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RATES AND PROCESSES OF BANK EROSION, ITAIPU RESERVOIR, PARAGUAY-BRAZIL BORDER, SOUTH AMERICA

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ABSTRACT

Measurement of erosion have been made on nine erosion stations along the south end of Itaipu reservoir, Paraguay-Brazil border, South America, between July 1993 and March 1995. Land-use, shoreline location (embayment or main truck of lake), fetch magnitude and associated wave energy are the critical factors influencing bank erosion. The cycle of erosion of banks at Itaipu reservoir consist of only a few steps: undercutting (wave abrasion), overhang formation, overhang failure and removal of debris from the toe bank. The amount of erosion is highly variable. Mean rates ranging from 0.62 m/yr to 4.80 m/yr and the average rate was 2.19 m/yr. Alternatives approach to mitigate the impact of operating schemes on bank erosion are suggested.

KEYWORDS: bank erosion, Itaipu reservoir, Parana river

INTRODUCTION

Numerous studies of erosion processes were completed along shores of inland lakes and reservoir in several parts of the world. The Great Lakes of the United States is the most studied natural lake (e.g., Buckler & Winters, 1983; Carter & Guy, 1983; Sterrett, 1980; Lawrence, 1994). In the case of reservoirs, the bodies of water most studied are the U.S.

Army Corps of Engineers reservoirs (e.g., Gatto & Doe, 1983; Reid, 1984; Reid et al., 1988), and reservoirs located in the extinct U.S.S.R. (e.g., Kondratjev, 1966; Avakyn, 1975; Shur et al., 1978) and Poland (Mazur, 1958; Cyberski, 1965, 1973; Lukac, 1982). This studies have documented historical and present rates of bank retreat and assessed erosion processes and factors contributing to them. The most study area is located in cold or temperate regions. Otherwise, are rare the studies executed in tropical regions. The aim of this paper is to elucidate the conditions under which bank erosion takes place in a reservoir located in subtropical climate. For this purpose was selected a largest reservoir, Itaipu Lake, located in Paraguay-Brazil border, South America (Figure 1). This lake is a hydropower generation reservoir constructed and operated by the Itaipu Binacional.

