Sediment Loads in Canadian Rivers

W. Stichling

TECHNICAL BULLETIN NO. 74

INLAND WATERS DIRECTORATE,
WATER RESOURCES BRANCH,
OTTAWA, CANADA, 197[illegible]

ERRATA

Page vii, col. 2, para. 4: "*grams per litre*" (gr/l) should read "*milligrams per litre*" (mg/l).

Page 14, col. 1, Figures 13 and 14: the submersible water pump for the PWS-3 automatic sediment sampler is illustrated in the photograph at the bottom of the column; the Fischer-Porter turbidity measuring system is illustrated in the photograph at centre.

Page 17, col. 2, item (12): *Red River channel* should read *Red Deer River channel.*

Environment Canada
Environnement Canada

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Illustrations

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Foreword

New development of water resources in Canada demands more and better information on hydrological and morphological processes in streams and watersheds.

This paper reviews the history of the sediment data collection program initiated in Canada in 1961, describes the latest equipment in use for measuring suspended sediment and bed load, and outlines the methods used by the Water Survey of Canada for collecting and processing data. The paper compares sediment data collection techniques in use in Canada with those of other countries, and also compares sedimentation conditions and sediment yield.

Because information on sediment in Canadian streams is limited, existing data were reviewed and expanded to a standard period using existing records where available, and by estimating where records were not available. Sediment load was estimated for as many watersheds as possible by establishing a relationship between sediment load on the one hand, and flow and other physiographical parameters on the other. The average suspended-sediment concentration and the average suspended-sediment yield per square mile per year were computed, and tentative maps for these two parameters prepared.

Glossary

Bed load is that material moving in almost continuous contact with the streambed, being rolled or pushed along the bottom by the force of the water.

Bed-load discharge is the weight of bed load passing a cross-section of a stream per unit of time.

Bed material is the deposited sediment of which the streambed is composed.

Depth-integrated sediment sample is a suspended sediment sample collected at a single vertical in a cross-section in a sampler moving vertically at a constant transit rate.

Daily sampling vertical is a selected vertical in a cross-section in which individual suspended sediment samples are collected.

ETR (equal-transit-rate) method of measuring suspended sediment discharge involves a determination of the average suspended sediment concentration in the cross-section obtained by moving the sampler at a constant rate on all sampling verticals and combining in one large sample.

Instantaneous suspended sediment sample is a sample taken instantaneously at a fixed point in a river cross-section.

Particle-size analysis is the process of determining the size distribution of sediment particles in a sediment sample.

Point-integrated sediment sample is a suspended sediment sample taken over a relatively short period of time at a fixed point in a river cross-section.

Sediment is fragmental material transported by, suspended in or deposited by a flowing stream.

Suspended sediment or *suspended* load is sediment that moves in suspension in water, either as a colloid or through the influence of the upward component of turbulent currents.

Suspended sediment concentration is the ratio of the weight of dry solids in a water-sediment mixture to the volume of the mixture, and is expressed herein as "grams per litre" (g/l).

Suspended sediment discharge is the quantity of suspended sediment transported through a cross-section per unit of time.

Suspended sediment hydrograph is a graph showing the variation of suspended sediment concentration or suspended sediment discharge with respect to time.

Suspended sediment sample is a quantity of water-sediment mixture representing the average concentration or the average particle-size distribution of suspended sediment.

Total sediment discharge or total sediment load is the sum of the suspended sediment discharge and the bed-load discharge.

Introduction

Canada is a very large country and rich in water resources. Her economic development depends on resource development, not least of which is her water resources. Millions of dollars have been expended in recent years to further this development or to alleviate the threat from floods and other natural phenomenon associated with water resources.

Erosion by water can cause soil losses from cultivated farm fields. Deformation processes stimulated by moving sediment in rivers can lead to the formation of meanders and sandbars, move river channels, interrupt navigation and adversely affect commercial and other activities along water courses. Deposited sediment creates many problems, the most serious of which are the reduction in storage capacities and change in regime of reservoirs and lakes, the silting of irrigation canals and ditches, and the formation of deltas.

The rapidly accelerating pace of development of water resources leads to growing demands for more complete and more accurate information on hydrological and geomorphological processes in streams and watersheds. As time goes on, the availability of basic sediment and river morphological data becomes increasingly important in the planning and design of waterwork projects. To meet the growing demands for such data, a comprehensive sediment survey program is vital, with special emphasis on alluvial regions of the country.

The sediment survey program in Canada is still in its infancy. The program has been under way within the Water Survey of Canada for only a few years; as yet, the number of sediment stations and the amount of data available for each, are limited. The next few years, however, should see a healthy expansion in the network itself and in the scope of the program generally, particularly the morphological survey.

This paper presents an outline of the sediment survey program and its current status, including very general information on technical methods, some of the new types of instrumentation and data available, and a look at what is planned for the future program. Also included is the first attempt to summarize the data available for a 10-year period up to 1970 and to interpret these data in terms of the watersheds in Canada—using maps depicting the average suspended sediment concentration and the average annual sediment yield per square mile.

Nature of Sedimentation Processes

Sedimentation incorporates four main processes: erosion, transportation, deposition and compaction of sediment. These processes are complex and dependent upon many factors.

EROSION

In general, erosion may be divided into two types: *geologic erosion* and *accelerated erosion.*

Geologic erosion is defined as erosion of the surface of the earth under natural, undisturbed conditions. Geologic erosion and deposition have occurred throughout geologic times and they exist today as they did in the past. It is difficult to control geologic erosion because it is difficult to change the natural conditions that have existed over long periods of time.

Accelerated erosion is defined as the increase in rate of erosion over geologic erosion brought about by man's activities. Accelerated erosion is generally caused by agricultural activities and river-development programs.

There are many factors which affect the rate of erosion from watersheds. The more important are: runoff, intensity of precipitation, snow cover, slope of drainage area, form of drainage area, types of soil, vegetative cover, man's activities, and channel-erosion processes.

The intensity of erosion is changeable with time. It has been observed that there is a different erosion rate in different seasons. For example, erosion during spring periods is more intensive because the vegetation is light and runoff is generally near the maximum.

SEDIMENT TRANSPORT

Sediment is transported in suspension, as bed load rolling and sliding on the riverbed, and as a combination of both suspension and bed load. Sediment transport under different conditions of velocity, turbulence and different particle size, shape and specific gravity, results in very complex processes. In general, the sediment is affected by many factors, the more important among them being:

(a) unsteady inflow of water and sediment into the channel system

(b) changeable particle-size distribution of material in time and location

(c) unsteady velocity distribution over the length of the stream, caused by different sizes and shapes of cross-sections

(d) different regimes of tributaries, including the effects of deltas created by tributaries

(e) changeable turbulence in streams created by the channel roughness, different obstacles and by the processes of erosion and deposition in river channels, and

(f) other types of water circulation in the channels.

It should be pointed out that moving sediment is not uniformly distributed in cross-sections. The suspended sediment concentrations close to the banks or close to the bottom may be several times as great as the average concentration in the cross-section. As a rule, the concentration on a vertical increases from the surface to the bottom of the stream. This increase occurs due to different sizes of particles of sediment; there are more large particles close to the bottom.

Change in the suspended sediment concentration over the length of a river is also dependent on the slope of the channel, the rate of discharge, erosion processes, etc. Because of the lack of information for Canadian rivers, this phenomenon cannot be examined at this time. From studies in other countries, it is known that in the majority of cases sediment concentration increases from the origin of the stream to a certain location on the river, following which both the concentration and yield start to decline. Usually, the break point is located at the beginning of the low-slope reaches of the stream. In some streams this point may be considered as the beginning of the area where deposition is higher than erosion. The distance from this point to the river's mouth varies for different streams. For instance, on the Assiniboine River (for natural conditions), such a point is located in the area close to Portage La Prairie.

The distribution of suspended sediment concentration and sediment yield during a year is unsteady. Larger portions of sediment are transported by flood waters during the spring or summer floods. Moreover, the sediment concentration does not vary uniformly with flow. In the mountain streams where slopes and velocities are high the peaks of suspended sediment concentration take place concurrently

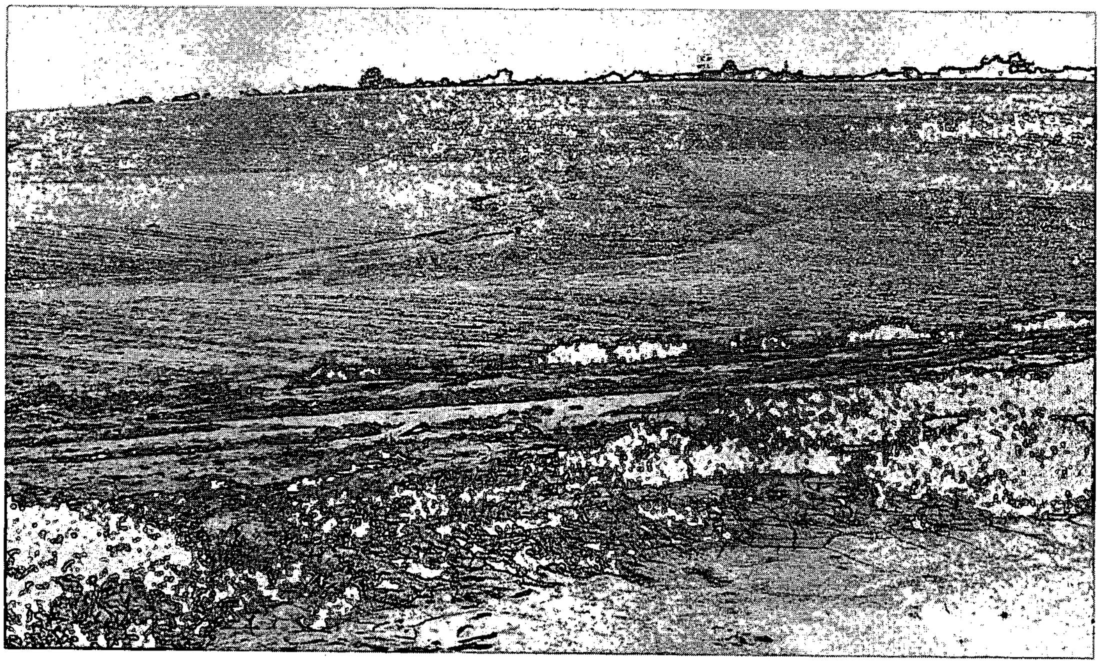


Figure 1. Pattern of surface erosion on cultivated land (Saint John River Watershed)

Figure 2. Pattern of channel erosion (Northwest Territories)

with the maximum flow. On the larger prairie streams the maximum sediment concentration occurs usually before the flow peak. The sediment concentration is dependent upon hydrometeorological factors: therefore, the distribution of sediment concentration may be different from year to year (Figs. 9, 10 and 11).

Bed load, that is, the material which is either moving in almost continuous contact with the streambed or rolling along the bottom of the channels, represents an important parameter in the river processes. Unfortunately, it cannot be thoroughly examined in this study because bed load information is lacking.

DEPOSITION

Deposition is the counterpart of erosion. The products of erosion may be deposited at any place starting immediately below their sources and extending down to a reservoir, lake or ocean. Usually the sediment deposits are divided into the following groups:

(a) deposits at the eroding slopes,

(b) flood plain deposits,

(c) channel deposits,

(d) deposits in lakes and reservoirs.

Sediment deposition may have positive and negative effects. Some deposits may form fertile flood plains which may be used as agricultural land. Other deposits may seriously damage high-cost property, crops, developments, etc. The deposition of sediment in irrigation canals reduces the rate of water delivered to irrigated areas and increases the cost of operation. The deposited sediment in navigable channels, waterways and harbors must be removed periodically to maintain necessary depths. The sediment deposited in natural streams decreases the channel capacity and results in higher and more frequent flooding. In artificial reservoirs or lakes, deposited sediment reduces storage capacity. This will affect the proper functioning of these lakes or reservoirs by reducing the effectiveness of flood control projects, lowering water supply or power output, and reducing water delivery for irrigation or other uses. Finally, the deposited sediment may create deltas which may also have positive or negative effects.

Particle-size distribution of sediment is a very important factor in sediment processes and particularly in the process of deposition. Streams have the capacity to carry only certain amounts of sediment in suspension. The coarse particles which streams are not able to hold in suspension may move on the river bed as bed load; larger particles of bed load may cause the movement to stop temporarily or permanently, creating deposited (alluvial) material or forming mud flats, sand or gravel bars, islands, etc. This phenomenon is important in the regime of river channels; therefore, the planners and engineers should give proper consideration to bed-load movement and the processes of deposition when designing water development programs or individual project.

Particle-size distribution of suspended sediment in every stream is dependent upon the geomorphological situation on the watershed and also on the regime of the flow and some other factors. It is evident, however, that the absolute amount of large particles in suspended sediment is large during flood periods.

