

The Impact of an Extreme Flood upon the Mixing Zone of the Todos os Santos Bay, Northeastern Brazil

F. Genz †, G.C. Lessa ‡ and M. Cirano ‡

† Pós-graduação em Geologia
Universidade Federal da Bahia, Salvador
40170-115, Brazil
fgenz@uol.com.br

‡ Centro de Pesquisas em Geofísica e
Geologia
Universidade Federal da Bahia, Salvador
40170-115, Brazil



ABSTRACT

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River dams, by impacting the discharge pattern of a drainage basin, may cause problems to the lower river course and associated estuarine areas, especially in relation to channel morphology and material exchange with the coastal environment. With the aim of investigating the effect a natural flood upon the hydrodynamics and mixing condition of a secondary estuary (Paraguaçu River) inside Baía de Todos os Santos, a simulated 8-day flood event was released by Pedra do Cavalo Dam, located 20 km up the river, on November 2001. Peak discharge reached $1534 \text{ m}^3 \text{ s}^{-1}$ (15 times the pre-dam average discharge) in the very first day of the simulation, and was reduced daily in a step-like fashion in the following 7 days. The flood had a major impact upon the water level of the closest monitoring station, 5 km downstream from the dam, but was not noticeable in the farthest station another 32 km downstream. Current measurements, performed at a fixed station 32 km downstream from the dam, registered velocities up to $1.8 \text{ m} \cdot \text{s}^{-1}$ during the ebbing time, and an apparent inversion of the residual current vector between spring (ebb directed) and neap (flood direct) tides. The salt intrusion zone travelled 14 km up river during the spring-tidal cycle prior to the flood. With the onset of the event it was pushed 16 km downstream and was maintained out of the lower river course, as the water column changed from a well-mixed to a partially mixed until the discharge dropped below $118 \text{ m}^3 \text{ s}^{-1}$.

ADDITIONAL INDEX WORDS: *Dam, freshwater, estuary.*

INTRODUCTION

The Baía de Todos os Santos (BTS) (Figure 1) is the second largest coastal bay in Brazil, with an area of 1223 km^2 and a catchment area of 60.000 km^2 . About 95% of the catchment (56.300 km^2) is drained by Paraguaçu River, that discharges into a secondary bay called Baía de Iguape, in the western side of the BTS (Figure 1). The Paraguaçu estuarine zone has a total length of 40 km, comprising 16 km of the lower river course (4 m deep), 6 km inside Baía de Iguape and 18 km of a tidal channel (Paraguaçu Channel - 25 m deep) that connects Baía de Iguape to the main body of the BTS (Figure 1).

The Baía de Iguape has a total area of $76,1 \text{ km}^2$ and is divided into 3 sectors: north, central and south sector (CARVALHO, 2000). The tidal channels (depths between 5 to 10 m) along the northern and southern sectors of Baía de Iguape have an average width of 200 m and an extension of 11 km and 7 km, respectively. The central part of the bay, with a prograding fluvial delta fronting Paraguaçu River, is very shallow, with large longitudinal sand banks emerging at low water (LESSA *et al.*, 2000). The vegetated and non-vegetated intertidal area inside Baía de Iguape represent 37% and 21% of the total bay area, respectively. The most common mangrove species is *Laguncularia racemosa* (CARVALHO, 2000), that covers 81% of the total mangrove area of the estuary.

The Paraguaçu River had an average river discharge of $102.7 \text{ m}^3 \cdot \text{s}^{-1}$ until 1985, when Pedra do Cavalo Dam (Figure 1), with a volume of $4,64 \times 10^9 \text{ m}^3$, was built 20 km upstream from Baía de Iguape. The original discharge, that accounted for 81% of the total fluvial input to the BTS, was reduced to $68.5 \text{ m}^3 \cdot \text{s}^{-1}$, or 60% of its previous average. Water extraction for urban consumption, direct evaporation from reservoir surface area and the decline of the natural river discharge are possible causes for this reduction.

The impact of river damming upon the water and sediment dynamic of lower river courses and the estuarine areas can vary from channel shoaling by marine and/or fluvial sediments (KJERFVE, 1989, LEVINSSEN and VAN DOLAH, 1997, Eyre *et al.*, 1998, COLLIER *et al.*, 2000, WOLANSKI *et al.*, 2001) to

modification of the tidal asymmetry and extent of salt intrusion along the estuary (WOLANSKI *et al.*, 1996, WOLANSKI *et al.*, 1998, GUILLÉN and PALANQUES, 1992, CARRIQUIRY and SÁNCHEZ, 1999 and VIEIRA and BORDALO, 2000, WOLANSKI *et al.*, 2001). Channel shoaling, generally associated to a reduction of the magnitude of the river floods may cause i) inlet morphologic instabilities (GUILLÉN and PALANQUES, 1997; BARUSSEAU *et al.*, 1998; MORRIS and FAN, 1998; MEDEIROS *et al.*, 1999; OLIVEIRA, 1999, CAMPOS, 2001) and ii) environmental degradation as a consequence of impaired water circulation, degraded water quality and consequent impact upon the ictiofauna and intertidal vegetation (PATTY *et al.*, 1999; RUBIN *et al.*, 1998).

