Some aspects of fluvial erosion in the watersheds of southern Ontario, Canada.

Md. Belayet Hossain. Khan
University of Windsor

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Ottawa, Canada K1A 0N4
SOME ASPECTS OF FLUVIAL EROSION IN THE
WATERSHEDS OF SOUTHERN ONTARIO, CANADA

by

Md. Belayet Hossain Khan

A Thesis
submitted to the Faculty of Graduate Studies
through the Department of Geography
in partial fulfillment of the requirements
for the degree of Master of Arts at the
University of Windsor

Windsor, Ontario, Canada

1980
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Abstract

The suspended sediment yield data for twenty southern Ontario streams was analyzed with respect to annual yields and seasonal distribution. The mean annual yields expressed per unit area ranges from 13303 to 116066 kg/km²/yr. March-April was found to be the most significant period of the year, since more than 55% of the annual loads are transported during these two months. Based on the temporal occurrences of the first major spring thaw, the entire study area has been divided into three major regions and significant spatial variation in the sediment yield has been noted between two regions.

The relationship between the magnitude of sediment transported after an event and the drainage area has also been examined. As expected, a significant negative correlation has been established between these two parameters. This indicates that in southern Ontario the proportion of annual loads transported through a cross-section of a large stream after an event is smaller compared to a small stream. It has been noted that more than 50% of the annual loads are carried in less than six days, which is only 1.64% of the annual time.

According to the final objective of the study, a multivariate analysis has been employed to examine the relationship between sediment yield and a set of landscape parameters. Total sediment yield correlated highly with relief, percentage of the basin area under ponds and lakes, drainage area, mean annual discharge and peak discharge. The significant regression model derived explained 66% of the total variations. It is, perhaps, necessary to include cultural variables to obtain a better model, which would explain more variation. Inclusion of cultural variables, however, was out of the scope of this study because of lack of proper data.
Dedicated
to
My Parents
ACKNOWLEDGEMENTS

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CHAPTER 1

THE NATURE OF THE STUDY

1.1 Introduction

The problem of accelerated soil erosion has been traditionally one of the principal concerns of geographers. Fluvial erosion refers to the entrainment and transportation of the material of the earth due to water flowing in the liquid phase. The distribution of water and its work on the surface of the earth are important factors in the location of human settlements, and the planning and development of the economy of a region. With ever increasing attention being placed on soil erosion in the United States and Canada, it has become more important to be able to obtain complete and accurate information on the factors which influence soil erosion and their controls. Sediment loads carried by streams through certain cross-section areas are an indication of the erosion in the upper catchment basin, and it is a function of varied physical, temporal, spatial and cultural factors. Geology, soil type, topography, vegetation type and cover, drainage network characteristics, slope, and drainage area are the physical controls of sediment production and transportation. The cultural controls include land use characteristics, urbanization, and deforestation, etc. Man has proven remarkably capable of accelerating the rate of erosion through the alteration of these controls. Historically, agriculture has
provided the catalyst to accelerate soil erosion (Toy, 1977).

It has been estimated that more than 282 million acres of land was seriously damaged and ruined for agricultural use by severe erosion in the United States alone (Foth and Turk, 1972). This kind of loss of agricultural land due to erosion is very distressing to a hungry world whose demand for agricultural products is increasing at a phenomenal rate. Nevertheless, there are various programmes which are practiced nowadays to control the erosion in the catchment area.

1.2 Purpose of the Study

This study of fluvial erosion has been undertaken to demonstrate the influence of physical, cultural, spatial, and temporal factors in the production and transportation of suspended sediments in the watersheds of southern Ontario. The aim will also be to assess the spatial and temporal pattern of sediment yield in the southern Ontario streams.

Although fluvial erosion studies have been carried out in the United States of America, the Soviet Union, and in Western Europe since the turn of the century in Canada, it is only in the last two decades that continuous sampling of sediment load for selected streams has been undertaken (Stichling and Smith, 1968). As a result, little work has been done on the erosion problems and prediction of sediment yield in this region. Therefore, there is a need to evaluate the relationships between different controlling factors and sediment yield for a better understanding of erosion.
problems in southern Ontario.

Through the analysis of the complex relationship between sediment yield and selected environmental phenomena of this region, an attempt will also be made to determine if any statistical model serve the purpose of prediction of sediment yield and transportation.

1.3 Review of the Literature

Canada is a vast country and its streams occur in a wide range of environments and drainage areas, varying from a few square kilometres to more than 5 hundred thousand square kilometres. Researchers like Stichling and Smith (1968), Stichling (1973; 1974), Ongley (1973; 1974; 1976), Slaymaker and McPherson (1973), Dickinson et al. (1975), McPherson (1975), and others have made significant contributions toward understanding the Canadian erosion problems; but most of these men have mentioned the problem of the shortage of sufficient data. Most of the gauging stations along the streams in Canada are relatively new compared to the U.S. stations, and many of the northern Canadian rivers do not have any record at all.

Suspended sediment data for seven southwestern Ontario streams have been analysed with regard to areal and temporal patterns, characteristics of sediment concentration, and relationships between sediment load and selected watershed parameters (Dickinson et al., 1975). The data were obtained from Water Resources Branch of Ontario, Environment Canada.
Analysis of data revealed that the distribution of sediment production and transportation over the whole year is very skewed and more than 50% of the annual load occurs during the months of March and April. This pattern of seasonal loadings were found similar for all the seven streams under consideration. Suspended sediment concentration was highly variable, varying from season to season and from stream to stream. To build a quantitative model which would predict the suspended sediment yield in the region, they considered relief and drainage density, which are regressed against the mean annual yield. The result of this analysis showed that no simple relationship existed between the relief ratio and the average annual suspended sediment yield \( r^2 = 0.0125 \), or between the drainage density and the same sediment variable \( r^2 = 0.0018 \). These results demonstrate that such physical parameters are probably not significant to the production of suspended sediment in southern Ontario, but a detailed analysis is needed to verify this contention.

Using the data for the period 1961-1970, Stichling (1973) has produced two maps showing the suspended sediment transportation in the Canadian watersheds. One of them illustrates the average annual suspended sediment concentration expressed in mg/l; and the other, the distribution of average suspended sediment yield in tons/sq. mi./yr. This was the first attempt to give a condensed picture of fluvial sediment transport in Canada. For some streams, however, he had to use data covering a shorter time period, and this
could be a source of considerable error. The highest yield is found in the area surrounding the Rocky Mountains, which is probably because of the high energy environment found in the region.

Ongley (1973) considered fifty-two medium-sized watersheds around Lake Ontario, obtaining data from Ontario Resources Branch of Environment Canada. The months of March and April contributed about 52% of the mean annual load which is obviously due to snow melting during Spring. Mean annual sediment yield for the study area, as calculated for a five water-year period (1965-1970) was found to be 12016.0 kg/km²/yr with a standard deviation of 0.26. Of course, the data have to be log transformed for its skewed nature in order to find the standard deviation. The annual yield is equivalent to 5.15 cms per 1000 years, which is similar to the rate in the United States basins at an effective precipitation of 75-100 cms, which has been suggested by Schumm (1963).

A study of 36 watersheds ranging in size from 78 to 1427 sq. kilometres in southern Alberta has been conducted by McPherson (1975). Long term sediment data were generated using the flow duration rating curves and water discharge flow duration curves using the method outlined by Piest (1964). Most of the geomorphic and hydraulic variables including sediment contributing area, basin diameter, local relief, elongation ratio, mean annual discharge, mean land slope and stream gradient were analysed, using stepwise
multiple regression for the determination and prediction of suspended sediment yield in the region. Highly significant relationships were found between the sediment parameters and the mean land slope, the sediment contributing area, and the main channel length. The predictor equation is in the following form:

\[
\log \text{SSE} = 0.5532 \log \text{MLS} - 0.5859 \log \text{SCA} + 0.8332 \log \text{MCL} + 1.37878
\]

(with multiple \( R = 0.5 \))

where: \( \text{SSE} = \) Suspended Sediment Yield

\( \text{MLS} = \) Mean Land Slope

\( \text{SCA} = \) Sediment Contributing Area

\( \text{MCL} = \) Main Channel Length

The range of yield also varied significantly from 4900.0 to 22,357.0 kg/km\(^2\)/yr. Fifty-eight percent of the basins contributed an annual load of less than 78,000.0 kg/km\(^2\). Calculations for 92 streams were based on published data obtained from Water Resources Branch of Environment Canada which revealed that 75% of the streams yield less than 98,000 kg/km\(^2\)/yr.

A model incorporating four distinct streamflow generating mechanisms for the interpretation of sediment loads in the alpine watershed of Miller Creek in the Pacific Ranges of the Coastal mountains of British Columbia, was suggested by Slaymaker (1975). The streamflow mechanisms are snowmelt runoff, glacialmelt runoff, runoff from rainfall events of medium frequency and intensity, and baseflow controlled runoff. June–July was found to be the most significant period
of the year, with more than 75% of the annual load being moved in those two months. Concentration values as high as 576 mg/l were also recorded. The period from November to April was found to be an unimportant period, because only 0.3% of the annual load was moved in those six months with an average concentration of less than 1 mg/l.

In the watershed studies, different researchers have used different approaches to the problem of predicting sediment yield, and the relative importance of the hydrologic and geomorphic parameters controlling them. From the pertinent literature reviews, three approaches toward watershed studies may be identified. These approaches are:

A. Before and After Approach: This approach was most popular during the early years of watershed management. In this approach, the investigator essentially monitors drainage basin parameters for a number of years prior to any kind of parameter changes, then monitors the same basin after any basin parameter changes, to evaluate the effect of the parameters which have gone through the change during the study period. In Lillooet River basin near the village of Pemberton, B.C., it has been demonstrated that sediment yield rates vary remarkably over time as a result of economic development in the region (Slaymaker, 1972). This stream has been trained through straightening and shortening its course which has increased the velocity resulting in a very high rate of erosion. A problem sometimes arises when any hydrologic event of an unusual magnitude takes place which changes
the whole mechanism of the watershed under study. This approach also involved many years of parameter monitoring.

B. Paired Watershed Approach: This approach involves the study of a pair of watersheds, which allows a comparison to be made between sediment yields of two adjacent watersheds. The basin characteristics of one watershed remain unchanged, whereas the other one is subject to basin parameter treatment. Conclusions can be drawn after a satisfactory calibration has been established between the two watersheds over a period of 5-10 yrs. However, there have been criticisms of paired watersheds which include the following, as has been mentioned by Slaymaker and McPherson (1973):

1. This method is very costly.
2. The representativeness may not be guaranteed.
3. The results may not be transferrable to a different hydrologic region.
4. The changes due to change is basin parameters may be too small for detection.
5. The integrated results may not be sufficient for the assessment of the processes that operated in the area (Howlett et al., 1969).

One of the advantages in the paired watershed approach over the routinely monitored fluvial sediment data is that it is possible to control the variables under study according to the need of the researcher.

C. Statistical Models Approach: Statistical models are used for the explanation and prediction of sediment yield in the
watershed. Most of these models are multivariate in nature, because they consider a spectrum of basin parameters, and in the form of multiple regression. Such models showing the relationships of sediment production and diversity of hydrologic, climatic, morphometric, landuse and physiographic parameters has been exemplified by many researchers including Gottschalk and Brune (1950), Anderson (1949; 1972), Flaxman and Hobba (1955), Wallis (1965), Wallis and Anderson (1965), Branson and Owen (1970), and McPherson (1975). This approach to watershed modelling has attained considerable popularity in the last few decades with the intensive use of computers, and most of the recent Canadian and U.S. studies fall within this category.

