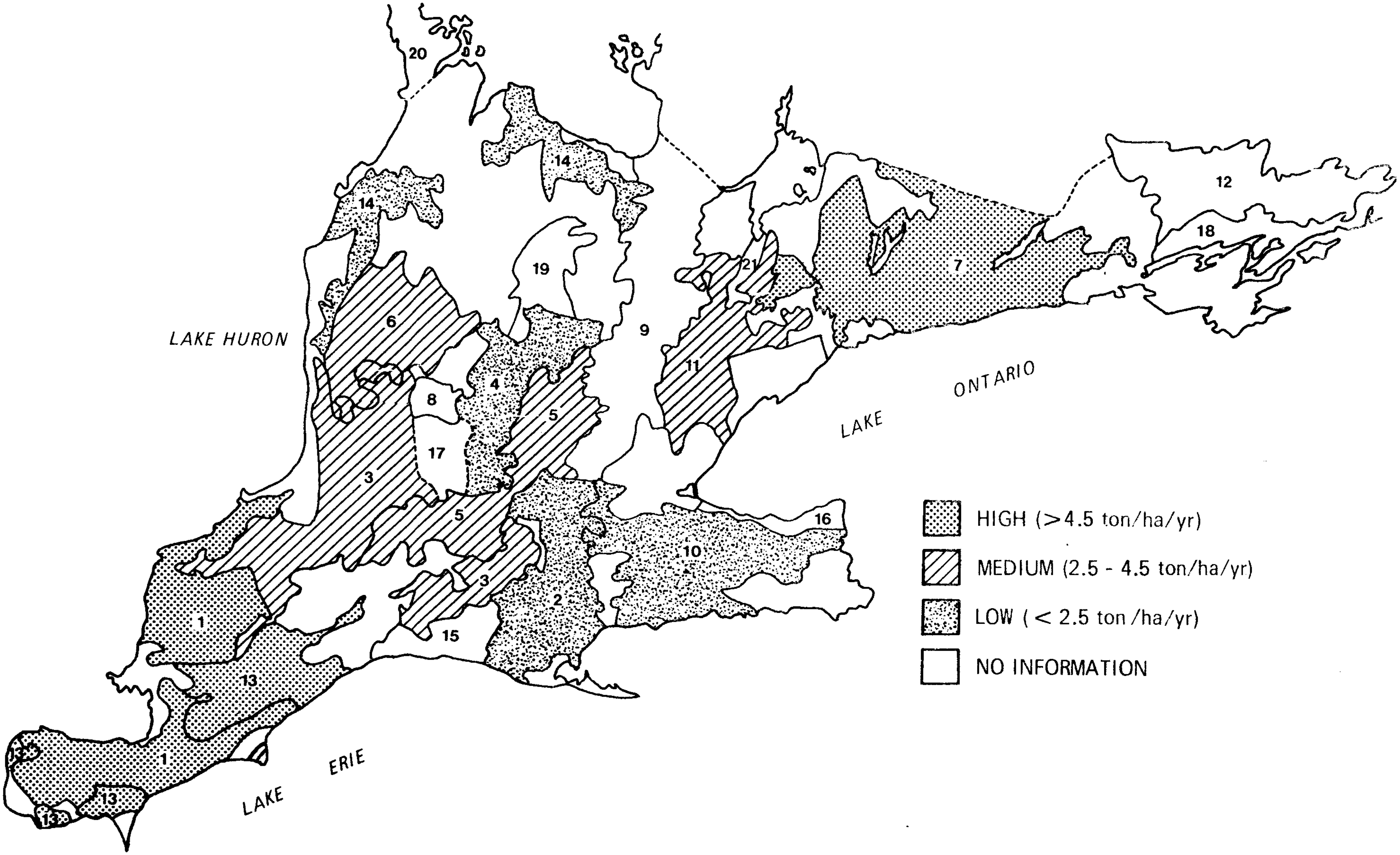

Figure 4: Spatial Distribution of Potential Soil Erosion in Southern Ontario

Table 4: Magnitude of potential sheet erosion losses from cropland in Southern Ontario

CROP	SHEET EROSION LOSSES BY CROP Mean (ton/ha/yr)	Range[1] (ton/ha/yr)
Horticultural crops (potatoes, tomatoes, etc.)	9.1	6.6 - 12.2
Beans (soy and white)	7.6	5.5 - 9.8
Continuous corn	6.7	2.9 - 11.7
Corn in rotation	3.7	0.9 - 6.9
Tobacco	3.5	2.1 - 4.9
Small grains	3.4	1.5 - 6.9
Meadow in rotation	2.6	0.9 - 5.0
Permanent pasture	0.4	0.1 - 0.8
Woodlands	0.2	0.05 - 0.4

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[1] Range values reflect a combination of soil, topographic and rainfall variations between watersheds.

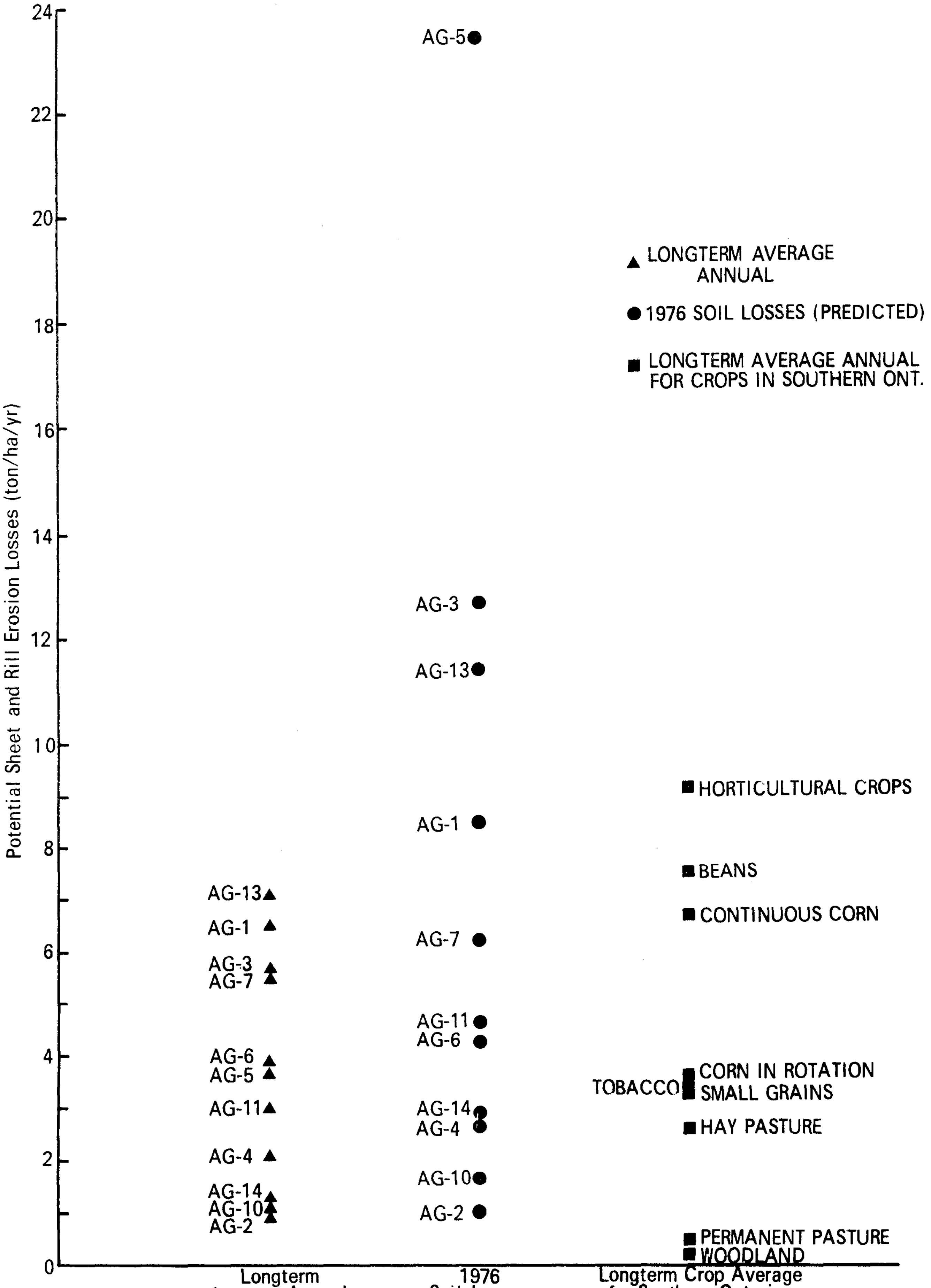


Figure 5: Potential Agricultural Watershed and Cropland Erosion Losses

In addition to long-term average annual potential erosion losses, short time period erosion losses (e.g. 1976) were computed. Results of the 1976 monthly and annual predicted erosion loss computations for the 6 detailed-study watersheds are presented in Table 1 for AG-1 and Appendix 1 for AG-3, AG-4, AG-5, AG-10, AG-13. Watershed soil erosion losses for 1976 are presented in Figure 5.

Table 5 summarizes the 1976 monthly distribution of soil loss and annual erosion losses for the 6 detailed-study agricultural watersheds. The monthly soil loss value expressed both in tonnes per hectare (ton/ha) and as a percentage of the yearly soil loss is presented for each watershed in Table 5. The variability among watersheds for a particular month or group of months (seasons) is large, mainly due to the variable nature of rainfall energy and intensity. This is clearly demonstrated by the following seasonal distributions of percent soil loss for the 6 watersheds:

	January-April	May-August	September-December
AG-1	56	23	11
AG-3	31	63	6
AG-4	46	48	6
AG-5	29	63	8
AG-10	39	57	4
AG-13	45	42	13

The seasonal range in soil loss is largest for the summer period (23-63%). This is of no surprise, since the summer period is characterized by highly variable rainfall properties (e.g. kinetic energy of raindrops on the soil, intensity of rainfall). The smallest seasonal range was found for the fall period (4-13%).

Table 5 has been summarized in a graph in Figure 6. Figure 6 shows average monthly soil erosion values for the 6 watersheds. The seasonal soil loss contribution is largest during summer (May-August), with over half (55%) of the yearly potential soil loss. About 1/3 of the annual potential soil loss occurs during the January-April period. The remainder took place during the fall period (September-December).

3.4 Data Analysis and Interpretation

The spatial picture of soil erosion reveals that most watersheds falling in the highest erosion-potential category (Table 3) are intensively farmed agricultural areas characterized by cash crop production and a high percentage of arable land (land used for crop production). Watershed AG-7 is a notable exception to these observations and will be discussed later.

Table 5: Summary of 1976 potential sheet and rill erosion losses for 6 agricultural watersheds.

	AG-1		AG-3		AG-4		AG-5		AG-10		AG-13	
MONTH	ton/ha	%	ton/ha	%	ton/ha	%	ton/ha	%	ton/ha	%	ton/ha	%
JANUARY	0.656	8	0.419	3	0.130	5	0.721	3	0.051	3	0.560	5
FEBRUARY	0.734	9	0.671	5	0.202	8	0.637	3	0.060	3	1.754	15
MARCH	2.124	25	1.198	9	0.451	17	3.777	15	0.305	18	1.785	16
APRIL	1.243	14	1.928	14	0.437	16	1.889	8	0.264	15	0.996	9
MAY	0.687	8	0.862	6	0.353	13	2.186	9	0.278	16	0.633	6
JUNE	0.587	7	1.725	13	0.848	31	0.658	3	0.557	32	2.459	21
JULY	1.552	18	5.605	41	0.105	4	5.772	23	0.132	8	1.764	15
AUGUST	0	0	0.467	3	0	0	6.959	28	0.014	1	0	0
SEPTEMBER	0.502	6	0.766	5	0.098	4	0.934	4	0.043	2	0.841	7
OCTOBER	0.409	5	0.132	1	0.049	2	0.679	3	0.019	1	0.405	4
NOVEMBER	0	0	0	0	0	0	0.191	1	0	0	0.218	2
DECEMBER	0	0	0	0	0	0	0	0	0.024	1	0	0
YEAR (1976)	8.496	100	13.773	100	2.673	100	24.402	100	1.746	100	11.417	100

The watersheds having medium erosion potential can be characterized by a mixed farming type of agriculture involving livestock operations in combination with some cash cropping. Agricultural watersheds demonstrating low erosion potential are generally found in the less intensively farmed agricultural regions with livestock farming operations and with a large percentage of meadow crops, permanent pasture and woodland. In addition, watersheds of this category exhibit the lowest percentage of arable land.

The high erosion potential for the Shelter Valley Creek Watershed (AG-7) results from the steep topography and highly erodible loamy sand and fine sandy loam soil. High erosion-potential values are clearly expressed by the large range values for AG-7 in Appendix 2. The watershed land use in AG-7 is analagous, however, to watersheds in the low erosion-potential category.

It should be noted that the three watersheds with highest erosion indices are not necessarily the watersheds contributing the most sediment into stream channels. The soil erosion categories only indicate how vulnerable the watersheds are to sheet erosion losses. Soil particles in the transport phase of the soil erosion process might easily become trapped in depressional areas, grassed waterways, etc., before they reach stream channels. For example, it is quite possible that a watershed in the category for low potential for sheet erosion losses could contribute more sediment into streams than watersheds of the high erosion category because of an efficient transport system from land to stream.

With respect to the effects of agricultural land use on erosion losses, results presented in Table 4 and Figure 5 indicate that maximum potential sheet erosion losses (>6.5 ton/ha/yr) occur in those crops (horticultural, beans, and continuous corn) that have the least soil cover during the growing season. In the soil loss equation the lack of soil cover is reflected in a high C-factor value. Lowest sheet erosion values (<0.5 ton/ha/yr) have been determined for permanent pasture and woodlands, as these land uses provide sufficient soil cover. Crops grown in rotations (corn and small grains) with a green cover crop result in reduced potential erosion losses as indicated by the fact that a corn crop in rotation yields 45% less potential soil erosion than the same corn crop grown continuously (Table 3). The cover crop is believed to reduce erosion losses both by affording protection from rainfall energy and by improving organic matter levels and soil structure. The somewhat lower erosion value (3.5 ton/ha/yr) for tobacco (Table 4), a row crop, is explained by the fact that this crop is generally grown on slightly erodible loamy sand and sandy loam soils on level to gently sloping landscapes. The high value for beans could also be attributed to the fact that they are often grown on highly erodible fine-textured clay loam and clay soils. All other crops are grown on the full range of soil textures and topographies present in the watersheds studied as evidenced by the range values of Table 4. A change in cropping practices in a particular area, e.g. growing more continuous corn at the cost of small grains and hay-pasture, results in significantly higher levels of soil erosion.

Results of the 1976 predicted erosion losses have been compared with the long-term average annual losses (Figure 5). The long-term average annual value of rainfall erosion "R" for the 11 agricultural watersheds is 66. For 1976, the average annual R for the 11 watersheds is 130, almost two times higher. This 1976 rainfall R value explains the higher potential sheet and rill erosion losses for 1976 (Figure 5). However, the contribution from snowmelt accounts for 10-15% of the increase in soil erosion during 1976 compared with the long-term values. Holiday Creek (AG-5) had an extremely high rainfall in 1976 during the months of July and August (Appendix 2) (e.g. on August 13 and 14, 121 mm fell within 27 hours, from which 70 mm fell in a two hour period); hence the very high potential soil loss for this watershed. It is apparent from Figure 5 that due to the variable distribution of rainfall, specific year soil losses (1976) can be highly variable in place and time. Such variability can significantly influence the relative ranking of watersheds compared to a ranking for long-term predicted soil losses.

The temporal aspect of soil erosion on agricultural lands, depicted in Figure 6 clearly demonstrates that the average soil erosion losses for the 6 watersheds are not equally distributed over the year. The temporal picture of potential erosion is one for which soil loss during the summer months is highest. For a clearer perspective, the monthly distributions of rainfall "R" values, expressed as a percentage of the yearly value, are presented in Figure 7 for both the 1976 and the long-term "R". The 1976 "R" distribution, similar to the long-term distribution, indicates that most (65%) of the annual "R" occurs during the high rainfall intensity summer period of May-August. Despite a generally good protective crop cover during this period, the distribution of average 1976 soil erosion losses follows the same pattern of the "R" values with over half of the yearly potential soil loss occurring during the summer period (Figure 6). In other words, the erosive rainfall values are well correlated with the soil erosion values. Rainfall data, such as the ones depicted in Figure 7, may also explain the usually high 1976 soil losses during the winter period January-April, in which 36% of the annual soil loss took place (Figure 6). During this 1976 winter period, "R" accounted for 25% of the yearly value compared with only 10% for an average year (Figure 7). This could also be a reason for high 1976 measured fluvial suspended sediment loads for the watersheds during the same period, as will be discussed in Chapter 4.

3.5 Conclusions

From this chapter, the following conclusions can be drawn:

- Agricultural watersheds with relatively medium to high potential soil loss (AG-1, AG-3, AG-5, AG-13) include intensively farmed agricultural regions where a high percentage of the crops grown are row crops (horticultural crops, beans, continuous corn). The remainder of the agricultural watersheds with a medium to low potential for sheet

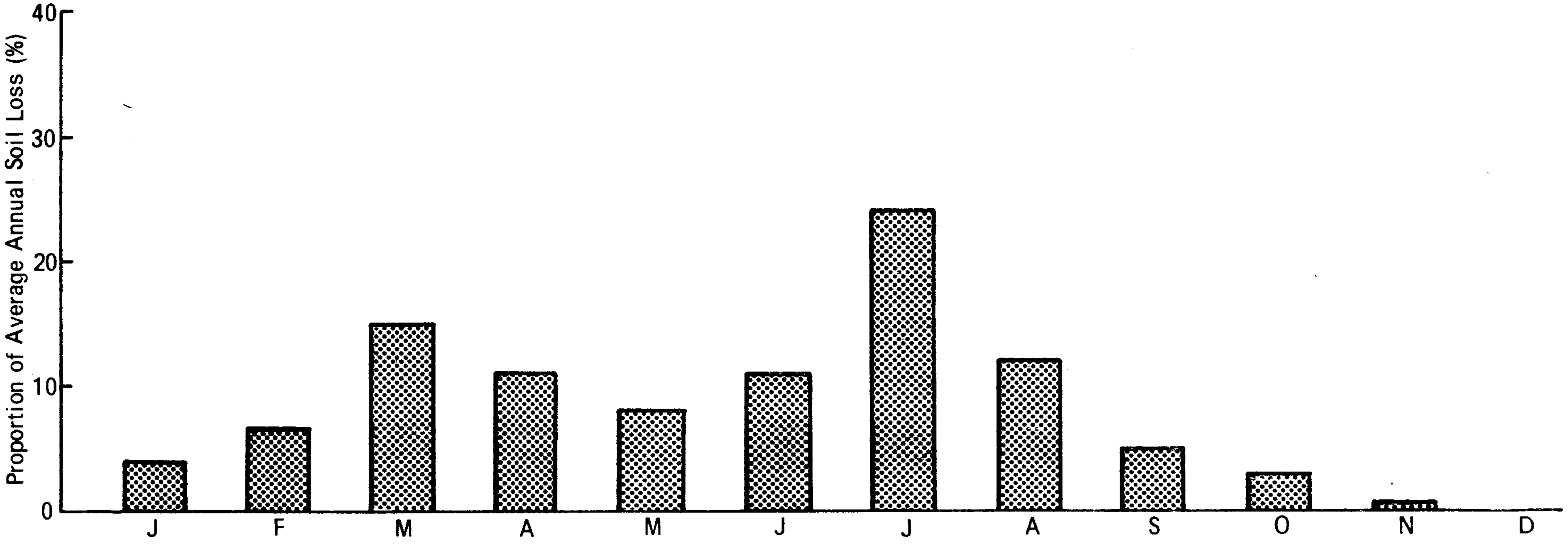


Figure 6: Average Monthly Distribution of 1976 Predicted Soil Erosion Losses for 6 Agricultural Watersheds

erosion losses are found in non-intensively farmed regions with mainly livestock operations, where most crops are grown in a rotation with one or more years of hay-pasture.

- Row crops (including horticultural crops, beans and continuous corn) have the potential to cause more than twice as much soil loss as crops grown in rotation with a green cover crop (such as corn, small grains, tobacco and meadow). Lowest sheet erosion losses may be expected to occur on permanent pasture and woodlands, amounting to less than 0.5 ton/ha/yr.

- Soil erosion losses in 1976 were computed to be higher than longterm average annual soil losses because of higher than average rainfall energy in 1976.

- Soil erosion losses are not equally distributed over the year. The temporal picture of potential soil erosion is one for which soil losses during the summer months are highest. In particular, the high intensity rainfall events that occur during the months of June, July and August account for almost half the total annual erosion potential.

- The 1976 rainfall "R" distribution, similar to the long-term distribution, indicates that most (65%) of the annual "R" occurs during the high rainfall intensity period of May-August. During the 1976 winter period (January-April), however, "R" accounts for 25% of the yearly value compared with only 10% for an average year. This is likely to have an effect on the 1976 measured fluvial suspended sediment loads for the 11 watersheds.

- Long-term average annual sheet erosion losses are not as high as values calculated for the Central United States. The lower estimates are mainly due to the relatively low rainfall "R" values (100) in Southern Ontario compared to the higher rainfall "R" values (175-300) in the Central U.S.A. (Wischmeier and Smith, 1965).

- Unless the efficiency of transport of soil materials from the land base to the stream system is known, potential soil erosion losses are not necessarily indications of sediment yield to the streams.

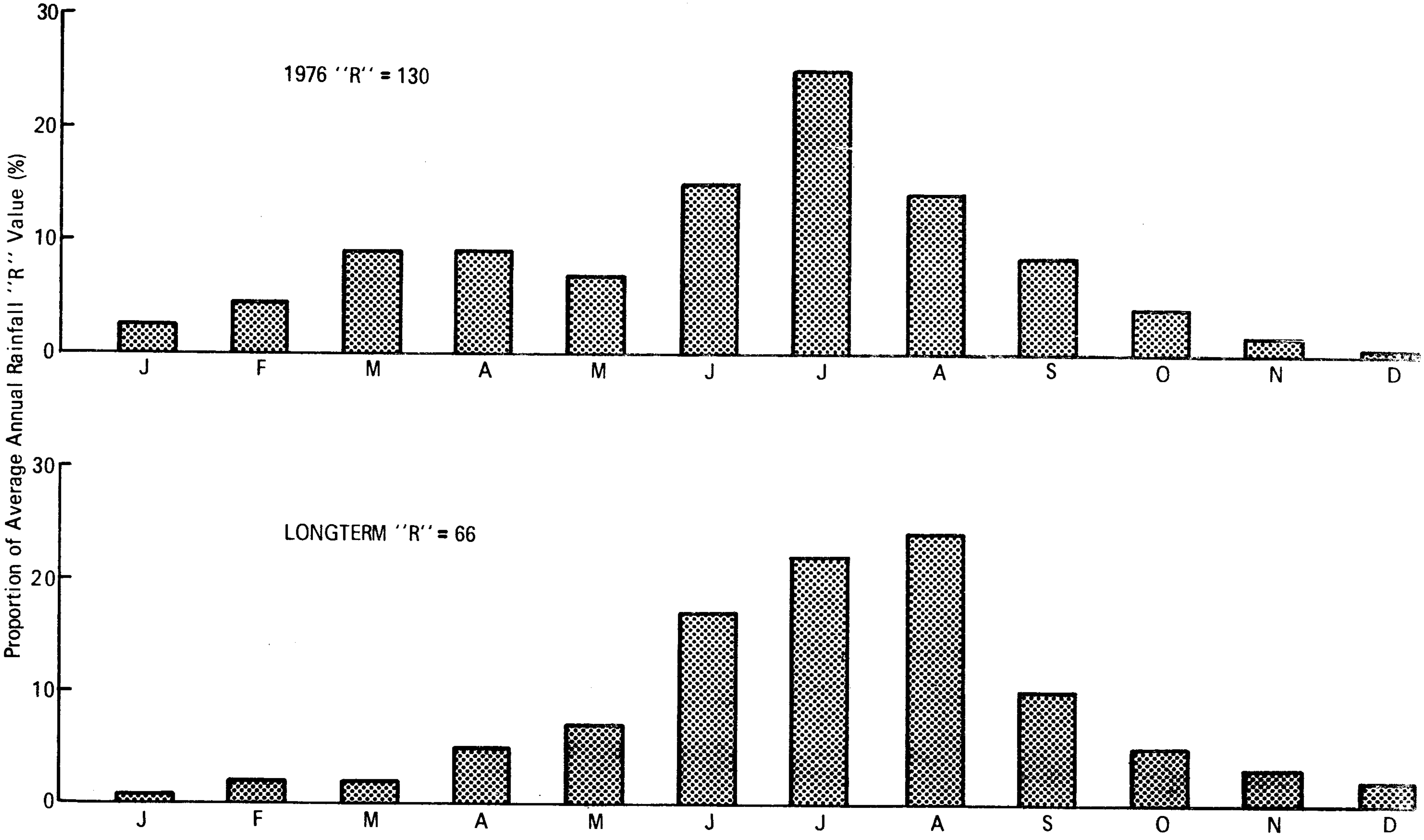


Figure 7: Average Monthly Distribution of Annual Rainfall "R" Values for 11 Agricultural Watersheds

4.0 MEASURED FLUVIAL SEDIMENT LOSSES FROM AGRICULTURAL LAND

4.1 Introduction

The objective of this chapter is to describe the spatial and temporal distribution of suspended sediment loads measured in the 11 agricultural watersheds. Suspended sediment load data were made available by the Ontario Ministry of the Environment (Project #2a) as part of the PLUARG Monitoring Studies.

Monthly and seasonal suspended sediment loads have been determined as well as the importance of extreme storm events relative to annual sediment load values.

Data on measured suspended sediment loads presented in this chapter have also been used for the consideration of sediment delivery ratios (Chapter 5), sediment load prediction models (Chapter 6) and extrapolation purposes (Chapter 9).

4.2 Data Collection Methods

As part of the PLUARG Monitoring Studies, Phase I, the Ontario Ministry of the Environment collected streamflow data and suspended sediment concentrations from stream samples for 11 agricultural watersheds in southern Ontario for the period from Spring 1975 through Spring 1977 (Project #2a). From this information, fluvial suspended sediment loads were calculated by the following four methods:

- Hydrograph integration (Porterfield, 1972)
- Naquadat (Demayo & Hunt, 1975)
- Beale ratio estimator (PLUARG, Quality Control Handbook, 1976, I.J.C., Windsor)
- M.O.E. regression (Onn, et al, 1978)

In addition, stream flow data and sediment concentrations were collected during 1976 for 4 subbasins in the AG-4 and AG-5 watersheds (Project #17). Sediment loads were computed for these subbasins by the

Hydrograph Integration Method. The locations of these subbasins are included in Figures 11 and 12 of Chapter 6.

Monthly suspended sediment loads were computed for 1976 for the 11 agricultural watersheds by the Naquadat Method and for the 4 subbasins by the Integration Method. Seasonal loads, based on the monthly suspended sediment load data, were also determined.

The importance of extreme storm events in comparison to annual sediment loads has also been investigated. An extreme value analysis of sediment load data for southern Ontario rivers (contained in publications entitled Sediment Data in Canadian Rivers and prepared by Fisheries and Environment Canada) and duration curve analysis of loads for these rivers and the PLUARG watersheds served as the base studies.

4.3 Experimental Results

The 1976 sediment loads computed by the four methods noted above are presented in Figure 8. Since the Beale and Naquadat Methods when applied to the estimation of suspended sediment loads produced quite different results, further analysis was conducted in this regard. Detailed analysis has revealed that the hydrograph integration method and the Naquadat Method best reflect the observed suspended sediment load conditions (Appendix 3). In addition, it was found that both methods present the most reliable relative rankings of the watersheds. Consequently, data analysis and interpretation of results have been based on these two methods only. When the watersheds are classified into three sediment load categories according to the integration and Naquadat approaches, AG-1 has an average annual unit area loading of 900 kg/ha; AG-3, 4, 5, 10 and 13 have averages in the order of 350 kg/ha; and AG-2, 14, 6, 7 and 11 have averages of about 80 kg/ha for 1976 load data (Figure 8). The average unit area loadings are representative of rural land and may include both cropland and streambank components.

The unit area loads consider the total load to be apportioned equally over the area of the watershed. The result is a general average unit area load for the particular agricultural "landscape" which is represented by each of the agricultural watersheds. It is the net effect of soil type, climatic zone, combination of crops grown with or without associated livestock enterprises, etc. and gives an approximation of the average agricultural contribution. These unit area loadings also include such nonagricultural interferences as private waste disposal, highways, forestry, etc. which occur within agricultural areas but which cannot be readily separated as to pollutant loads.

Monthly 1976 unit area loads (Naquadat Method) for the 11 agricultural watersheds are presented in Appendix 4. The average monthly suspended sediment loads have been extracted from this data set to reveal the temporal distribution presented in Figure 9. It is apparent from this distribution that most (75%) of the total annual suspended sediment load leaves the mouths of the watersheds during the months of February through April. This temporal

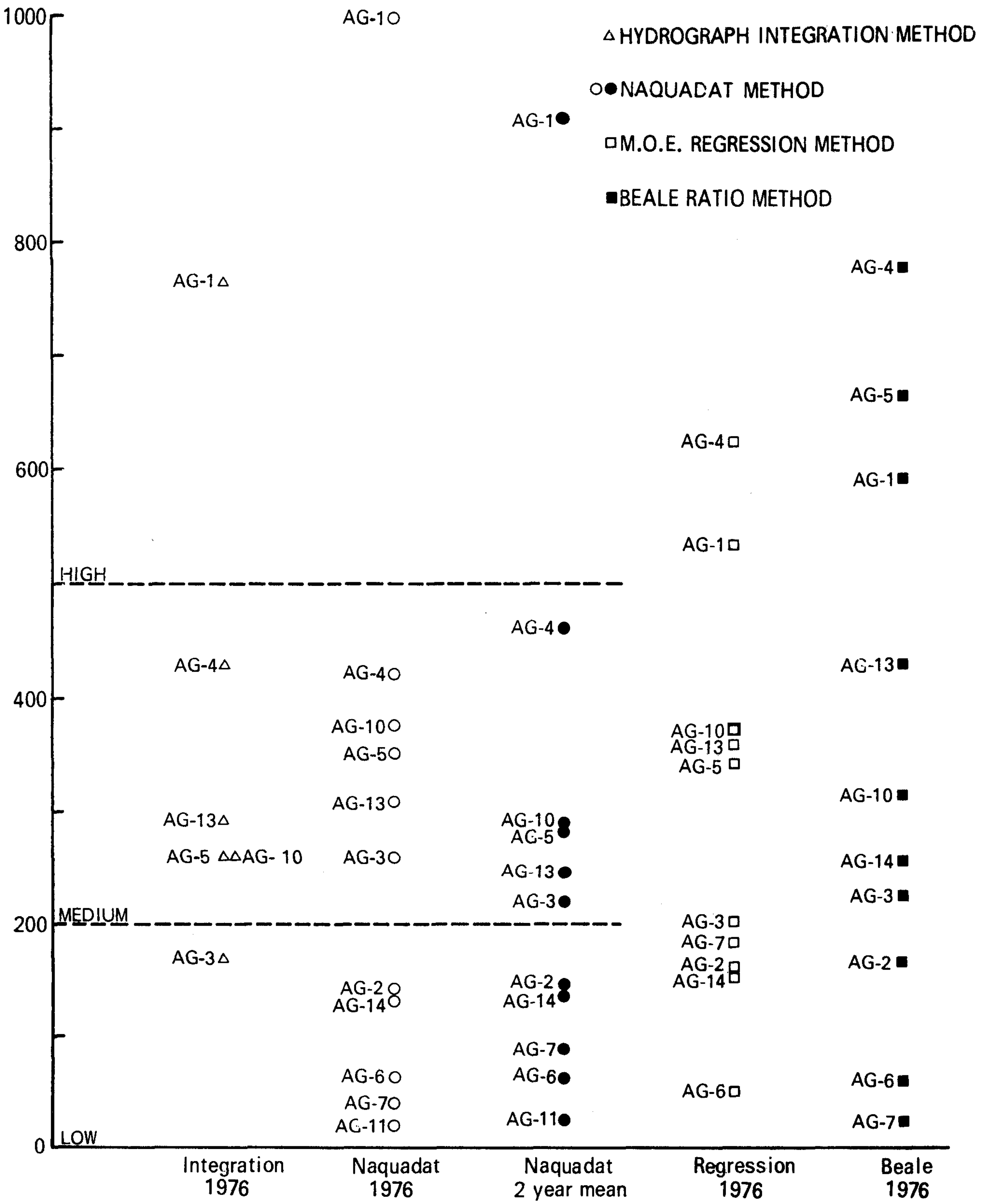


Figure 8: Measured Suspended Sediment Loads for Eleven Agricultural Watersheds Computed by Different Methods

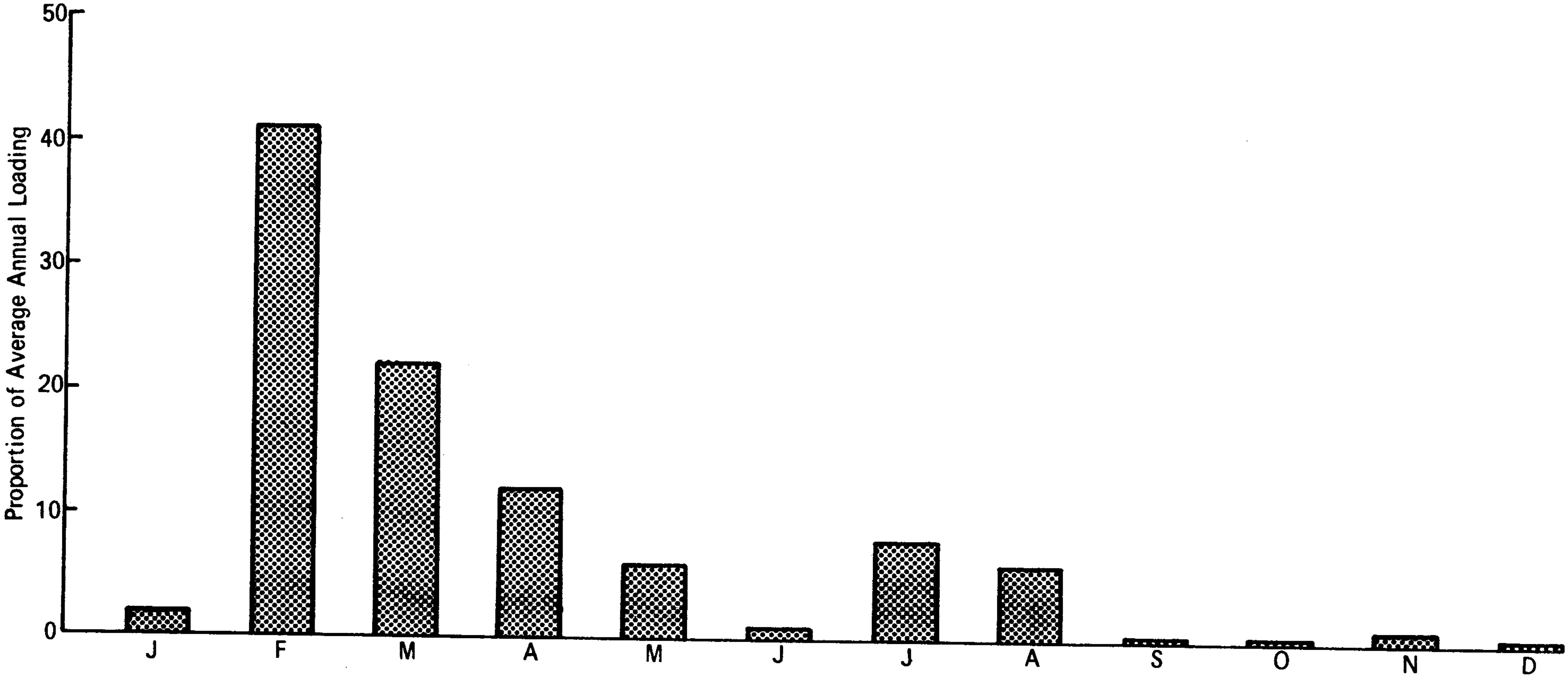


Figure 9: Monthly Distribution of Average Sediment Loadings for the 11 Agricultural Watersheds (Naquadat Method 1976 Data)

pattern closely parallels the seasonal distribution of flood occurrences in southern Ontario and has been confirmed for many rivers draining larger watersheds in the Great Lakes Basin (Dickinson et al, 1975).

Seasonal loads have been determined with the Naquadat approach and Beale ratio estimates for the periods: I. "dormant, cold - warming" - to include the latter part of winter and spring thaw, approximately January through April in southern Ontario; II. "active growing" - to include the active growth period from May through August; and III. "dormant - cooling - cold" - to include that time when little growth and rather little runoff occurs. The seasonal loadings appear to be about the same for both methods of sediment load computation (Table 6).

Monthly suspended sediment loads for about two years of measurements have been calculated by the Naquadat Method and are presented for the 11 agricultural watersheds in Appendix 5 and 6. Average annual sediment loads computed from the data of Appendix 5 were used for data analysis and interpretations in Chapter 5 (Delivery ratios). Also, monthly suspended sediment loads for 4 subbasins in AG-4 and AG-5 (Appendix 4) will be used in the next Chapter 5.

4.4 Data Analysis, Interpretation and Conclusions

Sediment yields for rural watersheds in Southern Ontario range from 100 to 1000 kg/ha/yr (when computed by the Hydrograph Integration and Naquadat Methods). The cause of the observed variations among watersheds can be related to soil and land use factors as well as watershed transport capacity. For example, some areas with highly erodible soils and erosion sensitive land uses (corn) do not always reflect high sediment loading rates (AG-3, AG-7, AG-13). Watershed transport factors such as stream channel buffering (with grass or trees) or stream channel density also have a large effect on determining unit area sediment loadings and in many cases appear more significant than soil erodibility and cropping factors.

Although the relative suspended sediment loadings from the land uses in the 11 agricultural watersheds are not available, the research field observations have revealed that the bulk of the 1976 load emanates from cropland. Further, agricultural practices which leave the soil relatively bare during the snowmelt and spring runoff period contribute heavily to suspended sediment loads.

Since sediment production from grasslands and woodlands is minimal, the primary sources of sediments in the agricultural watersheds are croplands and streambanks. To quantify these two sources, 1976 watershed sediment loads (Naquadat Method) have been partitioned into streambank and cropland erosion components (Table 7). Streambank erosion estimates have been made by Knap (1978). The amount of bank erosion transported downstream has been assumed to include the silt and clay fraction of the eroded

TABLE 6: Seasonal Distribution of Average Sediment Loadings for Agricultural Watersheds

		PROPORTION %		
METHOD OF SEDIMENT LOAD COMPUTATION	NUMBER OF WATERSHEDS	JAN.-APRIL I	MAY-AUGUST II	SEPT.-DEC. III
Naquadat	11	77	21	2
Beale Ratio Estimator	10 (AG-11 missing)	76	20	4

Table 7: Partitioning of 1976 Measured Suspended Sediment Loads in Streambank and Cropland Erosion Components

WATERSHED	1976 SEDIMENT LOADS[1] (kg/ha/yr)	1976 STREAMBANK[2] EROSION ESTIMATES (kg/ha/yr)		NET STREAMBANK AS PROPORTION OF TOTAL SEDIMENT LOAD (%)	CROPLAND AS PROPORTION OF TOTAL SEDIMENT LOAD (100-% STREAMBANK)
		NET	TOTAL[5]		
AG-1	998	223	286	22	78
AG-2	140	10	20[4]	7	93
AG-3	258	24	29	9	91
AG-4	419	137	241	33	67
AG-5	351	5	10	15	85
AG-6	64	10	14[4]	16	84
AG-7	43	7	18[4]	16	84
AG-10	375	17	18	5	95
AG-11[3]	19	65	93	--	--
AG-13	310	41	56[4]	13	87
AG-14	135	75	94[4]	--	--

[1] Using Naquadat Method of sediment load computation

[2] Knap (1978) PLUARG Project, Task C, Activity #6, I.J.C., Windsor

[3] Problems with streamflow measurements account for the very low sediment load

[4] Estimates for original selected watersheds, before relocation

[5] Values used in Chapter 5 for delivery ratio computations

material and is expressed as a percentage of the 1976 measured sediment loads (Table 7). It is evident that sheet and rill erosion from cropland contribute the largest percentage of the sediment (70-100%), while the bank erosion contributes between 0 and 30 percent (Table 7).

