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Sediment yield in the Velhas River basin (Minas Gerais, Brazil)

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Abstract This paper presents a sedimentological diagnosis in the Velhas River basin, a tributary of the São Francisco River, Minas Gerais State, Brazil. It is based on the sediment discharge measurements at stations along the river. The values of sediment yield and soil degradation depth were computed and compared with standard values obtained by research in other countries. The work also included a study of the increase in sediment yield of the basin through the period 1956–1983. Finally, some suggestions are made for the control of erosion and sedimentation.

Production de sédiments dans le bassin versant du Rio das Velhas (Minas Gerais, Brésil)

Résumé Ce travail établit un diagnostic sédimentologique du bassin du Rio das Velhas, un tributaire du fleuve São Francisco, dans l'Etat de Minas Gerais, Brésil. Il est basé sur les mesures de débit solide effectuées à plusieurs stations hydrométriques. Les valeurs de la production de sédiments et de la dégradation du sol ont été calculées, puis comparées aux valeurs standards obtenues en d'autres pays. L'étude de l'augmentation de la production de sédiment dans le bassin entre 1956 et 1983 est également examinée. Finalement, quelques suggestions visant le contrôle de l'érosion et de la sédimentation sont présentées.

INTRODUCTION

The Velhas River is a right-hand tributary of the main São Francisco, flowing in the direction northwestnorth. Its basin lies entirely within the state of Minas Gerais, Brazil and its total drainage area is almost 30 000 km^2. The river has high socio-economic importance for the development of the State since many cities are located in its basin, including the State capity Belo Horizonte. The constant increase in population, the necessity for agriculture and multifarious constructions along the basin are factors of great importance, which nevertheless result both in erosion of the land and degradation of the soil.

This can be perceived through the reduction in fertility of the soil which becomes nonproductive. Many factors contribute to the erosion in certain regions, such as absence of vegetal cover, agriculture, earthworks, road and housing constructions, deforestation for any purpose, but particularly for charcoal works, the burning of field vegetation, and finally a number of uncontrollable activities, also contribute to the erosion in the basin.

Sediment yielded by the basin due to the erosion is led to the streams by torrents, where it may be deposited in great quantities with undesirable effects. It may disturb regular navigation or be trapped in a reservoir, occupying volume necessary for flow control, hydropower generation or some other purpose. There are few dams in the basin but all their reservoirs are sedimented. They are as follows:

(a) ***Acabamundo,*** on Acabamundo Creek, flowing to the Arrudas, a tributary of the Velhas River, this reservoir was formed for flood control of a urban area. It is totally sedimented.

(b) ***Pampulhas,*** on Pampulha Creek, flowing to Oncas, a tributary of the Velhas River, a multipurpose dam was constructed for flood control, recreation and tourism, but is almost totally sedimented. It has already been dredged in several places, with the result that sediment has been removed from the backwater part. It is a reservoir located in an urban area which presents environmental problems.

(c) ***Santa Lúcia,*** on Leitao Creek, flowing to the Arrudas, was built for flood control, but is totally sedimented.

(d) ***Rio das Pedras,*** on the Velhas River, is the biggest of all with an initial volume of 24.2×10^6 m^3; the dam was constructed for hydroelectric utilization of 9280 kW, but the reservoir is completely sedimented, disturbing the energy generation.

Those reservoirs are located on the high basin; downstream, sediment deposits in the river channel have disturbed the navigation in the low reaches. An alluvial cone of sediment has formed where the river joins the São Francisco, causing navigational problems and also costs for channel maintenance.

SEDIMENTOMETRIC STATIONS IN THE BASIN

The natural path for the eroded sediment in the basin is the river channel, so sediment yield and soil degradation have to be studied through the sediment discharge in streamflow.

The sedimentometric network of the Velhas River basin is composed of six stations, all of them located in the main course (see Table 1). All those stations were already recording water level and discharge measurements before the beginning of sample sediment operation.

The suspended sediment samples were made by the equal transit rate method for all verticals. The bed material was sampled only in some measurements.

The suspended sediment discharge Q_{ss} (t $year^{-1}$) was computed by the average sediment concentration C_s and by the water discharge Q (m^3 s^{-1}), using the equation:

$$Q_{ss} = 0.0864\ C_s\ Q$$

The unsampled sediment discharge and the bedload were computed by the Colby and by the modified Einstein methods for those measurements with bed samples. These gave the average value to add to the suspended sediment discharge, giving the total sediment discharge.