In a study of seventeen watersheds in Colorado conducted by Branson and Owen (1970), the following regression equation has been derived:

\[ Y = 40.8 X_1 + 0.03 X_2 - 1.27 \quad (R^2 = 0.86) \]

where: \( Y \) = Sediment yield in acre feet per square mile

\( X_1 \) = Relief ratio

\( X_2 \) = Percent bare soil

In order to show the global effect of relief and precipitation Fournier (1960) has obtained the equation which is in the following form:

\[ \log F = 2.65 \log p^2 + 0.46 \log \frac{H}{F} \tan \theta - 1.56 \]

where: \( F \) = Suspended sediment yield (tons/km²/yr)

\( \frac{H}{F} \) = Mean relief
\( \theta_2 \) = Mean slope in drainage basin

\( P^2 \) = Ratio of the square of the wettest mouth to the mean annual precipitation

Anderson and Wallis (1965) has developed the following multivariate equation for the prediction and estimation of suspended sediment yield in the Pacific coast region of Oregon and California:

\[
\begin{align*}
\text{Log } SS &= -4.721 + 1.244 \log MQ + 1.673 \log FQ \\
&\quad + 0.116 \log A + 0.401 \log S \\
&\quad + 0.0486 SC + 0.482 SA + 0.942 R \\
&\quad + 0.0086 RC + 0.0280 BC - 0.0036 OC
\end{align*}
\]

where:

- \( SS \) = Suspended sediment discharge (tons/mi\(^2\)/yr)
- \( MQ \) = Mean annual runoff (cfs/mi\(^2\))
- \( FQ \) = Discharge peakedness
- \( A \) = Watershed area (mi\(^2\))
- \( S \) = Slope of stream of 1 mile (ft/mi) mesh length (ft/mi)
- \( SE \) = Silt and clay fraction of topsoil (%)
- \( SA \) = Surface aggregation ratio (%)
- \( R \) = Portion of catchment covered by rocks (%)
- \( RC \) = Portion of catchment cut over in last ten years (%)
- \( BC \) = Portion of catchment in bare cultivation (%) 
- \( OC \) = Portion of catchment in other cultivation (%)

One such widely used equation is the Universal Soil Loss Equation (USLE) developed by the U.S. Department of Agriculture (USDA) in the 1950's. The form of the equation is:
A = RKLSCP

where:

\( A \) = Soil loss per unit area

\( R \) = Rainfall intensity factor

\( K \) = Soil erodibility factor

\( L \) = Slope length factor

\( S \) = Slope gradient factor

\( C \) = Cropping management factor

\( P \) = Erosion control practices

The soil erodibility factor \((K)\) is a measure of the susceptibility of soil particles to be detached and transported by rainfall and runoff. It is a value experimentally determined for selected benchmark soils, and estimated for other soils based on their properties. They are readily available from the list of the published soil survey reports for the United States and Canada. The slope length \((L)\) and slope gradient \((S)\) factors can be estimated from soil surveys. The rainfall intensity factor \((R)\) is derived from climatic data. If these four factors are multiplied, the product of them \((RKLSCP)\) is the estimate of erosion potential index. This product is equal to the amount of erosion that would take place on a bare soil without any kind of conservation practices. \((C)\) is a dimensionless factor which accounts for the effect of cover and management variables that normally reduce the mechanical forces of water acting on the soil particles, increasing soil's resistivity to erosion. This cropping factor may be attributed from three distinct types of effects which reduce erosion (Wischmeier, 1976). They are:
(1) Canopy; (2) Mulch; and (3) Tillage and Residual. Like (C), (P) is also a dimensionless factor that accounts for any kind of erosion control practices including contouring, strip-cropping, and terracing.

This equation has been applied to southern Ontario by Van Vliet et al. (1976), and has been mentioned to be a useful tool for estimation of soil loss. However, it has been mentioned that for more precise results, a great deal of information is required to calculate the soil erodibility (K) values for the region.

One of the major problems in model building is that once one is developed for one region, it may not be perfectly transferable to another hydrologic region. Occasionally, the approach provides an understanding of the physical processes which are operating, but may fail to provide effective predictive ability. A great number of models are so complex that they have failed to operate in different regions due to lack of generality.

1.4 Aims of the Investigation

Since there is an urgent need to investigate the influence of the environmental factors in the fluvial sediment behaviour of southern Ontario watersheds, this study will attempt to quantify the relationships of some selected physical, cultural, spatial and temporal parameters for the prediction and calculation/estimation of suspended sediment yield in the region. The temporal distribution of sediment
production will also be analysed to determine the seasonal pattern. It is anticipated that the analysis of the data will allow the researcher to draw a portrait of the sediment transportation and erosion pattern in the study area. An attempt will also be made to derive a multivariate statistical model which could serve the purpose of prediction of sediment yield in the region. A successful outcome of this study may possibly be used as supplemental information for the erosion control programmes and agricultural planning in southern Ontario.
CHAPTER II

THE STUDY AREA

The drainage basins under study are dispersed throughout southern Ontario (Fig. 1). The region is bordered by the Great Lakes on the south, west and northwest, and the Ottawa and St. Lawrence rivers on the east. From the level plain bordering Lakes Erie and Huron, there is a gradual increase in elevation in a generally northeasterly direction to the Dundalk Uplands and the Niagara Escarpment. The area is a glaciated plain, underlain for the most part, by Paleozoic limestones and shales (Chapman and Putnam, 1966). The size of the selected watersheds under study range from 2.5 to 4300.0 square kilometers, with a relief ranging from 50 to 500 meters above sea level.

The climate of southern Ontario varies appreciably across the region because of the nature of the climatic controls. One of the most important climatic controls for this region is the lakes and their location. The effect of these lakes are most pronounced near their shores. Areas to the lee of the lakes experience significantly more precipitation and moderated temperatures than are found elsewhere. Areas having relatively uniform climate have been identified by Brown et al. (1968) (Fig. 2). The mean annual precipitation across southern Ontario ranges from 60 to 100 centimetres (Fig. 3) and this variation is closely related to the slope, elevation, and location relative to the Great Lakes.
Location of Sampling Stations in Southern Ontario

Legend:
- Sampling Station

Source: FISHERIES and ENVIRONMENT CANADA

FIGURE 1
The highest precipitation values are found on the slopes east of Lake Huron and Georgian Bay. The driest areas are found to the southwest of Toronto. There is hardly any seasonal variation of precipitation in southern Ontario. The mean annual snowfall ranges from 250.0 centimetres in the Huron and Georgian Bay area to less than 100 centimetres in the Kent–Essex region. Snowfall accounts for about 30 percent of the total precipitation. Apart from Kent, Essex and the Niagara Peninsula regions, the ground is usually covered with snow from the middle of December to the middle of March. The median date of last snow cover is about March 30, near the Lakes Erie and Ontario regions (Brown et al., 1968).

Various types of soils have been described by John (1971) in the southern Ontario region, and classified based on their texture for the assessment of water holding capacities. They include fine sandy loam soils in the northwest and southern sectors, silt-loam soils around the Dundalk Upland area, clay loam and clay type of soils on the bordering areas on the eastern and western sectors of the region.

The watersheds were chosen according to the availability of discharge and sediment data, as well as being representative samples of southern Ontario landscapes (Table 1).

Southern Ontario is one of the most densely populated areas of Canada, and supports more than 25% of the total population. Most of the natural landscape has been modified by built up areas, farms, industries, pastures, and fallow land. Southern Ontario, therefore, is a major site for agricultural
**TABLE 1**

**DRAINAGE BASINS OF SOUTHERN ONTARIO**

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<th>Sampling Station</th>
<th>Name of the Stream</th>
<th>Period of Record</th>
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<td>1</td>
<td>Sturgeon Creek near Leamington</td>
<td>Sept 71-Dec 76</td>
</tr>
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<td>2</td>
<td>Thames near Thamesville</td>
<td>Feb 73-Dec 76</td>
</tr>
<tr>
<td>3</td>
<td>Ausable River near Springbank</td>
<td>Jan 70-Dec 76</td>
</tr>
<tr>
<td>4</td>
<td>Maitland River near Donnybrook</td>
<td>Jan 70-Dec 74</td>
</tr>
<tr>
<td>5</td>
<td>Thames River near Ingersoll</td>
<td>Oct 63-Dec 73</td>
</tr>
<tr>
<td>6</td>
<td>Big Creek near Walsingham</td>
<td>June 66-Dec 76</td>
</tr>
<tr>
<td>7</td>
<td>Canagagigue Creek near Floradale</td>
<td>Jan 74-Dec 76</td>
</tr>
<tr>
<td>8</td>
<td>East Canagagigue Creek near Floradale</td>
<td>Jan 74-Dec 76</td>
</tr>
<tr>
<td>9</td>
<td>Canagagigue near Elmira</td>
<td>May 67-Dec 76</td>
</tr>
<tr>
<td>10</td>
<td>O.A.C. Farm Gauge #5 at Guelph</td>
<td>Apr 69-Oct 76</td>
</tr>
<tr>
<td>11</td>
<td>Credit River at Erindale</td>
<td>Aug 73-Dec 76</td>
</tr>
<tr>
<td>12</td>
<td>Humber River at Weston</td>
<td>Apr 65-Dec 76</td>
</tr>
<tr>
<td>13</td>
<td>Humber River at Elder Mills</td>
<td>Mar 66-Dec 76</td>
</tr>
<tr>
<td>14</td>
<td>West Duffins Creek at Green River</td>
<td>Mar 74-June 76</td>
</tr>
<tr>
<td>15</td>
<td>Stouffville Creek below Stouffville</td>
<td>Apr 74-June 76</td>
</tr>
<tr>
<td>16</td>
<td>Ressor Creek above Green River</td>
<td>Apr 74-June 76</td>
</tr>
<tr>
<td>17</td>
<td>West Duffins Creek above Green River</td>
<td>Apr 74-June 76</td>
</tr>
<tr>
<td>18</td>
<td>Ressor Creek near Altona</td>
<td>Apr 74-June 76</td>
</tr>
<tr>
<td>19</td>
<td>West Duffins Creek near Altona</td>
<td>July 74-June 76</td>
</tr>
<tr>
<td>20</td>
<td>Wixon Creek below Altona</td>
<td>Mar 74-June 76</td>
</tr>
</tbody>
</table>
and urban development. It is necessary to comprehend the relationships between soil erosion, stream suspended loads, and the factors influencing them, along with their temporal and spatial distributions; because soil erosion and stream sediment levels are key factors influencing the land and water resources. Therefore, there is an urgent need to examine the seasonal and spatial pattern of soil erosion, and also to quantify the relationships between numerous controlling factors and sediment production in this region.
CHAPTER III
MODEL, HYPOTHESES AND RATIONALE

3.1 Erosion Dynamics Model

Utilizing the systems analysis approach, the primary goal of this investigation is to develop a model relating stream sediment yield to those selected environmental phenomena that are assumed to control fluvial erosion and stream sediment behaviour. A model is a formal representation of the researcher's image of the real world, which portrays those relationships that are of greatest interest to the investigator. In this study, the hydrological cycle, the cascading system, describing the flow of water through the the landscape and the earth-atmosphere system, will be investigated as the key sediment erosion and transporting mechanism. Hydrologic factors influencing the flow of water over the landscape and through drainage network systems are also associated with the generation of the energy used to erode and transport the sediment loads of streams.