Suspended sediments are not transported from rural land uniformly throughout the year. Figure 9 illustrates the monthly distribution of sediment loads from rural lands in Southern Ontario for 1976 data. About 75% of the annual suspended sediment load is transported in February, March and April. These months are characterized by saturated soils, low rainfall energy and snowmelt events. Streambank erosion has also been observed to be maximum in the February-March-April time period.

The fall period is characterized by very low sediment movement in the order of 2-4% of the total yearly sediment load (Figure 9). High energy rainfall events that occur in the summer months can cause high on-site sheet erosion losses but because the soils are generally not water-saturated at this time of the year, infiltration of water is enhanced and the transport of eroded sediments is minimized. However, during 1976, about 20% of the yearly watershed sediment load was measured to leave small agricultural watersheds during the summer period (Table 6). This rather high percentage was caused by a relatively wet summer with frequent rainstorm activities (Appendix 3).

Examination of the temporal suspended sediment pattern in the agricultural watersheds in relation to patterns in the larger Southern Ontario watersheds referred to by Dickinson, et al. 1975, reveals a number of observations regarding the role of extreme events. Fifty percent of the suspended sediment load is transported in less than five percent of the time; and eighty percent of the load is transported in less than 10 percent of the time. Further, severe runoff events can flush as much or more suspended material out of the watersheds in a few days than is moved through the systems during an average year. For example, a suspended sediment storm event of ten year return period (i.e. the average period of time between events of sediment load equal to or greater than the specified storm event load is ten years) can be expected to contribute approximately three times the average annual load; the fifty year event contributes approximately ten times the average annual load; and the one hundred year event contributes sixteen times the annual load. These figures reveal that, the suspended sediment loading contributed to the lakes by events exhibiting return periods of less than 10 years is approximately equivalent to the loading contributed by events with return periods between 10 and 100 years. These results have important implications for the consideration of remedial measures.

5.0 SUSPENDED SEDIMENT DELIVERY RATIOS

5.1 Introduction

Stream sediment loads are dependent both on gross erosion in the watershed and on the transport capacity of the watershed. Generally only a part of the material eroded from upland areas in a watershed (gross soil erosion) is carried out of the watershed by streams. A variable proportion of the eroded materials may be deposited during the transport phase of the soil erosion process. The relationship between annual sediment yield and the annual gross erosion has often been expressed as the sediment delivery ratio. The greater this sediment delivery ratio (D.R.) for any given watershed, the greater is the sediment yield and the less is the amount of eroded material deposited within the watershed. The delivery of materials from point of origin (e.g. the field surface) to the stream is highly variable.

The objective of this chapter is to present and discuss sediment delivery ratios for the eleven agricultural watersheds in Southern Ontario and for some selected subwatersheds in AG-4 and AG-5. Information from the previous two chapters on erosion losses (Chapter 3) and on measured suspended sediment loads (Chapter 4) has been used for the computation of 1976 and average annual delivery ratios. Monthly and seasonal delivery ratios are also investigated. Computed watershed delivery ratios are compared with published delivery ratios based on drainage basin size. Both computed and published delivery ratios are used in Chapter 6 for sediment load prediction purposes.

5.2 Data Collection Methods

Watershed sediment delivery ratios can be expressed by the relationship;

Delivery ratio (D.R.) = Sediment load/Gross erosion

Gross erosion is the sum of all different sources of erosion taking place in the watershed and may include sheet and rill erosion, gully erosion, streambank erosion, roadside erosion and flood plain scour. It has been indicated previously in Chapter 4 that the two major sources of erosion producing sediments into the stream system of the eleven agricultural watersheds are sheet and rill erosion and streambank erosion. Consequently, these sources of erosion have been considered to be the gross erosion components for sediment delivery ratio computations.

Watershed delivery ratio computations were initially performed for the year 1976, since only one year of reliable measured suspended sediment loads was available. Sediment loads derived by the Naquadat Method of computation were used in this and subsequent delivery ratio computations. Sheet and rill erosion values for 1976 (from Chapter 3) and streambank erosion estimates for the agricultural watersheds (Knap, 1978; Table 7, Chapter 4) have been used to estimate delivery ratios by means of the relationships:

1976 D.R. = (1976 Sediment load - Streambank erosion)/1976 Sheet and rill erosion.

Streambank erosion estimates have been based on the assumption that the fine fraction (% silt + % clay) of the eroded material has been transported by the stream, which in fact represents the net streambank contribution. Therefore, this streambank erosion value has been subtracted from the 1976 sediment load.

In addition to net streambank erosion estimates, total streambank erosion values are available (Knap, 1978; Table 7, Chapter 2). Together with the 1976 sheet and rill erosion source, these values represent the gross erosion component. With this second approach, 1976 watershed sediment delivery ratios have been computed by the following equation:

1976 D.R. = 1976 Sediment Load /1976 Sheet and rill erosion + Total streambank erosion)

At a later stage during this investigation, 2 years of sediment load (Naquadat Method) became available (Appendix 6). In addition to this information, average annual sheet and rill erosion losses (Chapter 3) and total streambank erosion estimates were used to compute average annual watershed delivery ratios for the 11 agricultural watersheds by the following equation:

Average annual D.R. = Mean sediment load /Average annual sheet and rill erosion + Total streambank erosion)

This last approach has also been applied to delivery ratio computations for subbasins in the Grand and Saugeen Rivers (Chapter 9).

Based on 1976 monthly sheet and rill erosion estimates (Chapter 3) and 1976 monthly sediment load data (Naquadat Method), monthly delivery ratios have been computed for AG-1, AG-3, AG-4, AG-5, AG-10, AG-13 watersheds and for 4 subbasins in AG-4 and AG-5. Monthly streambank erosion estimates were not available; and therefore, have not been included in these computations. The equation used is of the form:

1976 Monthly D.R. = 1976 Monthly sediment load/1976 Monthly sheet and rill erosion

Monthly D.R. have been further analysed for seasonal trends.

Since the agricultural watersheds are all small in comparison to other PLUARG watersheds and since they are essentially free of lakes, dams and other impoundments, it is reasonable to assume that delivery of conservative materials through the watershed stream systems is relatively complete (e.g. Delivery ratio = 1). In other words, materials entering the stream system are assumed to be transported in full through the watershed.

5.3 Experimental Results

Results of the sediment delivery ratio computations for the 11 agricultural watersheds by three different approaches are presented in Table 8, column A, B and C. In most cases, small differences in delivery ratios are found between the three methods of computations. Relatively low delivery ratios (0-10%) have been determined for AG-3, AG-5, AG-6, AG-7, AG-11, AG-13 and AG-14 watersheds. Medium delivery ratios (11-20%) are shown for AG-1, AG-2 and AG-4 watersheds and the only basin with a relative high delivery ratio (>20%) is AG-10. No notable differences are observed between A and B methods of computation.

Published delivery ratios from two sources are also presented in Table 8 for comparison purposes. Column D represents D.R. based on drainage basin size. This method is extensively used by the United States S.C.S. (1971), but originally developed by Roehl (1962). These published D.R. have been further modified according to the predominant soil materials in the watershed (S.C.S., 1973b). The latter set of published D.R. is shown in column E of Table 8. For most of the watersheds, D.R. of column D are higher than any of the computed ones, except for basins AG-2, AG-4 and AG-10. The range of these published D.R. based on drainage basin size is smallest (14-19%), but the ones modified for soil textures (column E) have the largest range (7-38%) for between watersheds.

Results of D.R. computations for some subbasins of AG-4 and AG-5 are presented below:

Table 8: Results of Sediment Delivery Ratio Computation Using Different Methods of Computation and Published Delivery Ratios (%)

Watershed	Computed			Published	
	A	B	C	D	E
AG-1	9	11	13	16	30
AG-2	13	14	15	14	7
AG-3	1.7	1.9	4	15	20
AG-4	11	14	21	19	23
AG-5	1.4	1.4	7	18	21
AG-6	1.3	1.5	1.6	15	19
AG-7	0.6	1.0	1.5	15	9
AG-10	21	21	26	18	37
AG-11	---	0.4	5	18	38
AG-13	2.4	3	3	19	10
AG-14	2.0	4	10	16	30
Range	0.6-21	0.4-21	1.5-26	14-19	7-38

A: D.R. = 1976 sediment load, (Naquadat Method - Net streambank erosion)/ 1976 Sheet and rill erosion
B: D.R. = (1976 Sediment Load, Naquadat Method)/(1976 Sheet and rill erosion + Total streambank erosion)
C: D.R. = 2 year mean sediment load, Naquadat Method/(Average annual sheet and rill erosion + Total streambank erosion)
D: S.C.S. (1971) Based on drainage basin size
E: S.C.S. (1973) Based on drainage basin size, modified for soil texture

	Subbasin	Area (km^2)	Delivery Ratio (%)	
			Computed	Published (S.C.S., 1973)
AG-4	W	2.7	43	29
	W	25.6	21	19
AG-5	H	7.4	9	23
	H	7.4	10	23

Results of monthly D.R. computed for AG-1, AG-3, AG-4, AG-5, AG-10 and AG-13 and for some subbasins of AG-4 and AG-5 watersheds are presented in Table 9. Delivery of sediments to the streams is highest during the spring period (January-April).

5.4 Data Analysis, Interpretation and Conclusions

Results of the sediment D.R. computations have indicated no notable differences between methods A and B, based on 1976 data (Table 8). The D.R. based on 2 years of sediment load data (method C) are consistently higher than the 1976 values. Differences between 1976 and the 2 year average D.R. values however, are small for most watersheds. These differences are caused by factors such as:

(a) lower average 2 year annual soil losses compared with the 1976 soil loss values (Table 3, Chapter 3) and (b) lower average sediment loads compared with the 1976 sediment load data.

The latter is a less significant factor.

In most basins, streambank erosion contributes little to the delivery ratio computations by the three methods, since it represents a relatively small proportion of the total sediment load (Table 7, Chapter 2). Exceptions to this observation are evident in AG-10 and AG-4 watersheds, where 22 and 33% respectively of the 1976 sediment load have been attributed to net streambank erosion (Table 7, Chapter 2).

The reason for very low 1976 D.R. values in AG-5 (1.4%) is the very high potential sheet and rill erosion losses for this year (24 ton/ha), compared with a long-term average soil loss of 3.7 ton/ha/yr. Hence, the higher long-term D.R. of 7%. The same reasons are offered for the higher average D.R. in AG-3 and AG-14 (column C).

Of all the watersheds, the highest D.R. values computed by all 3 methods occur for AG-10 (>20%). These values are probably the result of relative low sheet and rill erosion losses during 1976 (1746 kg/ha) and low long-term annual losses (1055 kg/ha) relative to suspended sediment loads of 375 kg/ha for 1976 and a 2 year load of 290 kg/ha/yr.

Table 9: Monthly sediment delivery ratios for 1976 in 6 agricultural watersheds (%)

MONTH	AG-1[1]	AG-3[1]	AG-4[1]	AG-5[1]	AG-10[1]	AG-13[1]	W_1[2] AG-4	W_2[2] AG-4	H_1[2] AG-5	H_2[2] AG-5
JANUARY	0.8	1	0.4	1	12	2	0	5	0	0
FEBRUARY	114	6	7	7	92	7	0	26	0	1
MARCH	5	5	80	1	29	6	1402	574	91	163
APRIL	1	4	3	0.2	42	5	90	86	1	2
MAY	1	0.6	4	0.5	39	2	0	7	1	1
JUNE	1	0.03	0.4	0.03	0.1	0.3	0	1	0	0
JULY	2	1	2	2	3	0.03	0	1	9	19
AUGUST	0	1	0	2	3	0	0	0	39	26
SEPTEMBER	0.01	0.04	1	0.04	1	0.04	0	1	1	1
OCTOBER	0.01	0.2	6	0.1	4	0.2	0	2	0	0
NOVEMBER	0	0	0	4	0	0.1	0	2	1	1
DECEMBER	0	0	0	0	6	0	0	0	0	1
YEAR (1976)	9	1.7	11	1.4	21	2.4	43	21	9	10

[1] $$\text{D.R.} = \frac{\text{1976 Sediment load (Naquadat method, Appendix 4)}}{\text{1976 Sheet and rill erosion losses (Chapter 1)}} \times 100$$

[2] $$\text{D.R.} = \frac{\text{1976 Sediment load (Integration method, Appendix 4)}}{\text{1976 Sheet and rill erosion losses (Chapter 1)}} \times 100$$

Since the computations of average annual watershed sediment delivery ratios (column C) are based on more substantial data than the 1976 D.R., the former D.R. are preferred. However, limitations of using only 2 years of measured suspended sediment load data for D.R. computations should be recognized. Single year delivery ratios (e.g. 1976) can be highly variable and can deviate significantly from average annual D.R. (Table 8). Hence, they are not useful for sediment load prediction purposes.

Published D.R. in column D of Table 8 were originally computed for many drainage basins in the south-east part of the United States in 5 major physiographic areas (Roehl, 1962). The D.R. were plotted as a function of drainage area, decreasing slightly with increasing drainage area (Roehl, 1962). For most of the agricultural watersheds, published D.R. in column D are higher than the long-term computed ones in column C, except for AG-2, AG-4 and AG-10.

Published D.R. are about an order of magnitude higher (15%) for AG-6 and AG-7 compared with computed average annual D.R. of 1.6 and 1.5% respectively. Delivery ratios of column D, modified for soil texture (column E), cause even larger differences between computed and published D.R. except for basins with sandy soils, like AG-2, AG-7 and AG-13.

The computed average annual watershed sediment D.R. (column C), the line of best fit, and the line representing published D.R. (column D; S.C.S., 1971), are presented graphically in Figure 10 as a function of drainage area. D.R. for subbasins of AG-4 and AG-5 are also included in this figure.

The apparent trend has been reported several times for basins of similar size in the U.S. (Roehl, 1962; Spaberry _et al_, 1960). The wide scatter of data points is expected for basins with variable soils, topography and cropping practices, located in different climatic regions of southern Ontario. Hence, the low R^2 value of 0.26 for the equation of the best fitting line.

Monthly delivery ratios of Table 9 indicate highest D.R. during the spring period, in particular during the months of February, March and April. D.R. exceeding 100% are not uncommon during this period, since in addition to sheet and rill erosion, other sources of sediment reaching the stream system may be present. For example, it has been determined that streambank erosion is highest during the same period (Knap, 1978). D.R. during the summer and fall periods are insignificant compared with the spring period.

On the basis of all soil erosion and suspended sediment findings in the detailed studies, a qualitative picture has been developed for comparison of the 11 agricultural watersheds (Table 10). For this purpose, four watershed parameters have been categorized into a high, medium and low category. These parameters are:

(a) Average annual potential soil losses (Table 3, Chapter 3);

(b) Mean stream sediment loads, Naquadat Method (Table 8, Chapter 4);

(c) Computed delivery ratios (Table 8, column C, Chapter 5);

(d) Buffering capacity of the streams (field observations).

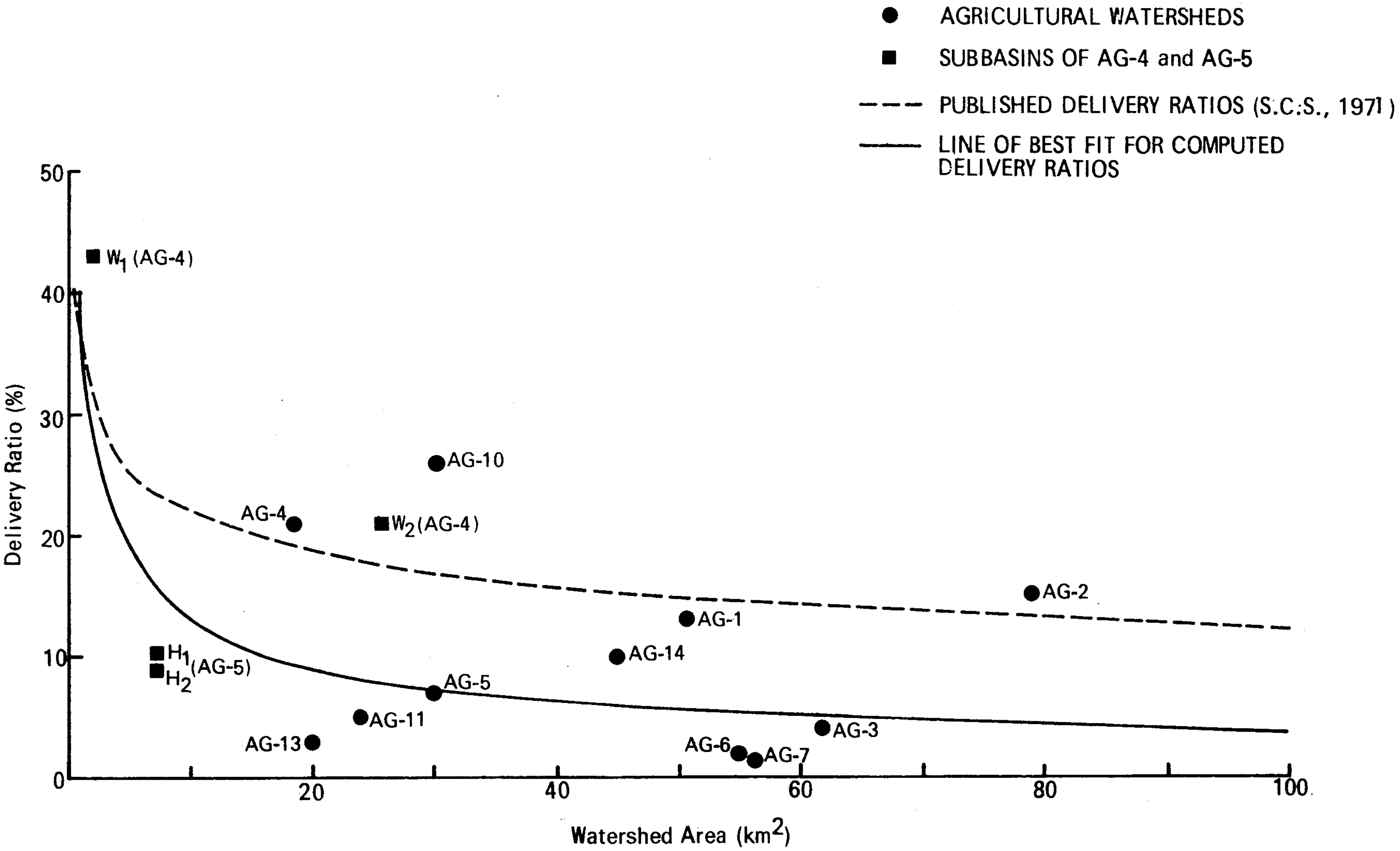


Figure 10: Computed Sediment Delivery Ratios for Agricultural Watersheds in Southern Ontario

The past parameter refers to the effectiveness of vegetation (or the lack of it) adjacent to the streambanks for trapping sediments in surface runoff before reaching the stream system.

Some interesting observations can be made from this table. Most basins with a low delivery ratio (AG-3, AG-5, AG-6, AG-7, AG-11, AG-14) have a high buffering capacity, except for AG-13 which has a medium buffering capacity. It appears that buffering can significantly affect the watershed delivery ratio. Even with a high or medium average annual soil loss, stream sediment levels are found to be low when the basin has a high capacity to buffer sediment before reaching the stream system (AG-6,AG-7, AG-11). Relatively high sediment loads are observed for those watersheds which exhibit low buffering capacity (AG-1, AG-4).

Table 10: The Relationship of Stream Buffering to Soil Erosion Losses

WATERSHED	AVERAGE ANNUAL[1] SOIL LOSS	MEAN SEDIMENT[2] LOAD	DELIVERY[3] RATIO	BUFFERING[4] CAPACITY ADJACENT TO STREAMS
AG-1	High	High	Medium	L
AG-2	Low	Low	Medium	H
AG-3	Medium	Medium	Low	H
AG-4	Low	Medium	High	L
AG-5	Medium	Medium	Low	H
AG-6	Medium	Low	Low	H
AG-7	High	Low	Low	H
AG-10	Low	Medium	High	H
AG-11	Medium	Low	Low	H
AG-13	High	Medium	Low	M
AG-14	Low	Low	Low	H

[1] Table 3, Chapter 3

[2] Figure 8, Chapter 4

[3] Table 8, Column C, Chapter 5

[4] From field observations

6.0 PREDICTION OF STREAM SEDIMENT LOADS

6.1 Introduction

The objectives of this chapter on suspended sediment load predictions are twofold:

- to present results of the application of existing methods and models for sediment load prediction in agricultural watersheds in Southern Ontario, and
- to compare predicted sediment loads with measured sediment loads.

The study approach has involved the use of three existing models for sediment load prediction. The models, which originated in the United States, have been modified for local conditions in Ontario.

The SEDEL Model (S.C.S., 1975) has been used to predict sediment loads in subbasins and the entire basins of AG-4 and AG-5 watersheds. This computerized model, which can be used for drainage areas of any size, does not require extensive data inputs. Hence, it is easy to understand and to apply.

The second model, mathematically more sophisticated than the previous one, is the Sediment Transport Computer Model (Kling and Olson, 1974). The model has also been applied to the subbasins and entire basins of AG-4 and AG-5 watersheds. This detailed model considers sediment routing over the landscape into the stream system. In addition to sediment prediction, the model can be used for identifying sediment producing areas. In Chapter 8, the same model is used for evaluating the effects of simulated land use changes on sediment loads in AG-4 and AG-5 watersheds. Due to the detailed data input required, this model is time consuming and expensive in computer time.

The simplest approach for sediment load prediction uses published sediment delivery ratios and gross erosion values computed with the universal soil loss equation. This method has been applied to the 11 agricultural watersheds.

Mean measured sediment loads (Naquadat Method; Chapter 4) for the study watersheds have been used to evaluate the models.

Finally, the models have been assessed as a basis for the extrapolation of sediment load information to other areas in the Canadian Great Lakes Drainage Basin.

6.2 SEDEL Model

6.2.1 Background

The SEDEL (or Sediment Delivery) model was originally developed by the Soil Conservation Service of the U.S.D.A. as a procedure for developing sediment storage requirements for reservoirs (S.C.S., 1975). The model was developed for use on drainage basins of any size and may be expressed:

$$Y = E\ (DR)$$

where:

Y = Sediment yield,
E = Gross erosion, and
DR = Sediment delivery ratio.

The gross or total erosion in a drainage basin is the summation of all water erosion occurring in the watershed. It includes sheet and rill erosion and channel-type erosion (gullies, valley trenches, streambank erosion, etc). The sediment delivery ratio, which is the proportion of gross erosion that is transported into the streams after deposition of the eroded material has been accounted for, is derived from a curve depicting its relationship with drainage basin size. This curve, originally developed by Roehl (1962) has been extensively used by the United States Soil Conservation Service (S.C.S., 1971). The product of gross erosion and sediment delivery ratio provides the predicted sediment yield.

6.2.2 Data Collection Methods

The Universal Soil Loss Equation is used to predict average yearly sheet and rill erosion losses from agricultural lands for use in the SEDEL Model. Since the model employs generalized values for the different factors in the U.S.L.E. for each land use or cropping-management category, the greatest precision is obtained when the model is applied to small drainage areas. Consequently drainage basins are often subdivided into subbasins to allow for a more detailed data input. When information on other sources of erosion are not available (such as in this study) the gross erosion term in the model equals average yearly sheet and rill erosion losses.

The agricultural watershed data have been analyzed by electronic computer using the SEDEL computer program made available by the Soil Conservation Service in Hyattsville, Maryland.

The SEDEL Model has been tested for the 5 subbasins of AG-4 Canagagigue Creek (Figures 11A, 11B) and the universal soil loss equation has already been described in Chapter 1. Average values have been used for the K, L and S factors for each land use category (crop-rotation) encountered in the subbasins. Based on subbasin size, a sediment delivery ratio has been obtained for each subbasin and for the entire watershed from the sediment delivery ratio-drainage area curve (S.C.S., 1971).

6.2.3. Experimental Results

Results of applying the SEDEL Model to AG-4 and AG-5 watersheds are presented in Tables 11 and 12 respectively. Average yearly gross erosion values, delivery ratios, predicted and measured sediment loads are shown in these two tables.

Delivery ratios for AG-4 range from 20-29% and for AG-5 from 17-31%. Predicted unit area loadings range from 456 to 1053 kg/ha/yr for AG-4. For AG-5, this range is much larger, from 73 to 3267 kg/ha/yr.

6.2.4 Data Analysis, Interpretation and Conclusions

Certain shortcomings of the SEDEL Model approach to sediment load prediction, mainly with respect to delivery ratios, have been discussed by Boyce (1975). In spite of these shortcomings, the results indicate that the model is successful in predicting watershed sediment load for AG-4 (456 kg/ha/yr) when compared with a 2 year measured load of 475 kg/ha/yr (Table 11). The delivery ratio of 20% obtained from the curve (Roehl, 1962) and a computed "long-term" watershed delivery ratio of 21% (Table 8, Chapter 3) are in very close agreement. For AG-5, however, the watershed delivery ratio obtained from the curve (17%) used in the model is more than twice as high as a computed "long-term" delivery ratio of 7% (Table 8, Chapter 5). This difference results in a high predicted sediment load (737 kg/ha/yr) as compared with a measured load of 279 kg/ha/yr. If the computed delivery ratio of 7% is used, sediment prediction for AG-5 amounts to 303 kg/ha/yr, which is very close to the measured value of 279 kg/ha/yr. These results suggest that a delivery ratio purely based on drainage basin size (Roehl, 1962) is not always a realistic ratio for agricultural basins of this area (Chapter 4).

While there may be many explanations for the above results, one factor that has been observed to be an important aspect in the transport of sediments from the land base into the stream system is the sediment buffering capacity of permanent vegetation strips along streams. This factor has not been considered in the published delivery ratio curve (Roehl, 1962). As has been discussed earlier, in Chapter 2, the buffering capacity in AG-5 is much higher than in AG-4 and this capacity is clearly reflected in the lower computed delivery ratio value of 7% for AG-5.

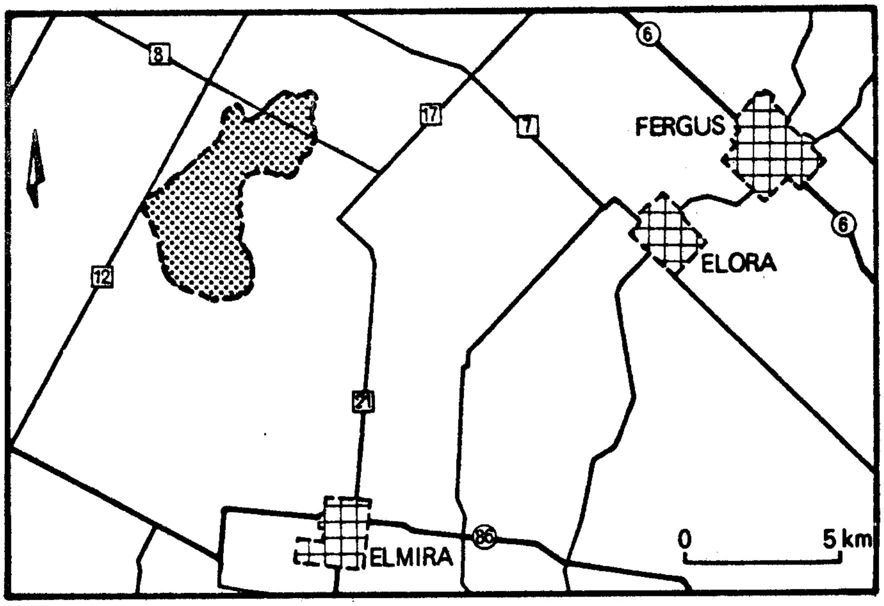


Figure 11 A: Location of AG-4 (Canagagigue Creek) Watershed

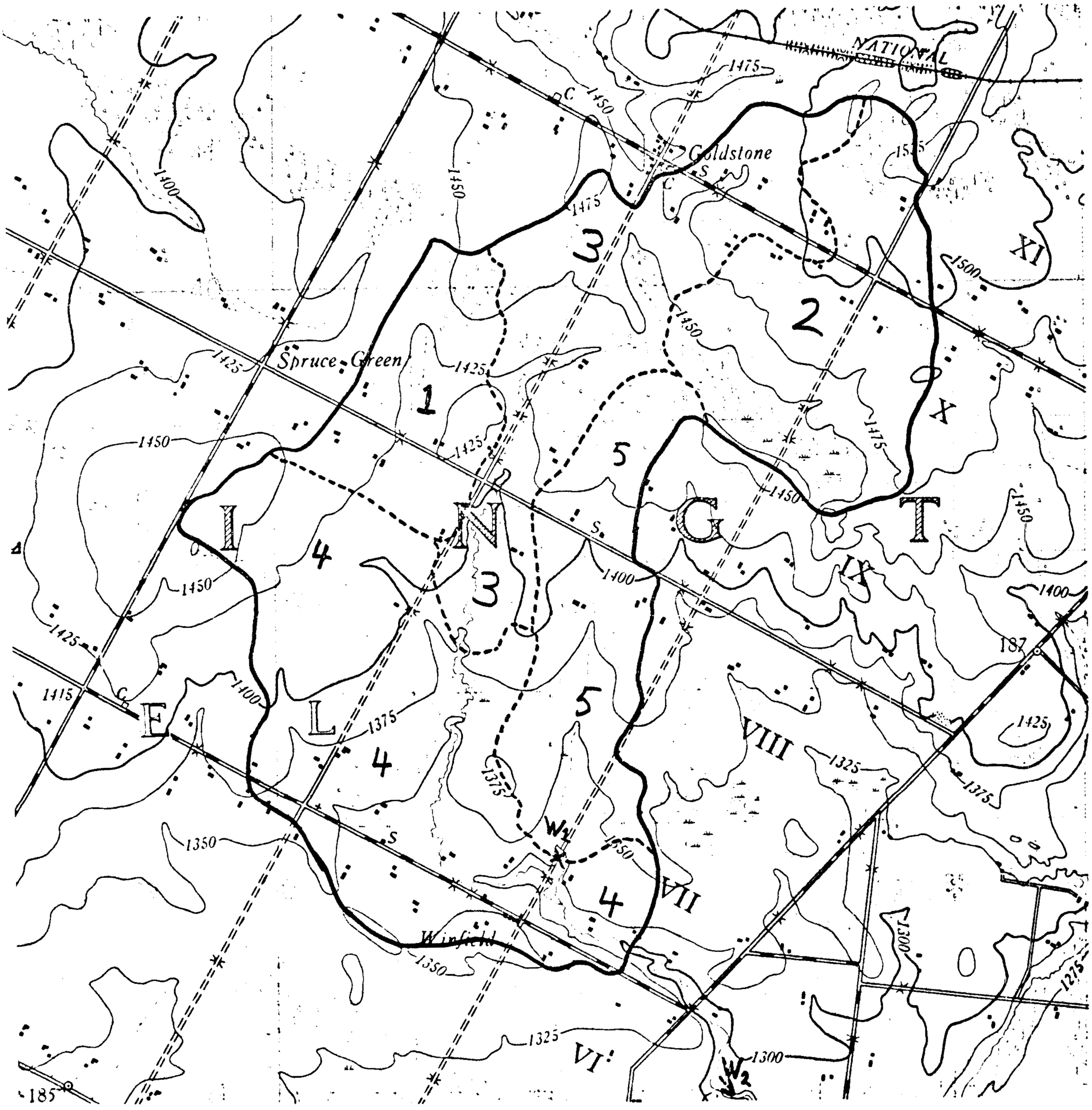


Figure 11B: Location of Subbasins in AG-4 (Canagagigue Creek) Watershed

Table 11: The prediction of stream sediment loads in AG-4 (Canagagigue Creek) with the SEDEL Model

				SEDIMENT LOAD	
SUBBASIN	DRAINAGE AREA (ha)	GROSS EROSION (ton/ha/yr)	DELIVERY RATIO (%)	PREDICTED (ton/ha/yr)	MEASURED (ton/ha/yr)
1	267	2.345	29	0.602	--
2	409	3.023	26	0.785	--
3	369	1.765	27	0.478	--
4	709	4.387	24	1.053	--
5	267	2.566	29	0.743	0.895[1]
AG-4	2021	2.279	20	0.456	0.475[2]

[1] Measured suspended sediment load (1976), computed by "Integration" Method

[2] Measured suspended sediment load (2 year mean; May 1, 1975 - April 30, 1977) computed by "Naquadat" Method (Appendix 4)

Table 12: The prediction of stream sediment loads in AG-5 (Holiday Creek) with the SEDEL Model

SUBBASIN	DRAINAGE AREA (ha)	GROSS EROSION (ton/ha/yr)	DELIVERY RATIO %	SEDIMENT LOAD PREDICTED (ton/ha/yr)	SEDIMENT LOAD MEASURED (ton/ha/yr)
1	273	3.237	29	0.937	0.329 [1]
2	463	3.050	26	0.792	
3	197	3.388	31	1.051	0.366 [1]
4	544	6.212	25	1.553	
5	332	7.286	28	2.040	--
6	342	11.669	28	3.267	--
7	437	4.474	26	1.164	--
8	343	3.503	28	0.980	--
AG-5	2931	4.330	17	0.737	0.279 [2]

[1] Measured suspended sediment load (1976), computed by "Integration" Method

[2] Measured suspended sediment load (2 year mean; May 1, 1975 - April 30, 1977) computed by "Naquadat" Method (Appendix 4)

A similar pattern is observed for some of the subbasins of AG-4 and AG-5 for which measured sediment loadings are available. For AG-5, subbasins 1-2 and 3-4 should be combined when comparing predicted values with measured values. Indeed, when the lower computed delivery ratios for these subbasins are used (Chapter 5) instead of published ratios (Table 11 and 12), predicted sediment loads are much closer to the 1976 measured sediment loads.

In conclusion, the SEDEL Model can be used successfully as a method for predicting stream sediment loads for small agricultural watersheds in southern Ontario, if locally developed delivery ratios are used instead of published U.S. ratios. The accuracy of the model to predict sediment loadings for large river basins in Ontario has not been ascertained.

6.3 Sediment Transport Computer Model

6.3.1 Background

The Sediment Transport Computer Model has been developed by Kling and Olson (1974) to predict long-term average yearly amounts of suspended sediment from a drainage area. The basic framework for the model is provided by the Universal Soil Loss Equation (Wischmeier and Smith, 1965), used to compute potential gross soil losses from different land uses. The complete methodology is presented and a brief outline of the approach is given below.

The drainage area is subdivided into numerous cells or landscape segments using a grid system which adequately represents land units that control the movement of sediment. It is assumed that each cell drains either entirely into only one of the surrounding eight cells or into a defined stream. Data input, data processing and results of the model are all based on this cell by cell approach. A transport factor (T), very similar to a sediment delivery ratio, is incorporated into the model to account for the intervening deposition of sediment between the initial point of soil detachment and the final sediment yield into a stream. T is expressed as the percentage of eroded material that will be carried across a cell from the cell upslope and assumes values $0<T<1.0$. T is calculated for each change in slope steepness from cell to cell, according to the following equations for two adjoining cells (J, 14) and (L, 14):

If slope cell (J, 14)< slope cell (L, 14),

then:

$T = \text{cell }(J, 14) / \text{cell }(L, 14)$

but if slope cell (J, 14) >slope cell (L, 14)

then: $T = 1.0$

where: cell (J, 14) = slope factor of immediate cell and

cell (L, 14) = slope factor of adjacent upslope cell

An ephemeral drainage network system is developed for combining the cell to cell routing of eroded material across the landscape to the point (end-cell) where it arrives at a defined drainage channel or stream. As soon as sediment enters the stream system, the model assumesT = 1.0. This means that the summation of all the amounts of sediment entering the streams at different locations is equal to the total amount of sediments leaving the drainage area.

Gross erosion is calculated for each cell after the cell to cell routing of the eroded material has been established. The net erosion is an estimate of sediment yield from an area or ephemeral drainage net (group of cells) to the stream. Net erosion is calculated for each ephemeral drainage net sequentially downslope by accumulating the sum of gross erosion or the product of gross erosion times the respective transport factor. The following equation is an example of this calculation at a point J in an ephemeral drainage net (Kling and Olson, 1974):

$$\underset{(\text{cell } J)}{\text{Net erosion}} = \Big(\underset{(\text{cell } J)}{\text{Gross erosion}} + \underset{(\text{cell } J,J+1)}{\text{"T"}}\Big) \times \underset{(\text{cell } J+1)}{\text{Net erosion}}$$

Total net erosion of the drainage area is calculated by summing the net erosion values from all ephemeral drainage nets. The partial effect is a value which approximates the actual net yield that is transported to the stream from each cell. It is the proportion of the gross erosion that reaches the streams after deposition of sediment during overland flow has been accounted for.

A mapping program, incorporated into the model, can produce maps that show on a cell by cell basis the spatial distribution of different preselected sediment load categories. By this method, erosion areas within a watershed can easily be located and identified on the map, e.g. areas with high sediment outputs.

The model also provides a method for evaluating the effects of changes in land use and cultivation practices on sediment losses, which will be discussed in Chapter 8.

6.3.2 Data Collection Methods Sediment Load Prediction

The model has been used to predict average yearly sediment yields in two detailed study watersheds: AG-4 Canagagigue Creek and AG-5 Holiday Creek. The basic input data for the model have been obtained from four map sources:

- topographic maps;
- soil maps (Acton, 1978);
- land use maps (Chapter 3);
- drainage maps (from field observations).

All maps have been redrawn to a common mapping scale of 1:15,840 (4" - 1 mile). A ½ inch (12.5 mm) cell grid has been superimposed over the maps, so that each cell is 4 ha (10 acres) in size at the 1:15,840 map scale. For each cell, the following information has been recorded:

- cell identification number;
- subbasin number (Figure 11 and 12);
- soil erodibility "K" values for each soil type;
- slope length "L" measured on topographic maps from the centre of each cell downslope to boundary of first mapped slope change;
- slope gradient "S" of the soil mapping units;
- cropping-management factor "C" for different land uses;
- distance from channel or stream;
- drainage vector, indicating in what down-slope cell the up-slope cell drains, determined by a combination of drainage maps, topographic maps and detailed information on contributing areas (Chapter 5).

Long-term average yearly rainfall "R" factors for both watersheds have been determined from the R-factor map for southern Ontario (Figure 2). To verify the model results, measured sediment loads for a 2 year period (Naquadat) have been used for AG-4 and AG-5 basins.

Sediment Mapping

Data input for the sediment mapping program has consisted of results of the final analysis of the Sediment Transport Computer Model using a modified T-factor. The model has been programmed to punch data cards for use in the mapping routine with the following information:

- cell identification
- gross erosion
- net erosion and
- partial effects. The net sediment load of each cell is classified in one of the following sediment producing classes:

  0, 0-4, 4-8, 8-16, 16-24, 24-32, 32-40, 40 ton.

By assigning each erosion class a symbol, a map showing the spatial distribution of net sediment loads is generated by the Computer Model.