In July 2002 a research project financed by the Brazilian Research Council was initiated on three dammed rivers (Paraguaçu River as one of them) of different sizes, morphology and hydrological regimes, in order to evaluate the impact of dams upon the estuary morphodynamics. A proper assessment of the changes imposed by the dammed flow upon the estuarine hydrodynamics requests some knowledge of the flow and mixing patterns prior to the construction of the dam.

In the case of Paraguaçu River, no data exists on the water quality, mixing or hydrodynamics before 1985. A sole exception is the paper of WOLGEMUTH *et al.* (1981) that, with longitudinal profiles (water surface sampling), shows that stronger salt gradient occur by the river delta with river discharges varying from 21 to $130 \text{ m}^3 \cdot \text{s}^{-1}$. A way to bypass this limitation is to generate artificial flood events or use numerical modelling techniques. This paper deals with the impact of a simulated flood, with a return period of more than 1 year, on the whole extent of the estuary. The results will show that, even with discharges that simulated an event with a return period of more than one year, only the riverine sector of the estuary was significantly impacted.

METHODS

A flood hydrograph was established based on available discharge data (40 years before 1985). The dataset consisted of

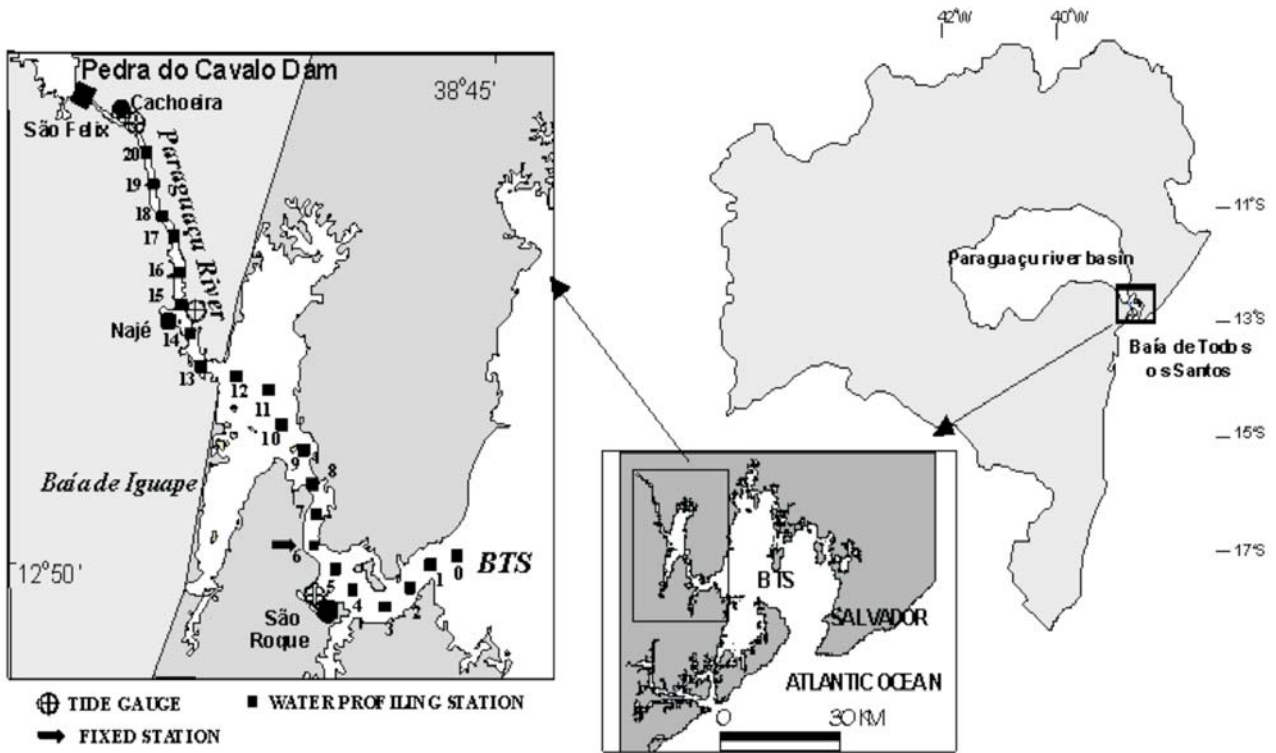


Figure 1. Location of study area and monitoring points

historical time series for the two major tributaries to the reservoir, namely Argoim station (at Paraguaçu River) and Ponte do Rio