The basic conceptual model in hydrology is the hydrologic cycle. In this systems model, (Fig.4) part of the system is centered in the earth's atmosphere and involves the precipitation process. Precipitation does not immediately start flowing on the ground, but is lost by evaporation, transpiration and infiltration to the soil, or is percolated to the ground water system. Some of the precipitation which was originally the input of the whole system (megasytem) is now surface runoff, a systems output.
This output is the input of the fluvial system. This system may be termed a cascading system, because all of the hydrologic models fall under the category of a cascading system (Chorley, 1967). This second system, the landscape, may be divided into subsystems, namely the natural landscape subsystem and the human use subsystem. It is the aim of this research to investigate how these two subsystems interact, to produce sediments as an output through the influence of surface runoff. The natural landscape subsystem has been divided into four major components: a) topography; b) soil type; c) vegetation; and d) drainage basin geometry.

The amount and rate of erosion are partially controlled by topography, principally, through the influence of slope angle and slope length. With an increase of slope angle the downslope component of force acting on the soil or water molecules increases. At the same time, it is likely that the water molecules will flow across the surface rather than to infiltrate into the ground. A steep slope will produce more runoff than a gentle slope and have more erosion. The relationship between slope length and erosion could be either positive or negative, depending on the intensity of the rainfall. Erosion may decrease with greater slope length for low intensity rainfall, which permits greater opportunity for runoff to be infiltrated. On the other hand, for higher intensity storms there is a progressive increase of runoff in the downslope direction, and erosion increases. Zingg (1940) mentioned that, other things being equal, soil loss varies as
the 1.4 power of the percent slope; and Smith and Wischmeier (1962) described a similar relationship. Zingg (1940) further mentioned that soil loss varied as the 1.6 power of slope length.

Soil characteristics, are, in part, derived from the soil parent material. Soil, developed on sand and sandstone typically have a high infiltration capacity, and hence a greater proportion of water is absorbed thereby reducing infiltration. Soils developed on a shale will have a high percentage of clay, which should increase runoff by reducing infiltration capacity. Therefore, there will be more erosion on sand and sandstone. Or, for any given storm, an area with clay rich soil will experience more erosion compared to an area with sandy soil.

Vegetation may operate in a variety of ways to retard soil erosion. The kinetic energy of rain droplets is expanded on the foliage rather than on the soil surface. In addition, plant roots help keep the soil in place. The stems of plants also act as an obstacle to the flow of the water. Furthermore, fine particles of soil are trapped by a vegetation cover. Therefore, it may be generalized that with an increase of vegetation density, the rate of erosion decreases. Results, showing the relationships of soil loss and different types of crops, published by F.A.O. (1965) suggest that the rate of soil erosion from row crops is more than thousandfold compared to continuous blue grass (Table 2).

Drainage basin characteristics may be characterized
### TABLE 2

SOIL LOSS FROM SILT-LOAM SOIL 1933-1942

<table>
<thead>
<tr>
<th>Cropping System</th>
<th>Soil loss (tons/acre)</th>
</tr>
</thead>
<tbody>
<tr>
<td>continuous maize (unfertilized rows up and down slope)</td>
<td>38</td>
</tr>
<tr>
<td>continuous maize (as above, but on subsoil)</td>
<td>52</td>
</tr>
<tr>
<td>Rotation</td>
<td></td>
</tr>
<tr>
<td>a. Maize</td>
<td>18</td>
</tr>
<tr>
<td>b. Oats</td>
<td>10</td>
</tr>
<tr>
<td>c. Clover</td>
<td>5</td>
</tr>
<tr>
<td>continuous lucerne</td>
<td>0.1</td>
</tr>
<tr>
<td>continuous blue grass</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Source: F.A.O. (1965)

by various parameters, including relief, relief ratio, basin diameter, main channel length, drainage density, and drainage area. Each of these independent parameters operate in a variety of ways in the watersheds as a factor of erosion. Some of these parameters have positive and others negative relationships with the dependent variable, sediment yield. As an example, the relationship between drainage area and sediment yield has been formulated by many researchers including Kirkby (1969), Hadley (1977), Hadley and Schumm (1961). Kirkby (1969) has established that sediment yield increases to the 0.15 power of the drainage basin area.

In the human use subsystem, two major components have been considered: 1) percent of cultivated land; and 2) erosion control measures used. Normally it has been found that interference by man, whether it is deliberate or accidental,
can set in motion a sequence of events that may extend throughout the whole drainage system, which in turn may change the sediment levels in the streams. Perhaps cultivation, which man has been practicing since the dawn of civilization has had the greatest impact on drainage processes. On the other hand various soil-conservation practices are being carried out to reduce erosion. These soil conservation practices may be broadly grouped as crop management practices, supporting erosion control practices, and practices designed to restore erosion (Cooke and Doonkamp, 1974). Each of these practices relates to the manipulation of one or more of the variables in the fluvial erosion system. The human use subsystem is included in the model because man is capable of altering other factors of the landscape subsystem, which in turn, alter the rate of soil loss. Hence, these two subsystems are controlled by each other.

According to the map of erosion produced by Strakhov (1967), the plains region of Europe have an annual yield of 30 - 50 tons/km²; which he argued that without the influence of man through agricultural practices in that region the yield would not have been more than 10 tons/km². Similarly, the Mississippi region of southern United States has an annual yield of 150 - 200 ton/km², whereas essentially similar land in Latin America has a yield of 50 - 100 ton/km² which is because of the fact that the influence of man is very little in the latter region. The influence of agriculture in terms
of modifying sediment yield values has been attributed in three levels by Gregory and Walling (1973) which are:

a) contrasts that can occur within a particular general land use type; b) those that occur within land use classes; and c) those consequent upon changes in the pattern of land use. Kuznik (1954) has also shown that in the Transvolga region, U.S.S.R. erosion caused by spring snow melt is 3.3 - 13 times greater in ploughed land compared to the unploughed land in the same region. Similar results were also found by Shewchenko (1962) in the central Chernozem Zone of U.S.S.R.

Until this century, abuse of soil was very common all over the world. With the beginning of soil conservation in 1935 in the USA, efforts were made to mitigate the effects of destructive agricultural practices (Toy, 1977). Accelerated erosion at the construction sites may result from the modification of topography, vegetation cover, and other components of the landscape subsystem. Therefore, these two subsystems are interdependent, while the development of technology and economy allows for the establishment of programmes effective for erosion control. These programmes include agricultural practices like contour farming, strip cropping, terracing, and gully reclamation, and establishment of shelter belts, putting dams and barrages, etc. All these erosion control programmes which are practiced today, act as a negative feedback loop between sediment production and the human use subsystem.

To gain a clear understanding of the factors affecting
erosion in Southern Ontario, it is necessary to consider each of these factors separately and in combination with each other, to derive a clear picture of their role, through the evaluation of this systems model in determining soil erosion and stream sediment load levels.
3.2 Hypotheses and Their Rationale

Based on the information derived from the literature review and proposal model, four hypotheses concerning the behaviour of the sediment variable, stream sediment yield, have been put forward.

$H_1$: Sediment production will vary from season to season, with maximum sediment production associated with snowmelt phenomena and the absence of protective vegetation cover.

The temporal distribution of precipitation in the southern Ontario region is fairly uniform throughout the year, however, the seasonal pattern of runoff is not as uniform. For almost one third of the year, the ground is normally frozen and precipitation often takes place in the form of snow. When the snow that falls between November and March melts in early spring, enormous amounts of surface runoff are generated. Spring snowmelt runoff is often accelerated by intense rainfall which significantly contributes to the production of sediments in the watersheds of southern Ontario. On the average, more than half of the total annual sediment is transported in the months of March and April showing a very distinct seasonal variation.

$H_2$: There will be a variation in the temporal maximum sediment yields between the basins, depending on the spatial location of the basin relative to the arrival of the spring runoff.

$H_3$: The percentage of total time taken to carry equal
proportions of sediment load in smaller basins will be lower than that of the larger drainage basins.

The temporal maximum sediment yield which should be occurring during the high runoff period of spring, should also vary from basin to basin. This, of course, will largely depend on the location of the sediment monitoring station relative to the time of the spring thaw. A study of eleven streams across Canada, using long periods of sediment records, suggested that during 5% of the year, which is approximately eighteen days, more than 58% of the annual sediment load is transported (Robinson, 1972). This 5% time period is attributed to the high magnitude runoff produced by spring snowmelt and thunderstorm activity. However, this time should also vary depending on the size of the watersheds because the fluctuation of flow decreases with the increase of drainage area. In other words, other conditions being similar, the percentage of annual time taken to carry equal proportions of sediment load should be smaller in smaller watersheds as opposed to larger watersheds. Also, the sediment delivery ratio, which focuses the ratio of eroded sediment to sediment transported as it moves from its source through the drainage network, will decrease with increase of drainage area through deposition during the transporting process thereby reducing sediment yield.

H₄: Sediment yields of the streams of southern Ontario will be a function of the following landscape parameters:

a. basin relief - the difference in elevation in a
drainage basin, which is a measure of the total hydraulic head in the basin;

b. mean land slope - the average slope inclination, which controls runoff velocities in the basin;

c. basin area - the total area within the drainage basin, which controls the total precipitation catchment area of the system;

d. soil drainage - the proportion of sand, silt and clay-sized particles in the soil, which control soil infiltration capacities;

e. basin relief ratio - an index related to the hydraulic gradient of the system, which should influence the probability of runoff genesis in the system;

f. mean stream discharge - this should be proportional to the normal flow force available to carry sediments;

g. peak stream discharge - this should be proportional to the magnitude of peak runoff events, and hence, sediment yield;

h. percentage of basins in lakes and ponds - this should be inversely proportional to stream sediment yields, since these features act as runoff storage regulators and sediment traps that retard sediment production.

From the review of literature and the proposed systems model, it is obvious that the sediment yield is a complex multivariate function of numerous environmental parameters. For the purpose of this study, some selected parameters will be considered for which sufficient data are available, to.
evaluate their influence on sediment yield.

The rate of erosion is affected by mean land slope. As the mean land slope angle increases, downstream component forces acting on the soil particles and water molecules increase which accelerates erosion rate. Relief and relief ratio play a vital role in the production of sediments in the drainage basins. With a higher relief and relief ratio, the gradient of the channels increases, producing greater sediment yields compared to the streams with lower relief and relief ratio (Maner, 1958; Schumm, 1954). Mean land slope, basin relief and relief ratio are, in fact, basin slope related characteristics which influence the erosion rate in the drainage basin and they are positively correlated with the sediment yield. This relationship of slope and sediment yield can further be derived from the Manning equation, which has been suggested for both artificial and natural data, given in the form:

\[ V = K \frac{R^{2/3} S^{1/2}}{n} \]

where: 
- \( V \) = mean channel velocity
- \( K \) = constant depending on units
- \( R \) = hydraulic mean radius
- \( S \) = slope of the channel
- \( n \) = Manning's roughness coefficient

In this equation, if all parameters except slope (S) are held constant then velocity should be directly proportional
to slope. High runoff velocities should be correlated with steep slopes and in turn with high sediment yield. Using sediment data for different regions of the United States, it has been demonstrated that sediment yield is highly correlated with basin slope, basin relief and relief ratio (Schumm, 1954; Maner, 1958; Ahnert, 1970).