Compaction of sediment, a complex process, is also related to the process of deposition and to the particle-size distribution of the material; the process of compaction is much slower with fine material. The study of density of deposited sediment is included in general sediment survey programs of reservoirs; however, this subject will not be discussed in this paper.

History of Sediment Survey in Canada

The first investigations of sediment transported by streams in Canada were undertaken by individual organizations or agencies in 1947. The International Columbia River Engineering Board carried out a sediment survey program on the Kootenay River during the period 1947 to 1949. A sediment survey program, begun on the South Saskatchewan River in 1948 by the Prairie Farm Rehabilitation Administration, was later extended to the North Saskatchewan, Saskatchewan and Red Rivers. The Water Rights Branch of the British Columbia Department of Lands, Forests, and Water Resources undertook a sediment survey program on the Fraser River upstream from Hope, in 1950. Thirteen hydrometric cross-sections were included in the program, with the continuous mean monthly suspended sediment yield being determined for several cross-sections for the years 1950, 1951 and 1952.

In addition to these programs, individual samplings and limited sounding programs to determine sediment deposition in lakes and rivers were undertaken by various agencies in parts of eastern Canada.

All these programs, too short and limited in scope, included only measurements of suspended sediment; the bed load in the river channel was never measured. The methods used for these early surveys were approximate and were limited by the equipment available; with advances in equipment design, however, improved methods have been developed and the results of today's surveys are definitely superior.

A continuous sediment survey program was initiated in 1961 by the then Water Resources Branch, Department of Northern Affairs and National Resources. Limitations on funds, equipment and personnel at that time restricted the scope of the program to a few stations on prairie streams. At these stations, only suspended sediment was sampled. As time went on, however, the number of stations was increased, taking in streams in other provinces. By mid 1972, the Water Survey of Canada, which now carries out hydrometric and sediment survey functions as part of the Inland Waters Directorate, Department of the Environment, was operating close to 150 sediment survey stations in Canada. (Fig. 3)

To oversee the planning of the hydrometric and sediment survey programs, the Network Planning Section was established several years ago. The duties of the section are to study the watersheds, to plan the hydrometric and sediment survey network in co-operation with other agencies and to recommend programs for the network. Because the Network Planning Section is as yet in the organizational state, the Sediment Survey Section performed some network planning studies and prepared a Sediment Survey Station Forecast (Fig. 4).

In addition to data collection, the sediment survey program includes special studies in the following fields: sediment surveys of reservoirs and lakes, surveys of rivers for degradation or aggradation processes (for example, the South Saskatchewan River below the Gardiner Dam), deformation of river channels and formation of deltas, morphological studies of watersheds, and different methods of carrying out bed load measurements, etc. The program was supervised and partially operated from the Headquarters in Ottawa. As the program became larger, more of the field work and responsibilities were transferred to District personnel at Vancouver, Calgary, Regina, Winnipeg, Guelph (Ontario), Montreal and Halifax. At the present time the survey and study of sediment in Canada and the respective responsibilities of the Districts and the Sediment Survey Section in Ottawa are divided approximately as follows:

	Districts	Ottawa
Data collection programs	80%	20%
River morphological survey and studies	50%	50%
Research programs applicable to the field work and field conditions	20%	80%

Publication of the sediment data as well as the other study reports is still the responsibility of the Sediment Survey Section in Ottawa.

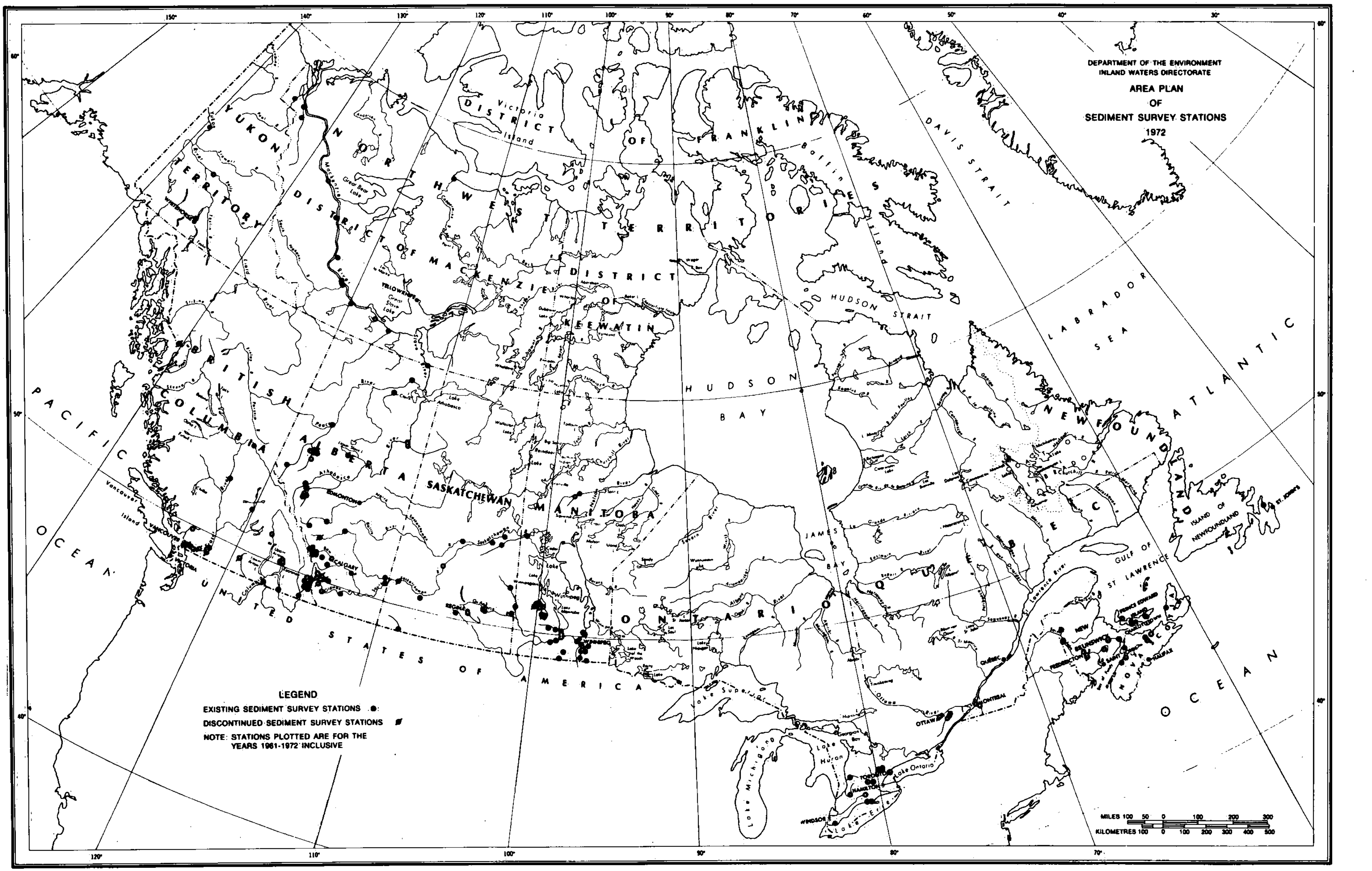


Figure 3. Area plan of sediment survey stations 1972

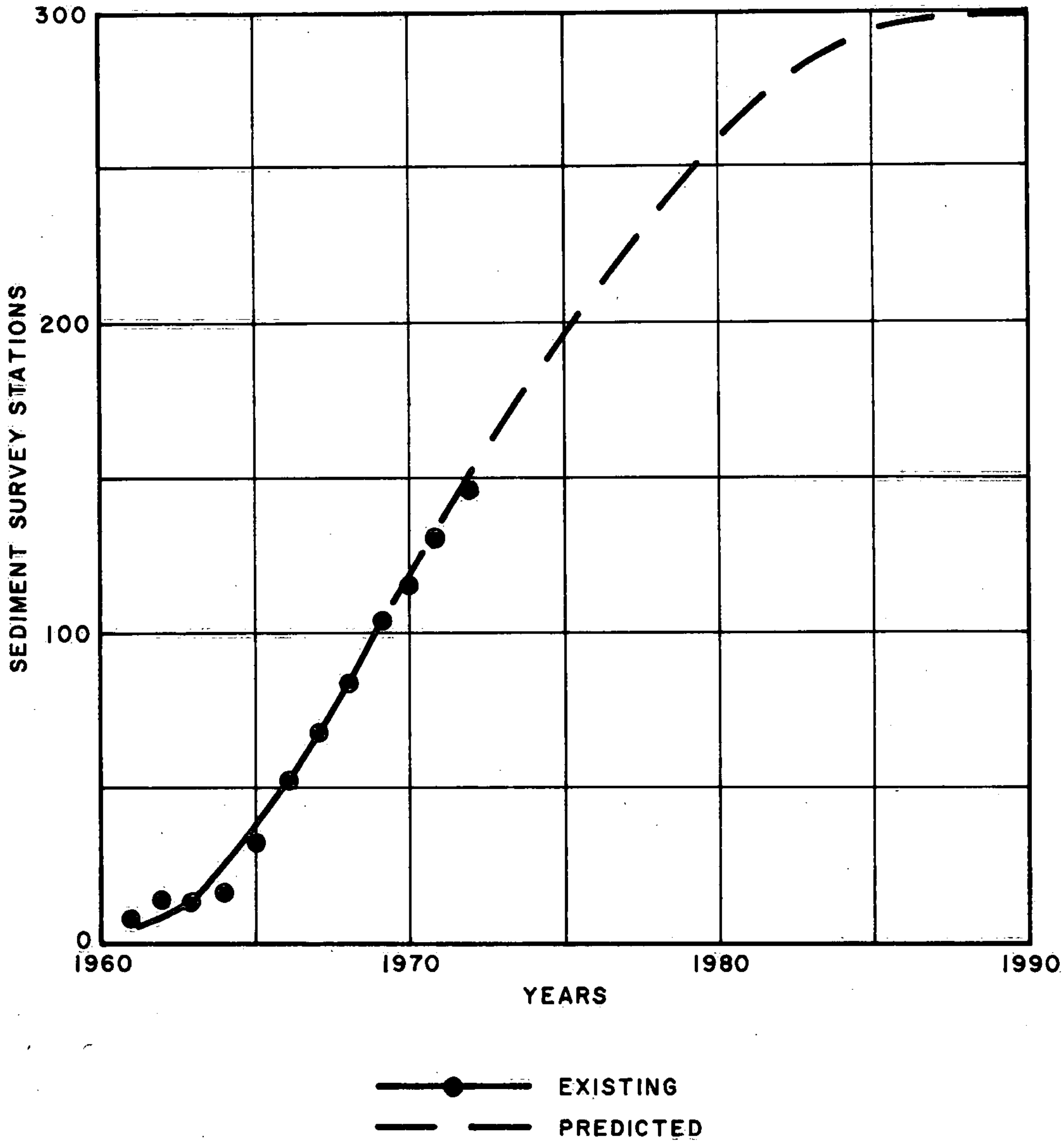


Figure 4. Sediment survey station forecast

Sediment Survey in Canada — 1971

The systematic sediment survey in Canada has now been under way for a little more than a decade. In 1971, sediment transport was being measured at 130 stations, a sizable growth in a ten-year period, but still considerably less than the three thousand hydrologic and hydrometric stations which are in operation. This preponderance of streamflow and water level stations over sediment stations can be explained by the fact that the sediment survey program was neglected in the early years.

In the sediment survey program organized in 1961, the ultimate plan has been to produce a network of sediment stations across Canada. It began with the measurement of sediment transport at selected stations in the important sediment producing streams on the prairies and has expanded into many areas of Canada on the basis of such factors as the morphological characteristics of the watershed and the need for data with which we would better understand the operation of existing and potential developments, flood control, channel improvement, etc.

SUSPENDED SEDIMENT DATA COLLECTION

To be meaningful, the determination of suspended sediment discharge in a stream must represent the full range of discharge in that stream. A few measurements or observations at irregular intervals could be seriously misleading. The observations should cover a long-term period and should include different seasons as well as wet and dry years.

Figure 5. The catamaran is an ideal sediment survey boat

At a given water level, the suspended sediment concentration when streamflow is increasing usually differs considerably from that when the flow is receding. The suspended sediment concentration is dependent upon many factors, most important of them being:

(a) changes in flow regime—either gradual or abrupt and either large or small,

(b) changes in the watershed management program—owing to diversions and storage of streamflow, bank or erosion protection programs, changes in land use or other changes in agricultural program

(c) variations in the distribution and frequency of precipitation on areas of the watershed (different tributaries produce unequal amounts of sediment)

(d) changes in vegetal cover on the watershed or changes in physical conditions of soil, banks and stream channels.

