THE ROLE OF DRAINAGE BASINS IN THE SILTING–UP OF RESERVOIRS: THE CAPIVARA PILOT PROJECT

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INTRODUCTION

In 1980, the Brazilian Electricity Company ELETROBRAS, in association with the Institute of Technological Research (IPT) of the state of São Paulo, initiated a series of studies on the development and application of a methodology for investigating silting processes in large reservoirs. The reservoirs involved were that of the Parigot de Souza hydroelectric dam on the upper Rio Capivari, Paraná, and the reservoirs of Passo Real and Ernestina on the upper Rio Jacui, Rio Grande do Sul.

The results have shown that silting, calculated on the basis of the material deposited on the lake bottom, was, contrary to expectations, insignificant: a greater degree of silting was predicted because of the intense erosion recorded in the contributing basins. This finding suggested that the sediments arising from erosion were being deposited along the river bed before reaching the reservoirs. On the other hand, and also contrary to the expectation that sedimentation was occurring in the dead water volume, it was found that silt was being carried in the circulating water, as evidenced by its deposition at the mouths of the water courses. The studies demonstrated, therefore, that the tributaries feeding the reservoirs were the principal source of sediments when compared to those arising directly from the lake margins, and that the sediments were on the river beds leading into the reservoirs. The next

step was to obtain estimates of the sediment volumes being transported by the drainage basins feeding the reservoir, and investigate the dynamics of the system as a means of predicting the degree of silting in the future.

Research carried out since 1986 by IPT and the Department of Waters and Electric Energy (DAEE) revealed the existence of recent sedimentary deposits along the drainage basins, which were classified as of technical origin, arising from human activities related to soil use. The discovery of these deposits and their origin was conclusive for the identification of the steps in the process of erosion-transport-silting, and explained the lack of silting in the reservoir despite the high rates of erosion detected in the basins of the tributaries. The sediments are undergoing a cycle of transport-deposition-transport, and moving gradually towards the reservoir. The dynamics of the process are a function of changes in patterns of soil use, rainfall regime, and the natural stability of the deposits themselves, influenced by vegetation cover and the fluvial dynamics where they occur. It is possible to predict that the alluvial fans at the mouths of the tributaries, the principal sources of silting, will tend to increase in size, entering the reservoir and diminishing its useful volume.

The Departament of the Environment and Natural Resources of the São Paulo Electricity Company (CESP) has for some time been studying the ways and means of resolving the environmental problems arising from its enterprises. As from 1978, as part of the Reservoir Management Plan and concerning questions related to the physical environment, the Department initiated programmes for the recuperation of leased areas and the reforestation of lakeshores and islands, in order to secure their stability and control erosion. Studies were also carried out, in collaboration with various research institutions, on the processes giving rise to and influencing the development of landslides, on the distribution of silt in the reservoirs, and on the land occupation and use and the associated degradation of the shores of a number of reservoirs. It is important to emphasize, however, that the measures adopted by CESP were restricted to the area under their jurisdiction (reservoirs and their shores), and the recognition of the role of the drainage basins in silting the reservoir

reinforced the need to understand the surface dynamics of the entire watershed, underlined by the need to restructure the Department's programs in order to take into account problems concerning the deterioration in the quantity and quality of the waters of its reservoirs.

THE CAPIVARA PILOT PROJECT

In 1989, CESP, in collaboration with IPT, began a study to examine erosion and silting in order to deepen their understanding of the sediment deposition and removal processes along the tributaries, from the source to the reservoir. The reservoir of the Capivara Hydroelectric dam on the Rio Paranapanema (see FIG. 1) was chosen