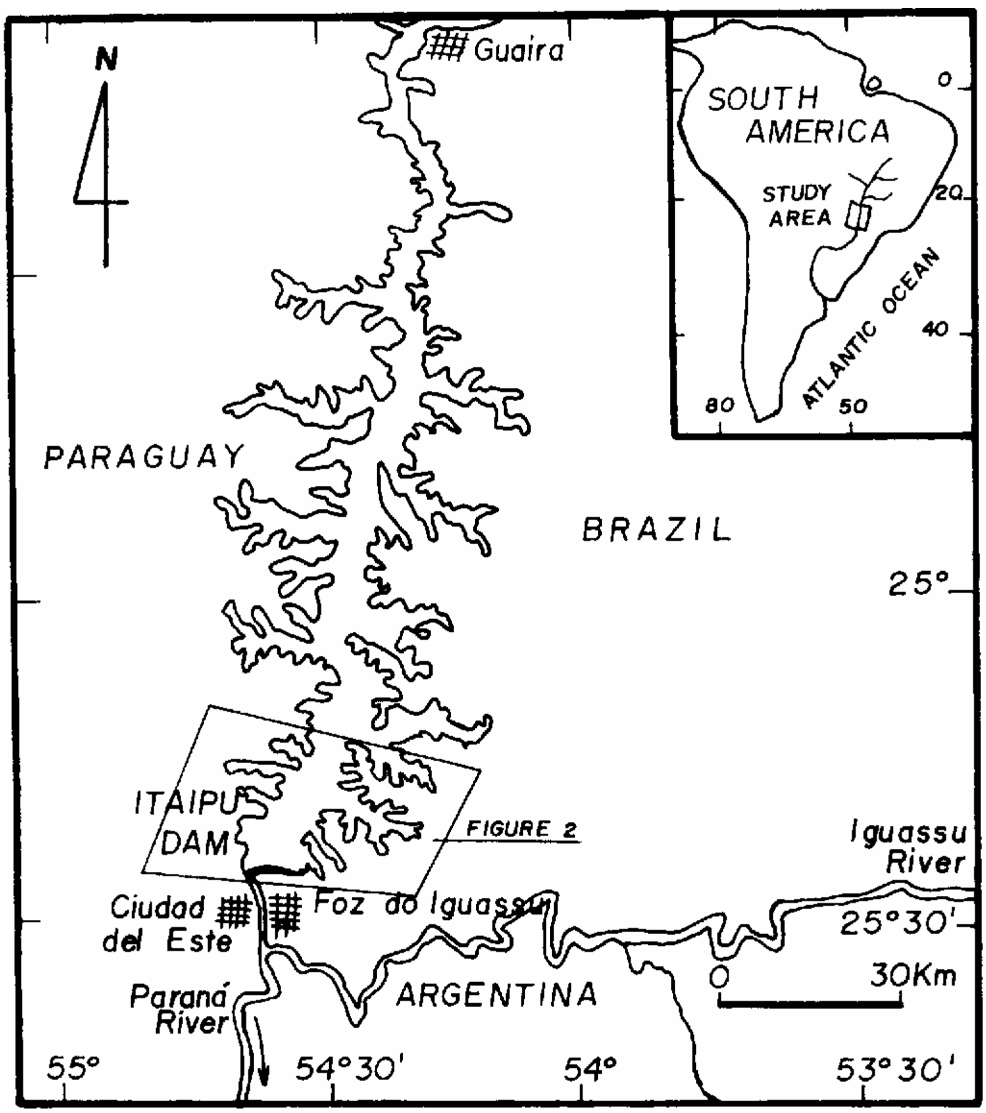

Figure 1: Location of Itaipu reservoir and study reach.

Itaipu reservoir, on the Parana river, was impounded behind homonymous dam in 1982. The lake was filling from 1982 to 1994, when the operating level (219.60 m) was reached. The reservoir have a geometry elongated (151 km in length and 6 km in width). The general characteristics of the reservoir are listed in table 1.

TABLE 1: Physical characteristics of Itaipu Reservoir at maximum normal level (220 m elevation) (Müller, 1987).

Drainage area above dam	820,000 km^2
Average width	6 km
Length	151 km
Surface area	1,460 km^2
Maximum depth	170 m
Mean depth	21.5 m
Volume	29×10^9 m^3
Hydraulic residence time	40 days

The climate of the area is subtropical, with 1,700 mm annual precipitation and 23 ^oC average temperature. The weather is variable. The period October-march is the wettest station and April - September is more dry with variable precipitation. The regional terrain is rolling to flat. The bank heights vary nearly 0 to more than 3 m, and the banks are composed of red latosol, product of in situ weathering of basalt. The reservoir shoreline is predominantly rangeland and farms. The native vegetation, composed by dense forest, remain only in six forests preserves, totaling 298.78 km^2, located along the shore of reservoir (Müller, 1987).

PROCEDURES

Measurements of bank erosion in Itaipu reservoir were monitored from july 1993 to march 1995. In july 1993, nine erosion stations were established along the south half of the lake (Figure 2), nos. 1-5 along the brazilian shore, and nos. 6-9 along the paraguayan shore. Details of the stations are given in table 2. The stations were selected on the basis of bank characteristics: height, slope, composition, orientation, and land-use prior to lake formation; and the offshore characteristics: slope and width of the wave-cut platform. In addition, was assessed the relationship of erosion stations to protected bays and headlands.