In view of these complexities, a suspended sediment survey program on a watershed should be undertaken only after the objective has been clearly defined and after working conditions and all facilities have been evaluated. The sampling program for a station should be designed to obtain average discharge-weighted concentration for the cross-section. Suspended sediment discharge, which is defined as the total weight of suspended sediment passing a cross-section in a certain period of time (usually in tons per day), is computed as the product of the average suspended sediment concentrations and stream discharge. Suspended sediment discharge may be determined by a number of different methods but the ones most frequently used are the point-integrating, depth-integrating and equil-transit-rate (ETR) methods.

Point-integrated method

The point-integrated method provides information on the suspended sediment concentration and particle-size distribution at individual points in the cross-section.

Suspended sediment samples are obtained using any one of a number of different samplers: the point-integrating sampler US P-61 or US P-63, point-integrating bottles, pumping samplers, and in some cases instantaneous trap samplers. Whatever equipment is used, the principle is the same—to provide a representative sample of suspended sediment taken from a fixed point in the stream during a fixed period of time.

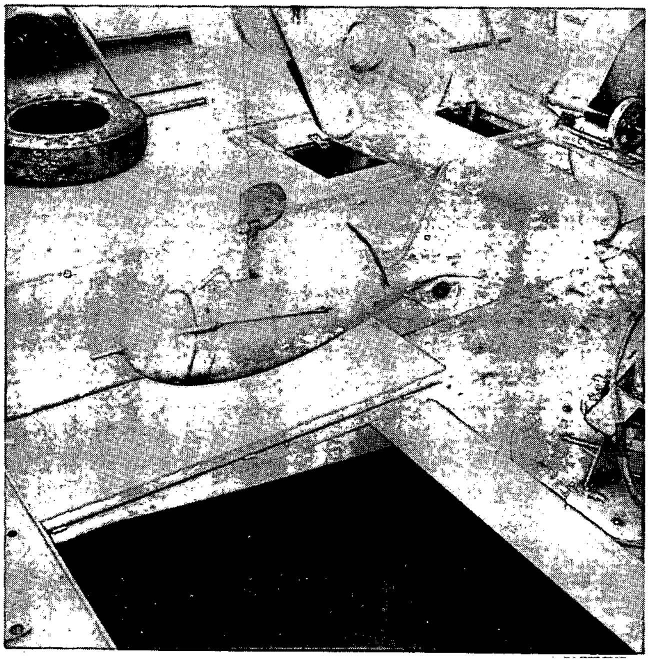


Figure 6. Suspended sediment sampling from a catamaran using the US P-63 sampler

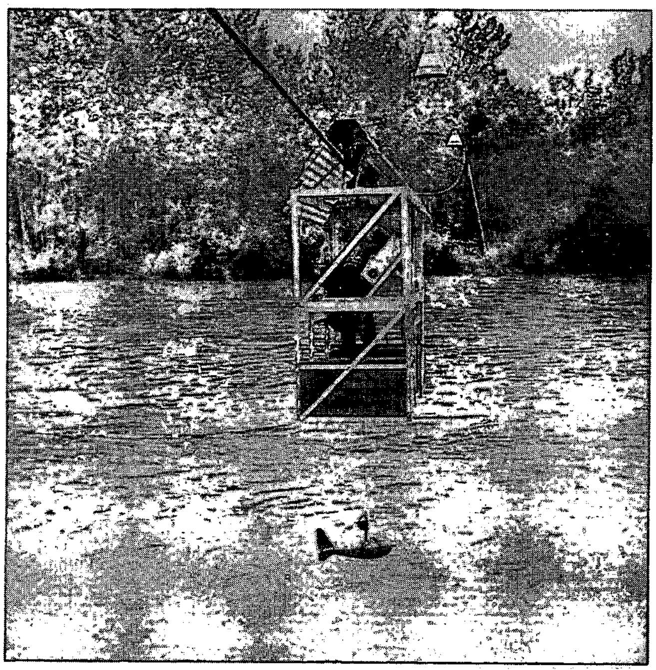


Figure 7. Suspended sediment sampling from a cable car using the US P-61 sampler

In carrying out the sampling procedure, it is the usual practice to select four or five verticals spaced at intervals along the cross-section. In each vertical, samples are taken at several points, the number of points depending upon depth as well as other factors. Frequently, as many as fifty sampling points may be required to give an accurate sediment measurement in the entire cross-section.

To compute the measurement, the graphical method is the most convenient.

Depth-integrating method

The depth-integrating method is essentially a simplified form of the point-integrating method and is used for most routine measurements of suspended sediment discharge. For depths up to 25 feet, the depth-integrating method requires only one sample at every sampling vertical. The sample is collected at a rate proportional to the velocity at the intake (nozzle), with the sampler lowered to the bottom of the stream and raised to the surface again at a uniform rate. If the depth is greater than 25 feet, more than one sample will be obtained by integrating in one direction only or by dividing the depth into two or more sampling verticals. The suspended sediment concentration from the depth-integrating sample is considered to be the average concentration in the vertical.

Suspended sediment discharges are calculated as the product of the average suspended sediment concentration and the streamflow in the corresponding vertical. The total measured suspended sediment discharge in a cross-section is the sum of the discharges in the verticals.

To determine the average concentration of suspended sediment in the cross-section, (for both methods) the total suspended sediment discharge is divided by the total streamflow.

Figure 8. Suspended sediment sampling by the wading method using the US HD-48 sampler

Equil-transit-rate (ETR) method

The equil-transit-rate method is a simplified form of the depth-integrating method. For this method, one speed is usually selected for the lowering and raising of the sampler. The sampling is performed at a number of verticals (as many as 20 or more) and all samples are combined in one large bottle. The suspended sediment concentration from the combined sample is considered as the average concentration for the whole cross-section.

Daily (individual) suspended sediment sampling

The measurement of suspended sediment by the point-integrating, depth-integrating or ETR methods can be a time-consuming and costly task. As it is necessary to obtain a continuous record of sediment discharge, obviously some less cumbersome, less expensive, but still reasonably accurate method had to be devised. This was done by selecting a representative sampling vertical (or point) in the cross-section of the stream and establishing a relationship between suspended sediment concentration for this vertical (or point) and the average concentration in the entire cross-section determined by a "control" measurement carried out by the point-integrating, depth-integrating or ETR methods.

Individual samplings on the vertical or at the point are taken by local observers or automatic samplers in accordance with a prepared guide program. During periods of high flow the observations are performed more frequently—in some cases several times each day.

Since every watershed has its own characteristics, there are different data requirements for each watershed. Because of this, the sediment survey program for each station is prepared on an individual basis. Some stations, particularly those on small streams with short flow periods, may require small numbers of samples to compute the total yearly sediment yield; on the other hand, some large streams, particularly during periods of unsteady flow may require as many as 2000 or 3000 samples properly distributed during the year.

Other particulars about suspended sediment

Sediment samples collected at the measurement cross-sections are processed in the sediment laboratories. The laboratory programs include the analysis of samples to determine suspended sediment concentration and particle-size distribution of collected sediment.

During winter seasons most watersheds in Canada are characterized by frozen and snow covered surfaces; therefore, the surface sediment erosion practically is non-existent or very small. Suspended sediment concentrations during the water periods are relatively low and largely created by processes of channel erosion. It should be pointed out that the hydrometric and sedimentation processes in the river channels during the winter season are more complex and it is more difficult to observe them, particularly at the beginning (freeze-up) and at the end (break-up) of the season. The formation of slush ice in the partially open channel or under ice cover creates a more confused situation which affects the distribution of the velocities and sediment concentration in the hydrometric or sampling cross-sections.

In general, the winter hydrometric-sediment programs are difficult, awkward and costly to carry out. Fortunately, many Canadian rivers (particularly small streams) have relatively low winter sediment yield; therefore, the winter programs in many cases are reduced substantially. Many rivers of small or average size have a winter sediment yield less than 5-10 per cent of the yearly sediment yield; some larger streams have winter sediment yields in the range 10 to 20 per cent.

The suspended sediment concentration during winter periods is relatively low, usually in the limit of 0-70 mg/l. Because of the low velocities under ice cover the suspended material consists of fine particles.

During recent years, the Water Survey of Canada has tended to use more automatic samplers. The new automatic sampler, PWS-3, (Figs. 12 and 13) developed recently, is most suitable for remote stations and those undergoing severe weather conditions. Very often automatic samplers have been installed in cross-sections with well mixed flow, at contracted reaches, below rapids, dams or control structures, etc. In many such cases they represent the average suspended concentration in the cross-sections. The Water Survey of Canada also has commenced the use of more monitoring units. Several units of the suspended solids recorder, type A.1690 (Southern Analytical) were installed in the last three years. (The unit was described in the paper presented at the 7th Symposium.) That type of unit produces satisfactory results; however, its maintenance and calibration sometimes creates complications. Also, the Water Survey of Canada purchases the Fischer and Porter type 17VC1000 Turbidity Measuring System consisting of a Turbidity Sensing Head and a Turbidity Indicator. The apparatus, used for measuring liquid turbidity, indicates the reading instantaneously in Jackson Turbidity Units (JTU). To get the suspended sediment concentration in mg/l the relationship between suspended sediment concentration and JTU must be established. The continuous recorder (Fischer and Porter, Series 51-4202BL Electronic Recorder) may be connected to such units (Fig. 14). The instrument is still not tested properly and cannot be compared with other solids recorders.

For all suspended sediment stations, concentration hydrographs are plotted on the basis of observed information. The concentration for the days without observations are interpolated or estimated. The computation of mean daily suspended sediment concentration is performed using the d-Mac Pencil Follower. Using computers, the daily suspended sediment discharges (in tons/day) are computed as a product of the mean daily sediment concentration, the