6.3.3. Experimental Results

Sediment Load Prediction

In order to have the Sediment Transport Computer Model successfully operated at other facilities using data from a different geographic area, a number of test runs have been necessary, resulting in modifications and adjustments of some factors in the model

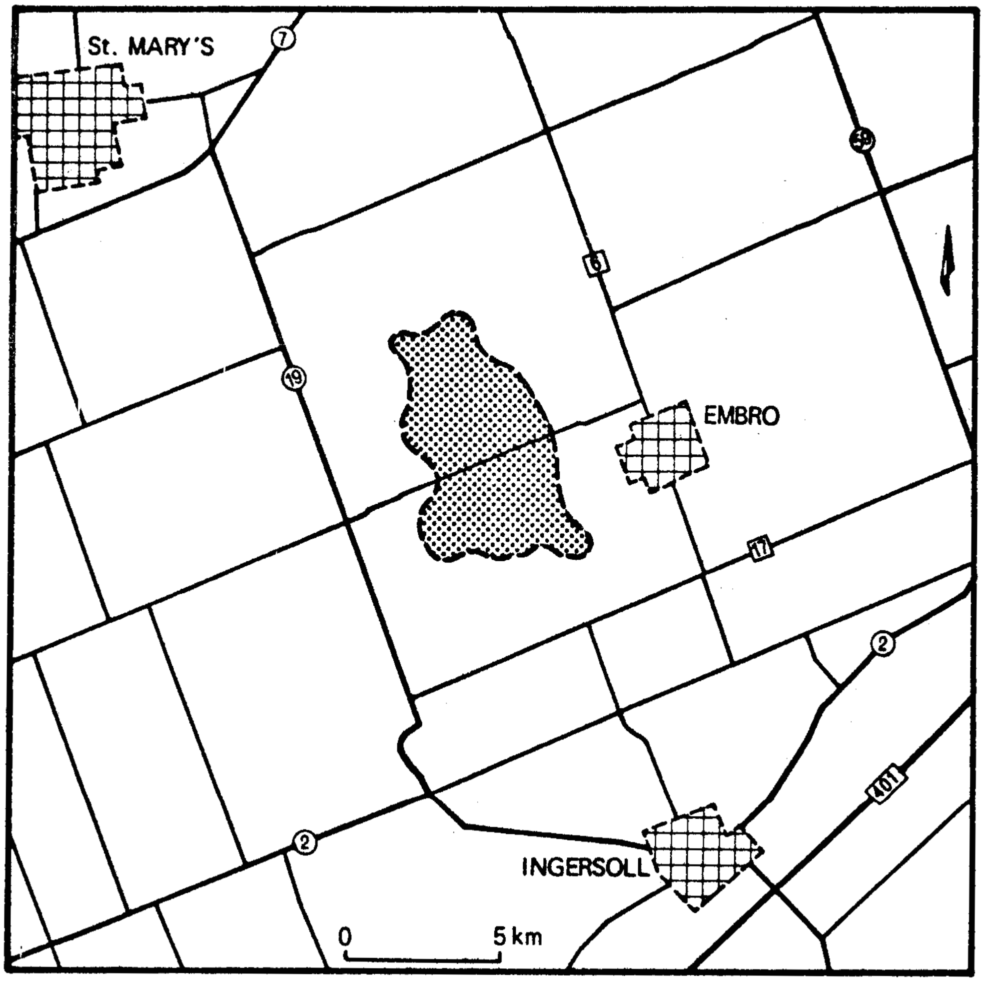


Figure 12A: Location of AG-5 (Holiday Creek)

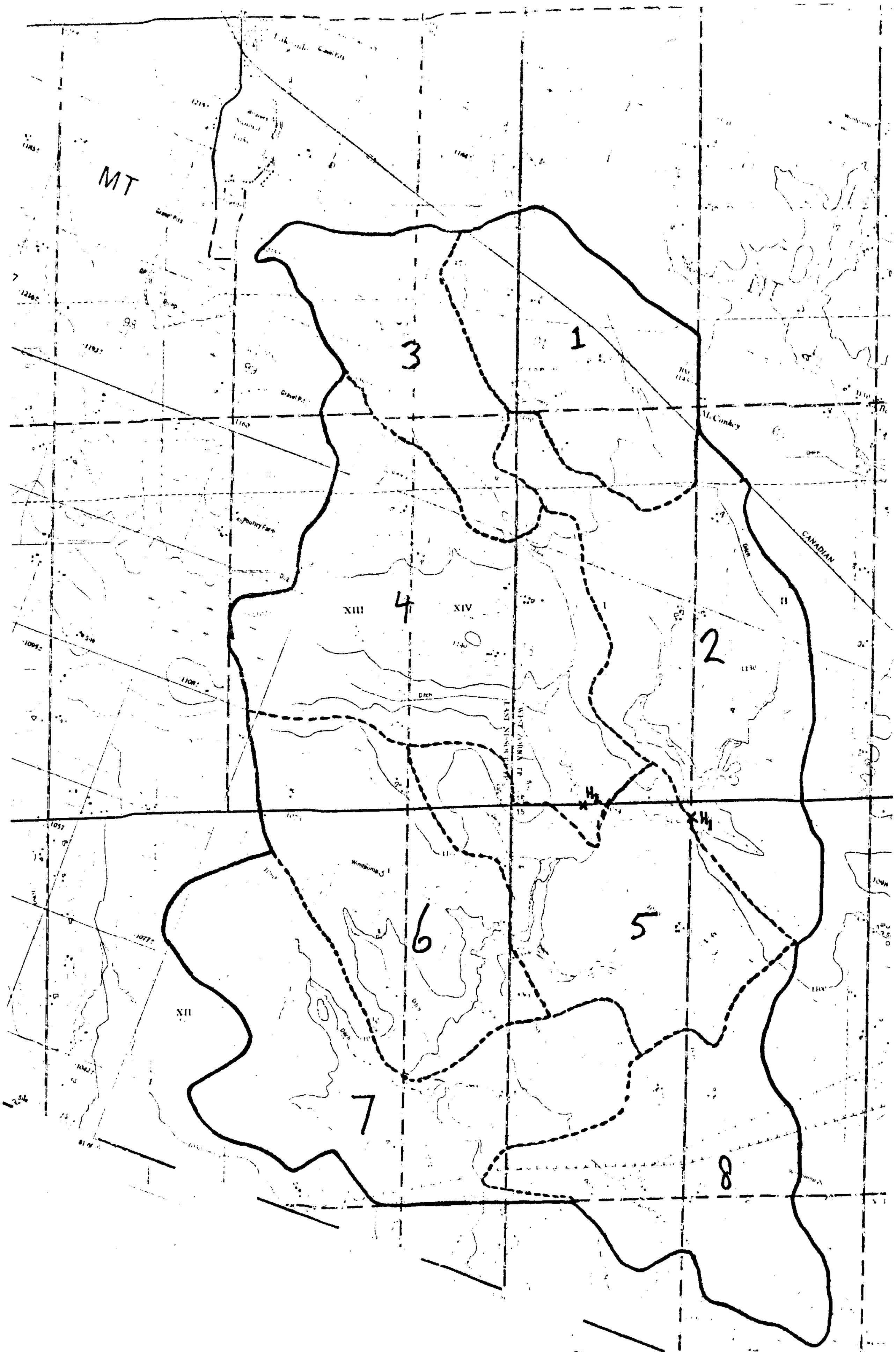


Figure 12B: Location of Subbasins in AG-5 (Holiday Creek) Watershed (e.g. rainfall, "C" values, slope). The model has been used for sediment yield prediction for subbasins of AG-4 and AG-5 watersheds with the results presented in Table 13 and 14. Location of subbasins is depicted in Figures 11 and 12.

Both Tables 13 and 14 indicate high predicted sediment loads compared with the measured loads. In other words the total amount of sediment entering the stream system, expressed as a percentage of gross erosion, indicates average T-values (or: watershed delivery ratios) of 75% and 46% for AG-4 and AG-5 respectively. For basins of this size (20-30 km^2) these delivery ratios are considered too high compared with either delivery ratios reported in the literature (Roehl, 1962) or with computed delivery ratios (Chapter 5). A close look at the data reveal that the transport factor "T" has been estimated to be too high. Such estimation has been repeatedly caused by either a minimum or a lack of slope variation when the eroded material moves overland from cell to cell. Indeed, for both watersheds, the majority of the land slopes have been mapped in the 0.5 - 2% and 2 - 5% classes (Acton, 1978). Also, a lack of variation in slope is reported by Kling and Olson (1974) as one of the reasons the model over-estimates measured sediment yield for a drainage basin with less distinct topography than the area for which the model has been developed. To eliminate this problem, a modified T, developed by the original authors, can be generated. This modification is based on a distance function whenever slope gradients of two adjacent cells in the ephemeral drainage networks are the same. For these conditions, T is set equal to an inverse function of the cell distance from a defined drainage channel. Results of the model with the modified T-factor are also presented in Table 13 and 14. It is obvious from these Tables that compared with the T factor based purely on slope, the modified T results in large reductions in the predicted sediment loads for AG-4 and AG-5, (51% and 66% respectively). Available measured sediment loads are also presented in Tables 13 and 14.

Sediment Mapping

Computer mapping results of eight categories of partial effects (net sediment yield transported to the stream from each cell) for AG-4 and AG-5 are presented in Figures 13 and 14. From these figures, the proportion of total watershed area for each category has been determined and is expressed as a percentage. The distribution is graphically summarized in Figures 15 and 16.

Since the total amount of sediment output from the entire basins AG-4 and AG-5 can be predicted by the model, the proportion of total watershed loading for each sediment producing category can be computed. A first approximation has been made by multiplying the sediment producing class

TABLE 13: The Prediction of Stream Sediment Loads in AG-4 (Canagagigue Creek) With the Sediment Transport Computer Model

SUBBASIN	DRAINAGE AREA (ha)	PREDICTED SEDIMENT LOAD "T" BASED ON SLOPE (ton/ha/yr)	PREDICTED SEDIMENT LOAD MODIFIED "T" (ton/ha/yr)	MEASURED SEDIMENT LOAD (ton/ha/yr)
1	267	1.873	0.648	---
2	409	1.988	0.790	---
3	369	2.048	1.206	---
4	709	2.847	1.437	---
5	267	2.250	1.174	0.895[1]
AG-4	2021	2.320	1.125	0.475[2]

[1] Measured suspended sediment load (1976), computed by "Integration" method

[2] Measured suspended sediment load (2 year mean; May 1, 1975 - April 30, 1977) computed by "Naquadat" method

TABLE 14: The Prediction of Stream Sediment Loads in AG-5 (Holiday Creek) With the Sediment Transport Computer Model

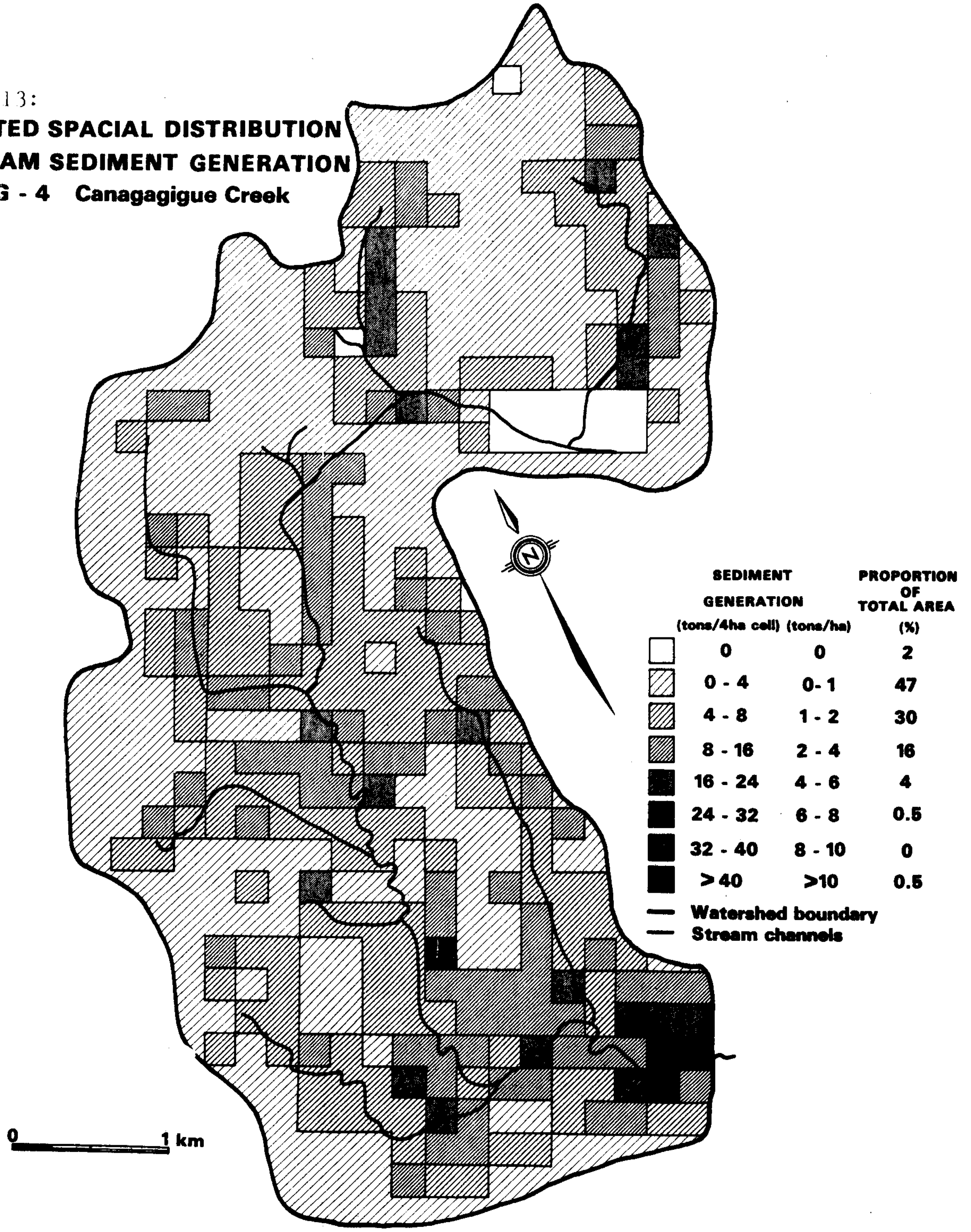
SUBBASIN	DRAINAGE AREA (ha)	PREDICTED SEDIMENT LOAD "T" BASED ON SLOPE (ton/ha/yr)	PREDICTED SEDIMENT LOAD MODIFIED "T" (ton/ha/yr)	MEASURED SEDIMENT LOAD (ton/ha/yr)
1	300	1.538	0.283	0.329
2	462	1.884	0.739	
3	223	1.619	0.249	0.366
4	539	3.391	1.065	
5	340	2.168	1.081	---
6	352	2.372	0.723	---
7	445	1.885	0.482	---
8	369	3.033	1.245	---
AG-5	3030	2.327	0.776	0.279

[1] Measured suspended sediment load (1976), computed by "Integration" method

[2] Measured suspended sediment load (2 year mean; May 1, 1975 - April 30, 1977) computed by "Naquadat" method

Figure 13:

PREDICTED SPACIAL DISTRIBUTION OF STREAM SEDIMENT GENERATION IN AG - 4 Canagagigue Creek



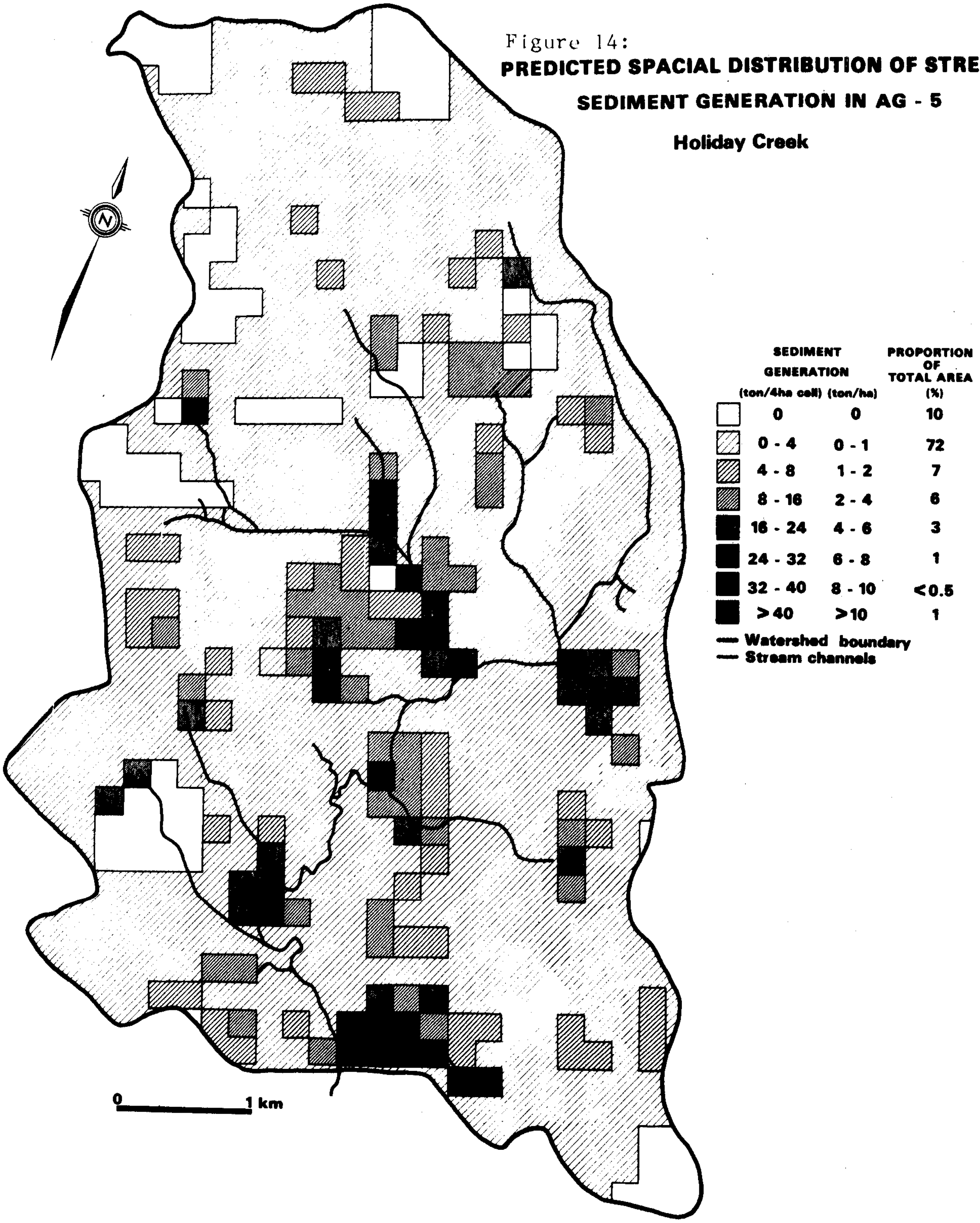


Figure 14:
PREDICTED SPACIAL DISTRIBUTION OF STREAM SEDIMENT GENERATION IN AG - 5
Holiday Creek

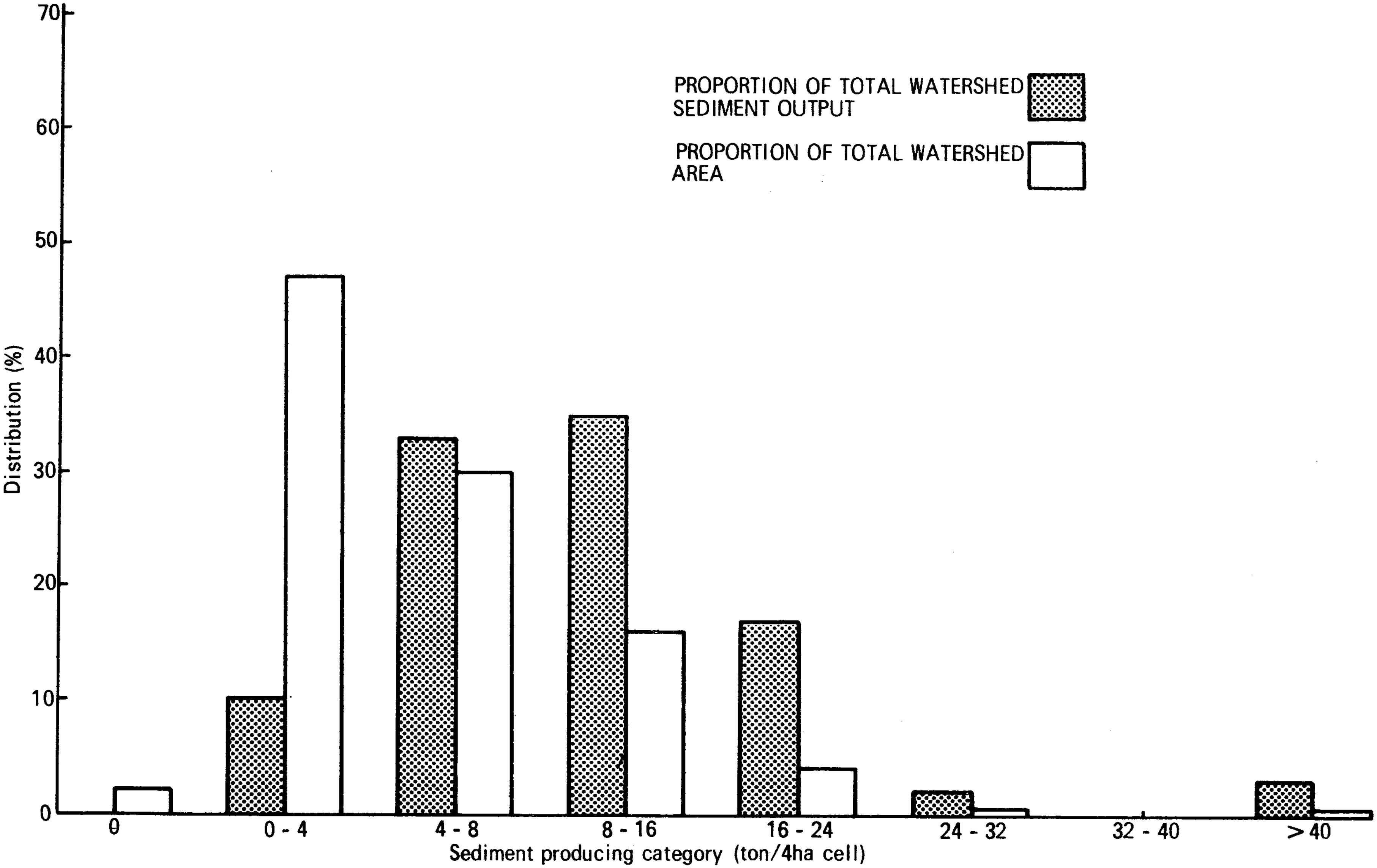


Figure 15: Distribution of the Magnitude and Watershed Area of Eight Sediment Producing Categories in AG-4 (Canagagigue Creek) Watershed

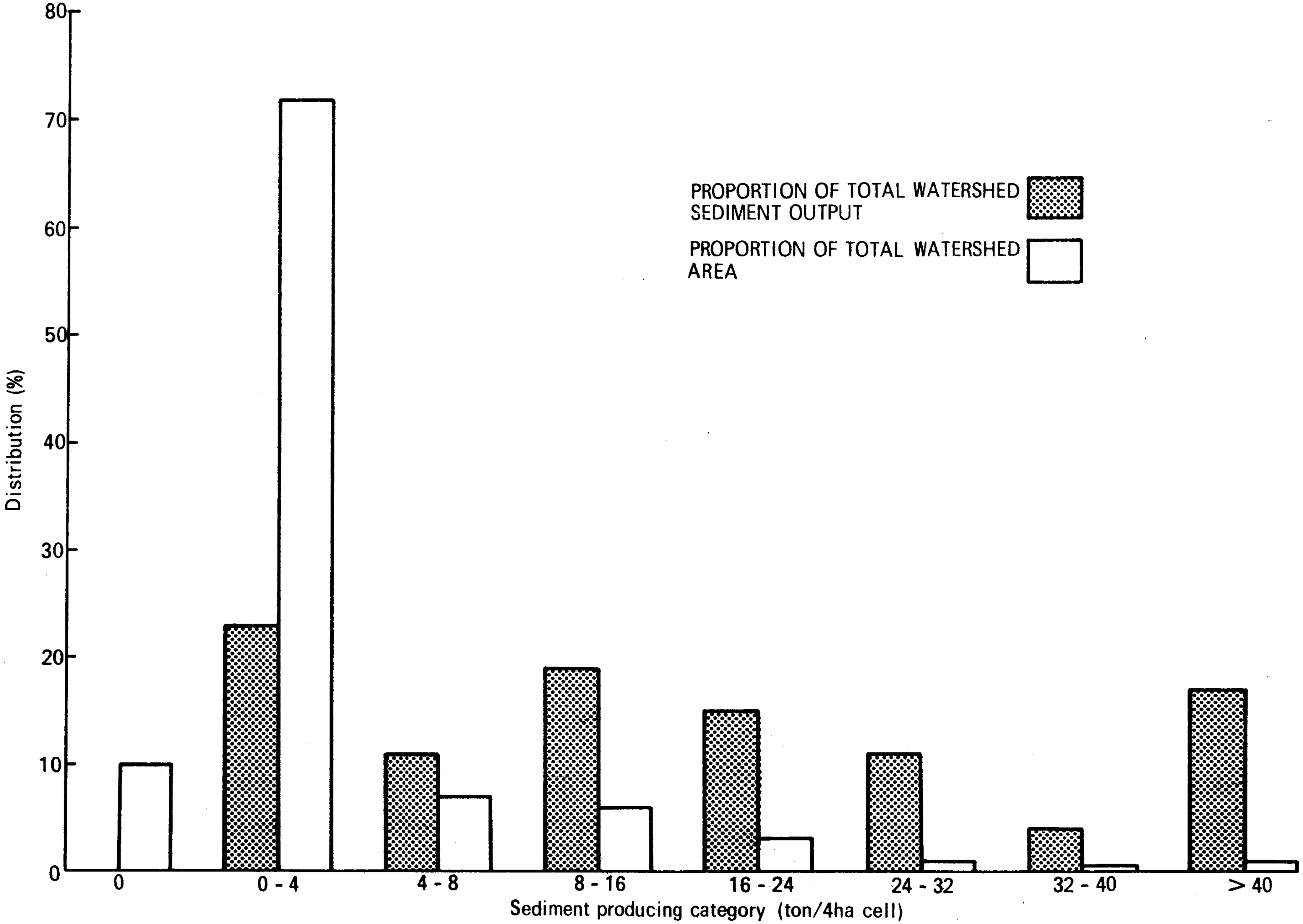


Figure 16: Distribution of the Magnitude and Watershed Area of Eight Sediment Producing Categories in AG-5 (Holiday Creek) Watershed

midpoints by the corresponding land area for each class. However, the sum of the computed loadings for the eight classes is much higher than the total sediment output predicted by the model. Inspection of the data reveals that the number of cells within each category is not normally distributed, but positively skewed. To account for this skewness, the class midpoints minus 1 have been used to compute the distribution of total watershed sediment production. With this adjustment the summation of computed loadings by category equals the total predicted values. The percentage of the annual sediment load contributed by each of the eight sediment load class are also depicted in Figure 15 and 16 for AG-4 and AG-5 respectively.

6.3.4 Data Analysis, Interpretation and Conclusions Sediment Load Prediction

On a watershed basis, Tables 13 and 14 indicate that the Sediment Transport Computer Model overestimates measured sediment loads by 137 and 178% for AG-4 and AG-5 respectively. Several reasons for this overprediction by the model are suggested.

(1) Sediment loadings predicted by the model are long-term average yearly sediment values. Long-term refers to the rainfall factor "R", which represents an average yearly value of at least 22 years of record. The long-term predicted sediment loads are then compared with 2 years of measured sediment load data. Since rainfall amounts and intensities can be very variable from year to year, the limitations of this comparison are apparent.

(2) The size of data acquisition cells of 4 ha (10 acres) has been initially chosen to minimize variation within cells compared to variation among cells. It is quite possible however, that variability among cells in AG-4 and AG-5 watersheds is less than was anticipated. This has already been observed with respect to slope, affecting the T-function in the model. The original author has indicated that selection of the initial cell size is very critical to the successful application of the model to a watershed (Kling, 1974). Time limitations have prevented experimentation with different cell sizes to improve model results.

The limited amount of measured sediment load data in Tables 13 and 14 indicates that at least on a subwatershed basis, the model seems to be predicting sediment loads better than for the entire watersheds. Predicted values, however, are consistently higher than the single year of measured sediment loads.

Sediment Mapping

The Sediment Transport Computer Model can also be used to make valuable interpretations with respect to the mapping of sediment producing areas.

A comparison of AG-4 and AG-5 (Figures 15 and 16) indicates a marked difference in the distribution of total watershed sediment production and watershed area for each of the 8 sediment producing categories. The highest sediment producing categories (>24 ton/4ha cell) account for about 32% of the total watershed sediment output in AG-5, but only for 5% in AG-4. The 3 highest categories, however, occupy only about 2% of the total watershed area in both AG-4 and AG-5. Most of the sediments (85%) in AG-4 are produced in the 3 sediment categories that range from 4-24 ton/4ha cell; while for AG-5, 45% of the total watershed sediment output comes from the same 3 categories. These 3 categories occupy half of the total watershed area in AG-4, but only 16% of the watershed in AG-5. In AG-5 (72%) has been mapped as the 0-4 sediment producing category, while the same category in AG-4 amounts to 47% of the watershed area.

Some implications of these results with respect to reducing watershed sediment loads are discussed later in Chapter 8.

The maps (Figures 13 and 14) also provide information as to the spatial distribution of sediment producing cells in relation to the drainage network. Where are the high sediment producing cells and low producing cells located with respect to proximity to streams and waterways? To answer this question, each sediment producing category (Figures 15 and 16) has been analysed to determine the number of cells that are either dissected by the stream system or cells that are directly bordering the streams. The number of cells have been expressed as a percentage of the total number of cells in each category. Results of this analysis are summarized in Tables 15 and 16.

For both watersheds AG-4 and AG-5, the general trend is that the higher the sediment producing category, the more cells in each category are located at or near the stream system. In other words, the higher the sediment producing areas are found closest to the streams, Tables 15 and 16 show that for each of the sediment producing classes, a consistently larger proportion of the area in each class is located in close proximity to streams in AG-4 than in AG-5. Tables 15 and 16 also indicate that in AG-5, 48% of the area producing 4 ton/4ha cell (1 ton/ha/yr) of sediment is located in close proximity to the streams. For AG-4, this amounts to 55%. The entire area (100%) producing an average of more than 6 ton/ha/yr (24 ton/4na cell) of sediments for AG-4 and AG-5 is located at or near stream channels and waterways.

The following conclusions are offered regarding the application of the Sediment Transport Computer Model:

Table 15: Cells in proximity to streams for AG-4 Canagagigue Creek

SEDIMENT PRODUCING CATEGORY (ton/cell)[1]	TOTAL NUMBER OF CELLS	CELLS DISSECTED BY OR DIRECTLY BORDERING STREAMS	
		NUMBER	% OF CATEGORY TOTAL
0- 4	234	30	13
4- 8	149	77	52
8-16	79	41	52
16-24	21	17	81
24-32	2	2	100
32-40	0	0	100
>40	2	2	100
ALL CELLS > 4	253	139	55
ALL CELLS > 8	104	62	60
ALL CELLS >16	25	21	84
ALL CELLS >24	4	4	100

[1] Each cell has an area of 4ha

Table 16: Cells in proximity to streams for AG-5 Holiday Creek

SEDIMENT PRODUCING CATEGORY (ton/cell)[1]	TOTAL NUMBER OF CELLS	CELLS DISSECTED BY OR DIRECTLY BORDERING STREAMS	
		NUMBER	% OF CATEGORY TOTAL
0- 4	535	--	--
4- 8	51	10	20
8-16	45	22	49
16-24	19	12	63
24-32	10	10	100
32-40	3	2	66
>40	10	10	100
ALL CELLS > 4	138	66	48
ALL CELLS > 8	87	56	64
ALL CELLS >16	42	34	81
ALL CELLS >24	23	22	96

---

[1] Each cell has an area of 4ha

- The model consistently overpredicts sediment loads in AG-4 and AG-5 watersheds with little or no calibration. One of the major limitations of validating long-term predicted model results is the 1 or 2 years of measured suspended sediment loads available.
- If cell sizes are carefully tuned to physiographic variability in the watershed for which the model is being used, the Sediment Transport Computer Model appears to have potential for future use in watersheds of similar or smaller sizes.

Despite the overprediction of sediment by the model, relative comparisons of results of sediment producing areas are very useful. Results indicate that:

- The higher sediment producing areas in both watersheds (AG-4, AG-5) are located closest to the streams. This observation is more pronounced in AG-4 than in AG-5 watershed.
- Highest sediment producing categories (cells > 24 ton/4ha cell) account for about 32% of the total watershed sediment output in AG-5, but only for 5% in AG-4. These high sediment producing areas, however, occupy only 2% of the total watershed area in both AG-4 and AG-5.

6.4 Universal Soil Loss Equation

6.4.1 Background

Some investigators have successfully explored the possibility of using the U.S.L.E. and delivery ratios to predict watershed sediment yield (Taylor, 1970; Williams and Berndt, 1972). Williams and Berndt have extended the U.S.L.E. for use on watersheds by modifying the soil, topographic and management factors. This simple approach for sediment load prediction uses delivery ratios based on either computed values or derived from the published delivery ratios versus drainage basin size curve (Roehl, 1962; S.C.S., 1973, 1973b). In this section, a similar approach has been used to predict sediment loads for the 11 agricultural watersheds in Southern Ontario.

6.4.2 Data Collection Methods

The method for predicting watershed sediment yield using potential sheet erosion losses computed by the U.S.L.E. and delivery ratios is comparable with the approach taken for the SEDEL Model for small subbasins. In this case, potential streambank erosion estimates (Knap, 1978) have been added to long-term predicted watershed sheet erosion losses in order to represent watershed gross erosion values

(Table 17). For each watershed, gross erosion values have been multiplied by a watershed delivery ratio from two different sources:

- one based on drainage basin size (Roehl, 1962; S.C.S., 1971).
- one based on drainage basin size but modified for predominant soil textures in the watershed (S.C.S., 1973).

The theory behind this last data base is that watersheds with predominantly clay soils have higher delivery ratios and watersheds with sandy soils have lower delivery ratios than the first data base. Predominant soil textures of the plow layer have been obtained from Table 2. The multiplication of delivery ratios with gross erosion results in long-term predicted watershed sediment loads.

6.4.3. Experimental Results

Table 17 shows gross soil erosion losses for the 11 agricultural watersheds. Gross soil erosion is the sum of long-term sheet erosion and estimates of 1976 bank erosion (Table 7). Sediment loads have been computed using 2 different sources of published delivery ratios (A and B). Predicted and measured sediment loads from this table are depicted graphically in Figure 17. This figure indicates that both sources of delivery ratios generally overpredict measured sediment loads for the watersheds from 0-11 fold increases. The first set of delivery ratios (A) is generally overpredicting less than the second set of delivery ratios (B).

6.4.4. Data Analysis, Interpretation and Conclusions

The best relationships between measured and predicted sediment loads are observed for watersheds AG-1, AG-2, AG-4, AG-10, AG-14, using S.C.S. (1971) delivery ratios (Figure 17). All the other watersheds, however, indicate a 3-11 fold increase between measured and predicted sediment loads, the largest increase being found for AG-6, AG-7 and AG-13. It should be recognized that for example, a 3-4 fold difference between predicted and measured loads is less significant for watersheds with low measured sediment loads (AG-2, 6, 7, 11, 14) than it is for watersheds with high measured sediment loads (AG-1). Differences in predicted loadings by the two approaches for the same watershed are most extreme for basins with either a high clay or high sand content in the surface soil (AG-1, AG-3, AG-7, AG-13). Such content drastically affects the delivery ratios derived from the second source of information (S.C.S., 1973).

In summary, both series of delivery ratios result in over-prediction of measured suspended sediment loadings. This discrepancy may be rationalized with the same reasons noted in the previous 2 sections of this chapter, namely that 2 years of measured sediment load data is insufficient to validate predicted loadings. Also, the published delivery ratios, developed in specific physiographic areas with specific soils do not appear to be applicable to small agricultural watersheds in Southern Ontario. Unfortunately delivery ratios previously computed from

TABLE 17: Predicted Stream Sediment Loads by the Universal Soil Loss Equation for 11 Agricultural Watersheds

WATERSHED	POTENTIAL SHEET EROSION LOSSES (kg/ha/yr)	POTENTIAL[1] STREAMBANK EROSION LOSSES (kg/ha/yr)	GROSS[2] EROSION (kg/ha/yr)	DRAINAGE AREA (sq. miles)	DELIVERY RATIO (D.R.) %		SEDIMENT LOADINGS (kg/ha/yr) PREDICTED (GROSS EROSION X D.R.)		SEDIMENT LOADINGS (kg/ha/yr) MEASURED[5]
					A[3]	B[4]	A[3]	B[4]	
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] From Table 7 Chapter 4

[2] Gross erosion is the series of potential sheet erosion losses and potential streambank erosion losses

[3] Delivery ratios based on drainage basin series (Roehl, 1962; S.C.S., 1971)

[4] Delivery ratios based on drainage basin series, but modified for predominant watershed soil textures (S.C.S., 1973)

[5] "Naquadat" method, mean of 2 years data (May 1, 1975 - April 30, 1977)

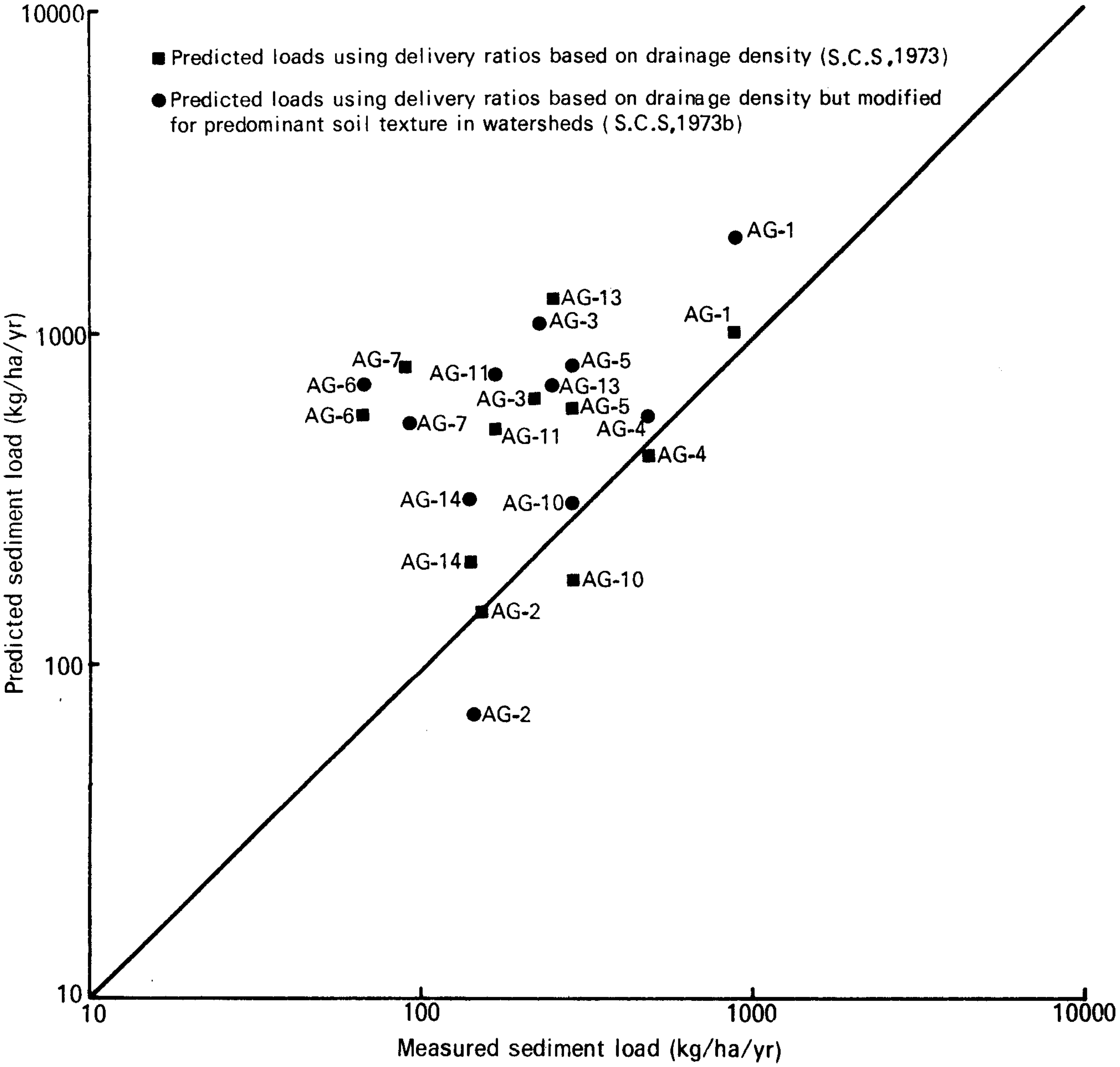


Figure 17: Relationship Between Measured and Predicted Sediment Loads by the Universal Soil Loss Equation for 11 Agricultural Watersheds in Southern Ontario

gross erosion and measured sediment yield data (Chapter 5, Table 8) could not be used for predicting sediment loads, since they were based on the same set of data.

