NWRI CONTRIBUTION 85-07

Dick (32)

RIVERS, RESEARCH AND SEDIMENT

by

T. Milne Dick, Ph.D., P. Eng.

Chief
Hydraulics Division
National Water Research Institute
Canada Centre for Inland Waters
867 Lakeshore Road
Burlington, Ontario, Canada

March 1985

FOREWORD

The impetus for this report began with a seminar on National Perspectives on Sediment organized by Dr. T. Day and held on March 5 and 6, 1985, in Ottawa. A bomb scare and subsequent evacuation of the building prevented delivery of the remarks contained in this report.

T. Milne Dick

AVANT-PROPOS

Le présent rapport a été rédigé à la suite d'un atelier sur les perspectives nationales en matière de sédiments organisé par M.T. Day et tenu les 5 et 6 mars 1985, à Ottawa. Le contenu du rapport n'a pu être présenté à cette occasion étant donne que l'immeuble dans lequel se déroulait l'atelier a fait l'objet d'une menace d'attentat à la bombe et a dû être évacué.

T. Milne Dick

ABSTRACT

An outline of the controlling independent variables for the sediment transport by rivers is given. Coarse sediment research is required to determine how rivers react to change. Fine and washload sediment is a major factor in environmental quality and transport of organic and non-organic pollutants. The thrust of both research programs should be to develop models for use in managing change. Relationships with other data gathering activities and quality control activities are illustrated. Finally a set of research priorities are proposed.

RESUME

On donne un aperçu des variables indépendantes principales dont dépend le transport des sédiments par les rivières. Il faut effectuer des recherches sur les sédiments grossiers pour déterminer comment les rivières réagissent aux changements. Les sédiments fins influent beaucoup sur la qualité de l'environnement et sur le transport des polluants organiques et inorganiques. Les deux programmes de recherche doivent viser à concevoir des modèles pour contrôler les changements. On décrit les rapports qui existent entre les activités de contrôle de la qualité et les autres activités de saisie de données. Enfin, on propose un ensemble de priorités en matière de recherches.

1.0 RIVERS AND CIVILIZATION

A river is a channel along which both water and sediment flow. Sediment and water interact to form the river, to create its meanders, ripples, banks and shallows. A river is dynamic and its form reacts to changes in the flow of water and the supply of sediment.

Civilization changes rivers which are used for many purposes. Exploitation of the river often brings about alterations in the discharge, or in the river geometry or in the sediment supply. Examples of the various uses and the typical action resulting from the use are briefly summarized in Table 1.

2.0 SEDIMENTS IN RIVERS

River form is dominated by the coarser-grained materials such as sand pebbles and cobbles. Finer material, such as silt and clay, is kept in suspension until it reaches a lake, a reservoir or the sea.

For natural rivers the fine silt and clay are not important hydraulically or morphologically. However, the silt and colloidal clay particles are significant for dammed rivers and for their role in conveying organic and inorganic substances. Scientifically, it is useful to consider separating the coarser sediments from the fine sediments which are often designated as wash load.

Sediment transported by a river has certain effects which are briefly indicated in Table 2.

3.0 BASICS OF COARSE SEDIMENT AND FLOW INTERACTIONS

The simple sketch in Fig. 1 illustrates the basic scientific situation with respect to river flow.