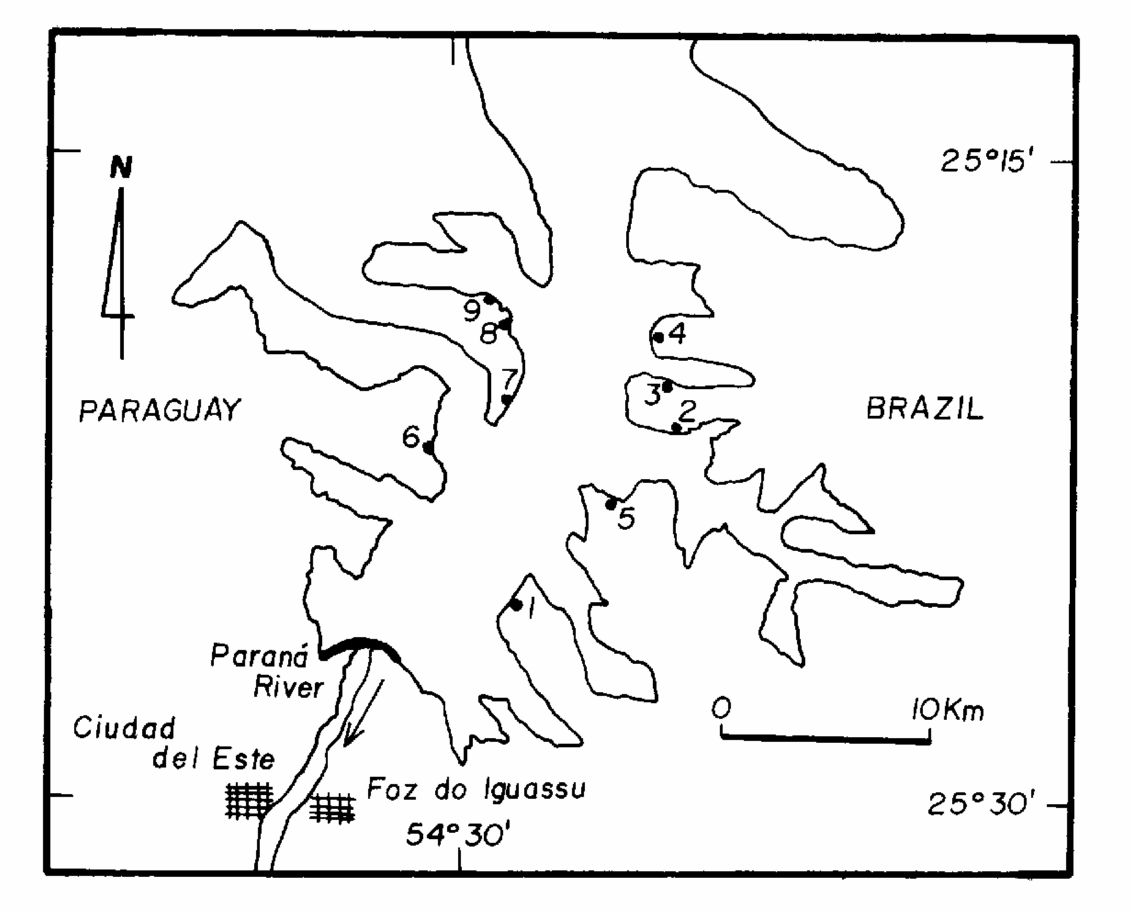

Figure 2: Location of stations erosion on the Itaipu reservoir.

TABLE 2: Details of erosion measurement stations.

Erosion Stations	Bank Height (m)	Bank face Orientation	Bank material (% silt-clay)	Vegetation and land-use
1	0,85	NW	93.5	Annual culture
2	1,51	S	97.0	Annual culture
3	1,30	NW	89.6	Afforestation
4	2,15	W	92.5	Forest
5	0,94	NE	96.0	Annual culture
6	1,50	SE	96.0	Pasture
7	1,80	E	90.0	Forest
8	2,36	E	92.0	Pasture
9	1,12	N	96.0	Forest

Rates of erosion were monitored using a series of reference wooden stakes positioned along the erosion stations. The stakes are established about 2-6 m back from bank edge and spaced 3 m apart. This marks are referenced to other farther inland, in case the former are removed with rapid erosion. Measurements of distance from stakes to banks edge were recorded nine times between July 1993 and march 1995. Exposed banks were measured, described, and sampled in the beginning field observations. Reservoir levels and precipitation data, recorded continuously at Itaipu Dam, are available upon request.

RESULTS

Processes of Bank Erosion

The processes of bank erosion were observed, noted and photographed during the field measurement. Erosion of basalt residual soil is controlled by waves activity in lower portion of bank and by cohesive and tensile strength of the soil in the upper portion of bank.

Steeply cut banks are present along most of the shoreline. The cycle of erosion of banks at Itaipu reservoir consist of only a few steps: undercutting, overhang formation, overhang failure and removal of debris from the toe bank. Basal erosion is caused by wave activity that attack the bank directly (corrasion); the upper portion of bank is undercut and large overhang is formed. Fernandez (1996) noted that overhangs in some reach of Itaipu reservoir shoreline were 70-100 cm in width. The collapse of overhangs taken place when extreme undercutting at the toe of the bank occurs. The failed blocks usually remains at the base of the bank until disintegrate and the sediment is speedily removed by waves.