The relationships of sediment yield and drainage area has been established by several researchers (Gottschalk and Brune, 1950; Gottschalk, 1964; Kirkby, 1969; Hadley, 1974). The relationship has been established as negative, indicating that with the increase of drainage area, the per unit sediment yield (tons.mi\(^{-2}\).yr.\(^{-1}\), Kg.Km.\(^{-2}\).yr.\(^{-1}\)) decreases. This relationship is supported by the fact that the probability of deposition of eroded materials in lakes, ponds, reservoirs and dams will increase with the size of the drainage area, hence reducing per unit area sediment yield. Roehl (1962) analyzed data from several scattered areas and developed a graph showing a general relationship between sediment delivery ratio and drainage area. According to this graph, the sediment parameter varies inversely at about the 0.2 power of the drainage area. Gregory and Walling (1973) have mentioned that in the United States, on average, watersheds of less than 25 Km\(^2\) produce seven times as much sediment per unit area as watersheds with catchment area greater than 2500 Km\(^2\).
This parameter, drainage area, in many aspects is very easy to relate to the sediment yield and other basin processes, but because it is correlated with other drainage characteristics, its significance may not be easy to interpret. With homogeneous rock type, soil type, vegetation type and uniform precipitation a catchment will generate a runoff magnitude according to its size. But such uniformity is seldom encountered in reality.

In order for fluvial erosion to take place, there must be runoff, that is, water movement across the surface of the drainage basin. Runoff only takes place when the rate of precipitation exceeds the infiltration capacity of the ground. Therefore, with an increase in the volume of runoff, the rate and volume of sediment discharge increases. Lusby (1963) found that in western Colorado the soil structure is altered during the year by freeze and thaw cycles. This results in a soil structure that is loose and friable in the spring, which becomes increasingly compacted and dense during the late summer as storms occur. This may apply to the watersheds of southern Ontario. McPherson (1975) demonstrated that in southern Alberta annual discharge is significantly positively correlated with annual sediment yield. The need for the collection of rarely occurring peak discharge data is also very important and justified because a major portion of the annual suspended sediment yield takes place during such periods. Unfortunately, however, relatively few peak discharge records are available.
Rates of soil erosion are controlled by different properties of soils of which the most important is the infiltration capacity. Soils with high infiltration capacities, reduce sediment yield by reducing the volume of surface runoff and vice-versa. Features like lakes, ponds, dams and barrages act as sediment traps because they store runoff and subsequently sediments are deposited. According to Gottschalk and Jones (1955) about one fourth of total sediments produced in a drainage basin may be stored in natural lakes and reservoirs. In southern Ontario, such features might have a considerable effect because of the presence of small lakes, reservoirs, dams and also artificial dams across the streams. The degree to which these factors influence erosion depends on the trap efficiency of the reservoirs, the slope and size of the suspended particles (Dickinson et al., 1975). The location of the sampling station with respect to the location of the reservoir also play an important role. Sampling stations close to the storage site will definitely have lower sediment level compared to stations located at a greater distance toward the downstream.

In most of the regions of the habitable world, man exerts an important control over the spatial pattern of fluvial erosion through the modification of natural landscape. Among all types of landuses, urbanization and agricultural practices are universally recognized. In the southern Ontario region, the affect of agriculture is inevitable but it varies appreciably. It is anticipated that agricultural
lands will produce more sediment compared to non-agricultural lands although differential rate of soil erosion may be noted within the agricultural landuse class. In southern Ontario, it has been noted that row crops contribute more than fifteenfold sheet erosion compared to woodland or permanent pasture (Van Vliet et al., 1976).

Evaluation of the proposed systems model and the literature review, through the verification or rejection of the stated hypotheses should, 1) reveal the seasonal pattern of sediment yield and 2) indicate the degree to which the environmental parameters influence the rate of sediment yield in the southern Ontario watersheds.
CHAPTER IV

METHODOLOGY

4.1 Introduction

In this study of the fluvial sediment behaviour of the streams of southern Ontario, four major aspects are given emphasis and they are:

a) the temporal distribution of sediment yield;
b) the spatial variation of mean maximum sediment yield;
c) the relationship of magnitude with respect to the drainage area;
d) the environmental parameters affecting the rate of erosion

The temporal distribution of sediment yield will be analyzed to determine the seasonal pattern of such distributions. Based on the time of the arrival of the major snowmelt of the spring period the whole study area will be regionalized to examine if there is any "maximum sediment yield" variation between the regions. Aim will also be directed to examine the aspects of magnitude of sediment yield with respect to the drainage area. Evaluation of the importance of the environmental parameters will be assessed to quantify the sediment yield of southern Ontario watersheds.

4.2 Definition of the Study Variables

Several variables have been considered for the evaluation of suspended sediment yields in the watersheds of the study area and they are defined as follows:
1. Sediment yield – the quantity of suspended sediment transported through a certain cross-section of a stream per unit of time expressed in Kilogram per square Kilometers per year (Kg/Km²/yr).

2. Discharge – the volume of water that passes through a certain cross-section of a stream per unit time measured in cubic meters per second (m³/sec).

3. Peak discharge – maximum discharge which occurs every year and also measured in cubic meters per second (m³/sec).

4. Drainage area – the entire basin upstream from the sampling station in square kilometers drained by the river network system (Km²).

5. Basin relief – the difference between the highest and the lowest point in the drainage basin measured in meters (m).

6. Basin relief ratio – the ratio between the basin relief and the drainage area expressed in meters per square Kilometers (m/Km²).

7. Mean land slope – the average of the gradient of the drainage basin measured in meters per Kilometer (m/Km).

8. Soil texture – the proportion of sand, silt and clay-sized materials in the soils of the drainage basins which regulates the infiltration capacity and runoff.

4.3 Data Sources

Collection and availability of relevant data are perhaps one of the most important aspects of research. The scarcity of data in such a study, which is a major problem, has been
mentioned by early researchers (McPherson, 1975; Slaymaker and McPherson, 1973; Stichling, 1974). Continuous sediment survey programmes in this country were initiated in 1961 (Stichling, 1974) for some selected streams across the nation and most of the sampling stations in southern Ontario are relatively new. Twenty streams of southern Ontario for which at least two years of continuous records were available have been used in order to achieve the goals of this study (Table 1). Sediment yield data were computed from these records in Kilo gram per square Kilometer per year (Kg/Km²/yr). Information on other parameters were collected from various sources which includes topographic maps, soil survey maps, temperature and discharge records.

4.4 Collection of Discharge and Sediment Yield Data

The water resources branch of Environment Canada maintains a number of suspended sediment monitoring stations in the southern Ontario region. At each station the basic aim is to procure a representative of suspended sediment transported through a cross-section of the stream for a certain period of time which is normally every twenty-four hours. In order to do so, sediment sampling is performed at a number of points along a representative vertical cross-section of the stream. The suspended sediment concentration obtained from the combination of the samples is considered as the average concentration of the cross-section of the stream. This technique for measuring sediment levels of streams is known as
the equal-transit-rate (ETR) method (Guy, 1970; Stichling, 1974). The suspended sediment sampling locations coincide with the flow gauging stations so that instantaneous discharge values are available at each sampling site.

Canadian watersheds are characterized by snow covered and frozen surfaces during the winter season. Therefore, during the winter period, the surface erosion or the sediment levels of the streams are very low and sometimes even non-existent. Many small and medium-sized streams have winter sediment yields which are less than 10% of their annual yields (Stichling, 1974).

Daily stream discharge and concentration data have been obtained from the Water Resources Branch of Environment Canada. Such data were used directly for the evaluation of the suspended yields of the watersheds under investigation. The following formula was employed to calculate the mean annual sediment yields of the streams:

\[
\bar{\bar{a}} = \sum_{i=1}^{12} \frac{\bar{C}_m \bar{Q}_m K}{D_a}
\]

where: \( \bar{\bar{a}} \) = mean annual sediment yield (Kg/Km\(^2\)/yr)
\( \bar{C}_m \) = mean monthly concentration (mg/l)
\( \bar{Q}_m \) = mean monthly discharge (m\(^3\)/sec)
\( D_a \) = Drainage area (Km\(^2\))
\( K \) = Scaling factor
High sediment discharge levels were noticed during the snowmelt period of the spring season for every year of record. This snowmelt period which is from February 16 to March 10 was considered as maximum sediment discharge period. Therefore, to calculate the maximum sediment yield in Kilograms per square Kilometer per day (Kg/Km²/day), the mean daily maximum sediment yield of this period was divided by the drainage area. Mean maximum sediment yield data were obtained by using 1975 and 1976 sediment yield records.

4.5 Collection of Soil Data

Soil drainage characteristics were directly obtained from the soil survey maps prepared by Canada Department of Agriculture (Hoffman et al., 1964). These maps are shown in six distinct classes of soils for the study area and the classification is based on texture as follows:

a) very fine textured soils
b) fine textured soils
c) moderately fine textured soils
d) medium textured soils
e) medium and coarse textured soils
f) coarse textured soils

These six categories of soil textures were ranked from 1 for very fine textured soils to 6 for coarse textured soils. After ranking, the proportion of area under different soil texture categories were obtained for each watershed. In order to obtain the soil texture data, the next step was the application of the following formula:
Soil texture = \( \sum_{i=1}^{6} \) (Soil Category X proportion of the basin area under that category)

4.6 Collection of Other Data

Information on basin relief, mean land slope, drainage area, percentage of the watersheds under natural lakes, ponds and reservoirs were obtained from standard topographic maps (1:50,000). Basin relief was obtained by taking the difference between the highest point and the lowest point in the watersheds. Mean land slopes were calculated by averaging 25 to 50 randomly selected grids for each watershed. Watersheds under 500 Km\(^2\), a mean of 25 grids were used, otherwise 50 sample grids were used. These slopes were measured by taking the elevation difference at the two ends of a one-inch straight line which is perpendicular to the nearest channel. Drainage area, which covers the entire basin upstream from the sampling location, were measured in square kilometers from topographic maps. The proportion of the basin under natural lakes, reservoirs and ponds were also obtained from topographic maps and have been expressed as the percentage of the catchment area. The ratio of basin relief and drainage area have been used as relief ratio. Peak discharge has been obtained from the discharge record by taking the mean one peak discharge per year for the period stream discharge record.
4.7 STATISTICAL TECHNIQUES

4.7.1 Temporal Variation of Sediment Yield

The hypothesis of temporal variation of suspended sediment yields of the streams of southern Ontario will be demonstrated graphically. Monthly yields, expressed as percentages of total yields, will be analyzed for all the streams in the study area (Tables 3 & 4). Seasonal pattern will be further analyzed by dividing the annual load into three time periods as have been suggested by Dickinson et al. (1975) (Table 5). The time periods are: a) January to May; b) June to September; and, c) October to December. Annual loads divided into three time periods will be subject to the analysis of variance test to evaluate if there is any significant differences between the mean sediment yields of the time periods. Identification of significantly different time periods will be conducted by employing parametric t-tests should the null hypothesis of equality of means be rejected. The t-statistic may be defined as follows for equal group sizes:

\[
t_{obs} = \frac{\bar{X}_1 - \bar{X}_2}{(2MSw/n)^{1/2}}
\]

where: \( \bar{X}_1 \) = mean of group \( X_1 \)
\( X_2 \) = mean of group \( X_2 \)
\( MSw \) = Mean square within
\( n \) = group sample size

Once \( t_{obs} \) values have been obtained for both pairs of time periods (1) January to May and June to September, and (2)
### TABLE 3 and 4

