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Techniques applied in determining sediment loads in South African rivers

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ABSTRACT The two main methods of measuring sediment loads in southern African rivers since 1920 have been daily "bottle" sampling and measurement of sediment deposit volumes. Techniques used for determining averaged sediment loads from these measured values are discussed in this paper.

Les méthodes employées pour déterminer les quantités de sédiments des fleuves Sud Africains
RESUME Les deux méthodes principales de mesure des quantités de sédiments dans les fleuves sud-africains depuis 1920 sont le prélèvement d'échantillons à la bouteille et les mesures des volumes des sédiments déposés. Les techniques utilisées pour déterminer les quantités cumulées de sédiments moyennes à partir de ces mesures sont décrites dans cet article.

INTRODUCTION

South Africa has been fortunate in that the Directorate of Water Affairs and its predecessors started *ad hoc* sediment monitoring before 1920 and regular sampling programmes during 1929. Although the existing records are by no means complete or perfect they have proven to be invaluable in water resource analyses, especially as far as reservoir sedimentation is concerned.

In order to generalize sediment yield figures, various attempts have been made to relate these figures to variables such as mean annual runoff or mean annual precipitation (e.g. Langbein & Schumm, 1958; Dendy & Bolton, 1976; Tabuteau, 1960; Douglas, 1967). Comprehensive sets of data indicate however that such simple relationships are unfortunately not generally valid (e.g. Walling & Kleo, 1979).

Variables such as mean annual runoff or mean annual precipitation may be taken to represent the capacity of the transporting medium in the form of runoff. As such these averaged values do not reflect the variability in runoff events during a given year. This variability is highly significant in determining transporting capacity. Furthermore, the intermediary role of other transporting agents such as winds and gravitational effects are not reflected.

More important however is the fact that the availability of transportable sediment, and not the transporting capacity of runoff very often forms the limiting or controlling factor in determining sediment yields from drainage basins or loads in streams (Rooseboom, 1975).

As it is still not possible to describe the capacity of transporting agents or variations in availability of transportable material mathematically in practical situations, continuous measurements over sufficiently long periods are required to obtain accurate average yield or load figures.

MEASUREMENT TECHNIQUES

Average sediment loads in rivers can either be determined through sampling of streams or by monitoring of the accumulated sediment deposits in impoundments.

Stream sampling

In the past suspended sediment samples from rivers in South Africa were obtained mainly by using simple sampling bottles. This method amounts to the lowering of an open sampling bottle 300 mm below the stream surface by hand and allowing it to fill. Although more sophisticated methods are gaining ground the "bottle" method is still in use, thanks mainly to its simplicity.

With a large data bank which had been built up on the basis of "bottle" samples control tests were undertaken during the period 1967-1969 to establish its representativeness. In these tests sediment concentrations obtained from bottle samples were compared with averaged concentrations obtained with more sophisticated samplers such as the "Turbidisonde" (Rooseboom, 1975).

It was found that sediment concentrations obtained with the bottle method were generally 25% lower than those obtained with the more sophisticated methods. This discrepancy was attributed partially to segregation taking place while the bottle is filled in the flowing water.

Due to the small particle sizes being transported in most South African rivers suspended sediment concentrations vary only slightly in the vertical direction. It is thus possible to relate the "bottle" results to averaged suspended sediment concentrations and to calculate total suspended loads.

Bed load sampling has not been undertaken on a routine basis for South African rivers. Calculations with accepted bed load formulae as well as indirect checks have led to the conclusion that practically the total load is carried in suspension. One of the methods used in these comparisons was proposed by Kriel (1972). In this method the grading characteristics of the eroding soils in a drainage basin are compared with those of the suspended loads of a river. The fractions of coarse material missing from the suspended sediment samples are taken as the maximum percentages of the total load which are likely to be transported as bed load. Although size distributions from different samples varied significantly, it was possible to conclude that the bed load could not be more than a few per cent of the suspended load.

A conventional method of determining average sediment yields is by making use of a sediment rating curve together with a flow duration curve (Colby, 1956). This method is likely to yield incorrect results if insufficient sediment data are used.

An alternative method which has been used in South Africa consists of applying the double mass curve of cumulative sediment discharge against cumulative water discharge not only to establish whether conditions are stationary but also to determine the long term average sediment concentration.

