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Average long-term sediment discharge investigations based on reservoir resurvey data and sediment yield rate factors

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Abstract This paper presents a summary of investigations, based on resurveys of existing reservoirs, developed in the state of Minas Gerais in the neighbourhood of Juíz de Fora and Belo Horizonte, the State Capital. Comparisons and adjustments are made based on sediment yield rate factors such as rainfall, soil type, topography, land use and drainage area size. The result was a tentative regional expression which correlates all these factors. Due to historical predatory land use ("shift cultivation"), recommendation is made for implementing corrective measures to control sediment yield rate.

Recherches sur le débit solide moyen à long terme à partir de l'alluvionnement de réservoirs et des facteurs affectant le taux de dégradation

Résumé Ce travail présente les résultats de recherches sur l'évaluation du débit solide qui pénètre dans les retenues de l'état de Minais Gerais, situées au voisinage des villes de Juíz de Fora et de Belo Horizonte, la capitale. L'importance des dépôts est en rapport avec les précipitations, le type de sol, la topographie, l'occupation du sol et la taille des bassins versants. Ces relations peuvent être résumées par une expression unique prenant en compte tous ces facteurs, valable pour la région. Les taux de dégradation obtenus révèlent un usage prédateur des sols dû surtout à l'agriculture itinérante (shift cultivation). Des recommendations sont proposées pour réduire la production de sédiments.

INTRODUCTION

The amount of sediment moving in a stream at a given site and at a given time is a function of a complicated set of active and passive forces acting on the drainage basin upstream from the site. These forces involve the erosion and transportation capacity of the seemingly inconsequential and largely unnoticed raindrop splash and the overland flow as it makes its way to stream channels by way of sheet and rill flows.

Sayre *et al.* (1963) listed five environmental factors affecting the supply of sediment moved into and through a stream channel. They are:

(a) the nature, amount, and intensity of precipitation;
(b) the orientation, degree, and length of slopes;
(c) geology and soil types;
(d) land use; and
(e) condition and density of the channel system.

These factors can operate either independently or in conjunction to deter or to advance the rate of erosion and transport. Precipitation, for example, if occurring under ideal conditions, may advance the growth of vegetation, and thereby increase the protective influences. On the other hand, if the precipitation is intense and follows a drought or occurs on an area without vegetative cover, it is likely to cause extensive erosion. Because of the high variability and interrelation associated with the preceding list of factors, it is difficult to attain desirable spatial and temporal definition of the sediment erosion and transport characteristics in most drainage areas.

All reservoirs formed by dams on natural water courses are subject to some degree of sedimentation. The problem confronting the project planner is to estimate the rate of sedimentation and the period of time before the sediment will interfere with the useful functions of the reservoir. Provisions should be made for sufficient sediment storage in the reservoir so as not to impair the reservoir functions during the period of economic analysis.

A resurvey of an existing reservoir in the same general area as a proposed development will provide valuable data in determining yield rates. The present report makes use of reservoir resurvey data to develop a tentative expression to predict average long-term sediment discharges. Predictions were made of sediment inflow rates to Três Marias and Furnas reservoirs, and compared to the measured results of some sediment sampling stations.

DISCUSSION

A general relationship for the prediction of erosion rates under a variety of land uses and environmental conditions was used with the general forms:

$$Q_s = Y A^{-n} \text{ (Roehl, 1962)}$$

and

$$Y = P_e K L S C P \text{ (Wischmeier, 1976)}$$

where

Q_s is the average annual soil loss in m^3 km^{-2} $year^{-1}$ from a specific area.

P_e is a rainfall factor that expresses the potential erosion of an average annual rainfall in the locality. In a correlation of rainfall characteristics with erosion and soil-loss data, it was shown that an index consisting of the product of rainfall energy and the maximum 30-min intensity of the storm is the most important measurable precipitation variable to explain storm-to-storm variation of soil loss from field plots. This concept is based on the fact that large, fast-falling raindrops with high kinetic energy will cause much splash erosion, thereby sealing the soil surface and increasing the amount of surface runoff. The maximum 30-min intensity is proportional to both the quantity of rainfall and the average intensity of a storm.

K is the soil erodibility factor and represents the percentage of average soil loss, related to the soil in cultivated continuous fallow, with a standard plot length and percent slope arbitrarily selected as 22.26 m and 9%, respectively.