The Várzea da Palma station, operated by CODEVASF in a previous period of DNAEE operation, had an identical sampling procedure (suspended and bed load samples both being measured). The total load was computed by the modified Einstein procedure.

Four among the stations were operated by DNAEE daily in the rain period (October–March) and fortnightly in the dry period (April–September). These measurements were not considered in this paper.

Taking account of the uncertainty in the sediment discharge measurement, an error of 10% is expected in the results.

Table 1 *Sedimentometric stations on the Velhas River*

Station	*Entity*	*Latitude (S)*	*Longitude (W)*	*Altitude (m)*	*Drainage area (km^2)*	*Date of installation*	*Period of sedimentometric observation*
Honório Bicalho	*DNAEE*	*20°01'*	*43°49'*	*721*	*1 642*	*July 1960*	*Nov.75/Dec.82*
Ponte Raul Soares	*DNAEE*	*19°33'*	*43°54'*	*637*	*4 780*	*Feb. 1938*	*Dec.75/Nov.82*
Jequitibá	*DNAEE*	*19°15'*	*44°02'*	-	*6 292*	*June 1965*	*Dec.75/Nov.82*
Ponte do Licínio	*DNAEE*	*18°40'*	*44°14'*	-	*10 980*	*Oct. 1941*	*Dec.75/Nov.82*
Santo Hipólito	*DNAEE* *CODEVASF*	*18°17'*	*44°14'*	*449*	*17 000*	*June 1938*	*Dec.75/Nov.82* *Jan.67/Mar.75*
Várzea da Palma	*DNAEE*	*17°36'*	*44°43'*	*464*	*26 600*	*June 1938*	*Dec.75/Nov.83*

DNAEE: Departtamento Nacional de Aguas e Energia Elétrica
CODEVASF: Companhia de Desenvolvimento do Vale do São Francisco

SEDIMENT YIELD AND SOIL DEGRADATION

The sedimentometric data were processed and analysed; for the measurement period, the sediment rating curve — the relation between the total sediment discharge (t year^{-1}) and water discharge (m^3 s^{-1}) was also computed. The equation of this curve was of the form $Q_{st} = K\ Q^n$. The sediment rating curve of the station of Velhas River at Várzea da Palma is presented as an example (see Fig. 1).

The value of the mean annual total sediment yield (t year^{-1}) in the station was made by using the mean annual water discharge (m^3 s^{-1}) in the equation above and divided by the drainage area for final result (t km^{-2} year^{-1}) (see Table

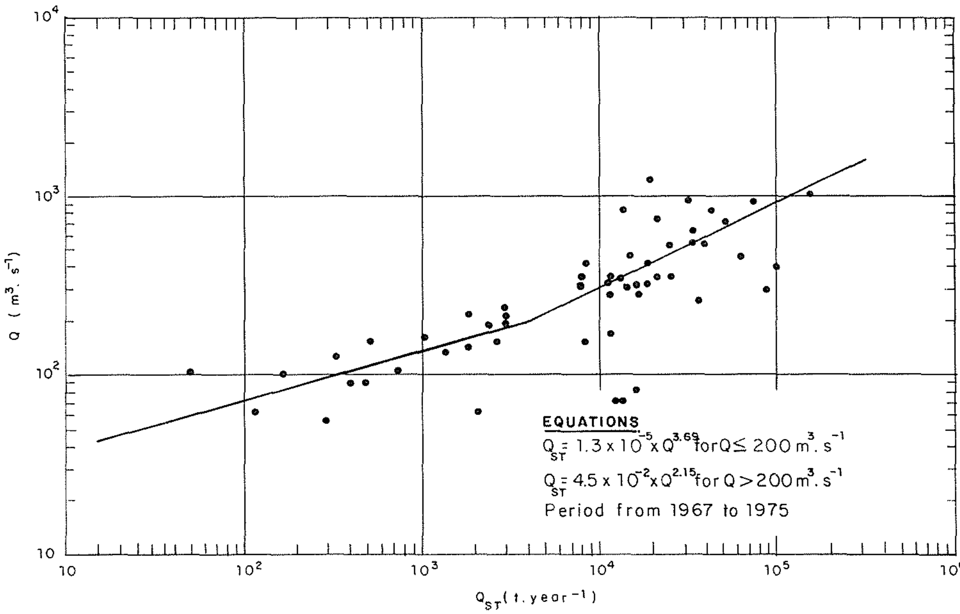


Fig. 1 Sediment rating curve of the Velhas River at Várzea da Palma (total solid discharge Q_{st} vs. water discharge Q).