Branco station (at Jacuipe River). These two stations are located just upstream of the reservoir and can give a good estimate of the total inflow. Selected hydrographs, with peak discharges above $400 \text{ m}^3 \cdot \text{s}^{-1}$, indicate that the ascending sector of the curve, prior to the peak discharge, varied a few orders of magnitude (from 10 to $1000 \text{ m}^3 \cdot \text{s}^{-1}$) within a day interval. The descending sector of the hydrograph was much smoother, characterized by the following equation:

$$Q_{i+1} = Q_i e^{-k \cdot \Delta t} \quad (1)$$

where k is the decreasing coefficient, t is the time interval, Q_i is the discharge and i is a given time (starting from the peak discharge). The mean k value, based on 59 flood events with return periods larger than one year, was 0.28. The selection of the final hydrograph to be reproduced was also based on:

- a) the volume of water available in the reservoir;
- b) the tidal conditions;
- c) the sluice operational guidelines.

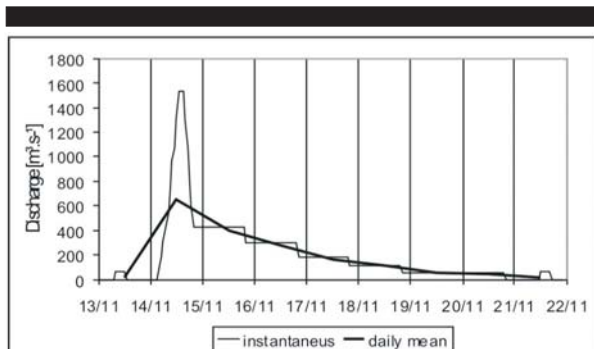


Figure 2. Hydrograph produced by the simulated flood event.

In order to avoid flooding of marginal cities (Cachoeira, São Felix and Najé), especially when discharges coincide with spring tides (that are up to 3 m high 5 km downstream of the reservoir LESSA *et al.*, 2001), the peak discharge rarely exceeds $1500 \text{ m}^3 \cdot \text{s}^{-1}$. However, to avoid illegal occupation of the lower river banks, floods are generated at least once a year. Based on all these facts, the hydrograph was set to last 8 days (November 13 to November 21, 2001) and to provide a peak discharge of $1600 \text{ m}^3 \cdot \text{s}^{-1}$, coincident with high water of a spring tide.

Tidal elevation was sampled along 3 different locations (Figure 1) using an analogic gauge, model LNG 7, made by Hidrologia. The tide gauges were deployed at distances of 4, 18 and 37 km from Pedra do Cavalto Dam (located 4 km upstream of the upper limit of the estuary). The water level records were digitized on a tablet and corrected for time and elevation offsets when necessary.

Vertical profiles of water quality (salinity, temperature, pH¹ and suspended sediment concentration) were executed with a

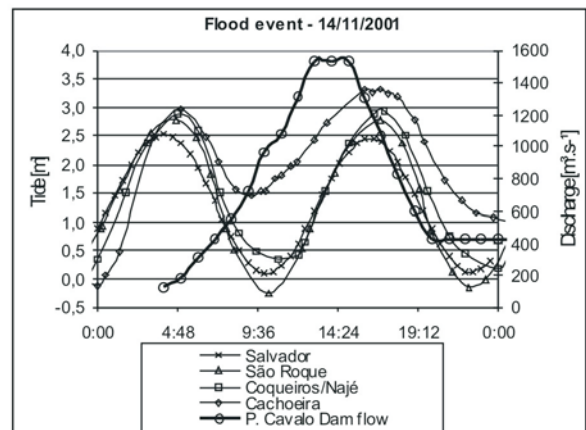


Figure 3. Tide and dam peak discharge - 14/11/2001.

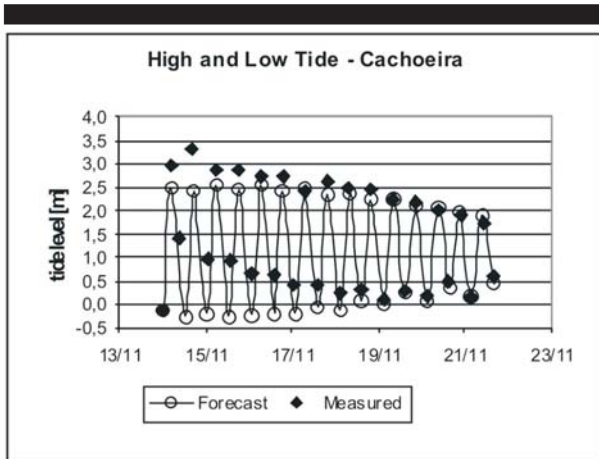


Figure 4. Predicted and observed high and low water elevations at Cachoeira

horiba multi-probe U-10 over 20 stations distributed along the mixing zone (40 km long) shown in Figure 1. The current field and the water quality were also monitored at a fixed station located 6 km downstream from Baía de Iguape, in Paraguaçu Channel.