S and L are topographic factors for adjusting the estimate of soil loss for a specific land gradient and slope length. The land gradient is measured in percent. Slope length is defined as the average distance from the point of overland flow to the point where runoff enters well-defined channels. The topographic factor may be computed by the expression (Wischmeier, 1976):

$$LS = (0.0136 + 0.0096S + 0.001385S^2)L^{1/2}$$

C is the cropping management factor and represents the ratio of the soil quantity eroded from land that is cropped under specific conditions to that which is eroded from clean-tilled fallow under identical slope and rainfall conditions.

P is the supporting conservation practice factor (strip-cropping, contouring etc.).

A is the drainage area of the basin.

The factor n is the mean delivery ratio.

PREDICTIONS AND TESTS

Table 1 shows the computed factors for four medium size reservoirs in Minas Gerais state near Belo Horizonte and Juíz de Fora. The soil erodibility was

Table 1 *Reservoir data and computed factors*

Reservoir name:	*Pampulha*	*V. Flores*	*R. Pedras*	*João Penido*
River:	*Pampulha*	*Betim*	*Velhas*	*Burros*
Reservoir age:	*36 years*	*12 years*	*50 years*	*52 years*
Sediment ($10^6 m^3$)	*4.00*	*0.50*	*18.00*	*4.50*
P_e	*2000*	*2000*	*2000*	*1950*
K	*0.25*	*0.25*	*0.25*	*0.25*
S *(%)*	*15.8*	*14.7*	*27.0*	*20.5*
L *(m)*	*266*	*200*	*212*	*250*
LS	*8.3*	*6.4*	*18.7*	*12.5*
C	*1.00*	*1.00*	*1.00*	*1.00*
P	*1.00*	*1.00*	*1.00*	*1.00*
A (km^2)	*100*	*121*	*525*	*68*
Q_s ($m^3 km^{-2} year^{-1}$)	*1110*	*350*	*910*	*1270*

computed based on the mean grain size of the soils of the basin (granitic-gneiss terrains subjected in the past to shifting cultivation. Parts of the basins are suburban development areas. Two of them (Vargem das Flores e João Penido) have occupation restricted by special norms (maximum subdivision of the area into parts of 2000–8000 m^2).

Table 1 also shows the locations of the reservoirs and some of their physical characteristics. The measured sediment yield rates for each reservoir were computed considering trap efficiencies according to Brune (1953). A combination with the given sediment yield rates gives the following general expression for the sediment yield rate:

$$Q_s = 0.25 P_e \; L \; S \; A^{-0.372}$$

or

$$\log Q_s = \log P_e + \log LS - 0.372 \log A - 0.602$$

This equation only fitted well on the results from the João Penido and Rio de Pedras reservoirs. Data from the Vargem das Flores and the Pampulha reservoirs were considered of poor quality: in the case of the former, because of the existence of several unmeasured small sediment trap reservoirs in the basin; and in the case of the latter, because of non-controlled surveying made by different agencies resulting seemingly in an overestimate of the sediment deposits.

A further evaluation of sediment inflow rates of Furnas and Três Marias reservoirs was made based on sediment sampling data collected at sediment stations. The parameters are seen in Table 2. The computed Q_s values show a fair agreement.

Table 2 *Sediment inflow data to Furnas and Três Marias reservoirs*

Reservoir:	*Furnas*	*Três Marias*	*Três Marias*
River:	*Sapucaí*	*Paraopeba*	*Paraopeba*
Location:	*Paraguaçu*	*Pte Nova*	*Pte Taquara*
A (km^2)	9424	5663	7980
LS	3.86	8.11	10.2
P_e	2240	2000	2000
K	0.25	0.25	0.25
C	1.00	1.00	1.00
P	1.00	1.00	1.00
Q_s ($m^3\ km^{-2}\ year^{-1}$) (measured)	78	180	176
Q_s ($m^3\ km^{-2}\ year^{-1}$) (computed)	72	163	180

CONCLUSIONS AND RECOMMENDATIONS

The sediment yield rates in all the basins are consistent with a predatory land use due to deforestation, use of fire followed by shifting cultivation, non-controlled cattle raising and absence of soil conservation measures. It is strongly recommended that corrective measures be implemented to control sediment yield rate by acting on the *C* and *P* factors. Further investigations and appropriate reservoir resurvey data are considered essential to improve the understanding of the sediment delivery system.

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