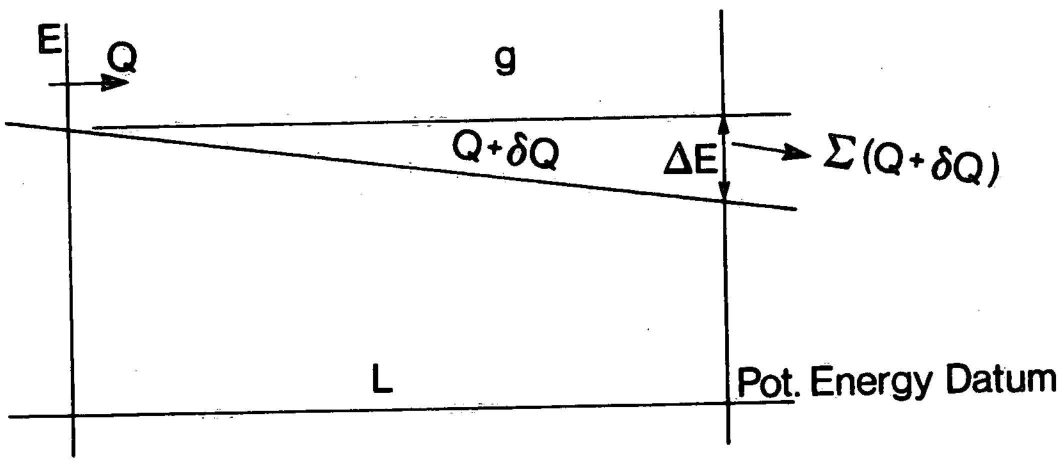
A river transports water and sediment from a point of higher potential energy to a lower one. Usually, because of lateral inflow or groundwater supply, the discharge Q in cubic metres per second increases

TABLE 1. Uses and Actions Affecting Rivers

Use	Action
Flood Control	Dam construction, water control gates Winnipeg Diversion Thames Barrage
Navigation	Dredging, water level control St. Lawrence Seaway Fraser River
Power	Water level control, dam construction, diversions La Grande 2
Land Development	Dykes, bridges, revetments Red River, Winnipeg
Aggregate Borrowing	Dredging - Fraser River
River Crossings	Bed excavations, tunnels St. Lawrence River
Irrigation	Reduction in flow of river, dams
Water Supply	Dams - river intakes
Waste Discharge	Outfalls
Cooling Water	Reduction in water flow, loss of water

TABLE 2. Effect of Sediment Transport in Rivers

Coarse Sediment	Fine Sediment
Controls river form and appearance	Transports chemicals and nutrients
Fills reservoirs	Fills reservoirs and lakes
Fills intakes and culverts	Lowers water quality
Controls river hydraulic roughness and consequently, water level	Clogs gravel beds
Forms banks, shoals and deltas	Fertilizes flood plains
- - - - -	- - - - -
Coarse sediment is transported as bed load and induced suspended load	Fine sediment and washload are transported in suspension



INDEPENDENT VARIABLES

- S – SLOPE OF ENERGY
- Q – VOLUMETRIC FLOW IN UNIT TIME
- ρ – DENSITY OF WATER
- μ – VISCOSITY OF WATER (SURFACE TENSION NOT INCLUDED)
- ρ_S – DENSITY OF SEDIMENT
- OTHER SEDIMENT CHARACTERISTICS
  - d – SIZE OF GRAIN
  - c – COHESION
  - ε – ERODIBILITY INDEX
- g – GRAVITATIONAL PARAMETER

FIG. 1

along the river. Obviously also it varies with time; therefore Q is both a function of position and time.

The independent variables are:

- S - slope or rate of loss of potential energy. The difference is not significant in short distances but the rate of loss of potential energy may be different than the geodetic slope, by a significant amount. For example, the International Great Lakes Datum is a potential energy datum and its bench mark values differ from the geodetic datum.
- Q - discharge as volume per unit time. Is also a function of position.
- ρ - unit density of water.
- μ - viscosity of water. Surface tension is not included.
- ρ_s - sediment unit density.
- Grading - no single value is available to describe grading of sediment size. Usually one particular diameter is chosen and as d_{50}.
- Cohesion - not usually considered of granular soils. Is defined by geophysical tests.
- Erodibility - not definable without some standard test index. It may be a function of cohesion.
- g - the gravitational constant. Note this parameter is usually associated with S, the slope. See note on Slope S above. Usual practice is to fix g and adjust S to include variations of g.