The current field was measured with a Sensoredata SD-30 in a fixed station, sampled every 0.5 hour during one complete tidal cycles at neap and spring conditions.

RESULTS AND ANALYSIS

The hydrograph for the monitored period is presented in Figure 2. The sluices were opened on November 14 (4 am), reaching a peak discharge of $1534 \text{ m}^3 \cdot \text{s}^{-1}$ at 1 pm. After 4 pm, the discharge started to be reduced hourly until it reached $423 \text{ m}^3 \cdot \text{s}^{-1}$ at 8 pm. From then on, the sluices were closed at an equal rate (based on k coefficient) every day at 8 pm until the November 21, producing a step-like profile in the hydrograph.

The daily average discharge between November 13 and 21 were 13, 656, 402, 278, 167, 108, 58, 48 and $13 \text{ m}^3 \cdot \text{s}^{-1}$.

Tide

The tide wave underwent amplification up the estuary, by a factor of 1.08 during spring and 1.19 during neap tides. On the spring tide of November 13, when the largest ranges were recorded prior to the flood, the tidal range was 2.86 m at São Roque, 2.98 m at Coqueiros and 3.1 m at Cachoeira. During neap tides on November 21, when the flood hydrograph was over, tide ranges in those same locations were 1.33 m, 1.45 m and 1.59 m, respectively.

The tide records at the three stations on November 14 are

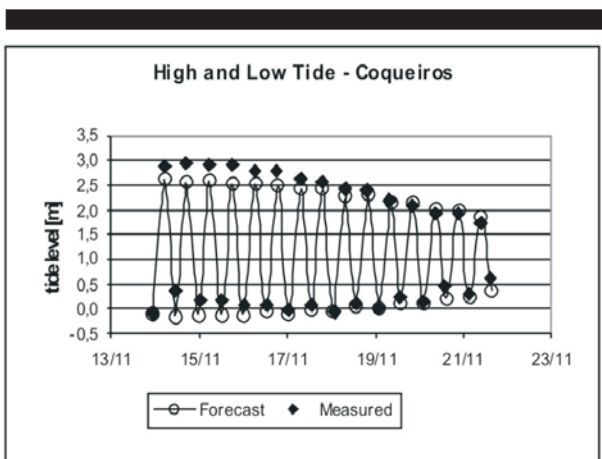


Figure 5. Predicted and observed high and low water elevations at Coqueiros.

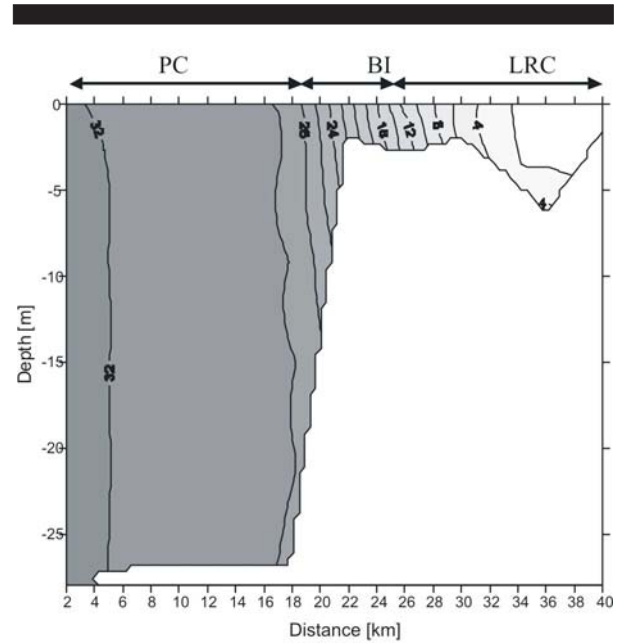


Figure 6. Longitudinal salinity profile at low tide on November 13 (PC Paraguaçu Channel; BI Baía de Iguape; LRC Lower River Course)

shown in figure 3 against the predicted tide level. Mean sea level was raised by about 1.5 m at the upstream most station (Cachoeira) during the flood peak on November 14. The high tide level reached an elevation 0.5 m higher than that predicted by the astronomical tides, but the tidal range was reduced in 1.2 m. At Coqueiros, the next downstream station, the river surge was only 0.5 m and tide range was reduced in 0.5 m.