**MEAN MONTHLY YIELDS (kg) AND MEAN ANNUAL YIELDS (Kg/Km²/Yr)**

<table>
<thead>
<tr>
<th>Stream Number</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Mean Annual Yield (Kg/Km²/Yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8.16</td>
<td>19.23</td>
<td>42.82</td>
<td>8.50</td>
<td>0.82</td>
<td>7.01</td>
<td>2.16</td>
<td>3.39</td>
<td>0.67</td>
<td>0.26</td>
<td>2.53</td>
<td>4.47</td>
<td>18405.46</td>
</tr>
<tr>
<td>2</td>
<td>15.17</td>
<td>12.54</td>
<td>29.21</td>
<td>14.20</td>
<td>8.15</td>
<td>3.00</td>
<td>3.99</td>
<td>3.20</td>
<td>3.01</td>
<td>1.10</td>
<td>3.88</td>
<td>2.56</td>
<td>104333.99</td>
</tr>
<tr>
<td>3</td>
<td>10.28</td>
<td>7.19</td>
<td>30.59</td>
<td>22.99</td>
<td>13.43</td>
<td>1.80</td>
<td>2.21</td>
<td>1.29</td>
<td>1.12</td>
<td>0.53</td>
<td>3.36</td>
<td>5.21</td>
<td>76173.93</td>
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<td>4</td>
<td>8.32</td>
<td>1.68</td>
<td>22.99</td>
<td>32.91</td>
<td>17.48</td>
<td>2.34</td>
<td>1.33</td>
<td>0.26</td>
<td>0.13</td>
<td>0.91</td>
<td>4.24</td>
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<td>13303.44</td>
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<tr>
<td>5</td>
<td>10.47</td>
<td>16.05</td>
<td>25.40</td>
<td>16.62</td>
<td>3.18</td>
<td>3.02</td>
<td>1.96</td>
<td>2.37</td>
<td>0.75</td>
<td>1.69</td>
<td>5.47</td>
<td>13.01</td>
<td>17952.67</td>
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**TABLE 3 and 4**

MEAN MONTHLY YIELDS (%) AND MEAN ANNUAL YIELDS (Kg/Km²/Yr) (con't)

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<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
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Mean: 85.40  7.30  7.30
January to May and October to December), they will be compared with \( t_{\text{crit}} \) values obtained from a \( t \)-Distribution Table (Taylor, 1976) at a chosen significance level and degrees of freedom \( N-g \) (degrees of freedom for within groups variance). If \( t_{\text{obs}} \) is found to be greater than \( t_{\text{crit}} \), the null hypothesis that means are equal \( (U_1=U_2) \) will be rejected and the inference of significant differences in means will be accepted. Finally the average monthly loads transported by the streams of the study area will be evaluated by plotting the mean of the percentages of annual yields for each stream against months. The variation and range within the monthly yields of the streams will be determined by calculating the standard deviations of each month's yield.

The basic assumption of any kind of parametric tests, the normal distribution of the data set, will be evaluated by employing Kolmogorov-Smirnov One Sample Tests. The other assumption of homoscedasticity which implies that group variances be roughly equal will be checked by employing a Bartlett's test. If the group variances vary greatly, an approximate test will be performed by setting higher levels of significance.

4.7.2 Spatial Variation of Maximum Sediment Yield

Variation in the spatial distribution of "maximum sediment yields" in the watersheds of southern Ontario will be evaluated as follows:

1) The occurrences of the mean maximum sediment yields
expressed in Kg/Km²/day for all the streams will be noted.

2) These data derived from the first step will be mapped;

3) The entire study area will be regionalized with respect to the temporal mean occurrences of the spring thaw involving the first major snowmelt;

4) Once the area is regionalized with respect to the time of the occurrences of the spring thaw, data on the temporal occurrences of the mean maximum sediment yields will be subject to the analysis of variance test, to see whether there is a significant regional effect on the relationship between spring thaw and sediment yield maxima.

If the null hypothesis has been rejected the next step will be to analyze the significance of differences in means between pairs of regions. This will be followed by a series of parametric t-tests for independent samples. The t-statistic may be defined as follows for unequal group sample sizes:

\[ t_{\text{obs}} = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\text{MSw} \left( \frac{1}{n_1} + \frac{1}{n_2} \right)}} \]

where:

- \( \bar{X}_1 \) = mean of group \( X_1 \)
- \( \bar{X}_2 \) = mean of group \( X_2 \)
- \( \text{MSw} \) = mean square within
- \( n_1 \) = sample size of group \( X_1 \)
- \( n_2 \) = sample size of group \( X_2 \)
After the $t_{obs}$ values have been obtained for all pairs of regions, they will be compared with $t_{crit}$ values by firstly determining the degrees of freedom $N-g$ (degrees of freedom for within groups variance); and secondly the chosen level of significance. Where the $t_{obs}$ will be found greater than $t_{crit}$ value, the null hypothesis will be rejected and the inference will be made that there is a significant difference in the sediment yield maxima in the two regions.

One of the basic assumptions of any kind of parametric tests, is the normal distribution of the data set; in this particular case the normal distribution of the observations for each region, will be evaluated. To ensure this assumption, Kolmogorov-Smirnov One Sample test will be employed. In this test, the cumulative frequency distribution of the observations for each region will be compared to a theoretical cumulative normal distribution. Greatest difference between the observed and theoretical (Dmax) will be compared to the $D_{crit}$ value under certain degrees of freedom and a chosen level of significance. The $D_{crit}$ value is available in standard statistics texts (Taylor, 1976). If the Dmax value is found to be smaller than the $D_{crit}$, the inference of normality is established.

The other assumption of homoscedasticity which implies that the regional group variances should be roughly equal will be tested by employing a Bartlett's test which approximates the $X^2$ distribution. "Approximate test" by setting higher levels of significance will be run if only moderate departure
from normality or homoscedasticity of variance are observed
otherwise data transformation techniques will be employed to
ensure these goals before the execution of the parametric test.

4.7.3 Magnitude and Frequency Aspects of Sediment

Yield in Relation to the Drainage Area

The hypothesis that percentage of total time taken to
carry equal proportions of sediment yields in smaller basins
is lower as opposed to larger basins, will be examined by
applying simple correlation analysis. The following steps
will be performed for the purpose of this part of the investi-
gation:

1) Data on the highest daily sediment yields for six
separate days of the year 1976 in tons per day will be noted
from the sediment yield records for each of the twenty streams
(Table 6). In case of discontinuous and incomplete records,
sediment yield data for other years will be used;

2) Obtained data from Step 1 for each of the streams
for six days will be ranked from highest to lowest;

3) Total yields for each of the streams for the first
four days (1.095% of annual time), five days (1.369% of annual
time), and six days (1.643% of annual time) will be calculated
in tons separately (Table 7);

4) These three separate totals obtained from Step 3 for
each of the streams will be converted to the percentages of
the annual yields (tons/year) of the respective streams. In
order to maintain a uniformity in the data set, annual yields
for the streams for which 1976 (leap year) data have been used
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<th>Year of Record</th>
<th>tons/year (adjusted annual yield)</th>
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<td>2630</td>
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<td>1590</td>
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<td>8030</td>
<td>4780</td>
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<td>6200</td>
<td>1190</td>
<td>1060</td>
<td>1020</td>
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<td>1975</td>
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</tr>
<tr>
<td>Stream #</td>
<td>Drainage Area (Km²)</td>
<td>Total Yield 4 days</td>
<td>% of Annual Yield</td>
<td>Total Yield 5 days</td>
<td>% of Annual Yield</td>
<td>Total Yield 6 days</td>
<td>% of Annual Yield</td>
<td></td>
</tr>
<tr>
<td>---------</td>
<td>---------------------</td>
<td>--------------------</td>
<td>------------------</td>
<td>-------------------</td>
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<td>1038</td>
<td>49.0</td>
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<td>56.4</td>
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<tr>
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<td>56600</td>
<td>13.0</td>
<td>67000</td>
<td>15.4</td>
<td>77200</td>
<td>17.7</td>
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<td>3</td>
<td>865.05</td>
<td>13720</td>
<td>19.0</td>
<td>15770</td>
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<td>174.90</td>
<td>24.3</td>
<td></td>
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<tr>
<td>4</td>
<td>1761.19</td>
<td>2848</td>
<td>21.9</td>
<td>3257</td>
<td>25.1</td>
<td>3610</td>
<td>28.2</td>
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<td>5</td>
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<td>3862</td>
<td>26.1</td>
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<td>6</td>
<td>590.51</td>
<td>6885</td>
<td>21.6</td>
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<td>8492</td>
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<td>7</td>
<td>17.87</td>
<td>627</td>
<td>56.2</td>
<td>695</td>
<td>62.2</td>
<td>763</td>
<td>68.3</td>
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<td>8</td>
<td>27.71</td>
<td>1159</td>
<td>72.4</td>
<td>1190.9</td>
<td>74.4</td>
<td>1220.8</td>
<td>76.3</td>
<td></td>
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<tr>
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<td>117.58</td>
<td>5790</td>
<td>58.8</td>
<td>6235</td>
<td>63.4</td>
<td>6619</td>
<td>67.3</td>
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<td>10</td>
<td>2.51</td>
<td>113</td>
<td>77.9</td>
<td>118.1</td>
<td>81.4</td>
<td>121.6</td>
<td>83.8</td>
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<td>828.79</td>
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<td>51.1</td>
<td>31730</td>
<td>53.9</td>
<td>33320</td>
<td>56.6</td>
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</tr>
<tr>
<td>12</td>
<td>800.30</td>
<td>32560</td>
<td>38.8</td>
<td>35720</td>
<td>42.6</td>
<td>37850</td>
<td>45.1</td>
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<td>13</td>
<td>303.02</td>
<td>17230</td>
<td>41.8</td>
<td>18250</td>
<td>44.3</td>
<td>19183</td>
<td>46.6</td>
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<td>14</td>
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<td>1123</td>
<td>56.0</td>
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<td>63.0</td>
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<tr>
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<td>15.28</td>
<td>182.7</td>
<td>71.3</td>
<td>195.7</td>
<td>76.4</td>
<td>200.8</td>
<td>78.3</td>
<td></td>
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<tr>
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<td>691</td>
<td>63.9</td>
<td>757.9</td>
<td>70.0</td>
<td>787.2</td>
<td>72.8</td>
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<td>17</td>
<td>42.91</td>
<td>728</td>
<td>47.6</td>
<td>796</td>
<td>52.0</td>
<td>828.5</td>
<td>54.2</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>15.02</td>
<td>241.7</td>
<td>54.7</td>
<td>258.7</td>
<td>58.6</td>
<td>267.1</td>
<td>60.5</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>17.61</td>
<td>167.7</td>
<td>40.0</td>
<td>193.9</td>
<td>46.2</td>
<td>200.8</td>
<td>47.9</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>10.61</td>
<td>511.1</td>
<td>58.7</td>
<td>531.0</td>
<td>61.0</td>
<td>550.5</td>
<td>63.2</td>
<td></td>
</tr>
</tbody>
</table>
will be adjusted by multiplying by a factor of 0.097:

5) Finally, drainage area measured in square kilometers will be regressed against the percentages obtained from Step 4 separately to examine if there is any relationship between the basin area and percentage of time taken to carry equal proportions of sediments in the streams of southern Ontario.

The significance of the correlation coefficient \( r \) obtained from the correlation analysis will be subjected to "student's t-test," to test the null hypothesis that there is no significant correlation \( (r = 0) \) between the parameters, the \( t_{obs} \) value will be compared with the \( t_{crit} \) value. If the \( t_{crit} \) value, for degrees of freedom \( (n-2) \) at a chosen level of significance, is smaller than the \( t_{obs} \) value, the inference of significant relationship will be made.

4.7.4 Factors Influencing Sediment Yield

The multivariate relationships between sediment yields and a selected set of environmental parameters, will be evaluated using multiple correlation and regression analysis. Individual relationships between sediment parameter and basin characteristics will be examined using partial correlation analysis to determine the strength of relationships. In order to measure the relative and total influence of the independent variables on the dependent variable, a stepwise multiple regression analysis will be performed. A computer package program, SPSS, will be employed to serve the purpose where sediment yield \( (SY) \) will be considered as the dependent variable and the following as independent variables:
DA = Drainage area
MAD = Mean annual discharge
RE = Relief
RERA = Relief ratio
PD = Peak discharge
SL = basin slope

STORAGE = percentage of basin area under lakes, ponds,
          etc.

