MODELLING OF THE SUSPENDED SEDIMENT LOAD IN SOME AREAS UNDERGOING DEVELOPMENT IN WEST QUEBEC

by

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A thesis submitted to the School of Graduate Studies
in partial fulfillment of the requirements
for the degree of Master of Applied Science

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March 1981

'Remember when discoursing about water to adduce first experience and then reason.'

Leonardo da Vinci

ABSTRACT

A study of the fine-grained suspended sediment load in the small streams flowing through some areas undergoing development in Western Quebec was undertaken in 1973, 1975 and 1976. The objectives of the study included a field study to collect data on suspended sediment concentrations in small streams, estimation of the fluvial suspended sediment load by various techniques, and investigation of the fine-grained suspended sediment transport characteristics in shallow flows. Accurate information on the fine-grained suspended sediments in streams could be useful in the design of water-supply schemes.

Field observations were carried out during the months of May through October in 1973 and 1975 and from June to September in 1976. A USD-59 sampler was used to collect samples from small streams in Hull, Touraine and Chelsea in Western Quebec.

Attempts were made to estimate the fine-grained suspended sediment load by two techniques. The techniques are: (1) statistical analysis, and (2) a deterministic analysis. The statistical analysis involved the use of factor analysis and multiple regression analysis. The application of the statistical analysis has been useful in understanding and screening the many variables involved in the production of suspended sediments.

The deterministic study of the transport of fine-grained suspended sediments requires a continuous flow model which will model daily flows. This approach included the use of a deterministic model (USDAHL-74) to estimate the streamflow. However, a sediment transport model needs to

be coupled to such a hydrology model. The USDAHL-74 hydrology model has the special advantage of being able to predict streamflow from a particular area within the watershed under consideration by using the zoning concept.

A poor correlation of the suspended concentration and velocity in the small streams derived from plots on full logarithmic scales suggests that the sediment flow, in shallow upland streams, differs from the sediment flow in large rivers. A sediment transport model has been proposed. It requires more detailed measurements to determine its value.

The results of the study have been helpful in providing an understanding of the variables and physical processes involved in the production of fine-grained suspended sediments in streams flowing through some areas undergoing development.

The recommendations made in the study include the need to better define the mechanisms involved in the deposition and resuspension of fine-grained sediments in natural streams. There is also a lack of information on the properties of and processes by which fine-grained soils are eroded and transported.

Improvements to the hydrology model USDAHL-74 are also suggested.

ACKNOWLEDGEMENTS

The author wishes to express his profound appreciation to his thesis advisor, Dr. Richard G. Warnock for suggesting this research topic and for his advice, encouragement, guidance and support over the years that this study has taken.

Special thanks are due to Mr. T. Raesbeck, technician at the Department of Civil Engineering, University of Ottawa for the help rendered in carrying out some of the field investigations. Mr. Fransico Aposaga is thanked for his assistance in setting up the labortory equipment.

The helpful discussions held with Mr. Gilbert Wilson, the engineering soil specialist at the Land Resources Research Institute, Agriculture Canada concerning the engineering characteristics of the soils in the study area are also acknowledged. The author appreciates the helpful discussions held with Dr. M. Yaramanoglu of the University of Maryland concerning the operation of the USDAHL model.

The author gratefully acknowledges the discussions, criticisms and suggestions of friends and colleagues at the Department of Civil Engineering, University of Ottawa during the course of the study.

Thanks are also due to numerous other friends and relatives for their ceaseless encouragement. The patience and keen interest shown by Miss Bintu Lagoke is especially acknowledged.

The financial support provided by the Elder Dempster Nigeria Independence Trust and the National Research Council Negotiated Development Grant N-42 is gratefully acknowledged.

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LIST OF SYMBOLS

The symbols used in this thesis and the various equations are defined at the time of their use. A partial list of the symbols used is outlined below.

Symbol	Meaning	Dimensions
C	Dimensionless volumetric concentration of suspended sediments at the level y	
C_o	Dimensionless concentration at the level $y = y_o$	
C_m	Dimensionless mean volumetric concentration of suspended sediments	
D	Grain size	L
e_b	bed load transport efficiency	
g	Acceleration due to gravity	L/T^2
H, h	Depth of flow	L
i_b	Fraction of specified size range of total bed sample by weight	
K_b	Sediment grain roughness	L
l	Mixing length	L
M	$\rho v_*^2/\gamma_s D$ = mobility number	
q	Unit fluid discharge	L^3/T
q_{bw}	Bedload discharge, per unit width, dry weight	F/LT
q_c	Unit critical discharge	L^3/LT
q_{ss}	Suspended load per unit width of flow	F/LT

R_s	Particle size Reynolds number	
S	Slope	
S_s	Specific gravity of sediment grain	
u	Local flow velocity in the directiony	L/T
V	Average flow velocity	L/T
$\bar{v}'$	Average speed of travel (in a vertical direction) of fluid lumps required to travel distance l	L/T
V_*	τ_o/ρ shear velocity	L/T
y	Is measured from the lowest point	
Z	h/D	
α	Coefficient of dynamic solid friction	
γ	Specific weight of fluid	F/L^3
γ_s	Specific weight of solids	F/L^3
γ_s''	Submerged specific weight of solids	F/L^3
ρ	Mass density of fluid	$FT^2 L^4$
ρ_s	Mass density of solids	FT/L^4
τ	Total shear stress boundary	F/L^2
τ_o	Total shear stress between the flow and the flow boundary (bed surface)	F/L^2
Φ	Intensity of transport (dimensionless bedload parameter	
χ	Von Karman Constant	
Ψ	Intensity of shear on particle (sediment characteristic)	
ω	Terminal settling velocity	L/T

CHAPTER 1

INTRODUCTION

1.1 General

An investigation of the suspended sediment concentration of a reach of the Ottawa River was conducted in 1972 as part of an overall study to determine the distribution and transport of pollutants in flowing water ecosystems (Ottawa River Project Report No. 1 1977).

During the study to determine the suspended sediment concentration of a certain reach of the Ottawa River, it was determined that there were temporal and spatial variations of suspended sediment concentration which suggested that these variations might be due to the flow of suspended sediments from some of the small streams, the watersheds of which were undergoing development. It was therefore decided to conduct a study of some of these local streams to determine the sources and mode of transportation of the suspended sediments in them.

The influence of man on the interface between the hydrological cycle and the physical environment has been receiving considerable attention among hydrologists and other interested scientific investigators in the last decade (Leopold 1968, Anderson 1957, Duda et al 1980; Tricentenaire de l'hydrologie scientifique Paris 1974, Symposia on Urban Hydrology, Kentucky 1974, 1975, 1976, 1977, 1978; Slaymaker and McPherson 1973; Environment Canada Research Reports 63, 1977, 81, 1978). These effects are particularly visible and pronounced in areas undergoing development, notably urban areas.

The sediments taken up by surface runoff from a location can be distributed in a variety of ways. Some of the dislodged sediments are redeposited within a short distance from the pick-up point. Others find their way into well defined water courses.

The total fluvial sediment load is made up of two components. These are the suspended sediment load and the bedload.

The problems posed by sediments generated from areas undergoing development can be many and various. These have been summarized by Guy (1970).

Although much attention has been paid to the increase of sediment loads due to development and constructional activities, there is not much information on the nature of the process of transport of fine-grained materials. Sediment traps and other control devices are often not effective in removing these. The prevailing opinion on the control of them is that it is best to try to prevent their erosion.

It is these particles which are often most significant in pollutional aspects of sediment. They increase turbidity, carry other chemical or bacteriological pollutants and may be deposited to cover food supplies of desirable fish species. The presence, mode of transport, and methods of control of these fine-grained particles is more deserving of attention.

Another particular problem that needs to be addressed is the lack of data on sediment concentrations in small streams. Most of the instrumentation to collect sediment data has been installed on large streams and rivers.

However, important processes of erosion, deposition and rescouring occur on small streams particularly in upland areas near the sediment sources. These need to be studied in order to develop effective control measures.

1.2 Objectives

The study objectives were therefore formulated as follows:

1. To carry out a limited field study to collect data on suspended sediment concentrations in small streams flowing through some areas undergoing development.
2. To try to determine a model for the estimation of the suspended sediment load for these areas undergoing development, bearing in mind the limitations of the data available.
3. To investigate fine-grained suspended sediment transport characteristics in shallow flows.

A more elaborate field study was not considered feasible because of the limitations in terms of funds and facilities available for this type of field study. It was felt that a field study of the scope indicated would be useful in the determination of models which could be studied further.

The scope of this study was limited solely to the measured suspended sediment load; the bedload was not considered.

CHAPTER 2

LITERATURE REVIEW

2.1 General Considerations

The literature review is divided into three parts. There is, firstly, a review of studies whose main emphasis has been on the determination of the effects of urbanization on the increase of sediment loads in the stream. Following this is a discussion of hydrological studies which have used multivariate analysis. Finally, a review is made of studies which deal with the prediction of sediment yield. In order to show the nature of the problem, a discussion (Simons and Senturk, 1977) is presented of the variables which are involved.

There are two groups of variables which interact and influence the amount of sediment transported or deposited in the stream under a given set of conditions. The two groups are:

1. Quantity and quality of the sediment brought down to the section of the stream under consideration. This group can be further subdivided into two parts:
   (a) Quality factors relate to the size, the settling velocity, specific gravity, shape, resistance to wear, state of dispersion and cohesion.
   (b) Quantity factors include the geology, topography of watershed, magnitude, intensity, duration, distribution

and season of rainfall, soil condition, vegetal cover, cultivation and grazing; surface erosion and bank cutting.

2. Capacity of stream to transport sediment. Two sections in this group are:
   (a) Geometric properties or shape of stream prism: depth, width, form and alignment.
   (b) Hydraulic properties of the stream channel: shape, roughness, hydraulic radius, discharge, velocity, velocity distribution, turbulence, tractive force, fluid properties and uniformity of discharge.

It should be noted that these variables are not independent. However, it is difficult to compute the variables in the first group. Some of the equations derived to compute sediment yield from sources are, as a result, varied in nature. Some of these equations are described in this chapter. Some of the equations developed for the second group are described in section 2.4.

2.2 Urban Sedimentation

The need for studies in sedimentation in urban areas has been emphasized in reports made by Dawdy (1967), Guy (1970), Guy and Jones (1972), Leopold (1968) and the U.S. Department of Housing and Urban Development (1970). Such studies have provided insight into sedimentation problems in urban areas. This has led to the development of control measures or procedures to rectify those problems.

Some investigations aimed at evaluating sediment yield from urban areas have been reported by Thompson (1970), Guy (1963), Guy and Ferguson (1962), Guy, Vice and Ferguson (1969), Wischmeier, Johnson and Cross (1971), Wolman and Schick (1967) and Keller (1962), Pitman (1978), Peavy (1976), Curtis (1976), Overton et al (1978), Simons et al (1978), (National Symposia on Urban Hydrology, hydraulics and sediment control 1974-1980), York and William (1978). The results appear to vary from one watershed to the other.

Leopold (1968) reported measurements of sediment yield made in small, urbanizing, developed, or industrial areas which showed a 10 to 100 fold increase over that in rural areas. In a study of sediment movement in an area of suburban highway construction at Scott Run Basin, Virginia, Guy et al (1969) reported a sediment yield per acre which was about ten times greater than that for cultivated land, 200 times greater than that for grass areas and 2,000 times greater than that for forest areas. The allocation of sediment to source areas revealed that highway construction areas varying from less than one to more than 10 per cent of the basin area at any particular time contributed 85% of the sediment. In another observation of sediments in a reservoir which is surrounded by urban sprawl, Guy and Ferguson noted that Lake Barcroft near Washington, D.C., contained 25,000 tons of sediment for each square mile (8.76×10^6kq/sq.km) of completed residential construction.

York and Davis (1971) carried out an investigation on sediment transport in a small drainage basin about 1.7 sq. mile (4.4 sq.km) in area. They analyzed data collected both before and after land use changes. It was observed that the main land-use change was due to constructional activities for residential buildings. Their studies led to the conclusion that urbanization as characterized by constructional activity, increased the amount of sediment for transport and resulted in an average increase of suspended sediment concentration 12 times that expected with the pre-urbanization land-use conditions. The constructional activities which averaged 15% of the basin area generated a sediment yield 14 times that expected for rural conditions.

Wolman and Schick (1967), reported their observations made on constructional activities and the associated sediment released to the stream in some urban and suburban areas of Maryland. Sediment concentrations from areas undergoing constructional activities ranged from 3,000 to 150,000 ppm, according to their report, whereas in natural or agricultural catchments, the highest comparative concentration was 2,000 ppm. In terms of annual values, sediment yields derived from areas undergoing construction varied from 1,000 $t/mi^2/yr$ to 140,000 $t/mi^2/yr$. (350,264.4 kq/sqkm/yr to 49.04×10^6 kg/sqkm/yr). It was pointed out that the average yield for a predominantly wooded watershed was 200-500 $t/mi^2/yr$. (70,052.88-175,132.2 kq/sqkm/yr).

Keller (1962) investigated the effect of urban growth on sediment discharge at Northwest branch, Anacostia river basin, Maryland. Two gauges were located on a stream such that the one upstream measures drainage from predominantly rural areas, and the one downstream from the urban area in addition to the other areas. For a specific value of flow, a six-fold increase in sediment discharge was observed and this increase was attribted to urban-growth activity. The sediment yield caused by urban growth was found to be 17 tons per day per square mile. (5954.5 kg/per day/sqkm) The author also established that suspended sediments concentration in urban-growth area persists longer and is about 2 to 5 times higher in value than that in rural areas.

In an attempt to evaluate sedimentation derived from a residential construction at Kensington, Md., Guy (1963) took measurements relating to sediment yield, water runoff and precipitation from July 1959 through January 1962, during which period a 58-acre (23.47 ha) area was being transformed by construction from rural to residential land use. He reported a yield of 189 tons per acre (42.37 kq/sq. meter) for the period considered.

Thompson (1970) conducted a study to determine quantitative values on the rates and amounts of erosion from urban construction sites. The results of the study carried out in the Detroit Michigan, metropolitan area indicated that the erosion on construction sites produced about the same amount of eroded material from 2.1 percent of the area. It is interesting to compare this observation with that made by Guy et al in the investigation at Scott Run Basin, Virginia. Thompson also recorded an erosion rate averaging 69 tons per acre (15.47 kq/sq.meter) per year for land under development.

Peavy (1976) conducted an investigation on sedimentation in an established urban area in Durham, N. Carolina. In the study correlations were made between the rate of sediment release and the hydraulic discharge rate and between sediment production and storm intensity, duration and antecedent rainfall conditions. 13 storm events were used in the analysis. Peavy's results showed that antecedent runoff conditions do not influence the quantity of sediment produced in any given runoff event.

Overton and Minear (1978) presented a report on a mathematical model designed to simulate suspended sediment load in urban watersheds. The model consisted of a storm hydrograph simulator and a suspended load modulus simulator: the model was derived from storm runoff and sediment data from 5 urban watersheds in Tennessee. The sediment loads of interest were during storm periods.

Guy (1963) investigated the sediment transported in storm runoff near Kensington, Md. during the transformation of part of a 58-acre area from rural to residential land use. Sediment concentration and water discharge data were collected for 25 storm events plus some miscellaneous single observations during other storm periods. He then obtained multiple regression equations by relating sediment concentration to runoff quantity or rainfall quantity, the mean air temperature, which was considered an indicator of the season, the storm intensity, and the antecedent condition of the basin expressed in terms of the base flow. The equations obtained were similar in form to the Flaxman's (1972) and Anderson's (1957) regression models.

Betson (1963) developed a non-linear multivariate regression model for sediment yield. The form of the empirical equation proposed was as follows:

$$Y = a + bP_1^{m}P_2^{m} + cP_1^{m}P_2^{n}(2-\sin M) + de^{-ft}$$

where Y = monthly sediment in tons per square mile;

P_1 = rainfall for current month, in inches

P_2 = rainfall for previous month, in inches

M = season, by months evaluated by arbitrarily setting January = 30^{o}, February = 60^{o}, etc.

T = time, by months (January 1944 = 0.01, February 1944 = 0.02, etc.)

e = base of natural logarithms; and

a, b, c, d, f, m and n are constants to be evaluated. The sediment yield analyses were performed on monthly data collected during the 10-year period, 1944-1953, in the Chestuee and Middle Creeks watershed.

Anderson and George (1966) conducted a state-wide reconnaissance of the water-quality characteristics of New Jersey streams. They made a graphical analysis of some of the water quality parameters and they pointed out that 'land use also has a major influence on water quality'.

George (1963) reported a 25% increase in sediment yield in the Stony Brook basin during the last half of the period 1956-1959, concluding that land stripped for urban expansion and reservoir construction in the basin was creating a temporarily high suspended-sediment yield. However, the investigators noted that most available data (1950-1962) on the suspended sediment in the state's streams did not suggest that there was an extensive problem in the state.

2.3 Analytical - Multivariate Analysis

The statistical approach has been suggested as an analytical tool for forecasts of long duration (several months). On the other hand, conceptual (deterministic) models may be a better alternative for forecasts of shorter durations (McCuen et al 1979).

When this study was begun, the literature survey on the effect of development (especially urban development) on the suspended sediment load in streams showed that the problem required better definition. The review of literature was therefore expanded to include a review of studies done in areas associated with predicting suspended sediment load, such as water yield forecasting and stream discharge predictions. It was felt that consideration of these associated problems might help to determine a solution to the problem, most especially in the selection of variables that might be relevant to the problem.

The multivariate method of analysis has been applied in hydrological studies by McCuen et al (1979), York and William (1978), Snyder (1962), Wallis (1967), Rice (1967), Eiselstein (1967), Wallis and Anderson (1968), Wallis (1968), Haan (1977).

In a study designed to make a comparative evaluation of some statistical methods for water supply forecasting, McCuen et al (1979) examined besides multiple regression analysis, three other alternative methods of calibrating the statistical methods: principal components regression analysis, stepwise regression, and constrained pattern search (numerical) analysis. Water yield data for the Upper Sevier River basin in Utah were used to demonstrate different statistical methods for calibrating water supply forecast models and to evaluate models using both hydrologic and statistical goodness-of-fit criteria. McCuen et al (1979) also summarized the advantages and disadvantages of multiple regression, stepwise regression, principal components regression analysis and the constrained pattern search analysis as methods of model calibration.

The conclusion made in the study was that the three other alternative methods (principal components regression analysis, stepwise regression and constrained pattern search analysis) were able to control the effects of multicollinearity in model calibration; therefore, these other methods were shown to be superior to the frequently used multiple regression technique in calibrating water supply forecast models. McCuen et al, suggested some criteria for evaluating a model. These criteria include the examination of residuals, evaluation of the relative importance of the predictor variables, and an examination of the rationality of model coefficients. These criteria were considered more important than statistical goodness-of-fit indices in assessing the reliability of forecasts, especially for periods of extreme observations like those with low snowfalls.

One of the disadvantages pointed out in connection with the use of principal components regression analysis was that the components were not measurable characteristics, but a weighted sum of the predictor variables. This disadvantage can lead to difficulty in assigning physical meaning to the components derived. Factor-analysis can be a helpful method in rectifying this difficulty.

The constrained pattern search analysis is a numerical optimization method. The difficulty associated with this method is that of estimating optimum values for the initial estimate of the unknowns. Iterative techniques often require more computer time to determine the optimum values.

McCuen et al (1979) suggested that while conceptual models might be a better alternative for forecasts of shorter duration, the statistical methods usually provide acceptable forecasts for durations of several months.

Snyder (1962) discussed two of the basic premises of multiple regression analysis which must be considered in using the method as a prediction tool. The first dealt with curve fitting by the use of the simultaneous normal equations of the method of least squares. In the derivation of these equations it is assumed that the independent variables are fixed variates and are measured without error. He pointed out that "in actuality the errors are inherited by the dependent variable". He commented that the multiple regression analysis is acceptable if the prediction of the dependent variable with minimum error variance is the objective. Also, he suggested that if the association of errors with variables is a consideration, there would be need to look for other curve-fitting techniques.

An application in which this type of error situation cannot be considered realistic arises from the paired watershed concept. The same chances for errors are present in the independent variate, determined from the control watershed, and in the dependent variate determined from the treated watershed.

The second basic premise is the assumption that the independent variables are not correlated with each other. In hydrologic studies, the independent variables may not be uncorrelated. Snyder pointed out that there is a positive correlation between amount and duration of rainfall.

Multivariate analysis, which is defined as a study of arrays of variables, is suggested as a technique that can eliminate some of the problems discussed above, when used to fit prediction equations to observational data. The concept allows association of error with more than one variable. Also, one of the subfields of multivariate analysis, principal component analysis, deals with the determination of all the truly independent components of variation in an array of variables.

Snyder applied the two methods of analysis (principal component and multiple regression) to rainfall-runoff data and showed that the multivariate analysis offered the more satisfactory solution to the problem of estimating independent effects when the independent variables are correlated. The regression coefficients were found to be all positive with the multivariate analysis, whereas, they were found unstable when the multiple regression analysis was used. The coefficients should be the weighting factors for each term. He, however, noted the drop in multiple correlation coefficient from 0.83 for the multiple regression solution to 0.75 for the multivariate solution.

Eiselstein (1967) analyzed the surface runoff data from small watersheds in New Zealand by principal component analysis with varimax rotation of the factor weight matrix. For comparison a standard multiple regression analysis was made and he concluded that the advantages derived from a prediction equation resulting from varimax rotation of the factor-weight matrix include: (a) clarification of the line of thought underlying both the components of the equation and the equation itself, (b) increased stability of the regression coefficients and (c) greater accuracy in predictions based on data from a new population. He selected 29 (twenty-nine) variables to account for variation in runoff from the seventeen plots he investigated.

Wallis and Anderson (1965) applied multivariate analysis to predict sediment yield for 46 watersheds in Northern California. The watershed characteristics used in evaluating the adequacy of sediment network design were physiographic, climatic, surface soil, lithologic, land-use and condition and hydrologic parameters. A prediction equation was developed from principal component analysis with varimax rotation of the factor weight matrix.

In his studies designed to develop a prediction model for mean annual flood in New England, Wong (1963) compared the use of multiple linear regression equation without the reduction of variables and the reformulated multiple linear regression resulting from a principal component analysis. Although the R^2 of the reconstructed model is the same as the original R^2 which used five independent topographic characteristics, he found the reformulated model used fewer variables (two variables), while at the same time resolved the problem of 'multicollinearity', that is the existence of a linear relation among the variables.

Dawdy and Feth (1967) applied factor analysis to the study of chemical parameters of groundwater from wells located in the Mojave River Valley in San Bernadino County, California. Their result showed that four principal components accounted for 90.8% of the covariance of the data. Eight variables were originally selected to describe the water quality characteristics. Owing to the fact that it was found difficult to interpret the principal components in any physical sense, the four components were then rotated. The rotation operation made for an easier interpretation of the factors in terms of the original variables. A brief mathematical description of factor analysis is given later in this thesis. Diaz, Sewell and Shelton (1968) determined the factors affecting the 17 watersheds in Ohio and 7 watersheds in Texas by applying principal component and factor analyses to annual precipitation and runoff data from the watersheds. The relative importance of the identified factors was also determined. Their result showed that, in Ohio watersheds, area and slope in that order were the two most important factors affecting water yield. For the Texas watersheds, the 'three almost equally important watershed factors were identified as the soil type, cultural practices, and land capability. A stepwise regression of runoff-precipitation ratio of the Ohio data on area-slope variables confirmed the effect of area and slope on runoff as identified by the factor analysis.

Hordon (1972) examined the spatio-temporal changes in water quality in central New Jersey during 1960-69 by the application of a factor analytic technique. The period of investigation included the continuation of suburbanization with its resultant effect on water quality. The result showed that the cumulative degree of explanation of the rotated factors declined during the decade (1960-69) under investigation for all the three sites considered. It was therefore hypothesized that urbanization with its consequent changes in land use and runoff patterns might be intervening in the natural ecology of the stream. It was concluded that urbanization might be interfering with in-stream interactions among the eleven variables considered.

Knisel (1970) analysed loss rates from five floodwater detention reservoirs. Out of 13 hydrologic and climatic variables included in a factor analysis to identify those significant for estimating reservoir loss rates, three variables were found to be significant for only one reservoir. The results of the analysis showed that the data cannot be pooled for all reservoirs. Reservoir stage was found to be the most important variable for four of the five reservoirs. Loss rate prediction equations were developed for the five reservoirs on the basis of the factor analysis result.

Haan (1977) used the regression on principal components to relate runoff, the dependent variable, to precipitation and eight other geomorphic variables. The principal components were determined for the eight geomorphic variables.

York and William (1978) published the results of a field investigation of the effects of urbanization and sediment-control measures on streamflow and sediment transport in Montgomery County, Md. In the study, which was made between 1962 and 1974, data were collected from nine drainage sub-basins in a 32-sq. mile area.

Multiple regression analysis was the statistical method used to relate the criterion variables (streamflow and stream discharge) to a number of other predictor variables that were selected. Guy's study (1964) (elsewhere reported in this thesis) seemed to have influenced York and William in their choice of the predictor variables. It was reported that the "large scatter indicates that factors other than the variables used in the regression equations affect the suspended-sediment yields of the basins". Sediment-transport curves were from logarithmic plots of daily suspended-sediment discharges and the corresponding daily water discharges. York and William (1978) pointed out that there was a complex relation between sediment discharge and the factors affecting erosion and sediment transport. A number of independent (predictor) variables were found to be significantly correlated with each other; for example, the rainfall intensity parameters. It was remarked in the study that 'much of the error (the standard error of estimate in the statistical analysis) is probably attributable to factors not analyzed by the regression model'. The advice offered was that 'factors such as the location of sediment source areas and differing soil and cover conditions with respect to the area distribution of rainfall must be analyzed'.

The conclusion derived from the review of the foregoing study is that there is a need for the consideration of many variables that best describe the numerous factors involved in sediment yield. These factors include physiography, soils, climate, land use and land cover. Some attempts have been made in this thesis to respond to such a need and are reported herein. They include statistical analyses (multiple regression analysis and factor analysis) and a deterministic approach using the USDAHL model (University of Maryland version).

Anderson (1957) used multiple regression analysis to relate suspended sediment discharge to two streamflow variables, two topographic variables, two soil variables, and one channel-bank variable. The data used were from 29 watersheds in western Oregon. Flaxman (1972) employed a similar tool to predict sediment yield in 11 western states of the U.S. His data were for 39 watersheds which varied in size from a few acres to more than 50 square miles (> 130 sq.km^2). His objective was to determine if a few watershed variables could describe the variation and influence of changes in land use and treatment on sediment yield, which was chosen as the dependent variable. The independent variables selected were X_1 for the climate; X_2 for the topography, and X_3 and X_4 for soil characteristics.

The foregoing review can be classified into two sections: (1) A review of the literature that dealt with the effect of land-use activity, most especially constructional activity, on the sediment yield within the basin. (2) Methods employed to relate the sediment yield to some variables which are considered relevant.

In the first classification above, the results of the studies reviewed reveals that there is a general increase of from one to six times in the level of the sediment yield generated from urban areas as compared to the sediment yield generated from non-urban areas. Although the studies have been invaluable in providing an understanding of the problem posed by the sediments generated in urban environments, the analytical methods employed to relate the sediment yields to some variables are not considered rigorous enough. Some important variables involved in the sediment yield process were not taken into consideration. Some investigators used graphical techniques (Leopold 1968, York, Davis 1971, Thomson 1970). Others used empirical equations (Wolman 1971), while some others tried statistical techniques (Anderson 1957, Wallis and Anderson 1965, Guy 1963).

It is doubtful whether the analytical methods employed by each of the different investigators are transferable to the problems relating to other basins. One investigator (Guy 1964) has counselled against extrapolation of the prediction equations derived to basins of different sizes and locations as the problems may vary from basin to basin.

Some of the parameters of the variables selected to derive some of the empirical equations appear to have been chosen rather arbitrarily (Betson 1963). In some other cases, the equations derived for predicting sediment load are only storm related (Peavy 1976, Overton and Mincar 1978). It seems only the variables considered were those deemed relevant to the particular problem at hand (Guy 1964). The studies of Anderson (1957) and Anderson and Wallis (1965) on the sediment yield process appeared to have taken into account a wide-ranging number of variables which describe the different aspects of the sediment yield process. However, the broad nature of such studies rarely permits the consideration of the variables that are of special interest to urban environment. For example, the studies of Anderson (1957) and Wallis and Anderson (1965) dealt with suspended-sediment concentration in fairly big rivers. The impact of land-use on the suspended sediment concentration in small streams of the order considered in this study flowing through areas undergoing development requires further study.

A literature review of some other form of statistical analysis, such as factor analysis was undertaken because of the inherent weakness of multiple regression analysis as a statistical tool in estimating a dependent variable when the independent variables associated with such a variable are correlated (Hawley et al 1980, Snyder 1962, Wong 1963, Wallis 1967). Most of the literature survey done in connection with this statistical tool, factor-analysis, falls in the general area of water resources. Eiselstein (1967) analysed the surface runoff data from small watersheds in New Zealand by a factor-analysis method. McCuen et al (1979) pointed out the effects of multicollinearity in model calibrations to justify recommending 'such other statistical model as principal component regression analysis in water supply forecasting'. However, a review of the literature was invaluable in understanding how the factor-analytic tool can be applied to the problem of estimating suspended sediment concentration in areas undergoing development. This included an understanding of how the variables are selected and the difficulties that may be ecountered in giving physical meaning to the factors and the greater freedom in being able to select a wide number of variables.

2.4 Sediment Yield

Two ways to determine sediment yield in a watershed are: (1) the Direct Method and (2) the Indirect Method.

(1) The direct method involves the sampling of the rivers and streams and other points in the watershed to determine the amount of sediment load that passes through a specific point. One sampling procedure adopted for this study is described in this thesis (Chapter 4). The sampling procedure, useful as it may be, is costly and time consuming. However, the initial data gathered from sampling form the basis for verifying other methods for estimating sediment yield.

(2) The Indirect Method

Indirect methods of estimating sediment yield include remote sensing and the derivation of equations that relate sediment yield to variables which may describe rainfall, runoff, land use, soil types and geomorphic characteristics or any of the variables listed in 2.1. Though some models have been constructed to estimate sediment yield, watershed sediment yield models are yet in a stage of 'infancy' (Sharma et al 1980). The modeling approaches include the following: (1) Statistical regression models, (2) Unit sediment graph models, (3) Parametric models, (4) Stochastic models, (5) System model, and (6) Multivariate analysis model (factor analysis).

Statistical regression models have been developed to estimate sediment yield by means of either computing gross erosion and sediment delivery ratio or directly determining sediment yield. The universal soil loss equation (USLE) is a common method of determining gross erosion rates (Wischmeier and Smith 1978, Wischmeier 1976). The USLE is the result of statistical analysis of many years of erosion experiment data. The equation is:

A = RKLSCP where ....(1)

A = the annual soil loss in tons/acre

R = the rainfall erositivity index

K = soil erodibility index

L = slope length factor

S = slope factor

C = crop management factor

P = conservation practice factor

The movement of sediments in rills and small channels is not well documented by the USLE. The downslope soil movement overland and in rills and small channels then becomes a function of sediment transport capacity (Sedimentation Engineering ASCE 1977). The USLE is designed to provide an estimate of average soil loss per year or on a long term basis. Subsequent modifications to the USLE (Williams 1975) suggested a runoff factor to replace the rainfall energy factor. Recent studies (Felton et al 1979) have attempted to use the modified form of the USLE using the runoff factor to estimate soil loss on an event basis. The physical processes involved in the erosion, transport and deposition triangle are not described in detail by the USLE.

Some other studies have used multiple regression analysis to compute sediment delivery ratio. The delivery ratio, DR, is defined as: $DR = \frac{Y}{T}$ where

Y = sediment yield at the measuring point, and

T = the total material eroded from the watershed and drainage system upstream of the measuring point. In common usage, the sediment delivery ratio is considered a percentage or 100(Y/T) (Sedimentation Engineering 1977).

Roehl's (1962) statistical analysis listed several morphological watershed characteristics that could be correlated with the delivery ratios. Some of the watershed characteristics listed included drainage area, average slope of the watershed, sediment source and its proximity and texture of the eroded material. The study used data gathered from field investigations in the southeast Piedmont region of the United States. Roehl (1962) developed the following relationship:

$\log DR = 4.5 - 0.23 \log 10\, W - 0.51 \log \frac{L}{R} - 2.79 \log B$ in which

DR = the sediment delivery percentage

W = the drainage area in square miles

L/R = the dimensionless basin length-relief ratio (watershed length as measured essentially parallel to the main drainageway divided by elevation difference from the drainage divide to the outlet)

and B = the weighted mean bifurcation ratio. Bifurcation ratio is the ratio of the number of streams of any given order to the number in the next higher order.

A similar study in southern Kansas, western Oklahoma, and western Texas produced the relation log D = 2.943 - 0.824 log L/R.

Upland erosion differs from the measured sediment yields because of possible measurement and estimation errors and other factors which include redeposition of the particulate in surface water storage, trapping of the sediment by vegetation and its residues, local scour and redeposition in rills and channels. The statistical relationships relying on the morphological characteristics of the watershed have some applicability for estimating long term (annual or more) deliveries. However, their reliability for event deliveries is almost nil (Norotny 1980).

In order to predict sediment delivery on an event basis, Norotny (1980) correlated the delivery ratio to the following variables, the rainfallenergy factor, the runoff volume, average storm intensity and storm duration. The delivery ratio, DR, was statistically related to a few storm and overland flow characteristics on the assumption that the DR is determined by the energy loss during the recession portion of the overland flow. Norotny (1980) suggests relating the delivery ratio to the hydrograph characteristics.

Some other multiple regression models (Anderson 1957, York and William 1978) have been described earlier in this chapter.

The unit sediment graph model was proposed by Rendon-Herrero (1974). Rendon-Herrero (1974) derived a sediment-graph method to estimate the washload on a storm-basis using the unit-hydrograph approach. The sediment-graph analysis is a form of unit sediment-graph whose standard unit was 910 kg (one ton) for a given duration distributed over the watershed area analogous in unit hydrograph analysis to 25 mm of effective rainfall over the same area. In order to utilize such a unit sediment-graph in generating sediment-graph for a particular storm event, the total amount of sediment mobilized during the event would have to be known or estimated. Rendon-Herrero remarked that the method 'does not apply to watersheds under treatment'.

Parametric Models. These are models designed to estimate the sediment yield in a watershed by simulating the physical processes involved in the sedimentation processes (Negev 1967, Bennett 1974, Gupta and Solomon 1977, Curtis 1976, Foster and Meyer 1972). These models are sometimes called mathematical sediment yield models. The parametric models are defined as 'hypothetical or stylized representations of the physical processes occurring during the erosion and transport of sediment from a watershed' (Bennett 1974).

Nearly all sediment yield models are second-stage components of runoff-generating models. Negev (1967) proposed a sediment yield model which is based on the Standford-Watershed model. Negev's model is designed for river basins (Sedimentation Engineering 1977).

Bennett (1974) proposed a deterministic structure initiating a sediment yield model based on three differential equations. These three equations would form the basis for modeling the two distinct phases of sediment yield, the upland phase and the lowland phase. The equations are (Fig. 2.1):

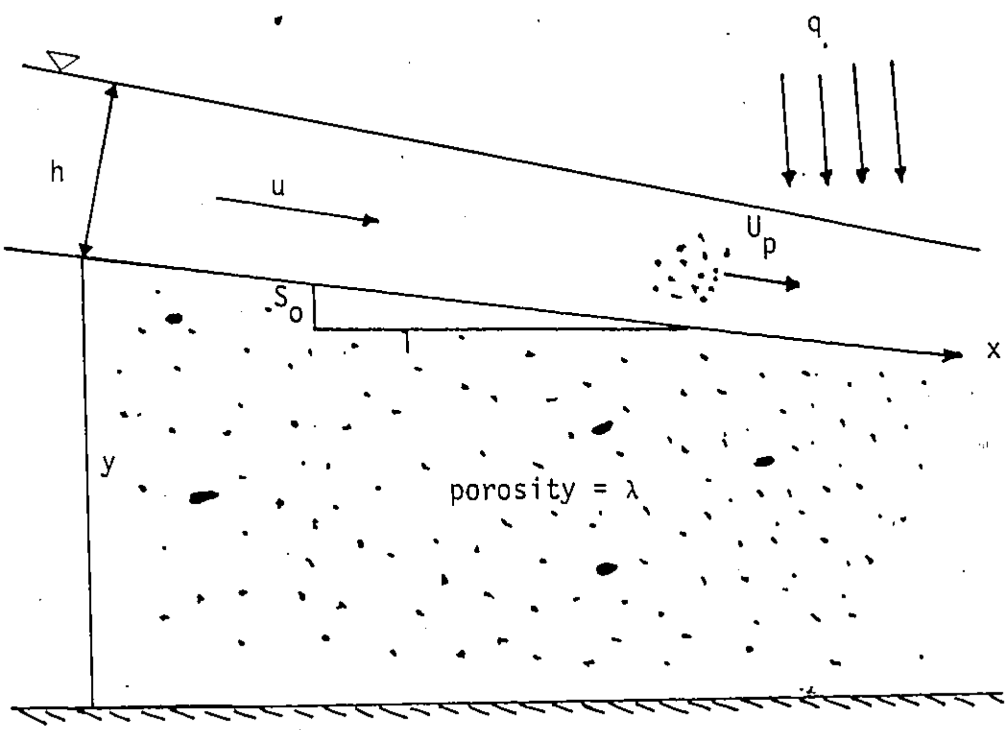


Fig. 2.1. Definition sketch of flow transport system (Bennett 1974).

$$\frac{\partial h}{\partial t} + \frac{u\partial h}{\partial x} + \frac{h\partial u}{\partial x} = q \qquad (1)$$

$$\frac{\partial u}{\partial t} + \frac{u\partial u}{\partial x} + \frac{u\partial h}{\partial x} = g(S_o - S_f) - \frac{qu}{h} \qquad (2)$$

and

$$\frac{\partial (hC)}{\partial t} + (1 - \lambda)\frac{\partial y}{\partial t} + \frac{\partial (hu_pC)}{\partial x} = \frac{\partial}{\partial x} \; h\varepsilon_p \frac{\partial C}{\partial x} \qquad (3)$$

in which C = sediment concentration

h = depth of flow

x = distance positive in the direction of flow,

y = local bed elevation

t = time

u = flow velocity

q = distributed water inflow

g = gravitational constant

S_o = local bed slope

S_f = friction slope, λ = porosity of deposited sediment

ε_p = sediment particle mass transfer coefficient

u_p = average velocity of sediment

These equations are designed to describe the movement of suspended sediment particles in a one-dimensional, infinitely wide, free surface flow. Actually, the flow in natural streams is not one-dimensional. Also, the type of streams sampled in this study cannot be considered infinitely wide. However, solution procedures for two and three dimentional equations may be complicated.

Equations (1) and (2) are the standard conservation of mass and momentum equations for the flow. Equation (3) in the conservation of mass equation for the sediment. The solutions to equations (1) and (2) can be obtained by numerical methods. The numerical methods of solutions can be costly, and may have stability and convergence problems. There are also the additional problems of determining the terms S_f and q. The friction slope S_f may be written as

$S_f = u^2/C^2h$ wherein .... (4)

C is the Chezy discharge coefficient. For shallow flows, it is difficult to estimate C on the basis of known physical measures of surface roughness (Bennett 1974). The parameter q, the lateral inflow, can be estimated by using a continuous simulation model such as USDAHL-74.

Equation (3) can be written as

$DF + R_{DT} = \partial G_F/\partial x$ in which

DF is the net flow detachment rate, R_{DT} is net raindrop detachment rate, in terms of both weight per unit time and unit area and G_F is weight transport rate per unit of width. In terms of (3)

$G_F = \gamma \rho u C h$

and $DF + R_{DT} = (1 - \lambda)\ \rho\ \frac{dy}{dt}$ wherein

λ is unit weight of water and ρ is density of the suspended solids.

Equation (3) is defined to describe the sediment transport. In Bennett's words, 'there is need to investigate the influence of plan non-uniformities, that is, of meanders, on material transport characteristics.

Curtis (1976) presented a conceptual model that utilizes a physically based rainfall runoff component and a set of relationships describing soil detachment and transport processes to simulate the discharge of sediment from an urban area. The solution procedure to determine the soil movement throughout a catchment is given in Fig. 2.2.

The rainfall/runoff model is based upon the kinematic approximation of the fluid continuity and momentum equations known as the St. Venant equations. The St. Venant equations are:

Continuity Equation

$$\frac{\partial q}{\partial x} + \frac{\partial y}{\partial t} = q \quad \text{...} \quad (1)$$

Momentum Equation

$$S - \frac{\partial y}{\partial x} - \frac{V}{g}\frac{\partial v}{\partial x} - \frac{1}{g}\frac{\partial v}{\partial t} = S_f \quad \text{..............................} \quad (2)$$

where q is the flow rate per unit width, y is the depth, q is the lateral inflow, S is the channel bottom slope, v is the flow velocity, S_f is the friction slope and g is the gravitational acceleration constant. Equations have been derived to describe the different sections in the diagram Fig. 2.2. However, it should be noted that equations (1) and (2) cannot be solved analytically at present. Numerical solutions are possible; however, they require large amounts of computer time. Also, the type of data required to solve these equations are not usually available in ungauged sites, such as those dealt with in this study.

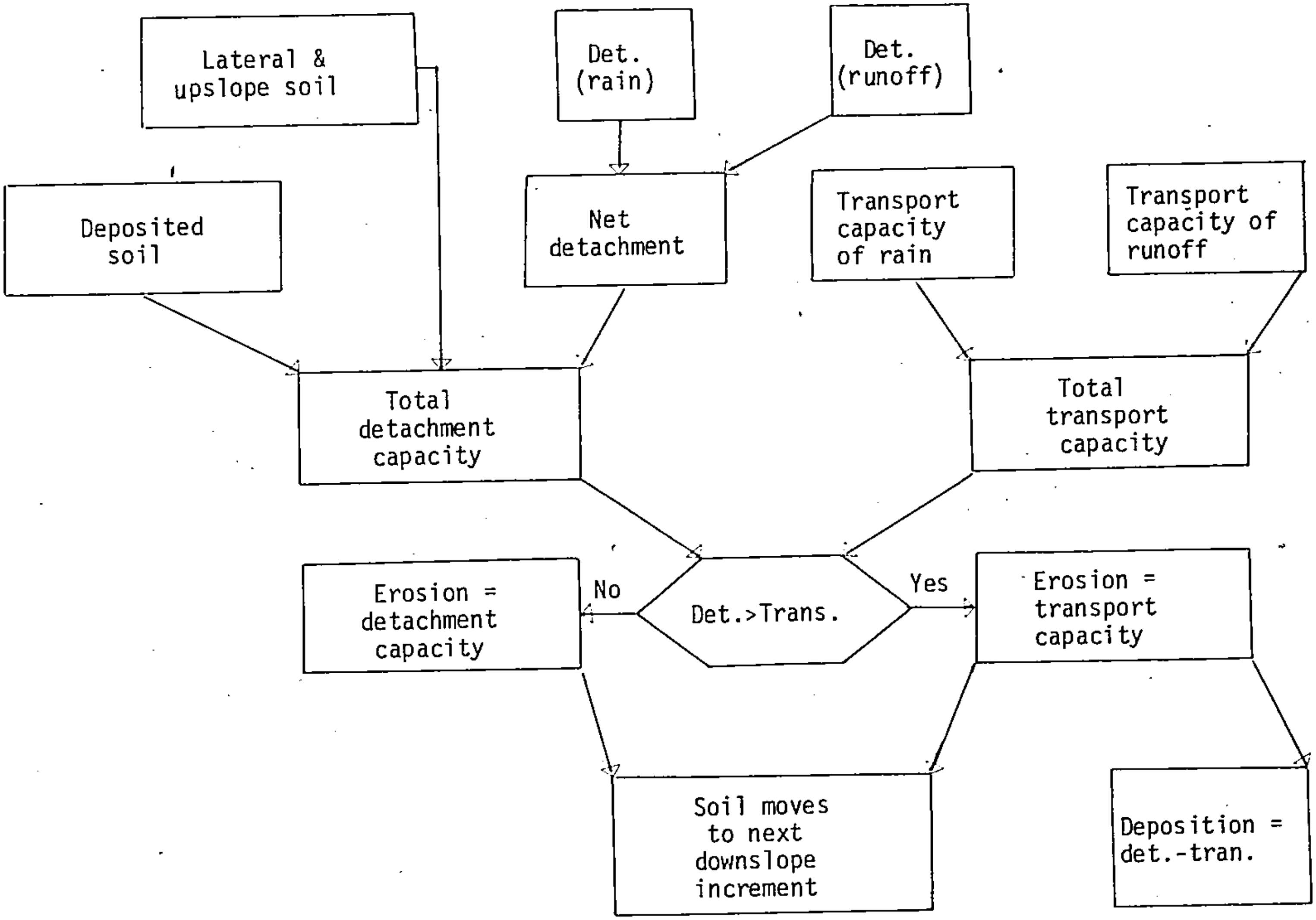


Fig. 2.2. Curtis erosion solution procedure.

Curtis (1976) presented equations that describe soil movement throughout the watershed for a storm event. These equations are based on the concept that the erosion in upland areas is governed by four processes: (1) detachment by rainfall, (2) detachment by overland flow, (3) transport by rainfall, and (4) transport by overland flow. The equations for detachment and flow transport can be written as:

$$d_R = C_{DR}K_{DR}I^2 \; ; \; T_R = S_{TR}SI$$

$$d_F = C_{DF}K_{DF}S^{2/3}q^{2/3}$$

$$T_F = C_{TF}K_{TF}S^{5/3}q^{5/3}$$

in which d_R and d_F are detachment rates per unit area at a location by rainfall and flow, respectively. T_R and T_F are the rainfall and flow transport capacity, respectively; K_{DR} and K_{DF} are soil erodibility factors; S_{TR} is a constant reflecting local soil and ground cover conditions; K_{TF} is a soil transportability factor (function of particle fall velocity, diameter, density, etc.); C_{DR}, C_{DF} and C_{TF} are management factors that are a function of land use; S is slope steepness and q is the per unit width discharge rate. For no erosion control, the value of C is assumed to be 1. I is rainfall intensity.

This is an event model. The logic of the model which permits both flow and transport simultaneously needs re-examination (Foster 1976).

Gupta and Solomon (1977) developed a parametric distributed numeric model for estimating runoff and sediment discharge of ungaged rivers. The model though based on physical analysis of the hydrologic processes contained a number of parameters (coefficients) which were obtained empirically or statistically. It is to be noted that some other parametric models (Negev 1967) had been built on a similar approach. The model appears to be for large river basins, though it is designed in part to estimate the changes in hydrology following changes in land use-land cover. The calibration work required could be significant. A particular feature of the distributed numerical model is the division of the river basin into grid elements. However, the size of each grid is fixed for any computation. Though in theory the sizes of the grid may be reduced when there is need for such reduction, the number of computations involved in such reductions could increase considerably.

Woolhiser and Todorovic (1971) and Woolhiser and Blinco (1975) have developed stochastic models of sediment yield on an event basis by considering the probablistic interrelationships among sediment yield, rainfall, and runoff processes (Sharma and Dickinson 1980). Rodriguez-Hurbe and Nordin (1968) performed time series analysis of the monthly runoff and suspended sediment yield for the Rio Grande River, New Mexico. The stochastic appraoch might have merit where there is some basic data to develop stochastic models. The data on sediment yield (particularly during low flows) in small watersheds undergoing land-use change are rather scanty.