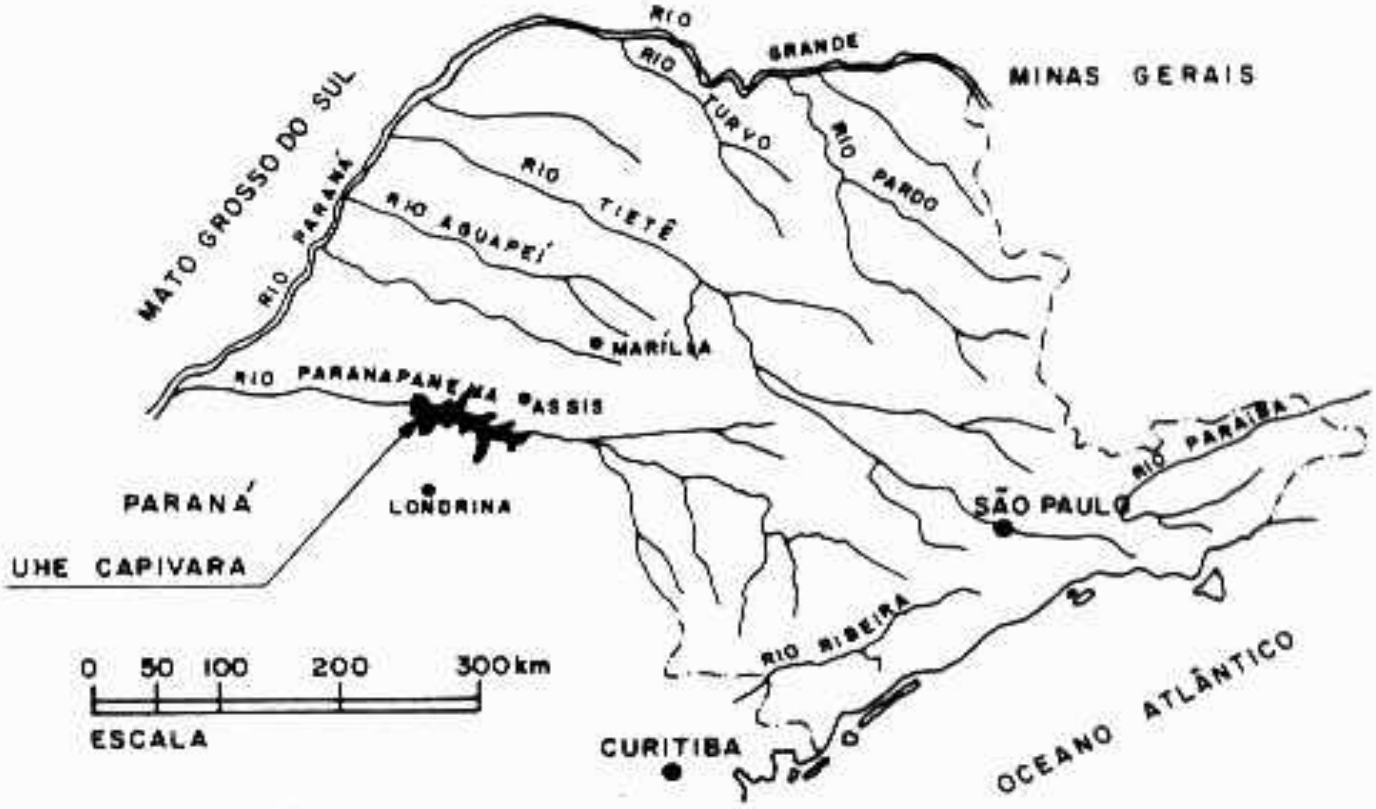

Fig. 1. Capivara Hydroelectric dam localization.

for a pilot project for two reasons: 1) the reservoir is for water storage, and loss of volume is therefore critical, and 2) the occurrence of basalt and sandstone, and their associated soils, throughout the basin, is a characteristic of a number of other reservoirs managed by CESP. The principal features of the reservoir and its hydrographic basin are as follows:

- Total volume. . . . . 11.7 km^3
- Volume increase during floods . . . . . 1.2 km^3

- Useful volume . . . . . 5.7 km^3
- Dead volume . . . . . 4.8 km^3
- Area inundated at maximum flood level for operation . . 576 km^2
- Maximum flood level mark . . . . . 336 m
- Maximum flood level mark for operation . . . . . 334 m
- Minimum flood level mark for operation. . . . . 321 m
- Area of drainage basin. . . . . 85,000 km^2
- Drainage area between the barrage and backwater. . . . 42,400 km^2
- Date of first operation March 1977.

The principal aims of the study were: to provide a diagnosis of the surface dynamics processes of the basin and its deposits (arising from human activities); and formulate measures to be carried out to minimize silting in the reservoir.

STAGES OF THE PROJECT

In order to fulfill the objectives defined above, the project was divided into four stages.

1) Characterization of the drainage basin and reservoir, specifically to examine potential soil loss and silting in the reservoir, and to select a sub-basin for a more detailed study.