Figure 4 shows that the effect of the flood at Cachoeira persisted until 19/11 (Figure 4), when the discharge was $58 \text{ m}^3 \cdot \text{s}^{-1}$.

At Coqueiros (Figure 5), distortions of the tide level were observed only until 17/11, when the discharge was $177 \text{ m}^3 \cdot \text{s}^{-1}$. At the farthest station, São Roque, the river surge was absent from the records. The predicted water levels used in figures 4 and 5 were obtained from harmonic analysis of a 15 day long water level record performed by the Brazilian Hydrographic Authority in 1976.

Without the flood, the tide wave distortions at Cachoeira and

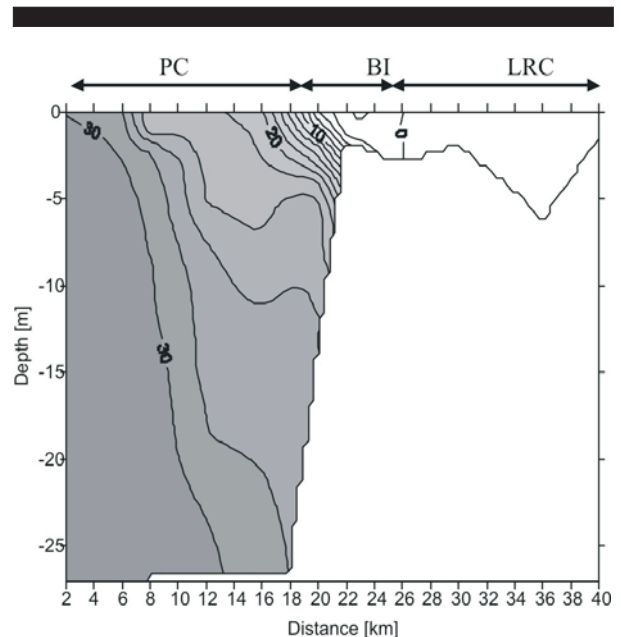


Figure 7. Longitudinal salinity profile at low tide on November 15

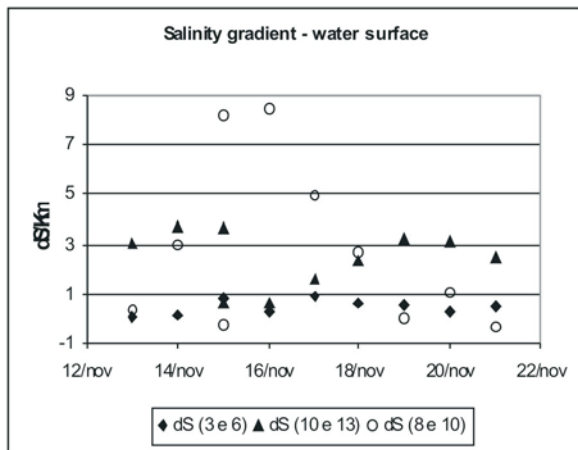


Figure 8. Daily variations of the surface water salinity gradient.

São Roque are opposing. In the former the rising tide is much shorter than falling tide, whereas in the latter falling tides are shorter. At Coqueiros, located between the above stations, the difference between flood and ebb periods is only of few minutes. During the flood, the original tidal asymmetries were enhanced at all the stations, with rising tides becoming 30 minutes shorter at Coqueiros and Cochoerira, and 23 minutes longer in São Roque. An exception occurred in Cachoeira on the November 14, during the discharge peak, when rising tides became longer (Figure 3). Increased asymmetries caused longer time lags at low tide between the stations in the river and São Roque. Shorter falling tides in São Roque are ascribed to the large intertidal areas inside the Baía de Iguape, that tend to retard the infilling of that section of the estuary (LESSA, 2000).

High and low water time lags during the flood were increased in relation to the predicted ones. Time lags between Cachoeira and Coqueiros changed from 0:07 hs to 0:23 hs at high tide, and from 1:06 hs to 1:26 hs at low tide.