Sharma and Dickinson (1979, 1980) have proposed a system model of daily sediment yield. An input-output system concept was applied to the daily modeling of daily runoff-sediment yield of the Thames River in Southern Ontario, Canada. Using 9 years of record, it was shown that a linear discrete dynamic model was possible in terms of the log-transformed daily runoff and sediment yield sequences. It was assumed that runoff is the best single indicator of sediment yield. There is still the need, however, to obtain the runoff records where records are not readily obtainable. The sediment supply, especially in areas undergoing development and during low flows, requires consideration.

A review of the literature on sediment yield models reveals that there is scope for trying out other approaches to estimate sediment yield in streams flowing through areas undergoing development in Western Quebec. It is to be noted that most of the sampling in this study were carried out during periods of low flow when washload might be significant. It was therefore considered important to use a continuous simulation model to predict the daily stream discharge. The details of the continuous simulation model used USDAHL-74 are discussed in Chapter 3.

The variables involved in the detachment and transport of sediments are many. Multivariate analysis, using step-wise regression analysis and factor analysis, were considered as appropriate tools in coping with such a large number of variables.

The second group of variables given in section 2.1 seem more amenable to mathematical analysis and quite a few investigators have derived equations for sediment discharge by concentrating solely on the variables in this group.

The most common of these equations are presented in Table 2.1. (Tywoniuk 1979). Most of these type of sediment discharge equations are bed-load equations. Most of the bed-load equations were derived mainly from laboratory flumes and have not been found adequate under field conditions

(Fleming 1969, Gupta 1974, Tywoniuk 1979, Simons and Senturk 1972), especially when tested beyond the range of data which served as the basis for their derivation. Einstein's equation and its modification have been known to perform better than others (Shen 1971, Tywoniuk 1979), though they require considerably more data than are readily available at an ungauged site.

It is to be noted that Einstein's 'bed-load function' is actually a mathematical procedure, analytically structured but complex and lengthy which requires some thirty steps for computing the bed-load. Subsequently, the procedure has been modified by other investigators (Tywoniuk 1979, Toffaleti 1969). The bed-load function presented in this thesis is one of the original analytical functions proposed by Einstein (1950).

Bagnold's stream power approach has been questioned on the basis of the non-uniqueness of the relation between sediment discharge and stream power, most especially when the bed changes from dunes to flat and the depth-discharge relation is discontinuous (Sedimentation Engineering ASCE 1977).

The bed-load was not considered in this study. The emphasis in this study is the suspended sediment load (particularly the fine grained sediments) derived from areas undergoing development in Western Quebec. Fine sediments are an important factor for consideration in water supply schemes because of the cost of removing them.

Table 2.1. List of bed-load equations.

Author	Bedload equation	Date	Type
Schoklitsch	$q_{bw} = \frac{A_2}{D_s^{1/2}} S^{3/2}(q - q_c)$	1934	Discharge equation (bedload)
Meyer-Peter	$q_{bw} = (A_3 q^{2/3} S - A_4 D)^{3/2}$	1934	Discharge equation.
Meyer-Peter and Muller	$\gamma q_{b/q}(K_B/K_G)^{3/2} HS =$ $0.047\gamma_s'' D_E + 0.25(\gamma/g)^{1/3} q_{bw}$	1948	Tractive force equation (bedload as a function of tractive force).
Straub	$q_{bw} = K\tau_o(\tau_o - \tau_c)$	1935	Tractive force equation.
Rottner	$(q_{bw}/\rho_s(((\rho_s - \rho)/\rho)H^3)^{1/2})^{1/3} =$ $(0.06715(D/H)^{2/3} + 0.01405)V/(((\rho_s - \rho)$ $- \rho))H)^{1/2} - 2.45(D/H)^{2/3}$	1959	Relative roughness.
Einstein	$i_B q_{bw} = \phi^* i_B \rho_s g^{3/2} D_s^{3/2}(S_s - 1)^{1/2}$ where $\phi^* = q_B/g\rho_s(\rho_f/\rho_s - \rho_f))^{1/2}(1/gD_s^3)^{1/2}$ and $\phi^* = (i_B/i_b)\phi$	1950	Statistical considerations.
Bagnold	$(\frac{\gamma_s - \gamma}{\gamma})q_{bw}\tan\alpha = \tau V e_b$	1966	Energy equation.

DEFINITION OF SYMBOLS

A_2 = 7000

A_3 and A_4 are constants where A_3 = 250 and A_4 = 42.5 are valid for sand with a specific gravity of 2.68

d_{50} = median size of bed sediment

D_E = the effective diameter of the bed material (m)

D_s = grain size in mm

e_b = bedload transport efficiency

g = acceleration due to gravity (cm/sec^2)

H = the depth of flow (m)

i_b = fraction of the grain size D

i_B = is the fraction of the bedload of a given grain size

K = correction factor

K_b = the particle grain roughness in m$^{1/3}$/sec

q = unit water discharge in cubic meters/sec/m

q_b = the part of the discharge apportioned to the bed and considered responsible for bedload transport in litres/sec

q_{bw} = bedload discharge by weight per unit width per unit time (kg/m/sec)

q_c = the critical discharge in m^3/sec/m; q_c is given by $Q_c = 0.00001944D/S^{4/3}$ for a sediment specific gravity of 2.65

S = the slope

S_s = specific gravity of sediment grains

V = average flow velocity in m/sec

α = coefficient of dynamic solid friction

γ = specific weight of water in metric tons per m^3

γ_s = the specific weight (in air) of the sediment grain

γ_s''	=	the submerged specific weight of the sediment grain (in water) in metric tons/^{3}
γ_s''	=	$(\gamma_s - \gamma)$
ρ	=	density of water in gram/cm^3
ρ_f	=	mass density of fluids lb/ft^3 (Einstein's equation)
ρ_s	=	mass density of solids lb/ft^3 (Einstein's equation)
τ_c	=	bed shear stress in kg/m^2
τ_o	=	unit tractive force exerted by the flow on the bed of a wide channel
τV	=	available stream power in kg/m/sec
Φ	=	is a dimensionless bedload parameter
Ψ	=	sediment characteristic

The following definitions of symbols and units apply to Rottner's equation

D	=	mean diameter of the sediment mixture in cm
g	=	acceleration due to gravity (cm/sec^2)
H	=	the depth of the sediment mixture in cm
q_{bw}	=	bedload in grams/sec/cm
V	=	velocity in cm/sec
ρ	=	density of water in gram/cm^3
ρ_s	=	density of the sediment grain (gram/cm^3)

It is to be noted that the following units apply for the corresponding equations:

Symbol	Equation
D (ft)	Einstein's equation
q_{bw} (lb/sec/ft)	Einstein's equation
q_{bw} (metric tons/sec/m)	Meyer-Peter and Muller equation

2.4.1. The Suspended Sediment Load

Theories have been developed to determine the distribution of the concentration of suspended sediments. These theories include (1) The Diffusional Theories and (2) Gravitational Theory.

Diffusional Theory

The fundamental equation that describes the distribution of the concentration of suspended sediments along the depth of a two-dimensional flow is the equation of diffusion. The equation of diffusion can be written as (Yalin 1977)

$$\frac{dC}{d\eta} + b_* C = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where

$$\eta = \frac{y}{h}$$

$$b_* = \frac{\omega}{v_*} \frac{\phi(\eta)}{\beta} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

$$\phi_\tau(\eta) = \frac{\tau}{\tau_o} \; ; \; \phi_u(\eta) = \frac{u}{v_*}$$

$$\phi(\eta) = \frac{1}{\phi_\tau(\eta)} \frac{d\phi_u(\eta)}{d\eta}$$

If equation (1) is integrated, one obtains

$$\frac{C}{C_o} = e^{-\int_{\eta_o}^{\eta} b_* d\eta} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

where $b_* = ha_*$ is the dimensionless parameter

and $\eta_o = \frac{y_o}{h}$

The proportionality factor β in equation (2) might be considered a function of the Reynolds number.

It is to be noted from the equations above that the accuracy of determination of C would depend on the accuracy of knowledge on the distribution of $\frac{u}{v_*}$ and $\frac{\tau}{\tau_o}$

However the exact distribution of $\frac{u}{v_*}$ and $\frac{\tau}{\tau_o}$ along the flow depth of the heterogenous dispersoid is not yet known. Therefore, when determining b_* from equation (2), the common practice is to express $\frac{u}{v_*}$ and $\frac{\tau}{\tau_0}$ by the formulae corresponding to the homogenous (clear) fluid. Such an approach can be justified only in the early stages of the transport in suspension and if the absolute value of C can be regarded as small in comparison to unity. However it can be shown that in the advanced stages of the transport of sediments in suspension, the velocity diagrams corresponding to the homogenous and heterogenous cases differ from each other considerably. (Yalin 1977). Various expressions of the mechanical properties of flow can be made to obtain different forms for b_* and for function $\phi(\eta)$.

Note that, for a given function $\phi(\eta)$, the nature of the distribution of the dimensionless concentration $\frac{C}{C_o}$ is solely dependent on the magnitude of the ratio $\frac{\omega}{v_*}$ (since β= constant). If the shear stress distribution is expressed as a linear function and the velocity distribution is expressed according to a logarithmic function, as assumed by Rouse , and Einstein (1950)

$$\therefore \quad \phi_\tau(\eta) = 1-\eta \quad \text{and} \quad \frac{d\phi_u(\eta)}{d\eta} = \frac{1}{\chi\eta} \quad \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

$$\text{i.e.} \quad \phi(\eta) = \frac{1}{\chi\eta(1-\eta)} \quad \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

$$\text{then} \qquad b_* = \frac{1}{\beta}\,\frac{\omega}{v_*}\,\frac{1}{\chi\eta(1-\eta)} \quad \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

When equation (6) is substituted in equation (3), one obtains

$$\frac{C}{C_o} = \exp\left[\frac{1}{\chi\beta}\,\frac{\omega}{v_*}\,\ln\left(\frac{\frac{1}{\eta} - 1}{\frac{1}{\eta_o} - 1}\right)\right]$$

Thus we have

$$\text{i.e.} \quad \frac{C}{C_o} = \left(\frac{\frac{1}{\eta} - 1}{\frac{1}{\eta_o} - 1}\right)^{\frac{1}{\chi\beta}\frac{\omega}{v_*}} \quad \ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Based on the results of experiments, (Yalin 1977), equation (7) can be written as

$$C = C_o\left(\frac{\frac{1}{\eta} - 1}{\frac{1}{\eta_o} - 1}\right)^{2.5\frac{\omega}{v_*}}$$

for $\eta_o = 0.05$

The mean concentration of the suspended sediments can be obtained as

$$C_m = \frac{1}{\eta}\int_{\eta_o}^{\eta} C.d\eta \quad \text{.......(8)}$$

The transport rate of the suspended sediments (per unit width of flow, otherwise known as the suspended sediment load, q_{ss} can be obtained from the relation

$$q_{ss} = \int_{\eta_o}^{\eta} C.\bar{u}d\eta \quad \text{.......(9)}$$

where $\bar{u}$ = time-averaged local velocity.

Gravitational Theory

The gravitational theory is based upon considerations of the energy exchange within the turbulent liquid-solid mixture. The gravitational theory was proposed by Velikanov and the equation for the theory can be written as

$$\frac{dC'}{d\eta} + E_*C = 0 \quad \text{.......(10)}$$

and its solution as

$$\frac{C}{C_o} = e^{-\int_{\eta_o}^{\eta} E_* d\eta} \quad \text{.......(11)}$$

with E_* being

$$E_* = \frac{h\gamma_s \omega}{v_* \tau_o} \cdot \frac{1}{\phi_u(\eta)\phi(\eta)} \qquad \text{(12)}$$

$$= \frac{\omega}{v_*} \frac{\gamma_s}{\gamma S} \frac{1}{\phi_u(\eta)\phi_\tau(\eta)}$$

It is to be noted that equations (10), (11), (12) are similar to equations (1), (2) and (3) of the diffusional theory. In fact, it can be observed that the differential equation (10) of the gravitational theory is completely analogous to that of the diffusional theory equation (1); only the multiplier of the second term is different.

Substituting for $\phi_\tau(\eta)$ and $\phi_u(\eta)$ the linear and logarithmic relations as assumed by Rouse and Einstein

$$\phi_\tau(\eta) = 1-\eta \quad \text{and} \quad \phi_u(\eta) = \frac{1}{\chi} \ln \frac{\eta}{a}$$

we have

$$E_* = \frac{\omega}{v_*} \frac{\chi\gamma_s}{\gamma S} \frac{1}{(1-\eta)\ln\left(\frac{\eta}{a}\right)} \qquad \text{(13)}$$

$$\text{thus} \quad \frac{C}{C_o} = \exp\left[-\frac{\omega}{v_*} \frac{\chi\gamma_s}{\gamma S} \int_{\eta_o}^{\eta} \frac{d\eta}{(1-\eta)\ln\left(\frac{\eta}{a}\right)}\right] \qquad \text{(14)}$$

Note that $\eta = a$ remains outside the region of integration in the expression on the right hand side of equation (14), because

$\eta_o > \varepsilon > a$ is valid (Yalin 1977).

It has been shown (Yalin 1977) that the family of curves representing the variation of $\frac{C}{C_o}$ with η is similar for the diffusional theory and the gravitational theory. For the diffusional theories, the variation of the distribution curve $\frac{C}{C_o}$ depends on the numerical value of the parameter

$$\frac{1}{\chi\beta}\frac{\omega}{v_*}$$

while in the case of gravitational theory, the variation of the distribution curve depends on the value of the combination $\frac{\omega}{v_*}\frac{\chi\gamma_s}{\gamma S}$.

It may be noted that $\frac{\gamma_s}{\gamma S}$ implies $\frac{Z}{M}$ whereas, $\frac{\omega}{v_*}$ can be expressed as a certain function of R_s and M. Thus we have

$$\frac{1}{\chi\beta}\frac{\omega}{v_*} = \phi_1(R_s, M)$$

and $$\frac{\omega}{v_*}\frac{\chi\gamma_s}{\gamma S} = \phi_2(R_s, M)\frac{Z}{M}.$$

The distinct difference of the gravitational theory from the diffusional theory is that the character of the distribution of suspended sediments in the gravitational theory is dependent on Z. Since the suspended load cannot be regarded as transported in the vicinity of the bed by its very definition, the gravitational theory would appear to have an advantage over the diffusional theories. In the diffusional theory, it has been assumed that the suspended load is derived from the bed material over which the flow passes, for only in such a case can the transport function ever be handled as a uniquely solvable problem (Rouse, 1950). The wash bed is made up of fine-grained suspended material, only a small amount of the material being at rest on the bed at any time. It is therefore doubtful whether the quantity of such fine-grained suspended sediments can be predicted from bed conditions alone.

Since the transport of suspended sediments is partly due to turbulence, the mechanism of turbulence would require a more detailed investigation than the data available in this thesis permit.

DEFINITION OF SYMBOLS

$a_* = \dfrac{2\omega}{l|\bar{v}|}$

C = dimensionless volumetric concentration of suspended sediments at the level y

C_o = the dimensionless concentration at the level $y = y_o$

C_m = dimensionless mean volumetric concentration of suspended sediments

D = grain size of a uniform material, typical grain size mixture

h = depth of flow

l = mixing length at the level y

$M = \dfrac{\rho v_*^2}{\gamma_s D}$ mobility number

q_{ss} = suspended sediment load or transport rate (per unit width of flow) in the region

R_s = grain size Reynolds number

u = local flow velocity in the direction of y

$\bar{v}'$ = average speed of travel (in a vertical direction) of fluid lumps required to travel distance l

$v_* = \dfrac{\tau_o}{\rho}$ shear velocity

y is measured from the lowest point of the bed upwards

$Z = \dfrac{h}{D}$

γ_s = specific weight of a grain in fluid

ε = the order of y which separates the regions of "bed load" and suspended load

τ = total shear stress

τ_o = total shear stress interacting between the flow and the flow boundary (bed surface)

χ = Von Karman constant

ω = terminal (settling) velocity

CHAPTER 3

ANALYTICAL METHODS

3.1 Introduction

The foregoing review of studies of sediment yield and transportation indicates that further studies for estimating sediment yield and transportation in small areas undergoing development are required. As indicated in Chapter 2, many variables of the stream watershed and precipitation affect the yield of sediment. Two approaches have been attempted in this study to allow for the complexity of the relationship among them. The two methods of analysis are:

A. A statistical approach. Factor analysis and multiple regression analysis are applied to the data collected in estimating the sediment load. Twenty-five variables were selected to describe geomorphic factors, hydrologic events, meteorologic events, land-use conditions and soil and geologic factors. The 25 variables were then subjected to factor analysis and multiple regression analysis. The procedure used is described below. A more detailed description of the variables selected is given in Chapter 4. A discussion of the analysis is given in Chapter 5.

B. A deterministic continuous simulation model. This model is used to generate a runoff component which is an essential requirement in predicting sediment yield. The hydrologic model described below is the University of Maryland version of the USDAHL-74 model (UOM/USDAHL-74).

Input to the model includes parameters to describe streamflow, watershed and weather. A complete list of the parameters required as input is listed in Appendix B. A list of daily stream discharges is one of the outputs available from the model. The daily discharge can then be used in conjunction with a sediment transport model to estimate the suspended-sediment load.

A sediment transport model requires as input characteristics of the fluid, the sediment, the flow and the channel geometry. It must account for the transport of the sediment from source areas to the point in question and provide for scour and deposition of material along the stream channels. Such a model is described below in section 3.4.

3.2 Multivariate Analysis

Two common methods of statistical analysis that can be used for prediction are:

(1) Multivariate analysis, and

(2) Regression analysis.

Regression analysis is discussed in Appendix A.

Multivariate analysis is a statistical technique that investigates relations among a set or among several sets of random variables. In such an analysis, a vector of means and a matrix of covariances of several random variables are used instead of the simple mean and the variance of a single dependent variable of the multiple regression analysis. Whereas in the regression analysis, it is assumed that the only random variable subject to error is the dependent variable, the multivariate analysis has provision to associate errors in two or more random variables (Yevjevich 1972).

Some of the topics that fall under multivariate techniques are:

1. Principal component analysis.
2. Factor analysis.
3. Multivariate regression analysis.
4. Canonical correlations.

A brief description of these topics is given in this chapter. For a more complete treatment of these topics, reference should be made to books by Kendall (1975), Harman (1967), Mulaik (1972), Cooley and Lohnes (1971).

3.2.1 Principal Components

The objective of principal component analysis is to transform originally correlated variables into n uncorrelated or orthogonal components.

To determine the principal components of a set of jointly distributed random variables, the set of n linear combinations of the original random variables is sought which are normalized combinations and orthogonally uncorrelated. The first linear combination is determined such that it has the maximum variance of all the n linear combinations, the second is determined such that it has the maximum variance of all the n linear combinations, the second is determined such that it has the maximum variance of the remaining (n-1) linear combinations and is uncorrelated with the first. Each other subsequent jth component is determined such that it has the maximum variance of the remaining (n-j) linear combinations. This operation is carried out until n such orthogonal linear combinations have been determined. It may be found that the first q components account for most of the system variance while the last n-q components account for little of the system variance. The mathematical operation can be expressed as

$$Z_i = \sum_{j=1}^{n} A_{ij} X_j \qquad (3.1)$$

in which j=1, 2, ...n and i=1, 2, ...,n a set of n random variables x_j is replaced by the set of n random Z_i variables (or components) which are mutually correlated.

In matrix notation, the expression becomes

$$Z = AX \qquad (3.2)$$

where Z is a x N matrix of n observations of N variables, and A is an N x M matrix of coefficients defining the linear transformation.

3.2.2. Factor Analysis

Factor analysis is a linear model which resolves variables linearly in terms of a small (usually) number of factors by taking advantage of the intercorrelations among the variables. The factors account for the linear relationships that exist between observed variables. This resolution can be accomplished by the analysis of the correlations among the variables. Thus, the chief aim is to attain scientific parsimony or economy of description. The factors produced should convey all the essential information of the original set of variables (Harman 1967). The two most important requirements of the factor-analytic model are (Mulaik, 1972):

1. Relationships between variables should be linear.
2. The variables to be analyzed should have non-zero correlations existing between them.

The two main purposes sought by a factor-analysis model are:

1. To extract maximum variance.
2. To reproduce best the observed correlations.

The first is known as the factor pattern and the second is called the factor structure.

The factor linear model may be written in the form

$$Z_j = A_{j1} F_1 + a_{j2} F_2 \quad \ldots\ldots A_{jn} F_n + b_j S_j + e_j E_j \qquad (3.3)$$

$$j = 1, \ldots\ldots n$$

or more generally as

$$Z_j = a_{j1} F_1 + a_{j2} F_2 + \ldots\ldots A_{jn} F_n + d_j U_j \qquad (3.4)$$

where Z_j is the standardized value of the jth variable

F is the common factor extracted

U is a unique factor for each variables

A_{ij} (j=1,2,...n, i=1,2,...n) are the coefficients of the factor loadings.

The significance of these loadings is discussed later on in this chapter. Equation 3.4 can be written as follows

$$Z_{ji} = \sum_{p=1}^{n} A_{jp} F_{pi} + d_j U_{ji} \quad (i = 1,2,\ldots N,\ j \quad 1,2,\ldots n) \tag{3.5}$$

$d_j U_{ji}$ is the residual error or unique factor in the theoretical representation of the observed measurement Z_{ji}.

Composition of Variance

The total variance of a variable in standard form when the common factors are uncorrelated among themselves may be expressed as follows

$$s_j^2 = 1 = a_{j1}^2 + a_{j2}^2 + \ldots + a_{jn}^2 + d_j^2 \tag{3.6}$$

The unique factors are always assumed to be uncorrelated with the common factors. The contribution of the unique factor to the total variance is known as the uniqueness d_j^2. The uniqueness indicates the extent to which the common factors fail to account for the total unit variance of a variable. The uniqueness of a variable can be decomposed into two portions of variance

1. That due to the particular selection of variables in the study, usually referred to as the specificity of the variables, and
2. That due to unreliability of measurement, usually called the error variance or unreliability of the variable.

In equation 3.3 S_j and E_j are the specific and error factors respectively and b_j and e_j their coefficients. The specific and error factors are usually assumed uncorrelated. Therefore, the following relation follows

$$d_j^2 = b_j^2 + e_j^2 \qquad (3.7)$$

For hydrological purposes, the factor-analytic model usually employed reduces to

$$Z_j = \sum_{p=1} A_{jp} F_{pi} \qquad (3.8)$$

That is the variable is described in terms of the common factors alone.

In matrix notation, the fundamental equation can be expressed as follows

$$Z = AF + DU \qquad (3.9)$$

or for the common factor section

$$Z = AF \qquad (3.10)$$

Procedures in Factor-Analysis

There are three basic steps in the factor analysis model.

1. Preparation of correlation matrix.
2. Extraction of initial factors.
3. Rotation to terminal factors.

Multivariate Regression Analysis

Most often in hydrology the interest is to develop a prediction equation. Such an equation can be derived from the rotated factor analysis. One such prodedure is to use regression on the rotated factors. The steps to be followed have been outlined by Haan (1977):

1. Compute the factor loading matrix, a.
2. Compute a varimax rotation of a.
3. Eliminate X variables that have no high (> 0.90) correlations with any of the rotated components (factors).
4. Repeat steps (1) and (2) with the remaining variables (i.e. with variables that have correlations > 0.90).
5. Perform a multiple regression of Y on Z where A = AF based on the results of step (4).
6. Eliminate the non-significant component from the regression.
7. Put the resulting equation in the form of regression equation

$$Y_i = \beta_0 + \Sigma_{j=1}^{p} \beta_j X_{ij} \qquad (3.15)$$

where the β are constant, Y is the dependent variable and X_i is the independent variables.

A comprehensive treatment of factor analysis can be found in Harman (1967) and Mulaik (1972).

3.3 USDAHL-74 - Continuous Simulation Model

The USDAHL-74 Model (United States Department of Agriculture, Hydrograph Laboratory) was chosen as a deterministic model. The model is a continuous simulation model; it takes into account the different phases of the hydrologic cycle in the prediction of the runoff continuously as opposed to a single event. The model was chosen for this study because it had been specifically developed to model land-use change (Langford and McGuinness 1976, Ghermazien et al 1979, Holtan et al 1977, Bengtson et al 1979).

The USDAHL model (Holtan et al 1975, Holtan and Yaramanoglu 1977) is an accounting system that apportions: precipitation to surface runoff, infiltration, evaporation, transpiration, lateral flow, and groundwater recharge. The input parameters are derived from physically measurable watershed characteristics (soil survey records, land use patterns, topography) and general climatic conditions. The USDAHL-model has the advantage of basing many of the model parameters on physical measurements. Such an advantage is especially helpful in the calculation of streamflow in areas where little or no data are available. The University of Maryland (UOM) version of the USDAHL-74 hydrology model is used in this study because it is designed to improve computational efficiency by using a variable routing interval (Holtan and Yaramanoglu 1977).

The distinctive features of the UOM version of USDAHL-74 are outlined in Figures 3.2 and 3.3. The basic concepts and philosophy of the model are completely described in Holtan et al 1974, Holtan and Yaramanoglu 1977 and Fleming 1975.

The model accepts input from two classifications of parameters:

1. Climatic Parameters.
2. Watershed Parameters.

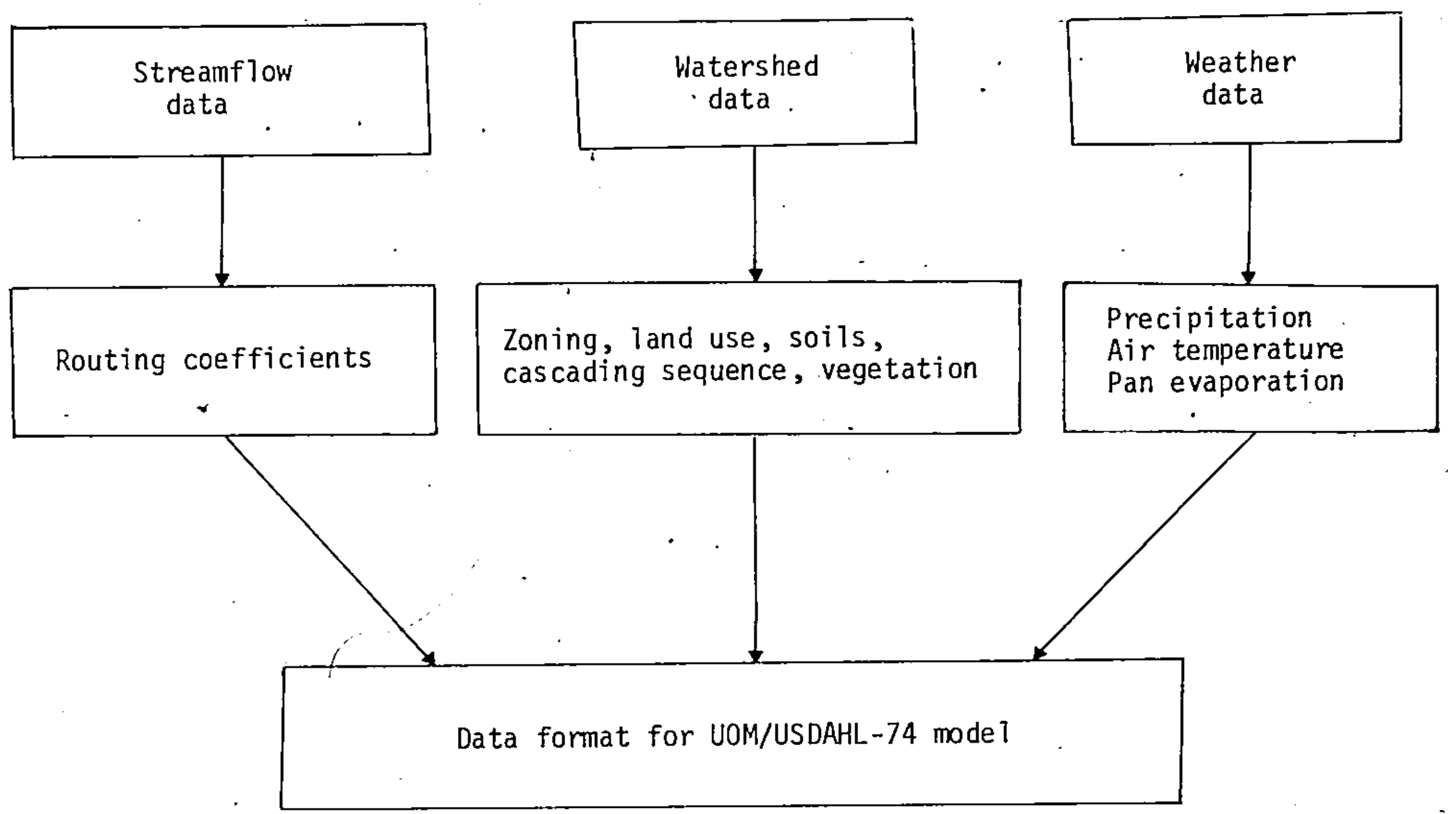


Fig. 3.1 Scheme of process of preparing inputs to the UOM/USDAHL-74 model (Fisher et al 1979).

Climatic Parameters

a. The rainfall values are to be input in either standard form (say, every five minutes) or preferably in breakpoint form. The breakpoint form of tabulating rainfall values ensures that the rainfall intensity is well recorded by noting the change in slope within a corresponding time interval on a rainfall chart (Agriculture Handbook No. 224, 1979).

b. Evaporation. The data required are the consecutive weekly averages of daily pan evaporation in inches.

c. Temperature. The data input required are the consecutive weekly averages of daily mean temperature in ^{o}F.

Watershed Parameters

Zoning. One of the fundamental concepts of the USDAHL-74 model is the idea of dividing a watershed into hydrologic response zones. Zoning aims at dividing a watershed into areas which are as homogenous as possible. Zoning is the first decision in applying USDAHL-74 (Holtan et al 1977). For the purpose of computing outflow from the watershed, zoning would be by soil types, by topography or by land use. Zones are numbered in an elevation sequence in a series so as to permit any cascading that is noted. After calculations of evapotranspiration, infiltration, and depression storage, excess surface water from each zone cascades to the next zone in the sequence or diverts into the stream or onto the alluviums next to the stream. Once established, zones are fixed for the entire computation series.

Soils. The USDAHL-74 model requires that the soil profile be divided into two layers. The model assumes that the total depth of soil is sufficient to include the deepest root system. The upper layer is interpreted as the layer from which the plants draw the majority of their moisture.

In the USDAHL-74 model, infiltration, moisture-holding capacity, and outflow rates are computed as functions of volume exhaustion (Holtan 1962). These hydrologic properties (infiltration, moisture-holding capacity and outflow rates) are based upon dimensional descriptions of zones and soil layers. For example, the percentage of cracks, and the final steady state rate of infiltration into a saturated soil are required to calculate infiltration. The moisture-holding properties are described by G, the percentage by volume of water in the soil between field capacity and saturation, and the available water capacity, the percentage by volume between field capacity and wilting point. The University of Maryland version uses inputs of total porosity, TP, field capacity, FCAP, and wilting point, WP (see Appendix C).

Routing. The routing parameters are obtained from recession curves plotted on semi-logarithmic scales. In all, five routing coefficients can be used in the model: M_c, for the stream channel, m_1 to m_4 for subsurface return flows in order of increasing of depth from the surface, that is, m_1 for the first layer of soil, m_2 for the second layer of soil and m_4 for the deep ground water storage.

Crop Parameters. In USDAHL-74 a crop is interpreted as land-use. Once a zone is defined, there can be many crops within the zone. For example, within a zone there can be a certain acreage of construction activity (a crop), a certain acreage of grass (another crop), a certain acreage of woodland (a crop).

There are two crop parameters that modify infiltration: (a) The A value or basal area rating is a measure of the surface connected porosity and shows a value between 0.10 and 1.; the higher the A value, the higher the initial rate of infiltration (Holtan et al 1975). (b) The second parameter is the depression storage. The depth of water stored in the depression.

Input to the model consists of the 51 items given in Table 3.1.

3.4 Sediment Transport Model

The purpose of this section is to describe a model proposed for the flow in the streams during the period of study. Consideration of this model will indicate the variables of importance in the transport of fine-grained sediments.

The seasonal period during which the measurements of this study were taken was from late May or early June until late October or early November. This is a period of relatively low flows in the streams studied except for occasional short rises due to storm rainfall.

The major event during the year in the hydrologic regime of these streams is the annual rise in flow during the spring snow melt. During this period, the stream flow not only transports suspended sediments from the system; also, sediments remaining in the system are redistributed so that they are within or nearer to the stream channels.

Flow in the streams of this study region recedes as the groundwater level drops during the late spring. As this occurs the hydraulic gradients in the stream decrease and are characterized by short reaches subject to local controls which are drowned out at higher flow levels. The streams become, in effect, series of pools interspersed by connecting reaches of narrower channels with higher velocities. This transition becomes more pronounced as summer proceeds and the flow rates in the streams drop.

These pools act as settling ponds for the suspended sediments transported by the flow. As the volume of stream flow falls after the influence of the snow melt, fine-grained sediments settle out in these natural settling ponds. It is principally in these quiescent regions of the stream in which deposition and resuspension of fine-grained sediments take place during the variations in summer stream flows.

The design of settling ponds to remove discrete sediment particles uses as parameters the particle fall velocity and the overflow rate which is the discharge divided by the surface area. The level of turbulence in the flow is also a significant factor in the performance of such ponds. However, it is doubtful that this theory is directly applicable to clay-sized particles because of the presence of other forces than the gravitational force. The hindered settling of concentrated suspensions is perhaps closer to the actual state of conditions, particularly in the lower, more dense, layers of the suspension.

Resuspension and transport of the fine-grained sediment which has settled to or towards the stream bottom will occur when the flow increases causing turbulence to resuspend the settled material. It should be noted that stratification of the liquid due to the density differences which exist because of the settling of the suspended sediments will tend to damp the turbulent fluctuations making the mixing less effective.

Thus, the existence and effectiveness of turbulence in quiescent areas of the streams where settling of fine-grained suspended sediments can occur during low flow rates is believed to be the principal hydraulic factor accounting for the presence or absence of these sediments in the summer flows. The possibility of turbulence would depend upon the exceedance of some critical value of a characteristic Reynolds Number composed of a velocity, depth and viscosity in the upper layer of the flow. Since the velocity and depth would be interrelated, it would be expected that the existence and degree of turbulence would be related to the flow velocity and surface water temperature.

The effectiveness of a given intensity and scale of turbulence in remixing the fine-grained sediments would depend largely upon the degree of density stratification. This, in turn, would be related to the time since the settling pool had last been disturbed. The process of settling is accompanied by the consolidation of the lower layers which, if it were to continue undisturbed, would create layers of solid material resistant to resuspension.

Thus, it is believed that the principal parameters affecting the concentration of fine-grained sediments in the summer flows of these streams are the velocity, the surface water temperature and the time since the last significant flow rise.

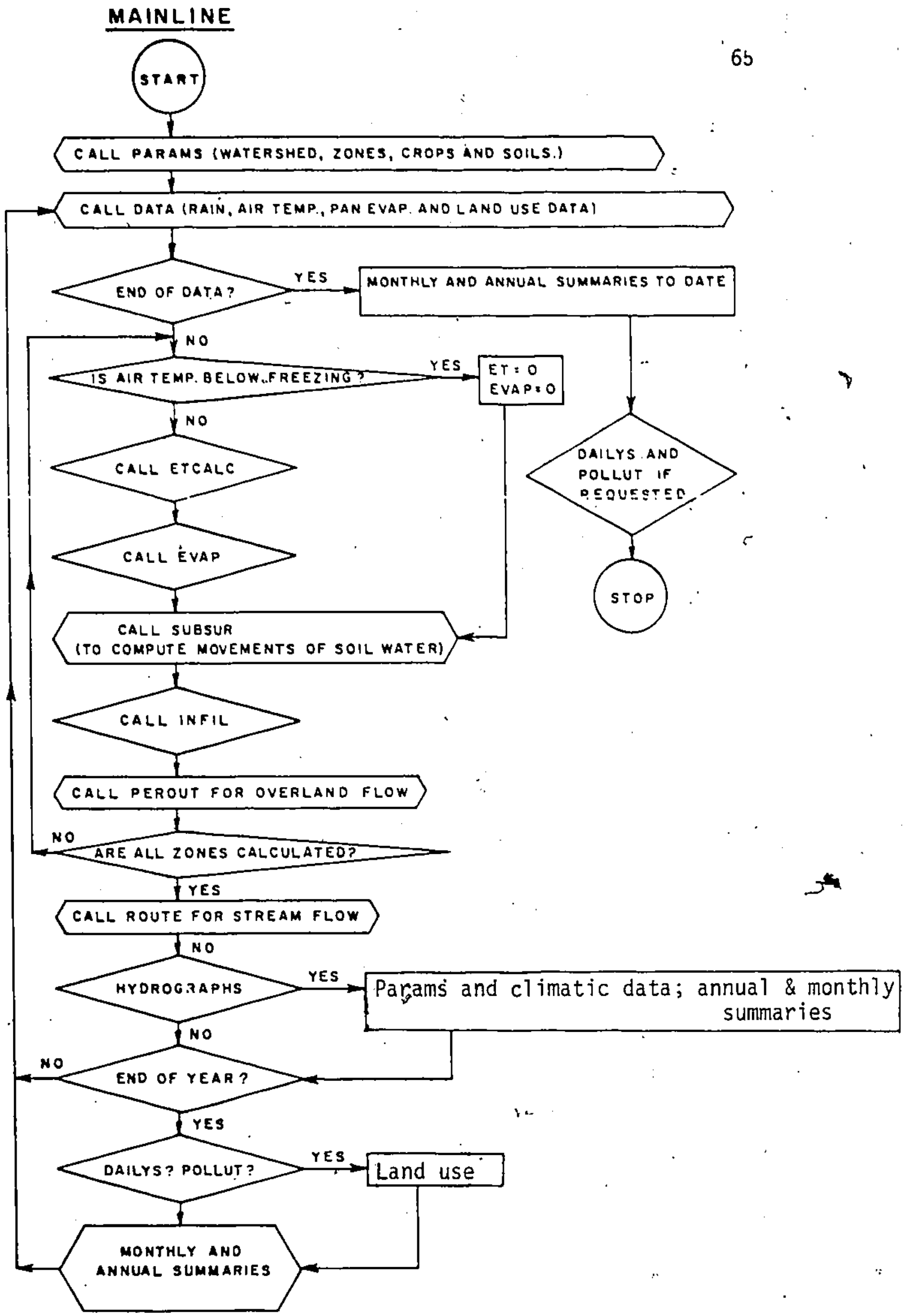


Fig. 3.2 Schematic flow chart of mainline indicating order in which subroutines are called (UOM version) (Holtan et al 1977).

Table 3.1. Input parameters required for UOM/USDAHL-74.

(Items 1-36 are read in subroutine PARAMS.)

(1) Comments	Watershed identity, rain gauge, period of record, and other information which will identify run.
(2) Dates for storm hydrograph output	Dates for which hydrographs are desired..
(3) W/S acres	Watershed acreage.
(4) Number of zones	Number of hydrologic response units.
(5) Routing coefficients. Total	Total number of straightline segments in recession curve of hydrographs plotting logarithms of flow rate versus an arithmetic ordinate of time.
Above weir	Total number of segments in recessions observed at outlet of watershed considered. (Additional segments may be included in total for downstream return flows below the weir.)
(6) Number of crops	Total number of crops or land-use practices (i.e. drilled and straight-row corn might be two crops).
(7) Deep groundwater recharge, IN/HR	Deep percolation rate which does not show up in the recession curve (usually regional estimate).
(8) Does land use change? Yes/No	If any crop percentages within zones change during the period of the run, answer Yes.
(9) Does tillage change? Yes/No	Is the tillage practice available yearly for each crop? (If No, include only practices for first year of calculation for every crop.)

(10)	Dailys? Yes/No	Do you want printout of daily stream flow?
(11)	Pollute? Yes/No	Do you want printout of daily zone and layer summaries?
(12)	Z number	Zones numbered in an elevation sequence.
(13)	% W/S	Percentage of watershed area in each zone.
(14)	Length FT.	Average length of overland flow on the zone (not to exceed half the distance between mapped streams or waterways).
(15)	% slope	Slope of the zone.
(16)	Fc IN/HR	Final rate of infiltration after prolonged wetting.
(17)	Topsoil IN.	Depth in inches of A horizon (topsoil).
(18)	Total soil IN.	Depth in inches to bottom of B horizon.
(19)	% ASM_1	Percentage soil moisture in topsoil at the beginning of calculations (volume).
(20)	% ASM_2	ASM for second layer.
(21)	Z number	Zone number.
(22)	% TP_1	Percentage total porosity in topsoil (volume).
(23)	% $F.CAP_1$	Percentage moisture in topsoil at field capacity (volume).
(24)	% $W.PT_1$	Percentage moisture in topsoil at wilting point (volume).
(25)	% $Cracking_1$	Percentage of topsoil volume occurring as cracks when soil dries out.
(26)	Subscript 2 for above	Same as previous for second layer. This refers to (22) through (25).

(27) ΔT hrs	Maximum time interval permissible for accuracy in channel routing. (Should approximate 1/5 of the channel routing coefficient.)
(28) M_c hrs	Channel routing coefficient. (Essentially time of concentration for the watershed.)
(29) Initial IN/HR	Rate of channel flow at the beginning of the calculation period.
(30) Initial snow cover	The water equivalent of average snow covering the ground at beginning of calculation period.
(31) Thaw ^oF	Temperature at which snow melt starts on the watershed.
(32) q_1 to q_4 IN/HR	Maximum rates of return flow associated with each segment of the recession curve except the channel flow segment. (Plot flow rates, storm or mean dailys, on a logarithmic scale versus an arithmetic time scale. Straight-line segments indicate flow regimes if present. q_1 is the largest rate, q_4 is the smallest.)
(33) m_1 to m_4 HRS	Routing coefficients for sub-surface return flows. $m = \Delta HRS/\Delta \ell ng$ (i.e. hours for segment slope to cross one log cycle)/2.3.
(34) % subflow diverted to channel	Percentage return flow from all zones above the alluvium which does not cascade the alluvium, but goes directly to the channel.
(35) % Z_n cascading Z_{n+1}	Percentage overland flow which cascades the succeeding zones. (Highly dissected zones do not cascade.)
(36) Remainder	Surface flow which does not cascade sequentially but goes either to the channel or alluvium, but not both.

(Items 37-51 are read in subroutine LANUSE.)

(37)	Crop name	Name of each crop (in fields of eight letters, starting in column 1).
(38)	A values	Basal area of vegetation used as an index of surface connected porosity.
(39)	Vd IN.	Volume of depression storage
(40)	ET/EP	Ratio of daily evapotranspiration to pan evaporation during full growth vigor of plant.
(41)	Root Depth IN.	Depth of significant roots. (Crops such as lawns or heavily grazed pasture have shallow root systems to balance root-top ratio.)
(42)	TU °F	Temperature above which crop's ET is impaired.
(43)	TL °F	Temperature below which crop does not transpire.

A more detailed description of the data required in Appendix C follows:

(44)	Temperatures °F	Consecutive weekly averages of daily mean temperatures (fields of eight columns).
(45)	Crop name	This name must match exactly the name given in item 37. Delete unused cards.
(46)	GZ	Percentage reduction in evapotranspiration attributable to grazing or other crop damage.
(47)	TIL	One of the four tillage codes.
(48)	MMDDYY	Month, day, and year of the tillage practice. Two dates for the same crop may not be in the same week.
(49)	Z number	Zone number.

(50) % Crop	Percentage of the zone in the crop. The sum of the percentages for a given zone must equal 100.
(51) E_p IN/DAY	Consecutive weekly averages of daily pan evaporation.

CHAPTER 4

STUDY SITES AND DATA COLLECTION

4.1 General Description of the Study Area

Location

The study area lies between 45^{o} 27' 00 and 45^{o} 33' north latitudes and 75^{o} 40' and 75^{o} 51' west longitude. Most of the study area lies within the Outaouais Regional Council. The sampling stations are located in the following counties: Gatineau, Templeton, Touraine, Chelsea and Hull. There were rapidly developing areas in this region when the project was begun.

Climate

The climate of Western Quebec is of the cool temperate type. The monthly precipitation is slightly greater in the summer than at other times. The temperature and precipitation values used for the area were values recorded at the Ottawa Experimental Farm, which is within the Ottawa Valley region and is the nearest station to the study area for which records are available.

Topography

The study area can be characterized by two main physiographic regions:

(1) The Ottawa Valley Lowland to the east, and

(2) The Laurentian Upland physiographic region to the north west.

The Ottawa River valley region rises from 140 feet above sea level at Touraine to 400 feet at Gatineau and Hull. The Laurentian Upland region, excepting river valleys and lacustrine basins, is an old peneplain that ranges from 800 to 1400 feet above sea level (Lajoie 1962). It is rolling to mountainous. The river valleys and lacustrine basins are undulating to level and are 400 to 800 feet above sea level. The Ottawa valley region is also characterized by an undulating to level topography. It is quite possible that there may be minor differences in the values of climatic data within the study area due to local factors such as elevation, air drainage, exposure of slope and proximity of large water bodies.

Drainage

The study area is a part of the Gatineau hydrographic basin. The Gatineau River flows southwards and drains into the Ottawa River. The Gatineau is the most important tributary of the Ottawa River. The four main creeks which drain the study area and on which the sampling stations were located drain into the Gatineau River. The four main creeks are Moreau, Desjardin, Chelsea and Leamy.

The whole Laurentian Upland region is characterized by a multitude of lakes and fast flowing streams. These have made the area an important tourist and vacation region (Lajoie 1962).

Natural Vegetation

Deciduous tress and some conifers are to be found on the part of the study area drained by Moreau Creek and Desjardin Creek. On the western part of the Gatineau River in the study area, the usual tree association is dominated by conifers. This part contains excessively drained soils. The particle-size distribution of some materials is shown in Appendix B2.

Parent Materials

The study area is mainly underlain by Precambrian rocks. The Precambrian rock formations belong mainly to the Grenville series, which consists largely of metamorphic rocks such as crystalline limestone, quartzite and various kinds of greissic rocks. Nearly all the Laurentian Uplands region is covered by till. The till consists of rock fragments and rock flour, and the particles range in size from clay and silt to sand, gravel and boulders. The tills are derived from the underlying hard metamorphic and igneous rocks.

Thick marine and lacustrine clayey deposits are found in the other part of the study area. The thickest is of marine origin and was apparently deposited in deep water. It is more than 60 percent clay and has a uniform massive structure (the upper part of Moreau and Desjardins). The lacustrine deposits are intermediate in clay and silt content (the lower part of Leamy Creek).

4.2 Sampling and Measurement

It was in this developing region (Figure 4.A) that gauging stations were established in 1973 on some streams for the purpose of collecting suspended sediment samples and measuring the stream discharges associated with such samples.