2) Characterization of the surface dynamics of the selected sub-basin, specifically to understand the relations between soil use, erosion and silting through studies of the deposits in order to estimate the potential sediment transfer from the sub-basin to the reservoir.

3) Diagnosis of silting processes in the part directly affected by the sub-basin, specifically to understand the distribution and quantities of silt in the reservoir.

4) Interpretation of the results, specifically with the aim of understanding the dynamics of the basin and the extent of silting in the reservoir in order to provide a basis for carrying out measures for its minimization.

PRELIMINARY RESULTS

The studies began in 1989 and were due to continue until mid 1992. The first stage has been concluded, but the second and third stages are still underway, and the fourth stage has yet to be initiated.

FIRST STAGE

The basin was subdivided into analytical units — the sub-basins delimited in terms of their function and impact in relation to silting. The basin, of 42,400 km^2, was divided into 24 sub-basins, classified according to size:

a) large, with an area of more than 253 km^2;
b) medium, of between 28 and 253 km^2;
c) a group of small basins, of less than 28 km^2.

The key parameters were the size of the area and the nearness to the reservoir. Soil loss through erosion, creating sediments in each sub-basin, depended on a series of factors, both natural and anthropogenic, as well as the size of the basin. All other things being equal, soil loss is proportional to sub-basin area.

The distance from the sediment source to the reservoir has both qualitative and quantitative consequences, considering that longer distances result in larger amounts being held back or retained, and also more time for the water dynamics to eliminate certain fractions, from the coarser to finer sediments, and reduce loads transported along the river bottom in comparison to those in suspension. With regard to this aspect, and contrary to that of size, importance should be given to the group of small basins, where sediment production rate relative to the rate of soil loss should be higher than in the larger sub-basins, given the proximity to the reservoir and the shorter transport distance.

The available data concerning geology, relief, soil types and their distribution (susceptibility to erosion), and land use were subsequently analyzed and interpreted using maps scale 1:500,000, in order to classify each sub-basin according to aspects relevant to silting processes. Helicopters and boats were used for ground-truthing, and to obtain

measurements of the width, length, depth, and nature of the deposits. This work revealed a wide variety of deposits at the mouth of the sub-basins, which in turn were highly diverse in their size and form and in the types of soils they drained. In simple terms, however, it is possible to consider two main types of deposit: one of the delta or sandy alluvial fan type, and the second deeper and comprised essentially of mud.

The significant number of points analyzed permitted a preliminary characterization of the reservoir's behaviour in terms of silting. The shore on the São Paulo state side, downstream of the Ribeirão Capivari, is comprised mainly of alluvial delta deposits, and the shore on the Paraná side, and the upstream shore on the São Paulo side, were typified by deep mud deposits. It was possible to verify correlations between the predominant lithology of the sub-basins and their deposits, and the degree of susceptibility to erosion, by cross-checking the data on potential sediment production from the sub-basins and the data obtained from the field work. At the mouths of the sub-basins with a predominantly basaltic substrate the deposits are of mud (the entire Paraná shore and the São Paulo shore upstream of the Ribeirão Capivari). Downstream of the Capivari, sandy deltas testify to the predominance of sandstone and the presence of medium sandy podzols which are highly susceptible to erosion, not only from surface run-off but also from gully erosion (*voçorocas*). In the basaltic areas the soils susceptible to superficial erosion are litolic, followed by black soils (terra roxa) which show a medium susceptibility to superficial erosion, furrows and shallow ravines. Current soil use is distributed according to the soils. Annual crops (soybean and wheat) and sugarcane predominate in areas of basalt-derived soils. Forest plantations and pasture predominate in the sandy soils.

At the end of this stage, three sub-basins, totalling 900 km^2, were chosen for further study: the large sub-basin of the Ribeirão Capivari, the medium-sized basin of the Ribeirão Bonito, and the so-called "F—Group" of small basins. These sub-basins were representative of the conditions observed throughout the basin in terms of physical environment and occupation (sandstones, basalt, annual crops, sugar cane, pasture, etc.), and their deposits.

SECOND STAGE

The first step involved the qualitative analysis of the surface dynamics of the sub-basins, using maps of scales 1:50,000 and 1:35,000, which allowed the selection of two microbasins for more detailed studies: the first was part of the group of small sub-basins near to the reservoir, and the second was located further upstream, in the headwaters of the Ribeirão Rancharia, part of the sub-basin of the Ribeirão Capivari. These were mapped (scale 1:25,000) and to date have been characterized in terms of their morphopedology, geology, land use and occupation, and erosive processes (gullies, ravines, furrows and deposits), for three different periods, using aerial photographs from 1962, 1972 and 1984.