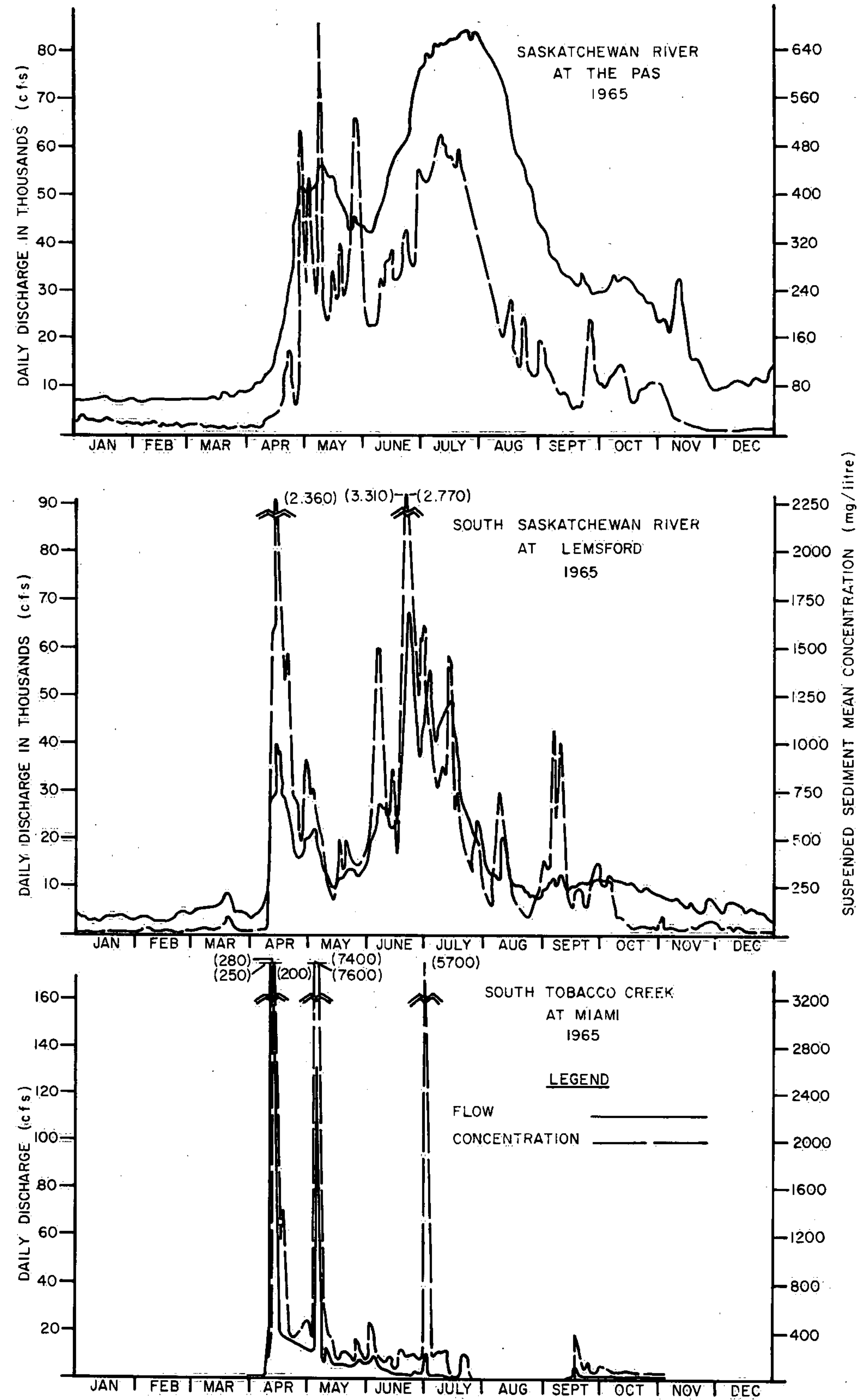
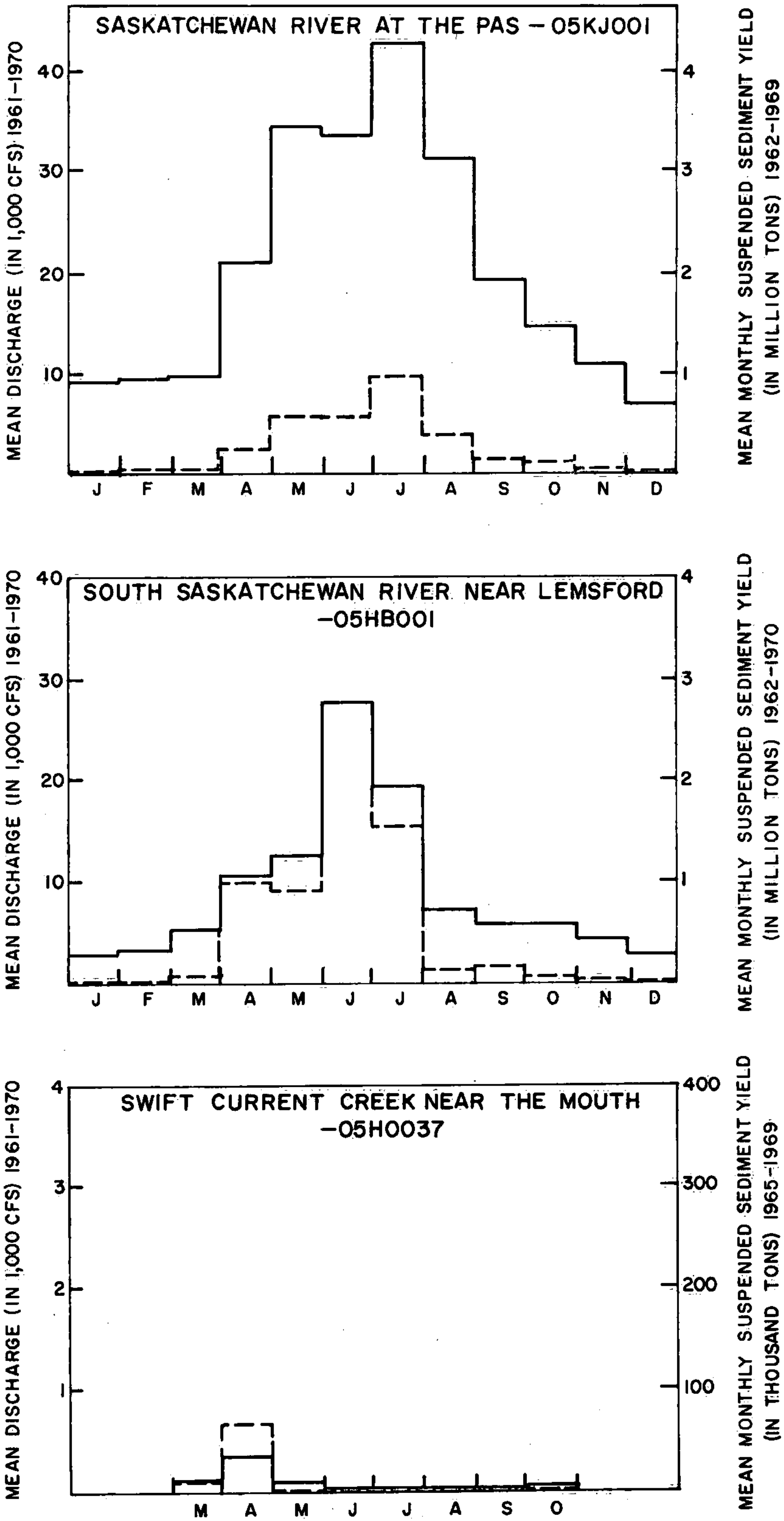


Figure 9. Flow and suspended sediment concentration hydrographs for 1965 for large, intermediate and small streams



DATA FOR 1961-1964 OBTAINED FROM CORRELATED ESTIMATES

Figure 10. Mean monthly flows and suspended sediment concentrations for large, intermediate and small streams

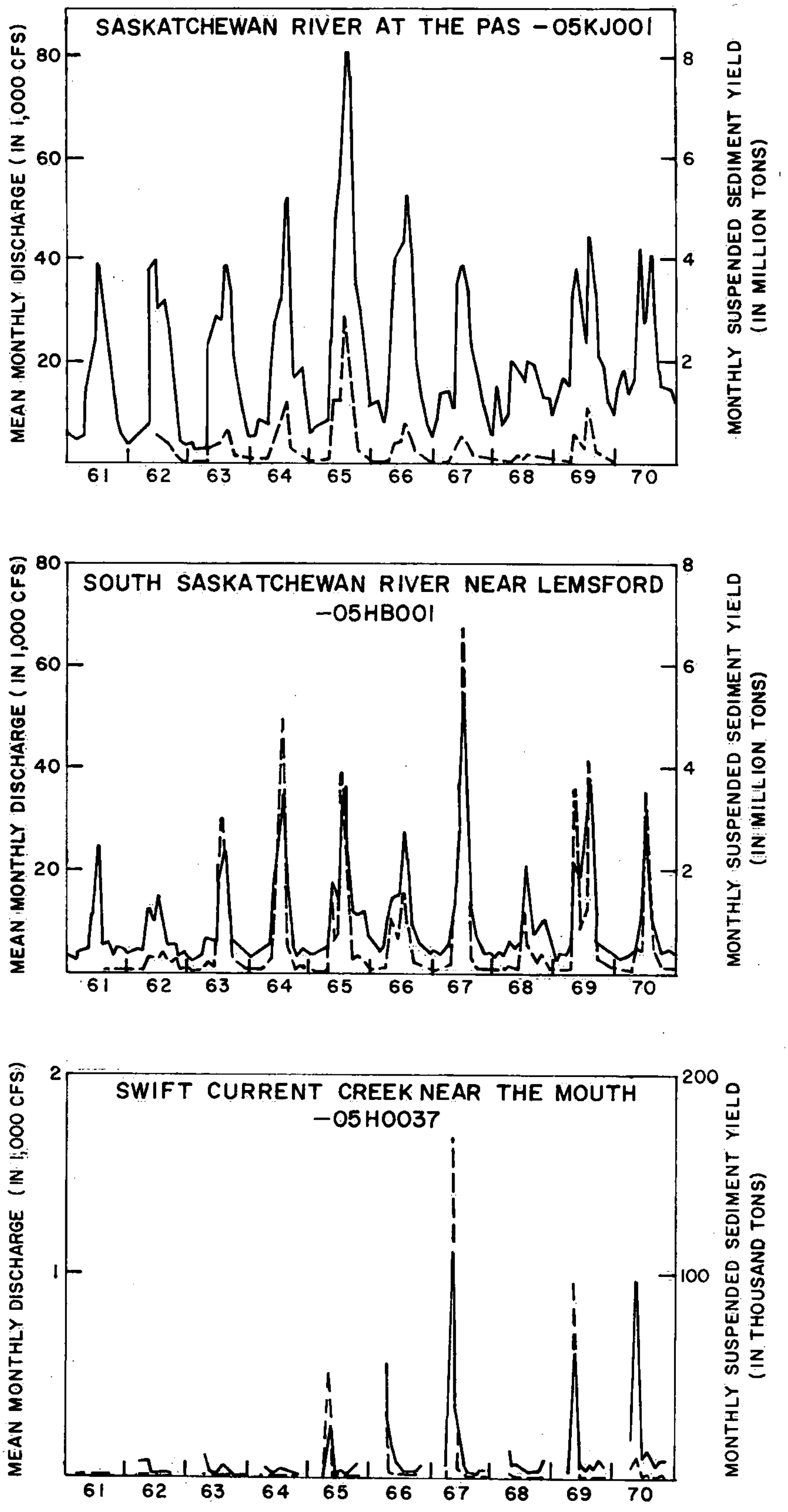


Figure 11. Flow and suspended sediment concentration hydrographs for the period 1961-70 for large, intermediate and small streams

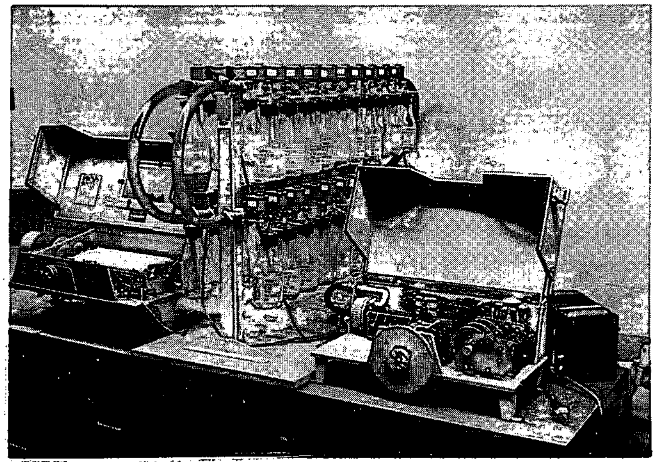


Figure 12. Automatic sampler (PWS-3) for sampling suspended sediment

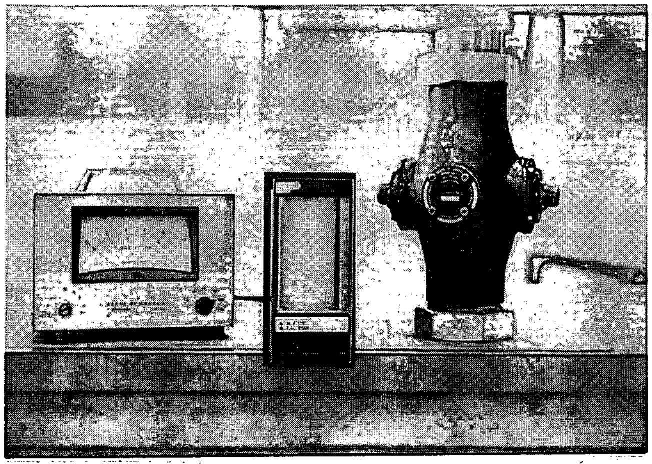


Figure 13. Submersible water pump for the PWS-3 automatic sediment sampler

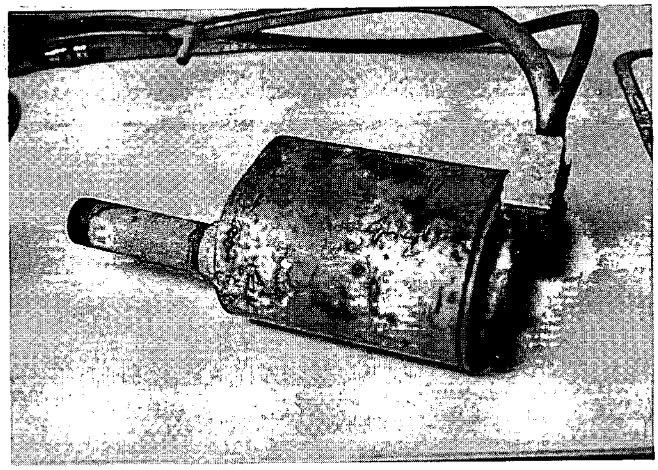


Figure 14. Fischer—Porter turbidity measuring system (17VC 1000) showing the recorder, indicator and sensing head

mean daily flow and the unit factor of 0.0027. The sediment data are published on an annual basis.

It should be pointed out that there is a need for further development of automated techniques for processing sediment information.

BED LOAD DATA COLLECTION

One of the main problems in the study of sediment is the determination of total sediment discharge, that is, the combined total of suspended sediment and bed-load discharge. Using newly-developed equipment and survey methods, it is not difficult to determine the suspended sediment discharge. To determine the bed load discharge—the sediment that rolls, slides or skips along the river bed—is, however, a much more difficult task. It should be borne in mind that what constitutes bed load at one cross-section may be suspended load at another section where stream velocity is greater.