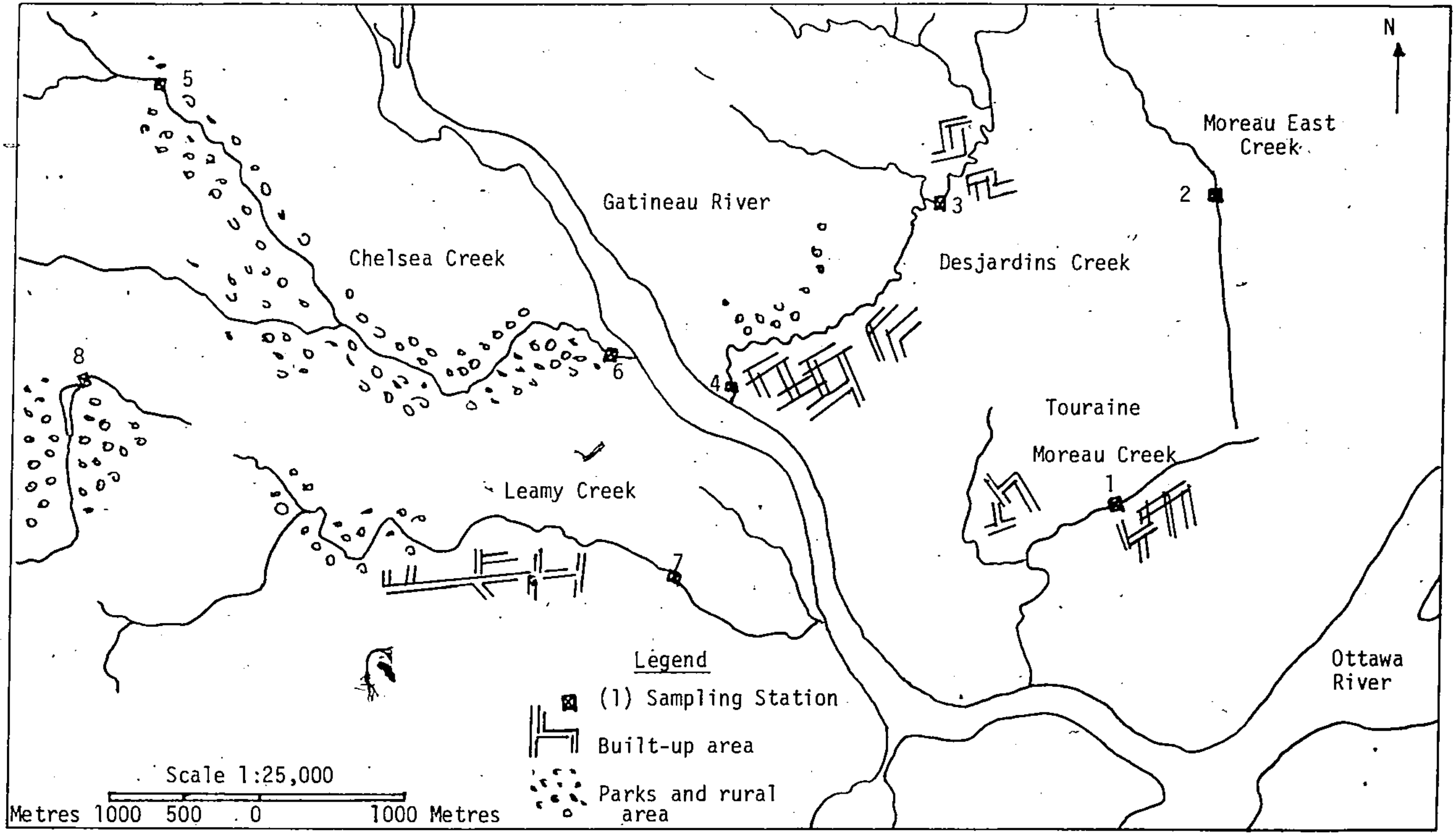


Fig. 4.A. The study area.

Some of the stations which drain areas undergoing development were located on streams which were close to one another, in order to facilitate the field investigation while still monitoring stream conditions associated with constructional development. Others were located on streams which drain predominantly rural areas, the rationale being that data gathered from such streams would be used to correlate with the data obtained from streams draining areas of development. Table 4.1 shows the locations of the gauging stations and the type of areas the streams drain. In some cases, more than one gauging station (two at most) were located on a stream. The aim was to determine the contribution, if any, made by the area between the stations to the sediment yield. In most of such cases, the upstream areas were rural or were not undergoing any significant development.

Sampling Frequency

Sampling was started in 1973. The samples were collected weekly from April 1973 through November 1973, April through November 1975, and June through September 1976. There were no field investigations in 1974. The periods of sampling coincided with the period of active development. At the end of 1973 sampling on the Gatineau River was discontinued as the control of the river upstream by reservoirs was known to cause considerable fluctuations of discharges so that the results were not meaningful for this study. The sampler used was the USDH-59 depth-integrating suspended-sediment sampler. The sampler is made up of cast bronze and partially encloses the sample container. It is equipped with tail vanes to orient the intake nozzle into the approaching flow.

This sampler is suspended on a suitable hand-line.

Sediment Measurement Techniques

There are different types of samplers that are used in fluvial sediment measurements. A comprehensive study of sampling equipment would include suspended sediment, bed-load and bed material samplers. However, for reasons stated in Chapter 1 only suspended-sediment sampling was carried out in this study. A description of suspended-sediment samplers can be found in Sedimentation Engineering (1977).

Depth-Integrating Samplers

Depth-integrating samplers are designed to collect a water-sediment mixture as they are lowered to the stream bed and raised to the surface at a uniform rate. During transit, the velocity in the intake nozzle is assumed to be equal to the local stream velocity at all points in the vertical. To avoid error in sediment content of the sampler due to outflow through the air exhaust, the transit time is usually adjusted so that the sample container is not completely filled. The filling times for a pint container for various intake velocities and three diameters of nozzles are shown in Fig 4.b.

Some of the different types of depth-integrated samplers include (1) the USDH-48 sampler, which weights 4.5 lb., (2) USDH-59 sampler, weight 24 lb. shown in Fig. 4.c, and (3) the cable suspended USD-49 sampler weight 62 lb. The three samplers mentioned above are equipped for pint milk bottle containers.

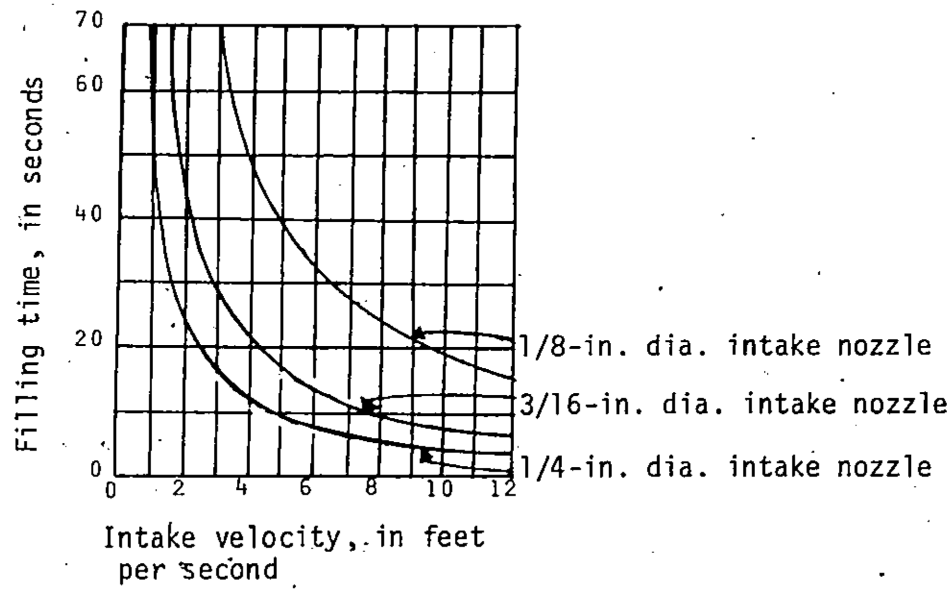


Fig. 4.B. Relation of filling time to intake velocity for 1-pint container (Sedimentation Engineering 1977).

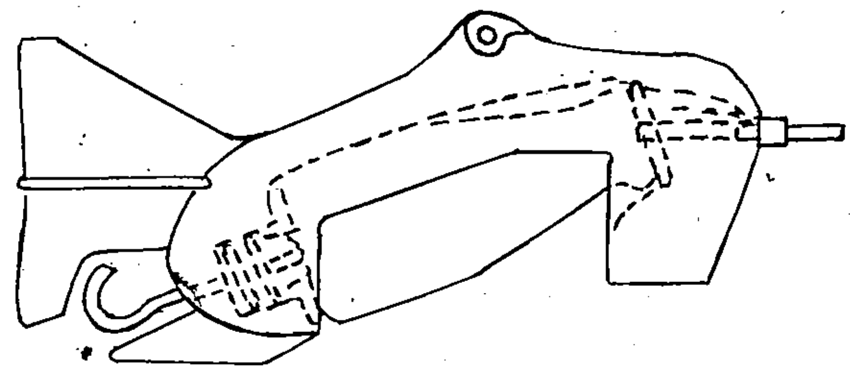


Fig. 4.C. US DH-59 depth-integrating suspended-sediment sampler (Sedimentation Engineering 1977).

The DH-48 sampler is equipped with a wading rod suspension and is used in shallow streams. The DH-59 sampler with a handline suspension is used in streams with low velocities but with depths that do not allow samples to be collected by wading. The USD-49 sampler is designed with a cable suspension and is used in streams beyond the range of the hand-operated equipment. Both velocity and suspended sediment concentrations observations can be made by these samples up to a point within 0.3 ft of the bed.

Depth-integrating samplers are designed to improve sampling accuracy and also to reduce the cost of obtaining records of suspended sediment discharge. The USDH-59 sampler was used in this study because of a combination of factors: (1) The sampler is not too heavy, weighing 24 lb. (2) It is equipped with a handline suspension which permits samples to be collected from a bridge or from the top of a culvert. (3) The USDH-59 is especially developed for use in streams with low velocities.

The samplers described so far were developed in the United States

Sources of Error in the Measured Suspended Sediment Concentration

The accuracy of suspended sediment concentration measurements is affected by the following factors (Gupta 1974):

1. The samplers do not traverse a region about 0.3 ft in depth adjacent to the bed. As sediment concentration is maximum near the bed, a significant portion of suspended sediment load may remain unmeasured. Special care was taken in this study to obtain samples at points

of constriction in the channel. The stream velocities at such points would be greater than the mean velocities of the stream and such relatively high velocities might entrain the sediments close to the bed.

2. Experimental evidence suggests that the standard deviation of the depth integrated suspended load concentration at a vertical may be 10 percent or more of the mean.

3. Standard deviation of point samples of the order of 10 percent of the mean is the best obtainable while limiting samples to a reasonable volume.

4. The depth integrated concentrations between two verticals in the cross-sections on the same day can differ by more than 100 percent. For sand bed streams, it is doubtful whether a single vertical in a cross-section can be representative of the entire cross-section for suspended sediment concentration.

   Furthermore, the verticals containing the maximum and minimum concentrations change position in the cross-section with time, so it is difficult to select which, if any, single vertical in the cross-section is representative of the whole. In this study, samples were collected from the central part of the stream by the depth-integrated method. It is difficult to guarantee that the concentrations of suspended sediments near the bank would be equal to the concentrations in the mid-portion of the stream. It is, however, assumed that the streams being small a thorough mixing of the sediments might occur especially at points of constriction.

5. In a cross-section, the verticals for maximum concentration of different size ranges may not coincide.
6. Local transport rate of suspended sediment, along a given bed form, may be more for sediments of coarser sizes than for sediments of finer sizes.

Laboratory Procedures

The following procedures were used for the analysis of the samples for suspended sediments.

Comparison of Millipore and Nucleopore Filters

A test was made to determine whether millipore and/or nucleopore .45μ filters lost weight during washing (filtering) with distilled water and Ottawa River water. Ottawa River water was used because it was at this time (1973) that the Ottawa River project was started.

The suspended solids (s.s.) analysis (for details see section on Suspended Sediments Analysis) was done using each of two millipore and two nucleopore .45μ filters utilizing 200 ml of distilled water as the filtered medium. After these filters were dried and weighed, the suspended solids analysis was carried out using 300 ml of Ottawa River water utilizing the same filters and an unwashed millipore filter. The results are as follows (Table 4.3).

Table 4.3. Comparison of Millipore and Nucleopore Filters.

Distilled Water

Filter	Tare Weight mg	Weight after s.s. analysis mg	Weight difference mg
Millipore Filter A	87.6	88.3	+ .7
Millipore Filter B	90.6	91.4	+ .8
Nucleopore Filter A	16.0	17.5	+ 1.5
Nucleopore Filter B	16.4	17.5	+ 1.1

Ottawa River

Filter	Tare Weight mg	Weight after s.s. analysis mg	Weight difference mg	Suspended solids mg/l
Millipore Filter A	88.3	89.0	.7	2.3
Millipore Filter B	91.4	92.1	.7	2.3
Millipore Filter C	91.4	92.5	1.1	3.7
Nucleopore Filter A	17.5	18.1	.6	2.0
Nucleopore Filter B	17.5	18.1	.6	2.0

Conclusions

Both millipore and nucleopore .45μ filters gained weight when filtered with distilled water. The weight gain is assumed to be approximately equal to the concentration of suspended solids in the filtered water. The unwashed millipore filter gave a significantly higher suspended solids concentration value (millipore filter C).

The extremely light weight of the nucleopore filters made them difficult to handle. It was felt that the suspended sediment concentrations in streams flowing through areas undergoing development were likely to have a higher value than the concentrations of the suspended solids in Ottawa River, hence it might not be advisable to use filters as light in weight as nucleopore filters. It was therefore decided to use millipore filters in the analysis of suspended solids. Besides there was a greater gain in weight when 200 ml of distilled water was filtered through nucleopore filters compared to the weight gain recorded for millipore filters using the same volume (200 ml) of distilled water. It is puzzling that the gain in weight recorded for each of the nucleopore filters was much smaller when Ottawa River water was filtered through each of the nucleopore filters than when the distilled water alone was filtered through the filters.

The filtering of the distilled water was carried out because some small amount of distilled water is used in washing down the sediments that stick to the receiving container during filtration. When a sizable quantity of distilled water is used for washing, the average weight gain due to washing should be determined and substracted from the value of the suspended solids concentration arrived at in step 10 (see next section).

Analysis of Suspended Solids

The following procedure was followed in the analysis of suspended solids. Millipore filter papers (0.45μ) were used:

1. The filter paper was placed on a glass dish.
2. The glass dish and the filter paper were then dried in the oven at a temperature of 103^{o}-$105^{o}C$ for fifteen minutes (the temperature should not exceed $105^{o}C$).
3. The glass dish and the paper were cooled in the dessicator for ten minutes.
4. The filter paper alone was weighed. The weight recorded was known as the tare weight. It has been experienced that the weighing of the filter paper alone rather than the filter paper plus the glass dish provides a more reliable set of readings.
5. The filter paper is then placed on the filtering equipment and some measure volumed ($\leq$ 300 ml) of aliquot sample was filtered. (Note: The maximum volume of each of the receiving cylinder on the filtering equipment is 300 ml.)
6. After filtering, the filter paper was placed on the glass dish.
7. Step (2) was then repeated.
8. Step (7) was followed by cooling as in step (3).
9. The filter paper alone was weighed. This was known as the dry weight.
10. The suspended solids = Dry Weight - Tare Weight. If y ml (y = $\leq$ 300 ml) of aliquot sample was filtered, the suspended solids (mg/l) =

$\frac{\text{Dry Weight - Tare Weight}}{y} \times 100$. For example, if 300 ml of aliquot sample was filtered, the suspended solids concentration (mg/l) = $\frac{\text{Dry Weight - Tare Weight}}{300} \times 100$.

4.3 Data and Selection of Variables for Multivariate Analysis

It was assumed that the observed suspended sediment is dependent on certain groups of variables, descriptive of the physical characteristics of the watershed and the hydrological and meteorological conditions of the area. These variables can be calssified as follows:

1. geomorphic factors
2. hydrologic events
3. meteorologic events
4. land-use conditions
5. soil and geologic factors

4.3.1 The Geomorphic Factors

Four variables selected to describe the geomorphic factors are:

V_{14} AREA (A) = Watershed area above stream gauging site, square kilometers.

V_{12} SLOPE (SLPC) = Average stream slope, defined as $\Delta H/Ls$ where ΔH is the difference in meters in elevation at the stream gauging point and the origin of the stream channel within the basis and Ls is the axial length of the main stream channel in meters (Magette, Shanholtz and Carr 1976). It is to be noted that for this type of study, this measure of average stream slope is found to be adequate and simpler to compute than Horton's (1932) method or that proposed by Bowden and Wallis (1964).

V_{13} ELEVATION (ELEV) = Mean elevation of the watershed area in meters. This was determined by the grid method.

V_{23} $\frac{\text{LENGTH OF FLOW PATH}}{A}$ (LPPHA) = Total length of the stream channel divided by the area, otherwise known as the drainage density. The drainage density is a measure of basin efficiency in removing excess precipitation inputs (Patton and Baker 1976). It is an indicator of the permeability of the surface of a drainage basin (Horton 1932).

4.3.2 The Hydrologic Factors

Eleven variables were selected to describe the hydrologic factors during the data collection periods. Since sediment discharge is closely related to the water discharge, it was considered appropriate to account for some of the runoff processes. Therefore, nine variables were selected to account for the soil moisture conditions prior to the day of sampling. The total 5-day antecedent rainfall had been found to be an important index in runoff production from other studies (Knisel 1970).

The hydrologic variables selected are:

V_9 API5 = The maximum 5-day precipitation (rainfall) antecedent to the day of sampling.

V_1 (AEI5) = The maximum antecedent 5-day EI, the rainfall energy and the maximum 30-minute intensity of the storm, that was derived to describe the relative erosion-producing capacity of individual rainstorms (Wischmeier, Smith and Uhland 1958).

V_2 (APRCPS) = The total maximum 5-day antecedent 6-hour precipitation intensity.

V_3 (APRCPT) = The total in mm. maximum 5-day antecedent 2-hour precipitation intensity mm.

V_4 (APRCPN) = The total maximum 5-day antecedent 1-hour precipitation intensity mm.

V_5 (APCPTH) = The total maximum 5-day antecedent 30-minute precipitation intensity mm.

V_6 (APRCPF) = The total maximum antecedent 5-day 5-minute precipitation intensity mm.

V_7 (APRDH) = The total precipitation-period in the 5 days prior to the day of sampling (hours).

V_8 (NPRCP) = The percent of the antecedent 5-day period which received no precipitation.

The other hydrologic variables selected are:

V_{24} (DISCHA) = Discharge of the stream measured at each gauging site during sampling period (litres/sec) divided by the area of the drainage basin.

V_{25} (SEDIMA) = The suspended sediment load kilograms|sq.km|per day divided by the area of the drainage basin. This variable is a function of the suspended sediment concentration and the sediment discharge.

A large number of antecedent precipitation intensity variables was considered necessary in order to satisfy the following criteria:

1. The length of input record antecedent to a particular out-put should be long so that the effects of long-term components such as the groundwater system are represented.
2. The time increment used for the input record should be short so that rainfall values affecting short-term surface runoff component are adequately described (Bidwell 1971).

4.3.3 Meteorologic Factors

Two meteorologic variables were selected:

V_{10} (AVTEMP) = The average atmospheric temperature at the time of sampling. This variable was considered as an indicator of water temperature and thereby of viscosity.

V_{11} (ATEMP5) = The average of mean 5-day temperature antecedent to the day of sampling. This variable was selected to describe the seasonal effect.

4.3.4 Land-Use Factors

A group of four variables was selected to characterize the effects of land use in the watersheds studied. Some of the measurements in this group are rather crude, for they were estimated from aerial photographs. It was also assumed that the condition depicted in any year's aerial photograph represented the conditions in the basin for the entire sampling period, the previous year. For example, to determine the land-use variables for the year 1973, the aerial photographs for 1974 were examined. This assumption is reasonable bearing in mind the fact that the photographs are made in spring (April-May) and the data-collection-period was from May-October. The variables are:

V_{17} (WDLD) = The percent of the drainage basin area made up of woodland.

V_{18} (GRSLD) = The percent of the drainage basin area made up of grassland.

V_{19} (DEVLPD) = The percent of the drainage basin area made up of developed land. The developed land here is defined as that portion of the drainage basin that is considered impervions, such as paved area, roofs, etc.

V_{20} (DISTRB) = The percent of the drainage basin area that is disturbed very near the stream channel. An estimate of this variable was made by the visual observation of the field conditions during the data-gathering exercise.

4.3.5 Soil and Geologic Factors

A set of four variables was selected to characterize the effect of soil and geology. As some portion of the drainage basin studies is known to be susceptible to landslides, it was considered appropriate to account for this phenomenon.

V_{16} (LANSLD) = The percent of the surface area of the basin considered as landslides (from the soil map of the area, Lajoie 1962).

V_{15} (CLAY) = The percent of the surface area of the drainage basin made up of clay. The topsoil texture up to a depth of 0.5 m. was considered. This variable was computed with the assistance of the personnel at the Federal Agricultural Research Station, Ottawa.

V_{21} (UNCONS) = The percentage of area covered by unconsolidated sediments. This is assumed to be all sediment equal to or younger than cenozoic.

V_{22} (CONSLD) = The percentage of area covered by consolidated sediments. This is assumed to be all sediments older than cenozoic.

The two foregoing variables are also indicators of slope stability (Wallis 1965).

4.3.6 Gauging Stations

Tables 4.1 and 4.2 show the list of stations sampled initially at the beginning of the project (1973). Table 4.2 shows the list of stations retained for sampling throughout the period of the investigation. Figures 4.1-4.8 show the pictures of the stations listed in Table 4.2.. Figure 4.9 is an illustration of a typical land-use activity (construction) which was in progress during the sampling period (1975). This particular activity was upstream station 7.

Access to station No. 10 (Table 4.1) was blocked during construction period (Figure 4.9), hence sampling on that station was discontinued. Station 8 which was located downstream of station 10 was then used to monitor the land-use activity of the drainage basin in which Station 10 was located.

Table 4.1. Sampling Stations.

Station No.	Location	Type of Activity within the Basin (1973)
1	Gatineau River, Highway 8, Pointe Gatineau	Drains predominantly rural area, flow controlled, upstream. Downstream of Station No. 6.
2	Moreau Creek, Pointe Gatineau	Drains area undergoing development. Residential building construction in 1973 season.
3	Moreau Creek East, Templeton	Flows through an area denuded of vegetation.
4	Desjardins Creek, Trailer Park, Touraine	Flows through area undergoing development, trailer park.
5	Desjardins Creek, Confluence Gatineau River, Touraine	Flows through Touraine, a rapidly developing residential settlement, downstream of Station No. 4.
6	Alonzo-Wright Bridge Gatineau River, Touraine	Drains predominantly rural area, flow controlled upstream.
7	Old Chelsea Creek, Fleury Road, Old Chelsea	Drains rural area.
8	Chelsea Creek, Hwy 11, Old Chelsea	Drains rural area, downstream of Station No. 7.
9	Leamy Creek, Mine Road, Old Chelsea	Outflow from a dam. Drains rural area.
10	Leamy Creek, Freeman Road, Old Chelsea	Flows through a highway construction area, located downstream of Station No. 9.
11	Leamy Creek, Hwy 11, Hull	Located downstream of Station No. 10, drains partly area undergoing development and partly rural area.

Table 4.2. Sampling Stations.

Station No.		Drainage Area	Type of Activity Within the Basin (1973)
1	Moreau Creek, Pointe Gatineau	8.0×10^5 sq m	Drains area undergoing development. Residential building construction in 1973 season.
2	Moreau Creek East, East Templeton	4.75×10^5 sq m	Flows through an area denuded of vegetation.
3	Desjardins Creek I, Trailer Park, Touraine	1.36×10^6 sq m	Flows through area undergoing development, trailer park.
4	Desjardins Creek II, Confluence Gatineau River, Touraine	3.42×10^6 sq m	Flows through Touraine, a rapidly developing residential settlement.
5	Old Chelsea Creek I, Fleury Road, Old Chelsea	8.94×10^5 sq m	Drains rural area.
6	Chelsea Creek II, Old Chelsea	11.97×10^6 sq m	Drains rural area.
7	Leamy Creek, Hwy 11, Hull	3.4×10^6 sq m	Drains partly area undergoing development and rural area.
8	Leamy Creek, Mine Road, Old Chelsea	2.94×10^5 sq m	Outflows from a dam. Drains rural area.

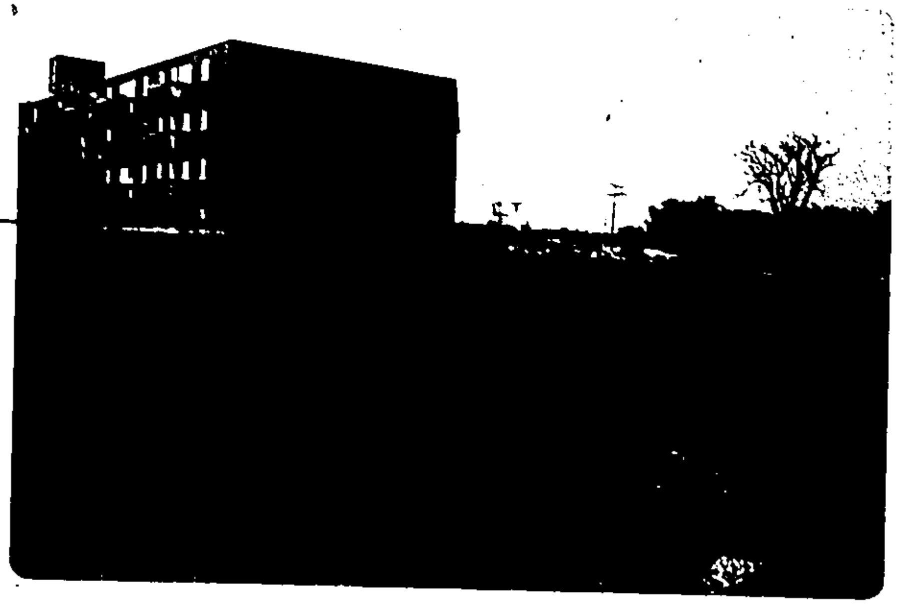


Figure 4.1 Moreau Creek

A

B

Figure 4.2 Moreau Creek East

A

B

Figure 4.3 Trailer Park - Desjardins Creek I

A

B

Figure 4.4 Highway 8 - Desjardins Creek II

Figure 4.5 Fleury Road, Chelsea Creek I

Figure 4.6 Chelsea Creek II

Figure 4.7 Leamy Creek II - Hull

Figure 4.8 Leamy Creek I - Mine Road

Figure 4.9 A Highway Construction Activity
(Upstream Station 7)

4.4 Data Reduction - Multivariate Analysis

The concentration of the suspended sediment in each of the samples collected was determined by filtering the sample or an aliquot sample. The filter used was a 0.45 μ millipore filter. The units were in parts per million.

The discharge at any one gauging point was calculated from the known values of the diameter of the nozzle of the sampler, the volume of the sample collected, and the cross-sectional area of the stream-channel at the point of collection.

The suspended sediment discharge was therefore determined as the product of the concentration of the suspended sediments and the discharge of the stream. The suspended sediment load (kg/day/sq.km) was derived from the foregoing calculations and was used as the dependent variable.

The other remaining twenty-four variables were determined from published data of Environment Canada's Atmospheric Service, the geological and soil maps of the area and the air-photographs taken of the basins for the year following each year of field sampling. Details of these variables have been discussed in this chapter.

4.4.1 Data Limitations

1. The values for the meteorological and some of the hydrological variables were computed from the publications of the Environment Canada's Atmospheric Service. Such values as precipitation intensities and temperature were taken for the stations located in Ottawa, which stations were about 25 kilometers from the points of stream sampling. It was assumed that the values obrained from the

Ottawa stations could be applied to the drainage basins sampled.

2. The percent of clay in the surface horizon was determined by comparing the soil-map of the areas under investigation with the knowledge of soil composition of similar soils in the Ottawa area (Lajoie 1962), Agriculture Canada.
3. It was assumed that to obtain a linear model all the variables had to be transformed logarithmically (Wallis 1965, Anderson 1957).
4. The period of sampling during the investigation was most convenient in terms of availability of facilities for experimentation and suitable weather conditions. However, this period also coincided with that of considerable activities of land-use (roughly from May through October).
5. For any specific year, some of the land-use variables were assumed to be constant (the percentage of woodland, the percentage of basin area made up of grassland ..., etc.). This assumption was applied to most of the variables except the hydrologic and meteorological variables. In fact, some of the variables, the soil and geologic variables, the percentage of clay in the surface horizon, the percentage of basin area considered as landslides, the drainage density hardly varied from year to year for any particular location. There was, however, some variation from one drainage basin to the other. Since these variables were derived from maps, air photographs or by comparisons, their measures are rather crude; they are thought to be the most practical methods of measuring them, however.

6. Those hydrologic and meteorologic variables except the discharge and sediment discharge measurements were assumed to have varied in time but not in space. The variables had different values for each sampling period, but the value derived for any particular period for any station was assumed applicable to all other stations for that time.

4.5 Model Parameters - USDAHL-74 Model

4.5.1 Climatic Parameters

The climatic data used were recorded at Central Department of Agriculture (CDA) in Ottawa, a location about 20 km from the test basin. The climatic data included the daily rainfall charts (from which the breakpoint data were abstracted), the daily temperature data, and the daily evaporation data for the period selected (1975).

The values for evaporation were deduced from the pan evaporation readings recorded at Central Department of Agriculture (CDA) station in Ottawa. The climatic data for CDA were used and applied to the test basin because recorded climatic data was not available for the test basin.

4.5.2 Watershed Parameters

Zones

Zones were selected on the basis of land use because the effect of land use on the fluvial suspended sediment load forms part of the major concern of this study. However, it seems the land-use zones selected closely approximate areas according to soil compositions for the

Leamy Creek watershed which was chosen (Fig. 5.1 and 5.2). The four selected zones are as follows:

Zone 1 - Woodland

Zone 2 - Pastureland

Zone 3 - Urban-Residential Industrial

Zone 4 - Alluvium

Soils

The soil types were derived from a soil survey map of the watershed (Lajoie 1962). The principal types of soil and the parameters were derived or estimated from data and principles given in USDAHL-74 manual (Holtan and Yaramanoglu 1977). The USDAHL-74 model requires that the soil profile be divided into two layers so that the total depth of soil is sufficient to include the deepest root system.

The two hydrologic properties that are to be described numerically are (1) infiltration, and (2) the moisture holding capacity. The parameters required to calculate infiltration are (a) the percentage of cracks in the soil, and (b) the final steady rate of infiltration into a soil after prolonged wetting which is based on Holtan's infiltration equation (Holtan 1961).

Holtan's infiltration equation is as follows:

$$f = A\, S_a^{1.4} + C$$

where f = infiltration capacity in inches per hour.

A = infiltration capacity in inches per hour per inch of available storage

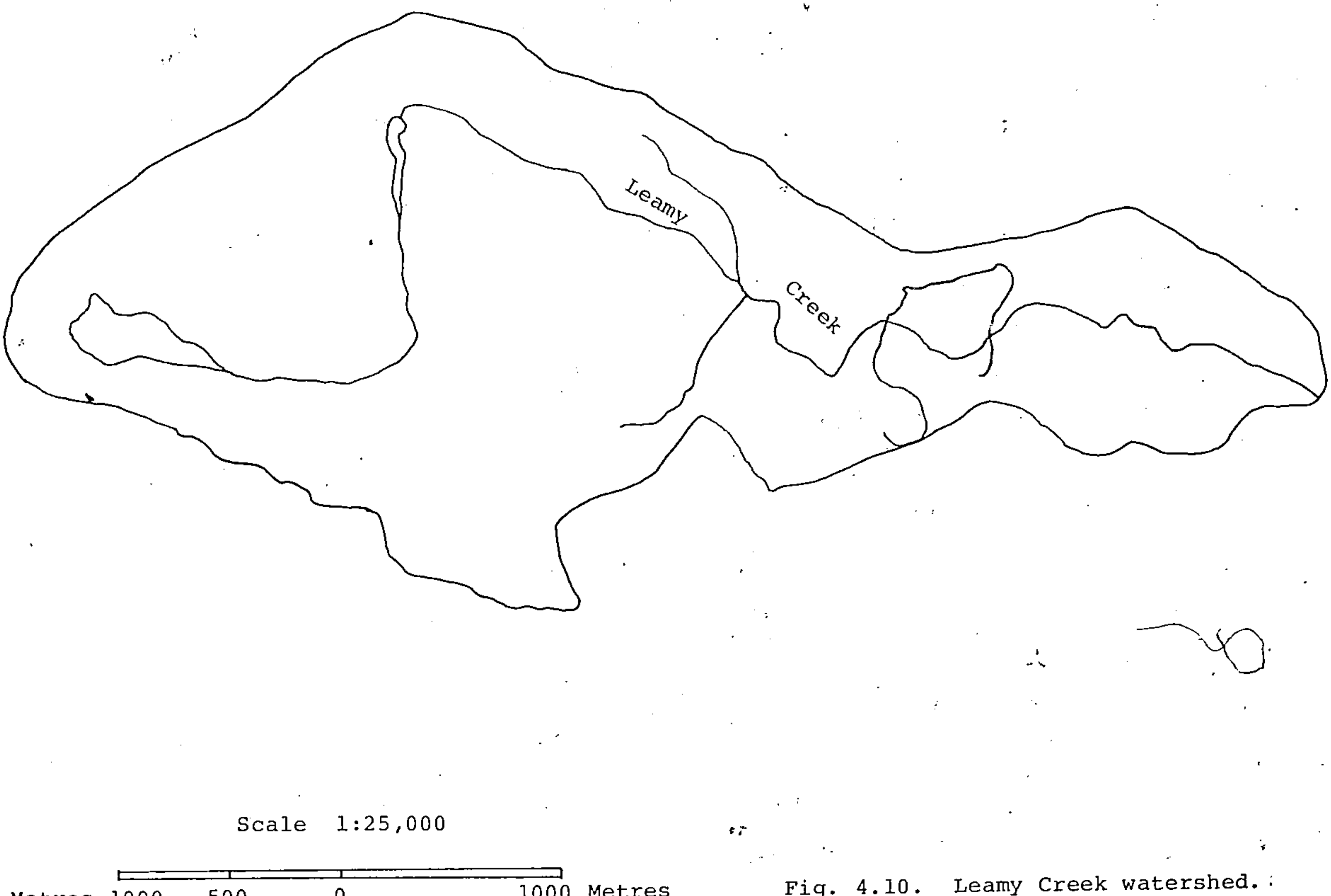


Fig. 4.10. Leamy Creek watershed.

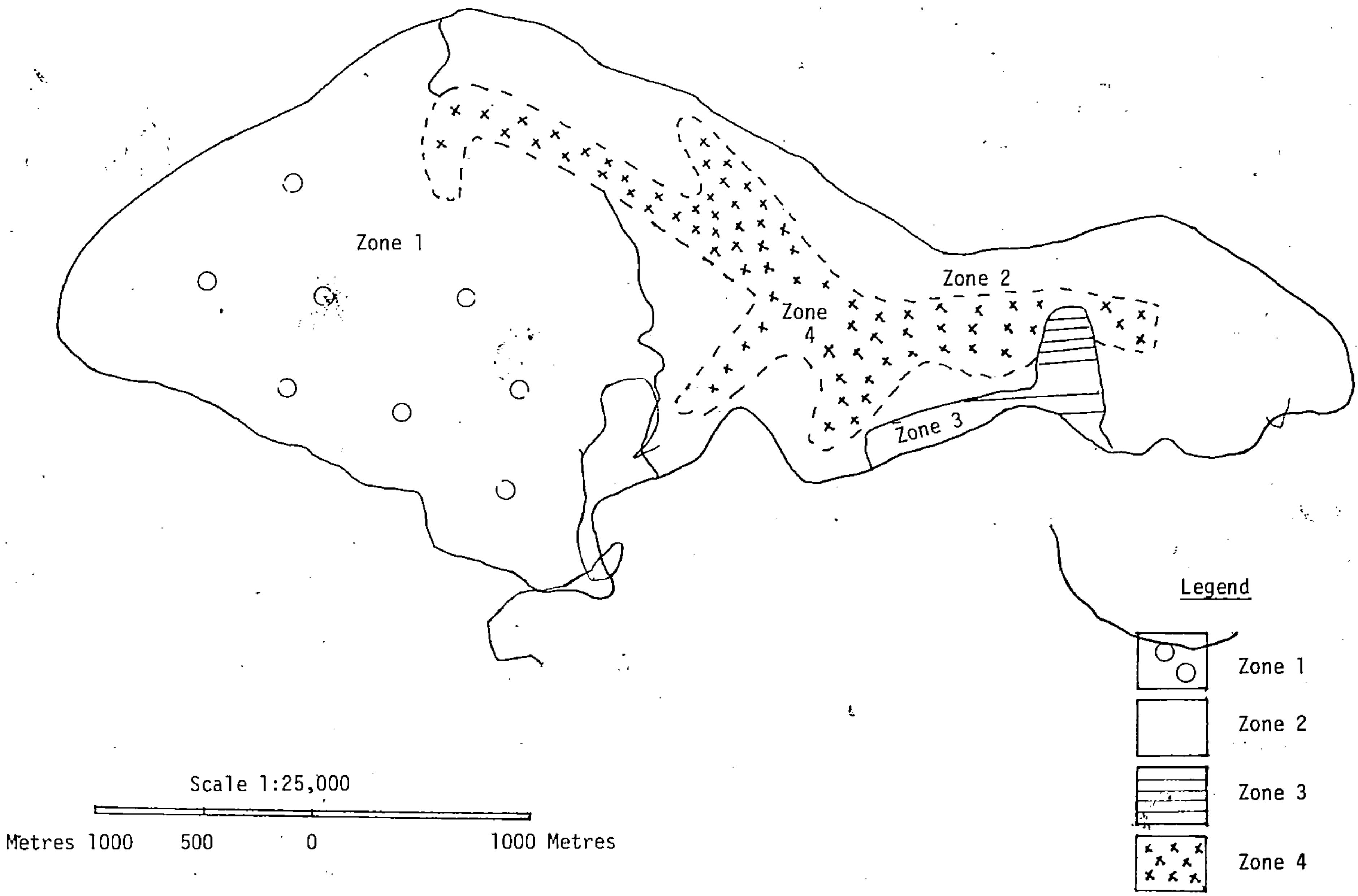


Fig. 4.11. Zone map of Leamy Creek watershed.

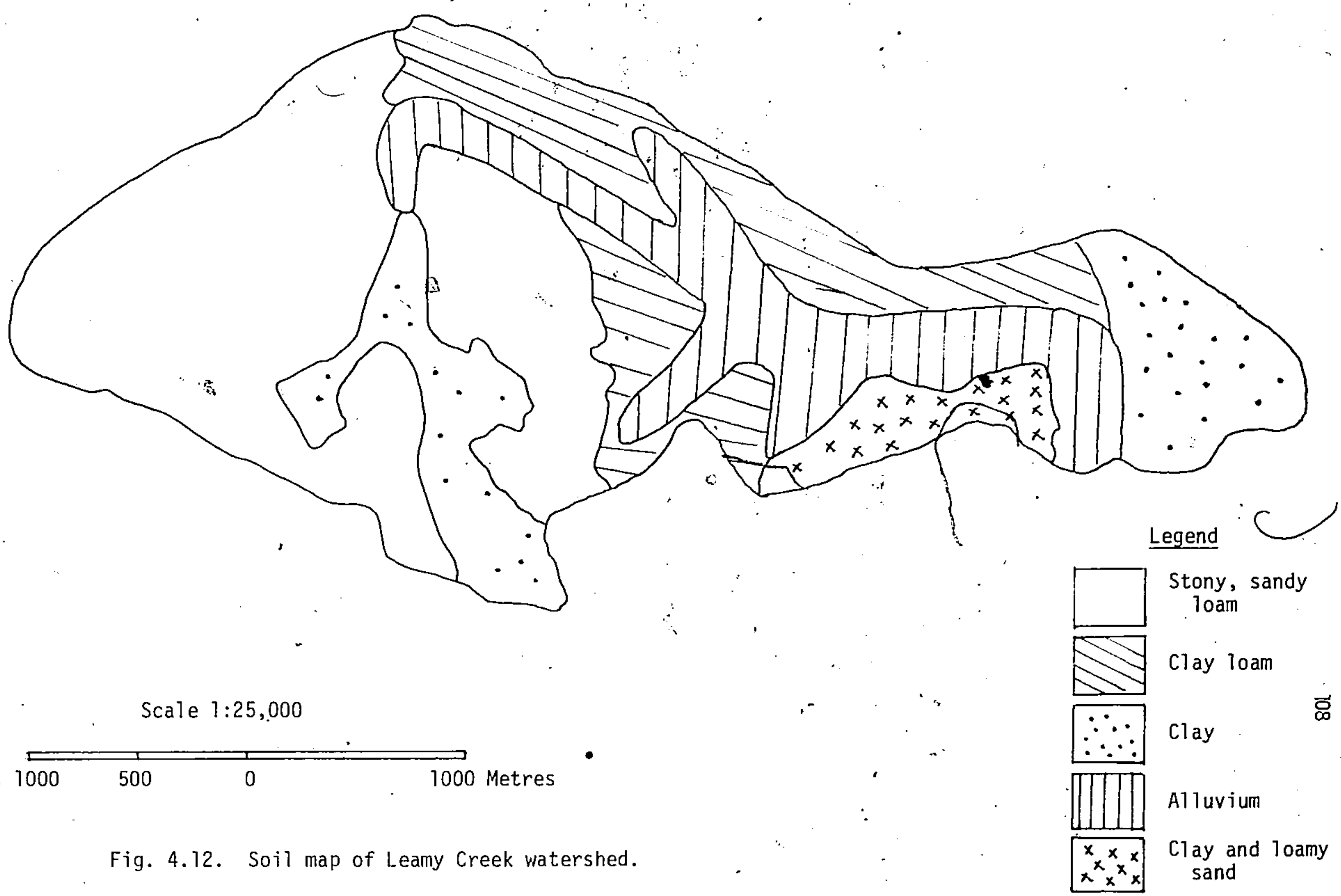


Fig. 4.12. Soil map of Leamy Creek watershed.

S_a = available storage in surface layer ("A" horizon in agricultural soils) in inches water equiv.

fc = final steady rate of infiltration into a soil after prolonged wetting.

The moisture-holding properties are described by TP, FCAP, and WP. Estimates of TP, the percentage of total porosity; FCAP, the percentage of moisture at field capacity; and WP, the percentage of moisture at wilting point were obtained from the literature (Holtan et al 1977), which gave values for several soil types. It should be noted that the soil properties measured in the laboratory tests are highly variable even from samples within the same soil type. It was therefore considered reasonable to obtain values which were determined on thousands of soil samples of various textures. Values of "a" as given in Holtan et al 1975 are given in Appendix C.

Estimates of fc, the final steady rate of infiltration were obtained from Holtan et al (1975, 1977), and England (1970) where soils are grouped in hydrologic classes A, B, C, and D. Table 4.5 shows the hydrologic soil groups.

There was no cracking. This fact was deduced from field observations and discussions with local residents.

Routing

The methods for determining the routing parameters M_c, m_1, m_2, m_3 are outlined in Holtan et al (1975). Routing parameters estimates were deduced from daily discharge data collected from Meach Brook below

Carmen Lake by the Department of Environment (Surface Water Data, Ontario, 1975). No discharge data were available for any of streams within the watershed under consideration. Meach Brook was selected for routing parameters because (1) the brook was near the Leamy Creek watershed being just about 12 km north east of Leamy Creek; (2) Meach Brook drains a small area of about 2944 acres (4.6 sq mi) (11.914 sq km). Leamy Creek drains an area of about 2080 acres (8.42 sq km); (3) Meach Brook is not regulated; (4) Meach Brook flows through a heavily wooded area within the Gatineau Park. It is to be recalled that zone 1 which is largest single zone within Leamy Creek watershed is a wooded area and within the Gatineau Park. However, judging from the soil survey map, the soil groups through which the two brooks flow are not quite the same. Meach Brook flows through a variety of soils, mainly made up of clay loam, silty clay loam and sandy loam. (For details of the soil composition within Leamy watershed see Table 4.4.)

The routing coefficient for subsurface return flows were determined by plotting flow rate (in/hr) against time on a semi-logarithmic paper. The days for which discharge data were plotted were from May 4 to May 18, 1975. Those were the days for which there were no recorded rainfall (1972) 1975. The year 1975 was the year examined because in that year there was a full year's discharge data on Meach Brook and a full year of rainfall data was available. However, there were a number of recorded discharge data which were marked as estimated.

Three routing coefficients for subsurface return flows were determined: m_1, m_2, and m_3 (Figure 4.13). The values of m derived for each linear segment of the semi-logarithmic plotting are assumed to represent successive flow regimes, starting with M_c for channel flow and proceeding through a series: m_1, m_2 and m_3 for successively deeper or more devious regimes of subsurface flow (Holtan et al 1975). The corresponding maximum rates of return flow q_1 to q_3 in/hr associated with each segment of the recession curve were also determined (q_1 is the largest rate, q_3 is the smallest).

A percentage of overland flow from each zone is designated to cascade across the subsequent soil zone with the remainder, if any, allocated to alluviums, or directly to channel inflow. The calculation of the parameters required to cascade overland flows from zone to zone could be a matter of judgement. However, such judgement should be based on the nearness of a zone to alluviums or on the presence or absence of diversions, graded terraces, listed furrows, or other interceptors leading directly to stream channel (Holtan et al 1975). Fig. 4.14 shows the basis for cascading flows from zone 1 to zone 2.

The percentage of subsurface flow diverted to the stream was calculated on the basis of the percentage portion of the stream estimated to be in the steep upper reaches of the watershed (Langford and McGuinness 1976).

Land-use or Crop Parameters

Once a zone is fixed, the type of crops or land-use in that zone can be determined from a knowledge of the land-use activity in the watershed. Five different types of crops were determined. The crops were: (1) construction, (2) forest, (3) basin, (4) impervious and (5) grass/pasture.