Salinity

The longitudinal profile of the water quality (Figure 6) show that for the low tide in the pre-flood situation of November 13, the estuary was mostly well-mixed, with salinity values above 30 psu penetrating 16 km up the Paraguaçu Channel (station 8 in Figure 1). An intense longitudinal salinity gradient was

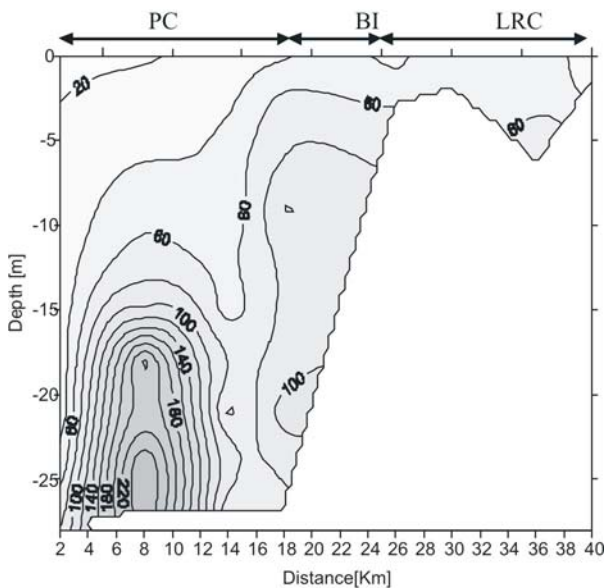


Figure 9. Longitudinal distribution of the suspended sediment concentration at the low tide on November 13.

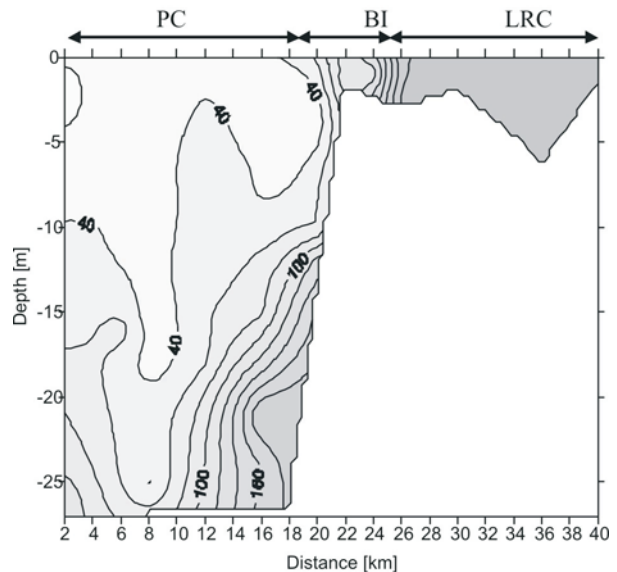


Figure 10. Longitudinal distribution of the suspended-sediment concentration at the low tide of November 15.

observed after station 9 (before reaching Baía de Iguape), where the salinity varied from 30 psu to 4 psu within 18 km. The farthest detectable salt concentration was at station 18, located 7 km downstream of Cachoeira, reaching 4 psu close to the bottom. This limit of salt intrusion may have moved farther upstream during the high tide.

With the beginning of the flood the estuary gradually changed from a well to a partially-mixed condition, with freshwater occurring along the whole lower river course (Figure 7). This mixing condition lasted until 18/11. At day 19/11, with discharges falling to $58 \text{ m}^3\text{s}^{-1}$ and tides changing from spring to neap condition, salt intrusion along the lower river course is again observed. The maximum salinity gradients during the flood were generally found at the vicinity of Baía de Iguape, located either at end of the lower river course or at the beginning of Paraguaçu Channel. Figure 8 shows that the average salinity gradient was 2.6 psu km^{-1} , with maximum gradients reached up to 8.5 psu km^{-1} .

At the fixed station (Figure 1), where water properties were sampled over a complete tidal cycle (14/11), the influence of the flood was clearer during ebb tide, when the surface salinity dropped from 31.3 psu to 11 psu within one hour (from 18:30 to 19:30).

Currents and Suspended Sediment

The current field sampled at the fixed station (Figure 1) indicates that the tidal wave is stationary.

During spring tide and peak flood discharge (14/11) the depth-averaged velocity, here represented by its mean and the associated standard deviation, had a value of $0.31 \text{ } 0.57 \text{ m}\cdot\text{s}^{-1}$ (the surface velocity had a maximum value of $1.80 \text{ m}\cdot\text{s}^{-1}$ during ebb tide). On the other hand, with the discharge reduced to $58 \text{ m}^3\cdot\text{s}^{-1}$ during neap tides (20/11), the depth-averaged velocity dropped to $0.05 \text{ } 0.17 \text{ m}\cdot\text{s}^{-1}$ (the surface velocity had a maximum value of $1.11 \text{ m}\cdot\text{s}^{-1}$), suggesting a reversion of the residual flow.

An increase of the suspended sediment concentration was observed along the estuary during the flood event. This was mainly caused by the higher turbulence and sediment resuspension in the lower river course (Figures 9 and 10). Turbidity maximum zones were found at the entrance of Paraguaçu Channel and at the entrance of Baía de Iguape.