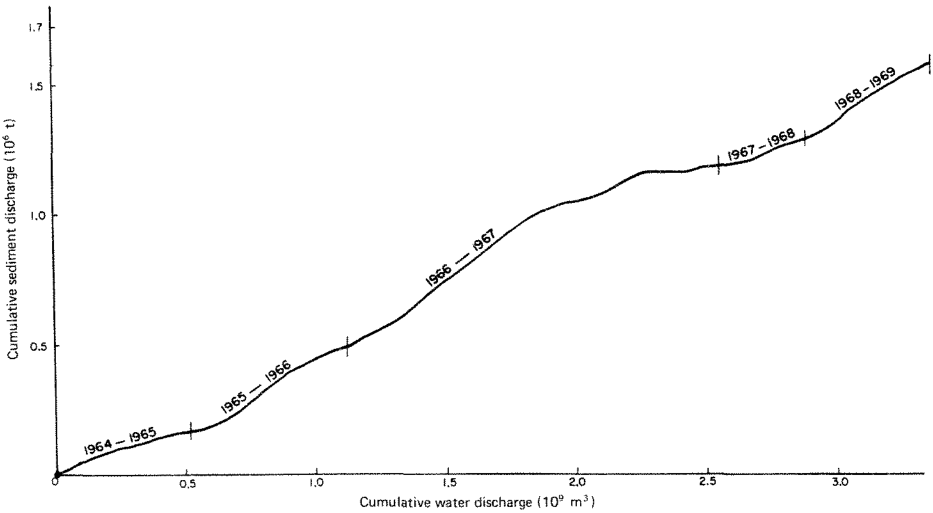

Fig. 1 Mass curve for Orange river at Bethulie.

The progression of the double mass curve (Fig. 1) represents the influence of the two controls: availability (cumulative sediment load) and transporting capacity (cumulative water discharge). If conditions are stationary the average progression has to be in the form of a straight line, the slope of which is mathematically equal to the average sediment concentration. Practical application of the double mass curve amounts to the fitting of a straight line through the points on the graph. Sampling should continue until the slope of the best fitting straight line does not change with time - this means that equilibrium between the two controls has been established. Under South African conditions it has been found that a minimum of approximately 5 years of continuous records are required to establish the long term average load to an accuracy accordant with the accuracy of measurement.

Sediment deposits in reservoirs

Average sediment loads in rivers can be measured indirectly by monitoring changes in storage capacity of existing reservoirs.

South African reservoirs are regularly resurveyed at a rate of at least 14 resurveys per annum.

Data on volumetric changes of sediment deposits in reservoirs form the best basis for the prediction of sedimentation rates in planned reservoirs. Comparisons should however only be drawn between reservoir drainage basins with comparable sediment yield characteristics.

In this method it is not necessary to estimate the density of sediment deposits providing that the trapped sediments are similar. An empirical volume-time relationship has been developed based on resurvey data of nine reservoirs in the USA and the Republic of South Africa (Rooseboom, 1975). This relationship is shown in Fig. 2, where V_t = sediment volume after t years, and V_{50} = sediment volume after 50 years. The logarithmic shape of this curve can partially be explained by the characteristic form of settlement curves for soils.

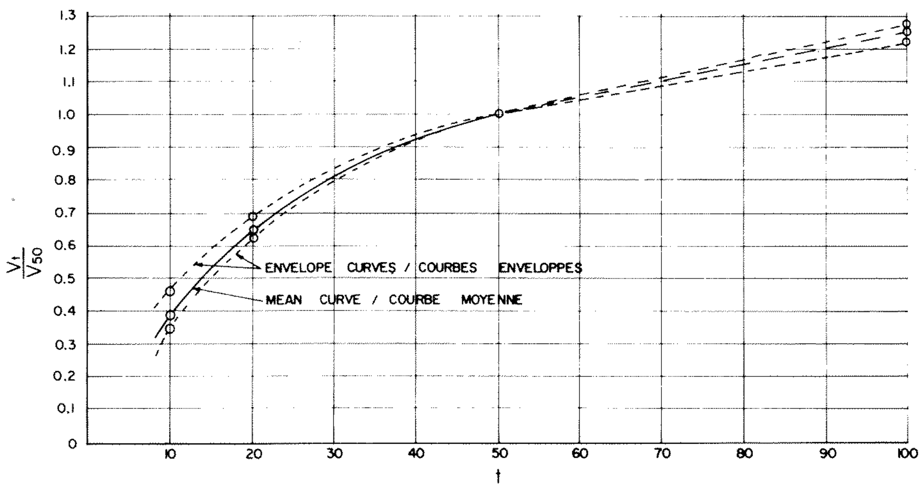

Fig. 2 Sediment volume after t years as fraction of 50-year volume.