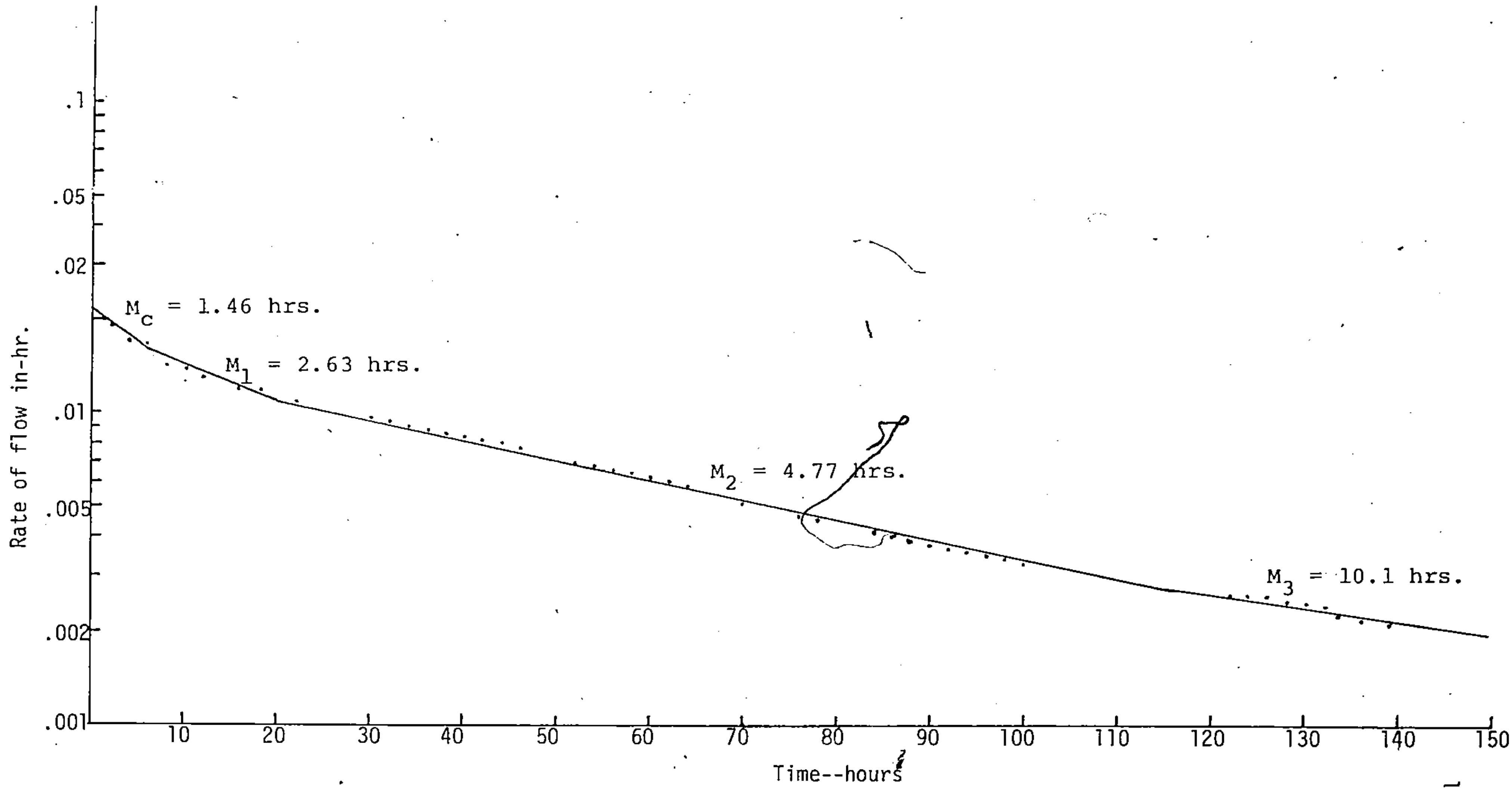
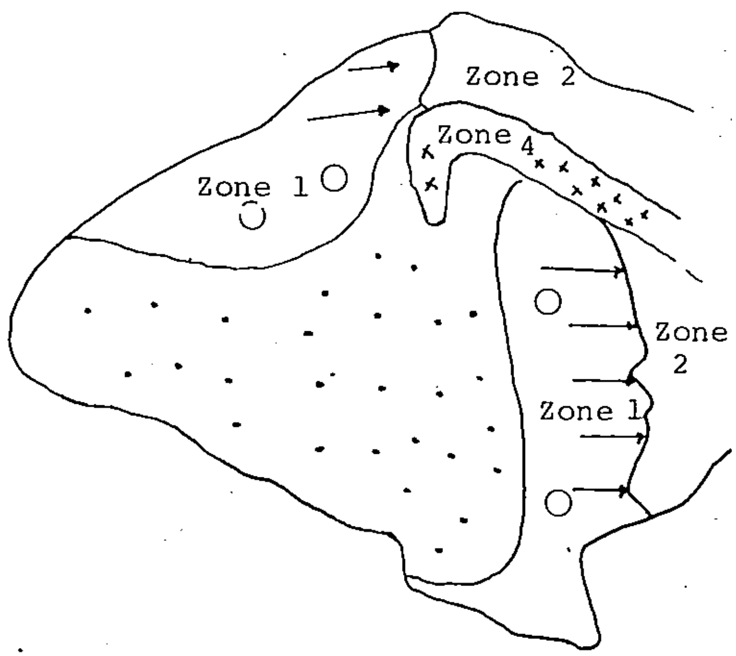


Fig. 4.13. Recession curve used to calculate routing parameters.



<u>Legend</u>

X% of Zone 1

Cascade X% of Zone 1
Overland flow into the stream channel because of the steep slopes

Cascade (1-X)% of Zone 1 overland flow into Zone 2

Fig. 4.14. Cascading overland flows.

The percentages of each crop determined for each zone are based on a recoinnansance survey of the area and the examination of the air-photographs of the watershed taken for the following year. Basin refers to a body of water, e.g. a lake or an impounded body of water.

Six parameters are required to describe each of the crops. The six parameters are: (1) (A), vegetative parameter in infiltration equation; (2) Vd (in), the volume of depression storage, the parameter estimates were obtained from literature (Chow 1964, Crow et al 1979, Holtan et al 1977); (3) ET/EP - the ratio of daily evapotranspiration to pan evaporation was evaluated from figures obtained in the literature for the type of crops selected in this study; (4) TU ^{o}F - temperature above which crop's evaporation is impaired (Holtan et al 1977, and Felton et al 1979); (5) TL ^{o}F - temperature below which crop does not transpire (Holtan et al 1979).

The literature quoted after each of the parameter indicates the source from which parameter estimates were obtained. (6) Root depth in - depth of significant roots (Ghermazien et al 1979, Holtan et al 1977).

The parameter estimates are listed in Table 4.4 and Appendix C.

4.6 Derivation of Parameter Values for USDAHL-74 Model

Precipitation

The period considered for input into the model was from June 1, 1975 to October 1975. The period was considered for two main reasons: (1) There was a construction of a highway through Leamy Creek watershed in 1975, (2) The sampling period of the streams was also within this period. However, only one year (1975) was considered. It should be noted that the requirements for precipitation input into USDAHL-74 model prefer that the precipitation input be in break-point values. The break-point values are derived from the rain gauge charts in the following manner.

The period within which there is a uniform intensity of precipitation is noted. A change in the intensity of precipitation is usually indicated by a change of slope of the lines on the graph of daily precipitation. The infiltration rate and the runoff are influenced in part by the precipitation intensities. The breakpoint values for precipitation are listed in Appendix C. The values are read as follows at 0830 a.m. on 5th June 1975 - precipitation begins. Between 0830 and 1100, there was recorded 0.06 in of rainfall at a uniform rate of intensity.

This method of deriving breakpoint values is rather time consuming if a number of years of data is to be considered.

Pan-Evaporation

The net water loss from the pan was calculated by subtracting from the rain gauge precipitation values, the amount of water removed (or added) from the pan. The rain gauge precipitation values and the amount of water added or removed were obtained from the Central Department of Agriculture, Ottawa. The consecutive weekly averages of daily pan evaporation are required and are shown in Appendix C. Note that the values of pan evaporation for June through October 1975 are recorded. The consecutive weekly averages of daily mean temperatures (in ^{o}F) are computed and shown in the same table (Appendix C).

Zone Parameters

Some of the zone parameters which are measurable were derived from the topographical maps. Some of these parameters include the length in feet of each zone and the percentage slope. The final rate of infiltration fc was estimated (Appendix C). The values for top soil and total soil for each zone were derived from the soil map of Gatineau and Pontiac counties. The parameter ASM was estimated using the principles as outlined in the manuals (Holtan et al 1975, 1977).

Soil Parameters

The USDAHL-74 model requires that four parameters for each of the two layers of soils be determined. These parameters are %TP, %FCAP, %WP, %CRACKING. For a given type of soil, the methods of determining %TP, %FCAP, and %WP are given in the USDAHL-74 manual (Holtan and Yaramanoglu 1977). Table 4.4 shows the values calculated for these parameters. The % cracking was set to zero.

Channel Parameters

ΔT was set at 0.10. This is a calculating interval desired for channel routing. The other channel parameters are M_c, initial snow, and thaw. M_c was derived as previously described, initial snow was set at zero because there was no snowfall or snow accumulation during the period for which the calculation was made (June through October 1975). Thaw was set at 35^{o}F. It should be noted that USDAHL-74 accepts the English system of units. It was difficult to establish the initial channel flow at the beginning of calculation because no measurement of channel discharge was taken on that day, Day 156 (i.e. June 5, 1975).

Table 4.4. Hydrologic zone and soil parameters for Leamy Creek watershed.

	Zone 1	Zone 2	Zone 3	Zone 4
Zone area % of watershed	50.80	28.48	2.28	18.43
Average slope %	35.	0.5	3.	10.
Overland flow length (ft.)	4,687.5	2,604.17	2,083.33	976.56
Principal soil series	St. Colomban	Dalhousie	Rideau	Landslides/escarpments/ gullies /alluvium
Soil texture	Stony sandy, loam	Clay loam	Clay	Clayey surface
Final rate of infiltration (in/hr)	0.45	0.02	0.02	0.02
Soil depth upper layer (in)	2	8	9	2
Soil depth lower layer (in)	28	22	15	58
ASM, upper layer %	18	45	48	48
ASM_2, lower layer %	20	48	50	49
TP, upper layer %	43	52	54	56
TP, lower layer %	42	54	56	56
FCAP, upper layer %	18	45	48	48
FCAP, lower layer %	20	48	50	49
WP, upper layer %	8	23	29	29
WP, lower layer %	8	28	30	29
Cracks, upper layer %	0	0	0	0
Cracks, lower layer %	0	0	0	0

However, channel flow measurements were recorded for May 27, 1975 and June 3, 1975. The discharges measurement taken for May 27, 1975 was initially used as an initial channel flow. The simulated flow printout underpredicted the flow as recorded for Day 156. The initial channel flow was then adjusted by various runs until the flow simulated was close to the recorded flow for Day 156. Initial channel flow was then set at 0.0191 in/hr. Three different results produced under varying rates of channel flow are discussed later on under Results and Discussion.

Subsurface Parameters

The subsurface parameters q_1, m_1, q_2, m_2, m_3 were derived from the recession curves plotted for Meach Brook (Fig. 4.13).

Land Use or Cropping Parameters

Five different crops or land uses were established for the Leamy Creek watershed for the period June through October 1975. The five crops derived are: (1) construction, a high construction was under way during the summer of 1975; (2) forest, part of Gatineau park was in the watershed; (3) basin, basin as used in this context refers to lakes or any big impounded body of water; (4) impervious, the impervious portion of the watershed consisted mainly of roads and rooftops of buildings. The impervious area was determined from air photographs; (5) grass, the crop labelled grass refers to any crop that includes grass and pasture.

Ghermazien et al (1979) applied the USDAHL hydrology model to a native grass watershed over a 24-year calibration period. The result of the investigation and the sensitivity analysis performed was that the model was found to be highly sensitive to ET/EP (evapotransporation/

evaporation) index and to "a" and to be just moderately or slightly sensitive to other land-use parameters. The values of a and ET/EP used in this study for grass are based on the results of the reports of Ghermazien et al (1979) and Bengston et al (1979). The values thus used differ from the values used by Holtan et al (1977) for grass.

Adjustments were also made to the parameters Vd and ET/EP for the crop, forest. Since the slope in the forest region of the watershed is rather steep (zone 1, slope > 35%), it was concluded that there might not be much of a depression storage in this zone, hence the value of Vd was set at 0.15 instead of .50 as used by Holtan et al (1975). The values suggested for ET/EP parameter (Holtan et al 1975) are 1.0-1.2 for short grasses, 1.2-1.6 for crops to shoulder height, and 1.6-2.0 for forest. A value as high as 2.5 for ET/EP for forest has been used (Felton et al 1979, Holtan et al 1977). However, it was found necessary to use the lower limit of the suggested value of 1.6 to obtain a fairly reasonable simulated flow. The use of a value of 1.6 for ET/EP for the crop forest in the Leamy Creek watershed may have some physical reasoning to support it. Zone 1 is the main zone with the highest percentage of crop forest in it. It would be recalled that zone 1 is part of Gatineau Park, a park that consists of grass, some impervious area, lakes, some outcrops and some other vegetation which is referred to as a forest, but not very dense forest as such.

Land Use Percentage

The percentage of crop (land use) in each zone was determined mainly from air photographs. Tables in Appendix C show a typical series of data used as input into the USDAHL-74 model programme.

Table 4.5. Hydrologic soil groups used by the Soil Conservation Service (England 1970).

Hydrologic soil group	Soils included[1]	Final constant infiltration rate, (fc), in/hr
A	(Low runoff potential) Soils having high infiltration rates even when thoroughly wetted, consisting chiefly of sands or gravel that are deep and well to excessively drained. These soils have a high rate of water transmission.	0.30-0.45
B	Soils having moderate infiltration rates when thoroughly wetted, chiefly moderately deep to deep, moderately well to well drained, with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.	0.15-0.30
C	Soils having slow infiltration rates when thoroughly wetted, chiefly with a layer that impedes the downward movement of water or of moderately fine to fine texture and a slow infiltration rate. These soils have a slow rate of water transmission (high runoff potential).	0.05-0.15
D	Soils having very slow infiltration rates when thoroughly wetted, chiefly clay soils with a high swelling potential; soils with a high permanent water table; soils with a clay pan or clay layer at or near the surface; and shallow soils over nearly impervious materials. These soils have a very slow rate of water transmission.	0 to 0.05

[1] Soils are classed in the next lowest category when a high percentage of stones is present.

CHAPTER 5

ANALYSIS AND DISCUSSION

5.1 Factor Analysis

Out of the eight gauging points sampled for the entire period of the investigation, five of them were subjected to factor analysis for the final results. The three stations that were not included were Moreau East, Highway 8 and Fleury Road.

Moreau East was not included because the stream flowing through it would dry up for a few weeks during the hot summer months. It was therefore not possible to obtain discharge and sediment discharge measurements for the dry period. Since it was not considered desirable to include many zero values for many variables, Moreau East station was therefore deleted from the final analysis.

The station on highway 8 (Figure 4.4) was observed to be a sedimentation pond. For most occasions, except when there were high flows due to heavy rainfall, the flow was noted to be small. In fact it appeared still. Besides, the surrounding bank area has been known to be a landslide-prone area. It was then concluded that this gauging station did not quite monitor the type of activity for which the investigation was designed.

The station at Fleury Road (Figure 4.5) drained a rural area (part of Gatineau Park). The station on Mine Road (Figure 4.8) also drained a similar rural area. It was felt that it would be enough to include only one of the stations draining rural areas. For this reason, the

Fleury Road station was omitted from the final factor analysis. However, in a preliminary factor analysis, the station was included. The results of these analyses are reported later on in this chapter.

There are many computer programmes for factor analysis. The programme that was used for the analysis in this study is the SPSS for OS/360 Version H. This programme was recommended for its relative simplicity and wide applicability. (SPSS is the statistical package for the social sciences.) Before the values of the variables were transformed logarithmically, each variable of value (X) was replaced by (X + 1), because of variables with zero values.

Two methods of factoring were tried. These were PA1, the principal factor without iteration and PA2, the principal factor with iteration. A description of these two methods is given by Kim (1975).

The PA1 method was used for the final analysis because it was the only method of factoring known that is applicable when the determinant of the correlation matrix is zero. In such cases, when the correlation matrix is singular (that is, the determinant of the correlation matrix is zero), the correlation matrix cannot be inverted. It should be recalled that a central problem in the factor analysis technique is the estimation of communality, hj^2 to be inserted in the principal diagonal of the correlation matrix (Chapter 3). One of the main characteristics that differentiates one method of factoring from another is the procedure used for estimating the communalities.

$$R^2_{j(n-1)} \leq hj^2 \leq 1$$

That is, the square of the multiple-correlation coefficient for predicting a variable from the n-1 other variables in a correlation matrix is a lower bound to the communality of variable.

A convenient method for obtaining the squares of the multiple-correlation coefficients for predicting each variable from the n-1 other variables in the correlation matrix is based upon inverting the correlation matrix. If one takes the diagonal elements of the inverse matrix of the correlation matrix and finds the reciprocals of these elements he will have the errors of estimate for each of the variables in the matrix. These errors of estimate can then be subtracted from the 1s in the diagonal of the correlation matrix, and the result will leave the square multiple correlations in the principal diagonal (Mulaik 1972).

The data analyzed in this study are stored on disk in the University of Ottawa computing centre. The data deck of cards is also available at the Department of Civil Engineering, University of Ottawa, Ottawa, Canada.

The data values for five of the watersheds sampled were analyzed. Table 5.1 shows factor matrix using principal factor without iterations. The following steps were followed before obtaining the results listed on Table 5.1.

1. The data were subjected to a logarithmic transform.
2. The transformed data were standardized.
3. The correlation matrix for the standardized transformed variables was then calculated.

Table 5.1. Factor Matrix Using Principal Factor, No Iterations of Data for Five Watersheds (25 Variables)

Variable	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6
AE15	-0.9113	0.1363	-0.0186	-0.0379	0.2353	-0.0221
APRCPS	0.9506	0.1368	-0.0423	-0.0549	-0.0957	-0.0172
APRCPT	0.9790	0.1428	-0.0326	-0.0467	0.0039	-0.0229
APRCPN	0.0514	0.1367	-0.0219	-0.0206	0.0300	0.0173
APCPTH	0.9655	0.1422	-0.0287	-0.0479	0.1235	-0.0277
APRCPF	0.9013	0.1354	-0.0253	-0.0532	0.2557	-0.0362
APRDH	0.7856	0.1119	-0.0705	-0.1003	-0.2261	-0.0653
NPRCP	-0.3873	-0.0500	-0.0009	0.0106	0.6501	0.0191
API5	0.9062	0.1353	-0.0101	-0.0543	-0.0638	-0.0073
AVTEMP	-0.0273	0.0037	0.0322	0.0176	0:4857	-0.1802
ATEMP5	0.0472	0.0067	0.0699	0.1205	0.8426	0.1890
SLPC	-0.1451	0.9531	-0.2027	-0.0373	0.0014	0.0466
ELEV	-0.1323	0.8392	-0.1324	-0.1563	0.0098	-0.1054
AREA	-0.0214	0.2365	0.8739	-0.3825	-0.0254	0.0956
CLAY	0.1269	-0.9032	0.2208	-0.2539	0.0124	-0.0564
LANDSLD	-0.1132	0.8166	0.4243	-0.1958	-0.0136	-0.0960
WDLD	-0.1297	0.9522	0.2407	0.0016	-0.0205	0.0385
GRSLD	0.0790	-0.4627	-0.4809	-0.2981	-0.0349	0.3602
DEVLPD	0.1518	-0.9328	0.1659	-0.1535	-0.0258	0.1161
DISTRB	-0.0166	-0.0374	-0.4844	-0.1076	-0.0013	0.5216
UNCONS	0.1080	-0.7821	0.3785	-0.0591	0.0237	-0.3245
CONSLD	-0.1401	0.9708	0.0353	-0.0504	-0.0119	0.1442
LPPHA	0.0023	0.0568	-0.4385	0.7024	-0.0015	-0.4812
DISCHA	0.2357	-0.0701	0.3349	0.7972	-0.1156	0.2670
SEDIMA	0.2962	-0.0484	0.4606	0.6933	-0.0678	0.3569

The Effect of Transformation of Data

Since natural processes are not necessarily linear in their mode of action, a logarithmic transformation is sometimes applied to data. This procedure may also be used for reduction of variable. However, the following points should be noted regarding the effects of transforming data to the logarithmic base:

1. Transforming data to $\log_{10}$ has been shown (N.R.C. 1966) to cause demagnification of the inaccuracies present in larger values, e.g.:

   If $y = f(x)$

   $$\frac{d(\log y)}{dx} = \frac{1}{f(x)} f'(x)$$

   Thus each f' is reduced by $1/f(x)$.

2. If an analysis such as a regression analysis is performed on transformed data, the confidence limits obtained apply to the transformed data and differ slightly from those obtained for the raw (untransformed) data.

The coefficients listed in the table usually called factor loading are measures of correlations between the variables and the factors. These factor loadings are used to attach physical significance to the factors. The correlations exceeding 0.90 are underlined. Only two factors contained variables with correlations equal or higher than 0.90. However, it can be observed that the factor loading matrix contains quite a few intermediate correlations (.40 to .75). The presence of the intermediate correlations renders the interpretations of the factors difficult. The six factors listed in Table 5.1 were those having eigenvalues greater than 1.0 and the six factors accounted for 84.4% of the total variance (Table 5.2). The first two factors combined account for 56.3% of the total variance.

Table 5.3 shows the varimax rotated factor matrix and the correlations exceeding 0.90 are underlined. There are still a few intermediate correlation values but they are fewer than those in Table 5.1. An attempt can now be made to assign physical significance to the factors.

FACTOR 1 - This factor is highly correlated with seven hydrologic variables that were selected to indicate soil moisture conditions, AEI5, APRCPS, APRCPT, APRCPN, APCPTH, APRCPF and API5. There is also a mild correlation with APRDH. The low correlation with NPRCP would seem to suggest that this variable should not be included in a study of sedimentation in areas undergoing development.

FACTOR 2 - This factor is highly correlated with the following variables, SLPC, CLAY (negative coefficient), WDLD, DEVLPD, CONS and mildly correlated with ELEV and UNCONS (negative coefficient). For the Ottawa River Valley area, this factor represents a steepness factor. The high negative coefficient on clay compared with the high positive coefficient on SLPC (slope) would seem to indicate an inverse relationship between slope and the variable CLAY. In a study of groundwater flow in Russell County, Ontario, Charron (1974) suggested that the clay areas are associated with gently slopes. 'The clay areas are generally flat'. Russell County is also in the Ottawa River Valley region. A visual observation of the study area reveals that the steep areas are wooded and relatively undeveloped. It should be borne in mind that a

Table 5.2. Eigenvalues - Factor Analysis of Data for Five Watersheds

Variable	Est Communality	Factor	Eigenvalue	Pct. of Var.	Cum. Pct.
AE15	1.0000	1	7.2236	28.9	28.9
APRCPS	1.0000	2	6.8573	27.4	56.3
APRCPT	1.0000	3	2.2800	9.1	65.4
APRCPN	1.0000	4	2.0564	8.2	73.7
APCPTH	1.0000	5	1.5921	6.4	80.0
APRCPF	1.0000	6	1.0848	4.3	84.4
APRDH	1.0000	7	0.9207	3.7	88.1
NPRCP	1.0000	8	0.8008	3.2	91.3
API5	1.0000	9	0.6121	2.4	93.7
AVTEMP	1.0000	10	0.5877	2.4	96.1
ATEMP5	1.0000	11	0.3042	1.2	97.3
SLPC	1.0000	12	0.1683	0.7	98.0
ELEV	1.0000	13	0.1585	0.6	98.6
AREA	1.0000	14	0.1086	0.4	99.0
CLAY	1.0000	15	0.0884	0.4	99.4
LANSLD	1.0000	16	0.0707	0.3	99.7
WDLD	1.0000	17	0.0609	0.2	99.9
GRSLD	1.0000	18	0.0202	0.1	100.0
DEVLPD	1.0000	19	0.0036	0.0	100.0
DISTRB	1.0000	20	0.0000	-0.0	100.0
UNCONS	1.0000	21	-0.0000	-0.0	100.0
CONSLD	1.0000	22	-0.0000	-0.0	100.0
LPPHA	1.0000	23	-0.0000	-0.0	100.0
DISCHA	1.0000	24	-0.0000	-0.0	100.0
SEDIMA	1.0000	25	-0.0000	-0.0	100.0

Table 5.3. Varimax Rotated Factor Matrix of Data for Five Watersheds

Variable	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6
AE15	0.9356	0.0015	0.0024	0.0519	0.0033	0.1684
APRCPS	0.9517	0.0003	-0.0029	0.0612	-0.0105	-0.1644
APRCPT	0.9869	0.0004	-0.0032	0.0650	-0.0008	-0.0663
APRCPN	0.9559	0.0019	0.0062	0.1026	-0.0224	-0.0354
APCPTH	0.9828	0.0003	-0.0014	0.0528	0.0026	0.0534
APRCPF	0.9298	0.0007	0.0009	0.0279	0.0074	0.1886
APRDH	0.7850	-0.0032	-0.0170	-0.0188	0.0039	-0.2885
NPRCP	-0.3392	0.0046	0.0046	-0.0814	-0.0301	0.6730
API5	0.9081	0.0023	0.0229	0.0708	0.0014	-0.1282
AVTEMP	0.0163	-0.0131	-0.0660	-0.0955	0.1504	0.4837
ATEMP5	0.0860	0.0099	0.0628	0.1515	-0.1026	0.8500
SLPC	0.0085	0.9779	-0.0279	-0.1234	-0.0423	-0.0040
ELEV	0.0206	0.8378	0.0146	-0.2551	0.0861	-0.0045
AREA	-0.0034	0.1265	0.8692	0.0859	0.4440	-0.0127
CLAY	0.0093	-0.9441	0.2122	-0.1058	0.0273	-0.0016
LANSLD	0.0077	0.7501	0.4125	-0.0564	0.4140	-0.0076
WDLD	-0.0052	0.9270	0.2413	0.0827	0.2426	-0.0050
GRSLD	0.0434	-0.3948	-0.0161	-0.2384	-0.6718	-0.0728
DEVLPD	0.0110	-0.9505	0.1900	0.0362	-0.1279	-0.0328
DISTRB	-0.0122	0.0586	-0.0308	-0.0393	-0.7166	-0.0184
UNCONS	-0.0031	-0.8541	0.0973	-0.0267	0.3702	0.0250
CONSLD	-0.0014	0.9759	0.1832	0.0066	0.0304	-0.0063
LPPHA	-0.0088	0.0984	-0.9197	0.1551	0.2012	0.0198
DISCHA	0.1037	-0.0753	-0.1387	0.9187	0.1023	-0.0529
SEDIMA	0.1683	-0.0744	0.0479	0.9322	0.0979	-0.0096

portion of Gatineau Park is in the study area. This park area is wooded and is located in an area with steep slopes. The geologic variables are also represented in this factor, with the CONSLD having a high positive correlation with the factor and the UNCONS having a negative correlation. For the area of study, such correlations appear to have some meaning in that areas of steep slopes are relatively undeveloped, wooded and contain some fair amount of older deposits. CONSLD has been chosen to represent all sediments older than cenozoic. In fact, a few outcrops are quite visible in the region of steep slope. Judging from the soilmap of the region (Lajoie 1962), the landslide areas are relatively steep in gradient. A mild correlation of the variable LANSLD with this factor would seem to make sense. It would be expected that a factor that represents steepness would be associated with elevation. Hence a fairly mild correlation with ELEV appears relevant.

FACTOR 3 - This factor represents the stream density. The factor has a fairly mild and positive correlation with A (AREA) though. This suggests an inverse relationship between area and stream density. This is not surprising for in the calculation of the values of stream density variable, only the main channels were considered.

FACTOR 4 - This is another hydrologic factor. The factor has high correlations with DISCH and SEDIM. It is to be expected that these two variables would go together since sediment load is related to stream discharge.

The first four factors account for 73.7% of the total variance. The last two factors with eigenvalues greater than one do not have any variables highly correlated with them. However, some variables have intermediate correlations with each of the factors.

FACTOR 5 - Appears to be a land-use variable, for it is mildly correlated with the variables GRSLD and DISTRB.

FACTOR 6 - The mild correlations of variables, ATEMS and NPRCP, would suggest that this is a dryness factor. In other words, the meteorologic variable and the variable depicting the period without rain would represent dryness of the study area.

From the initial factor-analysis, 15 of the original 25 variables have been retained. The 15 variables retained were then subject to another factor analysis with varimax rotation of the factor-weight matrix. The results are presented in Tables 5.4, 5.5, and 5.6.

Factor 1 still appears to represent the soil moisture conditions.

Factor 2 can still be considered a steepness factor.

Factor 3 is a sediment yield factor.

Factor 4 represents the stream density.

The four factors account for 93.4% of the total variance of the 15 variables subjected to factor analysis. Table 5.6 is then used to produce the regression formula

$$Z_{25} = 0.155\ F_1 - 0.037\ F_2 + 0.955\ F_3 - 0.021\ F_4 \qquad (5.1)$$

It is obvious that the most important factor for determining

Z^*_{25} (SEDIMA) is Factor 3. The variance of SEDIMA accounted for by the variation in Factor 3 is $(0.955)^2 = 0.912$. That is, 91.2% of the total variance of SEDIM is accounted for by Factor 3 alone. The proportion of the variance in SEDIMA accounted for by all four factors is:

$$(0.155)^2 + (0.037)^2 + (0.955)^2 + (0.021)^2 = 0.937$$

Compared with the variance accounted for by Factor 3 alone (0.912), the contribution of Factor 1, Factor 2 and Factor 4 to the variance of SEDIMA is only 0.937 - 0.912 = 0.025. Thus it can be assumed that it is sufficient to use F_3 in predicting SEDIMA.

Table 5.7 contains a matrix of factor-score coefficients. For each data case a vector of factor scores f can be calculated such that

$$f = F_Z$$

where f is the factor-score coefficient, and Z is the vector of standardized values of the variables which have been factor analyzed. Thus from Table 5.7:

$$\begin{aligned} \text{FACTOR 3} = & - 0.035Z_1 - 0.012Z_2 - 0.016Z_3 + 0.003Z_4 \\ & - 0.03Z_5 - 0.052Z_6 + 0.003Z_9 - 0.059Z_{12} \\ & - 0.023Z_{15} + 0.092Z_{17} + 0.043Z_{19} + 0.037Z_{22} \\ & - 0.049Z_{23} + 0.509Z_{24} + 0.54Z_{25} \end{aligned} \quad (5.2)$$

If it is assumed that equation 1 can be approximated by

$$Z_{25} = 0.955F_3 \quad (5.3)$$

*Z is the standardized form of the variables listed in Chapter 4.

Table 5.4. Eigenvalues Obtained from a Factor-Analysis of Data for Five Watersheds (15 Variables)

Variable	Est Communality	Factor	Eigenvalue	Pct. of Var.	Cum. Pct.
AE15	1.0000	1	6.4855	43.2	43.2
APRCPS	1.0000	2	4.6259	30.8	74.1
APRCPT	1.0000	3	1.8618	12.4	86.5
APRCPN	1.0000	4	1.0393	6.9	93.4
APCPTH	1.0000	5	0.2870	1.9	95.3
APRCPF	1.0000	6	0.1609	1.1	96.4
API5	1.0000	7	0.1219	0.8	97.2
SLPC	1.0000	8	0.1063	0.7	97.9
CLAY	1.0000	9	0.0940	0.6	98.6
WDLD	1.0000	10	0.0740	0.5	99.0
DEVLPD	1.0000	11	0.0697	0.5	99.5
CONSLD	1.0000	12	0.0471	0.3	99.8
LPPHA	1.0000	13	0.0216	0.1	100.0
DISCHA	1.0000	14	0.0044	0.0	100.0
SEDIMA	1.0000	15	-0.0000	-0.0	100.0

Table 5.5. Factor Matrix (Using Principal Factor No Iterations) of Data for Five Watersheds (15 Variables)

Variable	Factor 1	Factor 2	Factor 3	Factor 4
AE15	0.9358	0.0275	-0.0911	-.0329
APRCPS	0.9499	0.0223	-0.0589	-0.0119
APRCPT	0.9865	0.0250	-0.0657	-0.0160
APRCPN	0.9669	0.0221	-0.0364	-0.0011
APCPTH	0.9841	0.0266	-0.0865	-0.0289
APRCPF	0.9292	0.0282	-0.1152	-0.0474
API5	0.9060	0.0217	-0.0445	0.0165
SLPC	-0.0311	0.9665	-0.0788	-0.0191
CLAY	0.0172	-0.9525	-0.1470	0.1191
WDLD	-0.0145	0.9348	0.0546	0.2456
DEVLPD	0.0359	-0.9615	-0.0433	0.1613
CONSLD	-0.0236	0.9745	-0.0348	0.2142
LPPHA	0.0130	0.1207	0.4569	-0.8738
DISCHA	0.2348	-0.0951	0.9173	0.1372
SEDIMA	0.2959	-0.0904	0.8587	0.3242

Table 5.6. Varimax Rotated Factor Matrix of Data for Five Watersheds Using 15 Variables

Variable	Factor 1	Factor 2	Factor 3	Factor 4
AE15	0.9402	0.0009	0.0417	0.0063
APRCPS	0.9486	-0.0017	0.0809	-0.0028
APRCPT	0.9860	-0.0003	0.0786	-0.0009
APRCPN	0.9618	-0.0004	0.1080	-0.0054
APCPTH	0.9871	-0.0005	0.0546	0.0042
APRCPF	0.9378	-0.0002	0.0135	0.0119
API5	0.9019	0.0013	0.0972	-0.0250
SLPC	0.0107	0.9588	-0.1423	0.0441
CLAY	0.0033	-0.9468	-0.0379	-0.2130
WDLD	-0.0041	0.9518	0.0730	-0.1620
DEVLPD	0.0052	-0.9487	0.0757	-0.2184
CONSLD	0.0021	0.9854	-0.0243	-0.1602
LPPHA	-0.0097	0.0759	0.1333	0.9816
DISCHA	0.0944	-0.0511	0.9396	0.1735
SEDIMA	0.1551	-0.0367	0.9552	-0.0214

Thus equation 5.3 can be used to predict SEDIMA (the sediment load). It is to be noted, however, that the 15 variables need to be measured before applying this prediction equation. However, an examination of the coefficients in equation 5.2 would suggest that F_3 can be approximated as

$$F_3 \simeq 0.509Z_{24} + 0.54Z_{25}$$

$$\therefore \text{ from equation 5.3, } Z_{25} \simeq 0.955(0.509Z_{24} + 0.54Z_{25})$$

$$\text{i.e. } 0.48Z_{25} \simeq 0.49Z_{24}.$$

It is to be noted that Z_{24} is the standardized variable for V_{24} (Chapter 4), the discharge.

Another approach of predicting Z_{25} (SEDIMA) was to perform a multiple regression analysis on the four factors. The results are presented in Tables 5.8, 5.9 and 5.10. It should be noted that the equation derived is similar to equation 5.1. The only advantage here is that more statistics are given.

Significance of the Statistics

The usual t and F statistics are not directly applicable in a step-wise variable selection process (Bidwell 1971). It was therefore assumed that the goodness of fit of the regression equation can be evaluated by examining the square of the multiple correlation, R^2. The R^2 for the equation was 0.94 and the standard error of estimate was 0.25.

Table 5.7. Factor Score Coefficients Using Data for Five Watersheds (15 Variables)

Variable	Factor 1	Factor 2	Factor 3	Factor 4
AE15	0.1510	-0.0015	-0.0348	0.0144
APRCPS	0.1499	-0.0005	-0.0118	0.0011
APRCPT	0.1561	-0.0005	-0.0156	0.0036
APRCPN	0.1503	0.0006	0.0033	-0.0046
APCPTH	0.1579	-0.0015	-0.0301	0.0116
APRCPF	0.1525	-0.0029	-0.0516	0.0232
API5	0.1409	0.0017	0.0033	-0.0220
SLPC	0.0084	0.2051	-0.0587	0.0145
CLAY	0.0024	-0.2002	-0.0231	-0.1454
WDLD	-0.0104	0.2197	0.0923	-0.2016
DEVLPD	-0.0043	-0.1969	0.0426	-0.1651
CONSLD	-0.0034	0.2241	0.0369	-0.1887
LPPHA	0.0047	-0.0246	-0.0487	0.8745
DISCHA	-0.0398	0.0912	0.5086	0.0395
SEDIMA	-0.3382	0.0216	0.5396	-0.1401

Wallis (1965) suggested retaining not more than two variables per factor after the initial factor analysis. The aim is probably to minimize the multicollinearities that may exist in a set of variables. It was assumed that if the variables retained after the initial factor analyses are still to be factor-analyzed, such a procedure may not be necessary. However, it is considered advisable to screen the variables before performing a multivariate regression analysis. In this analysis, a prediction equation (equation 5.3) was developed by considering only one Factor.

Many other trials were made. Factor-analysis was performed on data for two, three and four watersheds separately. The purpose was two-fold:

1. To determine whether there was the need to transform the variables before analysis, and
2. To find which type of transformations yielded the type of factors that were interpretable in terms of the physical characteristics of the areas studied.

Table 5.13 shows the results of one of those attempts. The data for four watersheds, Highway 8, Moreau, Chelsea and Fleury Road, were subjected to factor-analyses. In this case, the logarithmically-transformed variables were analyzed.

The variables highly correlated with each factor was underlined. Four factors were extracted and the four factors accounted for 78.0% of the total variance (Table 5.14).

Table 5.8. Correlation Coefficients Between SEDIMA and Four Factors

Variable	Z25	F1	F2	F3	F4
*Z25	1.0000	0.1551	-0.0367	0.9552	-0.0214
F1	0.1551	1.0000	0.0000	0.0000	0.0000
F2	-0.0367	0.0000	1.0000	0.0000	0.0000
F3	0.9552	0.0000	0.0000	1.0000	-0.0000
F4	-0.0214	0.0000	0.0000	-0.0000	1.0000

*Z25 = SEDIMA

Table 5.9. Multivariate Regression Analysis Using Rotated Factors (Analysis of Variance)

Dependent Variable SEDIMA

Multiple R	0.9686	Analysis of Variance	DF	Sum of Squares	Mean Square	F
R Square	0.9382	Regression	4.	280.5436	70.1359	1121.0365
Adjusted R Square	0.9374	Residual	295.	18.4562	0.0625	
Standard Error	0.2501					

Variables in the Equation

Variable	B*	Beta**	Std. Error B	F
F4	-0.2141D-01	-0.0214	0.0145	2.191
F1	0.1551	0.1551	0.0145	114.981
F2	-0.3675D-01	-0.0367	0.0146	6.456
F3	0.9551	0.9552	0.0145	4360.515
(Constant)	-0.6093D-06			

* B is the unstandardized regression coefficient.
** Beta is the standardized regression coefficient.

Table 5.10. Results of Regression Analysis Using Rotated Factors

Dependent Variable SEDIMA

Variable	Multiple R	R Square	Rsq. Change	Simple R	B
F4	0.0214	0.0004	0.0004	-0.0214	-0.2141D-01
F1	0.1565	0.0245	0.0240	0.1551	0.1551
F2	0.1608	0.0258	0.0013	-0.0367	-0.3675D-01
F3	0.9686	0.9382	0.9124	0.9552	0.9551
(Constant)					-0.6093D-06

Factor 1 represents the moisture conditions

Factor 2 is a steepness factor

Factor 3 represents a land-use factor

Factor 4 is a streams density factor

The two variables that had high correlation with Factor 3 were LANSLD and GRSLD, and it would be recalled that the drainage basin on which the station at Highway 8 was located is a landslide-prone area.

A step-wise multiple regression analysis was then performed on the variables with high loadings on the factors. The results are presented in Tables 5.15 and 5.16. The step-wise regression was performed without subjecting the variables with high loadings on the factors to a second factor-analysis. The R^2 was 0.58 and the standard error was 1.71.

Another trial made was to perform a step-wise multiple regression analysis on the logarithmically transformed data for the five watersheds for which a prediction equation was formulated (equation 5.3) in a foregoing factor-analysis. The results are listed on Tables 5.11 and 5.12. The value of R^2 was 0.93 and the standard error of estimates was 0.94.

The high R^2 obtained in the results should be evaluated bearing in mind the closeness of the watersheds and the assumptions stated earlier in this chapter concerning the definition of some of the variables. Besides, in the case of multiple-regression analysis, there is the question about the reliability of the regression coefficients when multicollinearity exists among the variables.

Table 5.11. Multiple Regression Analysis Using Data for Four Watersheds (Analysis of Variance)

Dependent Variable SEDIMA

Multiple R	0.9282	Analysis of Variance	DF	Sum of Squares	Mean Square	F
R Square	0.8616	Regression	17.	1551.4715	91.2630	103.2780
Adjusted R Square	0.8532	Residual	282.	249.1931	0.8836	
Standard Error	0.9400					

Variable	B	Beta	Std. Error B	F
DISCHA	1.1151	0.7169	0.0447	622.153
ELEV	-2.0589	-0.2177	2.4894	0.684
APRCPN	0.1852	0.1082	0.1412	1.719
LANSLD	-0.1088	-0.0284	0.7901	0.019
AVTEMP	0.1884	0.0604	0.0755	6.221
DISTRB	-0.1743	-0.0376	0.1771	2.217
NPRCP	-0.1010	-0.0458	0.0590	2.927
ATEMP5	0.2744	0.0529	0.1607	2.913
APRCPF	0.3977D-01	0.0162	0.2767	0.021
LPPHA	0.4632	0.1569	0.1500	0.162
APRCPT	0.8869	0.4913	0.4242	4.371
APRCPS	-0.1653	-0.1025	0.1553	1.134
APCPTH	-0.8110	-0.4008	0.5505	2.171
APRDH	-0.7529D-01	-0.0475	0.0641	1.036
AE15	0.2157D-01	0.0235	0.0636	0.115
AREA	0.2918	0.0813	0.9373	0.097
AP15	-0.9826D-02	-0.0065	0.0864	0.013
(Constant)	7.8412			

Table 5.12 Results of Multiple Regression Analysis Using Data for Four Watersheds

Dependent Variable SEDIMA

Variable	Multiple R	R Square	RSQ. Change	Simple R	B*	Beta**
DISCHA	0.8674	0.7524	0.7524	0.8674	1.1151	0.7169
ELEV	0.9131	0.8338	0.0814	-0.6134	-2.0589	-0.2177
APRCPN	0.9204	0.8471	0.0132	0.2135	0.1852	0.1082
LANSLD	0.9228	0.8516	0.0045	0.1059	-0.1088	-0.0284
AVTEMP	0.9242	0.8543	0.0026	0.0099	0.1884	0.0604
DISTRB	0.9249	0.8554	0.0011	-0.1615	-0.1743	-0.0376
NPRCP	0.9253	0.8561	0.0007	-0.1314	-0.1010	-0.0458
ATEMP5	0.9261	0.8577	0.0015	0.0464	0.2744	0.0529
APRCPF	0.9266	0.8585	0.0008	0.1482	0.3977D-01	0.0162
LPPHA	0.9269	0.8591	0.0005	0.3741	0.4632	0.1569
APRCPT	0.9271	0.8596	0.0004	0.1918	0.8869	0.4913
APRCPS	0.9275	0.8602	0.0006	0.1783	-0.1653	-0.1025
APCPTH	0.9278	0.8609	0.0006	0.1793	-0.8110	-0.4008
APRDH	0.9281	0.8615	0.0005	0.1034	-0.6529D-01	-0.0475
AE15	0.9282	0.8615	0.0000	0.1626	0.2157D-01	0.0235
AREA	0.9282	0.8616	0.0000	0.0994	0.2918	0.0813
AP15	0.9282	0.8616	0.0000	0.1942	-0.9826D-02	-0.0065
(Constant)					7.8412	

* B is the unstandardized regression coefficient.
** Beta is the standardized regression coefficient.

Table 5.13. Varimax Rotated Factor Matrix of Data for Four Watersheds

Variable	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
AE15	0.9380	0.0153	0.0069	0.0050	0.1654
APRCPS	0.9519	0.0216	-0.0019	0.0039	-0.1605
APRCPT	0.9879	0.0219	0.0013	0.0052	-0.0637
APRCPN	0.9617	0.0261	-0.0000	0.0073	-0.0339
APCPTH	0.9835	0.0188	0.0046	0.0052	0.0540
APRCPF	0.9294	0.0133	0.0095	0.0045	0.1886
APRDH	0.7795	0.0090	-0.0097	-0.0039	-0.2868
NPRCP	-0.3503	-0.0230	-0.0085	-0.0078	0.6736
AP15	0.9037	0.0302	0.0154	-0.0216	-0.1236
AVTEMP	0.0049	-0.0095	0.0069	0.0000	0.4860
ATEMP5	0.0983	0.0026	0.0086	0.0081	0.8510
SLPC	0.0226	-0.9727	0.0433	0.1778	-0.0173
ELEV	0.0245	-0.8711	-0.0348	-0.4582	-0.0144
AREA	-0.0067	0.4486	0.4737	-0.7551	0.0020
CLAY	-0.0184	0.5119	0.1335	0.8357	0.0070
LANSLD	-0.0030	-0.0467	0.9073	0.3884	-0.0120
WDLD	0.0116	-0.4569	0.8281	-0.2820	-0.0179
GRSLD	0.0029	-0.0851	-0.9771	0.1190	0.0104
DEVLPD	-0.0214	0.9485	-0.1481	-0.2437	0.0181
DISTRB	-0.0145	-0.1672	-0.5585	-0.0924	-0.0341
UNCONS	-0.0216	0.9225	0.2855	-0.2210	0.0124
CONSLD	0.0251	-0.9303	-0.1039	-0.3069	-0.0146
LPPHA	-0.0108	0.1672	0.1612	0.9667	0.0007
DISCHA	0.1033	0.7090	-0.0617	0.1871	-0.0939
SEDIMA	0.1608	0.7647	0.0297	0.3260	-0.0194

Table 5.14. Eigenvalues Using Data for Four Watersheds

Variable	Est Communality	Factor	Eigenvalue	Pct. of Var.	Cum. Pct.
AE15	1.0000	1	7.2059	28.8	28.8
APRCPS	1.0000	2	6.3077	25.2	54.1
APRCPT	1.0000	3	3.1636	12.7	66.7
APRCPN	1.0000	4	2.8221	11.3	78.0
APCPTH	1.0000	5	1.5970	6.4	84.4
APRCPF	1.0000	6	0.9313	3.7	88.1
APRDH	1.0000	7	0.7935	3.2	91.3
NPRCP	1.0000	8	0.7745	3.1	94.4
AP15	1.0000	9	0.5579	2.2	96.6
AVTEMP	1.0000	10	0.3048	1.2	97.8
ATEMP5	1.0000	11	0.1837	0.7	98.6
SLPC	1.0000	12	0.1043	0.4	99.0
ELEV	1.0000	13	0.0881	0.4	99.3
AREA	1.0000	14	0.0812	0.3	99.7
CLAY	1.0000	15	0.0590	0.2	99.9
LANSLD	1.0000	16	0.0204	0.1	100.0
WDLD	1.0000	17	0.0039	0.0	100.0
GRSLD	1.0000	18	0.0000	0.0	100.0
DEVLPD	1.0000	19	0.0000	0.0	100.0
DISTRB	1.0000	20	0.0000	0.0	100.0
UNCONS	1.0000	21	0.0000	0.0	100.0
CONSLD	1.0000	22	0.0000	0.0	100.0
LPPHA	1.0000	23	-0.0000	-0.0	100.0
DISCHA	1.0000	24	-0.0000	-0.0	100.0
SEDIMA	1.0000	25	-0.0000	-0.0	100.0

Table 5.15. Multiple Regression Analysis Using Data for Four Watersheds (Analysis of Variance)

Dependent Variable SEDIMA

Multiple R	0.7598	Analysis of Variance	DF	Sum of Squares	Mean Square	F
R Square	0.5773	Regression	9.	920.5928	102.2880	34.9063
Adjusted R Square	0.5607	Residual	230.	673.9815	2.9303	
Standard Error	1.7118					

Variable	B*	Beta**	Std. Error B	F
ELEV	-6.1597	-0.6257	0.8929	47.584
APRCPT	0.5479	0.3043	0.2589	4.477
APRCPF	-0.2952	-0.1143	0.5227	0.319
SLPC	-0.9341	-0.3155	1.4355	0.423
DEVLPD	-0.4836	-0.1976	1.0714	0.204
APRCPS	-0.2525	-0.1488	0.3036	0.691
APRCPT	0.5366	0.2825	0.7453	0.518
APCPTH	-0.2781	-0.1306	1.0014	0.077
AE15	-0.2971	-0.0307	0.1186	0.063
(Constant)	35.0247			

* B is the unstandardized regression coefficient.
** Beta is the standardized regression coefficient.

Table 5.16. Results of Multiple Regression Analysis Using Data for Four Watersheds

Dependent Varaible SEDIMA

Variable	Multiple R	R Square	Rsq. Change	Simple R	B
ELEV	0.7922	0.5327	0.5327	-0.7299	-0.6257
APRCPT	0.7531	0.5672	0.0344	0.1857	0.5479
APRCPF	0.7561	0.5718	0.0045	0.1331	-0.2952
SLPC	0.7586	0.5755	0.0037	-0.6130	-0.9341
DEVLPD	0.7588	0.5759	0.0003	0.5734	-0.4836
ARPCPS	0.7590	0.5761	0.0002	0.1563	-0.2525
APRCPT	0.7595	0.5769	0.0008	0.1686	0.5366
APCPTH	0.7597	0.5772	0.0002	0.1584	-0.2781
AE15	0.7598	0.5773	0.0001	0.1468	-0.2971D-01
(Constant)					35.0247

5.2 USDAHL-74

The results of three runs for different types of input of initial channel flow are presented in Tables 5.17 and 5.18 and are shown graphically in Figures 5.1 and 5.2. The runs were made for initial channel flows of: (1) 0.00191 in/hr, (2) 0.000954 in/hr, and (3) 0.0191 in/hr. Table 5.19 shows the results of the runs made for different values of ET/EP. Data was collected for recorded flows weekly for over a 21-week period.