Considering the limitations of both predicted and measured sediment loads, the simple method of using the Universal Soil Loss Equation to predict sediment loads appears to have potential for future use in watersheds of similar size, particularly if better delivery ratios specific for southern Ontario were developed. With readily available data on soils, land use and topography, it also appears that this method of suspended sediment load prediction has potential for larger basins in the Canadian Great Lakes Drainage Basin for which no measured sediment load data is available.

7.0 SEDIMENT CONTRIBUTING AREAS IN AGRICULTURAL AREAS

7.1 Introduction

During the transport phase of the soil erosion process, deposition of eroded materials may take place (e.g. in depressional areas, at fence rows, along grassed buffer strips) before entrained sediments reach the stream system. This depositional process may result in all or part of the eroded material being deposited. When partial deposition occurs, it is usually the coarse sediments that become deposited leaving the remaining eroding materials enriched with fine textured sediments. As a result of depositional phenomena and closed micro drainage systems, it has been recently suggested that only part of an agricultural landscape contributes eroded soil materials to the stream (Dickinson and Whiteley, 1970; Moore et al, 1976). These studies have also indicated that contributing areas of a watershed are not constant, but vary over the year.

To give some insight to contributing areas in agricultural landscapes in southern Ontario, a study was initiated with the following objective:

- to physically define the seasonal variability in sediment source areas in two agricultural watersheds.

The study approach has involved defining and quantifying sediment source areas by field observations during or immediately following runoff events. In addition, a Sediment Transport Computer Model (see Chapter 6) has been used to predict sediment producing areas. Predicted and observed sediment source areas have been compared.

Results from the two year field investigation (1975, 1976) have also been compared to runoff producing estimates made by Whiteley (1978).

7.2 Data Collection Methods

A detailed field program to evaluate sediment source areas in (AG-4) Canagagigue Creek and (AG-5) Holiday Creek watersheds was initiated in March 1975 and continued to April, 1977. Field visits were made during or shortly after runoff - producing snowmelt and rainfall events to define and quantify field contributing areas by onsite visual observations. For each event, the proportion of individual fields observed to contribute runoff water was determined and noted. Observed fields were classified into the following runoff contributing area categories:

0% - no runoff
1 - 10% - low runoff
11 - 25% - medium runoff
26 - 50% - high runoff
>50% - very high runoff

For the determination of the relative amounts of sediment in runoff water leaving the observed fields at field boundaries, grab samples of runoff water were taken in 250 ml bottles. Water samples were analysed for turbidity (Jackson Turbidity Units). The fields were then classified into high, medium, low and no sediment producing classes.

Selection of fields in each watershed was mainly based on accessability so that observed fields were located at or near the roads. To determine the proportion of a landscape (watershed) that contributes to runoff, a small representative subbasin (about 3 km^2) within each watershed was selected in 1975 for detailed field observations (Figure 11, subbasin 1 and Figure 12, subbasin 2). All fields in each of these subbasins were added to the already selected fields for watershed contributing area observations. The number of fields for which runoff was observed during the 1975 climatic events varied. During 1976, however, the field program was intensified by emphasizing sediment source areas rather than runoff areas. This resulted in not only more fields observed, but also in all the fields being observed for each event. In other words, a constant number of fields were observed during every runoff producing climatic events. The number of fields observed, including all fields from the subbasin, during runoff events in 1975 and 1976, are summarized below:

	1975		1976
	Range	Mean	
AG-4	5-31	14	31
AG-5	4-30	15	53

Since the individual fields observed had variable dimensions, the area of each field was measured on aerial photographs (1:16,640 scale). Field zones varied between 1.5 and 40 ha for both watersheds. The fixed number of fields observed during 1976 events had a total area of 163 ha (31 fields) for AG-4 and 414 ha (53 fields) for AG-5. This represented 9% and 14% of the total watershed area for AG-4 and AG-5 respectively. During 1975, the total area observed varied for each event, since the number of fields varied for each event. To include 1975 events for data analysis, a minimum of 4 observed fields for each watershed and 3 fields for the subbasin were assumed to be sufficient. This minimum number of observed fields occurred only once (March 22, 1975). For all the other events, a larger number of fields were observed in 1975.

In order to clarify the picture of contributing areas on a subwatershed basin, field work during the spring period of 1977 (January - April) was limited to detailed field observations in both representative subbasins of AG-4 and AG-5 watersheds. The field program was discontinued in April, 1977.

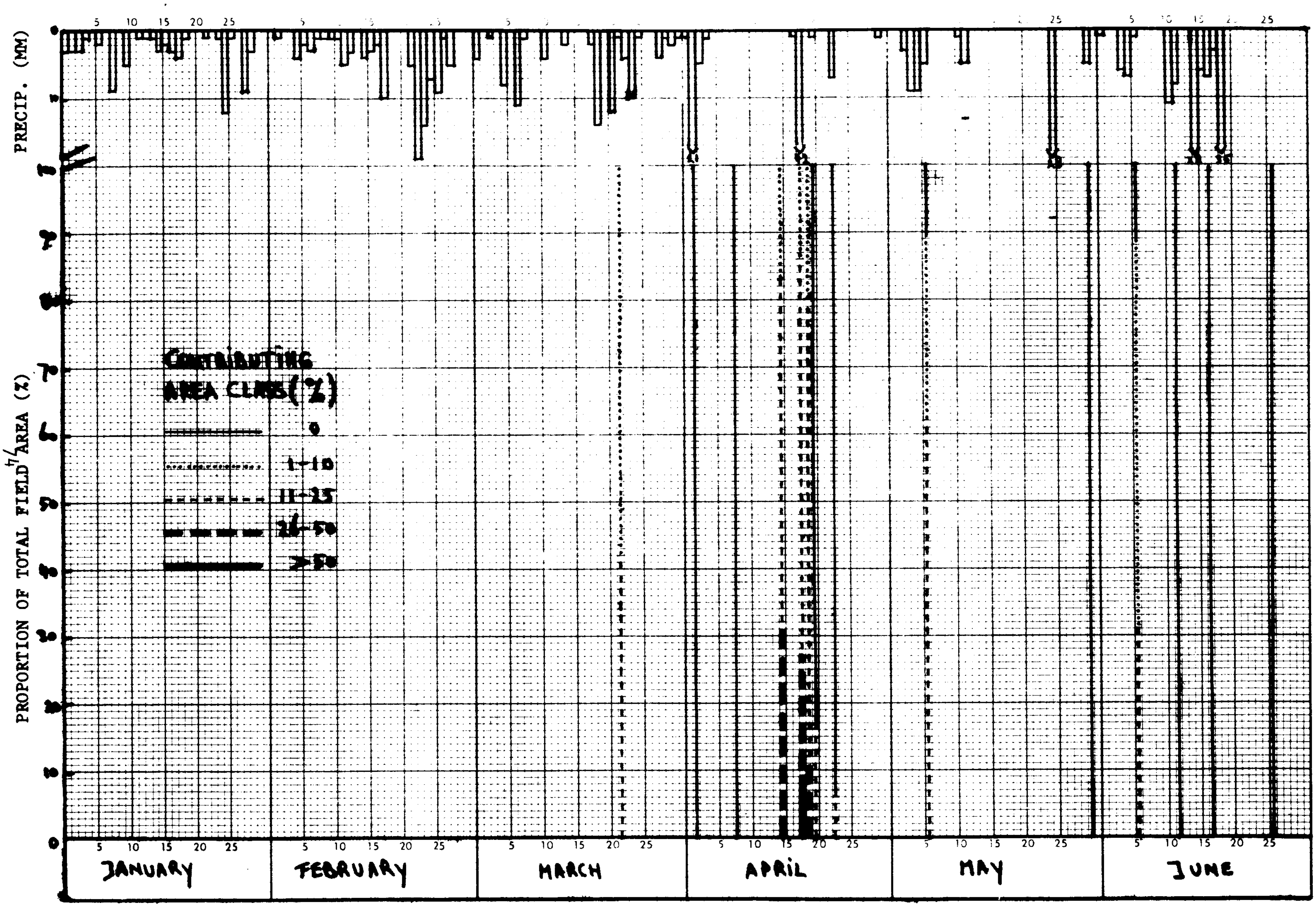


Figure 18: Observed Contributing Areas During 1975 For AG-4 (Canandaigua Creek)

7.3 Experimental Results

For each event observed in the field during 1975 and 1976, data on field contributing areas and field zones have been analysed to determine the proportion of total field area observed in each contributing area class. Results of this analysis are graphically presented in Figure 18 and Appendix 7. Contributing area results are discussed in an example for AG-4 watershed during the first 6 months of 1975 (Figure 18). The X-axis of Figure 18 represent a daily time scale, so that the exact date of field visits can be indicated.

Observations for AG-4 during 1975 commenced after March 26th. For each field visit (runoff event), the different runoff contributing area classes have been depicted by different graphical lines. The vertical length of each class (or line in figure) represents the proportion of total field area observed for that event, expressed as a percentage on the vertical axis of Figure 18. The dimensionless scale provides comparisons of the results in 1975 (having a variable total area observed) with the 1976 results (having a constant area observed for each event). Field visits for which no discernible contributing runoff areas were observed have been excluded from further data analysis. These events are indicated by a thin solid line, representing the zero on the contributing area class. For convenient interpretation of the results, precipitation depths in millimeters (Sanderson, 1977) are depicted as bar-graphs at the top of Figure 18. These amounts include both rainfall and water equivalent of snowmelt. Likewise, contributing area results are presented in Appendix 7 for 1975 for AG-4, AG-5, AG-5 subbasin and for 1976 for AG-4, AG-5, AG-5 subbasin respectively.

Since fields in the selected subbasin of AG-4 watershed were remotely located, observations during 1975 and 1976 were not frequent enough for data analysis purposes. Consequently, no data has been presented for the subbasin of AG-4 watershed during that period. Contributing areas, however, for both subbasins AG-4 and AG-5 were observed in detail during January - April, 1977 and have been presented in Table 18. These events have been included in further analysis of the data.

7.4 Data Analysis and Interpretation

7.4.1 Contributing Area Graphs

Results in Figure 18 and Appendix 7 indicate that field visits do not always coincide with the peak rainstorm events, depsite the fact that a farmer in each of the watersheds phoned the office after a certain amount of rainfall took place. Field visits shortly after runoff events have been used to reconstruct the contributing area picture, consideration having been given to runoff and erosion features, such as washout areas, rills and gullies (e.g. July 21, 1976 in AG-5). The limitations of this approach should be recognized.

Table 18: Percentage of landscape generating fluvial sediments in subbasins of two agricultural watersheds.

EVENT	AG-4 (Canagagigue Creek)	AG-5 Holiday Creek
March 9, 1977	5	25
March 10, 1977	5	20
March 11, 1977	5	10
March 13, 1977	15	--
March 14, 1977	25	--
Spring, 1977	11	18

The graphs indicate how well runoff events correlate with precipitation. Also, the results reveal that a certain amount of snowmelt or rainfall water is needed before field runoff occurs. This amount varies over the season, depending on the antecedent soil moisture conditions. A good example of this phenomenon is shown for AG-5 in June, 1975 (Appendix 7), where about 25 mm of rainfall on wet soils resulted in high runoff amounts indicated by large areas contributing in each class. However, the same amount and even double that amount of rainfall on dry soils in August of the same year did not cause any observable runoff for AG-5.

7.4.2 Contributing Area Index

In order to compare different events (field visits), within or among watersheds, a single contributing area index has been developed. The index has been computed by integrating field areas with contributing area classes, according to the following equation:

$$\text{C.A.I.} = \frac{\Sigma(A \times M) \times 100}{\Sigma A}, \quad \text{where}$$

C.A.I. = contributing area index of total area observed (in %),
A = number of hectares in each contributing area class,
M = contributing area class midpoint (%),
Σ = total area observed for each event.

Contributing area index values, which are in fact area-weighted mean contributing areas, have been computed for all snowmelt and rainfall runoff producing events observed during 1975 and 1976. Results of the computations for AG-4 and AG-5 are presented on a monthly basis (Table 19). Raw data are found in Appendix 7. Table 19 demonstrates that average monthly contributing areas for the same watershed are highly variable from year to year during the spring (February-April). For example, contributing areas vary from 4-14% in the month of April in AG-4, or from 5-22% in the month of March in AG-5. This variability is of no surprise, since contributing areas are strongly influenced by the highly variable climatic events.

Mean annual contributing areas show the same variable trends but ones not as extreme as for the monthly values (Table 19). The range in field contributing areas observed in any one year is large. For example, AG-4 (1975): 1-25%; AG-5 (1976): 1-65%; AG-5 subbasin (1976): 11-72% (table 19). Since the number of yearly observed runoff events is low (they vary between 8-11 events), it is desirable to look at the 2 year mean watershed contributing area, which was found to be 10% in AG-4 (17 observations) and 15% in AG-5 (21 observations). For the subbasin of AG-5, the 2 year mean contributing area was found to be highest i.e. 20% (17 observations).

Table 19: Average monthly sediment contributing areas (percent) for all snowmelt and rainfall runoff producing events observed during 1975 and 1976 for AG-4 and AG-5 watersheds.

														For Events		
WATERSHED	YEAR	J	F	M	A	M	J	J	A	S	O	N	D	RANGE	MEAN	NUMBER OF OBSERVATIONS
AG-4	1975	-*	-	11	14	13	9	-	12	-	-	-	-	9-25	13	9
AG-4	1976	-	-	11	4	4	6	4	-	1		-	-	1-18	7	8
AG-4	1975-76	-	-	11	13	9	8	4	12	1	-	-	-	1-13	10	17
AG-5	1975	-	-	22	12	-	17	-	-	-	-	-	6	6-25	16	11
AG-5	1976	-	6	5	2	4	-	18	65	3	-	-	-	3-65	14	10
AG-5	1975-76	-	6	15	10	4	17	18	65	3	-	-	6	3-65	15	21
AG-5 Subbasin	1975-76	-	-	9	9	3	27	28	72	3	-	-	-	3-72	20	17

* Rainfall and snowmelt events without observable surface runoff (0% contributing area class) are not included in this table.

7.4.3 Seasonal Contributing Areas

The data in Appendix 7 have been further analysed for seasonal trends. In addition, data for spring 1977 (Table 20) are included. Results of average seasonal contributing areas are presented in Table 20.

Table 20 indicates large variations in mean contributing areas among different seasons in any one year (e.g. 3-24% for AG-5, 1976; 3-32% for AG-5 subbasins during 1976) as well as between some seasons in different years (e.g. 4-17% winter 1976 and 1975 for AG-5). Low rainfall frequency and rainfall amounts during the fall seasons in AG-4, AG-5 and AG-5 subbasin, especially during the months of November and December (Appendix 7) are expressed by the low number of runoff producing field observations (Table 20). Hence the lowest seasonal runoff contributing areas occur during this September - December period, varying between 1-6%. Average seasonal contributing areas in AG-4 during the spring are higher than during the summer. This trend is reversed for AG-5 watershed and AG-5 subbasin. In AG-5, summer storms have been found to be more frequent with higher rainfall amount than in AG-4, in particular during 1976, (Appendix 7). Over the 2 year period 1975-1976 (1977), average contributing areas observed during the spring season have been found to be the same for AG-4, AG-5 and AG-5 subbasin (12%). During the summer season, contributing areas in AG-5 watershed and AG-5 subbasin are observed to be higher (21% and 30% respectively) than for AG-4 watershed (8%).

Results of detailed subbasin observations during the spring season of 1977 reveal that contributing areas in AG-4 subbasin (11%) are about the same as for the fields observed in the watershed during 1975-1976 (12%); whereas the AG-5 subbasin has exhibited more contributing areas during spring 1977 (18%) than the 3 year subbasin average of 12%.

7.4.4 Extrapolation of Results

With respect to landuse, the subwatershed in AG-5 appears to provide a better representation for the entire basin than the subwatershed in AG-4. The latter has a higher percentage of grass and woodlands compared with the entire watershed AG-4. The selected fields observed in AG-4 and AG-5 are generally felt to be a reasonable sample of the population of fields in the entire watersheds with respect to land use, soils and topography. Consequently, contributing area results based on these sampled fields may be used for extrapolation of results to the entire basin of AG-4 and AG-5.

7.4.5 Contributing Areas in Relation to Sediment Producing Areas

Since an objective of this contributing area investigation has been to define and quantify sediment source areas in the two watersheds AG-4 and AG-5, turbidity data from grab runoff samples have been

Table 20: Mean seasonal sediment contributing areas (percent) for all snowmelt and rainfall runoff producing events observed during 1975-1977 for AG-4 and AG-5 watersheds and subbasins.

WATERSHED AND SUBBASIN	YEAR	WINTER (Jan.--April)		SUMMER (May--August)		FALL (Sept--Dec.)		TOTAL YEAR (Jan.-Dec.)	
		MEAN	NO. OF OBSERVATIONS	MEAN	NO. OF OBSERVATIONS	MEAN	NO. OF OBSERVATIONS	MEAN	NO. OF OBSERVATIONS
AG-4	1975	14	6	11	3	--	--	13	9
AG-4	1976	10	4	5	3	1	1	7	8
AG-4	1975-76	12	10	8	6	1	1	10	17
AG-5	1975	17	6	17	4	6	1	16	11
AG-5	1976	4	4	24	5	3	1	14	10
AG-5	1975-76	12	10	21	9	5	2	15	21
AG-4 Subbasin	1977	11	5	--	--	--	--	--	--
AG-5 Subbasin	1975	13	4	27	4	--	--	20	8
AG-5 Subbasin	1976	4	3	32	5	3	1	20	9
AG-5 Subbasin	1977	18	3	--	--	--	--	--	--
AG-5 Subbasin	1975, 76, (77)	12	10	30	9	3	1	19	20

collected in order to classify the observed fields into a high, medium, low and no sediment producing class. Analysis of these data for each event reveals a scatter of turbidity values bearing no relationship with observed runoff contributing areas. This turbidity information has therefore been used in a general qualitative way to support field observations about the magnitude of sediments carried by runoff water leaving the fields.

With few exceptions, runoff contributing areas during the spring period (January-April) carry sediments from the field via an active drainage system of waterways, roadside ditches, intermittent streams and ephemeral streams, into the main channel. This spring period has been observed (i.e. through turbidity measurements) to have a high delivery of sediments from the fields into the stream sytem, mainly due to frozen soil or high antecedent soil moisture conditions and a lack of effective ground cover trapping soil material during the transport phase of the soil erosion process. Consequently, the runoff contributing areas observed during this period may be considered as sediment producing areas.

During the summer period (May-August), however, turbidity data indicate generally low amounts of sediment or often no sediments at all in runoff water leaving the fields. Even if sediment loaded runoff water during high rainfall events leaves the fields, it has been observed that most of the sediments are being trapped in transport through well vegetated surface drainage systems before reaching the main channel. In other words, a low delivery of sediments from the land base to the stream system takes place during this period, partly caused by a good vegetation soil protection. Consequently, runoff contributing areas observed during the summer and fall periods are considered as potential sediment producing areas, rather than actively sediment producing areas.

7.5 Conclusions

This two year study (1975, 1976) regarding areas that contribute sediments into the streams has revealed that on the average about 10% of the watershed area in AG-4 and 15% of AG-5 has the potential of contributing to stream sediment loads during the year.

Under high soil moisture conditions, such as the winter season (January-April), characterized by a high delivery of sediment loaded runoff water to the stream system, average sediment producing areas have been found to be 12% of the total watershed area for AG-4, AG-5 and AG-5 subbasin. Areas contributing to runoff during the summer (May-August) under low soil moisture conditions are lower for AG-4 (8%) than during the spring, but higher for AG-5 (21%) and still higher for AG-5 subbasin (30%) due to extremely high rainfall events during the summer of 1976. Contributing areas during the fall season (September-December) have been found to be lowest, ranging between 0-5% of the areas of AG-4 and AG-5 watersheds.

Since runoff water during the summer and fall season is observed to be carrying no sediment or low sediment amounts that become trapped before reaching the stream system, areas observed to contribute to runoff during these seasons are considered as potential sediment producing areas rather than active sediment producing areas.

8.0 THE REDUCTION OF SOIL EROSION AND FLUVIAL SEDIMENT LOADS

8.1 Introduction

In this chapter, several schemes for reducing soil erosion and sedimentation in small agricultural watersheds are discussed.

Two of the methods employed earlier in the investigation are readily adaptable to the assessment of remedial measures for soil erosion and sediment control. The first of these methods, the Sediment Transport Computer Model, has been used to evaluate the effectiveness of reducing soil loss from areas with the highest unit area loadings on total watershed sediment loads. In addition, simulation techniques with the Sediment Transport Computer Model have been used to evaluate the effects of different land uses and erosion control practices in reducing predicted watershed sediment yields. A second method used to assess the effects of remedial measures on soil erosion (e.g. minimum tillage, cross slope farming, strip cropping) is also discussed in this chapter.

8.2 Sediment Transport Computer Model: Effects of reducing soil loss from the most erosion sensitive areas on watershed sediment loads

8.2.1 Data Collection Methods

Data collection and methodology for mapping sediment-producing areas by the Sediment Transport Computer Model have been discussed in Chapter 4.

8.2.2 Experimental Results

Results from the mapping of sediment-producing areas in AG-4 and AG-5 watersheds have been presented in Figures 15 and 16 of Chapter 6. For the purpose of evaluating the effects of reducing soil loss from sediment-producing areas on total watershed sediment loads, results in Figure 15 and 16 of Chapter 6 have been subjected to further analysis. Beginning with the highest sediment-producing class (>40 ton/cell), the cumulative percent of both the predicted loading rates and aerial distribution for the eight sediment-producing categories have been computed. The results of these computations are presented in Tables 21 and 22.

TABLE 21: Aerial Distribution and Loading Rates for Different Sediment Producing Categories in AC-4 (Canagagigue Creek)

SEDIMENT PRODUCING CATEGORY (ton/ha/yr)	CUMULATIVE SEDIMENT PRODUCING AREAS (ha)	(%)	CUMULATIVE PREDICTED SEDIMENT LOADS (%)
>10	8	0.5	3
> 6	16	1	5
> 4	101	5	22
> 2	421	21	57
> 1	1025	51	90
> 0.1	1973	98	100

TABLE 22: Aerial Distribution and Loading Rates for Different Sediment Producing Categories in AG-5 (Holiday Creek)

SEDIMENT PRODUCING CATEGORY (ton/ha/yr)	CUMULATIVE SEDIMENT PRODUCING AREAS (ha)	(%)	CUMULATIVE PREDICTED SEDIMENT LOADS (%)
>10	40	1	17
> 8	53	1.3	21
> 6	93	2	32
> 4	170	5	47
> 2	352	11	66
> 1	558	18	77
> 0.1	2725	90	100

Also, the data points from both tables have been used to plot cumulative sediment-producing areas against cumulative predicted watershed sediment loads. Lines connecting these data points for AG-4 and AG-5 watersheds are presented in Figure 19.

8.2.3 Data Analysis and Interpretation

Tables 21 and 22 show the effectiveness of controlling different levels of sediment production. In AG-5, 17% of the total predicted watershed sediment load could be reduced by controlling the highest sediment-producing class (>10 ton/ha/yr) to low levels, assumed at <1 ton/ha/yr. This constitutes an area of 40 ha in close proximity to the streams. When all areas producing >8 ton/ha/yr of sediments (53 ha) are reduced to a low level of <1 ton/ha/yr, watershed sediment output could be reduced by about 21%. Reducing watershed sediment loads by about 20% in AG-4 Canagagigue Creek implies controlling sediment production on an area of about 100 ha (Table 21).

Figure 19 shows the relationship between sediment-producing areas and sediment loads for AG-4 and AG-5, as a means of assessing the relative distribution of sediment source areas. It is apparent from Figure 19 that AG-5 requires the application of remedial measures to a greater land area in order to reduce sediment loads by an equivalent percent on AG-4. For example, to reduce watershed sediment loads by half, remedial measures need to be instituted on only 6% of the watershed area in AG-5; while for AG-4, 16% of the area requires treatment for the same reduction in sediment load (50%).

The previous discussion on the effectiveness of controlling different levels of sediment production in reducing watershed sediment load was based on the assumption that the sediment-producing categories were reduced to a low level (<1 ton/ha/yr) of sediment production with the highest sediment-producing category (>10 ton/ha/yr) considered initially and progressing to the lowest sediment producing category (<1 ton/ha/yr). No attempt has been made to evaluate the effectiveness of reducing sediment loads (e.g. 25%, 50%) of a particular sediment-producing class by a fixed percentage.

8.3 Land Use And Erosion Control Simulation

8.3.1 Data Collection Methods

Simulation techniques with the Sediment Transport Computer Model have been used to evaluate the effects of different land uses and erosion control practices in reducing predicted watershed sediment yields. Model input values for the cropping-management "C" factor and the erosion control practices "P" factor under present land use conditions have been replace by newly computed values reflecting simulated conditions. The following simulated land uses and erosion control practices have been considered:

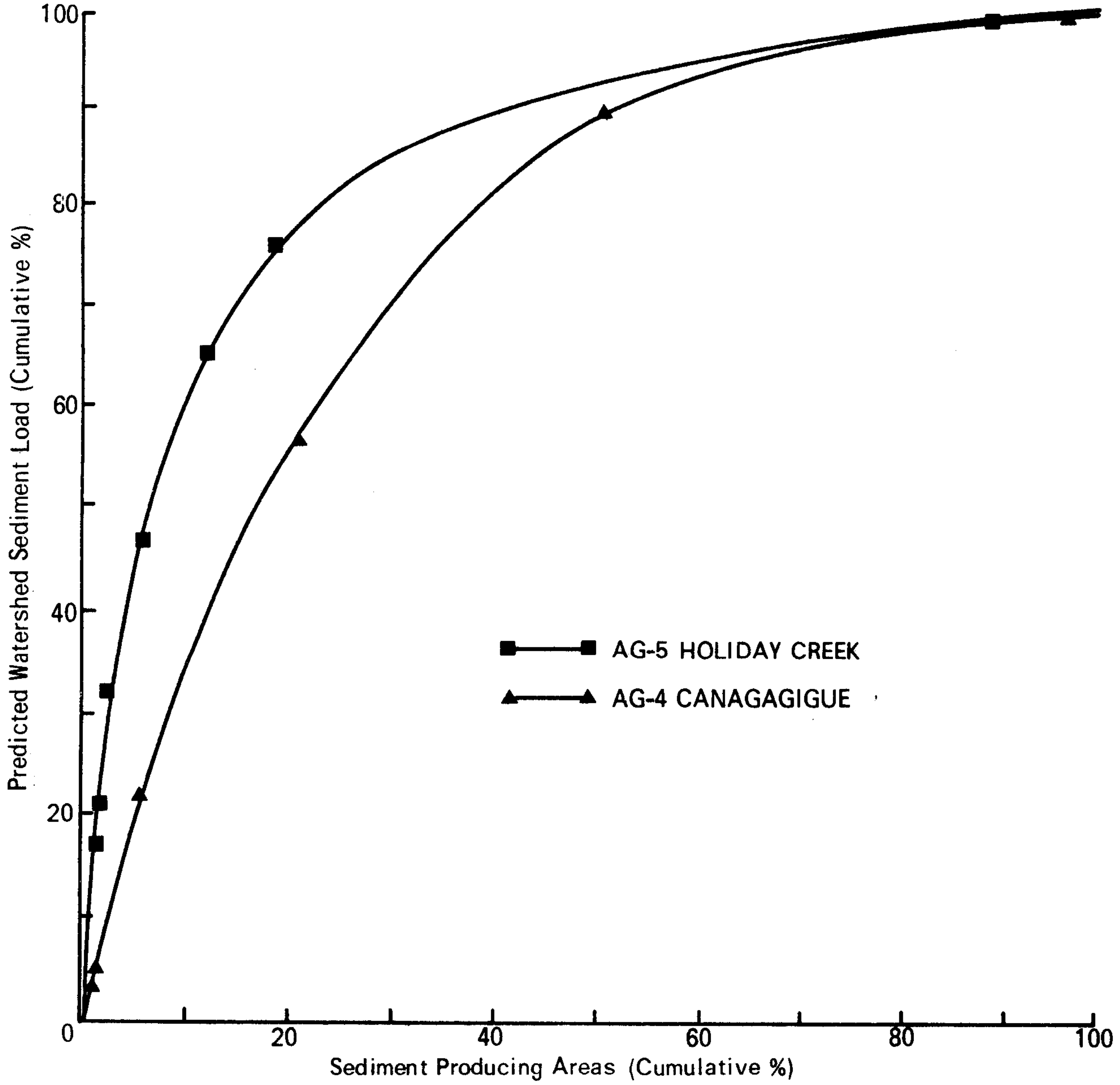


Figure 19: Relationship Between Sediment Producing Areas and Predicted Watershed Sediment Loads

	C	P
- fallow plowed	1	1
- entire watershed in forest cover	0.02	1
- all arable land in permanent pasture	0.03	1
- all arable land in continuous grain corn, fall plowed	0.45	1
- end cells of ephemeral drainage nets in permanent pasture		1
- cross slope farming		0.75
- contour farming		0.50
- strip cropping, across the slope		0.37
- strip cropping, on the contour		0.25

8.3.2 Experimental Results

Results of simulated land use and erosion control practices for AG-4 and AG-5 are presented in Table 23. This table indicates the effectiveness of each practice in reducing watershed sediment yields from current land use (fall plowed) and cultivation practices assumed to be up-down slope farming - fall plowed. With a few exceptions reductions in predicted watershed sediment loads are the same or about the same for both AG-4 and AG-5.

8.3.3 Data Analysis and Interpretation

Precultural levels of sediment yield in AG-4 and AG-5 were computed by assuming a complete forest cover (C value of .02). Table 23 indicates that under these simulated conditions, sediment yields in AG-4 were only 17% and in AG-5 only 9% of sediment levels found under present land use conditions.

Similarily when the cultivated land area, which is the total watershed area excluding permanent pasture and woodlands (81% of total watershed area for both AG-4 and AG-5) was assumed to have a permanent grass cover, the sediment load in both areas showed a potential reduction of 75% - 87% of sediment levels found under current land use conditions. Permanent grass cover is a very effective method for erosion and sediment control; but unrealistic from an agronomic point of view since croplands are taken out of production.

When all cultivated land was assumed to have grain corn (with conventional fall plow tillage) to simulate present trends towards more continuous row cropping systems in Ontario current predicted sediment loads were computed to increase by more than 3 fold for AG-4 and by 45% for AG-5. The dramatic increase for AG-4 is caused by the absence of continuous corn under the present cropping system.

Several control practices were also evaluated for their potential to reduce watershed sediment loads. This evaluation was

Table 23: Effectiveness of Simulated Land Uses and Erosion Practices in Reducing Sediment Loads in AG-4 (Canagagigue Creek) and AG-5 (Holiday Creek) Watersheds

LAND USE	SEDIMENT YIELD REDUCTION COMPARED WITH CURRENT LAND USE AND CULTIVATION PRACTICES (%)	
	AG-4	AG-5
Current land use, fall plowed	0	0
All cultivated land in permanent pasture	75	87
Complete forest cover	83	91
All cultivated land in continuous grain corn	300[1]	45[1]
EROSION CONTROL PRACTICE		
Current cultivation practice, up-down slope, fall plowed	0	0
Current land use, spring plowed	24	15
End cells in permanent pasture	32	18
Cross slope farming	25	25
Contour farming	50	50
Strip cropping, across the slope	63	63
Strip cropping, on the contour	75	75

[1] Figure represents an increase, rather than a reduction

accomplished by assigning to the erosion control factor "P" in the U.S.L.E. an empirical value that reflects each of the following four control practices: cross slope and contour farming, both with and without strip cropping. Since values are the same for both AG-4 and AG-5 watersheds, the potential reduction in sediment yield also remains the same.

Table 23 demonstrates that without strip cropping, contour farming is twice as effective as simple cross slope farming in reducing predicted sediment yields from the current practice of updown slope farming by about half. Wischmeier and Smith (1965) have found that contouring appears to be most effective on slopes in the 3-7% range. For steeper slopes, a more effective method could be used by planting alternate strips of grass and row crops or small grains across the slope or on the contour.

Results of the computer simulation indicated that these practices, called strip cropping, may reduce sediment yields from updown slope farming by 63-75% (Table 23). Strip cropping with grass and/or legume crops provides for greater infiltration of runoff water and deposition of eroded material.

Cross slope farming creates small ridges and depressions that reduces runoff. In spite of the fact that areas with complex slopes may preclude across slope planting, this method, with or without strip cropping, is more feasible and easier to adopt than contour farming, since following field contour lines with mechanized multiple row equipment can be cumbersome and time consuming. In addition, farm operations may be hampered by narrow rows and point rows (Jacobson, 1969).

Simulation techniques also reveal that when areas (4 ha cells) in the watershed where overland flow reaches a stream-channel (end of ephemeral drainage nets) are assumed to be a grass cover, the trapping of sediment in these areas results in reductions of average yearly sediment loads by 18% and 32% for AG-4 and AG-5 watersheds respectively. The disadvantage of this practice is that areas of prime agricultural land may be taken out of production at the farmer's expense.

When fall plowing of the land is delayed till spring, computed field erosion and sediment yields were reduced by 24% and 15% for AG-4 and AG-5 respectively. This practice results in crop residues remaining on the land to form an effective soil cover against the forces of raindrop splash and overland flow from runoff water.

Since the transport factor "T", which has been based on topographic differences, is not influenced by the computer model simulations, the effectiveness of erosion control practices in reducing watershed sediment loads is the same for reducing potential erosion losses.

8.4 Effectiveness of Conservation Tillage in Reducing Soil Erosion

8.4.1 Background

Soil erosion losses can also be reduced by conservation tillage practices. For use in the U.S.L.E., Wischmeier (1973) has developed new soil loss ratios for conservation tillage practices in a continuous corn crop for crop stage periods 1, 2 and 3, which are the seedling, the establishment of the crop, the growing and maturing periods respectively. Soil loss ratios are empirical measures of the erosion control effectiveness of a particular crop, as expressed by the cropping-management factor "C" in the universal soil loss equation (Wischmeier and Smith, 1965). No soil loss ratios for crop stage period 4, the period from grain corn harvest in the fall to conservation tillage operations in spring, have been presented by Wischmeier (1973), since they vary by local parameters that influence the percentage of effective groundcover by corn residue; e.g. yield levels, residue losses during winter.

8.4.2 Data Collection Methods

Average values of published soil loss ratios for crop stage periods 1, 2 and 3 were used for four soil conservation tillage practices, including zero tillage, disk and plant, chisel plow with points and rotary strip tillage (Wischmeier, 1973). Soil loss ratios for crop stage period 4 have been evaluated using average County grain corn yields for the 5 year period of 1971-1975 (Ontario Ministry Agric. Food, 1976) to estimate the amount of residue produced by applying the rule of thumb of a pound of residue for each pound of grain corn produced (Wischmeier, 1973). However, since residue losses during winter can be substantial, 80% of the residue weight has been considered as an average value for Ontario during crop stage period 4. This residue weight value has been used to find the percentage of total field surface covered by mulch during this period (Wischmeier, 1973). Using Wischmeier's (1973) methodology, soil loss ratios have been computed for crop stage period 4 for seven locations in southern Ontario. Conservation tillage practices and planting of corn are performed by a single operation, eliminating the fallow period, crop stage period F, that lasts from primary tillage operations to planting of the crop. Based on the new soil loss ratios for a continuous corn crop, values for the cropping-management factor "C", in the U.S.L.E. have been computed.

8.4.3 Experimental Results

Assuming other factors in the U.S.L.E. constant (rainfall, soil, topography, erosion control), a change of value in the cropping-management factor "C" results in an equal change of value in potential soil loss due to the linear relationship of the "C" factor in the equation with predicted soil erosion losses. Consequently, only values for the cropping-management "C" factor are reported.

Results of the computations of cropping-management values under a continuous grain corn cropping system for the four tillage treatments in seven locations in Southern Ontario are presented in Table 24. For evaluation of the degree of effectiveness of the four conservation tillage practices in reducing potential soil erosion losses from a grain corn crop, the average reduction in cropping-management values have been expressed as percentages of the control, which is fall plowed conventional tillage (Table 24).

8.4.4 Data Analysis and Interpretation

Table 24 indicates that zero-tillage is the most effective (79%) conservation tillage practice in reducing potential soil loss. This value (79%) is in close agreement with findings from a zero tillage study in the U.S. (U.S.D.A., 1975). Zero tillage involves no seedbed preparation other than planting in narrow slots (6 cm) opened by a fluted coulter. Zero tillage does not incorporate any residue, leaving it distributed over the soil surface throughout the year. This residue creates maximum soil protection against the erosive forces of raindrop impact and runoff water during the highly vulnerable crop-establishment period and is also effective during the growing season but to a lesser degree after harvest.

The next most effective soil conservation practice in reducing potential soil loss (70%) from the present system of conventional tillage is the disk and plant treatment, using a no-till planter in disked corn residue (Table 24). This practice leaves the soil surface rough with a small amount of residue incorporated, providing some less protective residue cover than the zero tillage method.

Rotary strip tillage has the potential of reducing soil loss from conventional tillage by about half (Table 24). Rotary strip tillage prepares seed rows of 20 cm wide and 10 cm deep, leaving the inter-row space in the original condition. Rotary tillage loosens the soil, makes it finer by breaking soil aggregates and mixes about 1/3 of the residue with the surface soil (Oschwald, 1973). This practice results in a greater erosion potential than previous treatments, since a smaller percentage of the total field surface is covered by mulch.

Computations indicate that the use of a chisel plow with points to 20 cm deep previous to planting corn is the least effective practice to control agricultural erosion (Table 24). Chisel plowing reduces potential soil loss from conventional tillage by approximately 30%. Chisel plowing disturbs more soil and incorporates more crop residues than any of the three previous conservative tillage practices.

Table 24: Computed Cropping Management "C" Values for Four Conservation Tillage Practices[1]

	ZERO TILLAGE	DISK AND PLANT	ROTARY STRIP TILLAGE	CHISEL PLOW WITH POINTS
Mean "C"	0.0814	0.1154	0.1778	0.2684
Range	0.0780-0.0828	0.1128-0.1210	0.1735-0.1823	0.2642-0.2754
Standard deviation	0.0018	0.0027	0.0034	0.0047
Reduction from conventional fall tillage (%)	79	70	53	30

[1] Data based on seven observations from different agricultural regions in Southern Ontario

It should be noted that percentage reductions by the four conservation tillage practices represent maximum potential values. If the same practices are performed in the fall as primary tillage or if crops other than grain corn are considered, the reduction in soil loss is more likely to be lower. It is anticipated that for different crops the relative potential of the conservation tillage practices in reducing soil loss from conventional tillage will remain the same. Unfortunately, no soil loss ratios have been developed yet to test conservation tillage for other crops than corn by this method.

On a watershed basis, the effectiveness of conservation tillage practices depends on the watershed area in continuous grain corn production. Since no apparent linear relationship exists between agricultural soil loss and sediment production, the reduction in sediment production and subsequent sediment yields in streams caused by using conservation tillage practices are expected to be much less than for agricultural erosion.

8.4.5 Conclusions

In this chapter, the following conclusions can be made regarding various ways of reducing soil erosion and sedimentation in small agricultural watersheds.

- The Sediment Transport Computer Model appears to be an excellent tool for evaluating the effectiveness of controlling different levels of sediment production in reducing watershed sediment loads. The area of land requiring erosion control measures to reduce sediment loads by a fixed percentage is higher in AG-4 than AG-5.

- Land use simulation with the Sediment Transport Computer Model indicates that permanent pasture and forest cover are the most effective land uses in reducing watershed sediment loads by 75-83% in AG-4 and by 87-91% in AG-5. These land uses are not very practical from a farming point of view, but may have an application in active sediment-contributing areas.