A preliminary analysis of these maps has allowed us to confirm that the majority of the erosive processes are old, that is they were already underway in 1962. In general, new sites of erosion have resulted from expansion of human occupation related to urbanization and bad and intensive agricultural practices. Information from local residents confirmed our previous conclusions regarding the transformation of the regional landscapes, indicating that intense erosive processes were already underway in the first decades of the century, arising from the deforestation at the time of the occupation of the western plains of the state of São Paulo.

Silting of the water courses is, however, increasing, with a significant displacement downstream due to the reworking of the oldest deposits of the drainage basins. The finding that the sediment supply to the drainage of these microbasins appears to be from gully erosion, and the fact that new erosion sites are arising in a limited number of localities, reinforces the need for institutional measures for the conservation of water resources, principally in those microbasins suffering intense agriculture, or of small size, or located in sandy soils near to the reservoirs. These measures should contemplate an integrated recovery plan for entire basins, with the participation of state and federal government institutions, local councils, and the community.

THIRD STAGE

Indirect (geophysical) and direct prospecting was carried out in the parts of the reservoir corresponding to the mouths of the following tributaries: Ribeirão Bonito, Ribeirão Água da Fábula, Córrego Agua da Piuna, and Ribeirão Capivari. Samples were collected for laboratory analysis. The map of isopachous lines obtained for this stretch of the reservoir provided evidence that the deepest deposits, without exception, occur at the mouths of the tributaries, and demonstrated the existence of gully erosion in the form of ravines in the vicinity of the reservoir. The contribution from the shores in these stretches of the reservoir appeared to be minimal, as did the contribution from superficial erosion in the sub-basins studied.

Calculations of the volume of material deposited in the reservoir are still underway, but a first approximation, considering only the stretches in question, provided the following results:

- Water volumes
  - Useful volume ..... 120.2×10^6 m^3
  - Dead volume ..... 20.4×10^6 m^3
  - Total volume ..... 140.6×10^6 m^3

- Volumes of sediment deposits
  - Deposits in the useful volume ..... 1.09×10^6 m^3
  - Deposits in the dead volume ..... 0.86×10^6 m^3
  - Total ..... 1.95×10^6 m^3

The data presented here give indications that an important part of the sediment load transported by the drainage basins is deposited as it enters the reservoir, creating sandy deltas and deep clay deposits. The data also give rise to the following questions:

— what are the consequences for the fish fauna of the accumulation of sandy or clay banks at the mouths of the tributaries?

— does even this small reduction (of the order of 2—5%) in the useful volume of the reservoir have negative consequences for electricity generation?

— does the reduction in the reservoir's useful volume affect the volume reserved during floods?

REFERENCES

BORDAS, M.P., LANNA, A.E., LEPRUN, J.C., SEMMELMANN, F.R. Diagnóstico preliminar dos riscos de assoreamento no Brasil. In: VII SIMPÓSIO BRASILEIRO DE HIDROLOGIA E RECURSOS HÍDRICOS, 1987, Salvador.

CARLSTRON-FILHO, C., GIMENEZ, A.F., PIRES-NETO, A.G., PRANDINI, F.L., MELO, M.S., PONÇANO, W.L. Estudo do assoreamento dos reservatórios de Passo Real e Ernestina (RS). In: III SIMPÓSIO REGIONAL DE GEOLOGIA, 1981, Curitiba.

MELO, M.S., STEIN, D.P., PONÇANO, W.L., BISTRICHI, C.A., GIMENEZ, A.F., CARLSTRON-FILHO, C. Geomorfologia aplicada ao estudo do assoreamento do reservatório do rio Capivari, Paraná. In: III SIMPÓSIO REGIONAL DE GEOLOGIA, 1981, Curitiba.

OLIVEIRA, A.M.S. Levantamentos preliminares sobre o papel da drenagem no assoreamento de reservatórios — projeto piloto Capivari. São Paulo: 1990a (Relatório nº 28.299 DIGEM/IPT).

OLIVEIRA, A.M.S. Depósitos tecnogênicos associados à erosão atual. In: VI CONGRESSO BRASILEIRO DE GEOLOGIA DE ENGENHARIA, 1990b, Salvador.