The statistical summary Table 5.11 provides an easy reference of results of the calibration of the USDAHL-model over a short span of 21 weeks.

One of the objectives of this study is to explore for a model which can simulate flow, hence sediment flow for an area undergoing development. The USDAHL-74 model was employed in this study because the model was especially developed for land-use purposes and the model has been tried on small watersheds (Bergston et al 1979, Ghermazien et al 1979, Holtan et al 1977, Felton et al 1979). A particularly distinctive feature of the model is the zoning concept which permits the investigator to reduce the areal complexity of flow paths across the watershed. The surface and return flows for each zone are also computed by the model. Such a feature allows for isolation of source areas of pollution loading. However, in this study the results of simulated flows for each zone could not be verified because flows were not recorded for each zone.

The results of the calibration show a better agreement between the recorded and the simulated flows for high flows, especially after heavy rainfall. The simulated flows for low flows are rather poor when compared with the recorded flows (Tables 5.15-5.19). It has been suggested (Holtan et al 1977) that an improvement in the simulated flow can be made by increasing estimates of maximum base flows and the corresponding storage coefficients. This would require some streamflow data. In this study such streamflow data are rather limited for Meach Brook.

If Run 3 (Table 5.18) is considered as the best run, the results of the run suggest that the USDAHL-74 model overpredicts streamflow shortly after periods of high precipitation and underpredicts streamflow after periods of low or no precipitation.

The determination of channel flow is important in predicting the fluvial sediment load. The channel flow may influence bank erosion in small streams, hence a fairly accurate method of predicting the channel flow is desirable. The results would have to be evaluated in terms of the shortness of record available. In this regard, the results of the model appear acceptable. That the model appears to underpredict during low flows has been attested to by Bergston et al 1979, and Holtan et al 1977.

Table 5.17. Simulated and measured streamflow using different initial values of channel flow.

	Run 1. Channel flow = 0.00191 in/hr				Run 2. Channel flow = 0.000954 in/hr		
Day	Observed flow(cfsd)	Simulated flow(cfsd)	Diff. (cfsd)	% Error	Simulated flow(cfsd)	Diff. (cfsd)	% Error
161	2.24	1.185	1.055	47.1	.800	1.44	64.3
168	.99	.626	.364	36.8	.375	.615	62.1
175	.96	.271	.689	71.8	.188	.772	80.4
183	.572	.134	.438	76.6	.098	.474	82.9
189	.76	.084	.676	88.9	.061	.699	92.0
196	.73	.073	.657	90.0	.057	.673	92.2
203	1.01	.048	.962	95.2	.036	.974	96.4
210	1.17	.081	1.089	93.1	.072	1.098	93.8
219	.53	.037	.493	93.0	.031	.499	94.2
224	.253	.023	.23	90.9	.018	.235	92.9
231	.49	.012	.478	97.6	.008	.482	98.4
238	.44	.005	.435	98.9	.002	.438	99.5
246	.34	.028	.312	91.8	.026	.314	92.4
252	.601	.042	.559	93.0	.040	.561	93.3
259	.521	.056	.465	89.3	.055	.466	89.4
266	.88	.097	.783	89.0	.096	.784	89.1
273	.854	.488	.366	42.9	.487	.367	43.0
280	.862	.375	.487	56.5	.375	.487	56.5
288	5.39	9.884	-4.494	-83.4	9.883	-4.493	-83.4
294	6.70	2.066	4.634	69.2	2.065	4.635	69.2
301	1.47	.510	.96	65.3	.509	.961	65.4
	Σ27.763	Σ16.125			Σ15.282		

Table 5.18. Simulated and measured streamflow using different initial values of channel flow.

Run 3. Channel flow = 0.0191 in/hr

Day	Measured (cfsd)	Simulated flow(cfsd)	Accumulated flow(cfsd)	Difference (cfsd)	% Error
161	2.24	3.022	3.022	-.782	34.90
168	.99	1.437	4.459	-.447	-45.2
175	.96	.376	4.835	.584	60.8
183	.572	.176	5.011	.396	69.2
189	.76	.108	5.119	.652	85.8
196	.73	.091	5.21	.639	87.5
203	1.01	.060	5.27	.95	94.1
210	1.17	.089	5.359	1.081	92.4
219	.53	.042	5.401	.488	92.1
224	.253	.027	5.428	.226	89.3
231	.49	.015	5.443	.475	96.9
238	.44	.008	5.451	.432	98.2
246	.34	.031	5.482	.309	90.9
252	.601	.044	5.526	.557	92.7
259	.521	.058	5.5[illegible]4	.463	88.9
266	.88	.099	5.683	.781	88.8
273	.854	.489	6.172	.365	42.7
280	.862	.376	6.548	.486	56.4
288	5.39	9.862	16.41	-4.472	-83.0
294	6.70	2.078	18.488	4.622	69.0
301	1.47	.511	18.999	.959	65.2
	Σ 27.763				

Channel flow = 0.0191 in/hr

Table 5.19. Simulated and measured streamflow using different values of ET/EP.

Initial channel flow = 0.0191 in/hr

Day	Measured Observed flow(cfsd)	ET/EP = 1.60 Simulated flow(cfsd)	Diff. (cfsd)	% Diff.	ET/EP = 1.80 Simulated flow(cfsd)	Diff. (cfsd)	% Diff.
161	2.24	3.022	-.782	34.9	2.995	-.755	33.7
168	.99	1.437	-.447	45.2	1.396	-.406	41.0
175	.96	.376	.584	60.8	.370	.59	61.5
183	.572	.176	.396	69.2	.168	.404	70.6
189	.76	.108	.652	85.8	.101	.659	86.7
196	.73	.091	.639	87.5	.084	.646	88.5
203	1.01	.060	.950	94.1	.054	.956	94.7
210	1.17	.089	.921	78.7	.082	1.088	86.2
219	.53	.042	.488	92.1	.036	.494	93.2
224	.253	.027	.226	89.3	.022	.231	91.3
231	.49	.015	.475	96.9	.010	.48	98.
238	.44	.008	.432	98.2	.004	.436	99.1
246	.34	.031	.309	90.9	.026	.314	92.4
252	.601	.044	.557	92.7	.038	.563	93.7
259	.521	.058	.463	88.9	.053	.468	89.8
266	.88	.099	.781	88.8	.093	.787	89.4
273	.854	.489	.365	42.7	.438	.416	48.7
280	.862	.376	.486	56.4	.320	.542	62.9
288	5.39	9.862	-3.23	-59.9	9.744	-4.354	80.8
294	6.70	2.078	4.622	69.0	1.864	4.836	72.2
301	1.47	.511	.959	65.2	.469	1.001	68.1

Table 5.20. Statistical summary of regression of simulated and measured flows.

	Statistic	Run 1	Run 2	Run 3
Regression equation measured Simulated = a + b(recorded)	a	-.54	-.53	-.39
	b	.95	.95	.98
	R	.73	.725	.73
	R^2	.53	.53	.53
	n	21	21	21
	Std. error of estimate	1.51	1.52	1.54
	Cumulative flow (c.f.s-day)	16.13	15.28	19.00

The measured cumulative streamflow = 27.8 c.f.s. days.

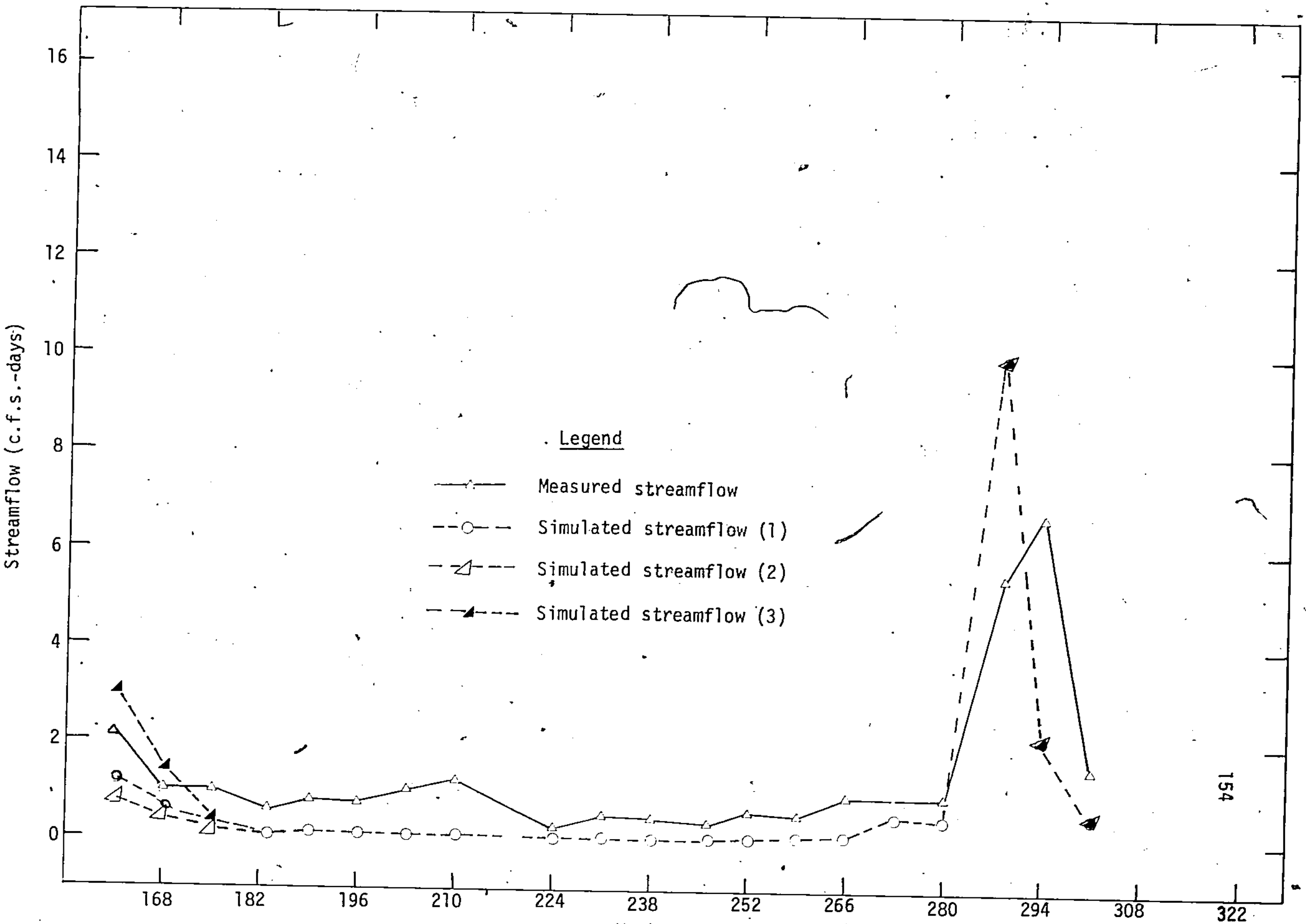


Fig. 5.1. Comparison of observed streamflow and simulated streamflow computed by UOM/USDAHL-74 model.

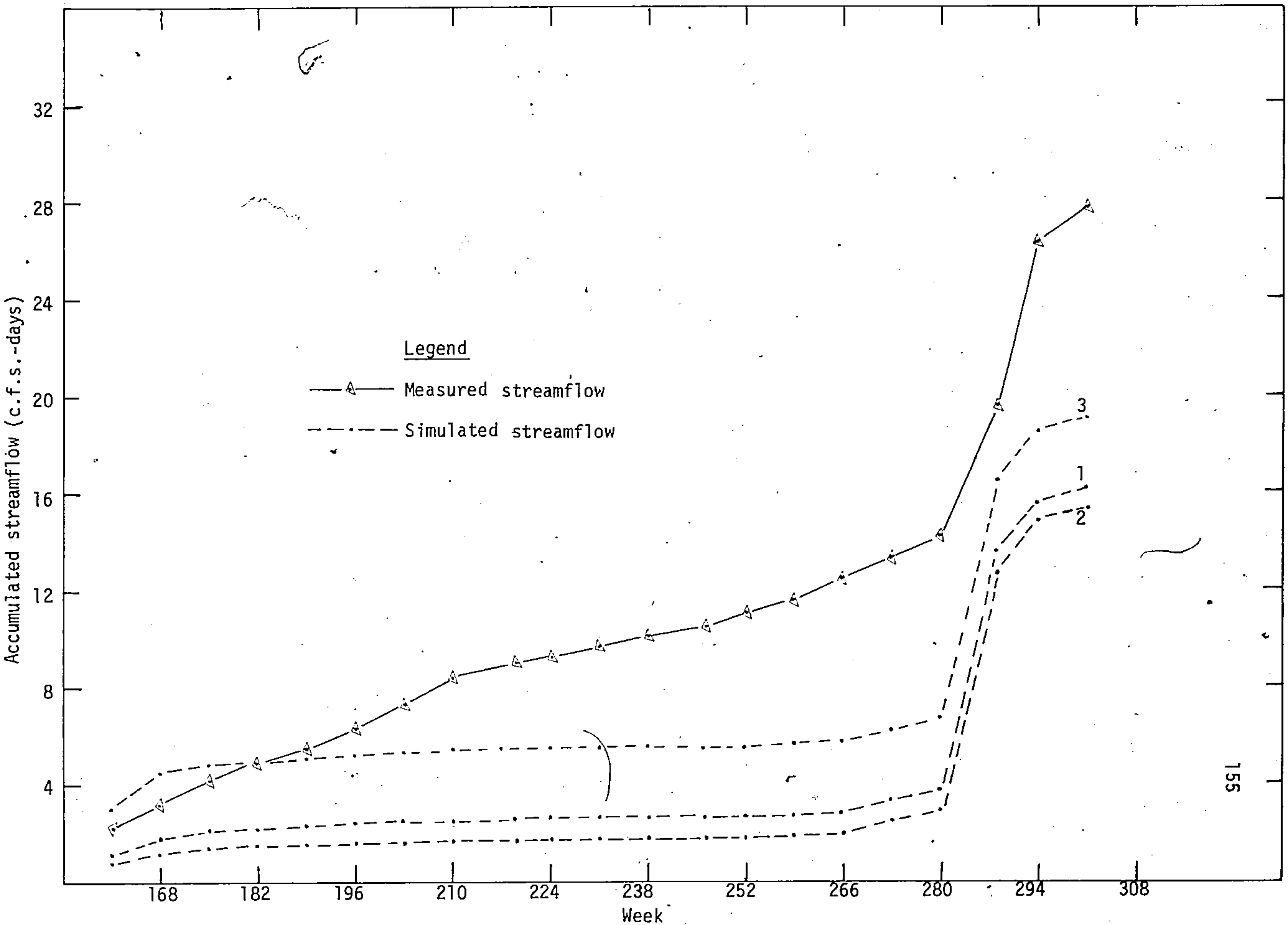


Fig. 5.2. Comparison of observed streamflow and simulated streamflow computed by UOM/USDAHL-74 model.

5.3 Concentration Versus Velocity Curve

To investigate the relationship between the measured suspended sediment concentration in the streams and the mean velocity, the concentrations observed and the mean velocities were plotted on log paper. Other investigators (Fleming 1969) have found these variables to be correlated. However, a wide scatter of points was noticed in most of the plots (Figs. 5.3-5.10). A regression run was made on the data for each station on a yearly basis, the year being defined as the period of sampling for that year. The statistical summary of the runs as presented in Tables 5.21 and 5.22, and the plots (Figs. 5.3-5.10) show the variations of the results both in time and space.

An examination of the Tables 5.21 and 5.22 shows that R^2, the fraction of log (C) variation accounted for by the regression, is rather small. Some general observations can be made from the results.

1. There seems to be a much weaker association between the log (C) and log (V) when a development such as a construction project was underway just upstream of the sampling point. Such weak association might suggest that the fine-grained suspended sediment concentration in the stream was more influenced by the supply upstream rather than by the velocity of the stream.
2. Flow conditions at one sampling station (Desjardins Creek) are affected by backwater from the Gatineau River. The results at this station show a negative correlation between log C and log V.
3. For at least one station (Moreau East Creek), it appeared that a better correlation resulted where it was known that the runoff was from storms causing surface runoff.

Also, it may be questioned whether the relations that are known to be valid for large rivers, such as log (C) a function of log (V), are applicable to small streams with shallow flows. Further study of fine-grained sediment movement in shallow flows is required.

It should be noted that the flows on the streams were not sampled at some specified time intervals on any particular day of sampling. In other words, only one sampling was carried out for each station on the day of sampling.

Table 5.21. Statistical summary of regression (log C and log V).

Regression equation: $\text{Log } C = a + b(\log V)$

	Moreau				Moreau E.		
Statistic	1973	1975	1976	Statistic	1973	1975	1976
a	1.46	-1.35	-1.11	a	5.03	-0.24	2.36
b	0.81	0.98	0.98	b	-0.104	0.98	.29
r	0.31	0.42	0.67	r	0.11	.74	0.15
r^2	0.093	0.17	0.45	r^2	0.011	.54	0.02
n	20	28	17	n	19	20	18
F	1.853	5.49	12.37	F	0.192	21.49	0.36
Std. error of estimate	1.14	1.26	0.65	Std. error of estimate	0.594	0.60	1.11

V = mean stream velocity (cm/sec)

C = suspended sediment concentration (mg/l)

Regression equation: $\text{Log } C = a + b(\log V)$

	Trailer Park				Desjardin		
Statistic	1973	1975	1976	Statistic	1973	1975	1976
a	4.34	-0.87	1.89	a	5.201	4.404	6.819
b	-0.064	0.94	0.41	b	-0.479	-0.205	-0.556
r	0.095	0.38	0.24	r	-0.317	-0.059	-0.198
r^2	0.009	0.15	0.06	r^2	0.10	0.003	0.039
n	24	28	17	n	16	24	17
F	0.199	4.464	0.922	F	1.56	0.08	.61
Std. error of estimate	0.79	0.95	0.75	Std. error of estimate	0.85	0.98	1.18

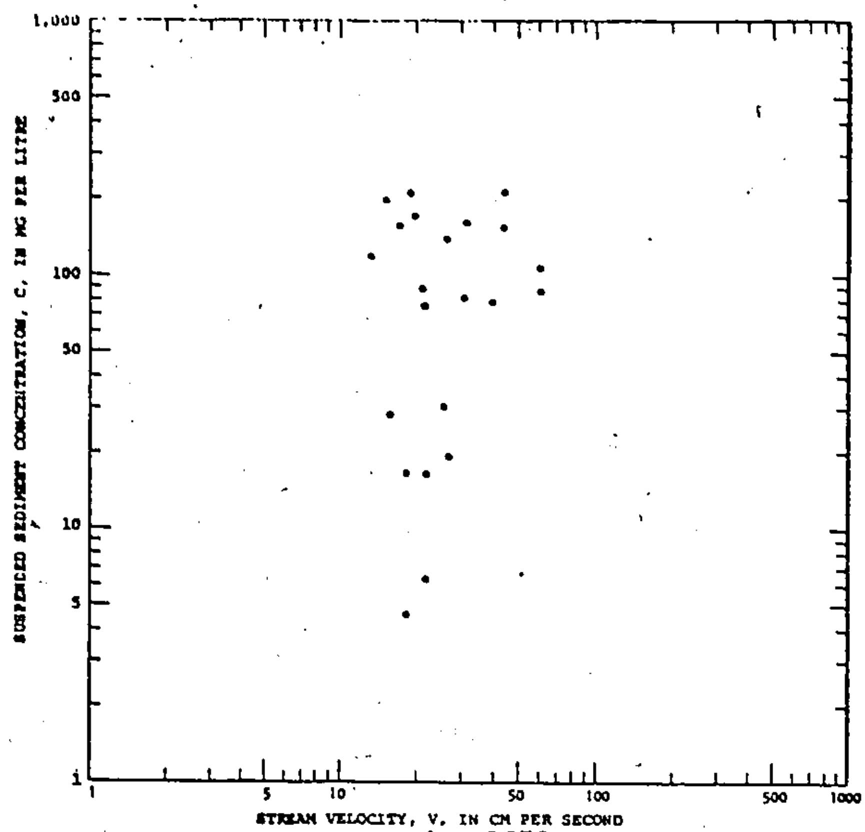
Table 5.22. Statistical summary of regression (log C and log V).

Regression equation Log C = a + b(log V)

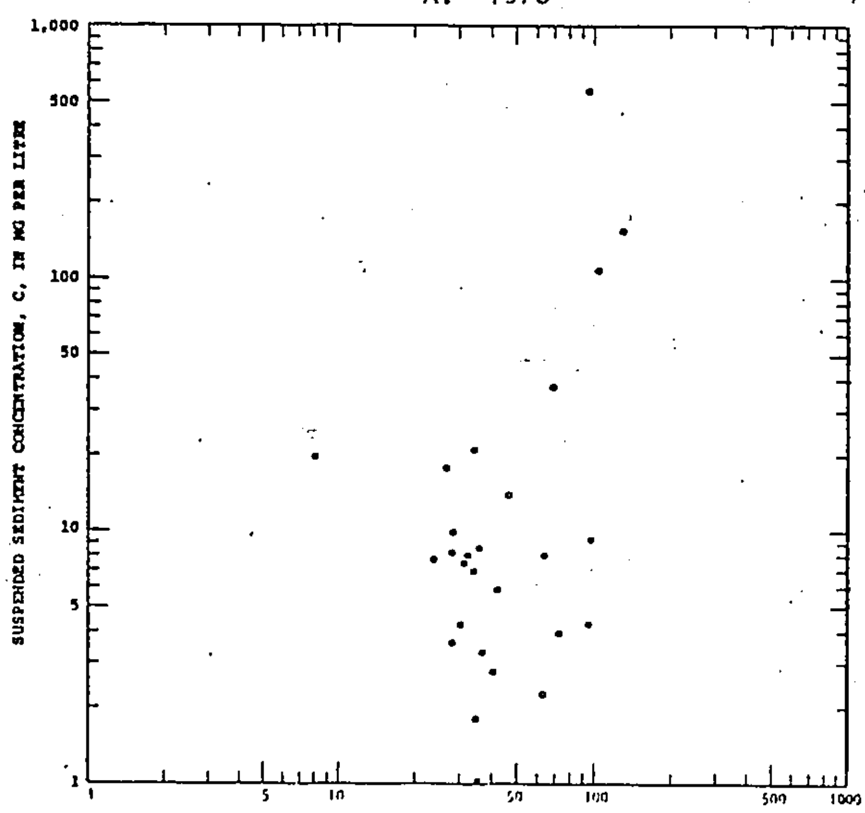
Statistic	Chelsea 1973	Chelsea 1975	Chelsea 1976	Statistic	Hull 1973	Hull 1975	Hull 1976
a	0.944	0.771	3.101	a	2.49	3.33	3.58
b	0.756	0.732	0.155	b	0.14	-0.25	-0.173
r	0.289	0.313	0.078	r	0.096	-0.15	-0.09
r^2	0.084	0.098	0.006	r^2	0.009	0.021	0.008
n	19	24	17	n	18	24	17
F	1.548	0.67	0.092	F	0.15	0.483	0.12
Std. error of estimate	1.00	0.67	0.90	Std. error of estimate	0.72	0.91	1.04

Regression equation Log C = a + b(log V)

Statistic	Mine Road 1973	Mine Road 1975	Mine Road 1976	Statistic	Fleury 1973	Fleury 1975	Fleury 1976
a	-0.66	1.27	-0.26	a	-2.443	-2.30	-0.71
b	0.69	0.19	0.68	b	1.033	0.871	0.67
r	0.68	0.17	0.37	r	0.322	0.328	0.21
r^2	0.47	0.03	0.14	r^2	0.103	0.108	0.04
n	19	24	17	n	19	24	20
F	14.85	0.64	2.432	F	1.96	2.66	0.82
Std. error of estimate	0.50	0.52	0.71	Std. error of estimate	1.20	1.04	1.50

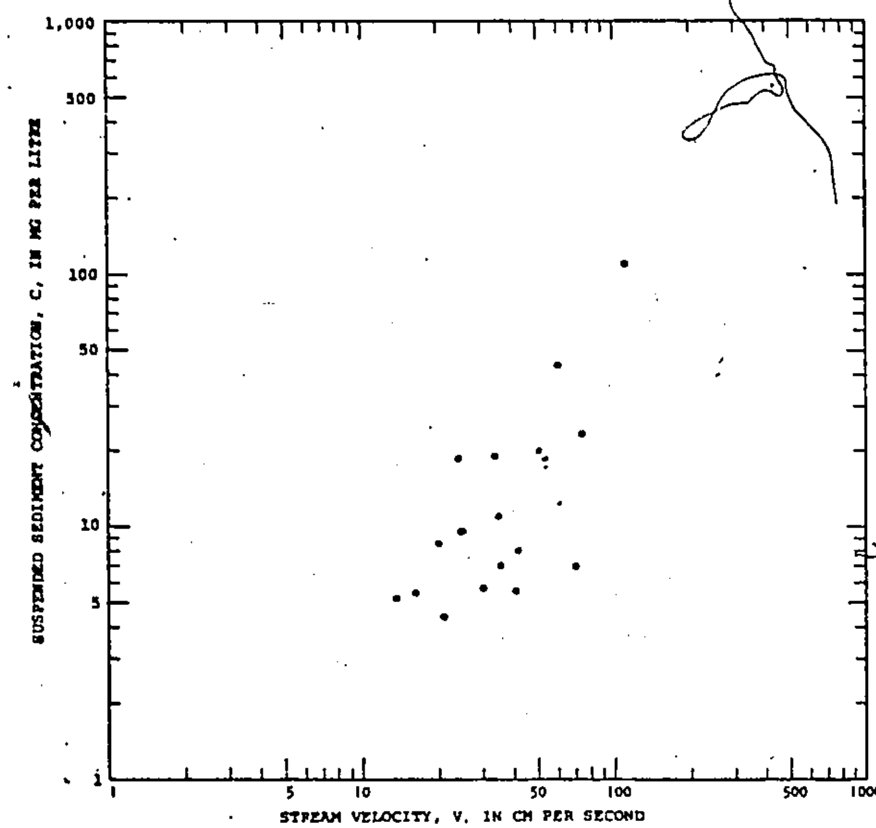


A. 1973



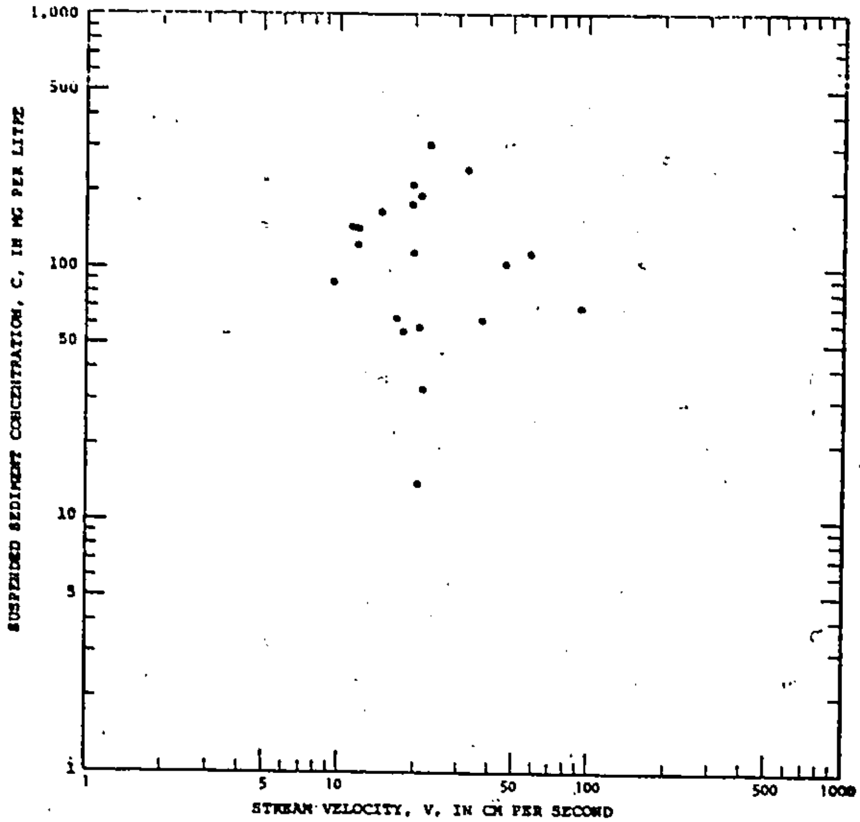
B. 1975

Fig. 5.3. Moreau Creek.

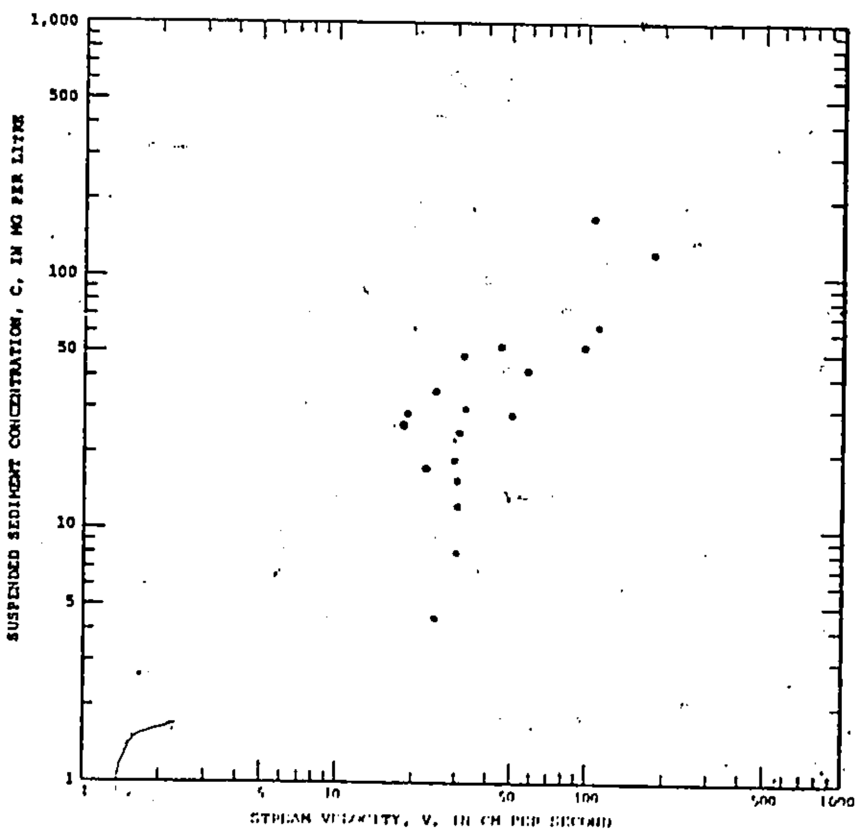


C. 1976

Fig. 5.3. Moreau Creek.

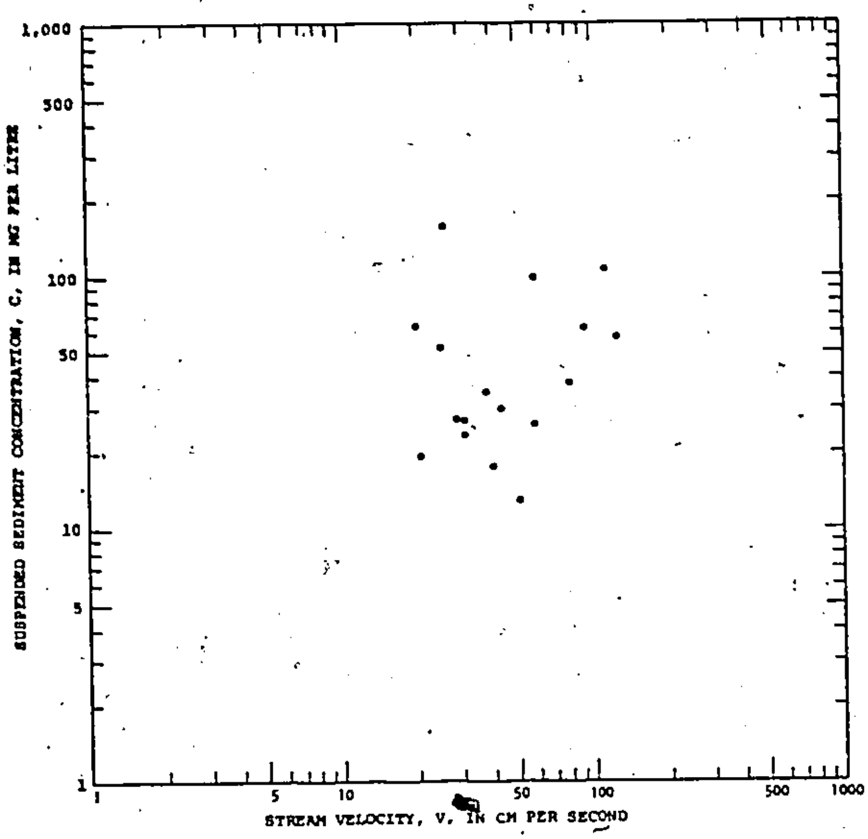


A. 1973.



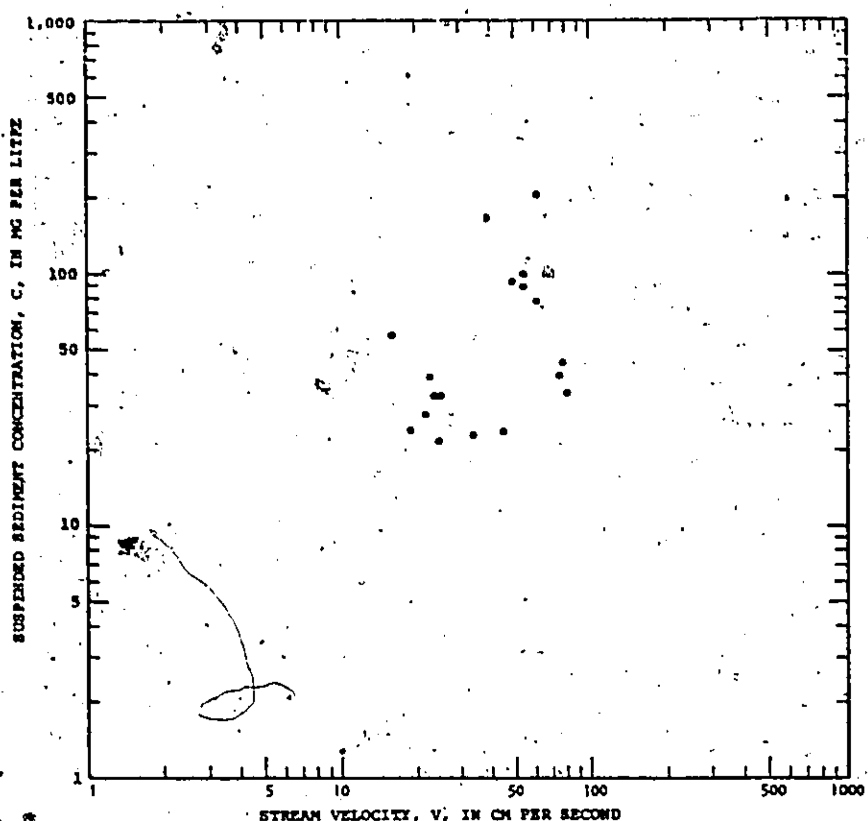
B. 1975.

Fig. 5.4. Moreau Creek East.

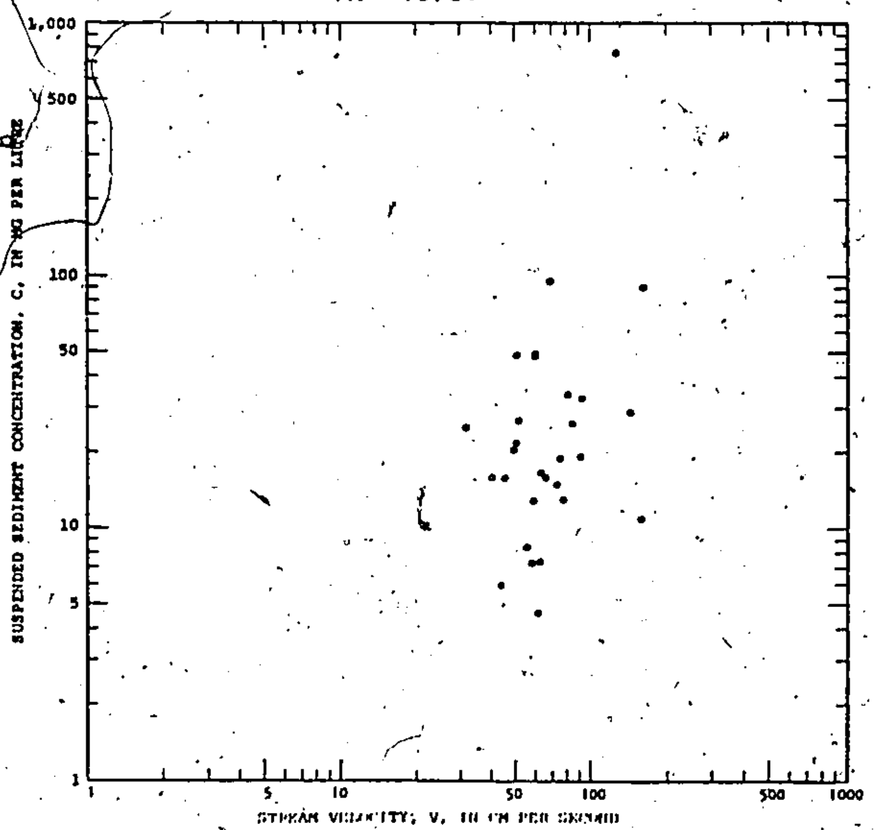


C. 1976

Fig. 5.4. Moreau Creek East.

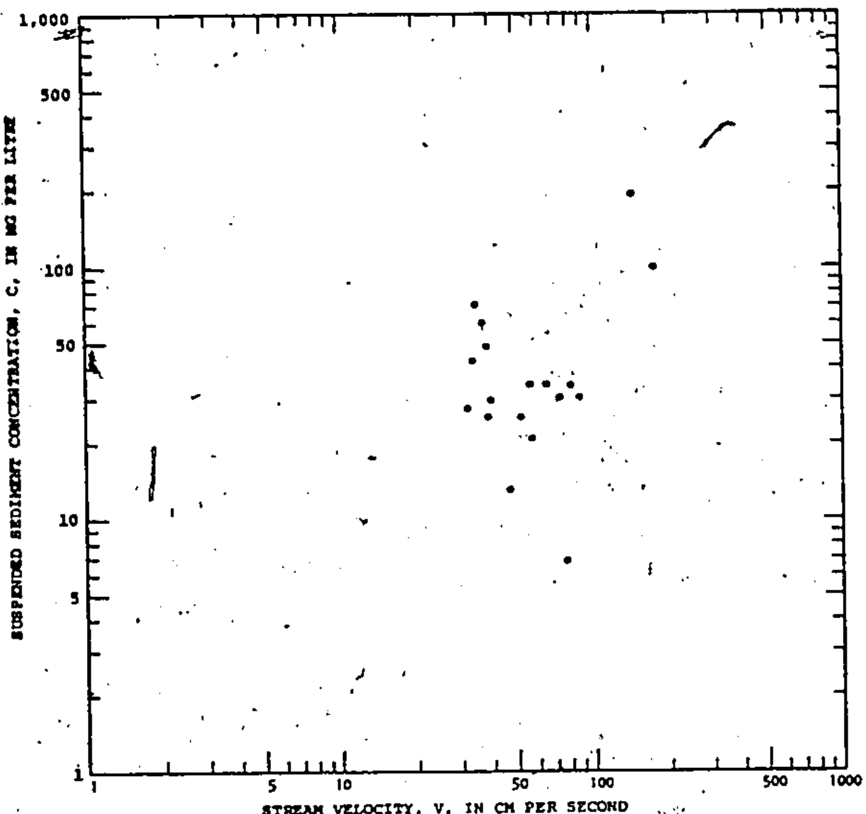


A. 1973.



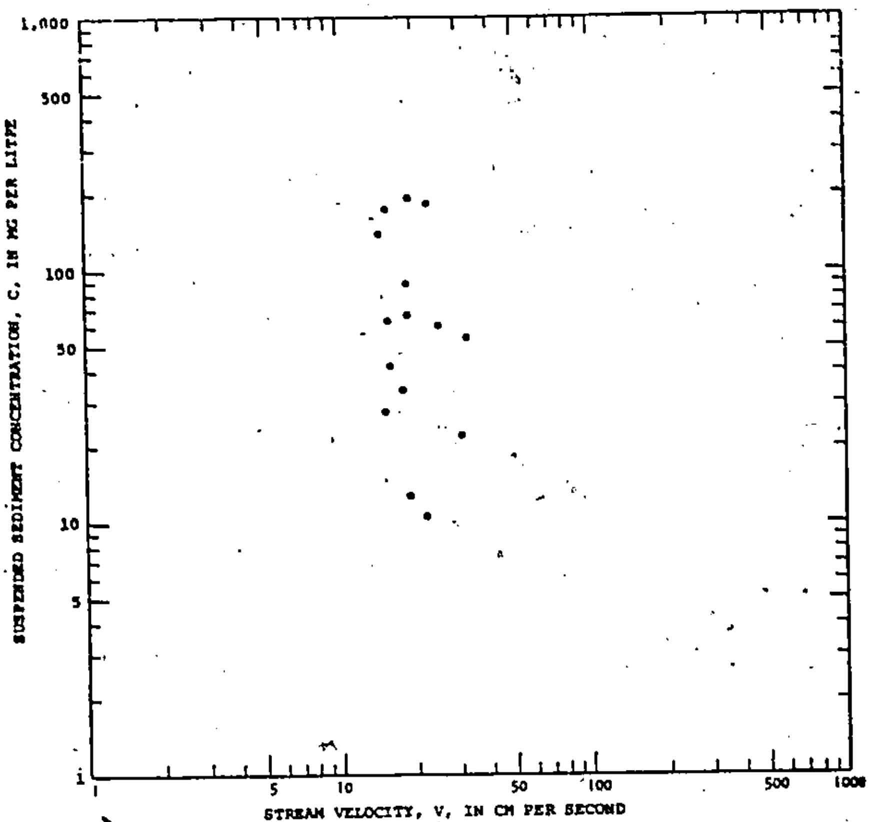
B. 1975.

Fig. 5.5. Desjardins Creek I (Trailer Park).

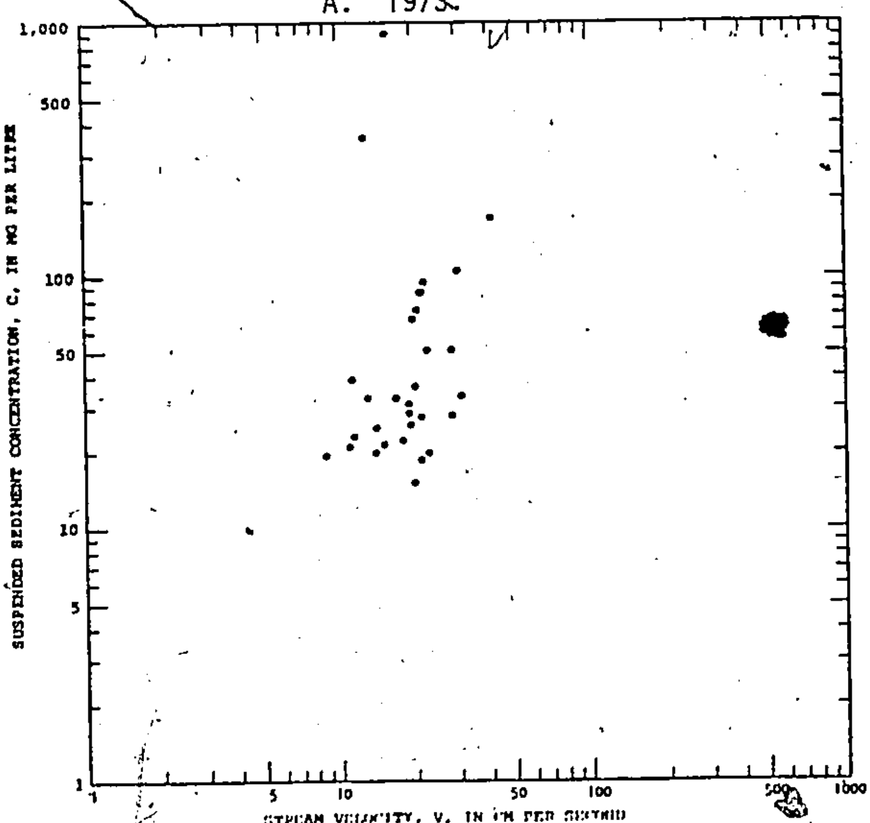


C. 1976

Fig. 5.5. Desjardins Creek I (Trailer Park).

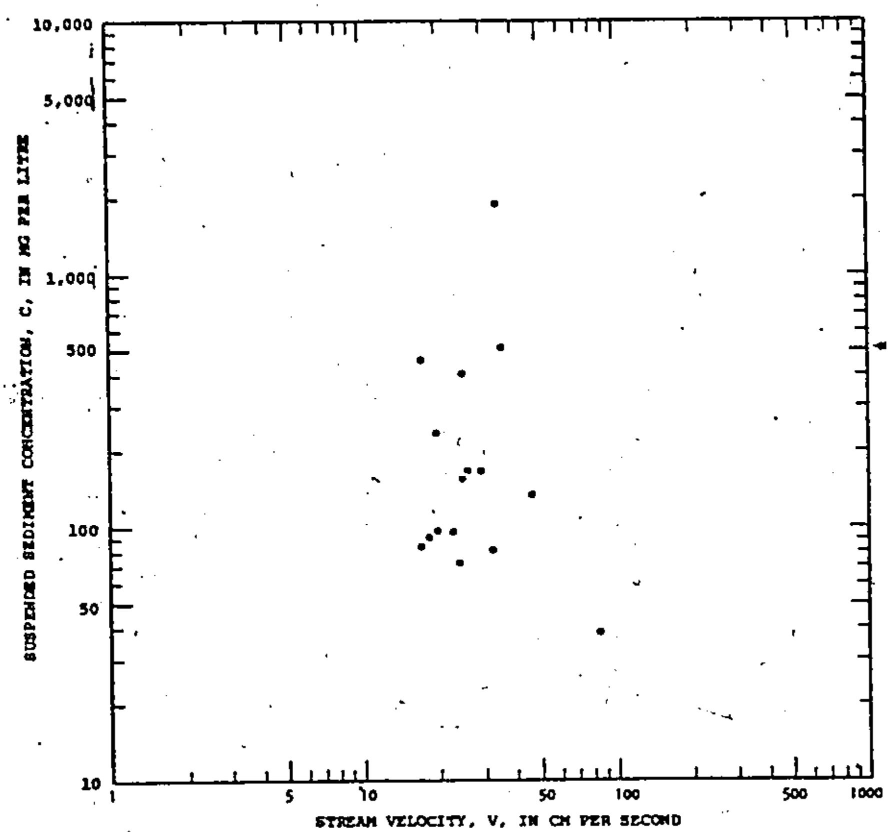


A. 1973.



B. 1975.

Fig. 5.6. Desjardins Creek II (Highway 8).



C. 1976

Fig. 5.6. Desjardins Creek II (Highway 8).