- Erosion control simulation by the Sediment Transport Computer Model indicates that cross slope farming and contour farming have the potential of reducing watershed sediment loads by 25-50%. These practices have been found to be more effective in combination with strip cropping, reducing sediment yields by 63-75% in both AG-4 and AG-5 watersheds.

- Simulation techniques and sediment mapping by the Sediment Transport Computer Model appear to be excellent tools with a great potential for use in small agricultural watershed in southern Ontario. The time consuming detailed data input is more than justified by the versatility of the model.

- From the different conservation tillage practices evaluated for a continuous grain corn crop, zero tillage has been found to be the most effective practice in reducing annual soil loss (79%), followed by the disk-plant method (70%). Rotary strip tillage has the potential of reducing average annual soil losses by half and chisel plowing by about 30%.

9.0 EXTRAPOLATION OF SEDIMENT LOADING RATES TO AGRICULTURAL LAND

9.1 Canadian Great Lakes Drainage Basin

Based on representative watersheds, suspended sediment loadings (2 year mean, NAQUADAT Method) were extrapolated spatially to the agricultural regions of southern Ontario. The spatial distribution of suspended sediments for southern Ontario is depicted in Figure 20.

Extrapolation of sediment loadings for the total agricultural land area in the Canadian Great Lakes Drainage Basin was attempted based on 1976 sediment loadings (NAQUADAT Method and Integration Method). The agricultural land area is 5,165,733 ha or 22.2% of the total Canadian Great Lakes Drainage Basin (Task B). The 11 agricultural regions in which the 11 representative watersheds are located, occupy 61.1% of the total agricultural area. The original 21 regions at the outset of the PLUARG program, for which some information is available, represent 83% of the total agricultural land area. The remaining 17% is in scattered low intensity farmed areas with a relatively low potential for sheet and rill erosion and a low potential for streambank erosion.

Figure 8 in Chapter 4 indicates that AG-1 has an average load of about 900 kg/ha. Each of AG-4, 10, 5, 13, 3, has an average load of about 359 kg/ha and each of AG-2, 14, 6, 7, 11, has an average load of 80 kg/ha. An equation was developed summarizing the products of percent area represented by each of the 3 loading categories and the loading values for each category. Consequently, the loading from agricultural land in the Canadian Great Lakes Drainage Basin has been determined to be:

$$\text{Annual unit area loading} = (7.8\% \times 900\ \text{kg/ha}) + (26.2\% \times 350\ \text{kg/ha}) + (66\% \times 80\ \text{kg/ha}) = 70.2 + 91.7 + 52.8 = 215\ \text{kg/ha}.$$

When mean sediment loads (NAQUADAT Method) were used for this calculation, a similar loading figure was obtained. In conclusion, the contribution from all agricultural lands in the Canadian Great Lakes Drainage Basin has been estimated to have a unit area suspended sediment load of 215 kg/ha/yr.

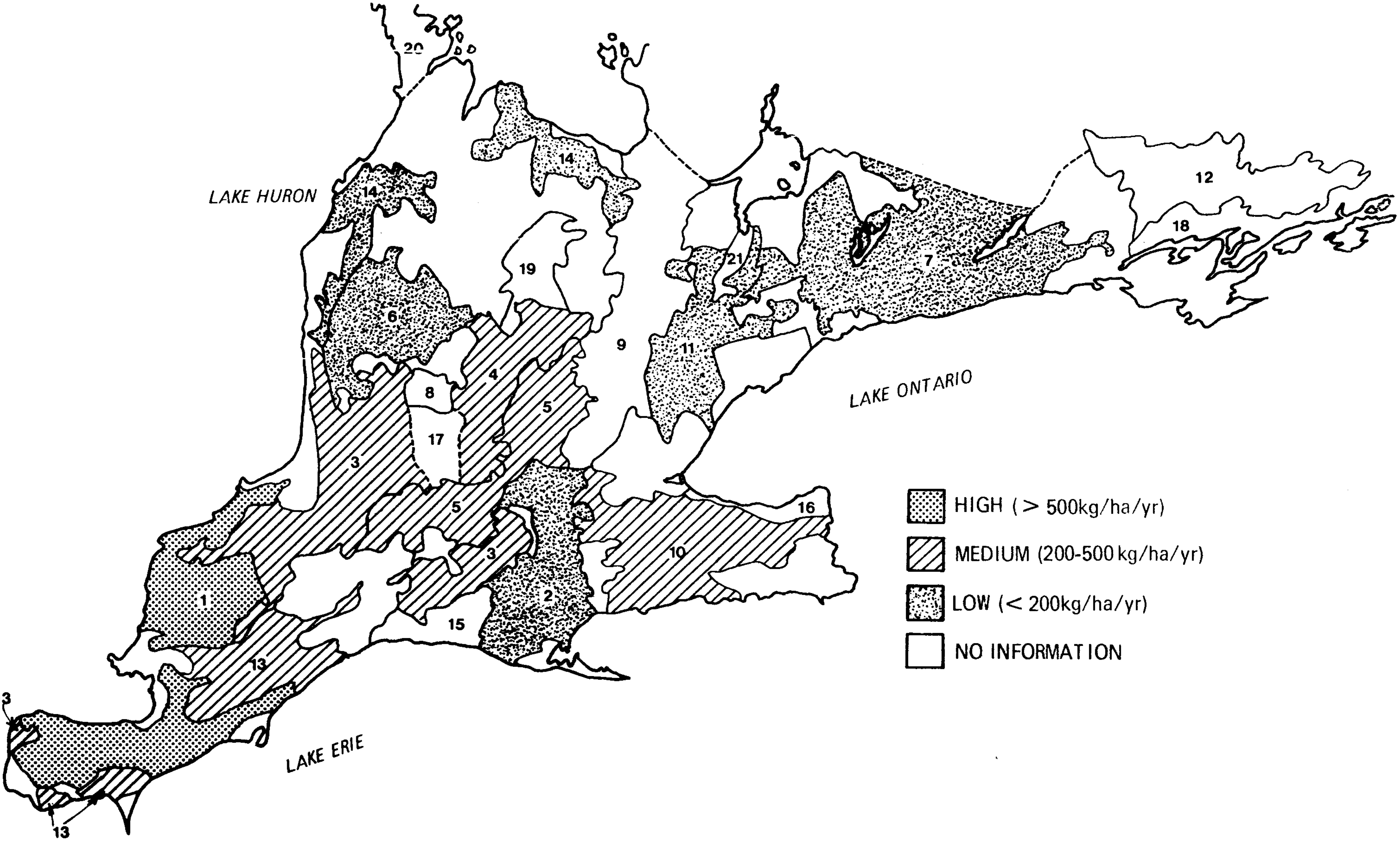


Figure 20: Spatial Distribution of Suspended Sediment Loads for Agricultural Land in Southern Ontario

9.2 Grand and Saugeen Rivers

This section discusses results of different approaches towards sediment load prediction in the Grand and Saugeen Rivers. Previous information and findings for the 11 agricultural watersheds have been used for extrapolation to both river basins.

9.2.1 Regression Equation

On the basis of generalized information for the 11 agricultural watersheds, a regression equation was developed for watershed parameters (independent variables) and 1976 unit area suspended sediment loads (NAQUADAT Method). The following watershed parameters were used in the regression analysis: % Clay, % Sand, Available P (ppm), Fertilizer P (kg/ha), Manure P (kg/ha), Total P added (kg/ha), % Hay + Pasture, % Alfalfa, % Woodlands, % Row Crops, % Corn, Animal units (per ha), Rural residences (houses/km^2), Stream density (km/km^2).

The sediment prediction equation has the form of:

$Y = -281.2 + (8.3 \times \%\ \text{row crops}) + (13.6 \times \%\ \text{clay})$, in which

Y is the predicted suspended sediment load.

This equation indicates that sediment load is a function of % row crops and % clay in the basins and explains 71% of the total variation in sediment load ($R^2 = 0.71$ at $P<0.05$).

The equation has also been used to predict sediment loads for the much larger subbasins of the Grand and Saugeen Rivers. For each subbasin, census data for 1976 has been used to extract % row crops and the % clay was determined from the Soil Association Map for Ontario. Results of the suspended sediment load predictions are presented in Table 25. Location of the subbasins for the Grand and Saugeen Rivers are shown in Appendix 8.

Comparison of predicted and 1976 measured suspended sediment loads for the subbasins of the Grand and Saugeen Rivers (Table 25) reveals that predicted loadings by the regression equation are lower than the measured ones, except for GR-6. The prediction for the Grand River is much better than that for the Saugeen River and within an order of magnitude of the measured values.

The predicted values reflect suspended sediment originating from cropland only. They do not include other sources that might contribute significantly to the measured sediment loads in the basins (e.g. streambank erosion, urbanization, construction). In addition, it has been observed in Chapter 2 that due to a relatively wet year, 1976 measured loadings might be higher than longterm average loadings. Differences between predicted and measured suspended sediment values are much smaller when the 2 year mean measured values (Onn *et al*, 1978) are used (Table 25).

Table 25: Suspended sediment loads, predicted for subbasins of the Saugeen and Grand Rivers in Ontario

SUBBASIN	ROW CROPS[1] (%)	CLAY (%)	SUSPENDED SEDIMENT LOADINGS (kg/ha/yr) Predicted	Measured[2]	Measured[3]
Saugeen					
SR- 1	7.1	16.1	-4	94	102
SR- 2	7.9	16.9	14	1758	930
SR- 3	8.7	16.5	15	188	210
SR- 4	16.6	16.4	80	139	92
SR- 5	5.3	19.3	26	191	162
SR- 6	10.8	18.3	57	298	-
Grand					
GR-13	7.7	20.0	55	69	51
GR-14	12.7	28.2	208	409	274
UL-22	23.3	19.0	171	915	417
GR-20	27.4	21.9	244	1240	688
GR- 6	36.5	15.3	230	145	142
GR-11	28.3	19.3	217	942	493
GR- 5	29.1	19.8	229	940	373
GR-15	28.3	20.1	227	459	332

$Y = -281.2 + (8.3 \times \%\ \text{row crops}) + (13.6 \times \%\ \text{clay})$

[1] Row crops include corn (silage + grain), soybeans, potatoes, tobacco, vegetables, expressed as % of total area in farmland

[2] Beale ratio estimator method, for 1976 data

[3] M.O.E. regression method, 2 year mean 1975-1976 (Onn *et al.*, 1978)

In light of the aforementioned findings, it is concluded that extrapolation to large basins (Grand and Saugeen Rivers) based on data collected for the small agricultural watersheds appears to give reasonable suspended sediment load predictions. Further data on extrapolation of sediment loads are included in the sediment integration paper (Wall *et al*., 1978).

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APPENDIX

APPENDIX 1

Predicted sheet and rill erosion losses for representative agricultural watersheds in 1976.

- 1976 sheet and rill erosion losses for AG-3
  (Little Ausable River)
- 1976 sheet and rill erosion losses for AG-4
  (Canagagigue Creek)
- 1976 sheet and rill erosion losses for AG-5
  (Holiday Creek)
- 1976 sheet and rill erosion losses for AG-10
  (North Creek Branch of Twenty Mile Creek)
- 1976 sheet and rill erosion losses for AG-13
  (Hillman Creek, West Branch)

1976 Sheet and rill erosion losses for AG-3 (Little Ausable River)

MONTH	"R" VALUE		AVERAGE SOIL LOSS RATIOS (C)	RxC	RxC (%)	SOIL LOSS			
							ADJUSTED FOR SNOW		
	1976	LONGTERM				(metric tons)	(%)	(metric tons)	(ton/ha)
JANUARY	1.78	0.46	0.35	0.623	1.5	1113.8	3.5	2598.8	0.419
FEBRUARY	3.21	0.69	0.35	1.124	2.6	1930.5	5.6	4158.0	0.671
MARCH	0	0.74	0.35	0	0	0	10.0	7425.0	1.198
APRIL	19.73	4.15	0.35	6.906	16.1	11954.3	16.1	11954.3	1.928
MAY	8.88	4.53	0.35	3.108	7.2	5346.0	7.2	5346.0	0.862
JUNE	12.88	9.06	0.48	6.182	14.4	10692.0	14.4	10692.0	1.725
JULY	60.79	15.34	0.33	20.061	46.8	34749.1	46.8	34749.1	5.605
AUGUST	10.51	15.99	0.16	1.682	3.9	2895.8	3.9	2895.8	0.467
SEPTEMBER	17.26	8.59	0.16	2.762	6.4	4752.0	6.4	4752.0	0.766
OCTOBER	1.97	3.48	0.23	0.453	1.1	816.8	1.1	816.8	0.132
NOVEMBER	0	1.68	0.35	0	0	0	0	0	0
DECEMBER	0	1.11	0.35	0	0	0	0	0	0
YEAR	137.01	65.82		42.901	100.0	74250.3	115.0	85387.8	13.773

1976 Sheet and rill erosion losses for AG-4 (Canagagigue Creek)

MONTH	"R" VALUE		AVERAGE SOIL LOSS RATIOS (C)	RxC	RxC (%)	SOIL LOSS			
	1976	LONGTERM				(metric tons)	ADJUSTED FOR SNOW (%)	(metric tons)	(ton/ha)
JANUARY	2.38	0.40	0.28	0.666	3.6	155.6	5.6	242.1	0.130
FEBRUARY	3.80	1.22	0.28	1.064	5.7	246.4	8.7	376.1	0.202
MARCH	6.22	1.18	0.28	1.742	9.4	406.3	19.4	838.6	0.451
APRIL	12.50	4.21	0.28	3.500	18.8	812.6	18.8	812.6	0.437
MAY	8.56	4.38	0.33	2.825	15.2	657.0	15.2	657.0	0.353
JUNE	34.06	17.33	0.20	6.812	36.5	1577.7	36.5	1577.7	0.848
JULY	16.66	19.99	0.05	0.833	4.5	194.5	4.5	194.5	0.105
AUGUST	0	19.25	0.05	0	0	0	0	0	0
SEPTEMBER	9.67	7.68	0.08	0.774	4.2	181.5	4.2	181.5	0.098
OCTOBER	4.93	6.42	0.08	0.394	2.1	90.8	2.1	90.8	0.049
NOVEMBER	0	5.63	0.28	0	0	0	0	0	0
DECEMBER	0	0.96	0.28	0	0	0	0	0	0
YEAR	98.78	88.65		18.610	100.0	4322.6	115.0	4970.9	2.673

1976 Sheet and rill erosion losses for AG-5 (Holiday Creek)

MONTH	"R" VALUE		AVERAGE SOIL LOSS RATIOS	RxC	RxC	SOIL LOSS			
							ADJUSTED FOR SNOW		
	1976	LONGTERM	(C)		(%)	(metric tons)	(%)	(metric tons)	(ton/ha)
JANUARY	2.45	0.46	0.54	1.323	1.4	891.2	3.4	2164.4	0.721
FEBRUARY	0	0.69	0.54	0	0	0	3.0	1909.7	0.637
MARCH	13.63	0.74	0.54	7.360	7.8	4965.3	17.8	11331.1	3.777
APRIL	15.55	4.15	0.54	8.397	8.9	5665.6	8.9	5665.6	1.889
MAY	14.99	4.53	0.65	9.744	10.3	6556.8	10.3	6556.8	2.186
JUNE	6.77	9.06	0.44	2.979	3.1	1973.4	3.1	1973.4	0.658
JULY	135.28	15.34	0.19	25.703	27.2	17315.0	27.2	17315.0	5.772
AUGUST	163.1	15.99	0.19	30.989	32.8	20879.9	32.8	20879.9	6.959
SEPTEMBER	11.7	8.59	0.36	4.212	4.4	2800.9	4.4	2800.9	0.934
OCTOBER	8.49	3.48	0.36	3.056	3.2	2037.1	3.2	2037.1	0.679
NOVEMBER	1.51	1.68	0.54	0.815	0.9	572.9	0.9	572.9	0.191
DECEMBER	0	1.11	0.54	0	0	0	0	0	0
YEAR	373.47	65.82		94.579	100.0	63658.1	115.0	73206.8	24.402

1976 Sheet and rill erosion losses for AG-13 (Hillman Creek Watershed, West Branch)

MONTH	"R" VALUE		AVERAGE SOIL LOSS RATIOS (C)	RxC	RxC (%)	SOIL LOSS			
							ADJUSTED FOR SNOW		
	1976	LONGTERM				(metric tons)	(%)	(metric tons)	(ton/ha)
JANUARY	5.32	0.53	0.45	2.394	4.4	908.8	5.4	1115.3	0.560
FEBRUARY	17.99	1.03	0.45	8.096	14.9	3077.5	16.9	3490.6	1.754
MARCH	12.33	1.81	0.45	5.549	10.2	2106.8	17.2	3552.6	1.785
APRIL	11.52	4.71	0.45	5.184	9.6	1982.8	9.6	1982.8	0.996
MAY	5.13	6.32	0.65	3.335	6.1	1259.9	6.1	1259.9	0.633
JUNE	24.23	16.69	0.53	12.842	23.7	4895.1	23.7	4895.1	2.459
JULY	35.36	26.27	0.26	9.194	17.0	3511.3	17.0	3511.3	1.764
AUGUST	0	20.72	0.26	0	0	0	0	0	0
SEPTEMBER	16.82	7.59	0.26	4.373	8.1	1673.0	8.1	1673.0	0.841
OCTOBER	4.79	4.48	0.45	2.156	3.9	805.5	3.9	805.5	0.405
NOVEMBER	2.49	1.65	0.45	1.121	2.1	433.7	2.1	433.7	0.218
DECEMBER	0	3.20	0.45	0	0	0	0	0	0
YEAR	135.98	95.0		54.241	100.0	20654.6	110.0	2272.0	11.417

1976 Sheet and rill erosion losses for AG-10 (North Creek Branch of Twenty Mile Creek)

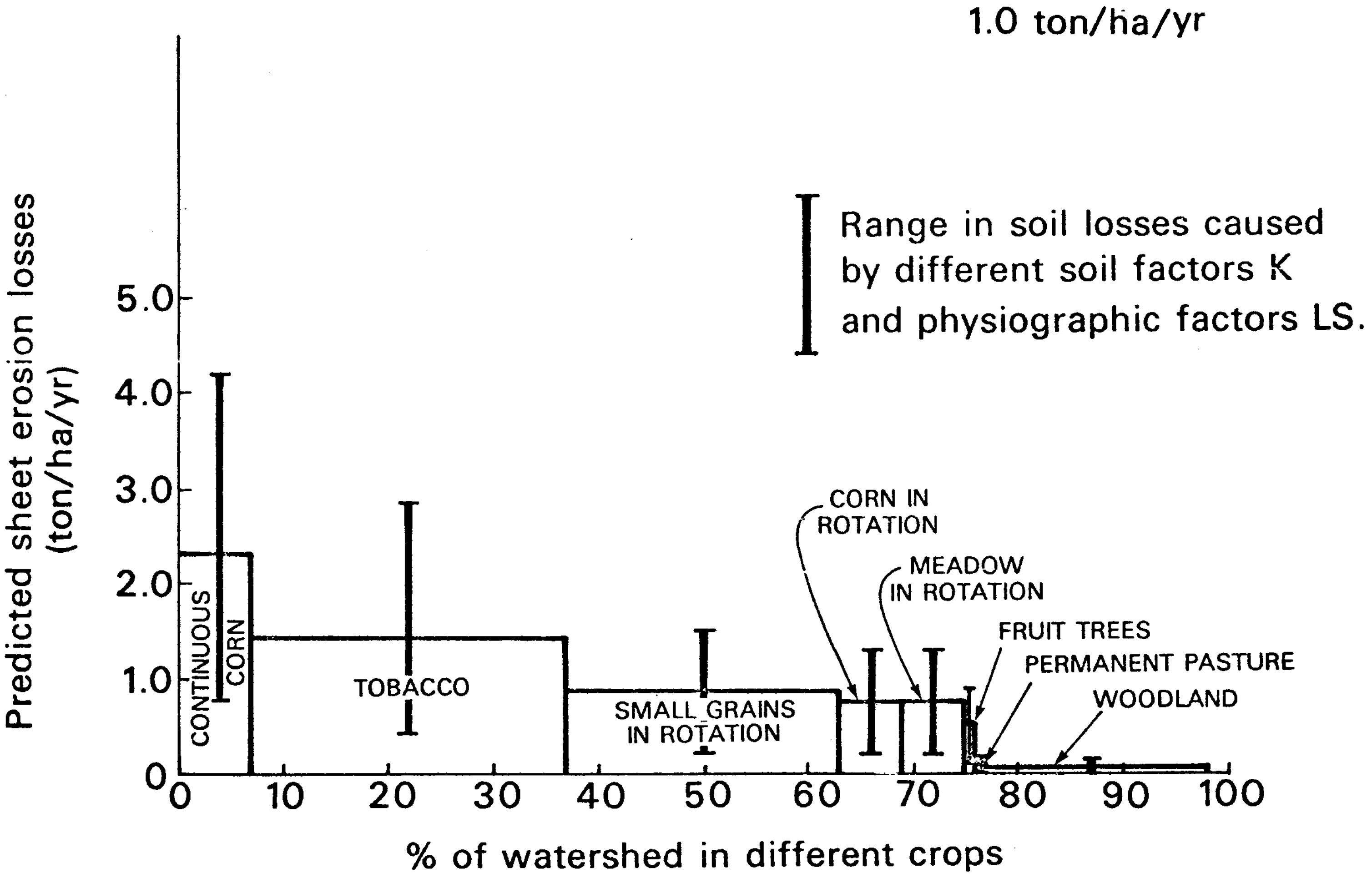
MONTH	"R" VALUE		AVERAGE SOIL LOSS RATIOS (C)	RxC	RxC (%)	SOIL LOSS			
	1976	LONGTERM				(metric tons)	ADJUSTED FOR SNOW (%)	(metric tons)	(ton/ha)
JANUARY	2.18	0.34	0.43	0.937	2.2	105.6	3.2	153.7	0.051
FEBRUARY	1.77	0.71	0.43	0.761	1.8	86.4	3.8	182.5	0.060
MARCH	12.02	1.50	0.43	5.169	12.2	585.8	19.2	921.9	0.305
APRIL	16.30	3.14	0.43	7.009	16.6	797.1	16.6	797.1	0.264
MAY	17.24	3.54	0.43	7.413	17.5	840.4	17.5	840.4	0.278
JUNE	25.67	11.00	0.58	14.889	35.1	1685.5	35.1	1685.5	0.557
JULY	9.24	12.76	0.38	3.511	8.3	398.6	8.3	398.6	0.132
AUGUST	2.37	16.18	0.16	0.379	0.9	43.2	0.9	43.2	0.014
SEPTEMBER	7.13	7.39	0.16	1.141	2.7	129.7	2.7	129.7	0.043
OCTOBER	2.60	5.61	0.19	0.494	1.2	57.6	1.2	57.6	0.019
NOVEMBER	0	2.21	0.43	0	0	0	0	0	0
DECEMBER	1.50	0.78	0.43	0.645	1.5	72.0	1.5	72.0	0.024
YEAR	98.02	65.16		42.348	100.0	4802.0	110.0	5282.2	1.746

APPENDIX 2

Predicted Longterm Average Annual Sheet Erosion Losses for Representative Agricultural Watersheds

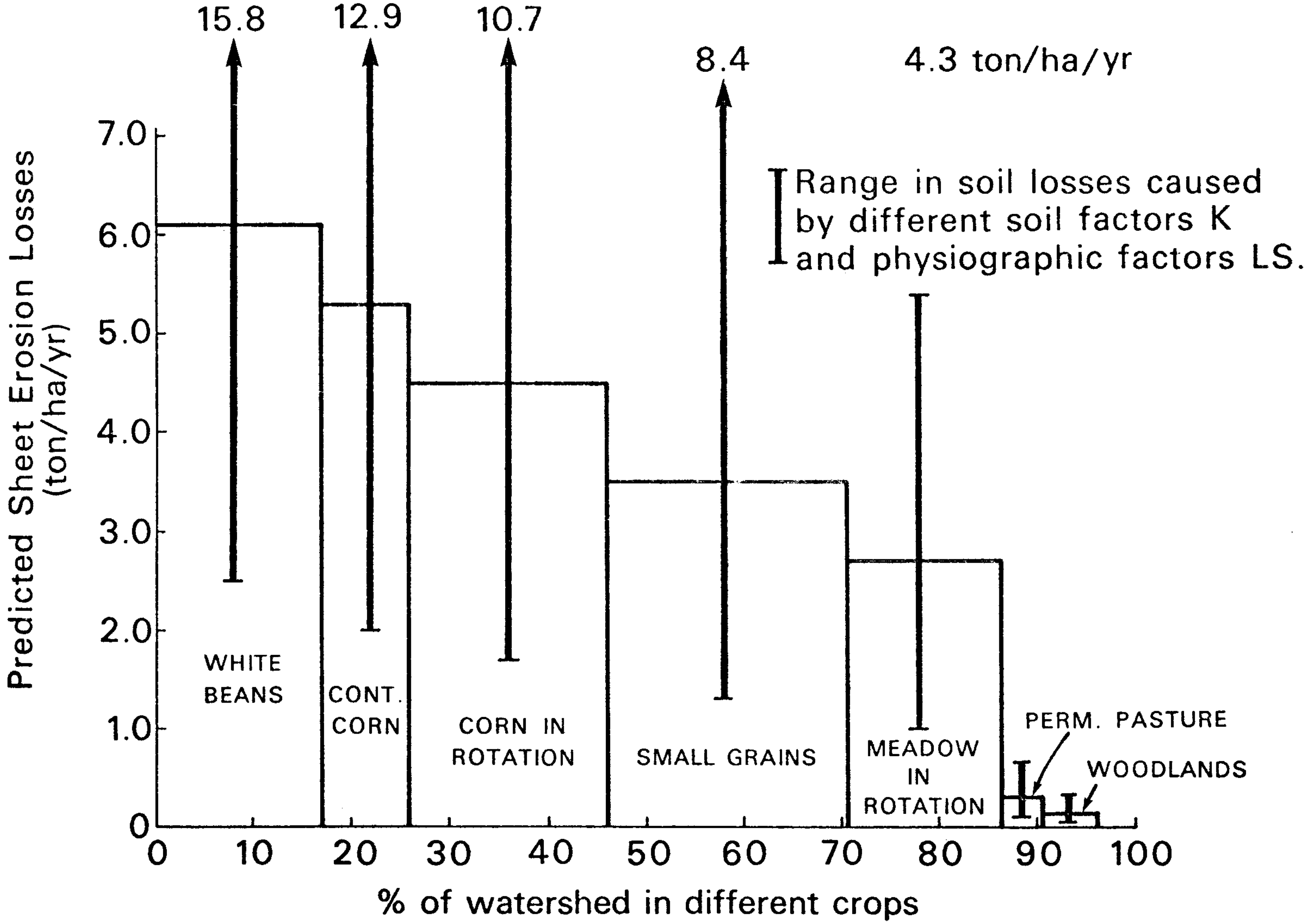
- Longterm average annual predicted erosion losses for AG-2
- Longterm average annual predicted erosion losses for AG-3
- Longterm average annual predicted erosion losses for AG-4
- Longterm average annual predicted erosion losses for AG-5
- Longterm average annual predicted erosion losses for AG-6
- Longterm average annual predicted erosion losses for AG-7
- Longterm average annual predicted erosion losses for AG-10
- Longterm average annual predicted erosion losses for AG-11
- Longterm average annual predicted erosion losses for AG-13
- Longterm average annual predicted erosion losses for AG-14

AG-2

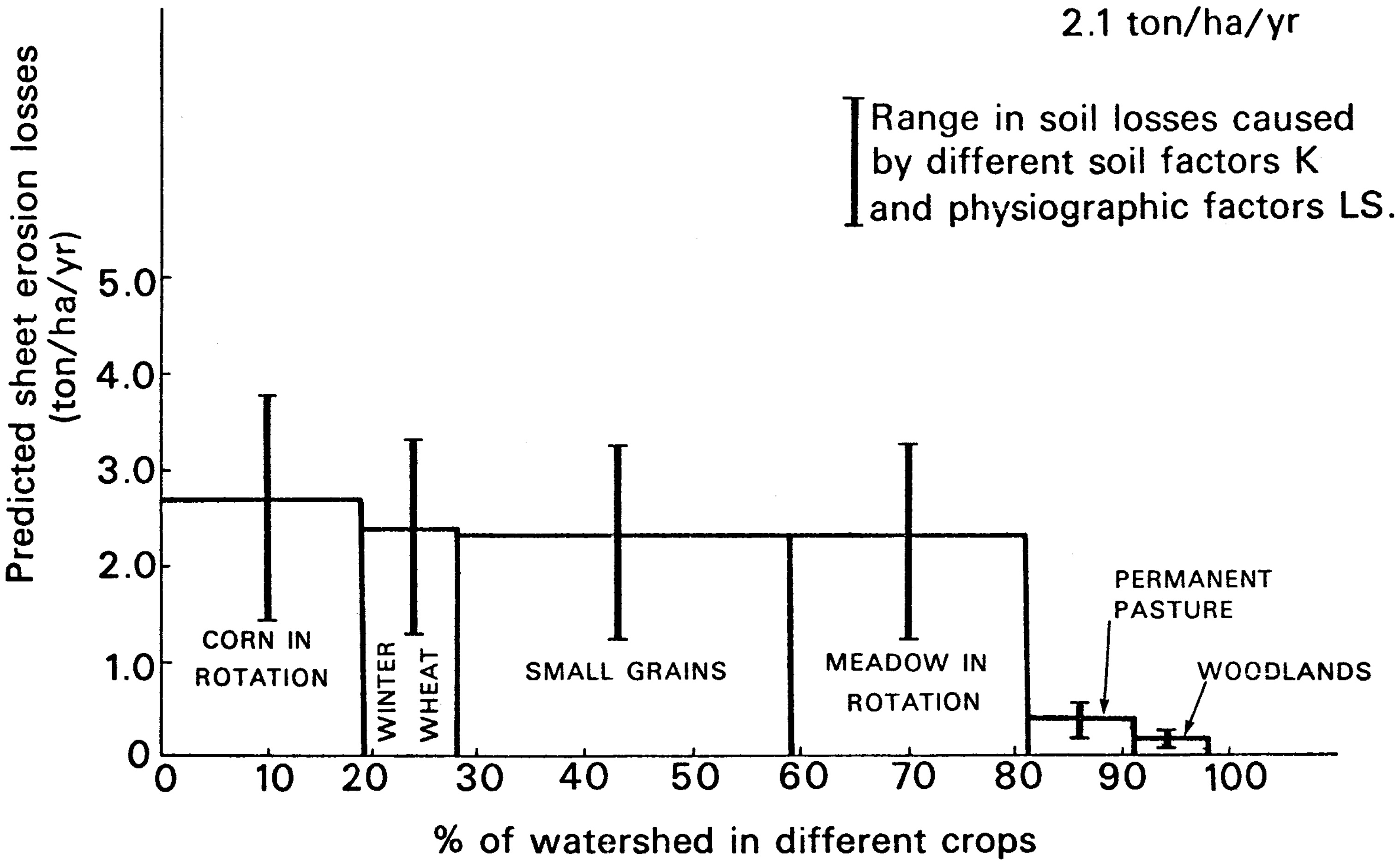


1.0 ton/ha/yr
Range in soil losses caused by different soil factors K and physiographic factors LS.
Predicted sheet erosion losses (ton/ha/yr)
5.0
4.0
3.0
2.0
1.0
0
CONTINUOUS CORN
TOBACCO
SMALL GRAINS IN ROTATION
CORN IN ROTATION
MEADOW IN ROTATION
FRUIT TREES
PERMANENT PASTURE
WOODLAND
0
10
20
30
40
50
60
70
80
90
100
% of watershed in different crops

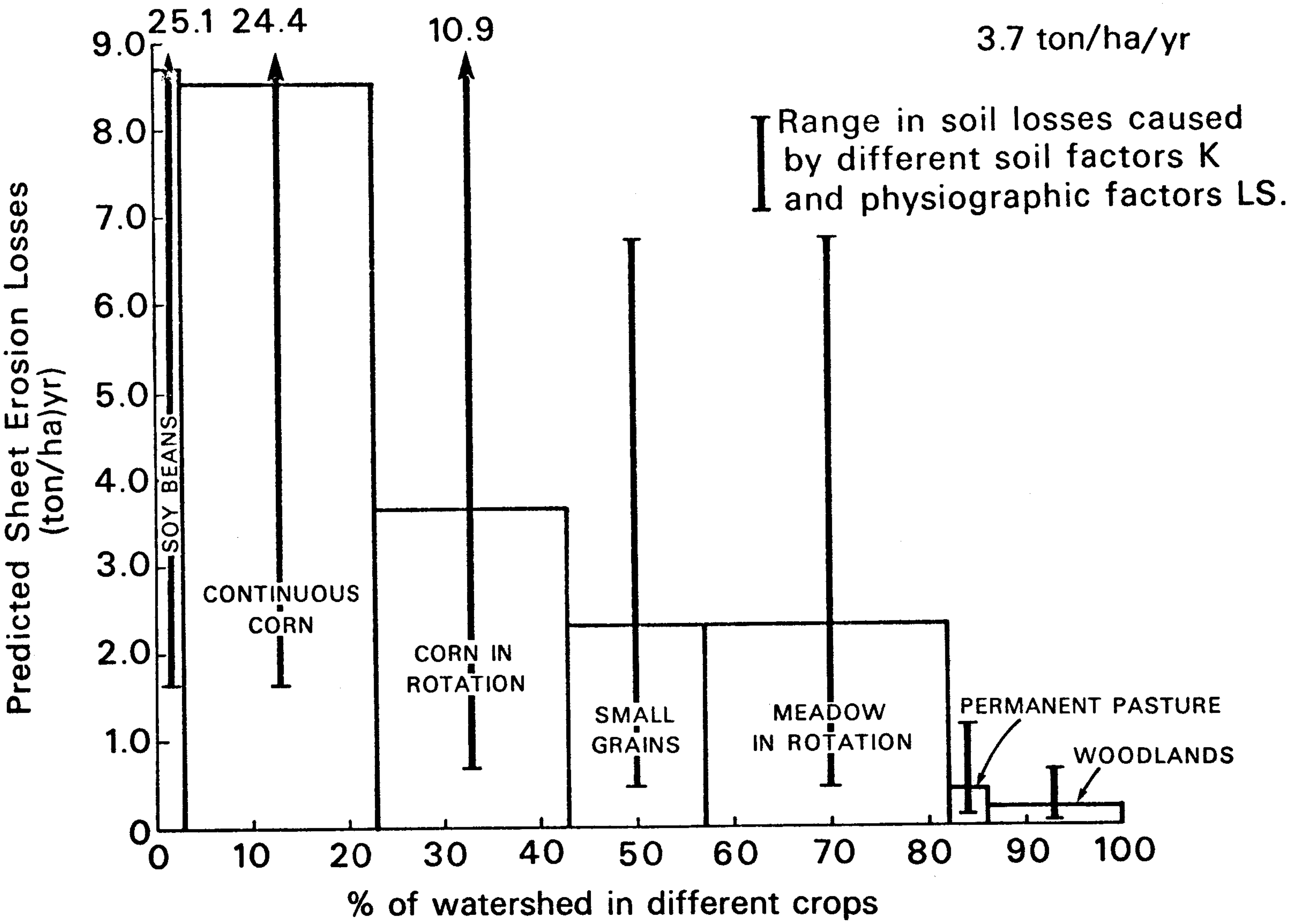
AG-3


15.8
12.9
10.7
8.4
4.3 ton/ha/yr
Range in soil losses caused by different soil factors K and physiographic factors LS.
Predicted Sheet Erosion Losses (ton/ha/yr)
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0
WHITE BEANS
CONT. CORN
CORN IN ROTATION
SMALL GRAINS
MEADOW IN ROTATION
PERM. PASTURE
WOODLANDS
0
10
20
30
40
50
60
70
80
90
100
% of watershed in different crops

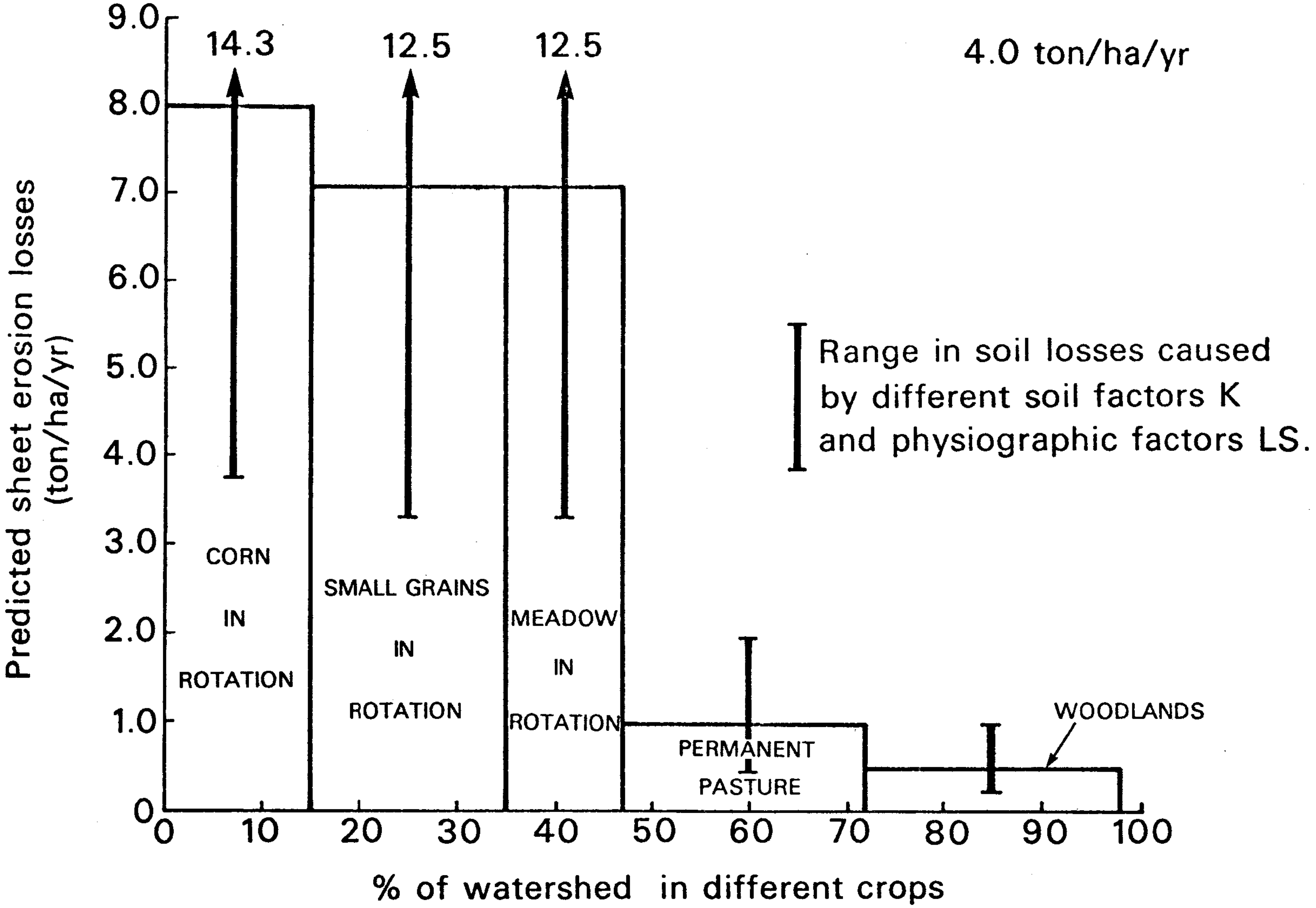
AG-4


2.1 ton/ha/yr
Range in soil losses caused by different soil factors K and physiographic factors LS.
Predicted sheet erosion losses (ton/ha/yr)
5.0
4.0
3.0
2.0
1.0
0
CORN IN ROTATION
WINTER WHEAT
SMALL GRAINS
MEADOW IN ROTATION
PERMANENT PASTURE
WOODLANDS
0
10
20
30
40
50
60
70
80
90
100
% of watershed in different crops