There are several methods used to determine the bed-load discharge. No single method is satisfactory for all rivers under different conditions of flow. Some bed-load measurement methods are suitable for some particular conditions: the volumetric method was used for small streams; some determinations have been made with some success of bed load combined with suspended load, sampled below weirs or in cross-sections where the channel is constricted and water velocity so accelerated that all particles in transport are in suspension. The bed-load measurement method using bed-load samplers has some weaknesses and requires additional study and improvement. An extra research program will be required to study this method and equipment (different types of samplers) in the natural conditions covering different streams, different types of bed load, different techniques, and calibration of the samplers for different conditions.

Because of the shortcomings in the present methods of measuring bed load, the Water Survey of Canada sediment program has provided for bed-load measurement at a few important stations only. Most such stations are on small experimental or representative watersheds where the measurements are performed by volumetric methods.

With a sparsity of bed load data, it has not been possible to reliably determine bed load as a percent of total sediment load and no attempt has been made in this study to include an analysis of bed load. However, it is estimated that bed load as a percentage of total sediment load varies between 5 and 20 percent.

To overcome some problems related to the bed-load measurement methods, the Water Survey of Canada has instituted a research program aimed at establishing the relative merits of the different methods of measuring bed load under natural conditions. Among other equipment for measuring bed load (described in the Publications for the

7th Symposium) which are under study and testing is the new type of hydrophone (Figs. 15 and 16). It is an electronically operated acoustic device to record and analyze the sound created by bed load on the bottoms of streams. The hydrophone system was designed by Ithaco in 1971 in accordance with Water Survey of Canada specifications. This instrument is portable and consists of three sections: the hydrophone or data acquisition section, the signal conditioning section, and the recording section.

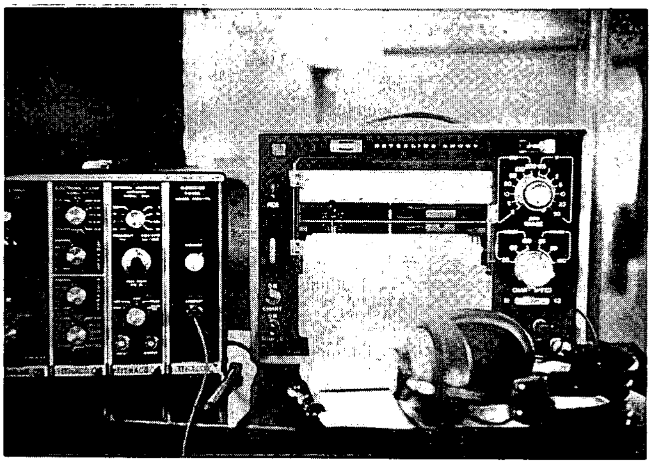


Figure 15. Hydrophone control system, a potential bed load measuring system

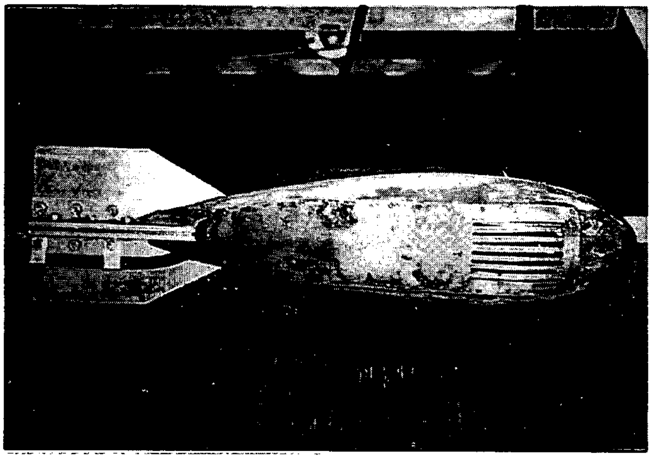


Figure 16. Hydrophone sensor mounted in a 150-lb lead sounding weight

Computation of bed load

Existing methods of measuring bed load are difficult and costly and generally give inaccurate results. Several analytical or empirical methods for computing bed-load discharge or total sediment discharge (suspended sediment and bed load) have been developed. Some of the more important methods are those by:

Du Boys, 1879
Meyer Peter, 1934
Schoklitsch, 1935
Meyer Peter-Muller, 1948
Einstein-Brown, 1950
Einstein Bedload function, 1950
Laursen, 1958
Blench Regime formula, 1964
Colby, 1964
Inglis-Lacey, 1968
Toffaleti, 1969

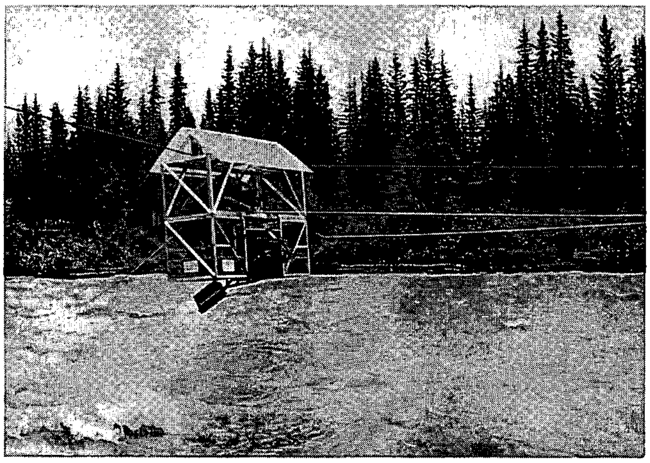


Figure 17. Bed load measurement from a cable car

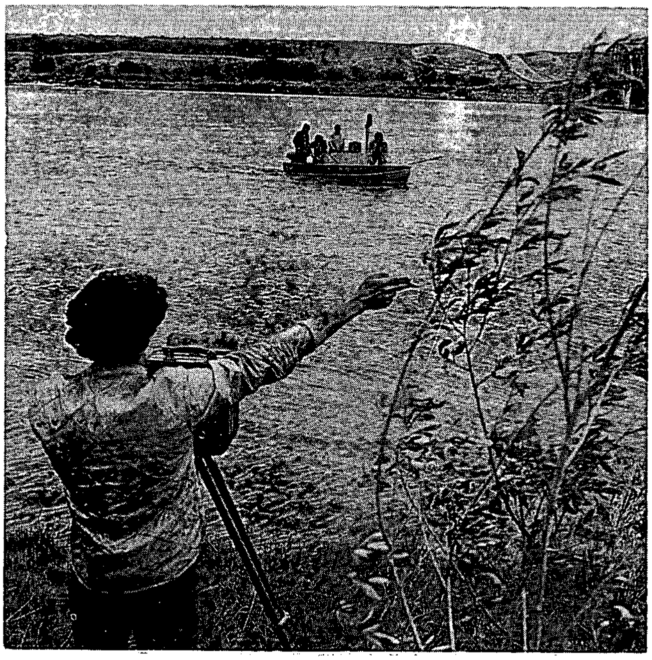


Figure 18. Fixing a sampling point using a tellurometer

In practice, however, suspended sediment discharge is usually measured, and bed load either computed or estimated, using some of the above mentioned formulas or as a percentage of either total load or suspended load. The bed-load formulas have been derived from studies in flumes; therefore, the error may be substantial in such estimates but it can be minimized by field observation of streambed and overbank deposits.

The computation of bed-load discharge by any of these methods requires a knowledge of the particle-size distribution of the bed material. To provide this information for future sediment studies, the Water Survey of Canada has included in its program the collection of bed-material data at all sediment survey stations. Information on particle-size distribution of bed material is published annually in the series of Water Survey of Canada sediment data publications.

SEDIMENT AND MORPHOLOGICAL SURVEYS FOR DIFFERENT PROJECTS

There are cycles of high and low flows, but over a period of time rivers adjust to the natural forces acting upon them. Within the general state of equilibrium, however, the morphological processes, such as erosion, sediment transport and deposition will normally continue on the watersheds and in the river channels and deltas. Experience has shown that the morphological characteristics and the regime of streams, lakes, deltas and watersheds must be taken into account in the initial planning of new water resources projects. A newly built reservoir can cause drastic changes to a river's regime. If it is large enough, a reservoir can permanently store practically the entire sediment load carried in the stream. The sediment so deposited settles in the upstream section of the reservoir and creates deltas which in turn cause backwater effects. The clear water released from the reservoir will have an entirely changed hydrograph from that of the sediment

Figure 19. Deposited sediment in Bassano Reservoir

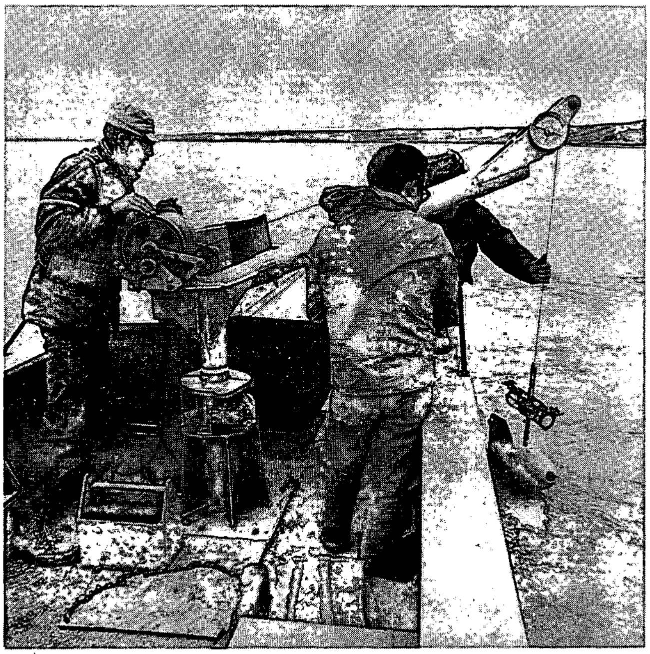


Figure 20. Combination bed material and suspended sediment sampler

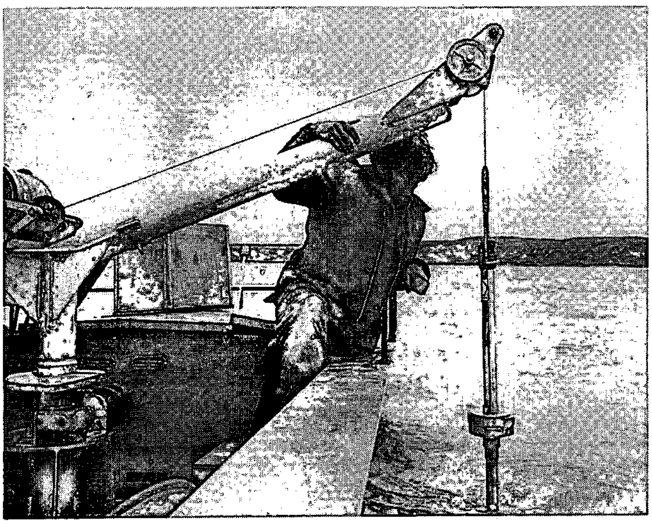


Figure 21. Sampling deposited material

laden waters, and channel degradation processes will probably take place.

It is evident therefore that any proposed project must not be evaluated on the basis of its positive benefits alone. It is becoming increasingly apparent that the damage or side effects which the project may cause must also be evaluated, not only over the short period of operation after the project is built, but covering the much later period when the river system starts to readjust to reach a new equilibrium. Neither the evaluation of the project itself nor of the side effects that it may cause can be achieved properly without resorting to adequate information in the field of hydrology, sediment transport or river morphology. The hydrological regimes of streams are dependent upon many factors (geographical, meteorological, etc.) and undergo considerable fluctuation from period to period (covering dry and wet cycles). Thus, the information if it is to be adequate should be based on a long period of observation, in some cases not less than 30 years. It follows, therefore, that if we are to provide the data necessary for future development and save millions of dollars, a data collection program for certain selected projects must be started as soon as possible.

Frequently, the data collection program for individual projects requires much more than the measurements of sediment discharges at a certain cross-section. Some large projects need information on watersheds upstream of the project, as well as information on other factors, such as the changes in the channels (below and above), erosion and deposition in tributaries, existing projects on the watersheds and operation of them, and other specific processes and phenomena on the watersheds. To provide such information, the Water Survey of Canada has been including in its program morphological surveys and studies of individual projects, watersheds, deltas, and estuaries. In the majority of cases, such programs were requested by the provinces or by other federal departments. Because some of the surveys and studies include a large volume of work, the programs are being performed in co-operation with the provinces or universities, or other departments. Very often, such programs require long periods of time (years) to complete the survey or study.

To better illustrate the numerous morphological problems in this country. A listing (by province) is provided for some larger and more important projects, river or deltas for which additional geomorphological survey and study programs will be required.

British Columbia

(1) River channel problems on the lower Fraser River (including hydrometric and sediment survey work in the unsteady flow reaches)

(2) The Fraser River delta (below Port Mann)

(3) Kootenay River channel and Kootenay Lake delta*

(4) The Columbia River delta at Revelstoke*

(5) The Kitimat River delta

(6) The Yukon River channel (including the White River)

(7) The deltas and bays of several streams on the western slopes of the Rocky Mountains.