4.0 RESEARCH APPROACH

Management of river systems should consider both the water phase and the solid phase of river flow. Often the solid phase is

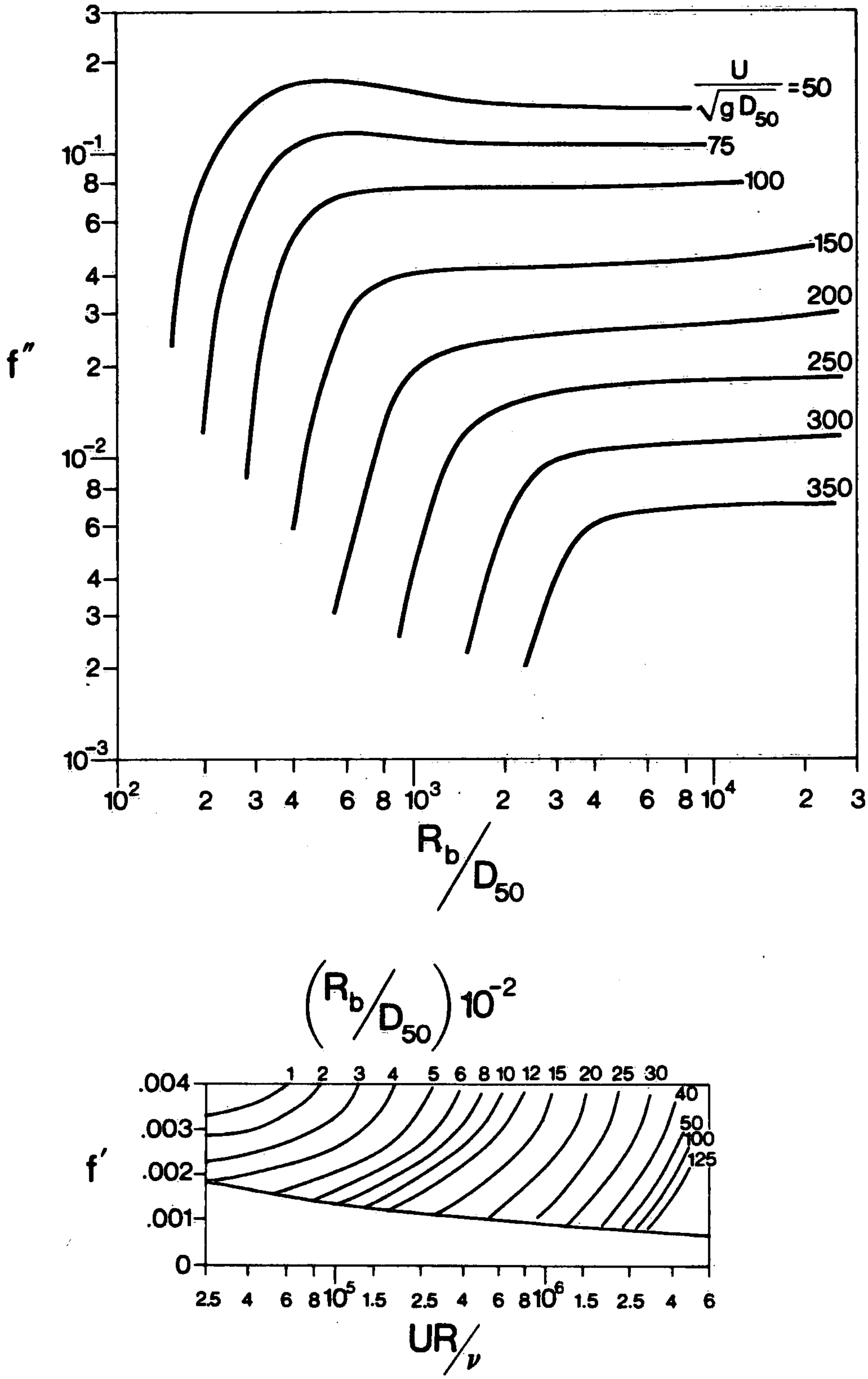


FIG. 2

after Alam & Kennedy

neglected because river engineering is sometimes approached from the point of view of traditional hard channel hydraulics.

River sediment interaction is also complex and uncertain. Fig. 2 provides a good example of the complexity and type of approach found in textbooks.

Fig. 2 is used with the equation

$$f\,u^2 = 8\,g\,h\,i$$

where h = depth here

$f = f^1 + f^{11}$

i = slope

Note, this is a steady state equation which is a poor approximation to the real situation. In this problem the following are known: discharge Q, the slope i, and the median sediment diameter on the bed d_{50}. R_b in the diagram is the hydraulic radius which is equal to depth h for rivers and b is the width.