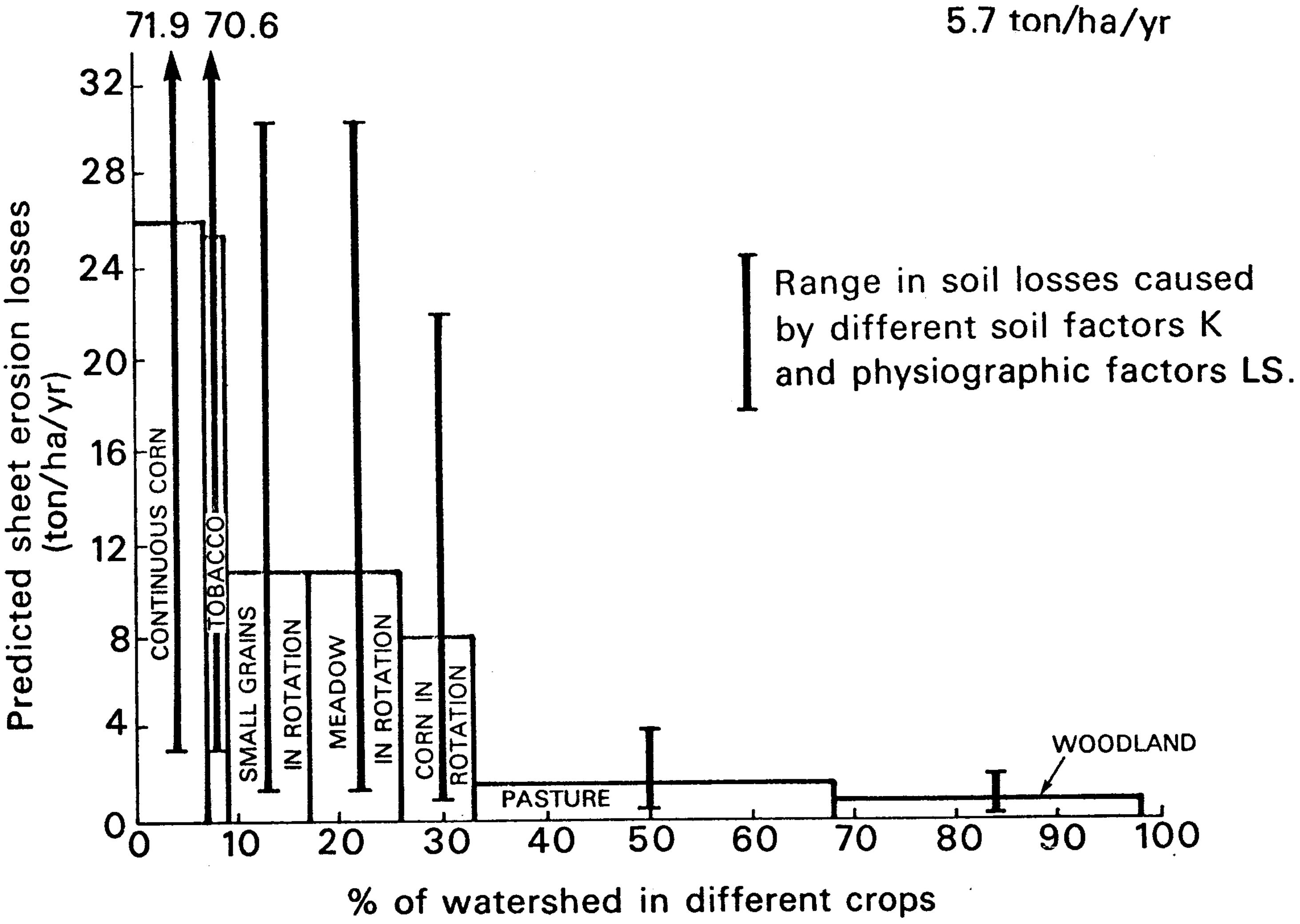
AG-5

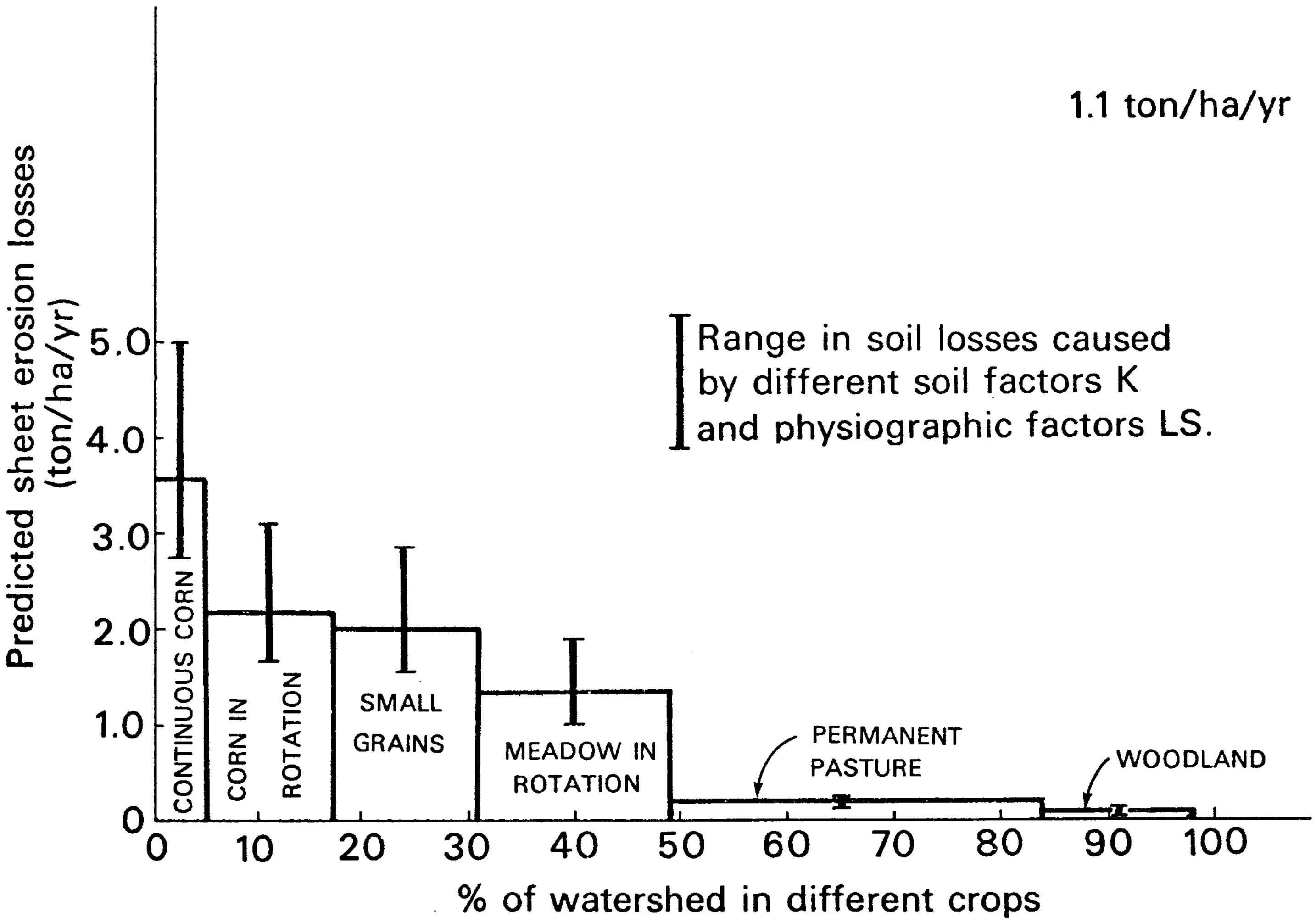

25.1
24.4
10.9
3.7 ton/ha/yr
Range in soil losses caused by different soil factors K and physiographic factors LS.
Predicted Sheet Erosion Losses (ton/ha)yr)
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0
SOY BEANS
CONTINUOUS CORN
CORN IN ROTATION
SMALL GRAINS
MEADOW IN ROTATION
PERMANENT PASTURE
WOODLANDS
0
10
20
30
40
50
60
70
80
90
100
% of watershed in different crops

AG-6

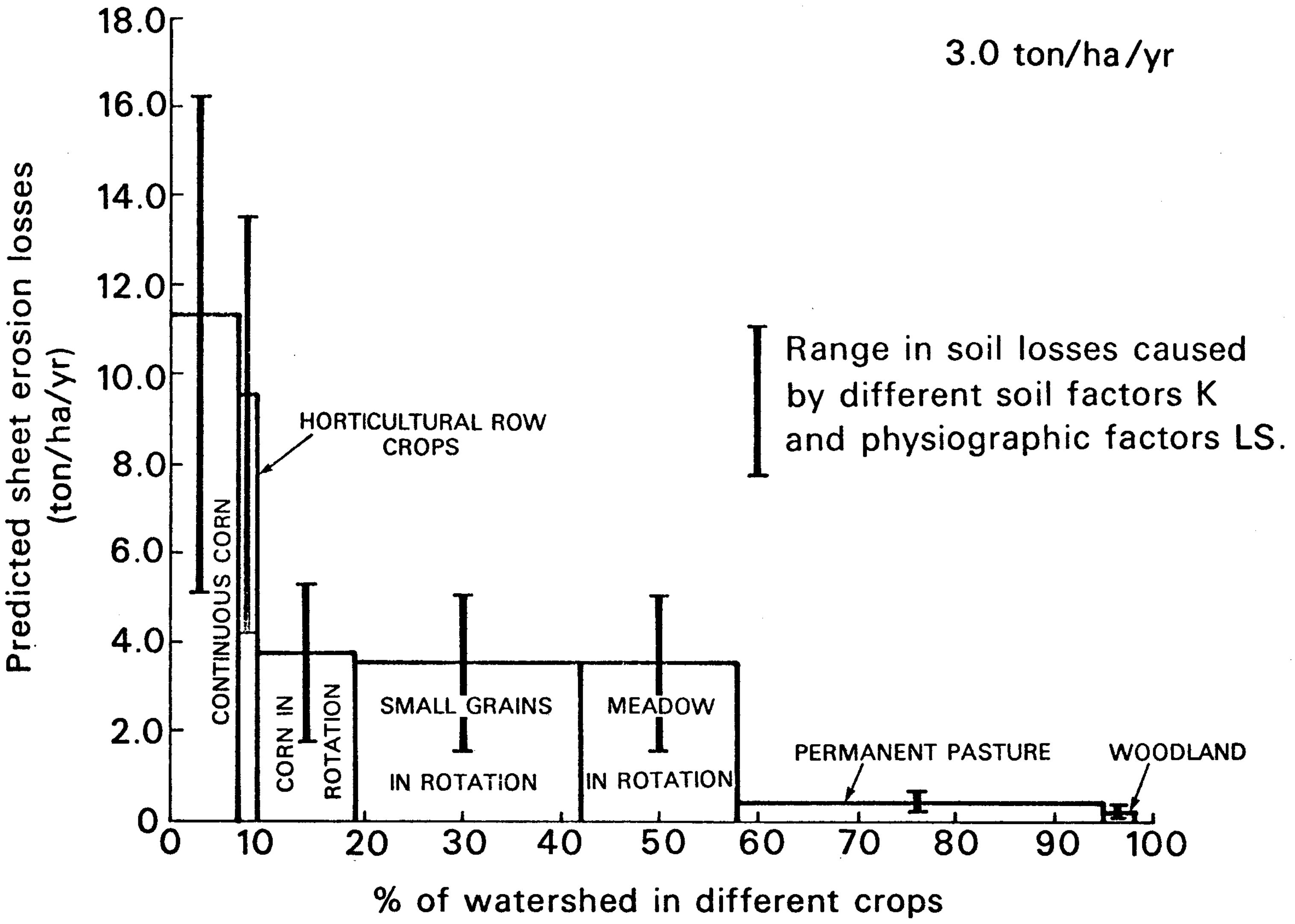

14.3
12.5
12.5
4.0 ton/ha/yr
Range in soil losses caused by different soil factors K and physiographic factors LS.
CORN IN ROTATION
SMALL GRAINS IN ROTATION
MEADOW IN ROTATION
PERMANENT PASTURE
WOODLANDS
Predicted sheet erosion losses (ton/ha/yr)
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0
0
10
20
30
40
50
60
70
80
90
100
% of watershed in different crops

AG-7

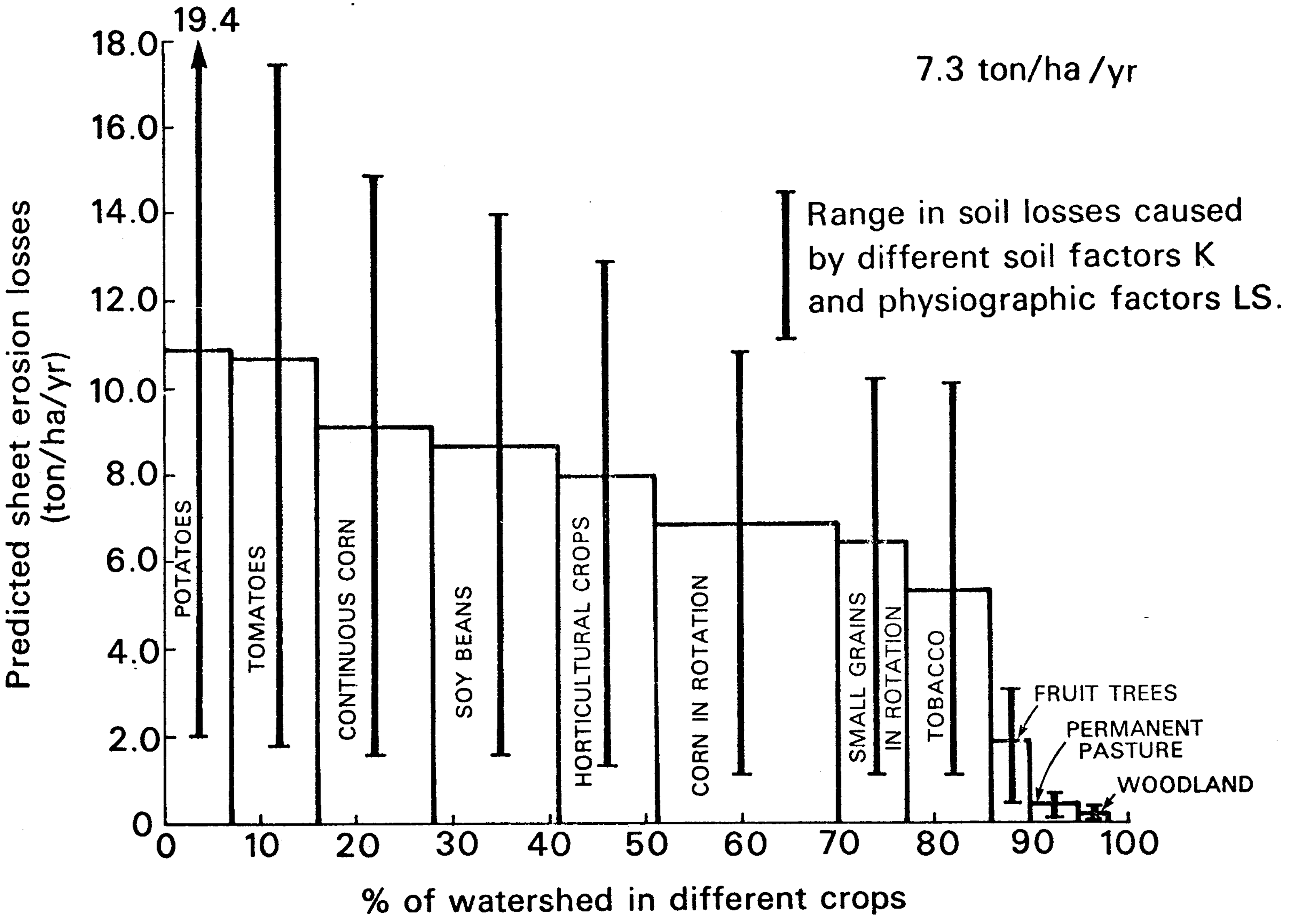

71.9
70.6
5.7 ton/ha/yr
Predicted sheet erosion losses (ton/ha/yr)
0
4
8
12
16
20
24
28
32
CONTINUOUS CORN
TOBACCO
SMALL GRAINS IN ROTATION
MEADOW IN ROTATION
CORN IN ROTATION
PASTURE
WOODLAND
Range in soil losses caused by different soil factors K and physiographic factors LS.
0
10
20
30
40
50
60
70
80
90
100
% of watershed in different crops


1.1 ton/ha/yr
Range in soil losses caused by different soil factors K and physiographic factors LS.
Predicted sheet erosion losses (ton/ha/yr)
5.0
4.0
3.0
2.0
1.0
0
CONTINUOUS CORN
CORN IN ROTATION
SMALL GRAINS
MEADOW IN ROTATION
PERMANENT PASTURE
WOODLAND
0
10
20
30
40
50
60
70
80
90
100
% of watershed in different crops

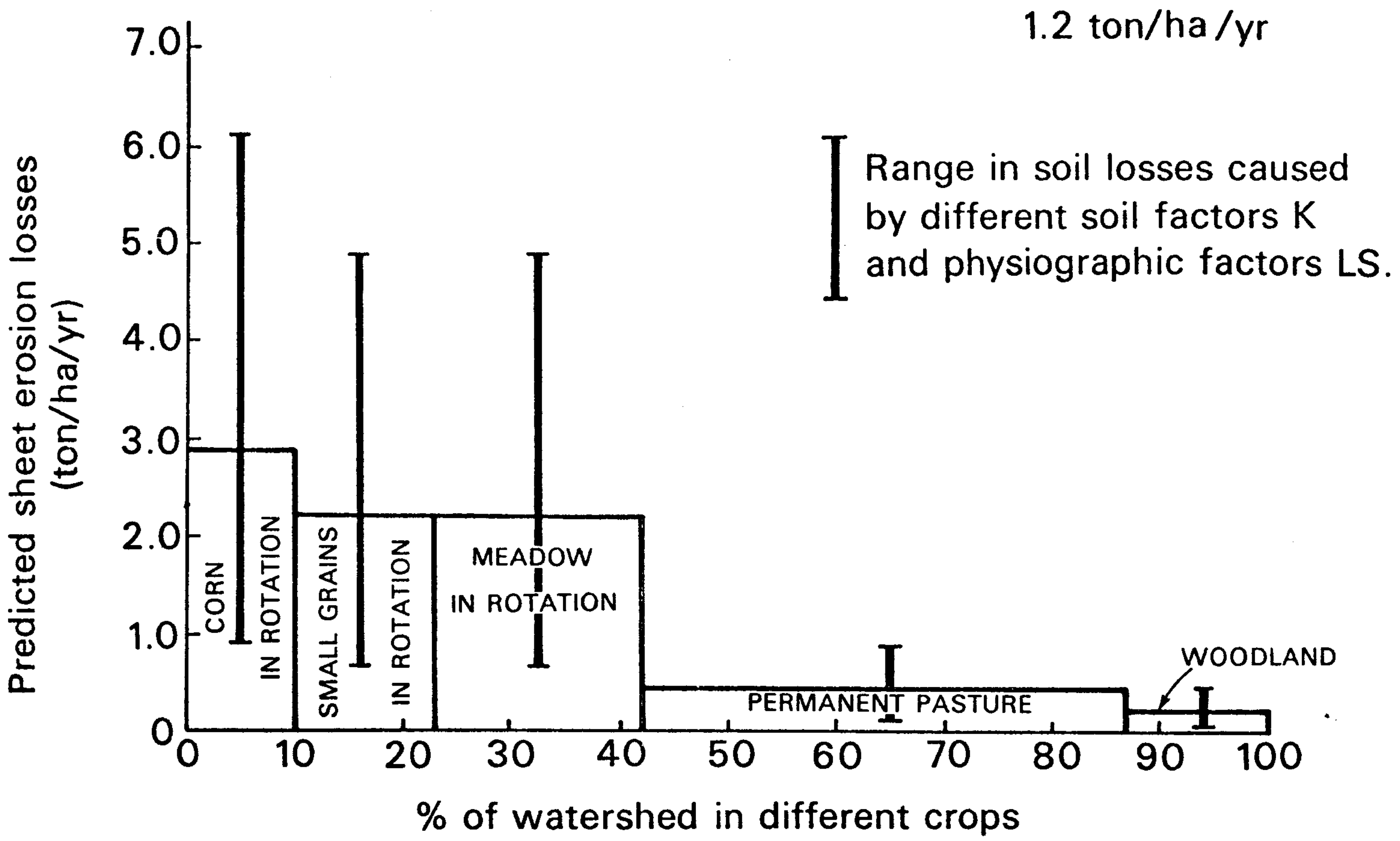
AG-11


3.0 ton/ha/yr
Range in soil losses caused by different soil factors K and physiographic factors LS.
Predicted sheet erosion losses (ton/ha/yr)
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0
CONTINUOUS CORN
HORTICULTURAL ROW CROPS
CORN IN ROTATION
SMALL GRAINS IN ROTATION
MEADOW IN ROTATION
PERMANENT PASTURE
WOODLAND
0
10
20
30
40
50
60
70
80
90
100
% of watershed in different crops

AG-13



19.4
7.3 ton/ha /yr
Range in soil losses caused by different soil factors K and physiographic factors LS.
Predicted sheet erosion losses (ton/ha/yr)
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0
POTATOES
TOMATOES
CONTINUOUS CORN
SOY BEANS
HORTICULTURAL CROPS
CORN IN ROTATION
SMALL GRAINS IN ROTATION
TOBACCO
FRUIT TREES
PERMANENT PASTURE
WOODLAND
0
10
20
30
40
50
60
70
80
90
100
% of watershed in different crops


1.2 ton/ha/yr
Range in soil losses caused by different soil factors K and physiographic factors LS.
Predicted sheet erosion losses (ton/ha/yr)
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0
CORN
IN ROTATION
SMALL GRAINS
IN ROTATION
MEADOW IN ROTATION
PERMANENT PASTURE
WOODLAND
0
10
20
30
40
50
60
70
80
90
100
% of watershed in different crops

APPENDIX 3

Detailed Analysis of Several Computational Methods for Estimation of Fluvial Sediment Loads

In order to ascertain the accuracy and precision associated with the application of various sediment loading computational methods to various sampling frequencies of suspended sediment concentrations, the following study stages were designed and performed:

1. Three years of daily suspended sediment loading data for the Big Otter Creek in Southern Ontario (Sediment Data for Canadian Rivers-1971, 1972, 1973) were selected as a base population. In addition to the daily suspended sediment loads, daily streamflow values, sampled concentration values and estimated mean daily concentrations were available.

2. Four sampling frequencies were selected for application to the base population. These frequencies included: (i) one concentration sample per month for only the summer months i.e. April through October, (ii) one sample per month for the year, (iii) one sample per week for the year and (iv) one sample per week plus one sample on each day when the daily flow exceeded a selected extreme value. The three year population was sampled three times at each frequency, yielding nine effective years of sampling.

3. Five computational methods were applied to the various samples of suspended sediment concentration values in conjunction with the record of daily flows to compute estimates of annual sediment loads. Each method is identified below:

   a) Simple equation:

$$Q_s = c \times Q$$

where

Q_s is the estimated annual suspended sediment load,

c is the mean of the suspended sediment concentration samples obtained during the year, and

Q is the annual streamflow.

b) Linear interpolation:

$$Q_s = \sum_{i=1}^{365} ci \ X \ Qi$$

where

Q_s is as defined above,
ci is the estimated mean daily sediment concentration (i.e. the sampled value for a sampled day, or a linearly interpolated value between sampled values for those days when concentration was not sampled), and
Qi is the mean daily streamflow.

c) Beale ratio estimates:

Q_s was estimated by the ratio estimator procedure outlined in 1977 by the IJC for use in PLUARG activities.

d) Single rating curve:

The equation given in (b) above was used, with the c_i values determined from a sediment concentration vs streamflow rating curve determined from the sampled concentrations for each year of sampling.

e) Moving rating curve:

This method was similar to (d) in that sediment rating curves were used. However, many rating curves were developed for each year of sampling on the basis of small groups of concentration samples appropriate to the particular flow conditions. This method is essentially the same as that which has been termed the Integration Method in this and other IJC reports.

4. The mean ratio of the estimated annual suspended sediment load to the population suspended sediment load (i.e. $\hat{Q}_s/Q_s$) was determined for each sampling frequency and each computational method as an index of the accuracy. In figure A-3.1, the summer month sampling is coded SM, monthly sampling M, weekly sampling W, and weekly sampling including extreme events WE. The simple equation for computing loads is referred to as SIMPLE ANNUAL, Linear interpolation and Beale ratio estimates as such, single rating curve as C x Q and Moving rating curve as C x (Q, season, etc.).

5. The standard duration of the $\hat{Q}_S/Q_S$ ratio was also determined for each sampling frequency and each method as an index of precision. (see Figure A-3.1).

The summary of results presented in Figure A-3.1 reveal the following:

- The multiple rating curve (or integration) method is the most accurate and the most precise method of those tested for all but the lowest sampling frequency.

- The simple annual equation is reasonably precise but very inaccurate. If the inaccuracy were consistent from river to river, a simple correction could be applied (in light of the precision).

- The Beale ratio estimator is reasonably accurate at the highest sampling frequencies, is the only method to overpredict on the average at the highest frequency and is the least precise of the methods tested. This last observation is critical when the method is applied to only one or two years of data.

- The linear interpolation and single rating curve are reasonably accurate and moderately precise at the highest sampling frequencies.

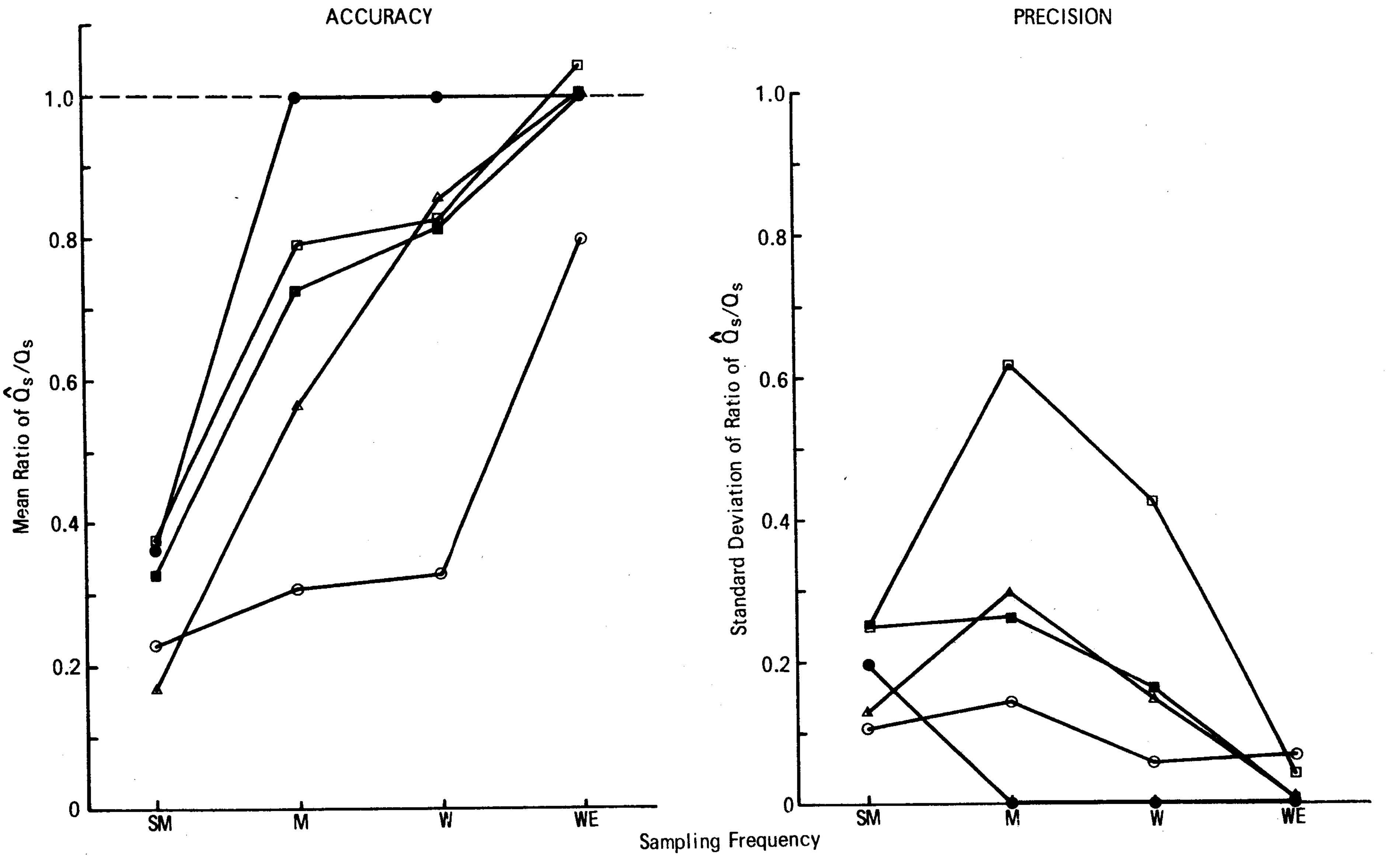


Figure A-3.1: The mean and standard deviation of the ratio $\hat{Q}_s/Q_s$ as indices of the accuracy and precision of various sampling frequencies and computational methods for determining sediment loads.

APPENDIX 4

Measured Monthly Suspended Sediment Loads for 11 Agricultural Watersheds and 4 Subbasins of AG-4 and AG-5 (kg/ha/1976).

APPENDIX 4: Measured Suspended Sediment Loads by Month for 11 Agricultural Watersheds[1] and 4 Subbasins of AG-4 and AG-5[2] (kg/ha/1976)

MONTH	AG-1[1]	AG-2	AG-3	AG-4	AG-5	AG-6	AG-7	AG-10	AG-11	AG-13	AG-14	AG-4		AG-5	
												W_1[2]	W_2	H_1	H_2
January	5	9	4	0.5	6	3	2	6	0.1	13	3	0	1[4]	0	0
February	834	30	42	15	42	4	3	55	5	121	7	0	16[4]	0	1
March	104	46	60	361	38	29	14	87	13	104	110	869	356	68	122
April	13	22	80	14	4	17	10	111	1	50	0.5	19	18	4	7
May	8	12	5	13	12	3	4	108	0.4	11	0.8	7	18	3	3
June	5	5	0.5	3	0.2	1	3	0.6	0[3]	7	3	0	4	0	0
July	28	3	54	2	105	2	2	4	0	0.7	2	0	7	45	92
August	0	4	5	0	135	2	1	0.5	0	0.3	0	0	0	204	135
September	0.1	2	0.3	1	0.4	1	0.6	0.5	0	1	0	0	1	3	3
October	0.1	1	0.3	3	1	1	0.5	0.8	0	0.8	0.2	0	2	1	1
November	0	2	9	7	7	0.5	2	0.2	0	0.2	9	0	7[4]	1	1
December	0.1	3	0.7	0.4	0.6	1	0.7	1.4	0	1	0.7	0	0[4]	0	1
Year (1976)	998	140	258	419	351	64	43	375	19.1	310	135	895	430	329	366

[1] Naquadat method of sediment load computation for the 11 watersheds

[2] Integration method of sediment load computations for the four subbasins

[3] Problems with flow measurements from June 1976 - December 1976

[4] Estimated values

APPENDIX 5

Monthly suspended sediment loads (Naquadat Method) for the 11 agricultural watersheds, measured data.

AG-1	(Big Creek)
AG-2	(Venison Creek)
AG-3	(Little Ausable)
AG-4	(Canagagigue Creek)
AG-5	(Holiday Creek)
AG-6	Nameless
AG-7	(Shelter Valley)
AG-10	(North Creek)
AG-11	(Salt Creek)
AG-13	(Hillman Creek)
AG-14	(Mill Creek)

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REQUEST 0001            CUMMULATIVE MASS FLOW OF WATER QUALITY CONSTITUENTS
                         RESIDUE LOADINGS FOR DICK
                        FOR PERIOD 010375  TO  300677


  00PA02GE0100              AG-1: BIG CK.,TRIB.OF THAMES R.,.25MI. W.OF  STRANGFIELD,W.TILBURY TWP.,ESSEX CO.,
                                  51.8 SQ.KM.;CASH CROP,TILE DRAINS;CLAY SOIL;HIGH SHEET AND BANK EROSION POT.

                                  CUMULATIVE POUNDS OF CONSTITUENT BETWEEN 01 03 1975 AND DATE SHOWN

           D A T E                 RESIDUE
                                  NONFILTR.

                                    10405L

      01  03      75 EST                   0
      01  04      75 EST           1,313,010
      01  05      75 EST           1,388,737
      01  06      75 EST           1,392,979
      01  07      75 EST           8,249,411

      01  08      75 EST           8,256,789
      01  09      75 EST           8,378,680
      01  10      75 EST           8,735,502
      01  11      75 EST           8,739,251
      01  12      75 EST           8,742,210

      01  01      76 EST           8,905,802
      01  02      76 EST           8,951,389
      01  03      76 EST          18,303,005
      01  04      76 EST          19,469,063
      01  05      76 EST          19,616,364

      01  06      76 EST          19,715,002
      01  07      76 EST          19,765,216
      01  08      76 EST          20,074,970
      01  09      76 EST          20,074,970
      01  10      76 EST          20,075,703

      01  11      76 EST          20,076,825
      01  12      76 EST          20,076,943
      01  01      77 EST          20,077,860
      01  02      77 EST          20,077,860
      01  03      77 EST          20,077,860

      01  04      77 EST          21,575,053
      01  05      77 EST          21,833,825
      01  06      77 EST          21,886,589
      30  06      77 EST          21,973,199
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REQUEST 0001          CUMMULATIVE MASS FLOW OF WATER QUALITY CONSTITUENTS
                       RESIDUE LOADINGS FOR DICK
                      FOR PERIOD 010375  TO  300677


  00PA02GC0200            AG-2:   VENISON CK.TRIB.OF BIG CK.,ABOVE CONC. 7-8 BRIDGE,N.WALSINGHAM TP.,NORFOLK C
                                   .73.2 SQ.KM.;TOBACCO AND ASS.CROPS ON SANDS;LOW SHEET AND BANK EROSION POT.;

                                  CUMULATIVE POUNDS OF CONSTITUENT BETWEEN 01 03 1975 AND DATE SHOWN

             D A T E                RESIDUE
                                  NONFILTR.

                                    10405L

        01  03     75  EST                  0
        01  04     75  EST          1,390,395
        01  05     75  EST          1,736,511
        01  06     75  EST          1,801,771
        01  07     75  EST          1,955,064

        01  08     75  EST          2,518,023
        01  09     75  EST          2,610,770
        01  10     75  EST          2,745,814
        01  11     75  EST          2,805,452
        01  12     75  EST          2,899,495

        01  01     76  EST          3,021,597
        01  02     76  EST          3,185,159
        01  03     76  EST          3,712,861
        01  04     76  EST          4,513,925
        01  05     76  EST          4,880,049

        01  06     76  EST          5,085,287
        01  07     76  EST          5,179,692
        01  08     76  EST          5,238,802
        01  09     76  EST          5,313,452
        01  10     76  EST          5,347,469

        01  11     76  EST          5,367,503
        01  12     76  EST          5,391,120
        01  01     77  EST          5,429,046
        01  02     77  EST          5,445,686
        01  03     77  EST          5,552,722

        01  04     77  EST          6,455,657
        01  05     77  EST          6,588,950
        01  06     77  EST          6,824,482
        30  06     77  EST          6,834,741
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REQUEST 0001             CUMMULATIVE MASS FLOW OF WATER QUALITY CONSTITUENTS
                          RESIDUE LOADINGS FOR DICK
                         FOR PERIOD 010375  TO  300677


  00PA02FF0300              AG-3: LITTLE AUSABLE R.TRIB.OF AUSABLE R.1ST BRIDGE N.OF HURON-MIDDLESEX CO.LINE
                                  54.1 SQ.KM.;BEEF AND DAIRY, FEED AND   SOME CASH CROPS ON CLAY;HIGH SHEET AN

                                  CUMULATIVE POUNDS OF CONSTITUENT BETWEEN 01 03 1975 AND DATE SHOWN

           D A T E                 RESIDUE
                                  NONFILTR.

                                   10405L

        01  03    75  EST                  0
        01  04    75  EST            369,551
        01  05    75  EST          1,180,378
        01  06    75  EST          1,218,372
        01  07    75  EST          1,268,383

        01  08    75  EST          1,273,733
        01  09    75  EST          1,296,666
        01  10    75  EST          1,314,116
        01  11    75  EST          1,315,931
        01  12    75  EST          1,346,660

        01  01    76  EST          1,442,197
        01  02    76  EST          1,499,182
        01  03    75  EST          2,061,495
        01  04    76  EST          2,678,397
        01  05    76  EST          3,930,737

        01  06    76  EST          3,995,017
        01  07    76  EST          4,093,115
        01  08    76  EST          4,742,338
        01  09    76  EST          4,810,490
        01  10    76  EST          4,814,352

        01  11    76  EST          4,820,300
        01  12    76  EST          4,937,942
        01  01    77  EST          4,947,994
        01  02    77  EST          4,953,923
        01  03    77  EST          4,960,911

        01  04    77  EST          6,751,380
        01  05    77  EST          6,791,420
        01  06    77  EST          6,799,080
        30  06    77  EST          6,804,924
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REQUEST 0001          CUMMULATIVE MASS FLOW OF WATER QUALITY CONSTITUENTS
                       RESIDUE LOADINGS FOR DICK
                      FOR PERIOD 010375  TO  300677


  03PA02GA0400          AG-4:  CANAGAGIGUE CK.TRIB.OF GRAND R. ABOVE  WELLINGTON-WATERLOO BORDER.
                               ;DAIRY AND FEED PRODUCTION;CLAY LOAM;  LOW  SHEET AND BANK EROSION POT..

                               CUMULATIVE POUNDS OF CONSTITUENT BETWEEN 01 03 1975 AND DATE SHOWN

          D A T E               RESIDUE
                               NONFILTR.

                                10405L

      01 03    75 EST                    0
      01 04    75 EST
      01 05    75 EST
      01 06    75 EST
      01 07    75 EST

      01 08    75 EST
      01 09    75 EST
      01 10    75 EST
      01 11    75 EST
      01 12    75 EST

      01 01    76 EST              197,963
      01 02    76 EST              200,061
      01 03    76 EST              258,931
      01 04    76 EST            1,760,598
      01 05    76 EST            1,813,377

      01 06    76 EST            1,869,424
      01 07    76 EST            1,880,080
      01 08    76 EST            1,889,562
      01 09    76 EST            1,889,884
      01 10    75 EST            1,894,169

      01 11    76 EST            1,905,887
      01 12    76 EST            1,942,238
      01 01    77 EST            1,944,115
      01 02    77 EST            1,944,654
      01 03    77 EST            1,945,039

      01 04    77 EST            3,246,812
      01 05    77 EST            3,294,641
      01 06    77 EST            3,295,631
      30 06    77 EST            3,295,631

*** REQUESTED RANGE EXCEEDS RANGE OF DATA  BY MORE THAN 10 PERCENT OF THE DIFFERANCE BETWEEN FIRST AND LAS
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REQUEST 0001          CUMMULATIVE MASS FLOW OF WATER QUALITY CONSTITUENTS
                       RESIDUE LOADINGS FOR DICK
                      FOR PERIOD 010375  TO  300677


  00PA02GD0500            AG-5:  HOLIDAY CK. TRIB.OF MIDDLE THAMES R. 3 MI. W.OF EMBRO,E.NISSOURI TP.OXFORD C
                                 29.5 SQ.KM.;DAIRY,INTENSE CORN,SOME      CASH CROPS;LOAM,SILT LOAM;MEDIUM SHEE

                                 CUMULATIVE POUNDS OF CONSTITUENT BETWEEN 01 03 1975 AND DATE SHOWN

         D A T E                 RESIDUE
                                 NONFILTR.