Alberta and the Northwest Territories

(8) The Peace-Athabasca delta*

(9) The Mackenzie River delta

(10) Meandering channels of some northern streams

(11) Bed load in the North Saskatchewan River (upper regions)

(12) Erosion, sediment transport and deposition in the Red River channel*

(13) Coarse bed load in natural streams in some northern streams in Alberta and the Northwest Territories

(14) Erosion and deposition processes in some irrigation districts

(15) Sedimentation of the large reservoirs in Alberta.*

Saskatchewan

(16) The Qu'Appelle River watershed (including the main channel lakes)

(17) The Saskatchewan River delta (Pond Area)*

(18) The unstable channel of the Frenchman River (including Cypress Lake)

(19) Sedimentation of the South Saskatchewan River Reservoir (Lake Diefenbaker)*

(20) Degradation-Aggradation of the South Saskatchewan River channel between the dam and Saskatoon*

(21) Sedimentation of larger reservoirs in Saskatchewan.

Manitoba

(22) Morphological processes on the Red River channel and floodway*

(23) The Lower Saskatchewan River (including Cedar Lake)

(24) The Red River delta

(25) The Assiniboine River diversion system

(26) Morphology of the Northern Riding Mountain watersheds (Edwards Creek, Vermilion River, Valley River, etc.)*

(27) Morphology of river channels in some northern streams

(28) Sedimentation of larger reservoirs in Manitoba.*

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*The Water Survey of Canada is involved in surveys and studies of these projects.

Ontario

(29) Erosion on small watersheds (tobacco regions)

(30) Sedimentation in streams affected by earth slides (South Nation River, etc.)*

(31) Navigational problems in the St. Lawrence River channel

(32) Deltas and bays formed by small streams in Southern Ontario

(33) Sedimentation in larger reservoirs in Ontario.*

Montreal Area

(34) The processes of deformation in the St. Lawrence River channel

(35) The St. Lawrence River delta (including the Bay).

Atlantic Provinces

(36) Survey and study of some Prince Edward Island estuaries (a study of importance to the oyster industry)

(37) Morphology of the Miramichi River (a study of importance to the salmon industry)

(38) Morphology of the Churchill River in relation to power development

(39) Morphology of the Saint John River watershed*

(40) The Saint John River delta

(41) The Bay of Fundy development complex

(42) Sediment survey of larger reservoirs in the Atlantic Provinces.

As an example of these projects a short description of the study under (26) is described in the following:

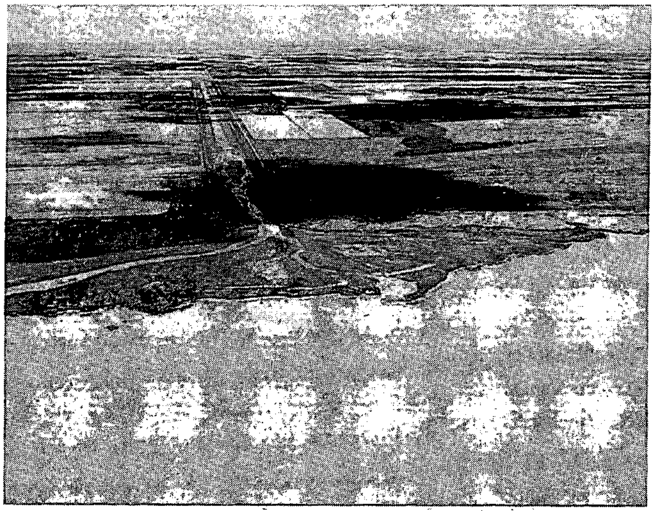


Figure 22. Edwards Creek delta formed during the period 1951-59

Morphology of the Edwards Creek Drainage Basin

The area surrounding the town of Dauphin, Manitoba, is an important agricultural region. Edwards Creek which flows through the middle of this region overflowed its banks repeatedly prior to 1948, causing widespread flooding. During the period 1948-51 the Prairie Farm Rehabilitation Administration constructed a silting basin on Edwards Creek and diverted Edwards Creek into Dauphin Lake. Since 1951 the capacity of the silting basin has been reduced substantially, the diversion has deteriorated considerably due to scour and lateral erosion, and a sizeable delta has formed in Lake Dauphin at the mouth of the diversion, threatening adjacent recreational areas (Fig. 22).

In 1968 the Sediment Survey Section was requested to undertake a morphological study of the Edwards Creek watershed to find solutions to the problems of scour and lateral erosion within the diversion and continued delta growths. The preliminary study of the watershed was completed and a report published in 1970. However, to substantiate the findings of this study, monitoring of sediment discharges in Edwards Creek must continue for a minimum of five years.

*The Water Survey of Canada is involved in surveys and studies of these projects. (see previous page for sample)

Sediment Surveys in Other Countries

In this section, an attempt will be made to compare the survey methods and techniques used in the Canadian sediment survey program with those in other countries. The sedimentation processes and the amount of sediment produced in Canadian Rivers also will be compared with the processes and amounts in other countries.

It should be mentioned that the lack of specific information on other countries and space limitations in this paper tend to restrict the scope of this chapter. Nevertheless enough general information has been available for a limited number of countries to serve as a basis for comparison.

From the rough comparison which follows, the sedimentation processes in Canada will be seen to be less intensive than those in other countries. It follows then that the sediment concentrations and yields from watersheds in Canada should therefore be much lower than the corresponding figures for other countries.

THE UNITED STATES

Canada cooperates closely with the United States in the survey and study of sediment transport, morphological processes in rivers, development of new equipment, etc. In many ways, the techniques used on either side of the border, are similar. The program in the United States began much earlier than the Canadian program with some observations being made more than a hundred years ago. It is readily seen then why the United States surpasses Canada not only in the number of sediment stations but also in the length of the continuous record available.

In company with the sediment data collection programs, the United States has carried out very extensive research programs in various fields such as: development of sediment survey techniques, study of hydraulic processes in flumes and natural streams, and development of measuring equipment and theoretical formulae for computing sediment transport under different conditions.

It should be pointed out that the United States, like other countries, has paid more attention to the studies of suspended sediment than to bed load. As a rule in the United States, suspended sediment has been measured while bed load has normally been determined by computational methods.

On the basis of sediment transport data available, a map of average sediment concentration in the United States has been published. Using this map, the sediment discharge can be determined for watersheds in almost every part of the country. Comparing such maps for the United States and Canada (though the Canadian map is not as well documented as that for the United States), it is not difficult to see that the rivers in the United States produce the greater amount of sediment. Three main factors stimulate the production of sediment in United States' Rivers: climatological conditions (winter in the United States is shorter than that in Canada); geological and geomorphological conditions; and more land affected by intensive agricultural activities.

The highest sediment concentration in the central and southern United States was observed on the Colorado, Rio Grande, Missouri, and Mississippi Rivers and tributaries. The extreme high concentration observed was close to 50,000 mg/l. For most of the country, however, the average concentration is in the range 200–2,000 mg/l.

THE UNION OF SOVIET SOCIALIST REPUBLICS (USSR)

Although the observation and measurement of suspended sediment discharge on selected watersheds began about 70–80 years ago, a large-scale systematic survey has been under way only for about 35–40 years. At present, some 2,000 sediment stations are surveyed.

Like the programs in other countries, the greatest stress has been placed on the study of suspended sediment. However, a considerable amount of work has been carried out on the study of bed load, with various types of equipment for measuring bed load being developed and a number of theoretical formulae to compute bed load being derived.

Enough information has been collected for the USSR to enable relatively accurate maps showing suspended concentrations and suspended sediment yield to be prepared. Many rivers, particularly in the southern mountainous regions, annually experience sediment concentrations up to 5,000 mg/l and sediment yields up to 2,500 tons/km^2. It is evident that the sediment in many USSR rivers is greater than that in Canadian rivers.

INDIA

For centuries India has practised large-scale irrigation and has experienced attendant problems of erosion, sediment transport, and river-channel processes. A systematic sediment survey program covering large rivers and tributaries was begun about 15–20 years ago. Some data were collected in earlier years for individual projects, but the data collection was not continuous and in the majority of cases the quality was not up to the level of the data published today. Although little is known about the sediment survey techniques generally in use on large rivers, it is known that newly advanced techniques are in use on several important watersheds.

From the information available for the three largest watersheds (nine stations) in India, the annual sediment yield was seen to fluctuate between 327 and 3,300 tons/km^2, while the annual sediment concentration was observed in the range from 520 to 4,000 mg/l.

AFRICA

The Sediment Survey Section does not possess any information on the sediment transported by the rivers of Africa. However, from the erosion map prepared by Dr. J. D'Hoore, Director of the Inter-African Ideological Service of the C.C.T.A., information on the average soil erosion for different areas of Africa was selected, and from this, some indication of the magnitude of the sediment yield was obtained. The annual soil erosion, in accordance with published maps fluctuates between 40 and 2,000 tons/km^2 per year.

YUGOSLAVIA

The sediment survey program was initiated about twenty years ago. The program covers only suspended sediment. Bed load was not measured because of the lack of reliable measuring methods. The survey technique for suspended sediment was relatively simple. In the majority of cases samples were obtained using integrating bottle-samplers, but in some cases instantaneous samplers were used. Maximum suspended yield was observed or estimated to be about 1,250 tons/km^2 per year, and maximum total sediment (inclusive of bed load) was estimated to be close to 1,375 tons/km^2 per year. However, there are many small streams in the country with much lower or higher sediment concentration.

THE NETHERLANDS

Unfortunately, sediment concentrations and yields of rivers in the Netherlands were unavailable for comparison with Canadian statistics. It should be pointed out, however, that the Netherlands contributed considerably to our understanding of sediment transport in streams.

Because there is a limited variety of streams in the Netherlands, work in that country has been confined to the study of the fine and medium particles of sand carried as suspended sediment and to the predominantly coarse sand carried as bed load. From these studies have come several useful techniques and a number of instruments with which to measure the sediment transport.

Sediment Survey Information

The total sediment discharge consists of two components—suspended sediment discharge and bed load discharge. Usually material in suspended sediment is finer than that in bed load discharge and constitutes a much larger part of the total sediment discharge. The measurement of suspended sediment discharge as a rule does not create many difficulties. The bed load movement, however, is more complex and depends upon many factors which often are difficult to evaluate. The technique and equipment for the measurement of bed load is still in the stage of development. In view of these facts, the program for measuring bed load on Canadian Rivers is growing slowly. The Water Survey of Canada operates only a limited number of such stations. The majority of them are located on small streams and measurements are performed by the volumetric method.

The results of the sediment survey operations are computed and published in the yearly papers, "Sediment Data for Canadian Rivers". The suspended sediment is computed and published in terms of the sediment concentration in milligrams per litre (mg/l) and in tons per day (t/day). The bed load computed in tons per day is measured by bed load samplers while the bed load expressed in cubic yards per day (or other unit of time) is determined volumetrically. The particle-size distribution of suspended sediment, bed material and bed load is expressed in percent.

OBSERVED SEDIMENT DATA

As was pointed out before, the sediment survey program in Canada is relatively new. The program began only a few years ago and as yet there are few stations for which lengthy periods of record are available. Of the 130 suspended sediment survey stations operating in 1970 only 20 stations have 10 years of record (1961-1970). There are 40 stations which have recorded information for more than 4 years but less than 10 years and the balance of 60 stations have less than 4 years of record (many of them with only 1 or 2 years). It should be noted that data for a few stations were not used in this investigation because the data were not representative of watersheds but were merely a measure of the sediment at cross-sections for some projects or research programs (diversion channels, spillways, cross-sections with particular characteristics, etc.).

So far as bed load is concerned, however, the information is less satisfactory. There are no stations with bed load records longer than 5 years and only a few stations with records between 1 and 5 years. Because of the lack of available bed load information this parameter was not investigated thoroughly in this study.

ESTIMATED SEDIMENT DATA FOR WATERSHEDS WITHOUT SURVEY PROGRAMS

In view of the shortage of recorded sediment survey information an effort was made to estimate, to reconstruct or to compute new (additional) sediment data for additional years, additional watersheds and new locations. Because every additional station represents a valuable plotted point on the maps, an attempt was made to estimate as many as possible of the new stations (locations). Since the survey program started in 1961, (there was no information previously) the standard or uniform 10-year period (1961-70) for this investigation was selected. Considering the broad variety of methods and approaches in the restoration of the data, the stations with estimated data were divided into four main groups:

(a) the stations with sediment observation periods longer than four years

(b) the stations with sediment observation periods less than four years

(c) the stations having both long hydrometric periods, and strategic locations on the watersheds

(d) the cross-sections which have few hydrometric or sediment records but which have strategic locations on the watersheds.