A maximum concentration of $586 \text{ mg}\cdot\text{l}^{-1}$ occurred at the bottom of station 3 on November 15 at high tide. After November 19, when the discharge was reduced to $58 \text{ m}^3\cdot\text{s}^{-1}$, measurements were performed during a high tide situation. For this scenario, a drastic reduction in the values of suspended matter was observed (generally below $20 \text{ mg}\cdot\text{l}^{-1}$).

DISCUSSION AND CONCLUSIONS

This survey allowed for a preliminary characterization of the estuary dynamics under a flood hydrograph (based on pre-dam flow conditions) simulated by Pedra do Cavalo Dam. The flood magnitude reproduced an event with a return period of more than 1 year, and severely affected the water level at the closest station (Cachoeira), where mean sea level was super-elevated in 1.2 m.

The surge waned out towards the second station (Coqueiros), still inside the more confined river valley, causing a super-elevation 0.5 m. This means a 68% reduction in the river surge height in 13 km, that is ascribed to a higher roughness coefficient of the river bed upstream Coqueiros. The surge must have been completely absorbed in Baía de Iguape, since it was undetected at the farthest station (São Roque). The highest discharge on November 14 also damped the tidal range in 1.2 m at Cachoeira.

Stronger flows along the lower river course impacted the propagation of the tidal wave upstream from Baía de Iguape. Tidal asymmetry was enhanced (even shorter rising times) and low-water time lags were increased by 0:30 hs. During the flood peak the normal tidal asymmetry at Cachoeira was inverted, as rising tide became longer than the falling tide.

Salt water intrusion became restricted to Baía de Iguape with river discharges higher than $118 \text{ m}^3 \text{ s}^{-1}$, or with the ratio of the integrated river discharge (R) over the tidal prism of the lower river course (P_{LC} - calculated through the hypsometric curve) higher than 0.05. The mixing pattern changed from a well-mixed to partially-mixed estuary with increasing river discharges. R/P ratios for the entire estuarine section (R/P_E - where P_E is the estuarine tidal prism) decreased from 0.09 on November 14 to 0.05 on November 20. It is observed that even with the highest river discharges, the ratio R/P_E was relatively small when compared with ratios from other partially mixed estuaries, and a well-mixed condition would be expected even on November 14. This situation is similar to that of Mersey River (DYER, 1973), where partially mixed conditions were identified with relatively low R/P ratios (0,01 and 0,02).

The suspended sediment concentration increased by 10 fold in the lower river course during a flood event, with two turbidity maximum zones occurring at both the exit of the Baía de Iguape and the exit of Paraguaçu Channel. Whereas the former was apparently caused by turbid waters coming down from the dam, the latter was associated with sediment resuspension.

The occurrence of intense salinity gradients and the complete damping of the flood wave past Coqueiros, indicate the importance of Baía de Iguape in filtering the flood effects towards the BTS. While in the middle of Baía de Iguape the salinity changed from 22 to 6 psu between November 13 and 14, at the outlet of the bay the salinity dropped from 30, in the whole water column, to 28 at the bottom and 24 on the surface. At the most downstream station, changes of only 2 psu was recorded (from 32 to 30psu).