                                   10405L

      01  03     75  EST                 0
      01  04     75  EST            11,884
      01  05     75  EST            41,828
      01  06     75  EST            55,670
      01  07     75  EST            77,695

      01  08     75  EST            79,262
      01  09     75  EST            85,518
      01  10     75  EST            91,679
      01  11     75  EST            93,580
      01  12     75  EST           105,611

      01  01     76  EST           162,221
      01  02     76  EST           201,321
      01  03     76  EST           489,220
      01  04     76  EST           741,206
      01  05     76  EST           768,421

      01  06     76  EST           847,919
      01  07     76  EST           849,109
      01  08     76  EST         1,571,025
      01  09     76  EST         2,462,513
      01  10     76  EST         2,465,192

      01  11     76  EST         2,471,525
      01  12     76  EST         2,517,933
      01  01     77  EST         2,522,036
      01  02     77  EST         2,525,373
      01  03     77  EST         2,537,614

      01  04     77  EST         3,727,539
      01  05     77  EST         3,796,931
      01  06     77  EST         3,798,161
      30  06     77  EST         3,802,589
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REQUEST 0001          CUMMULATIVE MASS FLOW OF WATER QUALITY CONSTITUENTS
                       RESIDUE LOADINGS FOR DICK
                      FOR PERIOD 010375  TO  300677


  00PA02FE0600          AG-6: UN-NAMED TRIB.OF MAITLAND R.,1.8 MI.N. OF FORDWICH HOWICK TWP.,HURON CO.;
                              52.3 SQ.KM.;BEEF,HOGS,FEED CROPS;SAND, LOAM;MEDIUM SHEET,LOW BANK EROSION

                              CUMULATIVE POUNDS OF CONSTITUENT BETWEEN 01 03 1975 AND DATE SHOWN

          D A T E              RESIDUE
                               NONFILTR.

                                10405L

     01  03     75  EST                  0
     01  04     75  EST             38,008
     01  05     75  EST            262,942
     01  06     75  EST            295,957
     01  07     75  EST            313,213

     01  08     75  EST            318,998
     01  09     75  EST            333,545
     01  10     75  EST            342,909
     01  11     75  EST            353,847
     01  12     75  EST            359,534

     01  01     76  EST            431,573
     01  02     76  EST            452,255
     01  03     76  EST            492,211
     01  04     76  EST            840,520
     01  05     76  EST          1,045,446

     01  06     76  EST          1,087,397
     01  07     76  EST          1,097,707
     01  08     76  EST          1,126,171
     01  09     76  EST          1,142,573
     01  10     76  EST          1,156,662

     01  11     76  EST          1,167,678
     01  12     76  EST          1,177,190
     01  01     77  EST          1,188,227
     01  02     77  EST          1,199,923
     01  03     77  EST          1,217,257

     01  04     77  EST          1,546,343
     01  05     77  EST          1,573,668
     01  06     77  EST          1,585,424
     30  06     77  EST          1,593,052
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REQUEST 0001          CUMMULATIVE MASS FLOW OF WATER QUALITY CONSTITUENTS
                       RESIDUE LOADINGS FOR DICK
                      FOR PERIOD 010375  TO  300677


  COPA02HD0700               AG-7: SHELTER VALLEY CK.,HWY.2 1.2 MI.E.OF    GRAFTON,HALDIMAND TP.NORTHUMBERLAND CC
                                   ;  68.1 SQ.KM.;FOREST TOBACCO,HOBBY     FARMS;SANDY LOAM;HIGH SHEET AND BANK

                                   CUMULATIVE POUNDS OF CONSTITUENT BETWEEN 01 03 1975 AND DATE SHOWN

          D A T E                    RESIDUE
                                   NONFILTR.

                                     10405L

        01  03    75  EST                      0
        01  04    75  EST             18,243,002
        01  05    75  EST             19,601,213
        01  06    75  EST             19,657,644
        01  07    75  EST             19,742,575

        01  08    75  EST             19,754,636
        01  09    75  EST             19,768,355
        01  10    75  EST             19,783,243
        01  11    75  EST             19,789,352
        01  12    75  EST             19,795,169

        01  01    76  EST             19,869,494
        01  02    76  EST             19,890,817
        01  03    76  EST             19,930,088
        01  04    76  EST             20,058,677
        01  05    76  EST             20,113,539

        01  06    76  EST             20,126,202
        01  07    76  EST             20,145,345
        01  08    76  EST             20,172,157
        01  09    76  EST             20,182,427
        01  10    76  EST             20,190,343

        01  11    76  EST             20,196,748
        01  12    76  EST             20,215,341
        01  01    77  EST             20,224,223
        01  02    77  EST             20,229,698
        01  03    77  EST             20,247,739

        01  04    77  EST             20,401,759
        01  05    77  EST             20,439,565
        01  06    77  EST             20,506,004
        30  06    77  EST             20,507,227
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REQUEST 0001          CUMMULATIVE MASS FLOW OF WATER QUALITY CONSTITUENTS
                       RESIDUE LOADINGS FOR DICK
                      FOR PERIOD 010375  TO  300677


  00PA02HA1000          AG-10: NORTH CK.TRIB.OF TWENTY MILE CK.BRIDGE S.OF SMITHVILLE,E.OF TRACKS,LINCOLN C
                               GAINSBOROUGH TP.29.8 SQ.KM.;DEPRESSED  DAIRY AND POULTRY;CLAY;MEDIUM BANK,LOW

                               CUMULATIVE POUNDS OF CONSTITUENT BETWEEN 01 03 1975 AND DATE SHOWN

          D A T E               RESIDUE
                               NONFILTR.

                                10405L

     01 03     75 EST                   0
     01 04     75 EST             288,950
     01 05     75 EST             359,594
     01 06     75 EST             384,694
     01 07     75 EST             445,825

     01 08     75 EST             445,825
     01 09     75 EST             446,773
     01 10     75 EST             450,861
     01 11     75 EST             648,090
     01 12     75 EST             723,247

     01 01     76 EST             988,119
     01 02     76 EST           1,026,914
     01 03     76 EST           1,394,413
     01 04     76 EST           1,977,130
     01 05     76 EST           2,717,762

     01 06     76 EST           3,441,402
     01 07     76 EST           3,445,531
     01 08     76 EST           3,470,087
     01 09     76 EST           3,473,413
     01 10     76 EST           3,476,449

     01 11     76 EST           3,481,545
     01 12     76 EST           3,482,699
     01 01     77 EST           3,491,944
     01 02     77 EST           3,492,408
     01 03     77 EST           3,526,675

     01 04     77 EST           4,044,411
     01 05     77 EST           4,197,571
     01 06     77 EST           4,198,190
     30 06     77 EST           4,198,739
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REQUEST 0001          CUMMULATIVE MASS FLOW OF WATER QUALITY CONSTITUENTS
                       RESIDUE LOADINGS FOR DICK
                      FOR PERIOD 010375  TO  300677


   00PA02HC1100            AG-11: SALT CK.TRIB.OF W.HUMBER R...8 MI.S.W. , 2 MI.S.OF WILDFIELD.TORONTO GORE TP.
                                  PEEL CO.,     22.8 SQ.KM.;DAIRY,BEEF;    URBANIZING;CLAY LOAM;MEDIUM SHEET,HIGH

                                  CUMULATIVE POUNDS OF CONSTITUENT BETWEEN 01 03 1975 AND DATE SHOWN

          D A T E                   RESIDUE
                                  NONFILTR.

                                     10405L

      01 03    75 EST                   0
      01 04    75 EST
      01 05    75 EST
      01 06    75 EST
      01 07    75 EST

      01 08    75 EST                   0
      01 09    75 EST                   0
      01 10    75 EST                   0
      01 11    75 EST                   0
      01 12    75 EST                   0

      01 01    76 EST                   0
      01 02    76 EST                 281
      01 03    76 EST              27,760
      01 04    76 EST             163,315
      01 05    76 EST             170,017

      01 06    76 EST             172,066
      01 07    76 EST             172,163
      01 08    76 EST             172,192
      01 09    76 EST             172,255
      01 10    76 EST             172,255

      01 11    76 EST             172,482
      01 12    76 EST             172,573
      01 01    77 EST             172,617
      01 02    77 EST             172,617
      01 03    77 EST             175,551

      01 04    77 EST             526,816
      01 05    77 EST             584,028
      01 06    77 EST             586,921
      30 06    77 EST             585,921

*** REQUESTED RANGE EXCEEDS RANGE OF DATA  BY MORE THAN 10 PERCENT OF THE DIFFERANCE BETWEEN FIRST AND LAS
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REQUEST 0001             CUMMULATIVE MASS FLOW OF WATER QUALITY CONSTITUENTS
                          RESIDUE LOADINGS FOR DICK
                         FOR PERIOD 010375  TO  300677


  00PA02GH1300            AG-13:  W.BR.HILLMAN CK.,BRIDGE,SOUTH ON FIRST ROAD E.OF HWY.3&CK.JUNCTION, ESSEX CO.
                                  , MERSEA TP.,  ..20.7 SQ.KM.;FRUIT,VEG. AND CASH CROPS;SAND ON CLAY;HIGH BANK

                                  CUMULATIVE POUNDS OF CONSTITUENT BETWEEN 01 03 1975 AND DATE SHOWN

            D A T E                RESIDUE
                                  NONFILTR.

                                    10405L

       01  03    75  EST                  0
       01  04    75  EST            174,535
       01  05    75  EST            192,450
       01  06    75  EST            198,025
       01  07    75  EST            235,991

       01  08    75  EST            237,173
       01  09    75  EST            323,195
       01  10    75  EST            353,753
       01  11    75  EST            355,412
       01  12    75  EST            358,303

       01  01    76  EST            407,533
       01  02    76  EST            463,664
       01  03    76  EST            994,124
       01  04    76  EST          1,450,495
       01  05    76  EST          1,702,389

       01  06    76  EST          1,751,432
       01  07    76  EST          1,781,716
       01  08    76  EST          1,785,043
       01  09    76  EST          1,785,268
       01  10    76  EST          1,790,321

       01  11    76  EST          1,794,025
       01  12    76  EST          1,795,092
       01  01    77  EST          1,799,838
       01  02    77  EST          1,801,651
       01  03    77  EST          1,863,217

       01  04    77  EST          2,283,990
       01  05    77  EST          2,422,382
       01  06    77  EST          2,513,148
       30  06    77  EST          2,597,274
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REQUEST 0001          CUMMULATIVE MASS FLOW OF WATER QUALITY CONSTITUENTS
                       RESIDUE LOADINGS FOR DICK
                      FOR PERIOD 010375  TO  300677


  00PA02FC1400          AG-14: MILL CK.TRIB.OF SAUGEEN R.,1.2 MI.S.E. OF HWY.21,ON CONC. 12-13,BRUCE CO.-TP;
                               EXTENSIVE BEEF;SANDY TO SILTY CLAY     LOAM;LOW SHEET AND MEDIUM BANK EROSION

                               CUMULATIVE POUNDS OF CONSTITUENT BETWEEN 01 03 1975 AND DATE SHOWN

        D A T E                 RESIDUE
                               NONFILTR.

                                 10405L

   01 03    75 EST                       0
   01 04    75 EST                 112,000
   01 05    75 EST                 323,865
   01 06    75 EST                 330,948
   01 07    75 EST                 331,687

   01 08    75 EST                 331,712
   01 09    75 EST                 338,220
   01 10    75 EST                 354,662
   01 11    75 EST                 359,611
   01 12    75 EST                 393,153

   01 01    76 EST                 441,222
   01 02    76 EST                 472,135
   01 03    76 EST                 545,154
   01 04    76 EST               1,633,947
   01 05    76 EST               1,639,025

   01 06    76 EST               1,647,225
   01 07    76 EST               1,677,839
   01 08    76 EST               1,696,095
   01 09    76 EST               1,696,096
   01 10    76 EST               1,696,321

   01 11    76 EST               1,698,027
   01 12    76 EST               1,783,386
   01 01    77 EST               1,790,237
   01 02    77 EST               1,791,588
   01 03    77 EST               1,792,451

   01 04    77 EST               2,769,996
   01 05    77 EST               2,806,875
   01 06    77 EST               2,807,103
   30 06    77 EST               2,807,103
```

APPENDIX 6

Monthly suspended sediment loads (Naquadat Method) for the 11 agricultural watersheds, measured and estimated data.

AG-1	(Big Creek)
AG-2	(Venison Creek)
AG-3	(Little Ausable)
AG-4	(Canagagigue Creek)
AG-5	(Holiday Creek)
AG-6	Nameless
AG-7	(Shelter Creek)
AG-10	(North Creek)
AG-11	(Salt Creek)
AG-13	(Hillman Creek)
AG-14	(Mill Creek)

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REQUEST 0001          CUMMULATIVE MASS FLOW OF WATER QUALITY CONSTITUENTS
                       RESIDUE LOADINGS FOR DICK
                      FOR PERIOD 010375  TO  300677

   00PA02GE0100          AG-1: BIG CK.,TRIB.OF THAMES R.,.2.5MI. W.OF  STRANGFIELD, .TILBURY TWP.,ESSEX CO.,
                                51.8 SQ.KM.;CASH CROP,TILE DRAINS;CLAY SOIL;HIGH SHEET AND BANK EROSION POT.,

                                CUMULATIVE POUNDS OF CONSTITUENT BETWEEN 01 03 1975 AND DATE SHOWN

         D A T E                 RESIDUE
                                NONFILTR.

                                 10405L

     01 03     75 EST                    0
     01 04     75 EST              661,769
     01 05     75 EST              733,499
     01 06     75 EST              737,742
     01 07     75 EST            7,471,068

     01 08     75 EST            7,478,447
     01 09     75 EST            7,662,677
     01 10     75 EST            7,970,802
     01 11     75 EST            7,973,551
     01 12     75 EST            7,976,510

     01 01     76 EST            8,259,355
     01 02     76 EST            8,305,518
     01 03     76 EST           16,946,791
     01 04     76 EST           17,984,297
     01 05     76 EST           18,132,098

     01 06     76 EST           18,213,961
     01 07     76 EST           18,270,175
     01 08     76 EST           18,578,929
     01 09     76 EST           18,578,929
     01 10     76 EST           18,579,662

     01 11     76 EST           18,580,784
     01 12     76 EST           18,580,902
     01 01     77 EST           18,581,819
     01 02     77 EST           18,581,819
     01 03     77 EST           18,581,819

     01 04     77 EST           20,075,575
     01 05     77 EST           20,334,347
     01 06     77 EST           20,387,111
     30 06     77 EST           20,473,721
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REQUEST 0001          CUMMULATIVE MASS FLOW OF WATER QUALITY CONSTITUENTS
                       RESIDUE LOADINGS FOR DICK
                      FOR PERIOD 010375  TO  300677

    00PA02GC0200           AG-2: VENISON CK.TRIB.OF BIG CK.,ABOVE CONC. 7-8 BRIDGE,N WALSINGHAM TP.,NORFOLK CO
                                  .73.2 SQ.KM.;TOBACCO AND ASS.CROPS ON SANDS;LOW SHEET AND BANK EROSION POT.;

                                 CUMULATIVE POUNDS OF CONSTITUENT BETWEEN 01 03 1975 AND DATE SHOWN

          D A T E                 RESIDUE
                                 NONFILTR.

                                   10405L

       01 03    75 EST                  0
       01 04    75 EST            359,904
       01 05    75 EST            564,270
       01 06    75 EST            629,530
       01 07    75 EST            797,355

       01 08    75 EST          1,120,840
       01 09    75 EST          1,196,574
       01 10    75 EST          1,333,081
       01 11    75 EST          1,403,438
       01 12    75 EST          1,511,239

       01 01    76 EST          1,722,047
       01 02    76 EST          1,900,781
       01 03    76 EST          2,674,716
       01 04    76 EST          3,551,310
       01 05    76 EST          3,811,679

       01 06    76 EST          4,077,964
       01 07    76 EST          4,175,855
       01 08    76 EST          4,234,965
       01 09    76 EST          4,309,615
       01 10    76 EST          4,343,632

       01 11    76 EST          4,363,666
       01 12    76 EST          4,401,266
       01 01    77 EST          4,464,142
       01 02    77 EST          4,482,814
       01 03    77 EST          4,589,849

       01 04    77 EST          5,492,784
       01 05    77 EST          5,626,078
       01 06    77 EST          5,861,610
       30 06    77 EST          5,871,868
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REQUEST 0001              CUMMULATIVE MASS FLOW OF WATER QUALITY CONSTITUENTS
                           RESIDUE LOADINGS FOR PICK
                          FOR PERIOD 010375  TO  300677


  00PA02FF0300              AG-3: LITTLE AUSABLE R.TRIB.OF AUSABLE R.1ST BRIDGE N.OF  URON-MIDDLESEX CO.LINE
                                  54.1 SQ.KM.;BEEF AND DAIRY, FEED AND  SOME CASH CROPS ON CLAY;HIGH SHEET AND

                                  CUMULATIVE POUNDS OF CONSTITUENT BETWEEN 01 03 1975 AND DATE SHOWN

           D A T E                  RESIDUE
                                  NONFILTR.

                                    10405L

     01 03      75 EST                      0
     01 04      75 EST                869,551
     01 05      75 EST              1,589,022
     01 06      75 EST              1,622,751
     01 07      75 EST              1,660,244

     01 08      75 EST              1,665,085
     01 09      75 EST              1,681,701
     01 10      75 EST              1,697,897
     01 11      75 EST              1,699,712
     01 12      75 EST              1,730,035

     01 01      76 EST              1,864,647
     01 02      76 EST              1,938,374
     01 03      76 EST              2,525,243
     01 04      76 EST              3,382,040
     01 05      76 EST              3,878,616

     01 06      76 EST              3,942,023
     01 07      76 EST              3,949,121
     01 08      76 EST              4,688,344
     01 09      76 EST              4,774,303
     01 10      76 EST              4,778,793

     01 11      76 EST              4,783,815
     01 12      76 EST              4,908,985
     01 01      77 EST              4,921,345
     01 02      77 EST              4,927,274
     01 03      77 EST              4,934,262

     01 04      77 EST              6,724,731
     01 05      77 EST              6,764,770
     01 06      77 EST              6,768,948
     30 06      77 EST              6,769,567
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REQUEST 0001          CUMMULATIVE MASS FLOW OF WATER QUALITY CONSTITUENTS
                       RESIDUE LOADINGS FOR DICK
                      FOR PERIOD 010375  TO  300677

  00PA02GA0400            AG-4: CANAGAGIGUE CK.TRIB.OF GRAND R. ABOVE  WELLINGTON-WATERLOO BORDER,
                                ;DAIRY AND FEED PRODUCTION;CLAY LOAM;  LOW  SHEET AND BANK EROSION POT..

                                CUMULATIVE POUNDS OF CONSTITUENT BETWEEN 01 03 1975 AND DATE SHOWN

          DATE                   RESIDUE
                                NONFILTR.

                                 10405L

     01 03    75 EST                     0
     01 04    75 EST               303,184
     01 05    75 EST             1,412,738
     01 06    75 EST             1,415,024
     01 07    75 EST             1,432,414

     01 08    75 EST             1,432,447
     01 09    75 EST             1,440,622
     01 10    75 EST             1,465,024
     01 11    75 EST             1,482,554
     01 12    75 EST             1,501,081

     01 01    76 EST             1,606,692
     01 02    76 EST             1,608,790
     01 03    76 EST             1,685,678
     01 04    76 EST             3,188,415
     01 05    76 EST             3,244,567

     01 06    76 EST             3,296,482
     01 07    76 EST             3,309,591
     01 08    76 EST             3,319,383
     01 09    76 EST             3,319,705
     01 10    76 EST             3,323,990

     01 11    76 EST             3,334,304
     01 12    76 EST             3,363,327
     01 01    77 EST             3,365,204
     01 02    77 EST             3,365,743
     01 03    77 EST             3,366,128

     01 04    77 EST             4,667,902
     01 05    77 EST             4,715,731
     01 06    77 EST             4,716,721
     30 06    77 EST             4,716,721
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REQUEST 0001          CUMMULATIVE MASS FLOW OF WATER QUALITY CONSTITUENTS
                       RESIDUE LOADINGS FOR DICK
                      FOR PERIOD 010375  TO  300677


   00PA02GD0500             AG-5: HOLIDAY CK. TRIB.OF MIDDLE THAMES R. 3 MI. W.OF EMB E.E.MISSOURI TP.OXFORD CO
                                  29.5 SQ.KM.;DAIRY,INTENSE CORN,SOME   CASH CROPS;L AM,SILT LOAM;MEDIUM SHEET

                                  CUMULATIVE POUNDS OF CONSTITUENT BETWEEN 01 03 1975 AND DATE SHOWN

           D A T E                 RESIDUE
                                  NONFILTR.

                                    10405L

     01 03     75 EST                       0
     01 04     75 EST                  11,884
     01 05     75 EST                 101,734
     01 06     75 EST                 115,576
     01 07     75 EST                 136,278

     01 08     75 EST                 137,646
     01 09     75 EST                 143,540
     01 10     75 EST                 149,158
     01 11     75 EST                 151,059
     01 12     75 EST                 163,091

     01 01     76 EST                 206,819
     01 02     76 EST                 243,362
     01 03     76 EST                 453,923
     01 04     76 EST                 712,543
     01 05     76 EST                 746,495

     01 06     76 EST                 825,993
     01 07     76 EST                 827,183
     01 08     76 EST               1,550,855
     01 09     76 EST               2,456,955
     01 10     76 EST               2,459,633

     01 11     76 EST               2,465,966
     01 12     76 EST               2,512,375
     01 01     77 EST               2,516,478
     01 02     77 EST               2,519,815
     01 03     77 EST               2,532,056

     01 04     77 EST               3,721,981
     01 05     77 EST               3,791,300
     01 06     77 EST               3,792,511
     30 06     77 EST               3,796,940
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REQUEST 0001          COMMULATIVE MASS FLOW OF WATER QUALITY CONSTITUENTS
                       RESIDUE LOADINGS FOR DICK
                      FOR PERIOD 010375  TO  300677

   00PA02FE0600            AG-6: UN-NAMED TRIB.OF MAITLAND R.,1.8 MI.N. OF FORDWICH  HOWICK TWP.,HURON CO.;
                                 52.3 SQ.KM.;BEEF,HOGS,FEED CROPS;SAND, LOAM;MEDIUM  HEET,LOW BANK EROSION

                                 CUMULATIVE POUNDS OF CONSTITUENT BETWEEN 01 03 1975 AND DATE SHOWN

          D A T E                RESIDUE
                                 NONFILTR.

                                  10405L

     01 03     75 EST                    0
     01 04     75 EST               38,008
     01 05     75 EST              262,942
     01 06     75 EST              295,957
     01 07     75 EST              313,213

     01 08     75 EST              319,366
     01 09     75 EST              367,449
     01 10     75 EST              393,849
     01 11     75 EST              408,333
     01 12     75 EST              419,088

     01 01     76 EST              514,622
     01 02     76 EST              547,056
     01 03     76 EST              614,467
     01 04     76 EST              961,810
     01 05     76 EST            1,160,719

     01 06     76 EST            1,200,314
     01 07     76 EST            1,211,798
     01 08     76 EST            1,243,667
     01 09     76 EST            1,261,561
     01 10     76 EST            1,279,376

     01 11     76 EST            1,290,392
     01 12     76 EST            1,301,496
     01 01     77 EST            1,313,059
     01 02     77 EST            1,324,755
     01 03     77 EST            1,342,089

     01 04     77 EST            1,671,174
     01 05     77 EST            1,698,499
     01 06     77 EST            1,710,256
     30 06     77 EST            1,717,884
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REQUEST 0001          CUMMULATIVE MASS FLOW OF WATER QUALITY CONSTITUENTS
                       RESIDUE LOADINGS FOR DICK
                      FOR PERIOD 010375  TO  300677


   00PA02HD0700            AG-7: SHELTER VALLEY CK.,HWY.2 1.2 MI.E.OF    GRAFTON,HALDIMAND TP,NORTHUMBERLAND
                                 ;  66.1 SQ.KM.;FOREST TOBACCO,HOBBY     FARMS;SANDY LOAM;HIGH SHEET AND BANK

                                 CUMULATIVE POUNDS OF CONSTITUENT BETWEEN 01 03 1975 AND DATE SHOWN

          D A T E                 RESIDUE
                                 NONFILTR.

                                   10405L

       01  03    75  EST                  0
       01  04    75  EST          1,835,910
       01  05    75  EST          2,360,081
       01  06    75  EST          2,433,337
       01  07    75  EST          2,518,268

       01  08    75  EST          2,530,331
       01  09    75  EST          2,544,048
       01  10    75  EST          2,566,205
       01  11    75  EST          2,592,728
       01  12    75  EST          2,629,630

       01  01    76  EST          2,684,024
       01  02    76  EST          2,702,572
       01  03    76  EST          2,954,243
       01  04    76  EST          4,166,164
       01  05    76  EST          4,295,503

       01  06    76  EST          4,377,489
       01  07    76  EST          4,412,200
       01  08    76  EST          4,442,386
       01  09    76  EST          4,452,657
       01  10    76  EST          4,460,572

       01  11    76  EST          4,471,930
       01  12    76  EST          4,495,799
       01  01    77  EST          4,504,681
       01  02    77  EST          4,510,156
       01  03    77  EST          4,526,197

       01  04    77  EST          4,682,217
       01  05    77  EST          4,770,023
       01  06    77  EST          4,786,462
       30  06    77  EST          4,787,685
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REQUEST 0001                  CUMMULATIVE MASS FLOW OF WATER QUALITY CONSTITUENTS
                               RESIDUE LOADINGS FOR DICK
                              FOR PERIOD 010375   TO   300677

   00PA02FA1000                    AG-10: NORTH CK.TRIB.OF TWENTY MILE CK.BRIDGE S.OF SMITHVILLE,E.OF TRACKS,LINCOLN CO
                                          GAINSBOROUGH TP.29.8 SQ.KM.;DEPRESSED  DAIRY AND POULTRY;CLAY;MEDIUM BANK,LOW

                                          CUMULATIVE POUNDS OF CONSTITUENT BETWEEN 01 03 1975 AND DATE SHOWN

             D A T E                        RESIDUE
                                          NONFILTR.

                                             10405L

         01 03     75 EST                           0
         01 04     75 EST                     288,950
         01 05     75 EST                     359,894
         01 06     75 EST                     380,083
         01 07     75 EST                     424,321

         01 08     75 EST                     424,321
         01 09     75 EST                     507,780
         01 10     75 EST                     551,298
         01 11     75 EST                     722,714
         01 12     75 EST                     803,834

         01 01     76 EST                   1,019,881
         01 02     76 EST                   1,070,701
         01 03     76 EST                   2,043,806
         01 04     76 EST                   2,647,205
         01 05     76 EST                   3,389,272

         01 06     76 EST                   3,646,091
         01 07     76 EST                   3,651,324
         01 08     76 EST                   3,677,184
         01 09     76 EST                   3,680,510
         01 10     76 EST                   3,683,545

         01 11     76 EST                   3,688,642
         01 12     76 EST                   3,689,796
         01 01     77 EST                   3,699,040
         01 02     77 EST                   3,699,505
         01 03     77 EST                   3,733,772

         01 04     77 EST                   4,251,507
         01 05     77 EST                   4,404,668
         01 06     77 EST                   4,405,286
         30 06     77 EST                   4,405,836
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REQUEST 0001          CUMMULATIVE MASS FLOW OF WATER QUALITY CONSTITUENTS
                       RESIDUE LOADINGS FOR DICK
                      FOR PERIOD 010375  TO  300677


   00PA02HC1100            AG-11: SALT CK.TRIB.OF W.HUMBER R...8 MI.S.W. . 2 MI.S.OF  OLDFIELD,TORONTO GORE TP.
                                  PEEL CO.,     22.5 SQ.KM.;DAIRY,BEEF;   URBANIZING;CLAY LOAM;MEDIUM SHEET,HIGH

                                  CUMULATIVE POUNDS OF CONSTITUENT BETWEEN 01 03 1975 AND DATE SHOWN

         D A T E                   RESIDUE
                                  NONFILTR.

                                    10405L

     01 03    75 EST                        0
     01 04    75 EST
     01 05    75 EST
     01 06    75 EST
     01 07    75 EST

     01 08    75 EST                        0
     01 09    75 EST                        0
     01 10    75 EST                        0
     01 11    75 EST                        0
     01 12    75 EST                        0

     01 01    76 EST                        0
     01 02    76 EST                      818
     01 03    76 EST                  547,089
     01 04    76 EST                1,115,395
     01 05    76 EST                1,131,566

     01 06    76 EST                1,149,288
     01 07    76 EST                1,149,448
     01 08    76 EST                1,149,477
     01 09    76 EST                1,149,540
     01 10    76 EST                1,149,540

     01 11    76 EST                1,149,768
     01 12    76 EST                1,149,858
     01 01    77 EST                1,149,902
     01 02    77 EST                1,149,902
     01 03    77 EST                1,152,836

     01 04    77 EST                1,504,101
     01 05    77 EST                1,561,314
     01 06    77 EST                1,564,207
     30 06    77 EST                1,564,207

 *** REQUESTED RANGE EXCEEDS RANGE OF DATA  BY MORE THAN 10 PERCENT OF THE DIFFERENCE BETWEEN FIRST AND LAST
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REQUEST 0001           CUMMULATIVE MASS FLOW OF WATER QUALITY CONSTITUENTS
                        RESIDUE LOADINGS FOR DICK
                       FOR PERIOD 010375  TO  300677

  00PA02GH1300            AG-13: W.BR.HILLMAN CK.,BRIDGE,SOUTH ON FIRST ROAD E.OF HWY.3&CK.JUNCTION, ESSEX CO.
                                 , MERSEA TP..  ..20.7 SQ.KM.;FRUIT,VEG  AND CASH CROPS;SAND ON CLAY;HIGH BANK

                              CUMULATIVE POUNDS OF CONSTITUENT BETWEEN 01 03 1975 AND DATE SHOWN

          D A T E              RESIDUE
                              NONFILTR.

                               10405L

   01 03   75 EST                    0
   01 04   75 EST              157,960
   01 05   75 EST              175,875
   01 06   75 EST              181,450
   01 07   75 EST              219,416

   01 08   75 EST              220,598
   01 09   75 EST              749,552
   01 10   75 EST              787,059
   01 11   75 EST              789,718
   01 12   75 EST              791,608

   01 01   76 EST              877,858
   01 02   76 EST              950,250
   01 03   76 EST            2,685,328
   01 04   76 EST            3,230,535
   01 05   76 EST            3,451,880

   01 06   76 EST            3,500,423
   01 07   76 EST            3,530,707
   01 08   76 EST            3,541,445
   01 09   76 EST            3,542,670
   01 10   76 EST            3,546,724

   01 11   76 EST            3,550,427
   01 12   76 EST            3,551,494
   01 01   77 EST            3,555,525
   01 02   77 EST            3,557,186
   01 03   77 EST            3,618,752

   01 04   77 EST            4,039,525
   01 05   77 EST            4,177,917
   01 06   77 EST            4,268,683
   30 06   77 EST            4,352,809
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REQUEST 0001          COMMULATIVE MASS FLOW OF WATER QUALITY CONSTITUENTS
                       RESIDUE LOADINGS FOR DICK
                      FOR PERIOD 010375  TO  300677


   00PA02FC1400           AG-14: MILL CK.TRIB.OF SAUGEEN R.,1.2 MI.S.E. OF HWY.21,ON CONC. 12-13,BRUCE CO.-TP;
                                 EXTENSIVE BEEF;SANDY TO SILTY CLAY     LOAM;LOW SHEET AND MEDIUM BANK EROSION

                                 CUMULATIVE POUNDS OF CONSTITUENT BETWEEN 01 03 1975 AND DATE SHOWN

            D A T E               RESIDUE
                                 NONFILTR.

                                  10405L

       01 03    75 EST                  0
       01 04    75 EST            112,000
       01 05    75 EST            323,865
       01 06    75 EST            330,948
       01 07    75 EST            331,687

       01 08    75 EST            331,712
       01 09    75 EST            341,567
       01 10    75 EST            358,948
       01 11    75 EST            363,896
       01 12    75 EST            407,516

       01 01    76 EST            540,399
       01 02    76 EST            572,327
       01 03    76 EST            676,847
       01 04    76 EST          1,845,719
       01 05    76 EST          1,851,210

       01 06    76 EST          1,862,898
       01 07    76 EST          1,884,802
       01 08    76 EST          1,904,343
       01 09    76 EST          1,904,343
       01 10    76 EST          1,904,568

       01 11    76 EST          1,908,164
       01 12    76 EST          2,040,656
       01 01    77 EST          2,057,329
       01 02    77 EST          2,060,030
       01 03    77 EST          2,060,894

       01 04    77 EST          3,038,438
       01 05    77 EST          3,075,317
       01 06    77 EST          3,075,545
       30 06    77 EST          3,075,545
```

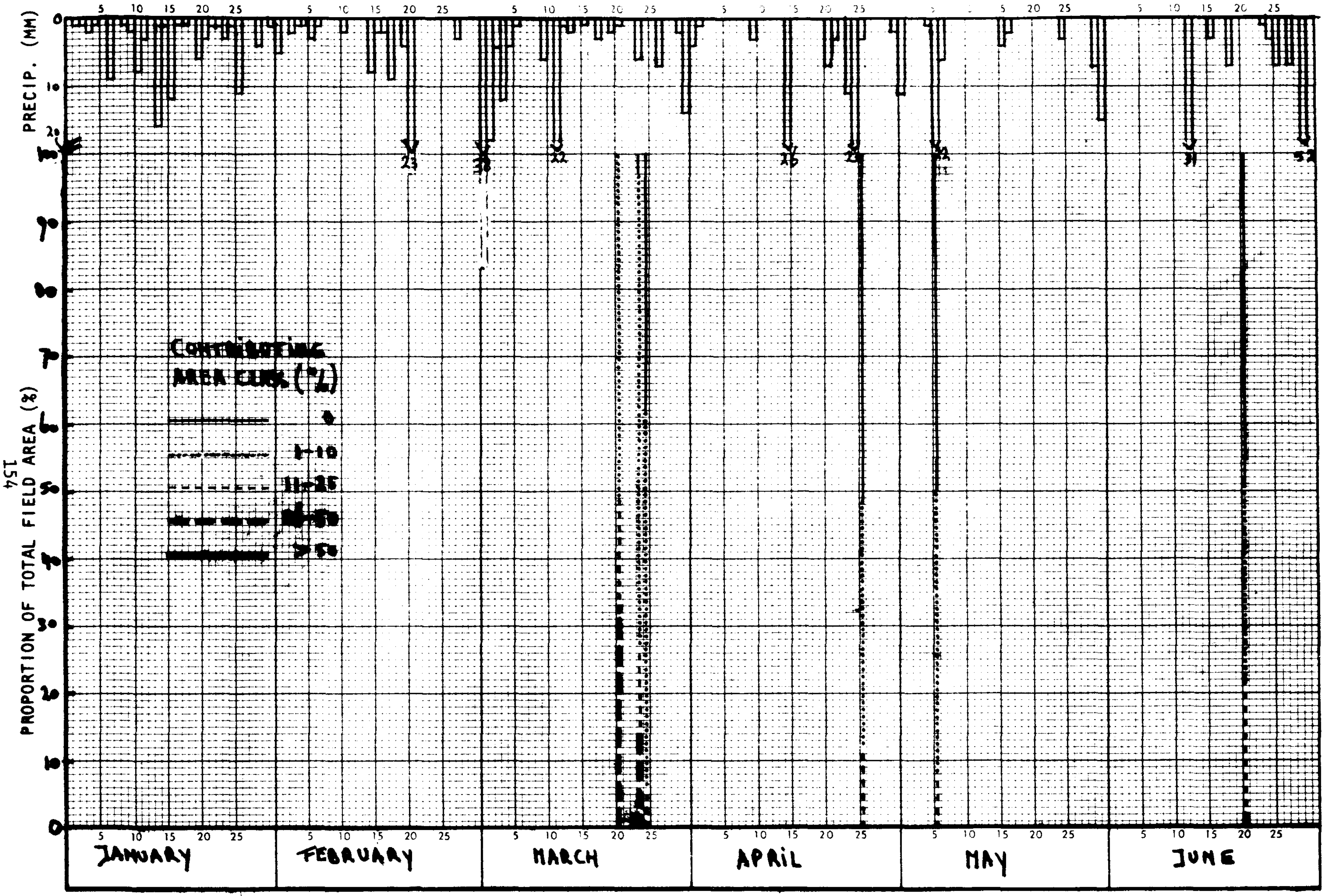
APPENDIX 7

Sediment Contributing Areas in the Agricultural Study Watersheds

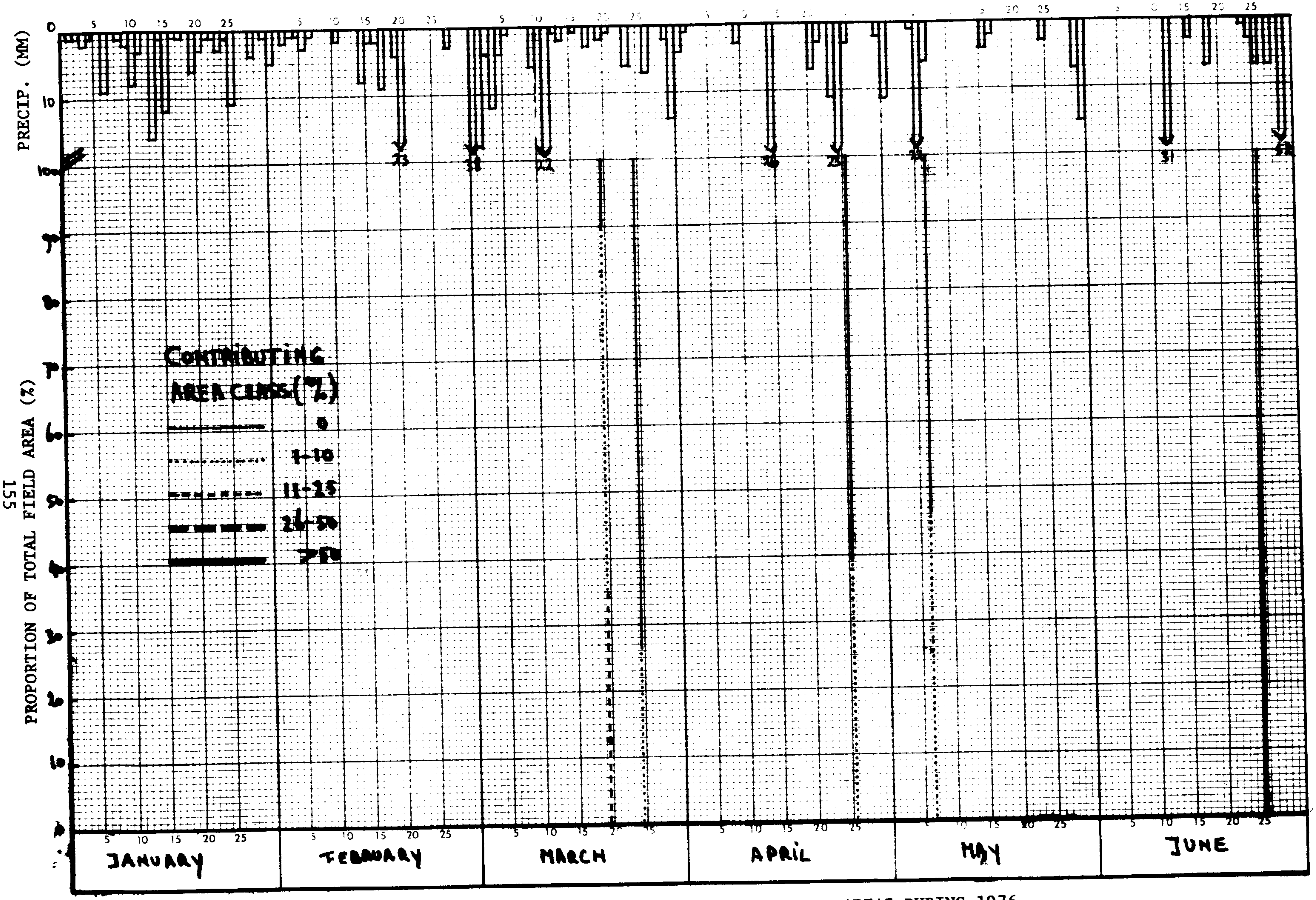
Appendix 7. Distribution of area weighted mean sediment contributing areas (percent) for all snowmelt and rainfall runoff producing events observed during 1975 and 1976 for AG-4 and AG-5 watersheds.