Other contributing processes are mass movement due to falling of trees. Collapse of trees may remove away as much as 5 to 15 m^3 of bank sediment.

Rates

Table 3 summarize the total and average recession rates of 21 months of measurement at each of the nine stations shown on figure 2. The recession rate ranged from 0.62 m/yr (station 1) to 4.80 m/yr (station 7) and average was 2.19 m/yr.

Generally, erosion stations located along shoreline of embayments show that bank erosion is less than along the main trunk of the reservoir. Wind-driven waves during tropical tempest is major cause of toe bank erosion in main trunk of reservoir, where fetches are much broader (6 to 9 km) than in embayment zone (2 to 5 km).

TABLE 3: Bank-top recession summary, Itaipu reservoir, July 1993-march 1995.

Erosion Stations	Recession rate (m/yr)	Total recession (m)
1	0.62	1.08
2	0.92	1.62
3	0.67	1.17
4	3.69	6.46
5	1.06	1.85
6	2.77	4.84
7	4.80	8.41
8	1.63	2.85
9	3.58	6.26
Average	2.19	3.84

ANALYSIS

The existence of steep banks surrounding Itaipu reservoir reflects the importance of wave erosion there. The combination of two factors producing reservoir bank erosion can be seen better by examining concurrent records of bank-top recession, precipitation and reservoir level fluctuation (Figure 3).

Normally the water level is maintained at about 219.7 m all the year. Between July 1993 and December 1994 the water level varied from 219.5 m to 219.9 m, and annual fluctuations were generally small. In January 1994 the reservoir level was raised up to 220.1 m, where it remained to the end of the period observation. Despite the waves erodes continually the toe of bank, water levels oscillation not shows direct relation with bank-top recession, due undercutting and overhang failure not occur at the same time. Overhang can delay until six months for failure. On the other hand, during the 21 months of record most of the erosion occurs in rain period. The strong relation between bank-top erosion and precipitation is due fail of overhangs. The amount of bank-top erosion occurred in August - October 1993 and November 1994 - January 1995 illustrates this. The measurement in march 1995 is of particular interest. Despite the high lake level (up 219.90 m) and moderate monthly precipitation (150 mm), erosion was negligible compared to high rate recession observed some before months. This fact suggest that banks has achieve a state of dynamic equilibrium, in very short interval times.