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LITERATURE CITED

- BARUSSEAU, J. P.; BÄ, M., DESCAMPS, C.; DIOP, E. S.; DIOUF, B.; KANE, A.; SAOS, J. L. and SOUMARÉ, A. 1998. Morphological and sedimentological changes in the Senegal River estuary after the construction of the Diama dam. *Journal of African Earth Sciences*, 26 (2), 317-326.
- CAMPOS, E. M. 2001. O assoreamento do baixo curso do rio de Contas: uma abordagem hidráulico-sedimentar. Salvador, Bahia: Universidade Federal da Bahia. Dissertação de Mestrado. 78 p.
- CARRIQUERY, J. D. and SÁNCHEZ, A. 1999. Sedimentation in the Colorado River delta and Upper Gulf of California after nearly a century of discharge loss. *Marine Geology*, 158, 125-145.
- CARVALHO, J. B. 2000. Caracterização morfoestratigráfica do preenchimento sedimentar da Baía de Iguape, Bahia influência das variações eustáticas do nível do mar e atividades tectônicas recentes. Salvador, Bahia: Universidade Federal da Bahia. Dissertação de Mestrado. 141 p.
- COLLIER, M., WEBB, R., SCHMIDT, J. C. 2000. *Dams and River: A Primer on the downstream Effects of Dams*. USGS. Circular 1126. 94 p.
- DYER, K.R. 1973. *Estuaries: A Physical Introduction*. London, Wiley. 140p.
- EYRE, B.; HOSSAIN, S. and MCKEE, L. 1998. A Suspended Sediment Budget for the Modified Subtropical Brisbane River Estuary, Australia. *Estuarine Coastal and Shelf Science*, 47, 513-522.
- GUILLÉN, J. and PALANQUES, A. 1992. Sediment dynamics and hydrodynamics in the lower course of a river highly regulated by dams: the Ebro River. *Sedimentology*, 39, 567-579.
- GUILLÉN, J. and PALANQUES, A. 1997. A historical perspective of the morphological evolution in the lower Ebro river. *Environmental Geology*, 30 (3/4), 174-180.
- KJERFVE, B. 1989. Physical Processes in Charleston Harbor. In: Charleston Harbor: Issues, Resources, Status and Management. U.S. Department of Commerce, NOAA Estuary-of-the-Month Seminar Series. 16, 13-24.
- LESSA, G.C.; BITTENCOURT, A.C.S.P.; BRICHTA, A. and DOMINGUEZ, J.M.L. 2000. A reevaluation of the Late Quaternary Sedimentation in Todos os Santos Bay (BA), Brazil. *Anais da Academia Brasileira de Ciências*, 72 (4), 573-590.
- LESSA, G.C. 2000. Morphodynamic controls on vertical and horizontal tides - field results from two macrotidal shallow estuaries: central Queensland, Australia. *Journal of Coastal Research*, 16(4), 976-989.
- LEVISEN, M. V. and VAN DOLAH, R. F. 1997. Spatial distribution of sediments within the Charleston harbor estuary following drainage modification. *Journal of Coastal Research*, 13 (1), 141-146.
- LESSA, G.C.; DOMINGUEZ, J.M.L.; BITTENCOURT, A.C.S.P.; and BRICHTA, A. 2001. The Tides and Tidal Circulation of Todos os Santos Bay, Northeast Brazil: a general characterization. *Anais da Academia Brasileira de Ciências*, 73 (2), 245-261.
- MEDEIROS, C. H. A. C.; DOMINGUEZ, J. M. L.; MEDEIROS, Y. D. P.; OLIVEIRA, M. Q. C.; SCHAER, M.; GENZ, F and TEIXEIRA, E. C.. 1999. Estudo exploratório do estuário do Rio São Francisco com vista a avaliação da dinâmica fluvial e sua influência na área estuarina. *XIII Simpósio Brasileiro de Recursos Hídricos*, (Belo Horizonte, Brazil).
- MORRIS, G. L. and FAN, J. 1998. *Reservoir Sedimentation Handbook: Design and Management of Dams, Reservoirs, and Watersheds for Sustainable Use*. McGraw-Hill. p. 212.
- OLIVEIRA, M. Q. C. 1999. Impacto de mudanças no uso do solo nas características hidrossedimentológicas da bacia hidrográfica do rio Joanes e sua repercussão na zona costeira. Salvador, Bahia: Universidade Federal da Bahia. Dissertação de Mestrado. 93 p.

- PATTY, S. S.; ROTH, N. and MOUNTAIN, D. 1999. Maryland, the Power Plant Research Program, and the Chesapeake Bay watershed. *The Science of Total Environment*, 240, 171-188.
- PRITCHARD, D.W. 1952. Estuarine hydrography. *Advances in Geophysics*, 1, 243-280.
- RUBIN, J. A., GORDON, C., AMATEKPOR, J. K. 1998. Causes and consequences of Mangrove Deforestation in the Volta Estuary, Ghana: some Recommendation for Ecosystem Rehabilitation. *Marine Pollution Bulletin*, 37 (8-12), 441-449.
- VIEIRA, M. E. C. and BORDALO, A. A. 2000. The Douro estuary (Portugal): a mesotidal salt wedge. *Oceanologica Acta*, 23 (5), 585-594.
- WOLANSKI, E.; HUAN, N.; GUYEN, N. L.; DAO, V.; NHAN, N. H., and THUY, N. N. 1996. Fine-sediment Dynamics in the Mekong River Estuary, Vietnam. *Estuarine Coastal and Shelf Science*, 43 (5), 565-582.
- WOLANSKI, E.; NHAN, N. H. and SPAGNOL, S. 1998. Sediment dynamics during low flow conditions in the Mekong River Estuary, Vietnam. *Journal of Coastal Research*, 14 (2), 472-482.
- WOLANSKI, E.; MOORE, K.; SPAGNOL, S.; D'ADAMO, N., and PATTIARATCHI, C. 2001. Rapid, Human-Induced Siltation of the Macro-Tidal Ord River Estuary, Western Australia. *Estuarine Coastal and Shelf Science*, 53, 717-732.
- WOLGEMUTH, K.M.; BURNETT, W.C. and MOURA, P.L. 1981. Oceanography and Suspended Material in Todos os Santos Bay. *Revista Brasileira de Geociências*, 11 (3), 172-178.