The procedure is to guess h and compute u, and hence

$$X = (f^1 + f^{11})\,U^2$$

$$Y = 8\,g\,h\,i$$

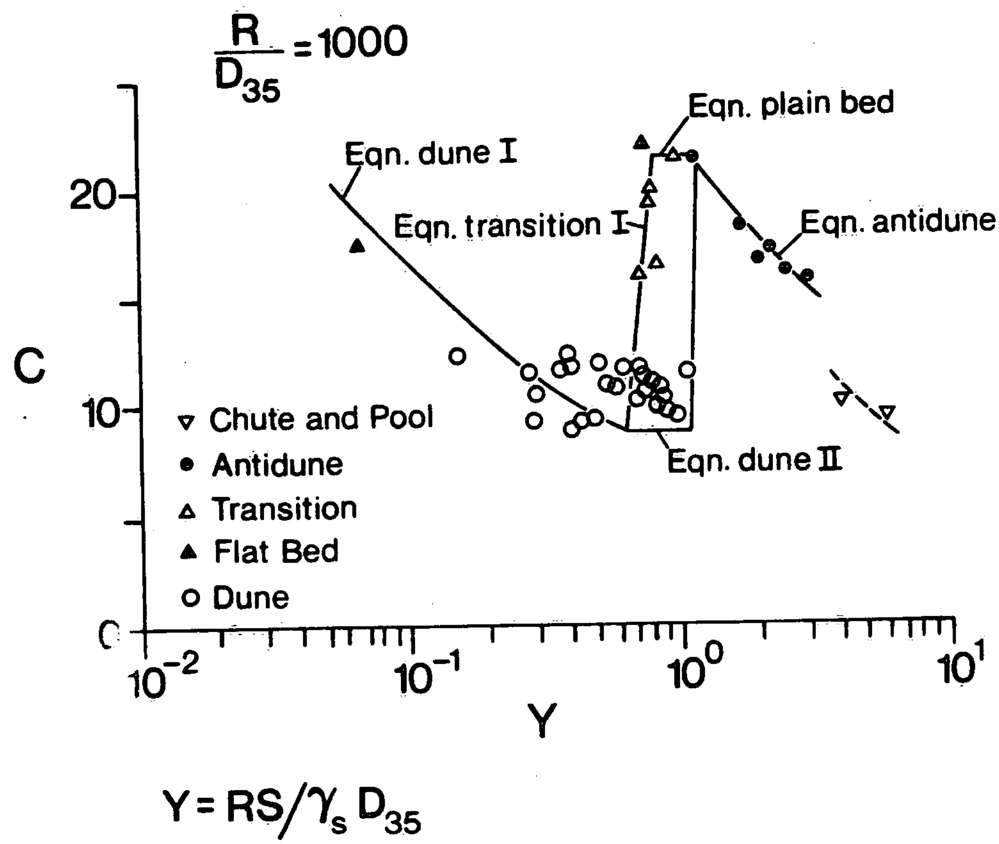
When X = Y then h is correct and u is known.

This procedure is obviously slow and even if correct, is only approximately so, because in real life steady state does not exist.

Another approach is given in Fig. 3 but similar methods must be used to obtain solutions. Fig. 3 is valid for parameter R/D_{35} = 1000 and the figure changes for other values of R/D_{35}.

In this diagram S is the slope, i and the equation is

$$V = C\sqrt{RS}$$



Kishi & Kuroki

FIG. 3

R = h, the depth as before.

Once again h is guessed, giving

$$V^1 = Q/hb \text{ and } V^{11} = c\sqrt{hs}$$

When $V^1 = V^{11}$ then the solution is known.

These procedures are clearly slow and approximate. It is virtually impossible to check them in nature because nature is dynamic.

The above methods are used for example, to compute flood levels. To obtain sediment discharge, another set of equations must be used and there is a large number of them. Let it suffice to say that the results obtained by different equations are seldom the same.

5.0 ORGANIZATION OF RESEARCH

The central objective of a research program in scientific terms boils down to devising ways to compute independent variables when the dependent variables are known. Dependent variables may be changed by man, or by longer term natural causes. Therefore, the research output is designed to produce ways and means to evaluate alternative actions by managers or to alleviate the effects of chosen actions.