ST = Soil texture

F-test will be employed as a means of screening insignificant
independent variables and selecting the best regression model.
A detailed description of the stepwise multiple regression
analysis is available in the SPSS Manual (1975) and in Ferguson
(CATMOG 15, 1977).

In order to meet the basic assumptions of the multiple
regression analysis, all the variables will be tested for
normality by employing Kolmogorov-Smirnov One Sample Test.
Finally, the residuals will be mapped to find the regions
of over prediction and under prediction of sediment yield
in the southern Ontario watersheds.
CHAPTER V

5.0 ANALYSIS AND DISCUSSIONS

5.1 Temporal Pattern of Suspended Sediment Loads

The data of suspended sediment loads, calculated from daily discharge and concentration values, for twenty streams of southern Ontario were analyzed with respect to annual and seasonal distribution. The mean annual yields of the stream expressed per unit area ranges from 13303 to 116066 Kg/Km²/Yr. (Table 4, Fig. 5). More than 50% of the streams have an annual yield of less than 50,000 Kg/Km²/Yr. The mean annual yield for all the streams of the study area has been determined as 50766.6 Kg/Km²/Yr. with a standard deviation of 33351.7. The mean annual yield is equivalent to a denudation rate of 1.7 cms/1000 years. Slaymaker and McPherson (1973) have found the denudation rate to vary from 0.26 to 4.0 cm/1000 years in a Canadian watershed study which provides quite close agreement with the findings of the southern Ontario watersheds.

The monthly sedimented yields were illustrated (Fig. 6.1 to 6.20) by plotting mean monthly sediment loads exported by each stream, expressed as a percentage of mean annual loads. Mean monthly yields for all the streams were also plotted along with their standard deviation (Fig. 7). March–April was found to be the most significant period of the year with more than 55% of the annual load being transported in those two months. Dickinson et al. (1975) have reported similar results in their analysis of the data for seven Ontario
Mean annual sediment yields of southern Ontario by streams (1000 kg/Km²/year)

FIGURE 5.
FIGURE 6
Mean monthly sediment yield (in percent) and standard deviations for southern Ontario watersheds.
streams. This pattern closely parallels the seasonal distribution of flood occurrences of the region, which reveals that 60% of the annual floods occur during March and April (Dickinson, 1972).

Sediment yields, expressed in percent of annual yields, for three time periods (1) January to May, (2) June to September, and (3) October to December (Table 5) were subject to an analysis of variance test to determine if there is any significant differences between the yields of the three time periods. The results of the analysis of variance are summarized in Table 8. A very high F-ratio indicates that there are highly significant differences between the yields of three different time periods. Further analysis of the seasonal yields were done by applying parametric t-tests. The results of the t-tests indicate that the yields of the period from January to May are significantly different from the other two seasons (Table 9). This is obvious because of the fact that 85% of the annual loads are transported during one period (January to May) whereas a small proportion is carried during the other two seasons.

Sediment yield data for all the seasons were tested for normality by employing Kolmogorov–Smirnov One Sample Tests prior to inclusion in the analysis of variance test. The obtained results confirms that they are normally distributed (Table 10). Seasonal data were also subjected to Bartlett's test to meet the homoscedasticity requirement. The results indicate that the seasonal yield variances are roughly equal (Table 11).
TABLE 8
SUMMARY TABLE OF THE ANALYSIS OF VARIANCE FOR SEASONAL DISTRIBUTION OF SEDIMENT YIELD

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>Degrees of Freedom</th>
<th>Sum of Squares</th>
<th>Mean Square</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between groups</td>
<td>2</td>
<td>81140.12</td>
<td>40570.06</td>
</tr>
<tr>
<td>Within groups</td>
<td>58</td>
<td>1576.09</td>
<td>27.65</td>
</tr>
<tr>
<td>Total</td>
<td>60</td>
<td>82716.21</td>
<td></td>
</tr>
</tbody>
</table>

\[ F_{obs} = 1467.23^* \]

\[ F_{crit} = 4.00 \]

* significant at the 0.05 level
### TABLE 9

**SUMMARY TABLE OF T-TESTS FOR SEASONAL YIELDS**

<table>
<thead>
<tr>
<th>Seasons</th>
<th>Mean Yields</th>
<th>Oct to Dec</th>
<th>Mean Square Within</th>
<th>$t_{obs}$</th>
<th>$t_{crit}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>May to June</td>
<td>June to Sept</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>January to May with June to September</td>
<td>85.4</td>
<td>7.3</td>
<td>-</td>
<td>27.65</td>
<td>66.42*</td>
</tr>
<tr>
<td></td>
<td>85.4</td>
<td>-</td>
<td>7.3</td>
<td>27.65</td>
<td>66.42*</td>
</tr>
</tbody>
</table>

* significant at the 0.05 level
**TABLE 10**

KOLMOGOROV-SMIRNOV TEST OF NORMALITY FOR SEASONAL DATA YIELDS

<table>
<thead>
<tr>
<th>Seasons</th>
<th>$D_{\text{max}}$</th>
<th>$D_{\text{crit}}(0.01)$</th>
<th>Distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>January to May</td>
<td>0.1005</td>
<td>0.356</td>
<td>Normal</td>
</tr>
<tr>
<td>June to September</td>
<td>0.1365</td>
<td>0.356</td>
<td>Normal</td>
</tr>
<tr>
<td>October to December</td>
<td>0.1466</td>
<td>0.356</td>
<td>Normal</td>
</tr>
</tbody>
</table>
### Table 11

**Bartlett's Test of Homoscedasticity for the Seasonal Yields Data**

<table>
<thead>
<tr>
<th>Seasons</th>
<th>Variances</th>
<th>M</th>
<th>V</th>
<th>g</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>January to May</td>
<td>46.72</td>
<td>0.700</td>
<td>6.00</td>
<td>3.00</td>
<td>1.22</td>
</tr>
<tr>
<td>June to September</td>
<td>15.06</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>October to December</td>
<td>21.15</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Test Statistic \( \frac{M}{V} = \chi^2 = 0.573 \)

Where:
- \( M/C \) = test statistic
- \( V \) = sum of the degrees of freedom
- \( g \) = number of variances
- \( M \) = numerator of \( M/C \)
- \( C \) = denominator of \( M/C \)
5.2 Spatial Variation of the Mean Maximum Sediment Yield

This section of the study investigates the spatial variation of the mean maximum sediment yield in the study area. Based on the temporal occurrences of the spring thaw involving the first major snowmelt, the entire study area was divided into three broad regions (Fig. 8). Region A contained seven drainage basins, region B contained seven drainage basins, and region C contained six drainage basins. In order to evaluate if there is any significant variation in the mean maximum sediment yield of these three regions, data (Table 12) were subject to analysis of variance.

The basic assumption of any parametric test, the normal distribution of the data set, was ensured by employing a Kilmogorov-Smirnov One Sample Test. In this test, the cumulative frequency distribution of the data is compared to that of the theoretical normal distribution. The greatest difference between the two (Dmax) is compared to the Dcrit value at a chosen level of significance, which is available in any standard statistics text (Taylor, 1976). In this case, Dmax values for the observations of all the three regions are smaller that the Dcrit values which satisfy the assumption of normality (Table 13). The other assumption of the analysis of variance, the homoscedascity, was evaluated by employing the Bartlett's test. The results indicated that the regional group variances are not equal and hence, an approximate test was performed by setting a higher level of significance (Table 14).
Spatial Variation of Mean Maximum Sediment Yield in Southern Ontario

FIGURE 8
### TABLE 12

**MEAN MAXIMUM SEDIMENT YIELD**  
(Kg/Km²/Day)

<table>
<thead>
<tr>
<th>Region A</th>
<th>Region B</th>
<th>Region C</th>
</tr>
</thead>
<tbody>
<tr>
<td>5091.8</td>
<td>314.8</td>
<td>1172.7</td>
</tr>
<tr>
<td>1686.1</td>
<td>1398.2</td>
<td>571.1</td>
</tr>
<tr>
<td>928.6</td>
<td>48.2</td>
<td>142.9</td>
</tr>
<tr>
<td>1642.7</td>
<td>354.5</td>
<td>52.2</td>
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<tr>
<td>299.9</td>
<td>151.1</td>
<td>559.0</td>
</tr>
<tr>
<td>1047.3</td>
<td>26.4</td>
<td>74.2</td>
</tr>
<tr>
<td>435.2</td>
<td>49.5</td>
<td>280.5</td>
</tr>
<tr>
<td>147.4</td>
<td>175.1</td>
<td>68.1</td>
</tr>
<tr>
<td>14.3</td>
<td>2417.4</td>
<td>269.9</td>
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<td>924.9</td>
<td>1216.3</td>
<td>58.9</td>
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<td>3324.4</td>
<td>1098.2</td>
<td>238.8</td>
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<td>3181.0</td>
<td>817.5</td>
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</tr>
<tr>
<td>89.8</td>
<td>1760.6</td>
<td></td>
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<tr>
<td>176.2</td>
<td>139.7</td>
<td></td>
</tr>
<tr>
<td>Regions</td>
<td>$D_{\text{max}}$</td>
<td>$D_{\text{crit}} (0.01)$</td>
</tr>
<tr>
<td>----------</td>
<td>------------------</td>
<td>---------------------------</td>
</tr>
<tr>
<td>Region A</td>
<td>0.2234</td>
<td>0.404</td>
</tr>
<tr>
<td>Region B</td>
<td>0.2529</td>
<td>0.404</td>
</tr>
<tr>
<td>Region C</td>
<td>0.2682</td>
<td>0.450</td>
</tr>
</tbody>
</table>
### TABLE 14

**BARTLETT'S TEST OF HOMOSCEDASTICITY FOR THE MEAN MAXIMUM YIELD DATA**

<table>
<thead>
<tr>
<th>Regions</th>
<th>Variances</th>
</tr>
</thead>
</table>
| A       | 2301437.13| $M = 22.25$  
| B       | 573767.42 | $V = 37.00$  
| C       | 110349.31 | $g = 3.00$  
|         |           | $c = 1.03$  

Test Statistic \((M/V) = X^2 = 21.47^*\)

Where:
- \(M/C\) = test statistics
- \(V\) = sum of the degrees of freedom
- \(g\) = number of variances
- \(M\) = numerator of \(M/C\)
- \(C\) = denominator of \(M/C\)

* Significant at the 0.05 level
5.2.1 Analysis of Variance Results

In order to evaluate the hypothesis which concerns the regional variation in the temporal mean maximum sediment yields, a one way analysis of variance was performed after the normality and homoscedasticity requirements were fulfilled. The results of the analysis of variance test are summarized in Table 15. The $F_{obs}$ value has been found to be greater than $F_{crit}$ value which allows the rejection of the null hypothesis and leads to the inference that there is significant regional variation in the mean maximum sediment yield in the watersheds of southern Ontario.