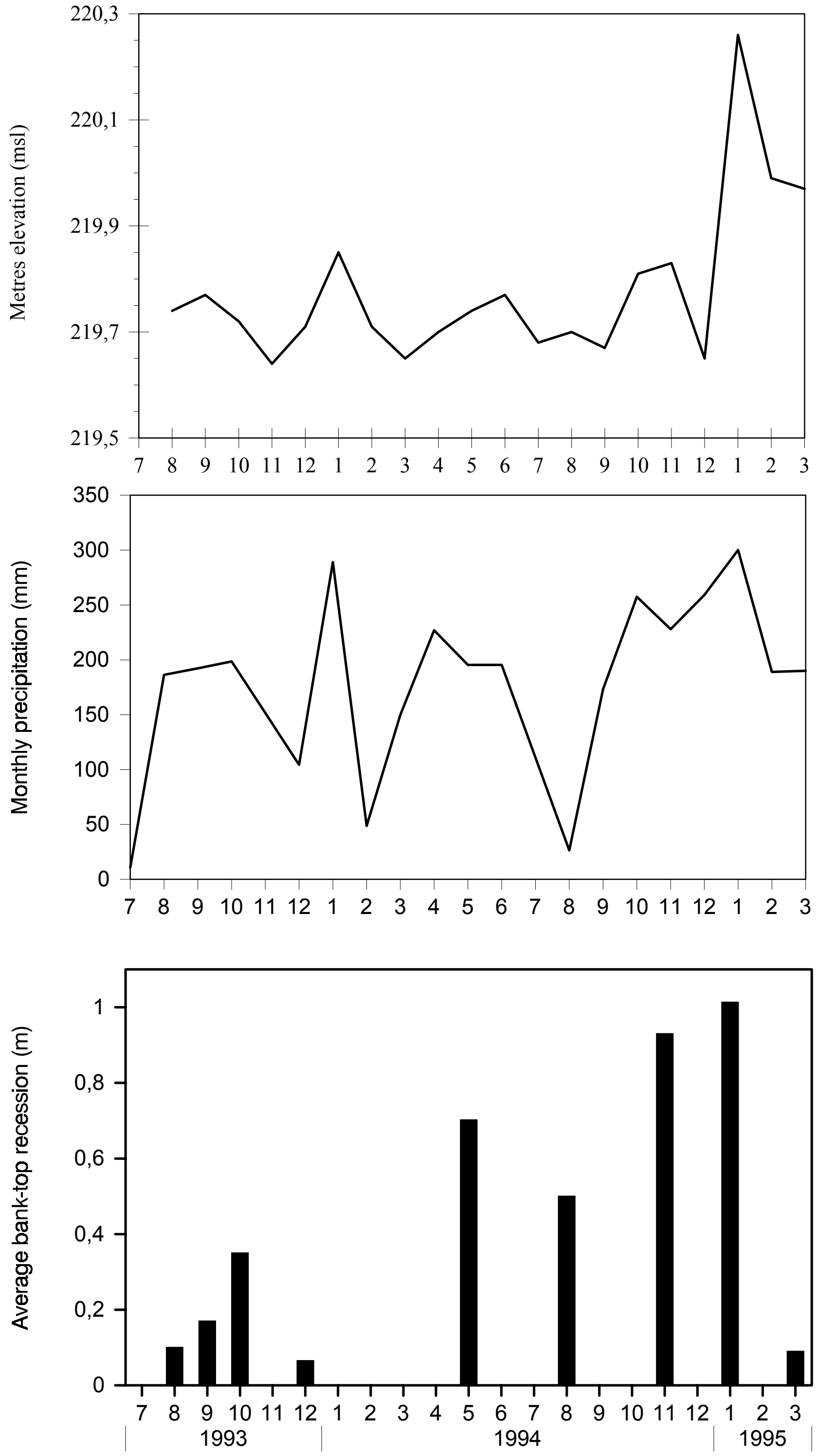

Figure 3: Concurrent records of bank erosion, precipitation and lake level for Itaipu reservoir.

Variations in shoreline orientation, couped with fetch influence the rates of bank recession on reservoir. Because of lake geometry (elongate N-S direction), westerly and easterly winds cause larger waves in main body of lake, because of the longer fetch and hence more bank erosion than the more common northerly and southerly winds. On the other hand, the largest waves that strike embayment shoreline (oriented E-W direction) are generated by wind come from the north and south.

In Itaipu reservoir shoreline was observed a closed relationship between erosion rates, bank height, vegetation and land-use. Agricultural activity with prolonged use of tractors produces a compactness in upper layer of soils. This soil secondary property associated to low bank (height < 1 m) cause low erosion rate (e.g. stations 1, 2, 3 and 5). On the other hand, high banks (height > 1 m) bordered by native forest shown high rates (e.g. stations 4, 7 and 9), apparently due lack of secondary compactness. In the last case, the presence of abundant vegetation not limiting the effectiveness of bank erosion processes.

If lake level oscillation is maintain within the present interval (219.5 - 219.8 m), assumedly the recession will decrease with time. Examination of erosion data revealed that rising level (above 219.80 m) cause notable increasing of erosion. This tendency was observed principally in banks located in main trunk of lake.

CONCLUSIONS

This study has given some information of the rate of bank erosion on Itaipu reservoir, a largest lake located in tropical region. It has also shown that erosion processes on the lake banks vary enormously, even on a recession stations, as well as between reaches located on embayments and main trunk of lake. The cycle of erosion of banks at Itaipu reservoir consist of only a few steps: undercutting (wave abrasion), overhang formation, overhang failure and removal of debris from the toe bank.

Wooden stakes have provided an accurate measurement at selected points around the south half of the reservoir; the average bank erosion between July 1993 - March 1995 was 2.19 m/yr, with a maximum rate of 4.80 m/yr at erosion station 7. Agricultural activity produces a secondary compactness in upper layer of soil, because prolonged use of tractors. Field measurements shown this area are much more resistant to wave abrasion than are native vegetated banks. An alternative approach to mitigate the impact of operating schemes on bank erosion, is to maintain the lake level within the present fluctuation interval (219.50-219.80 m). Field observations shown that rising of reservoir levels (above 219,8 m) cause greatest erosion.

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