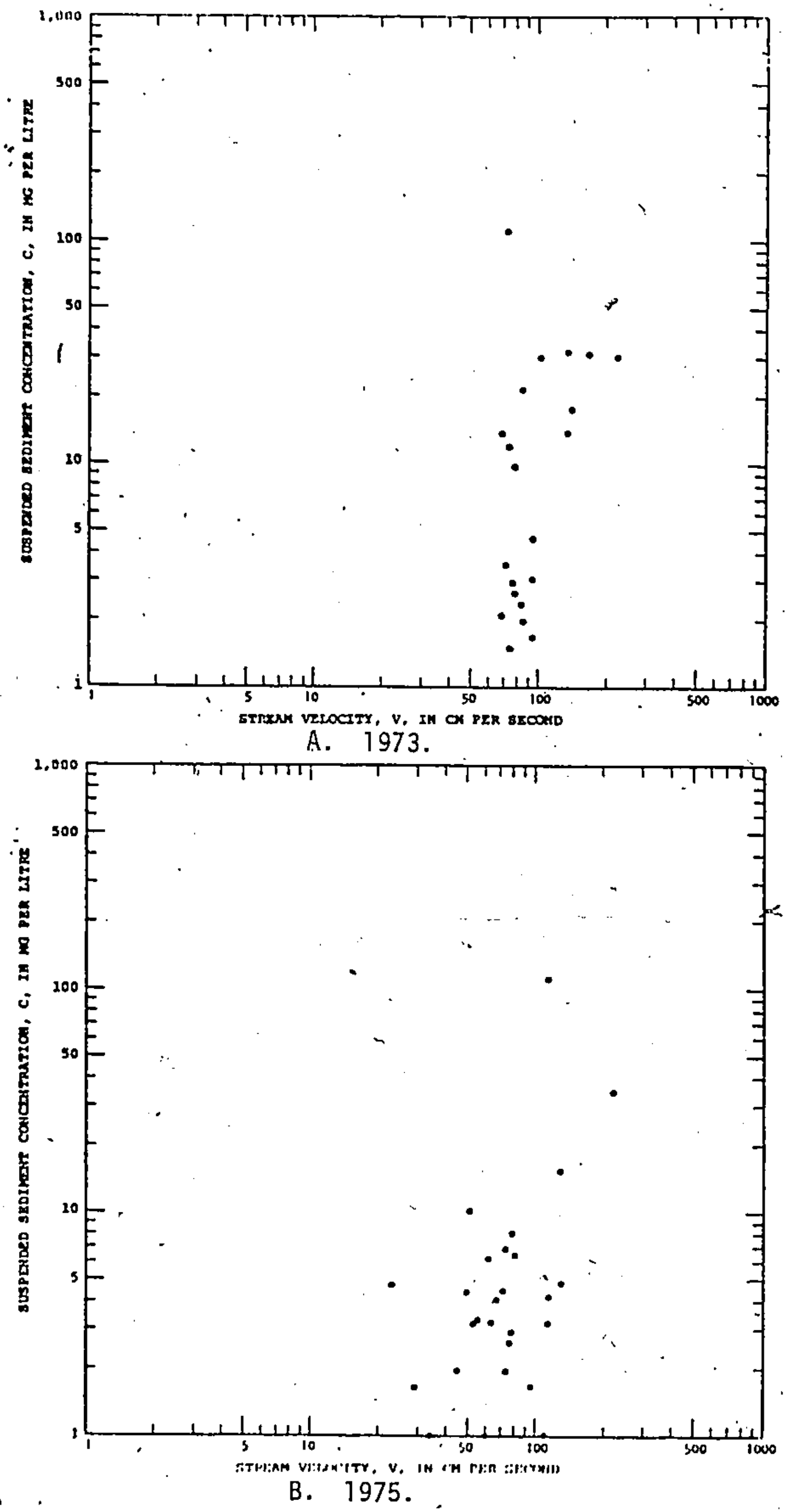
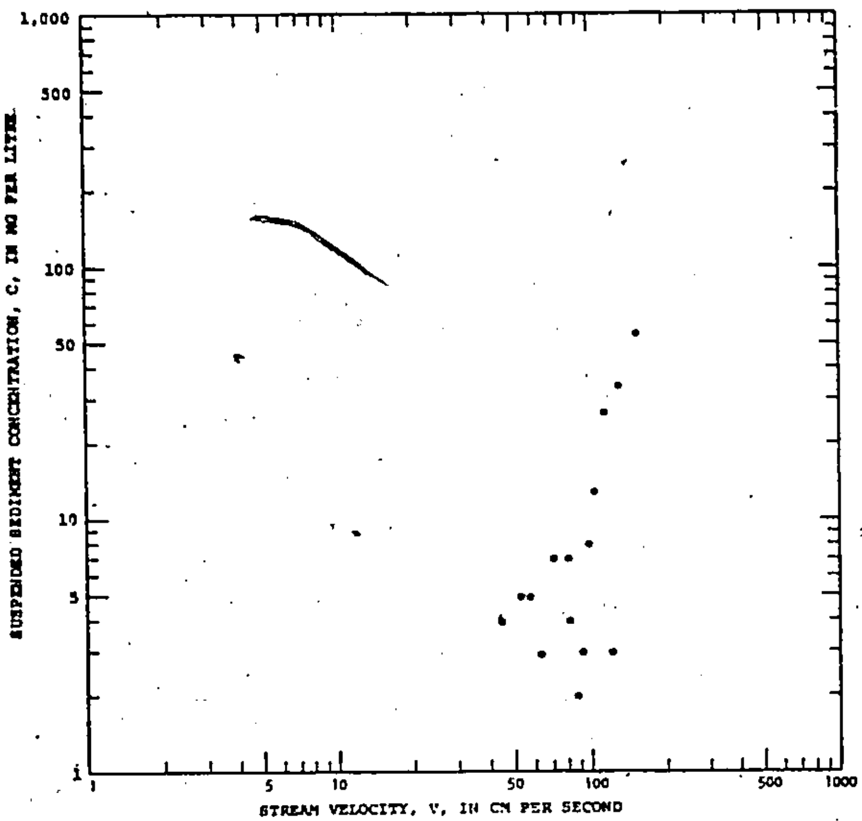
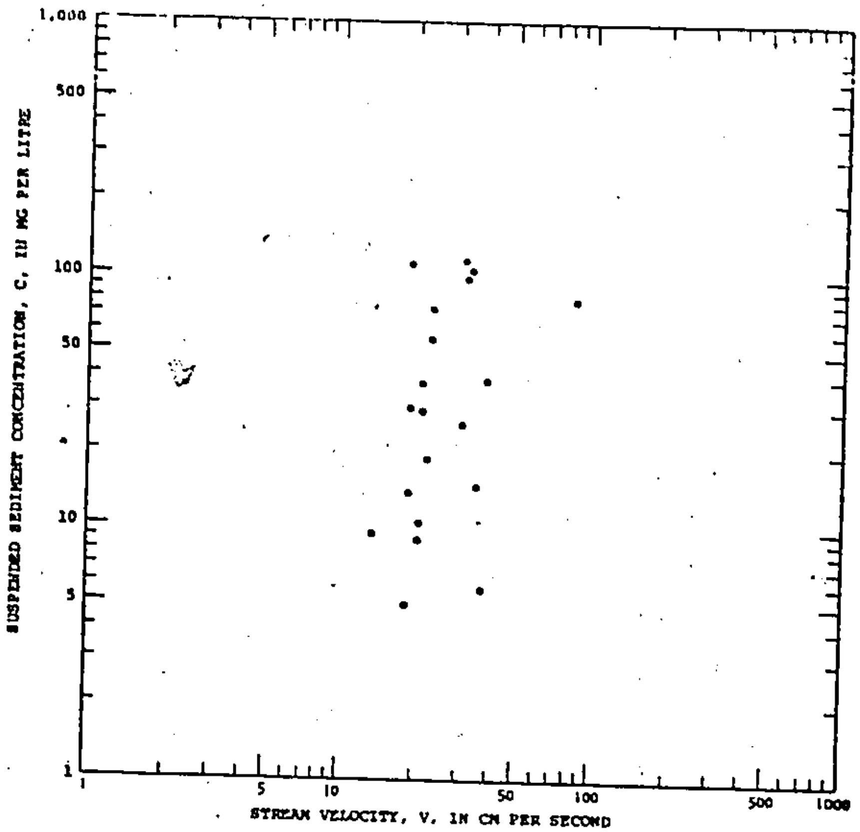


Fig. 5.7. Chelsea Creek I (Fleury Road).

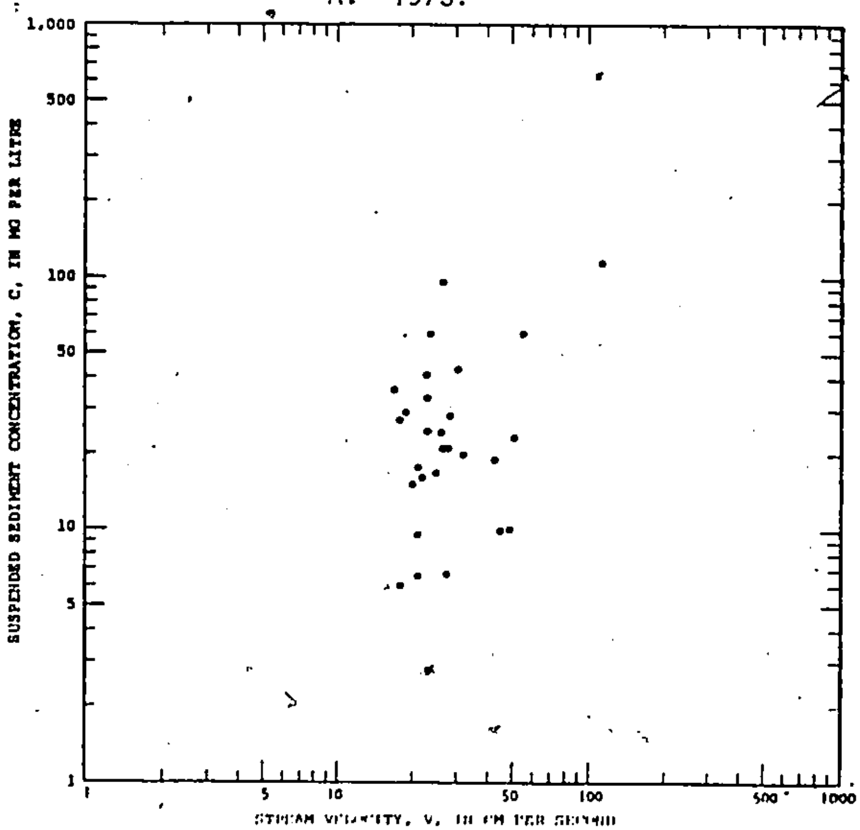


C. 1976

Fig. 5.7. Chelsea Creek I (Fleury Road).

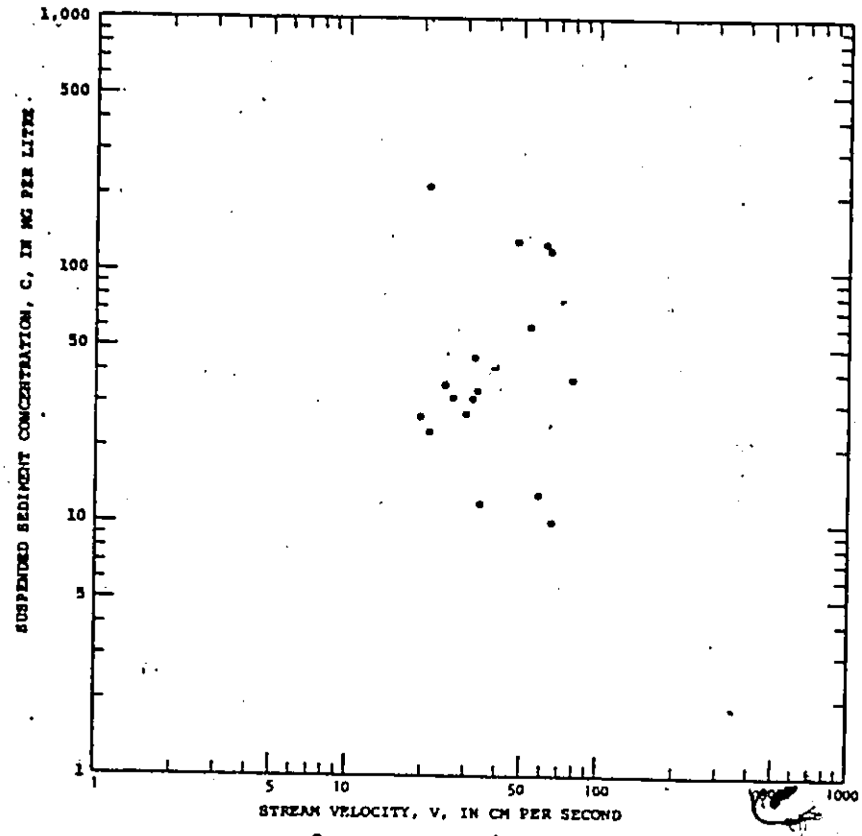


A. 1973.



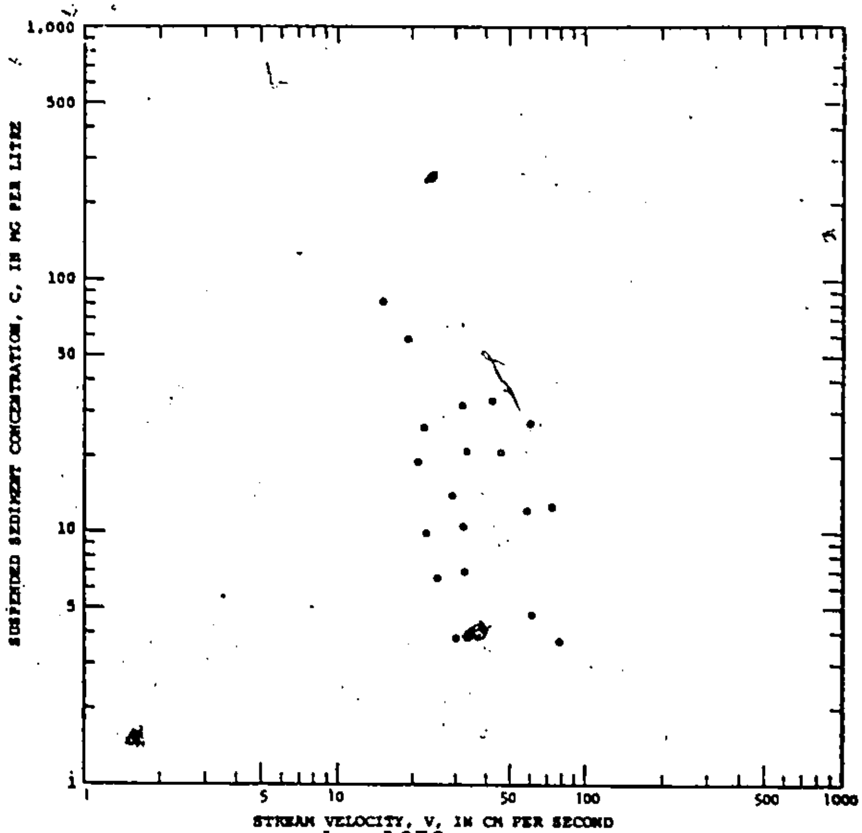
B. 1975.

Fig. 5.8. Chelsea Creek II.

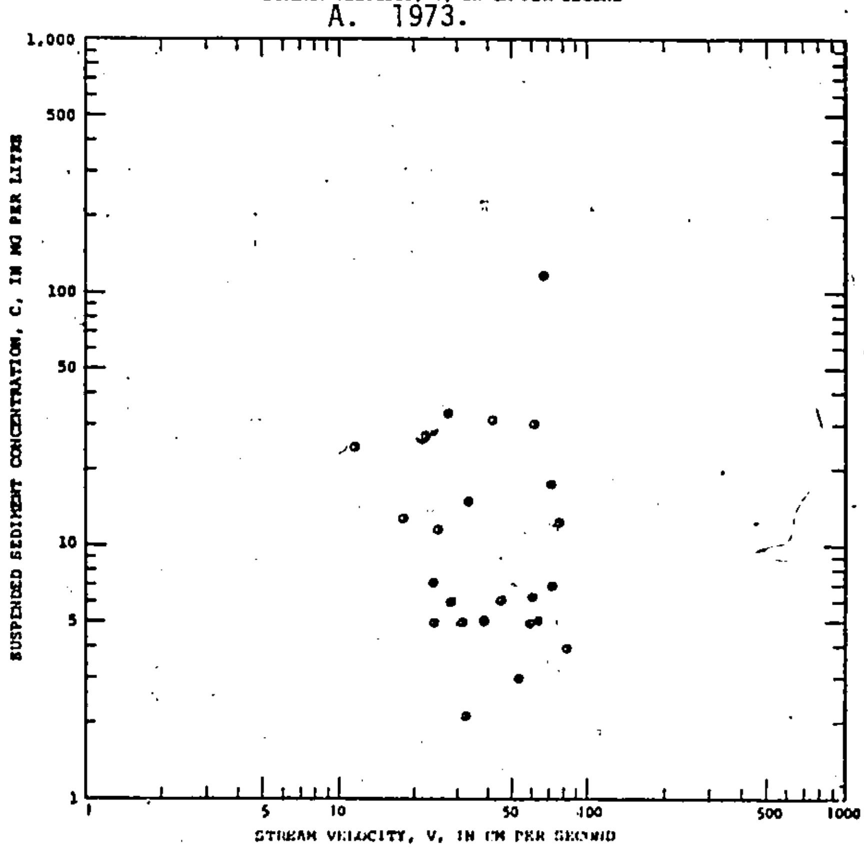


C. 1976

Fig. 5.8. Chelsea Creek II.

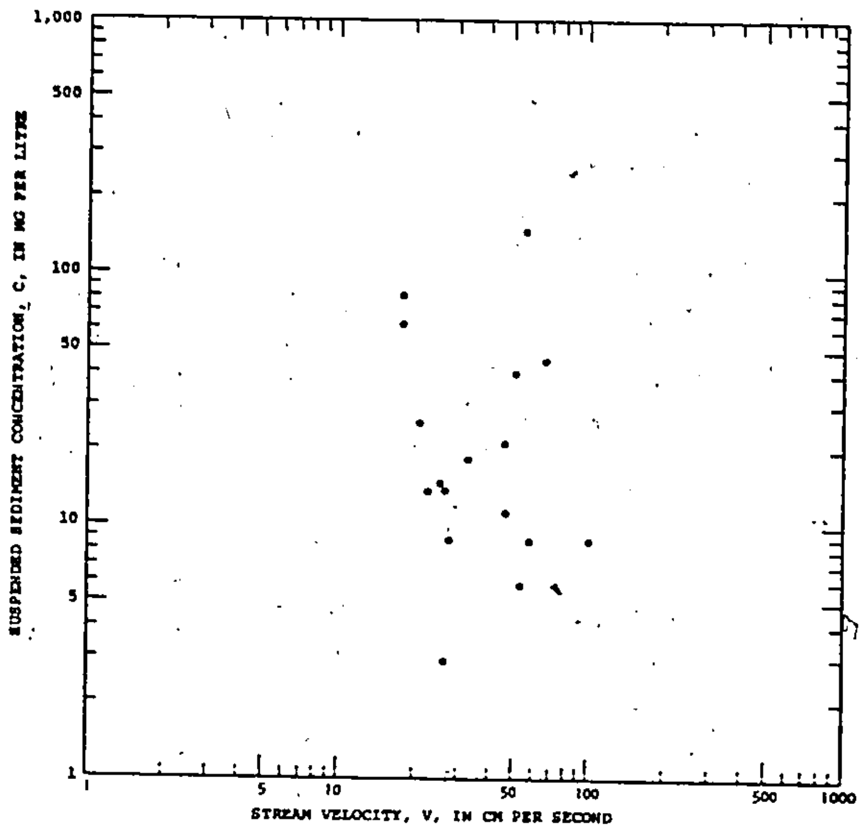


A. 1973.



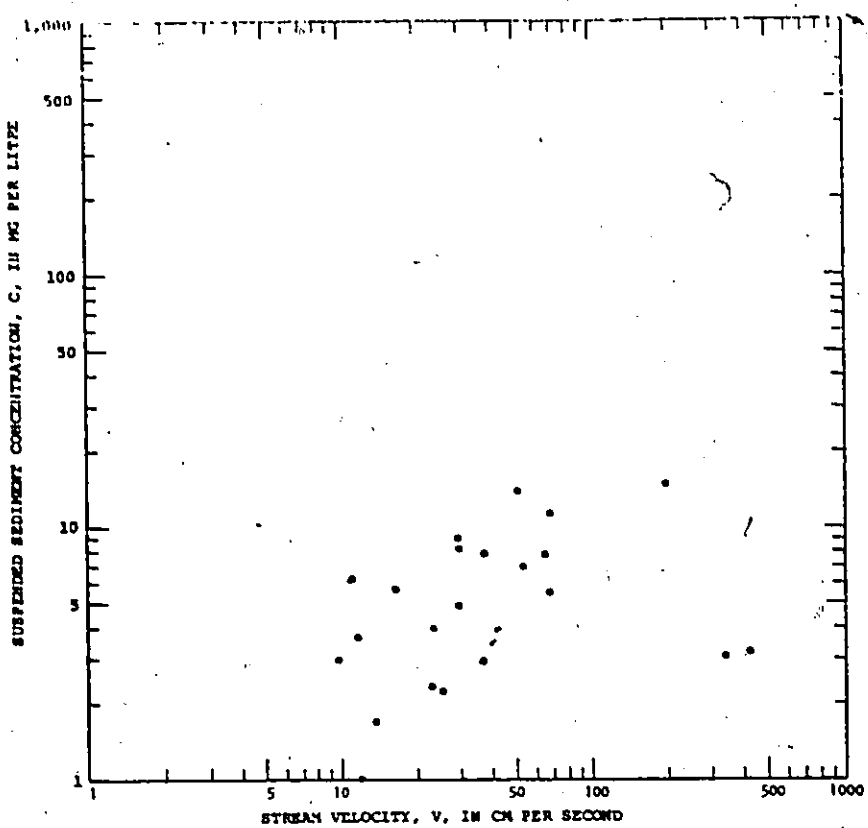
B. 1975.

Fig. 5.9. Leamy Creek II (Hull).

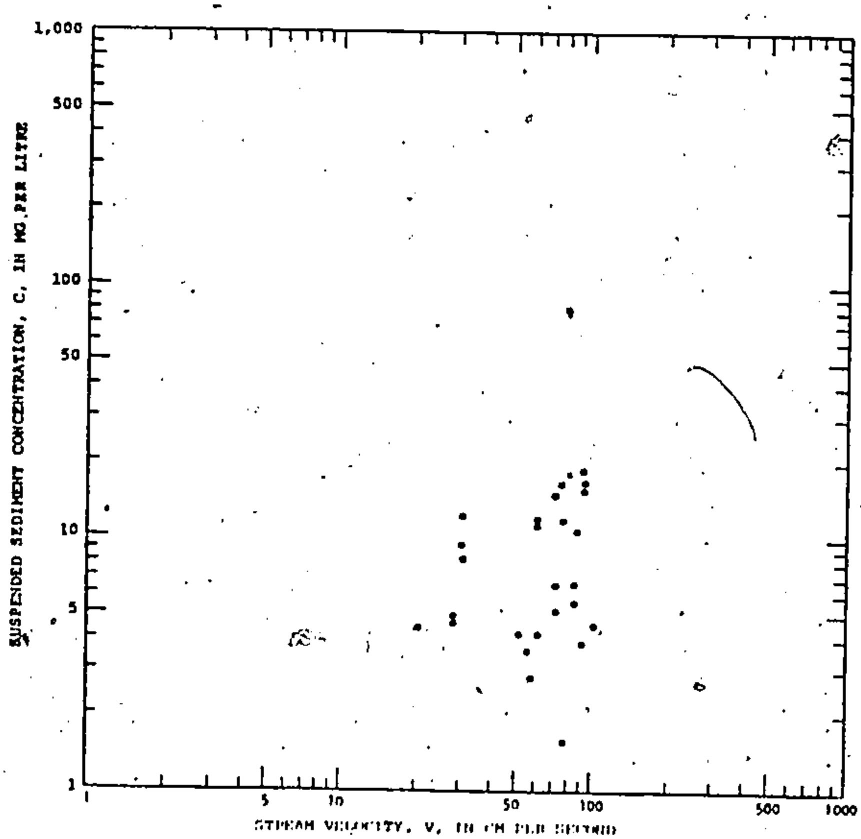


C. 1976

Fig. 5.9. Leamy Creek II (Hull).

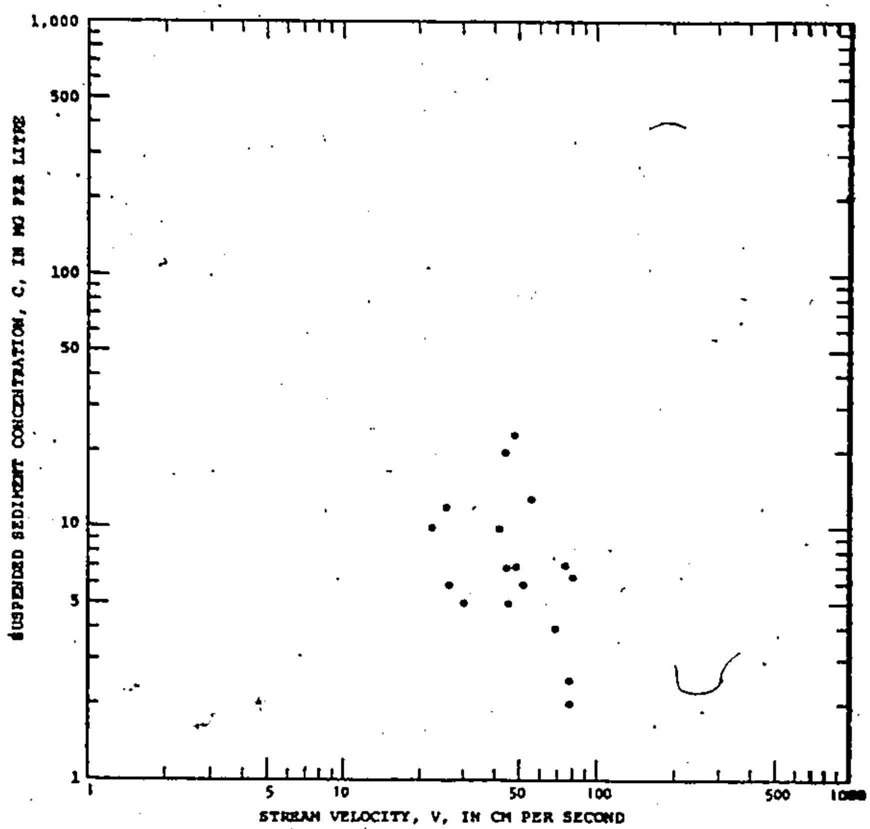


A. 1973.



B. 1975.

Fig. 5.10. Leamy Creek I (Mine Road).



C. 1976

Fig. 10. Leamy Creek I (Mine Road).

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

A study of the suspended sediment load in some areas undergoing development in Western Quebec has been described. Measurements of the suspended sediment concentration in some streams in the region of study were taken approximately once a week during late spring, summer and fall seasons in 1973, 1975 and 1976. The conditions of flow and area of sampling limit the study to the transport of principally fine-grained sediments in small streams during summertime flows.

Attempts were made to find a model to predict the suspended sediment load in small streams. The models considered can be classified into two parts:

1. Statistical models using factor analysis and multiple regression analysis.
2. A deterministic model using the USDAHL-74 hydrological model for flow predictions combined with a model for the transport of sediment in the streams. The USDAHL-74 hydrology model is a continuous simulation model that is designed to predict the daily streamflow discharge.

Factor analysis was used as an exploratory tool (1) to determine how the variables cluster, and (2) for the reduction of the number of variables. A total of 25 variables were defined and measured. The 25 variables were classified in the following groups:

1. Geomorphic factors
2. Hydrologic factors
3. Meteorologic factors
4. Land-use factors
5. Soil and geologic factors

A varimax rotation of the factor-weight matrix was performed to determine the variables that were highly correlated (> .90) with the factors. On the basis of the high correlation of the variables with the factors, four factors were selected as significant. An attempt was made to assign physical meaning to the factors.

A multivariate regression analysis was performed using the suspended sediment load as the dependent variable and the four factors considered significant as the independent variables. A prediction equation was thus developed (equation 5.3).

A step-wise multiple regression analysis was performed on the logarithmically transformed variables using the suspended sediment load as the dependent variable and the other 24 variables as the predictor variables. The equation derived was compared with the equation derived from the multivariate regression analysis performed on the four factors.

A deterministic continuous simulation model, the USDAHL-74 hydrology model was applied to the data available for the prediction of the daily stream discharge. The USDAHL-74 hydrology model uses as part of its input some readily measurable parameters to describe the watershed characteristics. The results of the calibration indicate the need to carefully select some of the regional parameters, such as the routing coefficients, m_1, m_2...etc., when applying the model. The result of the calibration also suggests the need to better define the range of values for some of the land-use parameters, especially the evapo-transpiration index and the surface-connected porosity parameters for the different crops. The conclusion drawn from the use of the model is that the USDAHL-74 is acceptable for prediction purposes on a long term basis, say yearly basis. The model appears to perform rather poorly in predicting low flows. In this case, the model might be of use in predictive storm-induced flows in ephemeral streams.

The zoning concepts used in USDAHL-74 makes it advantageous in studying sources of sediment. Finally, the results of the study afforded an opportunity to determine if there was a clear relation between stream velocity and sediment concentration. The suspended sediment concentration was related to the average stream velocity on full logarithmic scales. The results of the plot show a poor relationship between the two variables. The result suggests that the sediment concentration in shallow natural streams is limited by the supply of sediment from upstream sources.

Based on the result of this research, the following conclusions can be drawn.

1. To predict sediment yield from the fluvial sediment flow in small streams flowing through areas undergoing development in Western Quebec, sediment yield can be related to the stream discharge in the form given in equation 5.3.
2. Where elevation is of some concern, a slope parameter should be taken into account when relating sediment yield and sediment discharge.
3. A continuous simulation hydrological model such as the USDAHL-74 hydrology model can be used to predict the daily streamflow discharge. The USDAHL-74 hydrology model has the special advantage of being able to predict flow from a particular area within the watershed under consideration by using the zoning concept. However, it seems research needs to be carried out to give better definitions to the subsurface and land-use parameters in the USDAHL-74 model.
4. The sediment flow in shallow upland streams differs from the sediment flow in large rivers. This conclusion results from the poor relation derived from a plot of log of suspended sediment concentration and log of average stream velocity.

5. Further study of the relation between hydraulic stream properties and the suspended sediment concentration is needed. A model proposed in the thesis requires more detailed measurements to determine its value.
6. The application of a continuous simulation model has provided an understanding of the physical processes involved in watershed hydrology and the means of describing such processes.

The following suggestions are offered as topics for further investigation:

1. The mechanisms in natural streams involved in the deposition and resuspension of fine-grained sediments need to be better defined.
2. There is a lack of information on the properties of and processes by which fine-grained soils are eroded and transported.
3. Study of the transport of fine-grained suspended sediments requires a continuous flow model which will model a range of flows accurately. The application of the USDAHL-74 model was not entirely satisfactory in this regard as it did not simulate the low flows well. Improvements are needed for this purpose.

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APPENDIX A

REGRESSION ANALYSIS

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REGRESSION ANALYSIS

Regression analysis is one of the oldest statistical tools used in hydrology. Regression analysis provides equations for estimating individual values of one variable from the given values of the other variables. The regression equation gives the average amount of change in the dependent variable corresponding to a unit change in the independent variable.

Basic Assumptions

The basic assumptions required for regression are as follows (Tywoniuk and Wiebe 1970, Brown, Konoplyantsev, Ineson, Kovalevsky 1972):

1. The principal requirement of the regression method is that the deviations of the dependent variable about the regression line be normally distributed with the same variance for each value of the independent variable. The assumption of normality is required in establishing confidence limits and in conducting tests of significance, but not in obtaining the least squares fit itself.
2. Observations from which the regression is developed are statistically independent; for any value of the independent variable, observed values of the dependent variable are uncorrelated random events.
3. The independent variables are measured (or are known) without error. The dependent variable is considered as an observation on a random

variable, and the independent variable as some known constant associated with this random variable.

4. Each of the variables is homogenous, that is, all individual values of a variable measure the same thing. Data are considered homogenous if any subgroup to which certain of these data may be logically assigned has the same expected mean and variance as any other subgroup of the population.
5. A correct form of the model has been chosen.

It should be noted that analyses are often made on data which do not completely conform to the assumptions.

Multiple-Regression Equation

The general multiple regression relation may be expressed in the form (Yevjevich 1972)

$$Y_1 = f(x_1, x_2, \ldots x_n) + \varepsilon \qquad (A.1)$$

in which Y_1, x_1, $x_2, \ldots x_n$ are n + 1 variables and ε are the residuals. This equation gives the estimate of Y_1 for given values of all other variables. Equation A.1 can be linear or non-linear. Because linear relations are easier to deal with than non-linear relations, the variables of non-linear relations in hydrology are often transformed to linear relations for the multiple regression analysis. For example:

$$Y = \alpha X_1^{\beta_1} X_2^{\beta_2} \ldots X_p^{\beta_p} \qquad (A.2)$$

where Y is the dependent variable.

α and β are parameters to be estimated. The equation A.2 can be linearized by using a logarithmic transformation

$$\log Y = \ln \alpha + \beta_1 \ln X_1 + \beta_2 \ln X_2 \ldots + \beta_p \ln X_p \qquad \text{(A.3)}$$

Many hydrologic relations are non-linear (Haan 1977, Yevjevich 1972, Tywoniuk and Wiebe 1970). Yevjevich (1972) lists 15 ypes of functions and their transformations in linear form. In hydrology, the logarithmic transformation seems to be popular.

The advantages that may be obtained from transformations are as follows:

1. A simple linear relation is obtained among the transformed variables.
2. The marginal distributions of transformed variables approach more closely normal distribution than do those of untransformed variables, and
3. The variation of the points along the regression is more homogenous, that is, the variance is stablized.

These advantages may or may not all occur in a given transformation.

CURVE FITTING AND ESTIMATION OF PARAMETERS

Graphical Association

A great variety of graphical associations is used in hydrology. A common application is in the case of simple linear regression. The data are plotted on graph paper and a line of best fit is estimated by eye and drawn through the points. From the line so drawn, the coefficients α and β are obtained. Lyon and Cavadias (1966) pointed out some reasons for using graphical techniques in hydrology. Some of these are:

1. Graphical correlations are visible and thus can be more easily understood.
2. Little or no knowledge of statistical methods is necessary in applying graphical techniques.
3. Graphical techniques do not require the large number of manual computations necessary for analytical methods.
4. Graphical correlation curves can take any reasonable shape that can be drawn whereas the analytical methods must assume a shape for the curves at the outset.

Solomon (1966) pointed out that a preliminary graphical analysis is always beneficial because this may save many unnecessary computations and indicate which statistical model to use.

ANALYTICAL

Yevjevich (1972) lists five steps that are necessary in performing a regression analysis:

1. Selecting a function of correlative relation, simple or multiple, of linear or non-linear type.
2. Estimating parameters (statistics) that measure the degree of correlative association.
3. Testing the significance of statistics that measure the correlative association.
4. Estimating parameters of regression equation, and
5. Testing the significance of regression parameters, or drawing the confidence limits about the fitted regression functions.

The most commonly used analytical method is the least squares linear regression analysis.

A general linear equation of the form

$$Y = \alpha + \beta_1 X_1 + \beta_2 X_2 + \dots \beta_p X_p + e \qquad (A.4)$$

is considered where Y is a dependent variable, and X_1, X_2,...X_p are independent variables. The question is: for what values of α_1 $\beta_1 \dots \beta_p$ is the equation the best?

Least-Squares Estimation Method

This method consists of the estimation of parameters α, β, by fitting the chosen theoretical linear function to an empirical distribution. The sum of all squares of deviation, e, of observed points from the fitted function is minimized to produce least squares (Yevjevich 1972).

Thus values of a, bj, j = 1...p will be determined that minimize the sum

$$S = \sum_1^n e_1^2 = (y_i - Y)^2 = \sum_1^n \{Y_i - (\alpha + \beta_1 X_1 \dots + \beta_p X_p)\}^2 \qquad (A.5)$$

in which X_1 and Y_1 are coordinates of observed points, and α, β are replaced by their estimates a, b and N in the sample size. This sum can be minimized with respect to a and b by taking the partial derivatives of S with respect to parameters a, b, and setting the resulting equations equal to zero:

$$\frac{\partial \sum_{i=1}^n (Y_i - Y)^2}{\partial a} = 0; \qquad \frac{\partial \sum_{i=1}^n (Y_i - Y)^2}{\partial b} = 0; \dots \qquad (A.6)$$

These partial derivatives give n equations for the determination of n parameters. N should be so chosen so that $N > n$, that is, there should be more points than parameters to be determined.

Efficient Estimation

According to Yevjevich (1972) three conditions are necessary for the least squares method to be an efficient estimation method:

a. that the deviations of equation A.5 are normally distributed;

b. that the population variance of e_i is independent of the position of a given group of values e_i, or the deviations are mutually independent along the line;

c. that the population variance of e_i along the curve is a constant.

Often in hydrology, the deviations e_i depend on Y, and as a consequence, these conditions are rarely satisfied in hydrology. To rectify this anomaly, various transformations are used.

Another analytical method that can be used for the analysis of parameters in a regression model is the Maximum Likelihood Method (Tywoniuk and Wiebe 1970). By this method the value of a parameter is sought to make the probability of obtaining the observed outcome as high as possible. In mathematical terms, it is stated as: $\partial \log p(X)|\partial u = 0$ where p(X) is probability density and u is a statistical parameter. The use of this method is rather infrequent due to its complexity.

Haan (1977) pointed out that the total sum of squares can be partitioned into three parts. These are:

1. $n\bar{Y}^2$, the sum of squares due to the mean.
2. $\Sigma e_i^2 = S$, the sum of squares of deviations from regression or the residual sum of squares, and
3. $\Sigma(Y - \bar{Y})^2$, the sum of squares due to regression.

MEASURES OF ASSOCIATION

The degree of correlation of a dependent variable Y to many independent variables in a multiple linear association can be measured by any of five parameters:

1. The standard deviation of residuals.
2. The multiple correlation coeffient.
3. The coefficient of multiple determination.
4. The partial correlation coefficient, and
5. The beta coefficients.

The mathematical expressions for these measures of association are documented by Yevjevich (1972) and Haan (1977).

Multiple correlation coefficient, R, measures the degree of correlation of a dependent variable to other mutually independent variables. The coefficient of determination, R^2, which is the square of multiple correlation coefficient indicates the part of the variance of the dependent variables S_1^2 that has been accounted for mathematically.

$$R^2 = \frac{\text{sum of squares due to regression}}{\text{sum of squares about the mean}}$$

R is the multiple correlation coefficient. The standard deviation of residuals represents the spread of points around the regression line. The partial correlation coefficient measures the association of the dependent variable Y with any given independent variable X_i. A simple method of estimating the partial correlation coefficient r_{1-i} involves the determination of (1) multiple correlation coefficient R_1 between Y and all the independent variables, and (2) the multiple correlation coefficient R_{1-i} between X_1 and all the independent variables except the chosen X_i. The partial correlation coefficient r_{1-i} is then expressed as:

$$r_{1-i}^2 = 1 - \frac{R_1^2}{1-R_{1-i}^2} \tag{A.7}$$

The effect of individual independent variables on the dependent variable may be measured by a dimensionless form of the regression coefficient known as beta coefficient.

STATISTICAL INFERENCE

Since the regression lines and the degrees of association are measured by parameters, the reliability of these estimated parameters is important. A good discussion on the confidence interval associated with the statistical inference is given by Tywoniuk and Wiebe (1970) and Haan (1977).

Two Important Assumptions

There are two important assumptions in the derivation of regression analysis with which hydrologic studies do not quite comply.

1. In the derivation of the simultaneous normal equations from which curves are fitted by the method of least squares, it is assumed that the explanatory (independent) variables are fixed variates and are measured without error. The fact is that the errors are inherited by the dependent variable. There are applications in which this error association is not a realistic situation (Snyder 1962).

2. The second basic assumption is that the independent variables are not correlated with each other. In hydrologic studies, the independent variables may not be uncorrelated. In such cases, the regression coefficients become unstable and can not therefore provide a reliable and consistent estimate of the independent contributions of these variables.

APPENDIX B

DATA FROM DIRECT FIELD MEASUREMENTS

B1. SUSPENDED SOLIDS DATA SHEET

Nozzle area = 0.18 cm^2

(unless otherwise specified)

SUSPENDED SOLIDS DATA SHEET

June 3, 1973

Sample	Stream Velocity cm/sec	Stream Channel area (cm^2)	Daily Discharge l/sec	Mean Concentration mg/l	Sediment Discharge kg/day
Fleury Rd.	41.22	3,716.00	153.17	21.00	277.91
Chelsea Brook Hwy 11	36.96	23,225.00	858.40	5.76	427.19
Mine Rd.	38.83	2,787.00	10.82	5.67	5.30
Hwy 11 Hull	25.52	3,716.0	94.83	12.67	103.81
Desjardin Hwy 307	19.22	44,592.0	857.06	21.00	1555.05
Trailer Park	43.53	622.43	27.09	24.00	56.17
Moreau E.	37.61	390.18	14.67	10.33	13.09
Moreau	23.28	18.58	0.43	23.33	0.87

SUSPENDED SOLIDS DATA SHEET

June 4, 1973

Sample	Stream Velocity cm/sec	Stream Channel area (cm²)	Daily Discharge l/sec	Mean Concentration mg/l	Sediment Discharge kg/day
Mine Rd.	38.83	2,787.0	108.22	8.33	77.89
Leamy Creek Hull	30.48	3,716.0	113.26	38.33	375.08
Old Chelsea Hwy 11	31.33	13,935.0	436.58	99.40	3,749.42
Fleury Rd.	164.44	2,787.0	458.29	32.00	1,267.08
Trailer Park	44.11	27,870.0	1,229.35	212.00	22,517.76
Moreau, Hwy 8	61.00	3,948.25	240.84	88.00	1,831.15
Hwy 307	19.22	44,592.0	857.06	195.00	14,439.75
Moreau E.	37.61	390.18	14.67	64.00	81.12

SUSPENDED SOLIDS DATA SHEET

June 7, 1973

Sample	Stream Velocity cm/sec	Stream Channel area (cm^2)	Daily Discharge l/sec	Mean Concentration mg/l	Sediment Discharge kg/day
Moreau	43.72	5,574.0	243.70	159.00	3,347.85
Moreau E.	93.06	4,877.25	453.88	71.00	2,784.28
Trailer Park	75.11	743.2	55.82	40.33	194.51
Hwy 307	15.39	24,154.0	371.73	63.00	2,023.40
Fleury Rd.	219.44	2,322.5	509.65	31.33	1,379.58
Chelsea Hwy 11	87.11	13,935.0	1,213.88	81.33	8,529.83
Mine Rd.	76.2	1,235.57	94.15	11.33	92.16
Hwy 11 Hull	79.11	44,592.	3,527.67	36.50	11,124.86

SUSPENDED SOLIDS DATA SHEET

June 20, 1973

Sample	Stream Velocity cm/sec	Stream Channel area (cm^2)	Daily Discharge 1/sec	Mean Concentration mg/1	Sediment Discharge kg/day
Moreau E.	21.17	613.14	12.98	59.30	66.50
Hwy 307	28.89	27,870.0	805.16	35.50	2,469.59
Hwy 11 Chelsea	30.11	8,361.0	251.75	26.60	578.58
Hwy 11 Hull	60.96	1,393.5	84.95	26.50	194.50
Fleury Rd.	140.89	3,019.25	425.38	18.00	661.55
Mine Rd.	76.20	483.08	36.81	5.60	17.81
Trailer Park	79.89	1,244.86	99.45	34.00	292.14
Moreau	39.89	724.62	28.91	80.00	199.83

SUSPENDED SOLIDS DATA SHEET

June 28, 1973

Nozzle area = 0.18 cm^2

Sample	Stream Velocity cm/sec	Stream Channel area (cm^2)	Daily Discharge l/sec	Mean Concentration mg/l	Sediment Discharge kg/day
Moreau E.	21.56	4,877.25	105.15	33.00	299.80
Fleury Rd.	133.94	6,503.0	871.01	14.33	1,078.41
Mine Rd.	53.89	2,787.0	150.19	7.00	90.83
Leamy Creek Hull	45.72	4,645.0	212.37	21.33	391.38
Moreau Hwy 8	26.56	4,180.5	111.03	19.50	187.06
Trailer Park	76.72	27,870.0	2,138.19	45.20	8,350.23
Hwy 307	31.72	44,592.0	1,414.46	54.00	6,599.30
Old Chelsea Hwy 11	38.67	19,509.	754.41	39.50	2,574.65

SUSPENDED SOLIDS DATA SHEET

July 11, 1973

Sample	Stream Velocity cm/sec	Stream Channel area (cm^2)	Daily Discharge l/sec	Mean Concentration mg/l	Sediment Discharge kg/day
Hwy 307	14.67	74,320.0	1,090.27	142.00	13,376.46
Trailer Park	38.61	27,870.0	1,076.06	169.33	15,742.88
Moreau Hwy 8	59.78	7,432.00	444.28	106.66	4,094.23
Moreau E.	59.56	4,942.28	294.36	115.33	2,933.15
Mine Rd.	51.22	1,858.0	95.17	14.00	115.12
Fleury Rd.	133.67	27,870.	3,725.38	33.00	10,621.80
Old Chelsea	32.17	29,728.0	956.35	103.33	8,538.02
Hull Leamy Creek	60.96	9,290.0	566.32	48.00	2,348.64

SUSPENDED SOLIDS DATA SHEET

August 1, 1973

Sample	Stream Velocity cm/sec	Stream Channel area (cm^2)	Daily Discharge 1/sec	Mean Concentration mg/1	Sediment Discharge kg/day
Mine Rd.	24.38	464.5	11.32	4.00	3.91
Chelsea Hwy 11	35.50	13,935.0	494.69	14.66	626.59
Trailer Park	33.94	27,870.0	945.91	22.66	1,851.93
Moreau E.	11.94	2,471.14	29.51	125.33	319.55
Moreau.Hwy 8	15.89	3,716.0	59.05	29.33	149.64
Hwy 307	30.44	37,160.0	1,131.15	22.50	2,198.96
Fleury Rd.	69.44	3,716.0	258.04	3.66	81.60
Hwy 11 Hull	Stagnant				

SUSPENDED SOLIDS DATA SHEET

August 7, 1973
Nozzle area = 0.18 cm^2

Sample	Stream Velocity cm/sec	Stream Channel area (cm^2)	Daily Discharge l/sec	Mean Concentration mg/l	Sediment Discharge kg/day
Mine Rd.	30.48	1,161.25	35.40	9.20	28.13
Fleury Rd.	77.78	1,858.0	144.52	10.00	124.87
Hwy 307	18.89	22,296.0	421.17	89.00	3,238.63
Chelsea Hwy 11	18.39	13,935.0	256.26	108.00	2,391.21
reau E.	22.78	2,322.5	52.91	305.00	1,394.28
Hwy 11	15.24	11,148.0	169.90	80.00	1,174.35
Moreau Hwy 8	18.67	2,471.14	46.14	214.00	853.11
Trailer Park	54.56	3,065.7	167.26	90.00	1,300.61

SUSPENDED SOLIDS DATA SHEET

August 15, 1973

Nozzle area = 0.18 cm^2

Sample	Stream Velocity cm/sec	Stream Channel area (cm^2)	Daily Discharge l/sec	Mean Concentration mg/l	Sediment Discharge kg/day
Hwy 11	101.94	7,432.00	757.62	12.66	828.70
Mine Rd.	66.00	1,858.00	122.63	8.00	84.76
Old Chelsea Hwy 11	30.50	16,257.5	495.85	116.00	4,969.61
Fleury Rd.	91.67	3,716.0	340.65	3.33	98.01
Hwy 307	Stagnant				
Moreau Hwy 8	30.44	1,393.5	42.42	84.00	307.87
Moreau E.	19.89	1,393.5	27.72	213.00	510.14
Trailer Park	Stagnant				

SUSPENDED SOLIDS DATA SHEET

August 22, 1973

Sample	Stream Velocity cm/sec	Stream Channel area (cm^2)	Daily Discharge l/sec	Mean Concentration mg/l	Sediment Discharge kg/day
Trailer Park	60.96	1,858.0	113.26	208.00	2,035.42
Moreau E.	21.11	1,235.57	26.08	192.00	432.64
Moreau Hwy 8	13.11	1,858.	24.36	124.00	260.98
Fleury Rd.	73.39	3,716.	272.72	12.33	290.53
Chelsea Hwy 11	22.94	18,580.	426.23	73.33	2,700.47
Hwy 11 Hull	41.94	6,503.	272.74	32.50	765.85
Mine Rd.	30.48	1,393.5	42.47	5.00	18.35

SUSPENDED SOLIDS DATA SHEET

August 29, 1973

Sample	Stream Velocity cm/sec	Stream Channel area (cm^2)	Daily Discharge l/sec	Mean Concentration mg/l	Sediment Discharge kg/day
Mine Rd.	18.29	929.0	16.99	5.66	8.31
Moreau Hwy 8	21.56	1,858.0	40.06	16.66	57.66
Hwy 11	31.72	1,393.5	44.20	10.50	40.10
Chelsea Hwy 11	21.11	17,316.56	365.55	28.66	905.18
Fleury Rd.	74.94	1,858.0	139.24	3.00	36.09
Hwy 307	Stagnant			5.00	
Moreau E.	17.89	929.0	16.62	56.00	80.41
*Trailer Park			38.57		189.95

*Construction work in progress.