5.2.2 Results of t-tests

Following the acceptance of the hypothesis, the next step was to find the significance of differences in mean maximum sediment yields between the pairs of regions. This phase was evaluated by employing parametric t-test for independent samples. Three separate t-tests were performed to identify regional variations between A and B, B and C and C and A. The results of the t-tests are shown in Table 16. The $t_{obs}$ values for pairs of regions A and B and B and C have been found to be less than the $t_{crit}$ values. This leads to the acceptance of the null hypothesis that there are no significant regional variations between these two pairs. But the $t_{obs}$ value for the pairs of regions C and A has been found to be greater than the
### TABLE 15

**SUMMARY TABLE OF THE ANALYSIS OF VARIANCE**

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>Degrees of Freedom</th>
<th>Sum of Squares</th>
<th>Mean Square</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between groups</td>
<td>2</td>
<td>7488774.1</td>
<td>3744387.1</td>
</tr>
<tr>
<td>Within groups</td>
<td>37</td>
<td>38708501.7</td>
<td>1046175.7</td>
</tr>
<tr>
<td>Total</td>
<td>39</td>
<td>46197275.8</td>
<td></td>
</tr>
</tbody>
</table>

\[ F_{obs} = 3.58^* \]

\[ F_{crit} = 3.30 \]

* significant at the 0.05 level
TABLE 16

SUMMARY TABLE FOR T-TESTS BETWEEN REGIONS OF MEAN MAXIMUM SEDIMENT YIELD

<table>
<thead>
<tr>
<th>Region</th>
<th>Mean - Yields</th>
<th>Mean Square Within</th>
<th>$t_{obs}$</th>
<th>$t_{crit}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1356.4</td>
<td>711.9</td>
<td>-</td>
<td>1046175.7</td>
</tr>
<tr>
<td>B</td>
<td></td>
<td>711.9</td>
<td>295.6</td>
<td>1046175.7</td>
</tr>
<tr>
<td>C</td>
<td>1356.4</td>
<td></td>
<td>295.6</td>
<td>1046175.7</td>
</tr>
</tbody>
</table>

* significant at the 0.05 level
$t_{crit}$ value. This establishes that there is significant regional variation of mean maximum sediment yield between region C and A. This is perhaps attributed by the fact that the drainage basins of the region C are smaller in areas and the first major snowmelt of the spring period takes place at least two days ahead of region A. Furthermore, man's impact has changed the microclimatic conditions of the region C which is located near Toronto area, and perhaps has reduced the erosion rate greatly.
5.3 Frequency and Magnitude Aspects of Sediment Yield as Related to Drainage Area

This relationship between the percentage of annual yield transported after any event as a function of the drainage area has been evaluated by employing correlation analysis. Daily data on maximum sediment yields for all the streams of southern Ontario for the first four, five and six days were summed and converted to the percentages of their annual yields separately. In the next step these percentages were regressed against the drainage area of the respective basins. High significant correlation between these two parameters revealed that there is a relationship between them. In all three cases a negative correlation coefficient of more than 0.67 has been observed (Table 17). This indicates that the time taken to transport sediment from the drainage basin to the channel increases with the increase of drainage area. Furthermore, the probability of sediments being trapped and deposited on its way to the channel also increases with the increase of the drainage area by decreasing the delivery ratio. This relationship of drainage area and proportion of annual yield carried through a cross-section of a channel could be evaluated by the fact that the lag time between sediment yield and discharge always increases with the increase of the drainage area (Gregory and Walling, 1973).

5.4 Factors Influencing Suspended Sediment Yield

According to the final objective of the study, this section examines the role of selected environmental parameters (Table 18)
TABLE 17

SUMMARY TABLE FOR CORRELATION ANALYSIS OF
SEDIMENT YIELD WITH RESPECT TO DRAINAGE AREA

Sediment yield of 4 days (1.095% of annual time)
\[ y_1 = 53.55 - 0.012 x \]
\[ (r = -0.67) \]

Sediment yield of 5 days (1.369% of annual time)
\[ y_2 = 57.82 - 0.013 x \]
\[ (r = -0.69) \]

Sediment yield of 6 days (1.643% of annual time)
\[ y_3 = 60.79 - 0.013 x \]
\[ (r = -0.69) \]

* significant at the 0.05 level

Where:

\( y_1 \) = proportion of annual yield carried in 4 days (%)
\( y_2 \) = proportion of annual yield carried in 5 days (%)
\( y_3 \) = proportion of annual yield carried in 6 days (%)
\( x \) = drainage area (square kilometres)
<table>
<thead>
<tr>
<th>Stream Number</th>
<th>Sediment Yield (Kg/Km²/Year)</th>
<th>Drainage Area (Km²)</th>
<th>Mean Annual Discharge (m³/sec)</th>
<th>Peak Discharge (m³/sec)</th>
<th>Relief (m)</th>
<th>Relief Ratio (m/Km²)</th>
<th>Soil Texture</th>
<th>Slope (m/Km²)</th>
<th>Storage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>18405.46</td>
<td>12.69</td>
<td>0.158</td>
<td>3.61</td>
<td>4.57</td>
<td>0.36</td>
<td>5.0</td>
<td>13.1</td>
<td>0.127</td>
</tr>
<tr>
<td>2</td>
<td>104333.99</td>
<td>4299.38</td>
<td>46.97</td>
<td>513.00</td>
<td>170.73</td>
<td>0.03</td>
<td>3.5</td>
<td>35.5</td>
<td>0.138</td>
</tr>
<tr>
<td>3</td>
<td>76173.93</td>
<td>865.05</td>
<td>9.56</td>
<td>165.06</td>
<td>106.70</td>
<td>0.12</td>
<td>2.0</td>
<td>76.6</td>
<td>0.033</td>
</tr>
<tr>
<td>4</td>
<td>13303.44</td>
<td>1761.19</td>
<td>23.91</td>
<td>300.31</td>
<td>17.37</td>
<td>0.06</td>
<td>4.1</td>
<td>13.6</td>
<td>0.021</td>
</tr>
<tr>
<td>5</td>
<td>17952.67</td>
<td>517.99</td>
<td>5.12</td>
<td>65.37</td>
<td>96.03</td>
<td>0.18</td>
<td>2.2</td>
<td>35.5</td>
<td>1.130</td>
</tr>
<tr>
<td>6</td>
<td>44090.74</td>
<td>590.51</td>
<td>5.97</td>
<td>40.21</td>
<td>68.59</td>
<td>0.12</td>
<td>5.4</td>
<td>45.5</td>
<td>0.002</td>
</tr>
<tr>
<td>7</td>
<td>98835.05</td>
<td>17.87</td>
<td>0.24</td>
<td>7.49</td>
<td>15.24</td>
<td>0.85</td>
<td>4.0</td>
<td>48.8</td>
<td>0.180</td>
</tr>
<tr>
<td>8</td>
<td>55444.03</td>
<td>27.71</td>
<td>0.33</td>
<td>9.53</td>
<td>22.86</td>
<td>0.82</td>
<td>4.0</td>
<td>48.8</td>
<td>0.237</td>
</tr>
<tr>
<td>9</td>
<td>53440.18</td>
<td>117.58</td>
<td>1.21</td>
<td>24.69</td>
<td>96.64</td>
<td>0.86</td>
<td>4.0</td>
<td>48.8</td>
<td>0.329</td>
</tr>
<tr>
<td>10</td>
<td>18202.18</td>
<td>2.51</td>
<td>0.02</td>
<td>0.57</td>
<td>3.35</td>
<td>1.33</td>
<td>4.0</td>
<td>24.5</td>
<td>0.001</td>
</tr>
<tr>
<td>11</td>
<td>116066.31</td>
<td>828.79</td>
<td>7.78</td>
<td>193.00</td>
<td>259.14</td>
<td>0.31</td>
<td>1.0</td>
<td>30.3</td>
<td>0.062</td>
</tr>
<tr>
<td>12</td>
<td>92381.82</td>
<td>800.32</td>
<td>5.40</td>
<td>106.97</td>
<td>146.34</td>
<td>0.18</td>
<td>1.0</td>
<td>34.6</td>
<td>0.072</td>
</tr>
<tr>
<td>13</td>
<td>84667.76</td>
<td>303.02</td>
<td>2.31</td>
<td>3.86</td>
<td>102.13</td>
<td>0.33</td>
<td>2.6</td>
<td>63.0</td>
<td>0.196</td>
</tr>
<tr>
<td>14</td>
<td>30762.20</td>
<td>94.01</td>
<td>0.96</td>
<td>18.66</td>
<td>120.42</td>
<td>1.28</td>
<td>2.0</td>
<td>52.0</td>
<td>0.377</td>
</tr>
<tr>
<td>15</td>
<td>23609.63</td>
<td>15.28</td>
<td>0.13</td>
<td>1.41</td>
<td>7.62</td>
<td>0.49</td>
<td>2.3</td>
<td>52.0</td>
<td>0.422</td>
</tr>
<tr>
<td>16</td>
<td>22979.52</td>
<td>38.33</td>
<td>0.33</td>
<td>6.33</td>
<td>27.43</td>
<td>0.71</td>
<td>4.0</td>
<td>52.0</td>
<td>0.210</td>
</tr>
<tr>
<td>17</td>
<td>30519.37</td>
<td>42.91</td>
<td>0.54</td>
<td>9.25</td>
<td>68.59</td>
<td>1.59</td>
<td>4.0</td>
<td>52.0</td>
<td>0.740</td>
</tr>
<tr>
<td>18</td>
<td>31462.74</td>
<td>15.02</td>
<td>0.42</td>
<td>3.57</td>
<td>7.62</td>
<td>0.50</td>
<td>4.0</td>
<td>52.0</td>
<td>0.107</td>
</tr>
<tr>
<td>19</td>
<td>23567.97</td>
<td>17.61</td>
<td>0.28</td>
<td>3.28</td>
<td>7.62</td>
<td>0.43</td>
<td>4.0</td>
<td>52.0</td>
<td>1.550</td>
</tr>
<tr>
<td>20</td>
<td>59133.34</td>
<td>10.61</td>
<td>0.13</td>
<td>3.32</td>
<td>6.25</td>
<td>0.58</td>
<td>4.0</td>
<td>52.0</td>
<td>0.759</td>
</tr>
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</table>
for the prediction of sediment yield and at the same time attempts to give a quantitative evaluation of the proposed "Erosion Dynamics Model." In order to measure the influence of the selected basin parameters on the rate of suspended sediment, a stepwise regression analysis was performed. As a prerequisite, all the parameters were checked for normality by employing Kolmogorov-Smirnov One Sample tests before the execution of the stepwise regression. All the variables have been found to be normally distributed and hence no data transformation was necessary (Table 19). A summary (Table 20) of the stepwise regression analysis shows that out of eight independent variables, seven have emerged significantly at 95% level and one as insignificant. The seven variables, in order of importance, relief, slope, drainage area, mean annual discharge, peak discharge, soil texture, and percentage of basin area under lakes, ponds and reservoirs (storage) are responsible for 66% of the total variation in the suspended sediment yields of the watersheds of southern Ontario.