The inter-relationships are shown in Figure 4.

The central research activity is the development of theories or models which requires the measurement of variables and an awareness of developments elsewhere. Application of the results is in the hands of operational managers.

There are other benefits of the research which aid and support parallel activities by the Water Resources Branch. That is, better ways to measure water flow and sediment discharge are of equal value to the researcher as to the Water Resources Branch.

Interconnections River System Research and Measurement

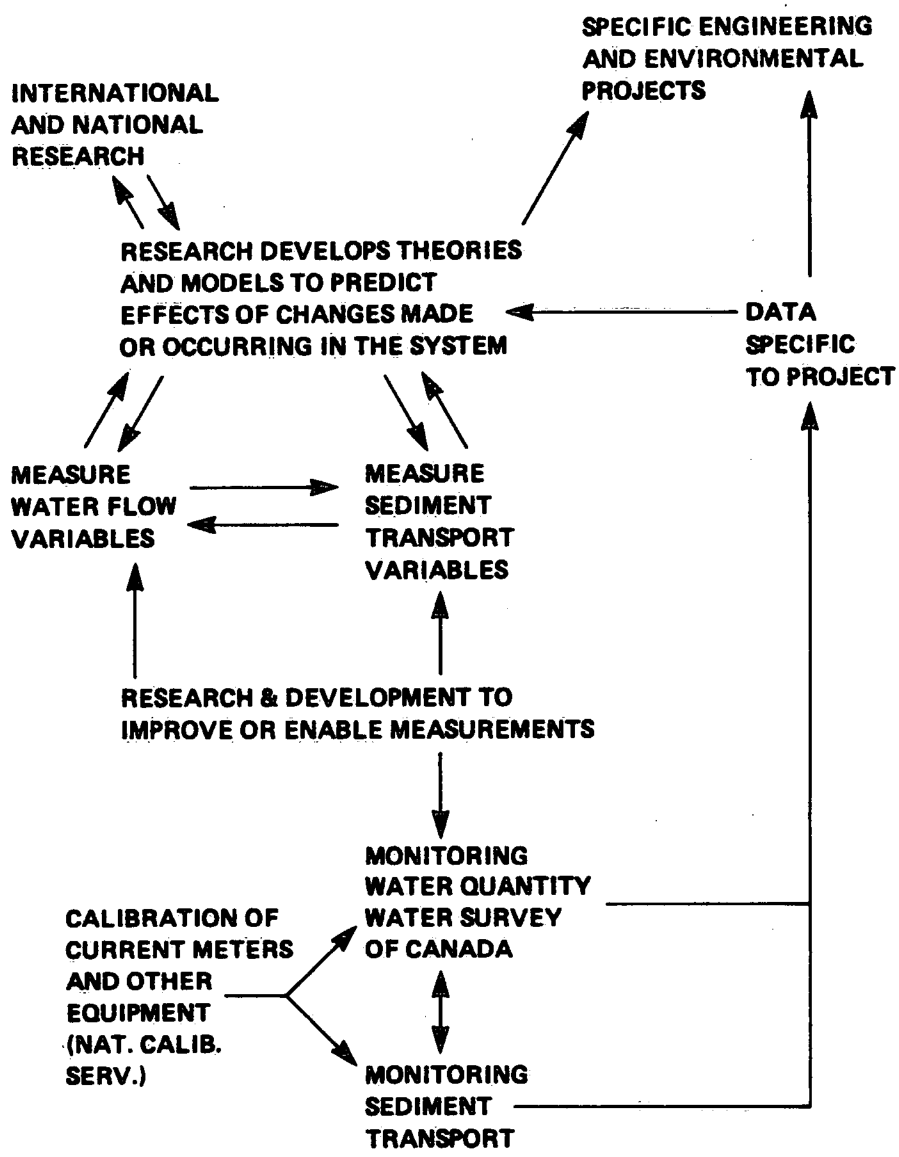


FIG. 4

In addition, the research group in Hydraulics operates the National Calibration Service to ensure that instruments perform to known specifications.