2). The corresponding values are lower than those for which the daily sediment discharge rate was used.

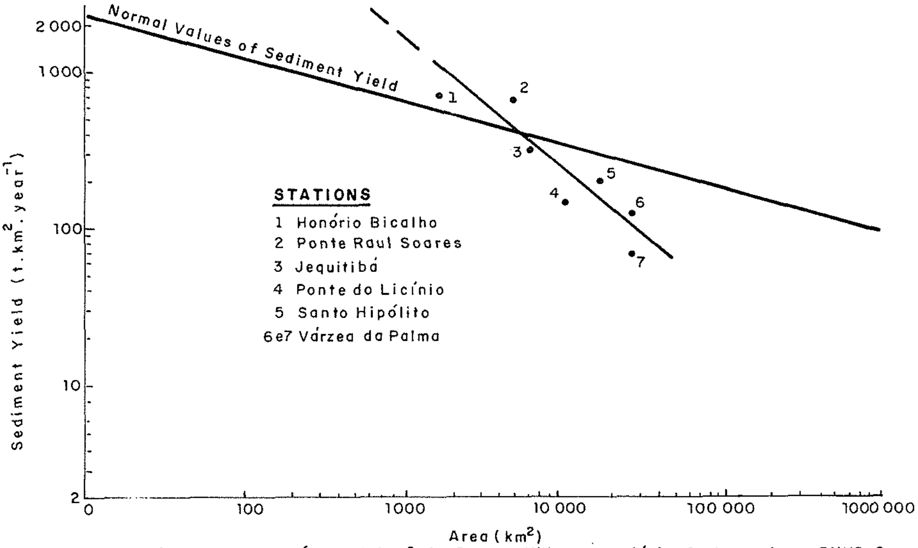
The soil degradation depth considered here corresponds to the soil loss or erosion rate (mm $year^{-1}$ or m × 1000^{-1} $year^{-1}$) in the drainage area. This computation was made by using a value of the sediment apparent specific weight as 1.60 t m^{-3} (see Table 2).

***Table 2** Annual average values of sediment yield and soil degradation rate in the Velhas River basin (mg)*

No.	*Station*	*Annual average discharge (m^3 s^{-1})*	*Annual average sediment yield (t km^{-2} $year^{-1}$)*	*Annual average soil degradation (mm $year^{-1}$)*	*Remarks*
1	*Honório Bicalho*	*32.7*	*705.2*	*0.44*	
2	*Ponte Raul Soares*	*74.4*	*661.9*	*0.41*	
3	*Jequitibá*	*75.1*	*312.1*	*0.20*	
4	*Ponte do Licínio*	*126.0*	*152.8*	*0.10*	
5	*Santo Hipólito*	*199.0*	*204.6*	*0.13*	
6			*130.3*	*0.08*	*CODEVASF*
7	*Várzea da Palma*	*287.0*			
			88.7	*0.06*	*DNAEE*

ANALYSES OF THE RESULTS

The values obtained for the stations in the basin were plotted on a graph of sediment yield versus drainage area (see Fig. 2). This figure also shows the line of normal sediment yield values obtained by research in 200 hydrographic basins in USA (Khosla, 1976: see Projecto Hidrometeorológico Centroamericano, 1977). The figure illustrates the high values for the Velhas River upstream of Jequitibá with sediment yields above the normal values.



Ref.: 1°) Estudos Hidrológicos; Pub. Nº 140, Proyeto Hidrometeorológico Centroamericano, PNUD. Governo Países Centro-América, Manágua, Nicarágua, 1977.
2°) Diagnóstico Sedimentológico na Bacia do São Francisco OEA/PLANVASF, Brasília, DF, 1986.

Fig. 2 Sediment yield on the Velhas River basin.

The comparison of the soil degradation heights was achieved using values obtained by international organizations and compiled by Pimenta (1981) in which were included the results of Velhas River (see Table 3).