WATERSHED	YEAR	J	F	M	A	M	J	J	A	S	O	N	D	RANGE	MEAN	NUMBER OF EVENTS
AG-4	1975	-*	-	11	24 25 18 3 1	13	9	--	12	--	--	--	--	1-25	12.8	9
AG-4	1976	-	-	18 12 4	4	4	6	4	--	1	--	--	--	1-18	6.6	8
AG-5	1975	-	-	25 25 15	14 13 9	- -	17 23 17 11	--	--	--	--	--	6	6-25	15.9	11
AG-5	1976	-	6	8 1	2	4	--	8 34 11	65	3	--	--	--	1-65	14.2	10
AG-5 Subbasin	1975	-	-	18	23 4 5	--	28 42 25 14	--	--	--	--	--	--	4-42	19.8	8
AG-5 Subbasin	1976	-	-	9 1	2	3	--	9 50 24	72	3	--	--	--	1-72	19.2	9

* Rainfall and snowmelt events without observable surface runoff (0% contributing area class) are not included in this table.

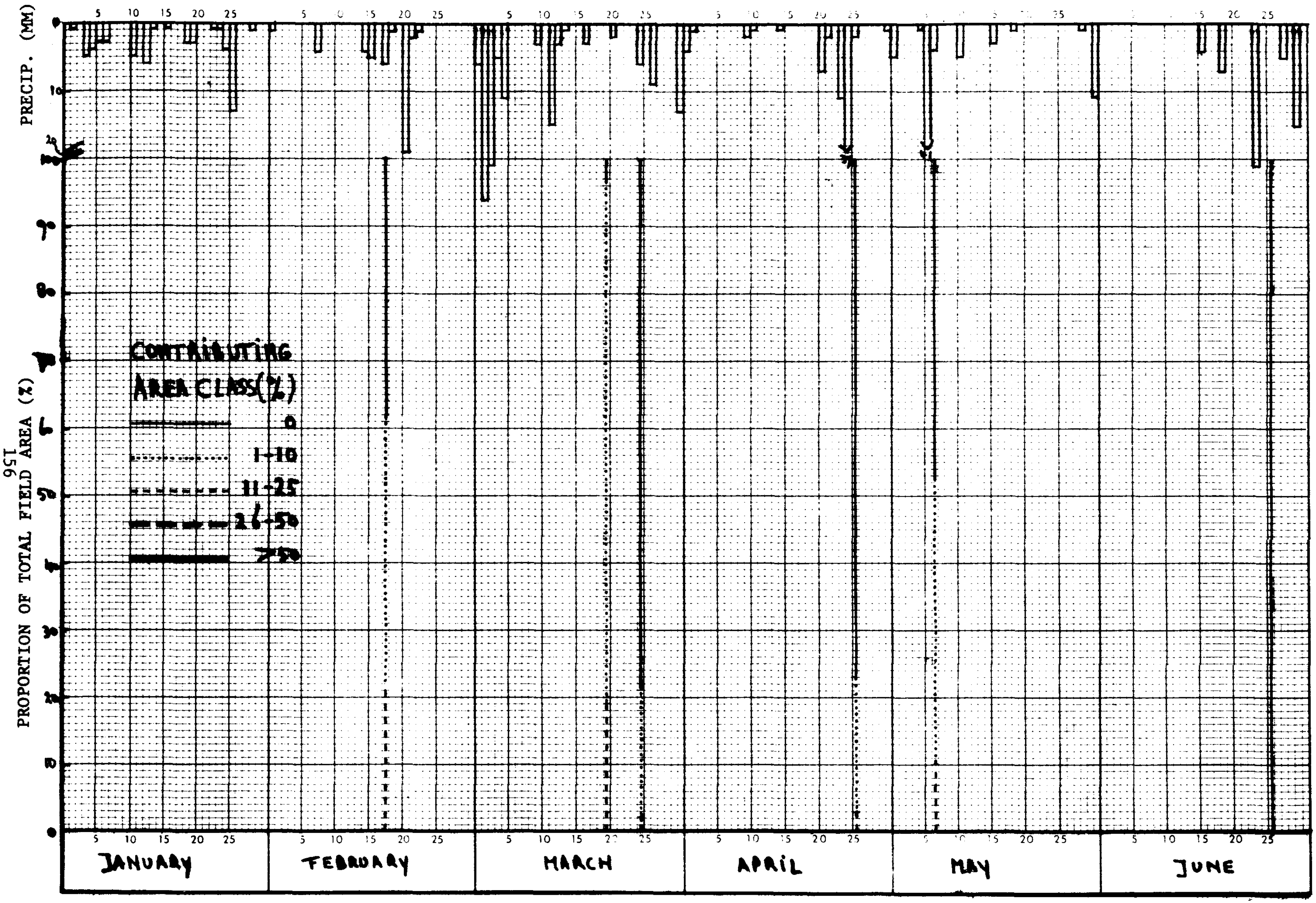


AG-4 CANAGAGIGUE CREEK OBSERVED CONTRIBUTING AREAS DURING 1976



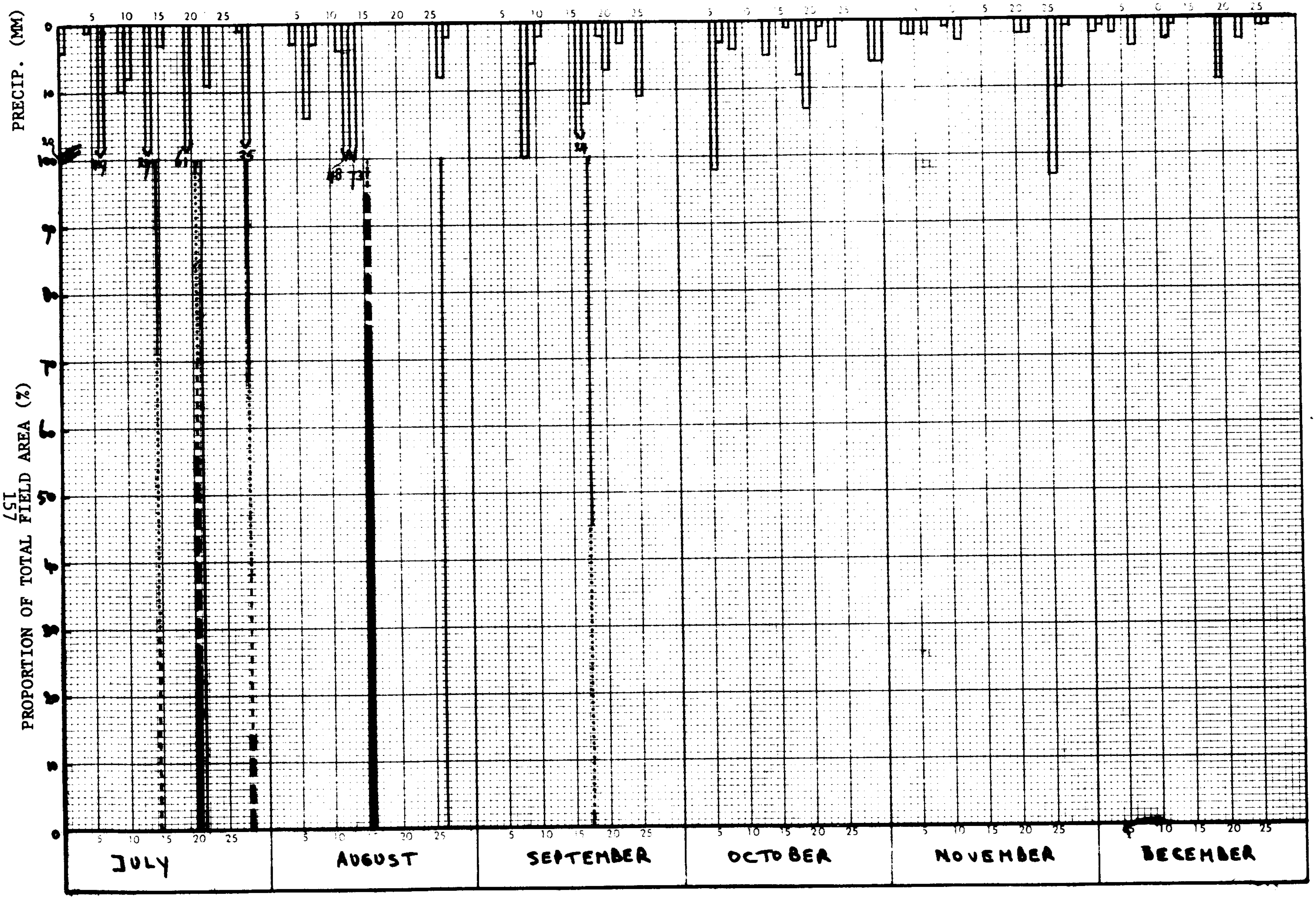
AG-5 HOLIDAY CREEK SUB-WATERSHED OBS. CONTR. AREAS DURING 1976

APPENDIX 7

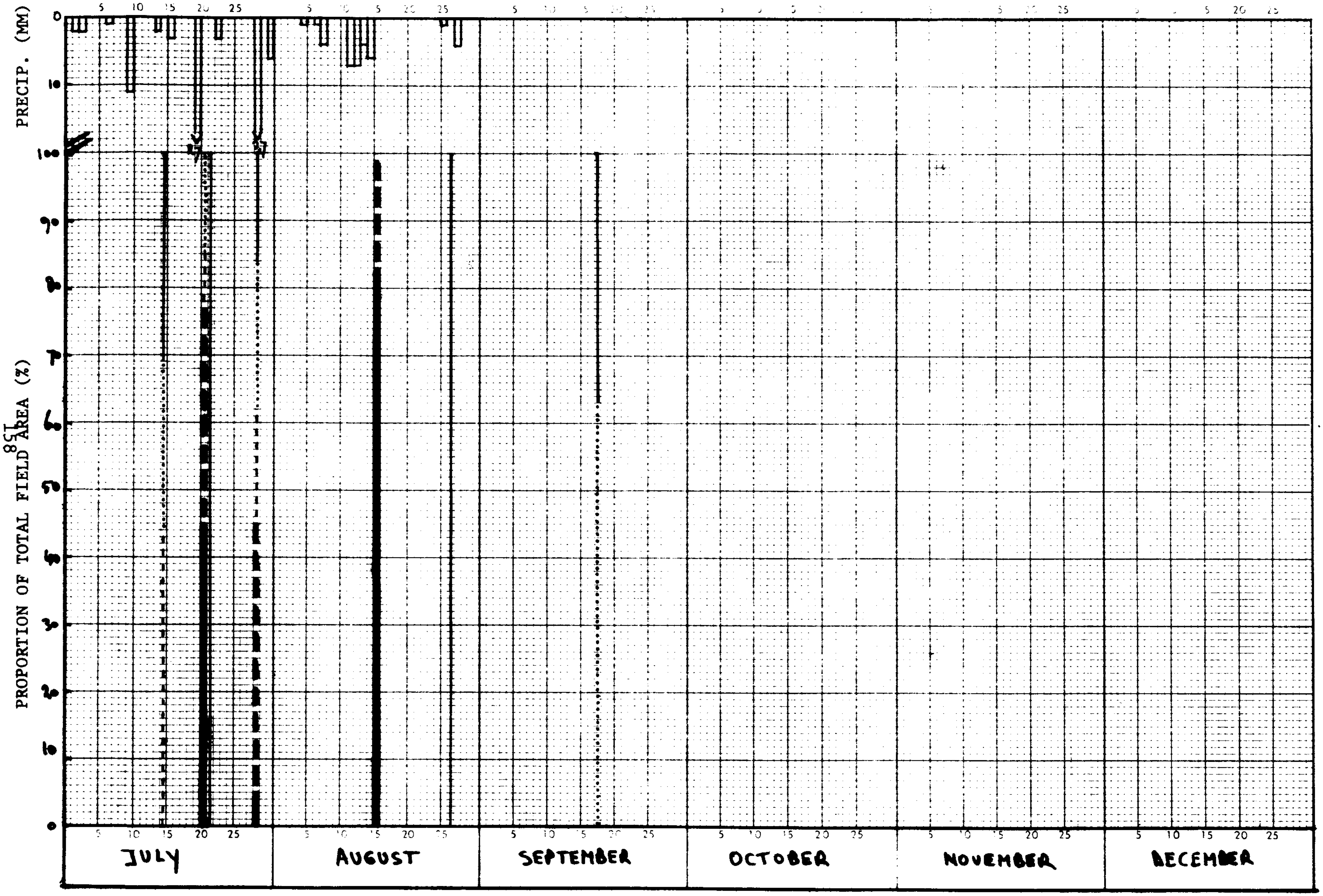


AG-5 HOLIDAY CREEK OBSERVED CONTRIBUTING AREAS DURING 1976

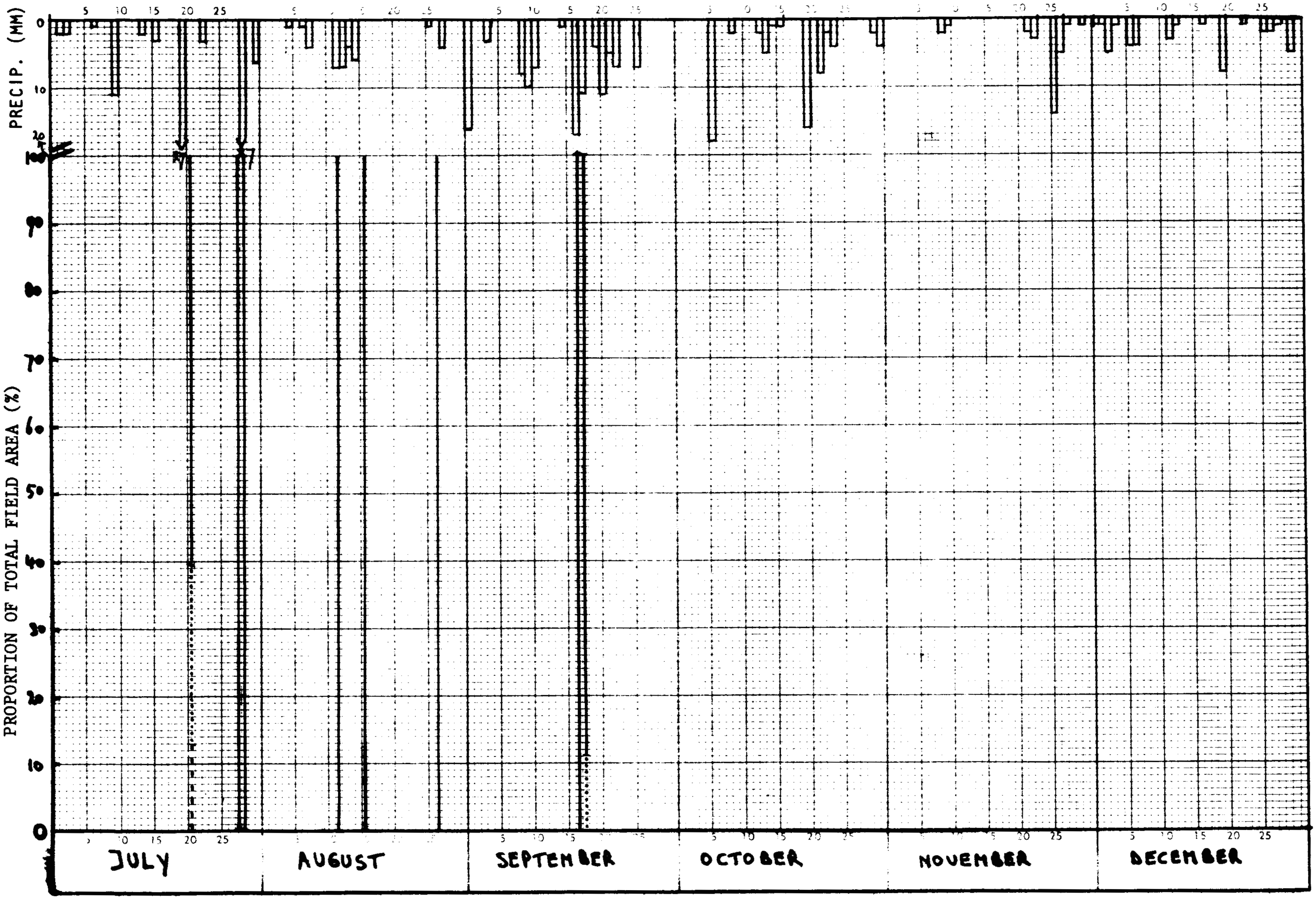
APPENDIX 7



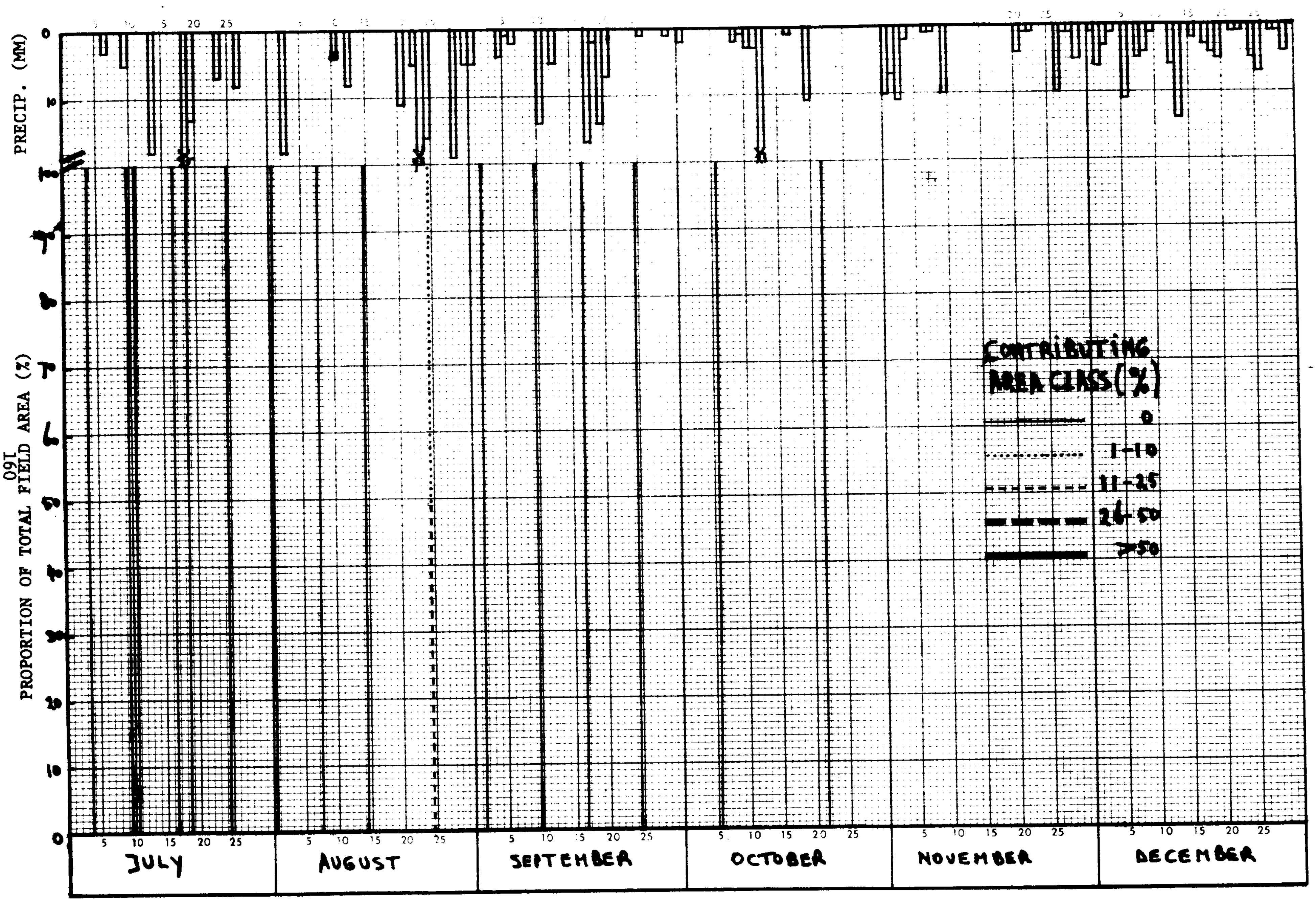
AG-5 HOLIDAY CREEK OBSERVED CONTRIBUTING AREAS DURING 1976



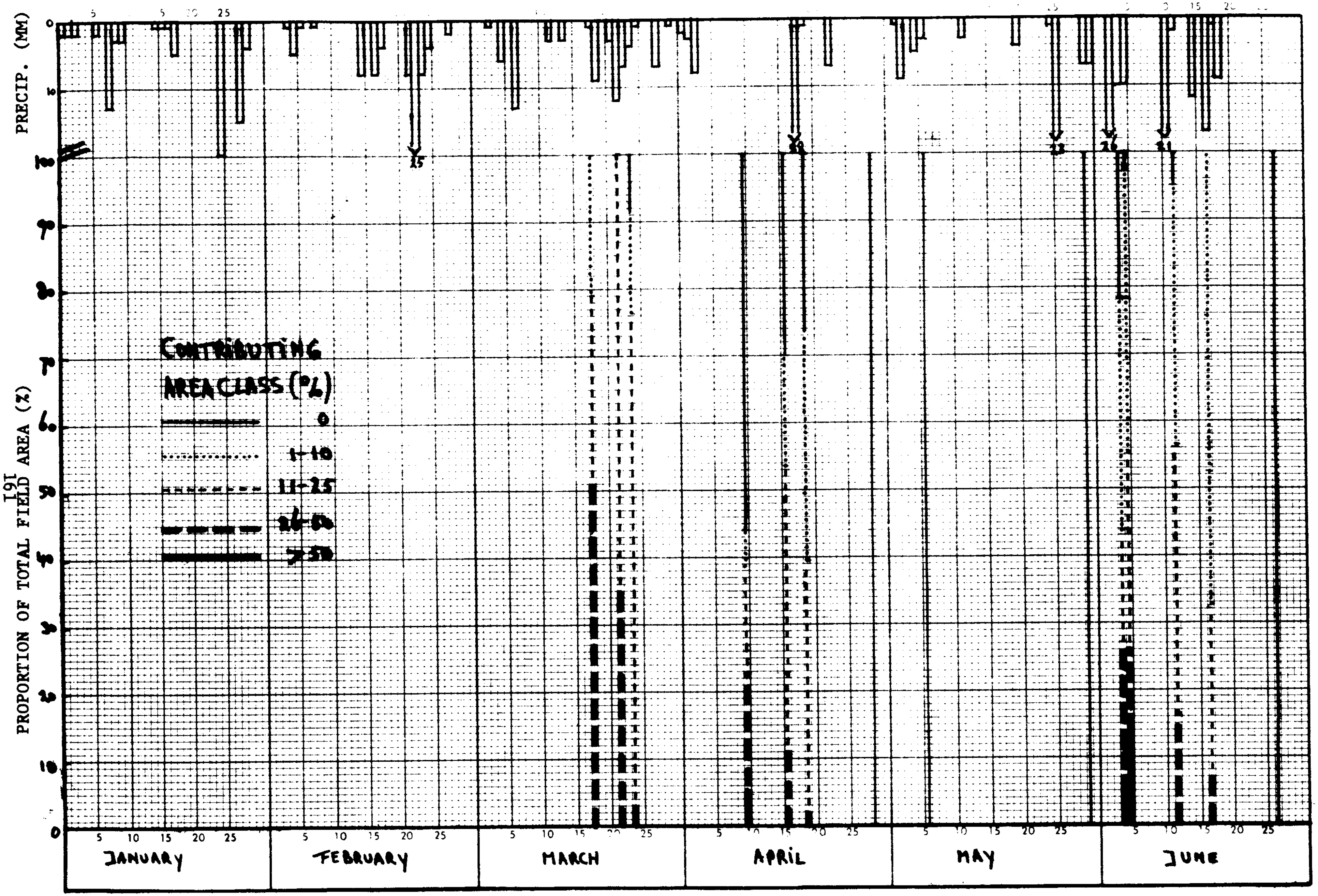
AG-5 HOLIDAY CREEK SUB-WATERSHED OBS. CONTR. AREAS DURING 1976



AG-4 CANAGAGIGUE CREEK OBSERVED CONTRIBUTING AREAS DURING 1976

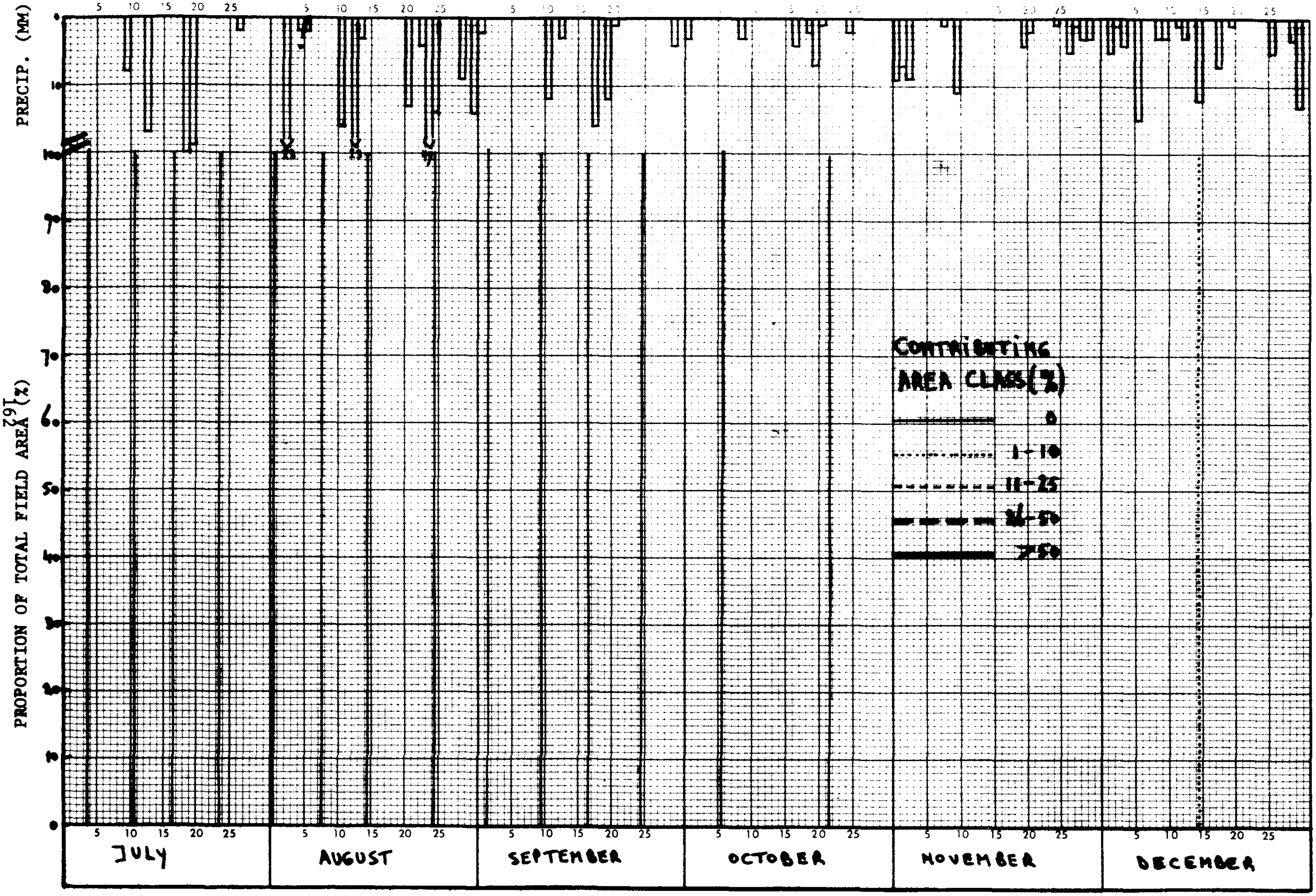


AG-4 CANAGAGIGUE CREEK OBSERVED CONTRIBUTING AREAS DURING 1975

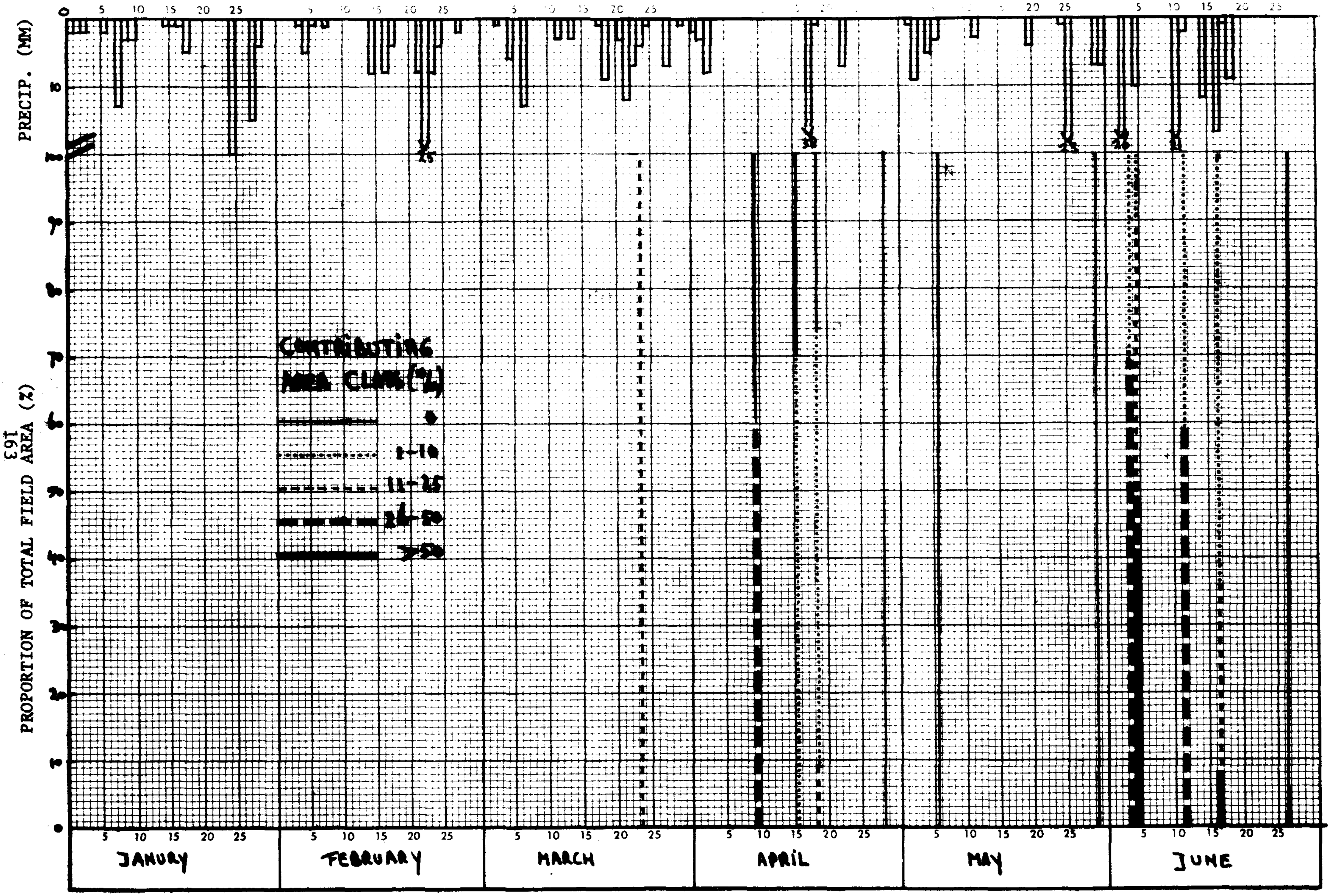


AG-5 HOLIDAY CREEK OBSERVED CONTRIBUTING AREAS DURING 1975

APPENDIX 7



AG-5 HOLIDAY CREEK OBSERVED CONTRIBUTING AREAS DURING 1975



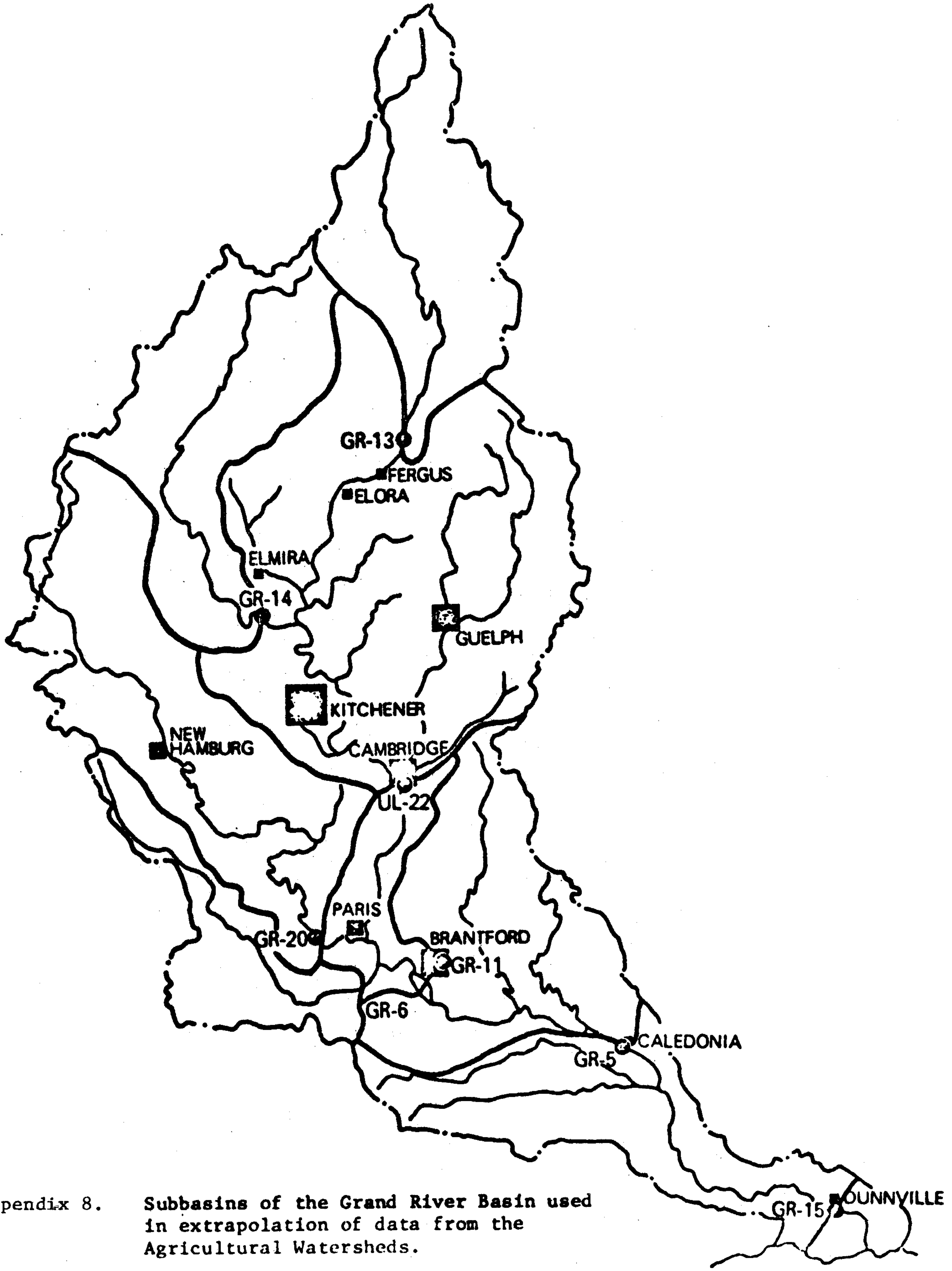
AG-5 HOLIDAY CREEK SUB-WATERSHED OBSERVED CONTRIBUTING AREAS DURING 1975

APPENDIX 8

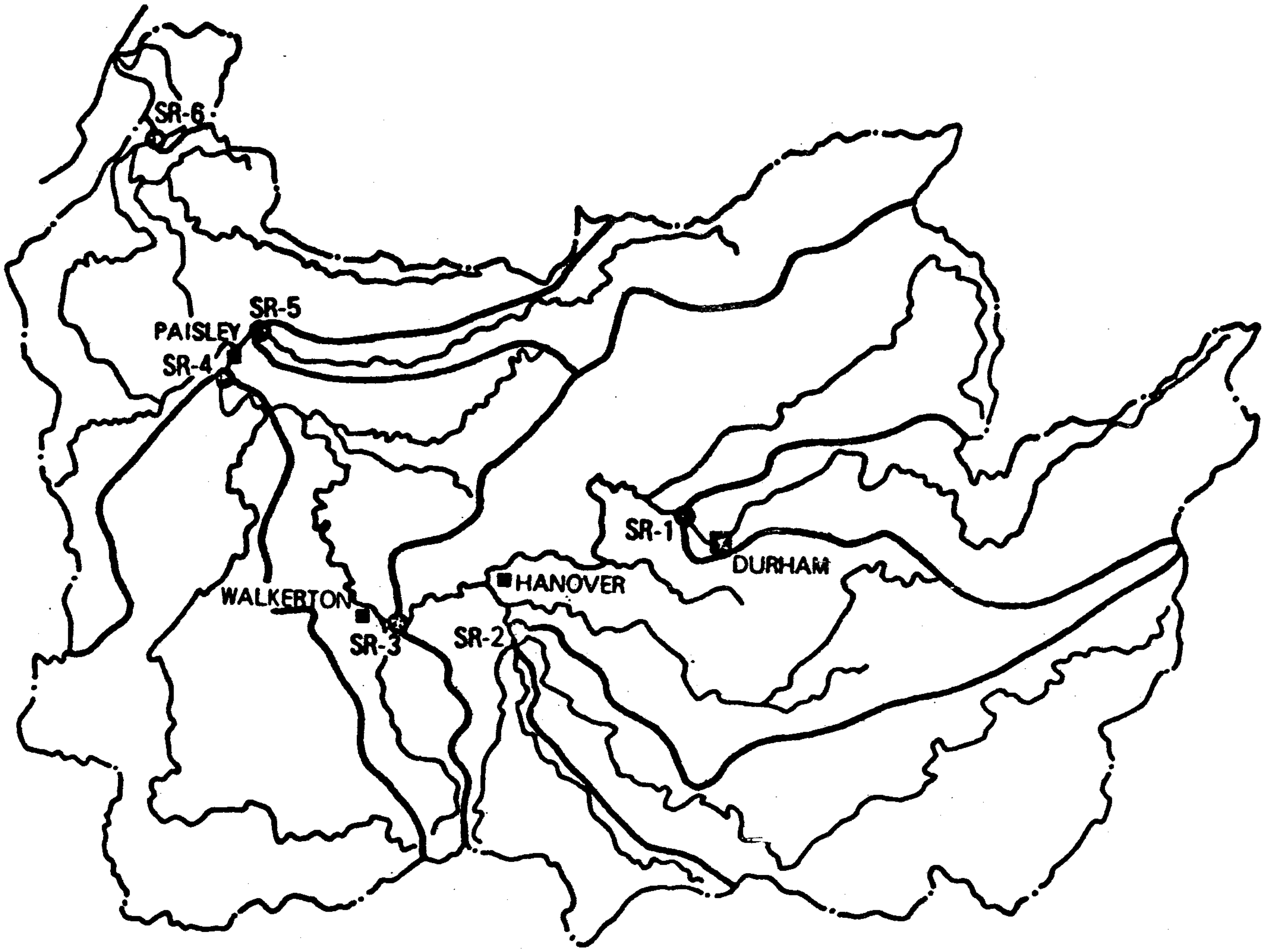
Location and sediment loading rates for subbasins of the Grand and Saugeen Rivers.

Measured annual suspended sediment loads in the Grand and Saugeen (kg/ha/yr).

	GRAND	SAUGEEN
1976 Regression	-	-
1976 Beale Ratio Method	459	298
2 year mean (1975, 1976) Regression Method	332	488
2 year mean (1975, 1976) Beale Ratio Method	380	309
2 year mean (1975, 1976) Integration Method (Water Survey of Canada	-	-



Appendix 8. **Subbasins of the Grand River Basin used** in extrapolation of data from the Agricultural Watersheds.



Appendix 8. **Subbasins of the Saugeen River Basin used in extrapolation of data from the Agricultural Watersheds.**

INTERNATIONAL JOINT COMMISSION
GREAT LAKES REGIONAL OFFICE
100 Ouellette Avenue
Windsor, Ontario N9A 6T3

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