SUSPENDED SOLIDS DATA SHEET

September 14, 1973

Sample	Stream Velocity cm/sec	Stream Channel area (cm^2)	Daily Discharge l/sec	Mean Concentration mg/l	Sediment Discharge kg/day
Moreau Hwy 8	21.44	1,858.0	39.84	6.50	22.37
Moreau E.	9.56	1,858.0	17.76	89.00	136.57
Trailer Park	15.61	2,471.14	38.57	57.00	189.95
Hwy 307	21.78	41,805.0	910.51	10.66	838.60
Fleury Rd.	72.39	1,858.0	134.50	112.00	1,301.53
Hwy 11 Chelsea	21.72	19,509.0	423.74	18.66	683.16
Mine Rd.	18.29	306.57	5.61	3.33	1.61
Hwy 11 Hull	25.89	4,180.5	108.23	1.05	9.82

SUSPENDED SOLIDS DATA SHEET

September 21, 1973

Sample	Stream Velocity cm/sec	Stream Channel area (cm^2)	Daily Discharge l/sec	Mean Concentration mg/l	Sediment Discharge kg/day
Hwy 11 Chelsea	18.72	14,864.0	278.25	30.00	721.22
Mine Rd.	23.28	1,161.25	27.03	2.38	5.56
Moreau E.	16.89	1,235.57	20.87	64.00	115.40
Trailer Park	18.61	2,090.25	38.90	24.00	80.66
Hwy 307	18.78	30,657.0	575.74	13.00	646.67
Moreau Hwy 8	18.06	1,235.57	22.31	17.00	32.77
Fleury Rd.	68.56	2,787.0	191.08	14.00	231.13
Hwy 11 Hull	32.94	3,716.0	122.41	7.00	74.03

SUSPENDED SOLIDS DATA SHEET

October 4, 1973

Nozzle area = 0.18 cm^2

Sample	Stream Velocity cm/sec	Stream Channel area (cm^2)	Daily Discharge l/sec	Mean Concentration mg/l	Sediment Discharge kg/day
Mine Rd.	14.07	1,161.25	16.34	1.66	2.34
Hwy 11 Hull	33.33	2,787.0	92.89	21.00	168.54
Hwy 11 Chelsea	20.89	19,509.0	407.54	38.00	1,338.04
Moreau	43.39	1,161.25	50.39	218.00	949.11
Hwy 307	22.44	30,657.	687.94	188.00	11,174.34
Moreau E.	32.39	1,235.57	40.02	246.00	850.60
Trailer Park	53.22	1,858.0	98.88	100.00	854.32
Fleury Rd.	83.50	2,787.0	232.71	22.00	442.34

SUSPENDED SOLIDS DATA SHEET

September 26, 1973

Sample	Stream Velocity cm/sec	Stream Channel area (cm^2)	Daily Discharge l/sec	Mean Concentration mg/l	Sediment Discharge kg/day
Fleury Rd.	73.28	2,471.14	181.09	1.00	15.65
Mine Rd.	12.19	464.50	5.66	1.00	0.49
Moreau Hwy 8	17.89	929.00	16.62	4.66	6.69
Moreau E.	14.67	929.00	13.63	170.00	200.20
Hwy 11 Chelsea	18.33	13,006.0	238.40	5.00	102.99
Hwy 11 Hull	24.89	3,093.57	77.00	6.66	44.31
Hwy 307	17.56	30,657.0	538.84	34.00	1,582.90
Trailer Park	22.78	1,542.14	35.13	39.00	118.37

SUSPENDED SOLIDS DATA SHEET

October 12, 1973

Nozzle area = 0.18 cm^2

Sample	Stream Velocity cm/sec	Stream Channel area (cm^2)	Daily Discharge l/sec	Mean Concentration mg/l	Sediment Discharge kg/day
Mine Rd.	12.19	464.5	5.66	3.66	1.79
Fleury Rd.	82.00	2,712.68	222.44	2.00	38.44
Hwy 11 Chelsea	20.28	19,509.0	395.64	9.00	307.65
Hwy 11 Hull	28.67	929.0	26.63	14.00	32.21
Trailer Park	24.72	1,858.0	45.93	22.00	87.30
Moreau E.	11.50	1,542.14	17.73	114.00	174.63
Moreau	25.33	1,235.57	31.30	31.00	83.83
Hwy 307	18.89	33,444.	631.76	66.00	3,602.55

SUSPENDED SOLIDS DATA SHEET

October 17, 1973

Sample	Stream Velocity cm/sec	Stream Channel area (cm²)	Daily Discharge l/sec	Mean Concentration mg/l	Sediment Discharge kg/day
Hwy 11 Hull	21.83	1,235.57	26.97	26.00	60.59
Trailer Park	23.44	1,542.14	36.15	33.00	103.07
Hwy 11 Chelsea	18.44	19,509.0	359.75	14.00	435.15
Fleury Rd.	79.61	2,787.0	221.87	2.40	46.01
Hwy 307	14.89	2,787.0	414.98	28.00	1,003.92
Mine Rd.	11.15	306.57	3.42	6.33	1.87
Moreau E.	19.61	929.00	18.22	178.00	280.21
Moreau	31.11	1,858.0	57.80	166.00	829.02

SUSPENDED SOLIDS DATA SHEET

October 24, 1973

Sample	Stream Velocity cm/sec	Stream Channel area (cm^2)	Daily Discharge l/sec	Mean Concentration mg/l	Sediment Discharge kg/day
Trailer Park	21.11	929.	19.61	28.00	47.44
Moreau	21.44	1,161.25	24.90	77.33	166.36
Mine Rd.	10.20	613.14	6.25	3.00	1.62
Hwy 11 Hull	22.78	929.0	21.16	10.00	18.28
Hwy 307	16.00	39,018.	624.29	42.00	2,265.42
Fleury Rd.	77.06	1,858.0	143.18	2.66	32.91
Hwy 11 Chelsea	20.22	18,580.0	375.69	10.50	340.83
Moreau E.	12.00	1,049.77	12.60	144.00	156.76

SUSPENDED SOLIDS DATA SHEET

October 31, 1973

Sample	Stream Velocity cm/sec	Stream Channel area (cm^2)	Daily Discharge l/sec	Mean Concentration mg/l	Sediment Discharge kg/day
Hwy 11 Hull	31.11	1,393.5	43.35	32.00	119.85
Mine Rd.	30.48	613.14	18.69	8.33	13.45
*Hwy 11 Touraine	22.83	14,631.75	334.04	56.00	1,616.22
Hwy 307	24.67	32,515.0	802.15	61.00	4,227.65
Fleury Rd.	92.11	2,787.0	213.93	4.66	86.13
Moreau	20.89	2,322.5	48.52	90.00	377.29
Trailer Park	48.39	1,393.5	67.43	95.00	553.47
Moreau E.	19.72	102.19	2.02	116.00	20.25

*Chelsea

SUSPENDED SOLIDS DATA SHEET

May 21, 1975

Sample	Stream Velocity cm/sec	Stream Channel area (cm^2)	Daily Discharge l/sec	Mean Concentration mg/l	Sediment Discharge kg/day
Trailer Park	32.00	4,877.25	156.07	25.00	337.12
Mine Rd.	53.89	873.26	47.06	3.67	172.71
Hwy 307	18.94	27,870.0	527.86	30.83	1,406.07
Fleury Rd.	72.22	4,645.0	335.46	2.00	57.97
Moreau	28.22	929.0	26.22	10.00	22.65
Hull	25.00	4,877.25	121.93	11.67	10.53
Moreau E.	21.34	390.18	8.33	14.05	10.11
Hwy 8 Chelsea	29.06	13,935.0	404.95	27.83	973.71

SUSPENDED SOLIDS DATA SHEET

May 27, 1975
Day 147

Sample	Stream Velocity cm/sec	Stream Channel area (cm^2)	Daily Discharge l/sec	Mean Concentration mg/l	Sediment Discharge kg/day
Mine Rd.	100.56	1,235.57	124.25	4.67	50.13
Trailer Park	51.72	2,480.43	128.29	27.41	303.82
Moreau E.	25.40	38.71	0.98	36.00	3.05
Moreau	32.67	92.90	30.35	8.00	20.98
Fleury Rd.	76.11	2,787.0	212.12	2.67	48.93
Chelsea Hwy 8	31.28	18,580.0	581.18	20.00	1,004.28
Hwy 307	22.22	55,740.0	1,238.54	51.33	5,492.82
Hull Hwy 8	76.00	1,161.25	88.26	12.80	97.61

SUSPENDED SOLIDS DATA SHEET

June 3, 1975

Day 154

Sample	Stream Velocity cm/sec	Stream Channel area (cm^2)	Daily Discharge l/sec	Mean Concentration mg/l	Sediment Discharge kg/day
Fleury Rd.	94.17	3,716.	349.94	1.70	51.40
Mine Rd.	55.93	157.93	8.83	4.33	3.30
Hwy 11 Hull	59.67	4,645.	27.72	5.33	12.77
Hwy 307	21.11	44,592.0	941.34	86.29	7,018.12
Moreau	23.72	5,574.0	132.22	7.66	87.51
Moreau E.	19.05	74.32	1.42	29.00	3.56
Trailer Park	64.89	622.43	40.39	16.00	55.84
Hwy 11 Chelsea	26.39	22,296.	588.39	95.33	4,846.28

SUSPENDED SOLIDS DATA SHEET

June 10, 1975

Day 161

Sample	Stream Velocity cm/sec	Stream Channel area (cm^2)	Daily Discharge l/sec	Mean Concentration mg/l	Sediment Discharge kg/day
Moreau	45.22	1,161.25	52.51	14.00	63.52
Mine Rd.	82.78	480.76	33.84	6.67	19.50
Fleury Rd.	72.67	3,716.0	270.04	7.00	163.32
Hwy 11 Hull	82.17	771.07	63.36	4.00	21.90
Moreau E.	32.56	1,235.57	40.23	30.50	106.01
Hwy 307	11.11	52,024.0	577.99	39.29	1,962.08
Hwy 11 Chelsea	21.11	23,225.0	490.28	9.57	405.39
Trailer Park	80.5	2,787.	224.35	34.50	668.74

SUSPENDED SOLIDS DATA SHEET

June 17, 1975

Nozzle area = 0.18 cm^2

Day 168

Sample	Stream Velocity cm/sec	Stream Channel area (cm^2)	Daily Discharge l/sec	Mean Concentration mg/l	Sediment Discharge kg/day
Fleury Rd.	106.11	3,483.75	369.66	0.67	21.40
Moreau E.	50.48	1,235.57	62.37	29.00	156.27
Mine Rd.	91.44	157.93	14.44	4.00	4.99
Trailer Park	84.39	1,858.0	156.80	26.50	359.01
Hwy 307	12.89	41.805.0	538.87	349.0	16,248.87
Hwy 11 Hull	60.39	464.5	28.05	6.50	15.75
Hwy 11 Chelsea	26.33	16,257.5	428.06	21.00	776.67
Moreau	42.06	771.07	32.43	5.71	16.00

SUSPENDED SOLIDS DATA SHEET

June 24, 1975

Nozzle area = 0.18 cm^2

Day 175

Sample	Stream Velocity cm/sec	Stream Channel area (cm^2)	Daily Discharge l/sec	Mean Concentration mg/l	Sediment Discharge kg/day
Moreau	32.11	287.99	9.25	6.92	5.53
Mine Rd.	60.96	37.16	2.27	4.33	0.85
Hwy 307	21.22	50.166	1,064.52	68.17	6,269.90
Hwy 11 Hull	69.78	390.18	27.23	7.00	16.47
Fleury Rd.	78.00	3,483.75	271.73	3.00	70.43
Hwy 11 Chelsea	25.78	1,858.0	47.90	24.00	99.33
Trailer Park	157.33	1,551.43	2,440.09	11.00	2,319.06
Moreau E.	30.48	157.93	4.81	25.00	10.39

SUSPENDED SOLIDS DATA SHEET

July 2, 1975

Nozzle area = 0.18 cm^2

Day 183

Sample	Stream Velocity cm/sec	Stream Channel area (cm^2)	Daily Discharge l/sec	Mean Concentration mg/l	Sediment Discharge kg/day
Mine Rd.	60.96	157.93	9.63	15.33	12.76
Moreau	8.33	929.00	7.74	19.30	12.91
Fluery Rd.	23.17	1,858.0	43.05	4.80	17.85
Moreau E.	Stagnant				
Trailer Park	77.61	2,090.25	162.22	13.00	182.21
Hwy 11 Hull	69.78	232.25	16.21	17.50	24.51
Hwy 11 Chelsea	16.44	13,006.0	213.82	36.10	666.91
Hwy 307	27.78	32,515.	903.27	28.00	2,185.19

SUSPENDED SOLIDS DATA SHEET

July 8, 1975
Nozzle area = 0.18 cm^2
Day 189

Sample	Stream Velocity cm/sec	Stream Channel area (cm^2)	Daily Discharge l/sec	Mean Concentration mg/l	Sediment Discharge kg/day
Hwy 11 Hull	60.96	353.02	21.52	5.00	9.30
Moreau	93.78	1,393.5	130.68	4.33	48.89
Fleury	49.06	1,858.0	91.15	4.53	35.68
Mine Rd.	60.96	37.16	2.27	6.67	1.31
Hwy 307	11.22	25,083.0	281.43	22.73	552.69
Trailer Park	55.56	2,480.43	137.81	8.40	100.02
Moreau E.	Stagnant				
Hwy 11 Chelsea	19.11	14,864.0	284.05	28.65	703.13

SUSPENDED SOLIDS DATA SHEET

July 15, 1975
Nozzle area = 0.18 cm^2
Day 196

Sample	Stream Velocity cm/sec	Stream Channel area (cm^2)	Daily Discharge l/sec	Mean Concentration mg/l	Sediment Discharge kg/day
Fleury Rd.	60.44	1,161.25	70.19	Trace	
Moreau E.	Stagnant	464.5		4.00	
Moreau	28.33	966.16	27.37	8.24	19.49
Hwy 11 Chelsea	23.56	5,774.0	136.04	59.02	693.71
Trailer Park	43.22	1,551.43	67.05	6.12	35.45
Hwy 307	15.94	16,722.0	266.55	911.33	20,987.86
Hwy 11 Hull	17.61	1,161.25	20.52	13.23	23.46
Mine Rd.	76.2	37.16	2.83	10.58	2.59

SUSPENDED SOLIDS DATA SHEET

July 22, 1975

Nozzle area = 0.18 cm^2

Day 203

Sample	Stream Velocity cm/sec	Stream Channel area (cm^2)	Daily Discharge l/sec	Mean Concentration mg/l	Sediment Discharge kg/day
Moreau	30.22	929.0	28.07	4.33	10.50
Moreau E.	15.24	18.58	0.28	18.00	0.44
Trailer Park	59.39	929.	55.17	48.00	228.80
Hwy 307	20.61	13,935.	287.20	28.00	694.79
Fleury Rd.	80.67	2,787.	224.83	6.56	127.43
Hwy 11 Chelsea	22.50	14,864.	334.44	32.50	939.11
Hwy 11 Hull	41.11	696.75	28.64	32.00	79.18
Mine Rd.	76.20	18.58	1.42	6.56	0.81

SUSPENDED SOLIDS DATA SHEET

July 29, 1975

Nozzle area = 0.18 cm^2

Day 210

Sample	Stream Velocity cm/sec	Stream Channel area (cm^2)	Daily Discharge l/sec	Mean Concentration mg/l	Sediment Discharge kg/day
Mine Rd.	30.48	102.19	3.11	12.33	3.31
Fleury Rd.	77.78	1,235.57	96.10	8.33	69.16
Hwy 11 Hull	23.78	1,393.5	33.14	7.00	20.04
Moreau	28.22	771.07	21.76	3.61	6.79
Trailer Park	40.89	817.52	33.43	16.00	46.21
Moreau E.	18.29	130.06	2.38	26.50	5.45
Hwy 11 Chelsea	23.17	11,148.0.	258.30	40.67	907.64
Hwy 307	18.50	41,805.0	773.39	28.50	1 ,904.40

SUSPENDED SOLIDS DATA SHEET

August 7, 1975
Nozzle area = 0.18 cm^2
Day 219

Sample	Stream Velocity cm/sec	Stream Channel area (cm^2)	Daily Discharge l/sec	Mean Concentration g/l	Sediment Discharge kg/day
Hwy 11 Chelsea	27.89	18,580.	518.20	.021	940.22
Fleury Rd.	62.78	585.27	36.74	.003	9.52
Trailer Park	62.50	390.18	24.39	.007	14.75
Moreau	26.39	622.43	16.43	.018	25.55
Hwy 307	20.0	22,296.0	445.92	.015	577.52
Hwy 11 Hull	32.28	464.5	14.99	.021	27.20
Mine Rd.	60.96	232.25	14.16	.011	13.46

*Moreau E. - dry

SUSPENDED SOLIDS DATA SHEET

August 12, 1975
Nozzle area = 0.18 cm^2
Day 224

Sample	Stream Velocity cm/sec	Stream Channel area (cm^2)	Daily Discharge l/sec	Mean Concentration g/l	Sediment Discharge kg/day
Hwy 11 Hull	11.5	622.43	7.16	.025	15.46
Fleury Rd.	33.89	585.27	19.83	Trace	
Hwy 307	20.89	24,154.0	504.58	.019	828.32
Hwy 11 Chelsea	19.72	6,503.0	128.24	.015	166.20
Moreau	35.0	622.43	21.79	.021	39.54
Trailer Park	61.67	390.18	24.06	.005	10.39
Mine Rd.	76.2	27.87	2.12	.005	0.92

*Moreau E. - dry

SUSPENDED SOLIDS DATA SHEET

August 19, 1975

Nozzle area = 0.18 cm^2

Day 231

Sample	Stream Velocity cm/sec	Stream Channel area (cm^2)	Daily Discharge l/sec	Mean Concentration g/l	Sediment Discharge kg/day
Mine Rd.	91.44	464.5	42.47	.019	69.73
Fleury Rd.	29.06	696.75	20.25	.002	3.50
Moreau	96.56	464.5	44.85	.009	34.88
Trailer	57.89	306.57	17.75	.007	10.74
Hwy 307	17.67	20,438.0	368.14	.022	699.76
Chelsea	17.67	10,841.43	191.57	.006	99.31
Hull	22.33	622.43	13.90	.028	33.63

*Moreau E. – dry

SUSPENDED SOLIDS DATA SHEET

August 26, 1975
Nozzle area = 0.18 cm^2
Day 238

Sample	Stream Velocity cm/sec	Stream Channel area (cm^2)	Daily Discharge l/sec	Mean Concentration g/l	Sediment Discharge kg/day
Hwy 11 Hull	26.56	464.5	12.34	.033	35.18
Mine Rd.	91.44	9.29	0.85	.016	1.18
Hwy 11 Chelsea	22.83	9,754.5	222.70	.025	481.03
Hwy 307	22.39	23,225.0	520.01	.020	898.58
Moreau	34.17	464.5	15.87	.002	2.74
Trailer Park	62.94	390.18	24.56	.017	36.07
Fleury Rd.	51.33	483.08	24.80	.010	21.43

*Moreau E. - dry

SUSPENDED SOLIDS DATA SHEET

September 3, 1975

Nozzle area = 0.18 cm^2

Day 246

Sample	Stream Velocity cm/sec	Stream Channel area (cm^2)	Daily Discharge l/sec	Mean Concentration g/l	Sediment Discharge kg/day
Hwy 11 Hull	33.28	287.99	9.58	.015	12.42
Trailer Park	91.00	287.99	26.21	.033	74.73
Hwy 11 Chelsea	30.89	1,858.0	57.39	.042	208.26
Mine Rd.	60.96	18.58	1.13	.012	1.17
Fleury Rd.	54.67	696.75	38.09	.003	9.87
Hwy 307	20.17	14,631.75	295.12	.072	1,835.88
Moreau E.	30.48	18.58	0.57	.013	0.64
Moreau	35.67	353.02	12.59	.008	8.70

SUSPENDED SOLIDS DATA SHEET

September 9, 1975

Nozzle area = 0.18 cm^2

Day 252

Sample	Stream Velocity cm/sec	Stream Channel area (cm^2)	Daily Discharge l/sec	Mean Concentration g/l	Sediment Discharge kg/day
Trailer Park	42.44	464.5	19.71	.016	27.25
Hwy 307	16.83	18,580.	312.70	.033	891.57
Fleury Rd.	58.78	696.75	40:95	.001	3.54
Moreau	40.89	390.18	15.95	.003	4.13
Hwy 11 Hull	27.78	613.14	17.03	.006	8.83
Mine Rd.	20.32	2.79	0.06	.005	0.03
Moreau E.	25.4	2.79	0.07	.005	0.03
Hwy 11 Chelsea	21.11	2,787.	58.83	.017	86.41

SUSPENDED SOLIDS DATA SHEET

September 16, 1975

Nozzle area = 0.18 cm^2

Day 259

Sample	Stream Velocity cm/sec	Stream Channel area (cm^2)	Daily Discharge l/sec	Mean Concentration g/l	Sediment Discharge kg/day
Fleury Rd.	44.39	929.	41.24	.002	7.13
Moreau E.	25.40	278.	0.07	.012	0.07
Moreau	34.56	390.18	13.48	.001	1.16
Hwy 307	15.17	13,006.0	197.30	.021	357.98
Hwy 11 Hull	24.06	613.14	14.75	.005	6.37
Chelsea	17.94	6,967.5	125.00	.027	291.6
Trailer Park	58.17	287.99	16.75	.013	18.81
Mine Rd.	30.48	39.02	1.19	.009	0.93

SUSPENDED SOLIDS DATA SHEET

September 23, 1975

Nozzle area = 0.18 cm^2

Day 266

Sample	Stream Velocity cm/sec	Stream Channel area (cm^2)	Daily Discharge l/sec	Mean Concentration g/l	Sediment Discharge kg/day
Fleury Rd.	61.22	16,257.5	995.31	.006	515.97
Hwy 307	30.28	30,192.5	914.23	.034	2,685.64
Trailer Park	50.50	613.14	30.96	.022	58.85
Hwy 11 Chelsea	24.50	8,361.0	204.84	.017	300.87
Mine Rd.	30.48	4.65	0.14	.009	0.11
Moreau E.	30.48	77.11	2.35	.016	3.25
Hull	53.44	464.5	24.82	.003	6.43
Moreau	31.78	696.75	22.14	.008	15.30

SUSPENDED SOLIDS DATA SHEET

September 30, 1975

Nozzle area = 0.18 cm^2

Day 273

Sample	Stream Velocity cm/sec	Stream Channel area (cm^2)	Daily Discharge l/sec	Mean Concentration g/l	Sediment Discharge kg/day
Moreau	72.00	696.75	50.17	.004	17.34
Moreau E.	30.48	39.02	1.19	.019	1.95
Trailer Park	49.72	2,787.0	138.57	.049	586.65
Hwy 307	27.50	18,580.0	510.95	.051	2,251.45
Fleury Rd.	71.06	1,161.25	82.52	.005	35.65
Hwy 11 Chelsea	21.61	3,716.0	80.30	.016	111.01
Hull	39.44	613.14	24.18	.005	10.45
Mine Rd.	30.48	77.11	2.35	.005	1.02

SUSPENDED SOLIDS DATA SHEET

October 7, 1975

Nozzle area = 0.18 cm^2.

Day 280

Sample	Stream Velocity cm/sec	Stream Channel area (cm^2)	Daily Discharge l/sec	Mean Concentration g/l	Sediment Discharge kg/day
Moreau	36.33	464.5	16.88	.003	4.38
Moreau E.	30.48	19.51	0.59	.008	0.41
Trailer Park	40.00	929.00	37.16	.021	67.42
Hwy 307	18.56	18,580.	344.84	.026	774.65
Fleury Rd.	53.28	1,161.25	61.87	.003	16.04
Chelsea	21.00	3,716.0	78.04	.007	47.20
Hull	31.67	771.07	24.42	.005	10.55
Mine	30.48	157.93	4.81	.005	2.08

SUSPENDED SOLIDS DATA SHEET

October 15, 1975
Nozzle area = 0.18 cm^2
Day 288

Sample	Stream Velocity cm/sec	Stream Channel area (cm^2)	Daily Discharge l/sec	Mean Concentration g/l	Sediment Discharge kg/day
Moreau	93.44	1,858.0	173.61	.560	8,399.95
Moreau E.	106.39	613.14	65.23	.174	980.64
Trailer Park	68.61	2,787.0	191.22	.096	1,586.06
Hwy 307	21.72	25,547.5	554.89	.093	4,458.65
Fleury Rd.	114.22	2,471.14	282.25	.113	2,755.66
Chelsea	50.33	11,612.5	584.46	.023	1,161.44
Hull	65.67	2,322.5	152.52	.119	1,568.15
Mine	76.2	77.11	5.88	.017	8.64

SUSPENDED SOLIDS DATA SHEET

October 21, 1975
Nozzle area = 0.18 cm^2
Day 294

Sample	Stream Velocity cm/sec	Stream Channel area (cm^2)	Daily Discharge l/sec	Mean Concentration g/l	Sediment Discharge kg/day
Moreau	102.78	2,164.57	222.47	.108	2,075.91
Moreau E.	109.28	613.14	67.00	.065	376.27
Trailer Park	162.67	2,787.	453.36	.091	3,564.50
Hwy 307	29.56	260.12	768.91	.104	6,909.12
Fleury Rd.	128.56	2,787.	358.30	.016	495.31
Chelsea	57.22	9,754.5	558.15	.059	2,845.22
Hull	61.33	3,093.57	189.73	.031	508.17
Mine Rd.	75.44	696.75	52.56	.012	54.49

SUSPENDED SOLIDS DATA SHEET

October 28, 1975

Nozzle area = 0.38 cm^2

Day 301

Sample	Stream Velocity cm/sec	Stream Channel area (cm^2)	Daily Discharge l/sec	Mean Concentration g/l	Sediment Discharge kg/day
Moreau	43.5	929.	40.41	.014	48.88
Moreau E.	32.0	613.14	19.62	.050	84.76
Trailer Park	90.94	1,858.0	168.97	.019	277.38
Hwy 307	13.72	23,225.	318.65	.025	688.28
Fleury Rd.	66.89	3,716.	248.56	.004	85.9
Chelsea	27.17	6,967.5	189.31	.007	114.49
Hull	44.67	929.0	41.50	.006	21.51
Mine Rd.	84.17	464.5	39.10	.006	20.27

SUSPENDED SOLIDS DATA SHEET

June 8, 1976

Nozzle area = 0.18 cm^2

Sample	Stream Velocity cm/sec	Stream Channel area (cm^2)	Daily Discharge l/sec	Mean Concentration g/l	Sediment Discharge kg/day
Fleury Rd.	121.94	2,787.	339.85	.003	88.09
Hull	22.94	3,716.	85.24	.014	103.11
Chelsea Creek	34.94	12,541.5	438.20	.012	454.33
Dam Site	30.48	696.75	21.24	.005	9.18
Hwy 307	18.39	52,024.	956.72	.092	7,604.78
Moreau	40.56	1,393.5	56.52	.006	29.30
Trailer Park	38.22	3,716.0	142.02	.047	576.71
Moreau E.	50.80	390.18	19.82	.013	22.26

SUSPENDED SOLIDS DATA SHEET

June 15, 1976

Nozzle area = 0.18 cm^2

Sample	Stream Velocity cm/sec	Stream Channel area (cm^2)	Daily Discharge l/sec	Mean Concentration g/l	Sediment Discharge kg/day
Fleury Rd.	103.17	5,574.0	575.07	.013	645.92
Hwy 307	23.78	30,657.	729.02	.073	4,598.07
Chelsea Creek	81.39	13,006.	1,058.56	.037	3,384.0
Hwy 11 Hull	66.44	2,480.43	164.80	.047	669.22
Trailer Park	36.83	1,858.0	68.43	.058	342.92
Moreau E.	91.44	39.02	3.57	.062	19.12
Mine Rd.	45.72	1,161.25	53.09	.005	22.93
Moreau	74.83	1,393.5	104.28	.023	207.23

SUSPENDED SOLIDS DATA SHEET

June 22, 1976

Nozzle area = 0.18 cm^2

Sample	Stream Velocity cm/sec	Stream Channel area (cm^2)	Daily Discharge l/sec	Mean Concentration g/l	Sediment Discharge kg/day
Moreau	70.33	696.75	49.00	.007	29.64
Moreau E.	30.48	696.75	21.24	.027	49.55
Trailer Park	33.33	929.0	30.96	.041	109.67
Hwy 307	36.56	20,438.0	747.21	.010	645.59
Fleury Rd.	87.39	1,658.0	144.89	.002	25.04
Chelsea	21.83	8,361.0	182.52	.023	362.70
Hull	26.72	1,235.57	33.01	.009	25.67
Mine Rd.	76.20	232.25	17.70	.007	10.70

SUSPENDED SOLIDS DATA SHEET

June 29, 1976

Nozzle area = 0.18 cm^2

Sample	Stream Velocity cm/sec	Stream Channel area (cm^2)	Daily Discharge l/sec	Mean Concentration g/l	Sediment Discharge kg/day
Moreau	58.94	3,251.5	191.64	.043	711.98
Moreau E.	111.33	613.14	68.26	.057	336.17
Trailer Park	130.72	929.00	121.44	.096	1,007.27
Hwy 307	35.61	16,722.0	595.47	.522	2,656.17
Fleury Rd.	129.78	1,161.25	150.71	.034	442.73
Chelsea	66.56	6,503.0	432.84	.120	4,487.69
Hull	45.72	1,858.0	84.95	.022	161.47
Mine Rd.	22.86	622.43	14.23	.010	12.29

SUSPENDED SOLIDS DATA SHEET

July 6, 1976
Nozzle area = 0.18 cm^2

Sample	Stream Velocity cm/sec	Stream Channel area (cm^2)	Daily Discharge l/sec	Mean Concentration g/l	Sediment Discharge kg/day
Moreau	34.39	622.43	21.41	.010	18.50
Moreau E.	37.11	622.43	23.10	.035	69.85
Trailer Park	39.39	873.26	34.40	.029	86.19
Hwy 307	24.61	23,225.0	571.57	.156	7,703.85
Fleury Rd.	97.44	1,393.5	135.78	.008	93.85
Hwy 11 Chelsea	53.94	5,574.0	300.66	.060	1,558.62
Hwy 11 Hull	32.83	1,858.	61.00	.019	100.14
Mine Rd.	45.72	154.84	7.08	.007	4.28

SUSPENDED SOLIDS DATA SHEET

July 13, 1976

Nozzle area = 0.18 cm^2

Sample	Stream Velocity cm/sec	Stream Channel area (cm^2)	Daily Discharge l/sec	Mean Concentration g/l	Sediment Discharge kg/day
Moreau	59.72	622.43	37.17	.013	41.75
Moreau E.	56.0	204.38	11.45	.025	24.73
Trailer Park	87.78	966.16	84.81	.030	219.83
Hwy 307	22.67	18,580.0	421.21	.097	3,530.08
Fleury Rd.	116.17	1,858.0	215.84	.027	503.51
Hwy 11 Chelsea	48.83	6,503.0	317.54	.130	3,566.61
Hwy 11 Hull	61.44	4,180.5	256.85	.041	909.87
Mine Rd.	48.5	1,235.57	59.93	.023	119.09

SUSPENDED SOLIDS DATA SHEET

July 20, 1976

Nozzle area = 0.18 cm^2

Sample	Stream Velocity cm/sec	Stream Channel area (cm^2)	Daily Discharge l/sec	Mean Concentration g/l	Sediment Discharge kg/day
Moreau	30.88	464.5	14.34	.006	7.43
Moreau E.	20.28	260.12	5.28	.019	8.67
Trailer Park	51.94	929.0	48.25	.025	104.22
Hwy 307	26.39	18,580.0	490.33	.169	7,159.60
Fleury Rd.	70.78	1,161.25	82.19	.007	49.17
Chelsea	34.0	2,787.0	94.76	.033	270.18
Hull	26.67	1,858.0	49.55	.014	59.94
Mine Rd.	49.44	353.02	17.45	.007	10.55

SUSPENDED SOLIDS DATA SHEET

July 27, 1976

Nozzle area = 0.18 cm^2

Sample	Stream Velocity cm/sec	Stream Channel area (cm^2)	Daily Discharge l/sec	Mean Concentration g/l	Sediment Discharge kg/day
Moreau	24.28	1,161.30	28.19	.018	43.84
Moreau E.	30.5	5,574.0	170.01	.023	337.84
Trailer Park	76.67	966.16	74.08	.007	44.80
Hwy 307	84.89	26,012.0	2,208.16	.039	7,440.62
Fleury Rd.	41.44	1,858.0	77.0	.001	6.65
Chelsea	27.28	13,006.0	354.8	.031	950.30
Hull Hwy 11	26.33	2,787.0	73.38	.003	19.02
Mine Rd.	26.33	464.5	12.23	.012	12.68

SUSPENDED SOLIDS DATA SHEET

August 3, 1976

Nozzle area = 0.18 cm^2

Sample	Stream Velocity cm/sec	Stream Channel area (cm^2)	Daily Discharge l/sec	Mean Concentration g/l	Sediment Discharge kg/day
Mine Rd.	44.17	315.86	13.96	.020	24.12
Hwy 11 Hull	25.39	157.93	4.01	.015	5.20
Trailer Park	56.17	287.99	16.18	.034	47.53
Chelsea	20.28	7,432.0	150.72	.026	338.58
Fleury Rd.	64.11	929.0	59.56	.003	15.44
Moreau E.	39.39	130.06	5.12	.018	7.96
Moreau	41.56	287.99	11.97	.008	8.27
Hwy 307	46.94	23,225.0	1,090.18	.138	12,998.43

SUSPENDED SOLIDS DATA SHEET

August 10, 1976

Nozzle area = 0.18 cm^2

Sample	Stream Velocity cm/sec	Stream Channel area (cm^2)	Daily Discharge l/sec	Mean Concentration g/l	Sediment Discharge kg/day
Moreau	19.78	157.93	3.12	.009	2.43
Moreau E.	42.11	55.74	2.36	.030	6.12
Trailer Park	72.78	232.25	16.88	.030	43.75
Hwy 307	29.72	16,722.	496.98	.171	7,342.58
Fleury Rd.	81.17	966.16	78.42	.007	47.43
Chelsea	30.5	4,180.5	127.51	.027	297.46
Hull Hwy 11	58.17	157.93	9.19	.009	7.15
Mine Rd.	42.22	287.99	12.16	.010	10.51

SUSPENDED SOLIDS DATA SHEET

August 17, 1976

Nozzle area = 0.18 cm^2

Sample	Stream Velocity cm/sec	Stream Channel area (cm^2)	Daily Discharge 1/sec	Mean Concentration g/1	Sediments Discharge kg/day
Moreau	24.39	390.18	9.52	.01	8.23
Moreau E.	28.44	130.06	3.70	.027	8.63
Trailer Park	64.78	232.25	15.05	.034	44.21
Hwy 307	32.83	13,006.	426.99	.083	3,062.03
Fleury Rd.	81.78	1,858.	151.95	.004	52.51
Chelsea	49.06	2,787.	136.73	.013	153.58
Hull	102.22	157.93	16.14	.009	12.55
Mine Rd.	53.67	622.43	33.41	.006	17.32

SUSPENDED SOLIDS DATA SHEET

August 24, 1976

Nozzle area = 0.18 cm^2

Sample	Stream Velocity cm/sec	Stream Channel area (cm^2)	Daily Discharge l/sec	Mean Concentration g/l	Sediments Discharge kg/day
Moreau	13.44	353.02	4.74	.005	2.05
Moreau E.	25.22	130.06	3.28	.154	43.64
Trailer Park	38.17	390.18	14.89	.025	32.16
Hwy 307	24.67	14,864.	366.69	.420	13,306.45
Fleury Rd.	26.28	929.0	24.41	.001	2.11
Chelsea	21.28	6,503.0	138.38	.212	2,534.68
Hull	18.0	622.43	11.20	.082	79.35
Mine Rd.	82.11	929.0	76.28	.064	421.8

SUSPENDED SOLIDS DATA SHEET

August 31, 1976

Nozzle area = 0.18 cm^2

Sample	Stream Velocity cm/sec	Stream Channel area (cm^2)	Daily Discharge l/sec	Mean Concentration g/l	Sediments Discharge kg/day
Moreau	15.94	353.02	5.63	.0055	2.92
Moreau E.	59.50	120.77	7.19	.099	61.5
Trailer Park	33.89	464.5	15.74	.070	95.2
Hwy 307	19.61	22,296.	437.22	.099	3,739.8
Fleury Rd.	53.33	1,049.77	55.98	.005	24.18
Chelsea	32.56	9,290.	302.48	.045	1,176.04
Hull	20.78	929.	19.30	.026	43.36
Mine Rd.	55.67	232.25	12.93	.013	14.52

SUSPENDED SOLIDS DATA SHEET

September 7, 1976

Nozzle area = 0.18 cm^2

Sample	Stream Velocity cm/sec	Stream Channel area (cm^2)	Daily Discharge l/sec	Mean Concentration g/l	Sediments Discharge kg/day
Moreau	20.39	306.57	6.25	.004	2.16
Moreau E.	24.67	65.03	1.60	.052	7.19
Trailer Park	47.39	696.75	33.02	.013	37.09
Hwy 307	16.5	19,509.	321.90	.085	2,364.03
Fleury Rd.	44.39	929.0	41.24	.004	14.25
Chelsea	33.11	4,645.0	153.80	.031	411.94
Hull	18.0	696.75	12.54	.063	68.26
Mine Rd.	68.61	232.25	15.93	.004	5.51

SUSPENDED SOLIDS DATA SHEET

September 14, 1976
Nozzle area = 0.18 cm^2

Sample	Stream Velocity cm/sec	Stream Channel area (cm^2)	Daily Discharge l/sec	Mean Concentration g/l	Sediments Discharge kg/day
Moreau	35.61	306.57	10.92	.007	6.6
Moreau E.	19.44	37.16	0.72	.063	3.92
Trailer Park	56.89	696.75	39.64	.021	71.92
Hwy 307	19.89	18,580.0	369.56	.242	7,727.06
Fleury Rd.	56.61	585.27	33.13	.005	14.31
Chelsea	25.28	9,754.5	246.59	.035	745.69
Hull	54.17	622.43	33.72	.006	17.48
Mine Rd.	27.11	157.93	4.28	.006	2.22

SUSPENDED SOLIDS DATA SHEET

September 21, 1976

Nozzle area = .17 cm^2

Sample	Stream Velocity cm/sec	Stream Channel area (cm^2)	Daily Discharge l/sec	Mean Concentration g/l	Sediments Discharge kg/day
Moreau	111.97	3,483.75	390.08	.10867	3,662.45
Moreau E.	112.19	3,251.5	364.79	.104	3,277.86
Trailer Park	134.55	4,645.0	624.98	.187	10,097.68
Hwy 307	34.44	25,083.0	863.86	1.9	141,811.26
Fleury Rd.	152.42	3,251.5	495.59	.05467	2,340.91
Chelsea	62.53	12,541.5	784.22	.127	8,605.09
Hull	56.18	3,483.75	195.72	.151	2,553.44
Mine Rd.	79.49	1,393.5	110.77	.02533	239.26

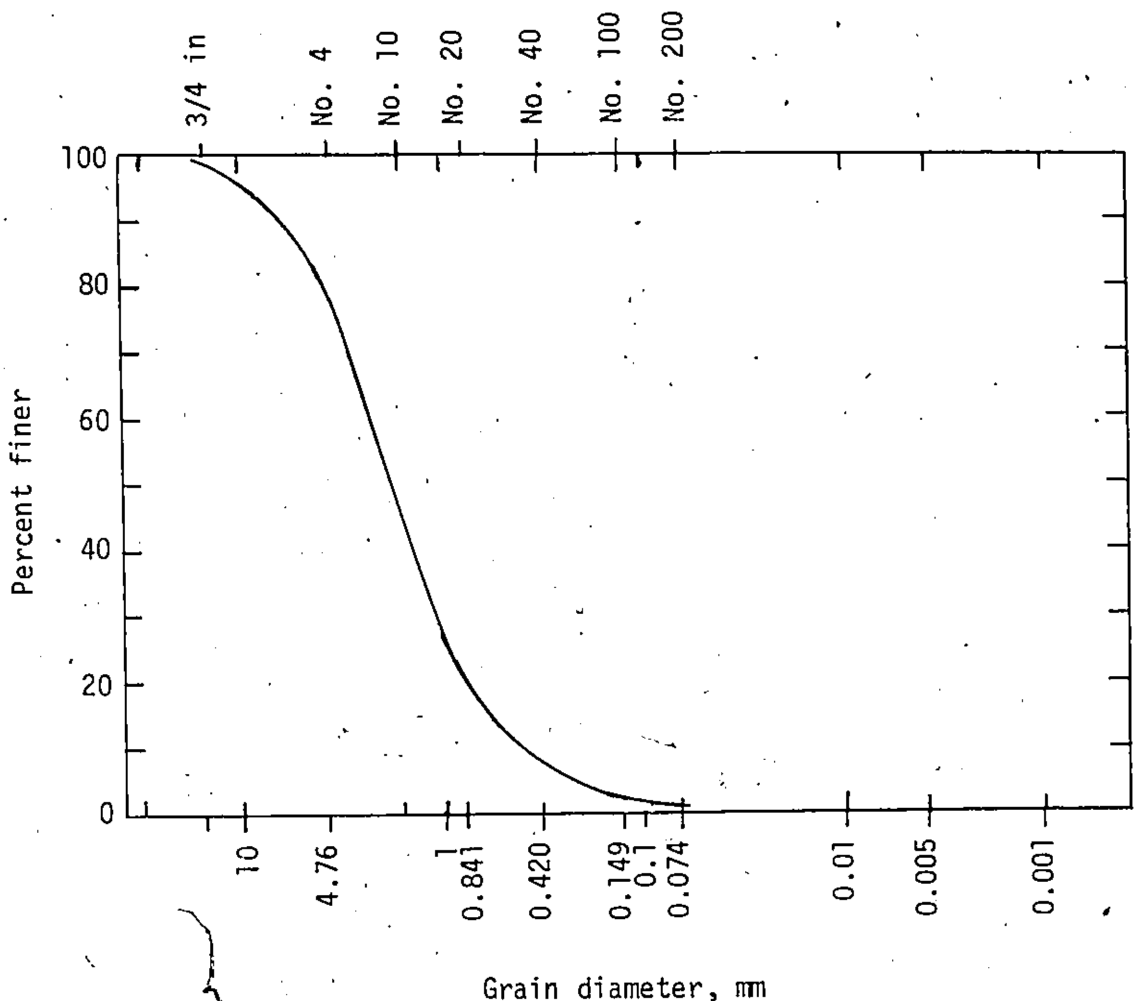
SUSPENDED SOLIDS DATA SHEET

September 28, 1976

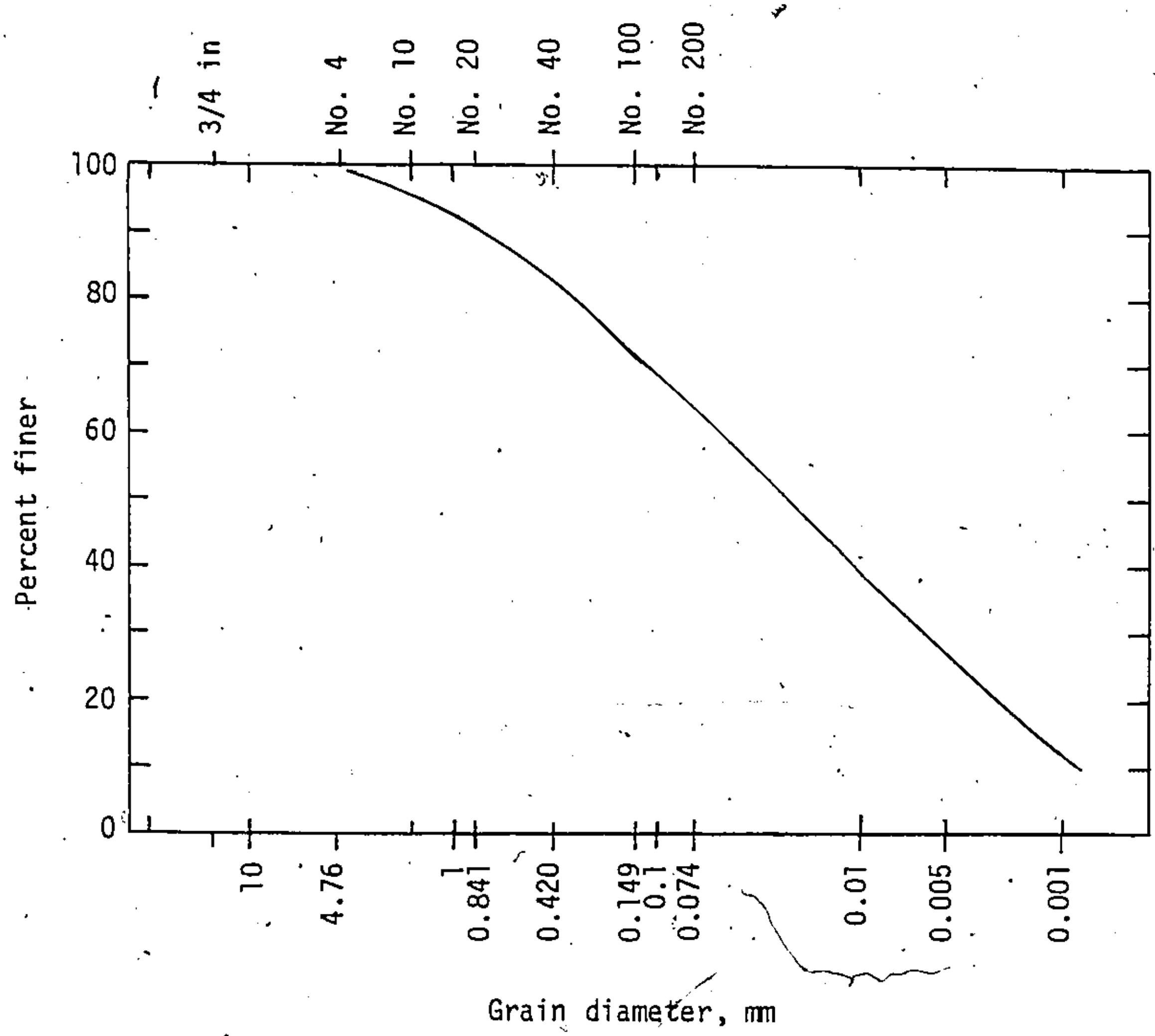
Nozzle area = .178 cm^2

Sample	Stream Velocity cm/sec	Stream Channel area (cm^2)	Daily Discharge l/sec	Mean Concentration mg/l	Sediment Dishcarge kg/day
Moreau	34.89	390.18	13.613	6.21	7.30
Moreau E	79.61	696.75	55.468	38.00	182.11
Trailer Park	83.43	1,235.57	103.084	33.00	293.91
Hwy 307	17.47	19,509.	340.822	474.00	13,957.89
Fleury Rd.	90.96	1,858.	169.004	3.00	43.81
Chelsea Creek	66.40	6,967.5	462.64	10.00	399.72
Hull	46.91	1,161.25	54.47	11.50	54.13
Mine Rd.	79.04	622.43	49.2	20.00	85.02