Among the stations in group (a) were some which required that data be estimated for only a few months or a limited number of years. In the majority of such cases the sediment discharges were correlated with corresponding streamflow and with sediment discharges on neighboring streams or on the same stream but below or above the considered cross-section. For the most part the correlation coefficients were very high (about 0.90). The correlation for the stations with short periods (4–5 years) were similarly carried out using the information from neighboring streams or upstream-downstream stations. However, the correlation unit periods used were much shorter, usually monthly or the period of individual floods. Usually, there were fewer points in the correlations, and the correlation coefficients ranging between 0.60 and 0.80 were lower.

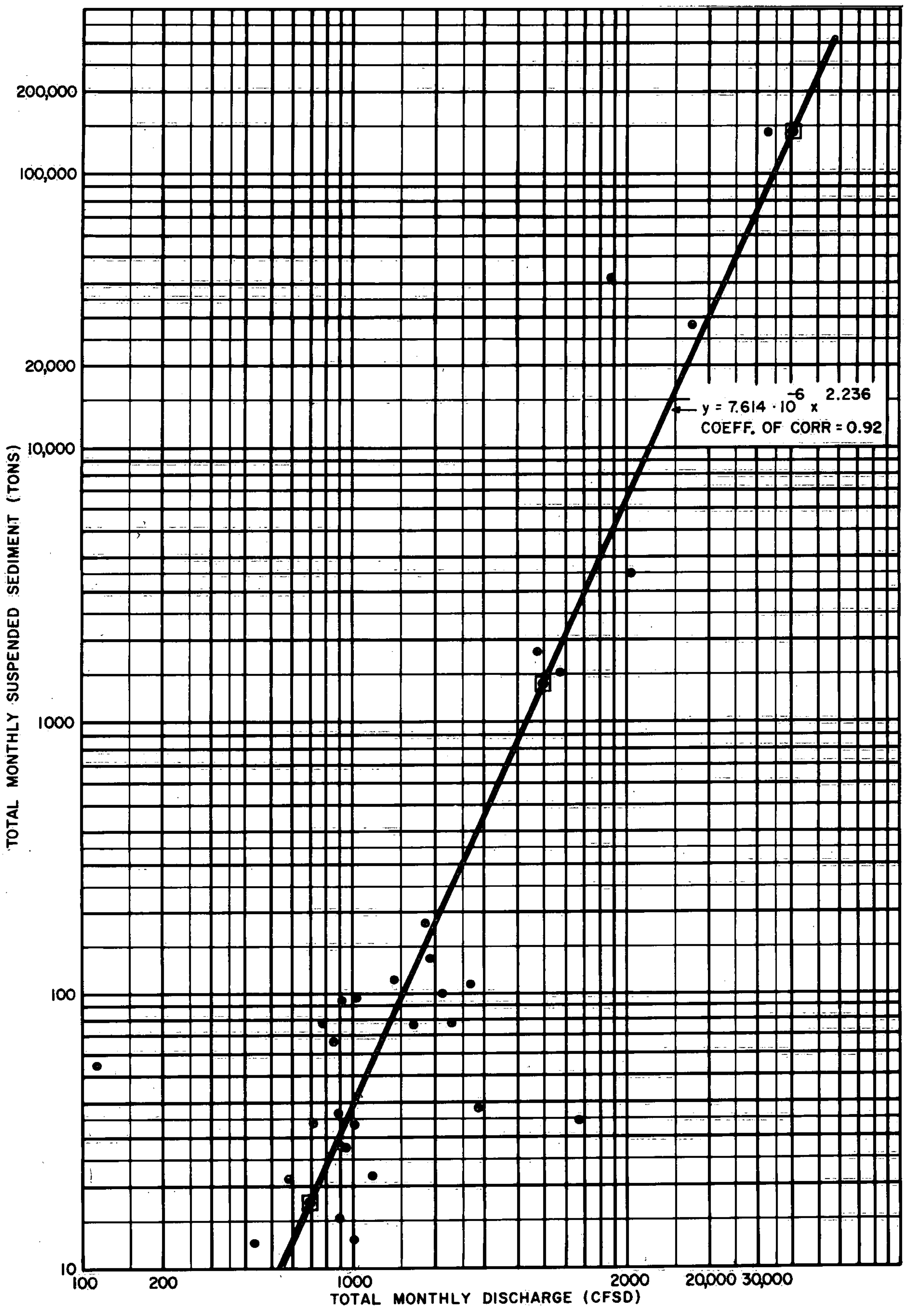


Figure 23. Relationship between total suspended sediment and total discharge for Swiftcurrent Creek near the Mouth

The missing data for the stations in group (b) were estimated or restored by the combined methods. Ordinarily, to achieve this, correlation was used quite often, but in some cases multiple correlation had to be used. Usually, the sediment and flow discharges of the neighboring streams were used as the independent variables. For some stations with very short periods (1–2 years) for which the correlation method was not applicable, missing sediment information was estimated using a simple ratio between the flow data for the comparable watersheds.

It was more difficult to estimate sediment data for group (c) since only the hydrometric records were available. In such cases, three main approaches were investigated. The first one involved the selection of a similar watershed for which both hydrometric data and sediment observations were available. If the similarity in the physiographical characteristics was very close, then the sediment records were transferred to the considered watershed without any adjustments. The second approach involved the computation of the suspended sediment discharges using some analytical methods. Unfortunately, information on channel parameter was not normally available and not very often used. The third method used the results of the miscellaneous samplings obtained occasionally or periodically by the Water Survey of Canada or by some other organizations (power corporations, universities, provincial organizations, etc.). Though there were few such samples, the average sediment concentrations were estimated by using this information.

The method of estimating missing data for group (d) is very approximate. This method is based on a very limited number of single sediment samples (sometimes just one sample), and a general inspection of the watershed and the channels in the river system. The method was used mostly as a last resort.

It should be pointed out that this paper represents only the first attempt at estimating the sediment concentration in Canadian rivers. Because of the limited data available, the methods of estimation had many shortcomings and weaknesses. For that reason, this reconstructed period of information represents a very preliminary document and anyone using it should be mindful of these shortcomings.

Territorial Distribution of Sedimentation Processes

In order to illustrate the distribution of sedimentation processes in Canadian rivers, two main parameters were selected for use on maps of Canada. One map illustrates the average yearly suspended sediment concentration in Canadian streams, expressed in milligrams per litre (Fig. 24), and the second map illustrates the average suspended sediment yield in the streams in tons per square mile per year (Fig. 25). It should be pointed out that the maps were prepared giving more weight to the large and medium sized watersheds; therefore, these maps should be considered only for these types of watersheds. The maps represent the first approximate attempt to give a condensed picture of the processes of sedimentation in Canadian rivers. The preparation of more appropriate maps would require many more stations than are available at the present time.

SUSPENDED SEDIMENT CONCENTRATION MAP

The sediment concentration may be considered as an indicator of the erosion activities on a watershed, even though there are many other geographical or morphological factors which may have influenced these processes in one way or another. It's safe to say then that this map shows the results of the morphological processes performed by a unit of runoff on various watersheds of the country. For individual watersheds the sediment concentration has been adjusted to reflect the suspended sediment concentrations existing before newly built waterwork projects, reservoirs, diversions, etc., were created.

Because the sediment concentration fluctuates from year to year, the map was prepared using the ten-year average concentration (1961-1970). There were a few places, however, where shorter periods had to be used. The average sediment concentration was plotted at the centre of gravity of the respective drainage basin. The sediment concentrations for the drainage areas between sediment stations in a single watershed were computed (with adjustments where necessary) from the recorded concentrations at these stations and then plotted at the centre of gravity of the respective areas of the watersheds.

Variations in the average sediment concentration in mg/l are shown on the map using six zones with the following average concentrations: 0-50, 51-200, 201-400, 401-700, 701-1000 and 1000 mg/l. Because it was difficult to determine the boundaries of the concentration zones on large watersheds, and also on the smaller watersheds where the information on individual and miscellaneous sampling programs or observations were used, the boundaries between such zones were estimated and they are shown with a different symbol on the map (Fig. 24). It should also be pointed out that some additional methods of interpolation for the adjustment of the boundaries of zones inside watersheds was made. In some cases of the stream runoff distribution between the watersheds was used.

An approximation of sediment concentration for different rivers may be estimated from this map. For this purpose, the watershed area of the considered stream should be plotted on the map and the corresponding concentrations shown on the map for adjacent watersheds should be properly determined. The average concentration for the whole watershed may then be estimated using these determined values.

It is evident that all territory of Canada from the point of view of sedimentation and erosion, could be divided into regions but the lack of data prevented making such division. It is not difficult, however, to find even from the analyses of the available information that there are four main factors affecting the erosion and sedimentation processes which formed the separate regions:

(a) geological formation:

The rivers on the prairies or other regions with similar alluvial formations have high sediment concentrations. Such rivers include many streams in the Prairie Provinces, such as the South Saskatchewan, North Saskatchewan, Red, Athabasca, and Peace Rivers.

(b) slope of river channels or elevation of watersheds:

It is not difficult to identify that the rivers in the mountain regions have more intensive erosion and also higher sediment concentration, particularly during the spring runoff periods. This is caused by high velocities in the streams and in some cases by the action of moving glaciers.

(c) climatological condition or geographical locations:

The results on the map also illustrate that the erosion processes and consequently the sediment concentrations in the southern regions are higher than those in the northern regions. Two main factors are stimulating to such distribution of erosion and concentration: there is more tillable land in the southern regions, and the runoff periods in the northern regions are much shorter.

(d) man's activities, reduction of forested areas, other development activities:

An important factor in the acceleration of erosion and the production of sediment in the streams is man's activities, particularly in the field of agriculture. Widespread use of land for the production of food started several thousand years ago, and since then, more land has been brought under cultivation. It is this increase in man's activities that has caused more disturbance to nature and, in turn, has resulted in more land erosion and more sediment in the streams. The removal of forest cover and conversion of land into cultivated land can accelerate the process of erosion tremendously.

SEDIMENT YIELD MAP

Like the concentration map, the yield map represents an interpretation of the quantitative characteristics of suspended sediment produced by Canadian rivers. Here an attempt was made to show the distribution of the average annual suspended sediment yield, which is expressed in tons per square mile per year. For this purpose, the total suspended sediment yields for each of the years 1961-1970 were divided by the corresponding drainage areas of the basins and then the unit sediment yield for the 10-year period (if the information was available) was computed. The unit suspended sediment yield, which is proportional to the flow and concentration, represents an amount of sediment produced by a river system from a unit of drainage area in one year; therefore it may be compared with the other unit sediment yields from different watersheds regardless of the size of drainage basins.

It should be pointed out that in all calculations of the unit sediment yield the watershed's gross drainage area was used. The fluctuation in connection with the size of contributing areas of watersheds (even for the glaciated regions) was not taken into consideration. The unit sediment yield was computed for parts of watersheds if there were large reservoirs in operation in the last 10 years. Otherwise, whole drainage areas were used.

Because of steady changes in the natural conditions in different areas, the unit sediment yields show a large fluctuation from basin to basin. The lowest sediment yield (t/sq. mi./year) was observed in the northern regions and the highest, on the glaciated prairies and watersheds of some mountain streams.

For the purpose of convenient illustration on the map (Fig. 25), the unit sediment yield (before plotting on the map) was subdivided into the following ranges:

1st range—for the sediment yield lower than 5 tons/sq. mi./yr.,

2nd range—for the sediment yield 5-25 tons/sq. mi./yr.,

3rd range—for the sediment yield 26—50 tons/sq. mi./yr.,

4th range—for the sediment yield 51—250 tons/sq. mi./yr.,

5th range—for the sediment yield 251—1000 tons/sq. mi./yr., and

6th range—if the sediment yield is >1000 tons/sq. mil. per year.

It is evident, however, that the unit sediment yield was higher in the mountain regions with higher precipitation, i.e. with higher runoff and also higher slopes, and also in the regions with high concentration of suspended sediment in their streams. To such regions may be included the streams of the glaciated and hilly watersheds such as the upper parts of the Athabasca, Peace and Red Deer Rivers, some intensively cultivated areas in southern regions of Ontario, and other watersheds.

Because of lack of observed information, many areas on the map, particularly in the northern regions, are not covered. Though the map represents only a part of the country, it gives a general indication of the sediment transport from a unit of drainage area produced by various rivers.

Conclusion

The damages created by sediment processes are varied and flexible and depend mainly upon the amount of erosion and sediment in the watersheds, sediment transport in the river channels, and the sediment deposition. An understanding of these processes will require not only sediment records, but also additional long-term information on the hydraulic parameters of river channels.

It has already been mentioned that Canada is a comparative latecomer to the field of sediment survey. This is because Canada started late to develop its water resources, and also relatively few of the Canadian rivers produce large amounts of sediment. However, even in this comparatively short period of time during which the sediment survey and study program has been in operation in this country, much has been learned and a great deal accomplished.