6.0 RESEARCH RESULTS RELEVANT TO SEDIMENT SURVEY

Samplers: Bed load samplers are used to obtain estimates of coarse sediment being transported near the bottom. At the request of Water Survey of Canada, two samplers have been tested and evaluated. Research studies showed that the efficiency or ratio of sediment caught in a unit of time compared to the real transport was a function of a dimensionless variable is tU_*/L. Data has been collected using a fixed efficiency of 60%. Research shows that the efficiency is a variable, that it is calculable, and that the VUV sampler has a higher efficiency than the basket sampler.

Hydrographic Method: The concept of using two profiles of a duned bed taken at different times to compute bed transport is a simple one. However, it is not so easy operationally. Research studies showed how the available hydrographic survey system HYDAK could be used to estimate bed load with reasonable accuracy. The method worked out in collaboration with WSC has been adopted by the International Standard Association.

Acoustic Method: This idea of using the noise made by bed load was investigated. The results were negative so no further development was done.

MOBED Model: The mathematical model MOBED could be used to assist the sediment monitoring program. In contrast to the sampler measurements, it uses a total load relationship which includes suspended load derived from the coarse bottom sediments.

MOBED uses the independent variables of river discharge as a function of time and location (boundary conditions) with sediment grain size plus initial values of water surface and bed elevations to calculate the values of these elevations as functions of time as well as the solid transport rate. Therefore, the model has the potential to form an integral part of the sediment monitoring program. For example, if one wished to estimate the time series of sediment transport rate at a particular location in a river reach, MOBED would be used as follows:

A river reach is selected in such a way that it is bounded by two gauging stations and also includes the reach of interest. MOBED is applied to this reach using the flow conditions (i.e., discharge and water elevation as a function of time) measured at these gauging stations as boundary conditions. The model needs sediment characteristics such a grain size distributions and the initial cross-sectional geometries along the reach. The model will then predict sediment transport rate at all stations within the reach as a function of time. The model could be roughly checked initially by making actual measurement of sediment transport rate and comparing it with the predicted rate. If necessary, the value of grain size responsible for skin friction can be adjusted in this model so that the model predictions fully agree with the measured value. However, it must be noted that field measurements of solid transport are subject to large error.

Once this has been done, then the model could be used to provide an accurate estimate of sediment transport rate at a given time and location. This same thing could be done for different reaches in the same river or in reaches in different rivers. Model MOBED can accommodate different sediment transport rate relations and hence it is possible to use relationships that are more suited for the type of river reach being modelled. The advantage of using MOBED is that it can provide estimates of sediment transport rate at locations where the access to the river may be limited, and during flood events where conditions are unsteady and making direct, reliable measurements could be very difficult.

7.0 OTHER STUDIES

Research into other aspects of sediment transport are relevant to particular problems or to the formulation of models, theories, or research directions. A list of subject areas studied is:

1. Model of the Motion of a Solid Particle in Turbulent Flow with a Free Surface.
2. Fall Velocity of Irregular Solid Particles.
3. Mathematical Models of Sediment-Laden Flows in Natural Streams Leading to MOBED Model.
4. Stochastic Aspects of Saltation Paths of Cohesionless Sediment.
5. Suspended Sediment Profiles for Ice-Covered Flows.
6. Prediction of Bed Scour due to Constrictions in River Flows.
7. Friction Factor of Duned Beds.
8. Formation of Meanders in Rivers.
9. Critical Mean Velocity over Coarse Bed Material.
10. MOBED and HEC 6 Comparison.
11. Effects of Diversions on River Regime.

8.0 BASIS OF FINE SEDIMENT TRANSPORT WASHLOAD

Washload is not primarily a function of river flow. Rather, it is a function of the land draining into the river and its tributaries so that the wash load is a function of the soils, vegetation, geological formations, land use, agricultural and forestry practices, and climate control.

Obviously the relationships between wash load and the sediment found in the stream are complex. From the deterministic point of view, it is difficult to obtain a clear set of independent variables.