The dimensionless volume-time curve can also be used to estimate sediment yield rates from catchments on a mass basis. Results obtained in this way can thus be compared to those obtained from direct measurements.

The basic approach is to estimate the volume of sediment in all reservoirs at a constant age (say 50 years) and then, working from this common basis to translate the volume into mass. The density commonly used in South Africa for 50 year old deposits is 1350 kg m^{-3}.

SEDIMENT YIELD MAPS

Research results become meaningful if they can be presented in a generalized form. A popular form of representing sediment yield data is in the form of a sediment yield map, as shown in Fig. 3.

Delineation of regions with equal theoretical yield potential was done by Harmse (1975) on the basis of geomorphology, geology and soil types. Harmse ranked the different regions in order of yield potential and the actual measured values corresponded remarkable well with the predicted rank order.

Due to the fact that observed yield values within a region with given yield potential may vary not only with space but also with time (Rooseboom & Harmse, 1979) a sediment yield map has to be drawn and used with great care. Yield figures indicated on

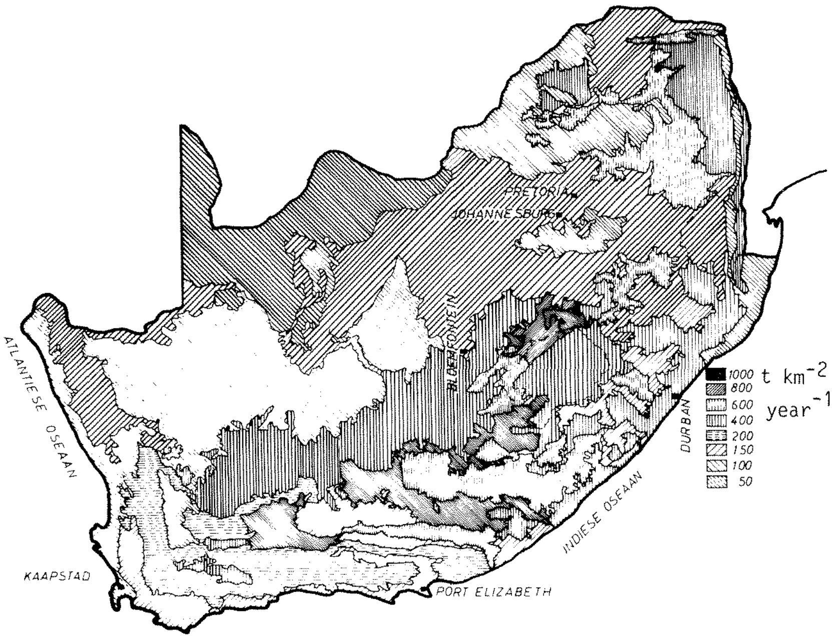

Fig. 3 Sediment yield map of South Africa.

this map are based on maximum observed yield values and do not necessarily reflect true current values.

The value of such a map lies therein that it does give relative yield values for different regions and that it can be used to obtain conservative prediction values for certain purposes, such as reservoir design.

CONCLUSIONS

(a) Both the availability of transportable sediment and the transporting capacity of the transporting media vary with time and act as controls in determining the sediment yield from a particular drainage basin during a given period. *Monitoring of* sediment loads therefore has to be continuous and over a sufficient period so that the equilibrium between these controls can be established.

(b) The double mass curve of cumulative sediment discharge *vs.* cumulative water discharge can be used to establish whether sediment loads are stationary and also to establish the minimum period of sampling which is required to determine the long term average sediment concentration with sufficient accuracy. This concentration when multiplied by the long term average water discharge yields the average sediment load.

(c) Monitoring of sediment volumes in impoundments offers a convenient way of determining average sediment loads and offers the best basis for prediction of storage volume losses in existing and planned reservoirs. In the latter case uncertainties regarding average densities of deposits are bypassed.

(d) Sediment yield figures can be generalized in the form of a sediment yield map, but such a map should be applied with great care as sediment yield is both a function of space and time.

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