If the present pace of development of water resources in Canada accelerates within the next few years, demands for information and data on sediment processes in Canadian rivers will multiply. In anticipation of these demands, the Water Survey of Canada plans, in co-operation with the other organizations and departments, to expand the sediment data collection network to cover every area in Canada in which streams are affected by sediment processes. Also being planned are expanded river morphological surveys and studies to cover all important fields. The survey programs should provide necessary sediment and other related data for morphological studies of the watersheds and river channels for different areas of the country, many of which are listed in this paper.

Because advance sediment survey and study programs require different and more modern types of equipment and a variety of techniques in field, laboratory, and computation procedures, future planning calls for advanced research to be carried out on those factors.

Although the sediment survey program in this country is still in its infancy, the work being done in these, its formative years, is providing a sound foundation upon which to build expanded and more comprehensive survey programs in the future.

Bibliography

Inter-Agency Committee on Water Resources. Subcommittee on Sedimentation, U.S.A. Measurement equipment and analysis of sediment loads in streams. Reports No. 1-14. 1940-1963.

Jovanovic, S., and M. Vukcevic. Suspended sediment regimen on some watercourses in Yugoslavia and analysis of erosion processes. Publication No. 43 of the I.A.S.H. Volume I, Land Erosion, Instruments, Precipitation, pp. 337-359. 1958.

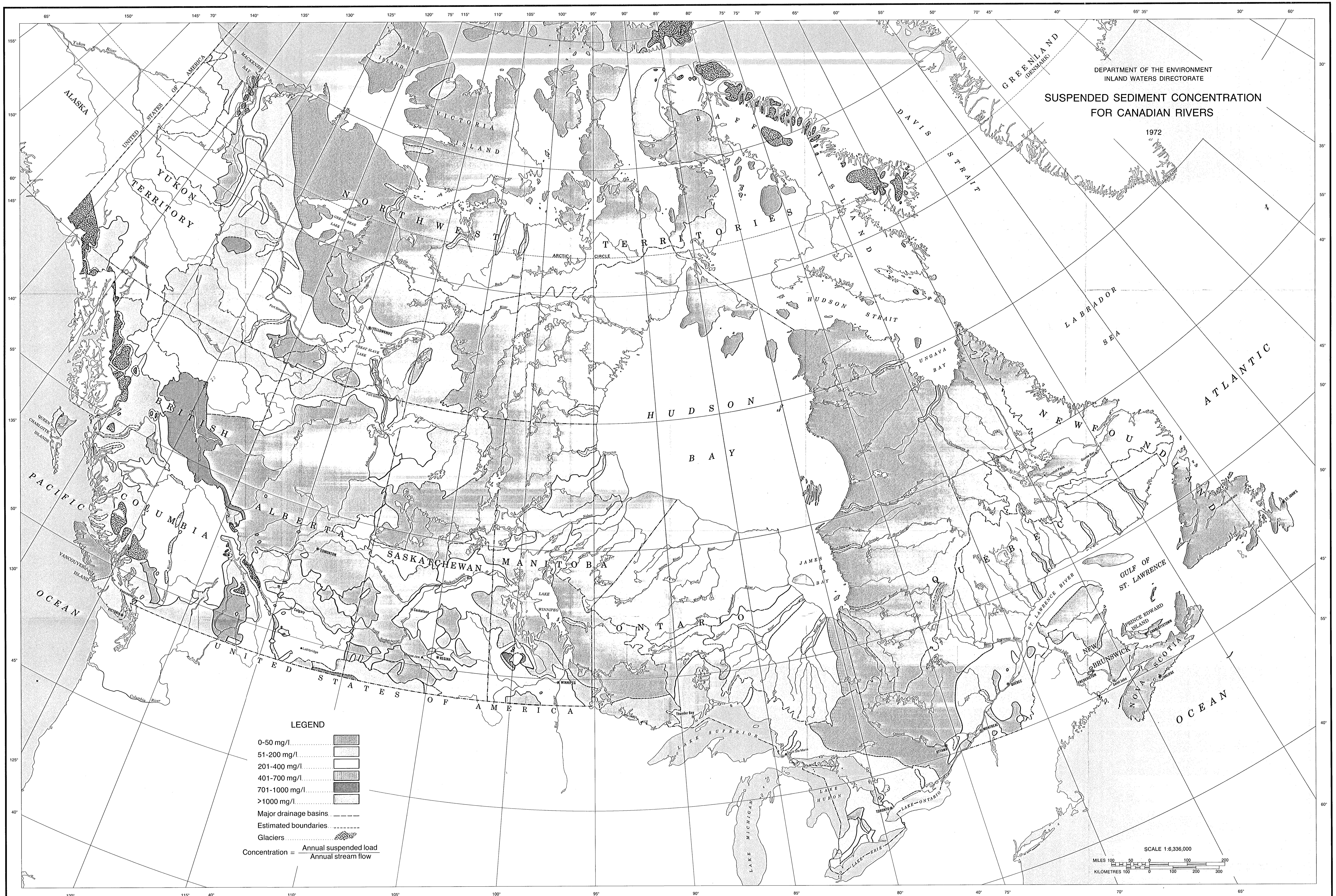
Lopatin, G.W. 1952. Sediment of Rivers of USSR. Ed. Geographical Literature, Moscow, USSR.

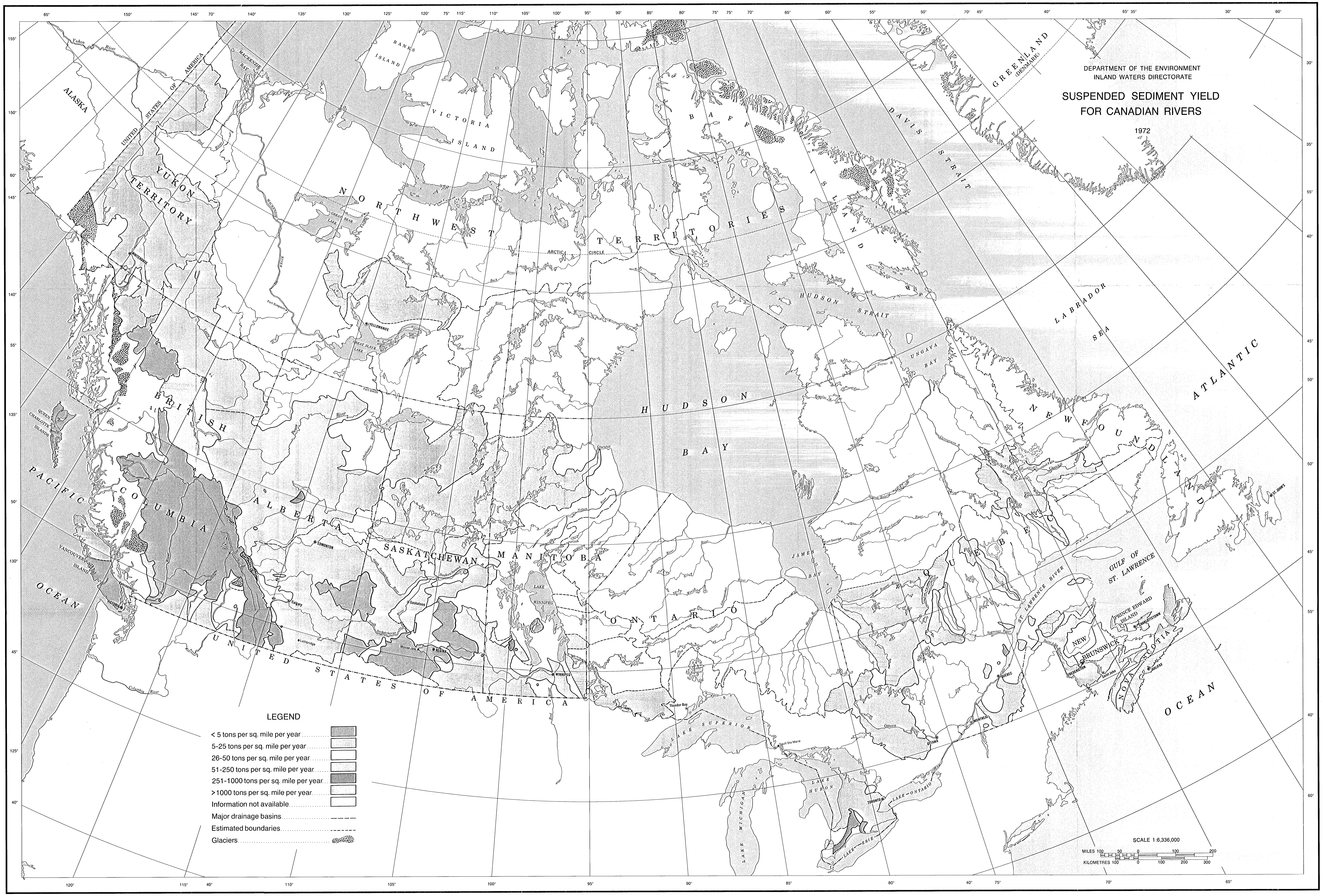
Proceedings of Hydrology Symposium. No. 7, 1969. Inland Waters Directorate, Dept. of the Environment, Ottawa.

Sediment Data Publications. Department of the Environment of Canada, Ottawa, 1961-1970.

Shamov, G.I. "River Sediments." Hydrometisdat, Leningrad, 1959 (Regime, computations and methods of measurement of sediment).

Stichling, W., and T.F. Smith. 1968. Sediment Survey in Canada. Inland Waters Directorate, Dept. of the Environment, Ottawa.


DEPARTMENT OF THE ENVIRONMENT
INLAND WATERS DIRECTORATE
SUSPENDED SEDIMENT CONCENTRATION
FOR CANADIAN RIVERS
1972
LEGEND
0-50 mg/l
51-200 mg/l
201-400 mg/l
401-700 mg/l
701-1000 mg/l
>1000 mg/l
Major drainage basins
Estimated boundaries
Glaciers
Concentration = Annual suspended load / Annual stream flow
SCALE 1:6,336,000
MILES 100 50 0 100 200
KILOMETRES 100 0 100 200 300
ALASKA
UNITED STATES OF AMERICA
YUKON TERRITORY
NORTHWEST TERRITORIES
BANKS ISLAND
VICTORIA ISLAND
BAFFIN ISLAND
GREENLAND (DENMARK)
DAVIS STRAIT
LABRADOR SEA
HUDSON STRAIT
UNGAVA BAY
HUDSON BAY
JAMES BAY
ARCTIC CIRCLE
BRITISH COLUMBIA
ALBERTA
SASKATCHEWAN
MANITOBA
ONTARIO
QUEBEC
NEWFOUNDLAND
NEW BRUNSWICK
PRINCE EDWARD ISLAND
NOVA SCOTIA
GULF OF ST. LAWRENCE
ST. LAWRENCE RIVER
PACIFIC OCEAN
ATLANTIC OCEAN
QUEEN CHARLOTTE ISLANDS
VANCOUVER ISLAND
LAKE WINNIPEG
LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
LAKE ONTARIO
LAKE ERIE
GREAT BEAR LAKE
GREAT SLAVE LAKE
YELLOWKNIFE
EDMONTON
Calgary
Lethbridge
Saskatoon
REGINA
WINNIPEG
Thunder Bay
TORONTO
OTTAWA
MONTREAL
QUEBEC
FREDERICTON
CHARLOTTETOWN
HALIFAX
Yukon River
Columbia River


DEPARTMENT OF THE ENVIRONMENT
INLAND WATERS DIRECTORATE
SUSPENDED SEDIMENT YIELD
FOR CANADIAN RIVERS
1972
LEGEND
< 5 tons per sq. mile per year
5-25 tons per sq. mile per year
26-50 tons per sq. mile per year
51-250 tons per sq. mile per year
251-1000 tons per sq. mile per year
>1000 tons per sq. mile per year
Information not available
Major drainage basins
Estimated boundaries
Glaciers
SCALE 1:6,336,000
MILES 100 50 0 100 200
KILOMETRES 100 0 100 200 300
ALASKA
YUKON TERRITORY
NORTHWEST TERRITORIES
BRITISH COLUMBIA
ALBERTA
SASKATCHEWAN
MANITOBA
ONTARIO
QUEBEC
NEWFOUNDLAND
NEW BRUNSWICK
NOVA SCOTIA
PRINCE EDWARD ISLAND
UNITED STATES OF AMERICA
GREENLAND (DENMARK)
BANKS ISLAND
VICTORIA ISLAND
BAFFIN ISLAND
QUEEN CHARLOTTE ISLANDS
VANCOUVER ISLAND
HUDSON BAY
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ST. JOHN'S
YELLOWKNIFE
WHITEHORSE
VICTORIA