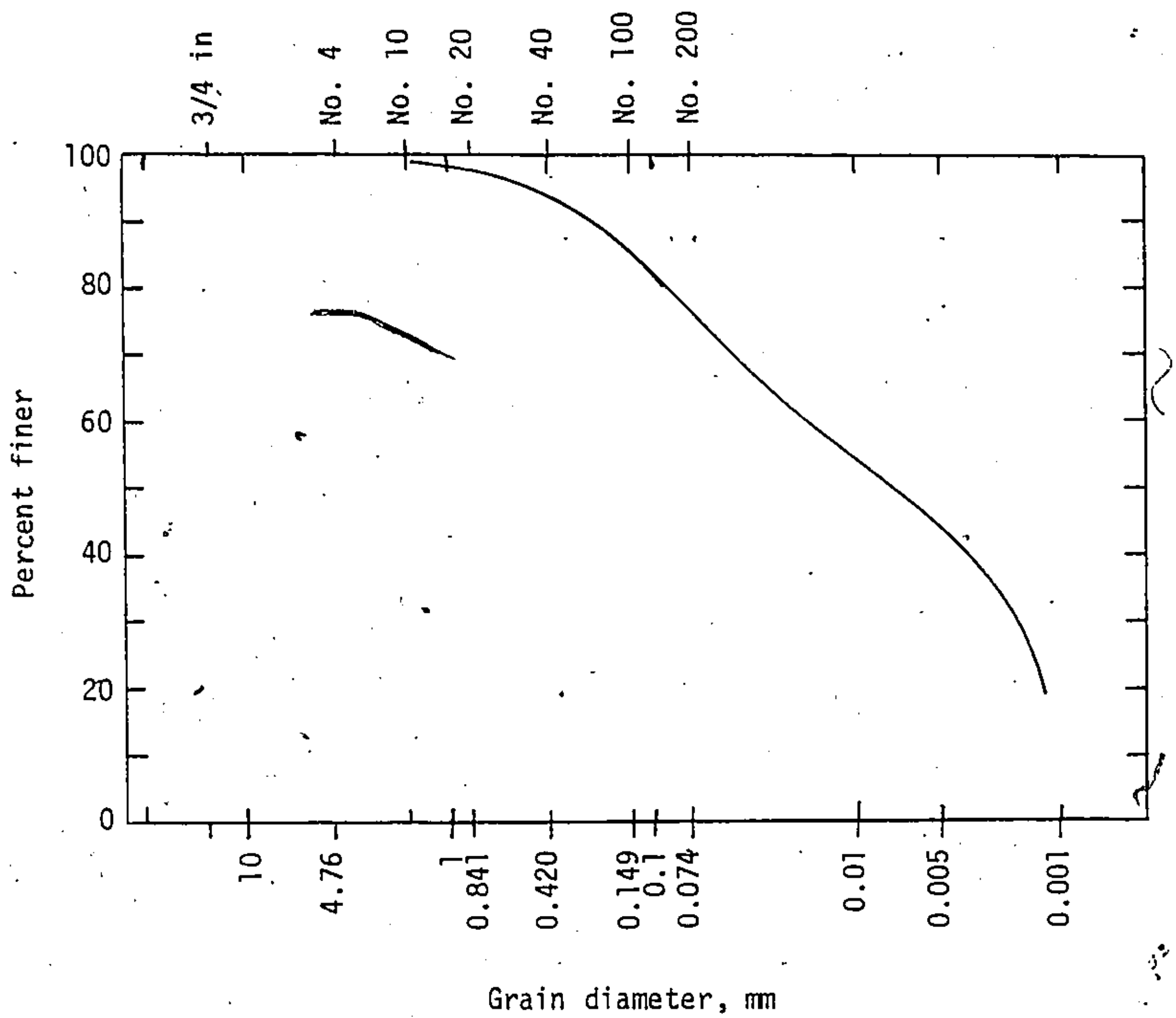
B2. PARTICLE-SIZE DISTRIBUTION



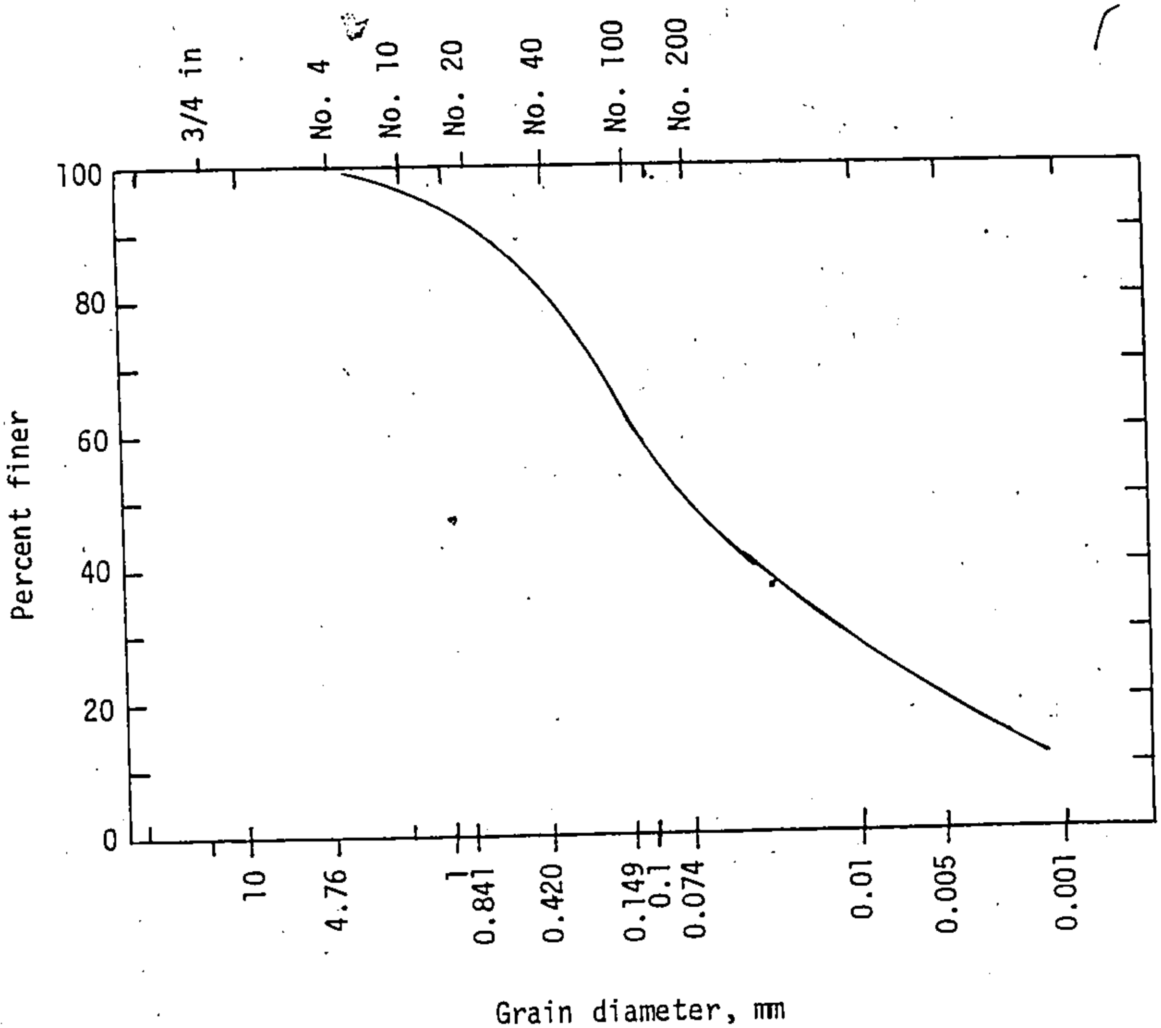
Particle-size distribution, Moreau Creek (Bed material)



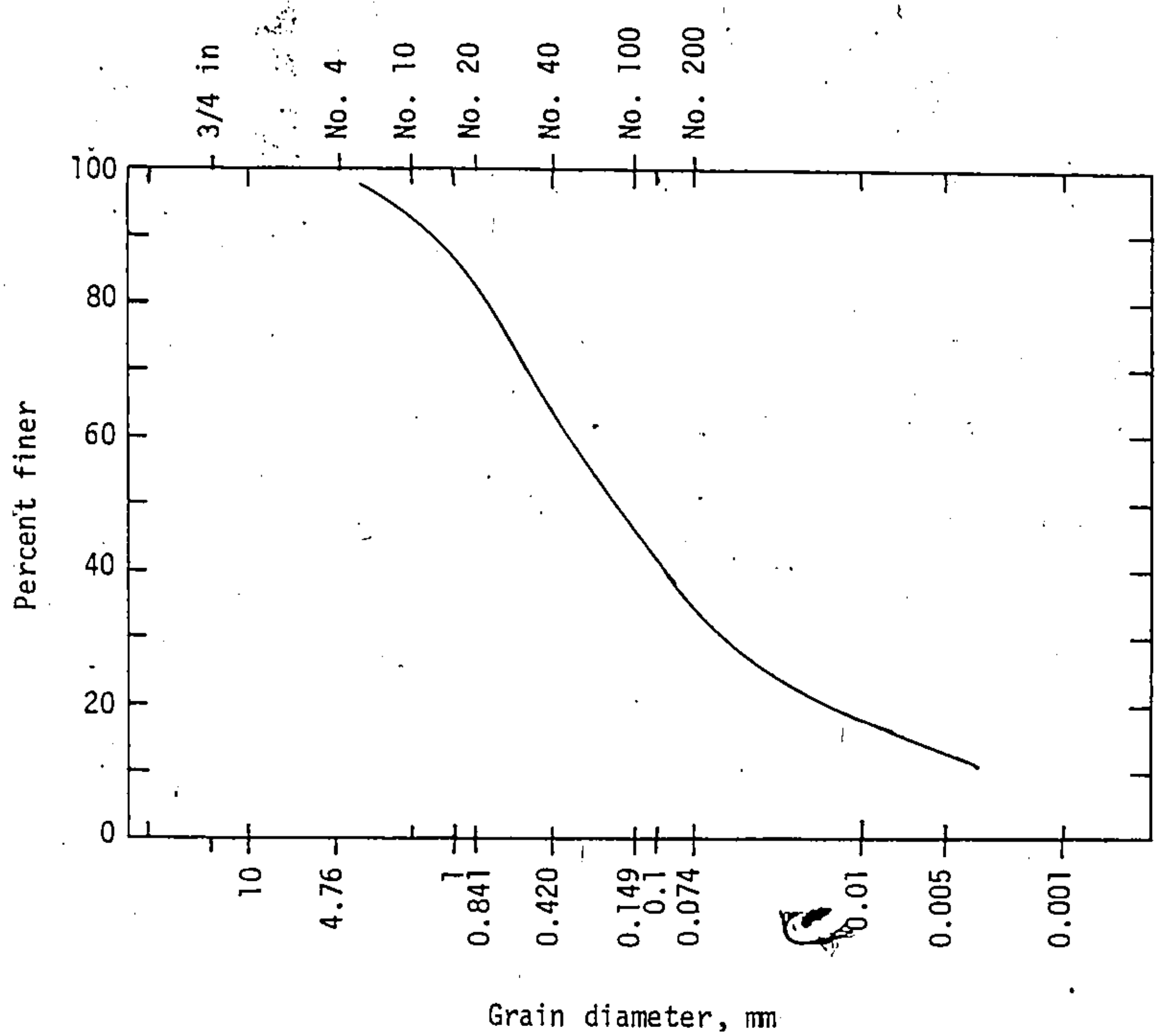
Particle-size distribution, Moreau Creek (Bank material)



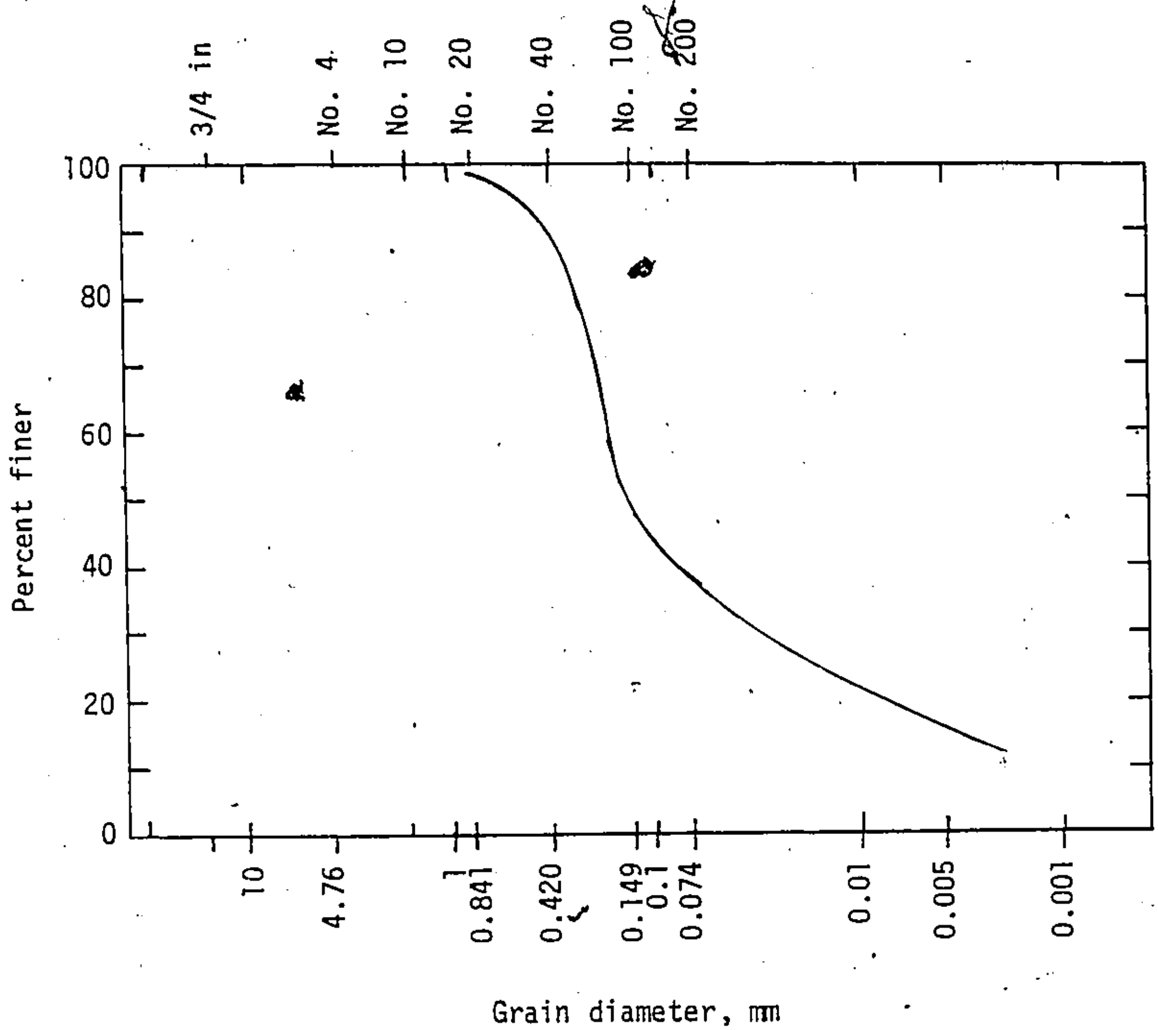
Particle-size distribution, Desjardins, Trailer Park (Bank material)



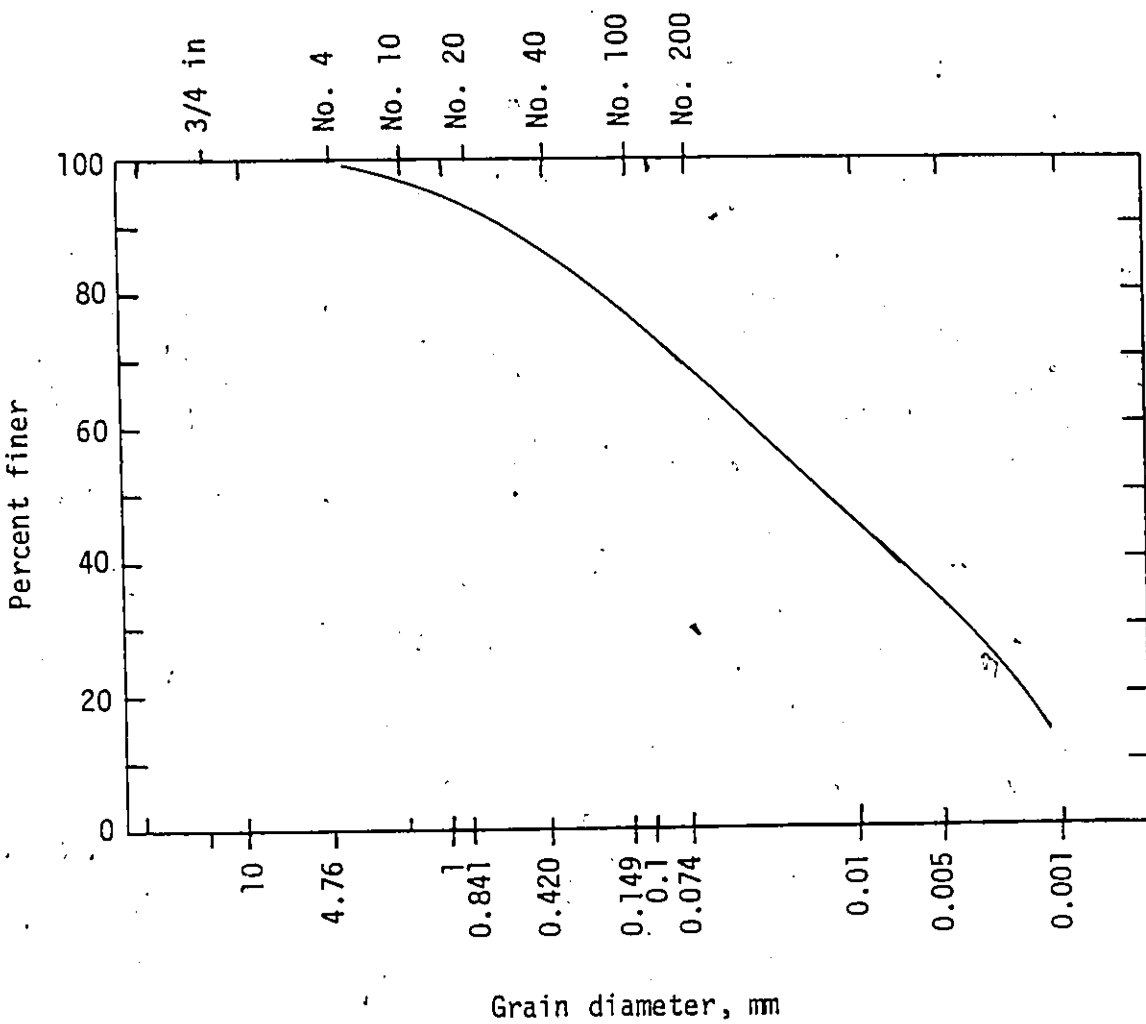
Particle-size distribution, Chelsea II (Bank material)



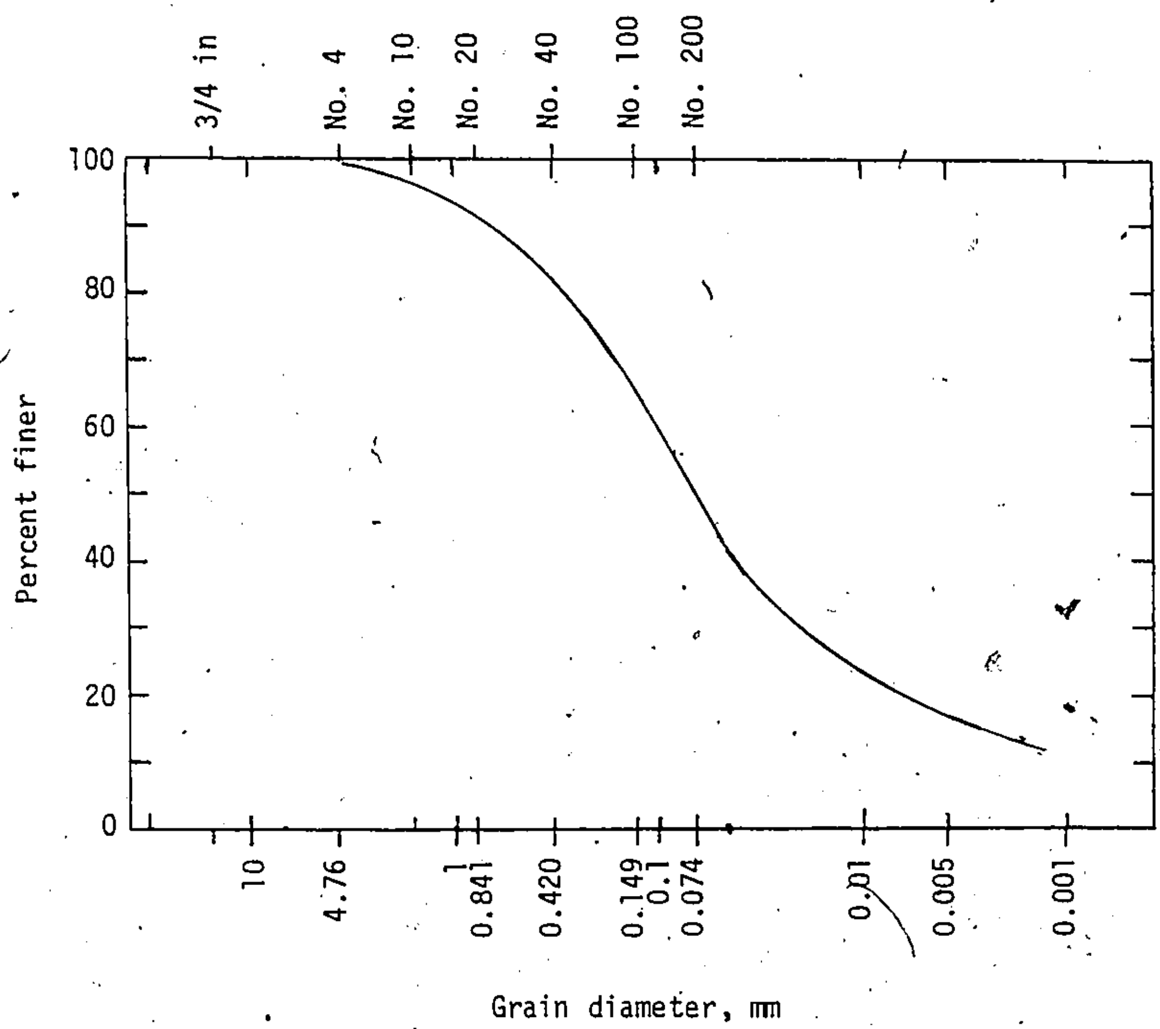
Particle-size distribution, Chelsea II (Bed material)



Particle-size distribution, Leamy Creek, Hull (Bank material)



Particle-size distribution, Leamy Creek, Mine Road (Bank material)



Particle-size distribution, Mine Road (Bed material)

APPENDIX C

INPUT DATA FOR USDAHL-74

1.	060575	08300.00	060575	09000.06	060575	10000.08	060575	10300.12
2.	060575	11000.36	060575	11500.10	060575	12300.09	060575	13300.05
3.	060575	14000.03	060575	14200.00	060575	14500.04	060575	16300.00
4.	060575	16400.02	060575	16500.13	060575	17200.03	060575	19220.01
5.	060675	07550.00	060675	08000.15	060675	08100.33	060675	08200.10
6.	060675	08300.07	060675	08340.11	060675	09000.09	060675	09200.02
7.	060675	20200.30	060675	20320.02	060675	21000.01	060675	23050.08
8.	060675	23300.00	060675	23320.01	060775	00390.00	060775	00400.01
9.	060775	01350.30	060775	01400.01	060775	02290.00	060775	02300.01
10.	060775	02550.00	060775	03000.01	060775	03400.00	060775	03420.01
11.	060775	09580.00	060775	10000.01	060775	10150.03	060775	15350.00
12.	060775	15400.01	060875	07500.00	060875	08000.02	060875	08200.05
13.	061175	19120.00	061175	20200.12	061175	20300.00	061175	20320.01
14.	061175	20500.00	061175	21300.04	061175	21450.00	061175	22250.02
15.	061175	22350.01	061275	00400.00	061275	00500.01	061275	01300.00
16.	061275	[illegible]	061275	[illegible]	061275	02450.01	061275	03100.00
17.	061275	05350.04	061275	07050.00	061275	07100.01	061275	19200.00
18.	061275	18350.03	061275	18400.00	061275	18450.01	061375	01350.00
19.	061375	01400.04	061575	19350.09	061575	19390.01	061575	20020.00
20.	061575	20200.04	061575	20580.00	061575	21280.04	070275	07100.00
21.	070275	07350.03	070275	07500.03	070275	10050.00	070275	10110.04
22.	070275	11050.00	070275	11100.01	070275	14400.00	070275	14550.02
23.	070875	07100.00	070875	07200.01	070875	07250.16	070875	08550.00
24.	070875	09030.07	071075	13400.00	071075	13590.03	071075	14350.00
25.	071075	15000.11	071075	15050.00	071075	15150.02	071075	16250.16
26.	071075	17050.00	071075	17150.02	071075	18050.00	071075	18100.01
27.	071075	19250.00	071075	19300.01	071075	21500.00	071075	21550.07
28.	071075	22150.00	071075	22200.01	071075	22300.00	071075	22350.08
29.	071075	22450.02	071075	22550.14	071175	02200.00	071175	02250.14
30.	071175	02300.01	071175	02320.14	071175	02350.01	071975	07350.00
31.	071975	07400.35	071975	07450.04	071975	07550.00	071975	07580.01
32.	072075	07150.00	072075	07200.05	072075	07250.18	072075	07350.04
33.	072075	07550.00	072075	08050.05	072075	08150.08	072075	08300.19
34.	072075	08350.08	072075	08400.12	072075	08450.06	072075	08550.03
35.	072075	09100.00	072075	09300.03	072075	10500.00	072075	10550.01
36.	072075	23400.00	072175	00050.05	072175	00200.00	072175	00250.01
37.	072275	13550.00	072275	14000.01	072475	00350.00	072475	00400.09
38.	072475	00500.03	072475	00550.06	072475	01000.10	072475	03450.00
39.	072475	03500.01	072475	04020.00	072475	04050.01	072475	04400.00
40.	072475	05250.13	072475	05350.00	072475	05400.04	072475	05500.00
41.	072475	05550.04	072475	06050.00	072475	06100.10	072475	09050.00
42.	072475	08150.03	072775	03350.00	072775	03500.02	072775	05150.00
43.	072775	06000.10	072775	06200.30	072775	06250.01	072775	06520.00
44.	072775	06550.01	072775	08100.00	072775	08300.07	072775	10050.00
45.	072775	10250.06	072775	10350.00	072775	10400.05	072775	10550.00
46.	072775	11050.09	072775	11250.00	072775	11300.08	072775	11450.00
47.	072775	11500.01	072875	05020.00	072875	05030.00	072875	05120.11
48.	081375	04500.00	081375	05150.08	081375	05450.05	081375	06050.00
49.	081375	06100.01	081375	06250.00	081375	07350.05	081775	03450.00
50.	081775	08500.01	081775	10450.00	081775	10500.01	081775	11000.00
51.	081775	11020.02	082175	16250.00	082175	16270.01	082475	06350.00
52.	082475	06500.10	082475	06550.01	082475	07200.00	082475	07300.08
53.	082475	14300.00	082475	14350.09	082475	14370.02	082475	14550.00
54.	082475	14580.01	082475	15400.00	082475	15420.01	082875	21100.00
55.	082875	21150.01	082875	22400.00	082875	22450.01	082875	23020.00
56.	082875	23050.01	082875	23250.00	082875	23550.03	082975	00100.00
57.	082975	00250.02	082975	00550.00	082975	01000.01	082975	05250.00
58.	082975	05100.01	082975	06250.00	082975	06450.02	082975	07200.00
59.	082975	07350.02	082975	10150.00	082975	10200.01	082975	10550.00
60.	082975	11050.02	082975	11250.00	082975	12150.02	090175	00200.00
61.	090175	00320.02	090175	02550.00	090175	03000.01	090175	03350.00
62.	090175	03450.03	090175	04450.00	090175	04550.03	090175	22450.00
63.	090175	22500.07	090175	23050.00	090175	23100.02	090275	00200.00
64.	090275	00300.03	090275	00400.09	090275	00550.02	090275	01250.00
65.	090275	01350.06	090275	01400.05	090275	01550.06	090675	00050.00
66.	090675	00100.05	090675	00250.11	090675	00450.00	090675	00500.03
67.	090675	00550.01	090675	01350.00	090675	02000.02	090675	02350.00
68.	090675	03000.05	090675	03300.06	090675	04000.00	090675	04050.02
69.	090775	18150.00	090775	18250.02	090775	18420.05	090775	23100.00
70.	090775	23150.03	091175	10350.00	091175	10450.06	091175	11400.00
71.	091175	11550.09	091175	12050.03	091175	13150.00	091175	13200.01
72.	091175	14050.00	091175	14100.01	091175	14250.00	091175	14350.03
73.	091175	14400.17	091175	14500.11	091175	15050.19	091175	15150.11
74.	091175	15450.11	091175	16050.02	091175	16350.00	091175	16450.02
75.	091175	17200.09	091175	17350.03	091175	18000.00	091175	18920.02
76.	091175	19250.00	091175	19300.02	091175	19450.01	091275	15580.00
77.	091275	16000.01	091375	01250.00	091375	01300.01	091375	07580.00
78.	091375	08000.01	091375	10480.00	091375	10500.01	091375	12580.00
79.	091375	13050.02	091675	18400.00	091675	18450.01	091875	08350.00
80.	091875	08400.01	091875	09050.00	091875	09100.01	091875	09450.00
81.	091875	10250.03	091875	10550.00	091875	11000.01	091875	11250.00
82.	091875	12150.04	091875	12500.00	091875	13550.04	091875	16200.00
83.	091875	16500.03	091875	17100.00	091875	17400.02	091875	18300.00
84.	091875	19000.03	091875	19380.00	091875	19400.01	091875	20200.00
85.	091875	21280.07	091875	22000.00	091875	22050.01	091875	22200.00
86.	091875	22350.03	091975	00200.00	091975	00220.03	091975	00300.00
87.	091975	00550.12	091975	01050.00	091975	01200.02	091975	01450.09
88.	091975	01550.05	091975	02450.00	091975	02500.01	091975	03250.00
89.	091975	03400.02	092075	02500.00	092075	02550.01	092075	03050.00
90.	092075	03250.04	092075	04050.00	092075	04300.04	092075	04400.14
91.	092075	05000.09	092075	05200.00	092075	06150.11	092075	06350.04
92.	092075	07250.00	092075	07300.01	092175	10400.00	092175	10450.02
93.	092175	10480.01	092175	13450.00	092175	13510.02	092375	21150.00
94.	092375	21200.02	092375	21480.00	092375	22300.03	092375	22500.00
95.	092375	22550.01	092375	23150.00	092375	23400.03	092475	00200.00
96.	092475	00250.01	092575	07050.00	092575	07250.03	092575	12400.00
97.	092575	13400.09	092575	14050.00	092575	14100.01	092575	14250.00
98.	092575	14400.01	092575	15100.08	092575	15500.08	092575	17000.20
99.	092575	18100.30	092575	18250.04	092575	18350.01	092575	18450.03
100.	092575	19050.00	092575	19250.11	092575	20100.08	092575	20400.02
101.	092575	21350.01	092575	22350.00	092575	22400.01	092575	23200.00
102.	092575	23500.03	092675	00050.00	092675	00150.08	092675	01100.10
103.	092675	03450.00	092675	03500.01	092675	05250.00	092675	05300.01
104.	092675	06150.00	092675	06350.03	092675	10550.00	092675	11000.01
105.	092775	01450.00	092775	02000.02	092775	09150.00	092775	09300.02
106.	092775	14050.00	092775	14200.05	092775	14450.01	092775	15100.03
107.	092775	15300.01	092775	16200.00	092775	16250.01	100175	06350.00
108.	100175	07250.09	100175	07350.00	100175	08000.11	100175	09050.01
109.	100175	08300.00	100175	08400.01	100175	08550.02	100175	09350.02
110.	100175	10400.09	100175	10550.01	100175	12100.00	100175	12250.02
111.	101175	05050.00	101175	05150.04	101175	05250.01	101175	06050.00
112.	101175	06100.03	101175	06250.02	101175	07050.00	101175	07350.06
113.	101175	08050.02	101175	08250.02	101175	08450.07	101175	08550.03
114.	101175	09250.00	101175	09400.01	101175	10200.07	101175	10350.00
115.	101175	11100.05	101175	13400.00	101175	13500.05	101175	14300.01
116.	101175	15350.00	101175	15400.01	101175	16220.03	101175	16250.01
117.	101175	18550.00	101175	19000.01	101375	03500.00	101375	04250.05
118.	101375	04400.01	101375	05000.00	101375	05050.01	101375	06250.00
119.	101375	06300.02	101375	07000.06	101375	07250.08	101375	07300.05
120.	101375	07550.01	101375	08450.01	101375	09000.07	101375	09200.05
121.	101475	12150.00	101475	12200.01	101475	22350.00	101475	22500.03
122.	101475	23150.01	101575	00010.00	101575	00250.05	101575	00450.01
123.	101575	01000.04	101575	01150.00	101575	01250.07	101575	01500.03
124.	101575	01550.02	101575	03550.00	101575	04000.01	101575	04250.02
125.	101575	08550.00	101575	09000.01	101575	16550.00	101575	17100.04
126.	101575	17150.02	101775	16350.00	101775	17050.03	101775	18000.04
127.	101775	19150.10	101775	20050.02	101875	03100.00	101875	03150.01
128.	101975	09200.00	101975	10200.09	101975	10500.02	101975	11550.14
129.	101975	12150.00	101975	12250.02	101975	12350.00	101975	12450.02
130.	101975	13000.04	101975	13150.01	101975	13450.00	101975	14000.03
131.	101975	17250.00	101975	17300.01	101975	20450.00	101975	20500.01
132.	101975	22550.00	101975	23100.03	102075	00550.00	102075	01000.01
133.	102075	02150.00	102075	02200.01	102075	04100.00	102075	04150.01
134.	102575	08500.00	102575	09150.04	102575	09450.02	102575	10100.01
135.	103175	22050.00	103175	22550.05	103175	23550.11		
136.	000000000000000000000000000000000000000000000000000000000000000000000000000000000000							

PRECIPITATION DATA

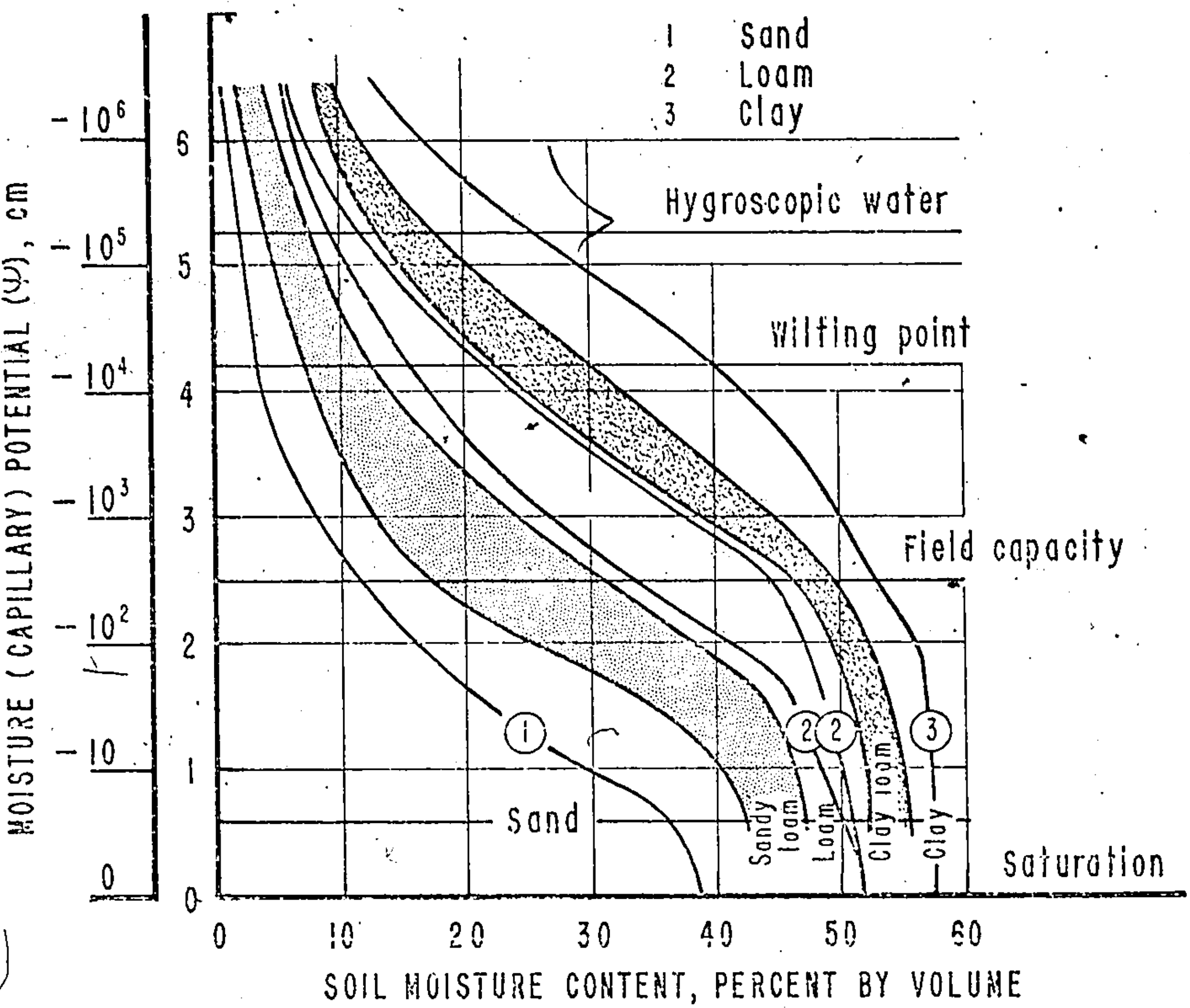
Temperature and pan evaporation.

LEAHY CREEK 1975 AV WEEKLY TEMP.

WEEK 1				
WEEK 5				
WEEK 9				
WEEK 13				
WEEK 17				
WEEK 21			60.86	54.29
WEEK 25	69.71	72.14	73.07	72.03
WEEK 29	73.29	69.51	74.05	70.68
WEEK 33	71.78	63.61	65.25	58.51
WEEK 37	55.27	55.64	53.4	51.87
WEEK 41	48.61	46.92	52.18	41.18
WEEK 45				
WEEK 49				

LEAHY CREEK PAN EVAP 1975

WEEK 1				
WEEK 5				
WEEK 9				
WEEK 13				
WEEK 17				
WEEK 21			.193	.211
WEEK 25	.221	.317	.330	.279
WEEK 29	.324	.294	.237	.274
WEEK 33	.240	.246	.160	.149
WEEK 37	.174	.096	.059	.111
WEEK 41	.106	.076	.079	.085
WEEK 45				
WEEK 49				



NOTE: Adapted from "Representative and Experimental Basins," edited by C. Toebes and V. Ouryvaev, published by UNESCO, 1970.

Soil moisture constants by texture

Tentative estimates of vegetative parameter "a" in infiltration equation (Holtan et al 1975).

Vegetation	Basal area rating a Poor condition	Good condition
Fallow	0.10	0.30
Row crops	0.10	0.20
Small grains	0.20	0.30
Hay:		
Legumes	.20	.40
Sod	.40	.60
Pasture:		
Bunchgrass	.20	.40
Temporary (sod)	.40	.60
Permanent (sod)	.80	1.00
Woods and forests	.80	1.00

Format for input parameters to UOM version of USDAHL-74 Model

Left justify. Use decimal in all fields except those of STORMDATES and TILLAGE.

SECTION (reference)	COLUMNS 1 thru 8	9 thru 16	17 thru 24	25 thru 32	33 thru 40	41 thru 48	49 thru 56	57 thru 64	65 thru 72	73 thru 80
	WATERSHED IDENTITY, DRAINAGE, PERIOD OF RECORD, ETC.									
IDENTITY	Leamy Creek, Hull, Quebec, Canada									
	Land use activity highway 5 construction (June to Oct. 1975)									
[illegible]	MMDDYY	(10 dates per card. Data must end in 8 col. blank field unless there are 50. insert blank if none.)								
(Figs. 1, 7, 8, 9)	W/S ACRES	NUMBER OF ZONES	NUMBER OF COEFFICIENTS TOTAL	ROUTING COEFFICIENTS ABOVE WEIR	NUMBER OF CROPS	DEEP GROUND-WATER RE-CHARGE IN/HR.	LAND USE CHANGES-YES OR NO?	TILLAGE CHANGES-YES OR NO?	PRINTOUT NEEDED DAILYS YES OR NO	POLLUT YES OR NO
[illegible]	2080.00	4	3	3	5	.00006	NO	NO	YES	NO
[illegible]	Z NUMBER	% W/S	LENGTH FT.	% SLOPE	FC IN/HR.	TOP SOIL IN.	TOTAL SOIL IN.*	% ASM1	% ASM2	
	1.	50.80	4687.5	35	.45	2	30	18.	20.0	
	2.	28.48	2604.17	.5	.02	8	24	45.0	48.0	
	3.	2.28	2083.33	3.	.02	9	24	48.0	50.0	
	4.	18.43	976.56	10.	.02	2	60	48.0	49.0	
SOILS [illegible]	Z NUMBER	% TP1	% FCAP1	% WP1	% CRACKING1	% TP2	% FCAP2	% WP2	% CRACKING2	
	1.	43.	18	8.0	0.	42.0	20.0	8.	0.0	
	2.	52.0	45	23.0	0.	54.0	48.	28.0	0.0	
	3.	54.0	48.0	29.0	0.	56.0	50.	30.0	0.0	
	4.	56.	48.0	29.0	0.	56.0	49.	29.0	0.0	
[illegible]	ΔT HRS .10	Mc HRS 1.46	INITIAL IN/HR. .0001	INIT. SNOW** 0	THAW** 35.					
[illegible]	a1 IN/HR. .016	m1 HRS. 2.63	a2 .011	m2 4.77	a3 .003	m3 10.17	a4	m4	Delete card if all zeros.	
[illegible]	% SUB FLOW DIVERTED TO CHANNEL	% Z1 CASCADING Z2	REMAINDER TO "CHANNEL" OR "ALLUVIUM"?	% Z2 TO Z3	REMAINDER	% Z3 TO Z4	Delete if only one zone.			
[illegible]	0.65	33.	Channel	20	Alluvium	80	Channel			
LAND USE [illegible]	CROP 1	CROP 2	CROP 3	CROP 4	CROP 5	CROP 6	CROP 7	CROP 8	CROP 9	
	Constrc.	Forest	Basin	Imperv	Grass					CROP NAMES
	.05	.90	.05	.00	.80					A VALUE
	.05	.50	2.00	.05	.05					Vd IN.
	.01	2.50	.01	1.0	1.00					ET/EP
(Sect. 2)	2.00	24.00	2.00	.00	10.00					ROOT DEPTH IN.
	200.00	75.00	200.00	75.00	72.00					TU °F
	10.00	45.00	10.00	32.00	32.00					TL °F
COLUMN	1-8	9-16	17-24	25-32	33-40	41-48	49-56	57-64	65-72	73-80

NOTES:

* Total soil inches are determined as depth of aerated soil; may be limited by water table, but must exceed topsoil by at least 1 inch to avoid error checks.

** INIT. SNOW is in water equivalent; THAW is temperature at which snowmelt starts.

*** WP_1 and WP_2 = Wilting point of topsoil and layer 2, respectively, in percentage volume.

**** TP = G + AWC + WP; FCAP = AWC + WP.

Format for input data to UOM version of USDAHL-74 Model

SECTION	COLUMNS 1–48	49–56	57–64	65–72	73–80
TEMPERATURE (52 values)	IDENTIFICATION AND YEAR	TEMP WEEK1	WEEK2	WEEK3	WEEK4
	1				
	2				
	3				
	4				
	5				
	6				
	7				
	8				
	9				
	10				
	11				
	12				
	13				

COLUMNS	1-8	9	11-13	14-19	21-23	24-29	31-33	34-39	41-43	44-49	51-53	54-59	61-63	64-69	71-73	74-79	80
TILLAGE *	CROP NAME	GZ	TIL	MMDDYY	TIL	MMDDYY	TIL	MMDDYY	TIL	MMDDYY	TIL	MMDDYY	TIL	MMDDYY	TIL	MMDDYY	
				BLANK		BLANK		BLANK		BLANK		BLANK		BLANK			

SECTION	% NUMBER	% CROP1	% CROP2	% CROP3	% CROP4	% CROP5	% CROP6	% CROP7	% CROP8	% CROP9
LAND USE %	1.	0.0	88.0	3.4	1.6	7.0				
	2.	5.4	0.0	0.0	5.6	89.0				
	3	0.0	0.0	0.0	80.0	20.0				
	4.	2.1	28.4	0.0	8.5	61.0				
	5	BLANK CARD**								

SECTION	COLUMNS 1–48	49–56	57–64	65–72	73–80
PAN EVAPORATION (52 values)	IDENTIFICATION AND YEAR	EP WEEK1	WEEK2	WEEK3	WEEK4
	1				
	2				
	3				
	4				
	5				
	6				
	7				
	8				
	9				
	10				
	11				
	12				
	13				
COLUMNS	1-8 / 9-16 / 17-24 / 25-32 / 33-40 / 41-48	49-56	57-64	65-72	73-80

*If TILLAGE CHANGE is answered YES in Table 1, enter cards each year. If answered NO, enter no cards after first year. First year TIL symbols: GZ = % reduction by grazing or damage; PLO = plow, PLA = plant; HAR = harvest; CUL = cultivate.

**If LAND USE CHANGE is answered YES in Table 1, (1) blank card follows "% crop" cards each year or (2) blank card only if no change. If answered NO in Table 1, blank card follows "% crop" cards first year only.