The first independent variable entered in the multiple regression equation was relief, that is, the difference between the highest and the lowest point in the drainage basin. This produced a multiple R of 0.593 and $R^2$ of 35.19%. One variable, thus, explains more than one-third of the total variance in sediment yield. This relationship is positive, as expected, and highly significant; and shows that relief is a very important factor in producing sediments in the drainage basins.
**TABLE 19**

KOLMOGOROV-SMIRNOV TEST OF NORMALITY FOR THE VARIABLES IN THE MULTIPLE REGRESSIONS

<table>
<thead>
<tr>
<th>Variables</th>
<th>( D_{\text{max}} )</th>
<th>( D_{\text{crit}}(0.01) )</th>
<th>Distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>SY</td>
<td>0.2186</td>
<td>0.352</td>
<td>Normal</td>
</tr>
<tr>
<td>DA</td>
<td>0.3028</td>
<td>0.352</td>
<td>Normal</td>
</tr>
<tr>
<td>MAD</td>
<td>0.3109</td>
<td>0.352</td>
<td>Normal</td>
</tr>
<tr>
<td>PD</td>
<td>0.3015</td>
<td>0.352</td>
<td>Normal</td>
</tr>
<tr>
<td>RE</td>
<td>0.1923</td>
<td>0.352</td>
<td>Normal</td>
</tr>
<tr>
<td>RERA</td>
<td>0.1501</td>
<td>0.352</td>
<td>Normal</td>
</tr>
<tr>
<td>ST</td>
<td>0.2736</td>
<td>0.352</td>
<td>Normal</td>
</tr>
<tr>
<td>SL</td>
<td>0.2174</td>
<td>0.352</td>
<td>Normal</td>
</tr>
<tr>
<td>STORAGE</td>
<td>0.2704</td>
<td>0.352</td>
<td>Normal</td>
</tr>
<tr>
<td>Step Number</td>
<td>Variables entered in the equation</td>
<td>Multiple R</td>
<td>Increase in R²</td>
</tr>
<tr>
<td>-------------</td>
<td>----------------------------------</td>
<td>------------</td>
<td>----------------</td>
</tr>
<tr>
<td>1</td>
<td>RE</td>
<td>0.593</td>
<td>35.19%</td>
</tr>
<tr>
<td>2</td>
<td>SL</td>
<td>0.660</td>
<td>43.63%</td>
</tr>
<tr>
<td>3</td>
<td>DA</td>
<td>0.679</td>
<td>45.82%</td>
</tr>
<tr>
<td>4</td>
<td>MAD</td>
<td>0.764</td>
<td>58.41%</td>
</tr>
<tr>
<td>5</td>
<td>PD</td>
<td>0.789</td>
<td>62.36%</td>
</tr>
<tr>
<td>6</td>
<td>ST</td>
<td>0.808</td>
<td>65.36%</td>
</tr>
<tr>
<td>7</td>
<td>STORAGE</td>
<td>0.812</td>
<td>65.94%</td>
</tr>
</tbody>
</table>

Source: SPSS Computer Printout
In the second step, the slope variable was added to the regression equation and produced a multiple $R$ of 0.660 and a $R^2$ of 0.436. The relationship of slope and sediment yield have been demonstrated by early researchers (Wong, 1963; McPherson, 1975) and as expected, this has been found to be strongly positive. Hence, the first two variables already explained 43.63% of the total variance.

When drainage area was added in the next step, a multiple $R$ of 0.676 and $R^2$ of 45.82% were obtained. The relationship found was positive which is very unexpected. Usually the sediment yield per unit area decreases with the increase of the drainage area as has been shown in early watershed researches (McPherson, 1975; Kirkby, 1969). The positive relationship indicated in the southern Ontario watersheds are perhaps attributable to the fact that more than half of the watersheds under investigation are controlled by artificial dams and reservoirs. The other reason could be the highly skewed nature of the flow distribution which is due to the fast snowmeltng of the spring.

Mean annual discharge emerged as the fourth most important variable and the regression equation produced a multiple $R$ of 0.76 and $R^2$ of 58.41%. The relationship is obviously positive as expected, because sediment yield is practically a product of discharge and concentration

\[ Q_s = Q \times s \]

where $Q_s =$ sediment yield,

\[ Q = \text{discharge and} \]

\[ s = \text{concentration} \]
In the next step the peak discharge was incorporated into the regression equation. The multiple $R$ increased to 0.789 and the $R^2$ to 62.36%. The relationship has also been found to be positive and similar to mean annual discharge.

When soil texture was incorporated in the regression equation, the multiple $R$ increased to 0.808 with $R^2$ value of 65.36%. The relationship has been found to be negative as expected which indicates that with the increase of diameter of the particle size the amount of sediment produced in the drainage basin decreases. Coarse textured soils typically have higher infiltration capacity, and hence greater proportion of the precipitation will enter the soil and reduce run-off, thereby reducing sediment yield. Inversely, soils with very fine textures have lower infiltration rates which allow for higher rates of erosion. The last independent variable entered in the multiple regression equation is the proportion of the drainage area covered by lakes, ponds, and natural reservoirs. The relationship has been found to be negative as anticipated with a multiple $R$ of 0.812 and $R^2$ of 65.94%.

The intensity of the influence of the reservoirs on suspended sediment load depends largely on the use and operating procedure for the reservoirs. In addition, the location of the reservoirs with respect to the sampling station largely influences the degree of influence on the rate of sediment yield. Most of the southern Ontario streams considered have a variety of reservoirs, ponds and lakes. As a result of the
lack of data regarding storage sites and complexity of the situation, the relationship of sediment yield and storage features is not very well understood.

Finally, the significant regression equation obtained for the purpose of prediction and estimation of suspended sediment yield in the watersheds of southern Ontario is of the form:

\[ Sy = -25916.9 + 94.1 \text{ RE} + 770.8 \text{ SL} + 147.2 \text{ DA} \]
\[ -16983.4 \text{ MAD} + 439.5 \text{ PD} + 6930.0 \text{ ST} \]
\[ -5344.5 \text{ STORAGE} \] (with multiple \( R = 0.812 \))

In summary, it may be reported that seven selected parameters are responsible for the explanation of 65.94% of the variation in the suspended sediment yields of the southern Ontario watersheds.

5.4.1 Study of Residuals

All studies that use multivariate analysis can not eliminate all unexplained variance and the present study of southern Ontario watersheds involving sediment yields is no exception. The predictive regression model explains 65.94% of the total variance leaving nearly 34% unexplained. Therefore, before further inclusion of variables, an analysis of residuals from the regression equation might be useful. A plot of the residuals (Fig. 9) shows that the drainage basins located around the Toronto area are over-predicted. This is perhaps because of the fact that most of those basins have artificial dams and barrages along their courses which
reduces the sediment yield substantially. However, the over-predicted and under-predicted basins in southern Ontario are randomly distributed and may be due to various reasons. One of the major reasons which might account for this, is the lack of consideration of cultural factors which influence sediment yields in the drainage basins including construction activities, changes in the vegetation and agricultural types, etc.

All the residuals fall within ±1.96 S.E. which indicates that they are normally distributed, which is an assumption of regression analysis.
CHAPTER VI

CONCLUSIONS

6.1 Introduction

This research involving the fluvial erosion of the watersheds of southern Ontario was conducted to determine the seasonal pattern of sediment yields in the region. This was done by dividing the annual yields of the individual streams into the months of the year and three different time periods. Data were further analyzed to evaluate if there is any spatial variation in the mean maximum sediment yields of the chosen watersheds. The aim was also directed to investigate the magnitude aspect of sediment yield with respect to drainage area. A model, utilizing asystems analysis approach, has also been introduced in order to gain a clear understanding of the relationship between sediment yield and selected environmental parameters. Partial evaluation of the model was done by employing a multivariate statistical analysis. It is anticipated that the derived multivariate statistical model will serve the purpose of prediction and estimation of sediment yield in this region.

6.2 Sediment Yields and Their Seasonal Patterns

Analysis of the data reveals that mean annual sediment yields of the watersheds of southern Ontario ranges from 13303 to 116606 Kg/Km²/Yr. The mean annual yield for all the streams is equivalent to a denudation rate of 1.7 cms/1000 years which is similar to the results obtained by other
researchers (Slaymaker and McPherson, 1973).

The temporal distribution of sediment yields in this region has been found to be highly skewed. This is, of course, related to the runoff patterns which intensifies during the snowmelting period of the spring. The months of March and April are found to be a most significant period because more than 55% of the annual load is transported during these two months. The sediment yields for the period from June to December are relatively insignificant since they contribute less than 15% of the annual load. Analysis of the sediment data further reveals that although mean annual yields of the southern Ontario streams are highly variable, the seasonal pattern of yields are basically the same for all the streams.

6.3 **Spatial Variation of Mean Maximum Sediment Yields**

Mean maximum sediment yields of the streams of the study area were examined with respect to spatial variation. For this purpose, the watersheds were divided into three regions based on the temporal occurrences of the spring thaw involving the first major snowmelt. These regions have been identified as A, B, C (Fig. 8). Results of statistical tests reveals that region A and B and regions B and C are similar in terms of mean maximum sediment yields of their watersheds, but a significant difference between region C and A was noticed. This is perhaps because of the reason that the streams of region C, which are located near the Toronto area, are regulated, which largely reduces the sediment yields in the streams.
Moreover, the sizes of the drainage basins in region C are smaller than the sizes of the drainage basins in region A. This "scale" factor might have a significant effect on the sediment yields of the region (Gregory and Walling, 1973).

6.4 The Relationship Between Magnitude of Sediment Yield and Drainage Area

Sediment yield data pertaining to the proportion of annual load carried in unit time after an event, were correlated with drainage basin sizes of southern Ontario. It has been found that, as expected, proportion of annual loads transported through a cross-section of a larger stream is smaller as opposed to a smaller stream. The indicated relationship is supported, however, by the fact that the chances of deposition of eroded particles increase with drainage area size. This is because the sediments are trapped in the transportation process especially when they have to travel a longer distance thereby reducing the delivery ratio. This could further be related to the lag time between sediment yield and discharge which is known as hysteresis effect. Besides, the probability of complete storm coverage of larger basins, with resulting high erosion rate, is lower (Gottschalk and Brune, 1959). It has been found that more than 50% of the annual loads are carried in less than six days which is only 1.64% of the annual time.
6.5 Factors Influencing Sediment Yield

The final objective of the present study was to quantitatively evaluate the proposed systems model. This has been done by applying multivariate analysis to examine the relationships between sediment yield and a set of selected environmental parameters. Total sediment yield correlated highly with relief, percentages of the basin area, drainage area, mean annual discharge and peak discharge. The significant regression model derived explained 66% of the total variations. It is perhaps necessary to include cultural variables to obtain a better model which would explain more variation. Inclusion of cultural variables was out of the scope of this study because of the lack of proper data.

6.6 Conclusions

Despite the limitation of the availability of relevant data, the study of the fluvial erosion of the watersheds of southern Ontario reveals that seasonal sediment yield varies greatly. The months of March and April transport more than 85% of the annual load. Spatial variation in the mean maximum sediment yields has also been noticed. The fact that the proportion of annual load transported through a cross-section of a larger stream is smaller compared to a smaller stream has been established. Finally, the proposed model has been quantified by applying a multivariate analysis. The significant regression model derived explained 66% of the total variations.
Bibliography


Research Paper No. 116, Chicago, University of Chicago, Department of
Geography, 1969.

Nelson, M. E. and Benedict, P. C., 1951. Measurement and Analysis of
Suspended Load in Streams. *Am. Soc. Civil Engrs.,* Vol. 116, pp. 891-
918.


Ongley, E. D., 1973. Sediment Discharge from Canadian Basins to Lake
Ontario. *Canadian Journal of Earth Sciences,* Vol. 12, No. 2, pp. 146-
156.

Ongley, E. D., 1974. *Hydrophysical Characteristics of Great Lakes Tribu-

tary Drainage,* Canada. International Joint Commission - Pollution
From Land Use Activities Reference Group, p. 1555.

Ongley, E. D., 1976. Sediment Yields and Nutrient Loadings from Canadian
Watersheds Tributary to Lake Erie: An Overview. *Journal of the

Nutrient Loadings to Lake Ontario: Methodological Arguments.

Nutrient Loadings to Lake Ontario. *Canadian Journal of Earth Sciences,*
No. 14, pp. 1555-1565.


Zingg, A. W., 1940. Degree and Length of Landslope as it Effects Soil Loss in Runoff, *Agricultural Engineering*, No. 21, pp. 59-64.

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