The most widely quoted relationship cited in textbooks is the Universal Soil Loss equation which was developed in the U.S.A.:

Independent variables are typically:

R - rainfall factor
LS - slope length gradient
C - crop factor
D - erosion control factor

These variables, defined in some way, are combined to obtain the load (L) in a unit time.

Wash load, as the name implies, is associated with rainfall events. So, by nature, it follows a Poisson type distribution and tends to be event-governed, that is, the washload events are stochastic and largely unpredictable.

In Canada it is also likely that snow and freeze-thaw cycles are also significant.

Because of the stochastic nature of wash load, which is held in suspension by the flow and does not settle out until it reaches a lake or river, it is unlikely a regular series of surveys will obtain representative measurements.

Wash load material is also intimately tied to the transport of heavy metals, toxic inorganic substances, and pesticides. In urban areas, it is the primary method of transporting toxic substances and the same probably holds true to agrarian areas.

9.0 ORGANIZATION OF RESEARCH

As management must be able to take action on toxic substances, the transport and generation of wash load becomes an essential tool. So far, studies in the production and measurement of wash load have not produced widespread coordination of effort. The PLUARG studies represent one of the more integrated efforts and some studies in the Western and Northern Region represent Departmental efforts at this time.

Research aimed at providing predictive capabilities is not active right now. In this case, the impact would be the changes in land use and control and the output would be the change in the wash load flux.

Fig. 5 shows an organization similar to Fig. 4.

The basic research effort is concentrated on developing theories or models, but complimentary research is required to improve the basic measurement of sediment plus defining the correct descriptions controlling the yield from the catchment basin.

Organizational changes in behaviour are required to integrate the toxic measurements of sediments, with the transporting processes.

Supplementary research services provided are the research on chemical analytical measurements, the engineering research to devise samples of bottom sediments and suspended sediments and grain size analysis.

10.0 FUTURE RESEARCH AND DEVELOPMENT

Remembering that the basic objective is to provide management tools, the R&D should pursue the following:

1. Develop MOBED to two dimensions. This permits the breadth b to be a dependent variable.

Interconnections River Washload and Research

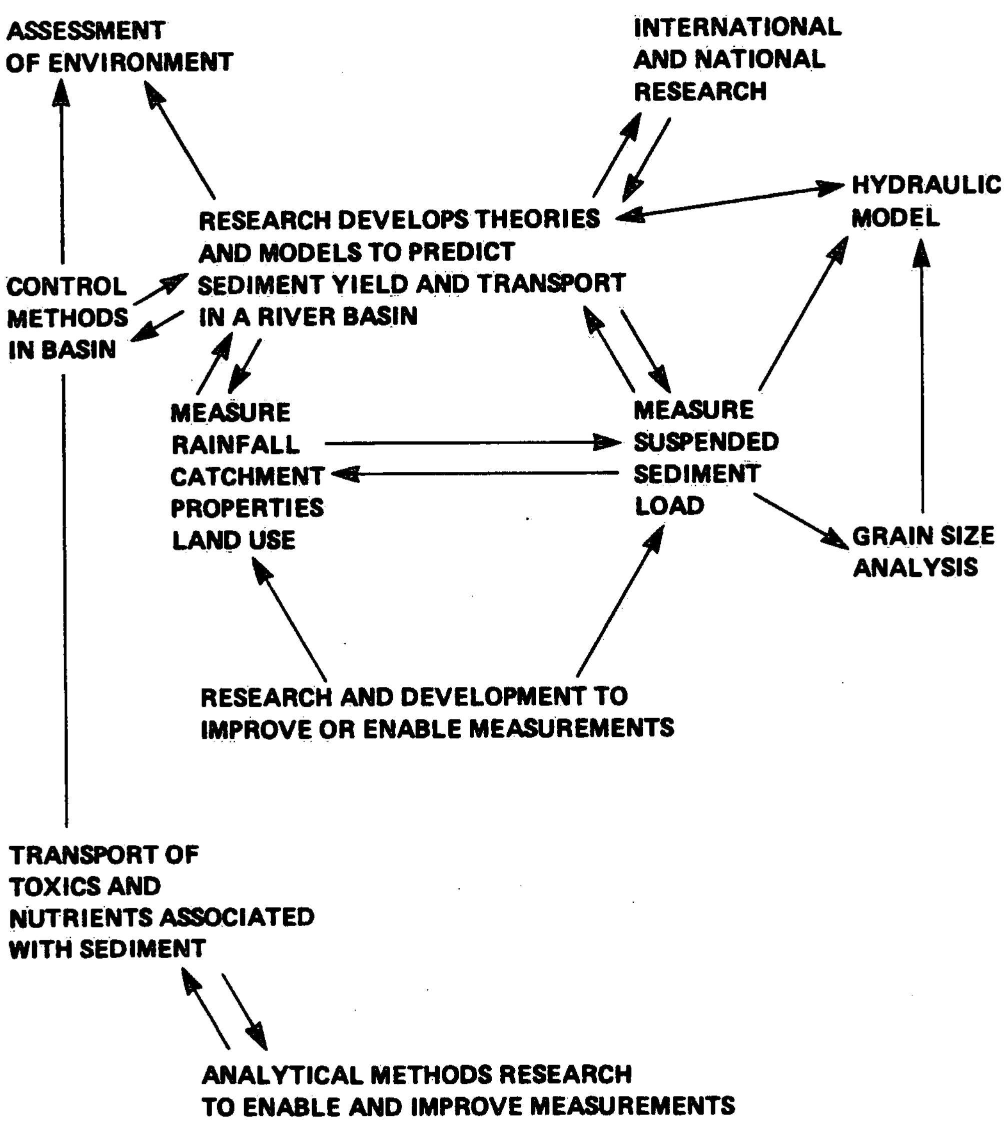


FIG. 5

2. Investigate the effects of river sediment gradation. Solutions would improve flood level prediction, sediment transport prediction, and improved forecasting of aggradation or degradation in the river bed.
3. Develop a model to predict river forms. Diversions of flow may change a river's dimensions enormously, a regular river could begin meandering or the width could change.
4. Improve flood plain flow predictions. The flood level in a river is a function of the flood plain flow. Manmade changes are usually in the flood plain. The consequences of change in this important economic area should be able to be evaluated.
5. Improve methods to measure sediment transport. Field measurements to develop confidence in predictive models are essential for long term programs.
6. Improve theoretical basis for including cohesive soils in models. Rivers often have cohesive soils forming their banks. Very little information is available on the erodibility of cohesive soil.
7. Develop improved techniques to measure wash load. Owing to their low fall velocity, wash load sediment concentration is generally uniformly distributed from the surface to the bed. Methods are required to catch the wash load events when they happen which in turn suggests the development of automated samplers, triggered at the right time.
8. Last but not least, there is no reliable way to predict the effects of pesticide controls, fertilizer controls or land use controls on lake and reservoir quality without studying the factors controlling sediment yield from the catchment basin. This also holds true for the sediment yield with attached heavy metals and organics discharged from urbanized areas.

11.0 WATER RESOURCES BRANCH

The continued monitoring of river flows by the Water Survey of Canada serves obvious needs. Planning for the management of water resources or for other developments needs data on river flow. Data is used to confirm models or is used statistically to determine flood frequencies, drought frequencies, or firm supplies.

Projections formed from the data imply that conditions are static or, in mathematical terms, the set is stationary. In many locations this is not so and more attention should be paid to basin changes. For example, increased drainage may alter flood peak levels and a new embankment or bridge may create backwaters in floods. Research to improve data collection methods could possibly reduce costs of acquiring data. The connections to R&D have been shown already. For some research projects it could be useful to have closer liaison between WSC and the research so that variables important to that research are obtained.

Sediment discharge measurements by the Sediment Survey are obviously more difficult to do. Sediment flow is a stochastic event-dominated phenomenon. Regular surveys are therefore not going to get useful results. A "flying squad" approach is required and is the method used for research of urban areas. Data obtained is local but if attached to a theory or model it becomes universally applicable.

Obviously the "flying squad" cannot be everywhere at once so it is essential to develop automated sampling measurement. Engineering developments of effective automated sampling systems would be, at minimum, a three-year project and require special funding.

In conclusion, the sediment survey work should be linked to an overall strategy for the management of the water quality and quantity in a basin.