EVOLUTION OF SEDIMENT YIELD IN THE BASIN

The measurements of sediment discharge made since 1967 in the Várzea da Palma station show how the sediment yield has evolved up to 1983. The majority of these data are the values of suspended sediment discharge which present better consistency in the results. A figure was drawn corresponding to a mass curve with annual average yield sediment accumulated values versus the correspondent annual average water discharge accumulated values (Fig. 3). The gradual increase in slope of this line proves that there is an increase of the sediment yield in the basin. Greater amount of sediment load, during the flood of 1979 and 1980, can also be demonstrated.

Table 3 Average soil degradation rate in several hydrographic basins of the world

River	*Country*	*Sediment discharge ($t\ year^{-1}$)*	*Soil degradation ($mm\ year^{-1}$)*
Lo	*China*	190×10^6	4.18
Ching	*China*	408×10^6	4.09
Yellow	*China*	1889×10^6	1.60
Ganges	*India*	1451×10^6	0.87
Bramaputra	*Bangladesh*	726×10^6	0.62
Red	*Vietnam*	130×10^6	0.62
Velhas (honório Bicalho)	*Brazil*	1.2×10^6	0.44
Yangtse	*China*	499×10^6	0.15
Colorado	*USA*	135×10^6	0.12
Mekong	*Thailand*	170×10^6	0.12
Velhas (Várzea da Palma)	*Brazil*	3.5×10^6	0.08
Mississippi	*USA*	312×10^6	0.06
Amazon	*Brazil*	363×10^6	0.04

Origin: Curso de Hidráulica Geral, vol. 2, p. 386, Carlita Flávio Pimenta, order of the table modified by PLANVASF and including values for the Velhas River basin.

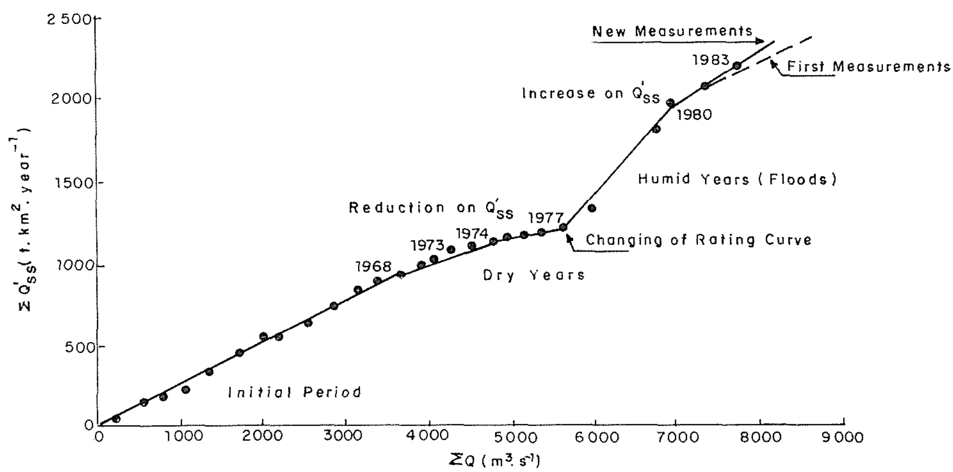


Fig. 3 Evolution of the suspended sediment yield on the Velhas River at Várzea da Palma (mass curve of water discharge vs. suspended sediment yield).

CONCLUSIONS

The sediment yield in the Velhas River basin may be considered as moderate but not alarming. However, it was shown that the upper basin presents a sediment yield bigger than normal values encountered in the USA. It was also shown that sediment yield has increased throughout the period of time. So it is concluded that there is a need for action to decrease the erosion in the basin. The following are suggestions:

(a) laws to prevent the exploitation of the remaining forest in the basin, and, where possible, the creation of forest parks which may be used for research, leisure and tourism;
(b) to provide incentives for reforestation;
(c) laws to prohibit the burning of field vegetation;
(d) the adequate management of the soil in the agriculture through terracing techniques, planting in contour lines, and so on;
(e) laws for adequate use of appropriate methodology for earthwork;
(f) protection of slopes and uncovered areas which are subject to erosion;
(g) care and protection of the catchment areas draining to reservoirs;
(h) studies of causes and risks of erosion and sedimentation, mainly in the high basin, including where and how the processes work;
(i) economic evaluation of the damage caused by erosion and sedimentation;
(j) educational campaign for local inhabitants showing the methods for avoiding or minimizing erosion and sedimentation.

Several other guidelines could be put forward, including the necessity of a national programme of education for environmental preservation.

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