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Long-term morphological impacts on the coastline of Sergipe State, Brazil, caused by the construction of dams in the São Francisco River Basin

By

Jefferson Vianna Bandeira[1], Lécio Hannas Salim[2] and Oswaldo Enrique Calisto Acosta[3]

ABSTRACT

The paper describes morphological impacts, especially at the mouth of São Francisco River and also at other river mouths in the Sergipe State coastline (Brazilian north-east) due to the retention of sediments in reservoirs, related to hydroelectric power plants (HPP), constructed along the São Francisco river course.

1. INTRODUCTION

Spanning 2,863 km of river stream length and a draining area of 645,000 km^2, the São Francisco River headwaters originate in Minas Gerais State (Capital: Belo Horizonte), in the southeast of Brazil. Running to the northeast of the country, the São Francisco River discharges into the Atlantic Ocean, at a place located between the states of Alagoas (Capital: Maceió) and Sergipe (Capital: Aracajú) (Figure 1). The São Francisco River is the fifth biggest river in South America and its mouth is situated in a huge sand delta formed naturally with material from continental origin, because the amount supplied was larger than the littoral transport capacity (figures 2 and 3).

Figure 1: São Francisco River hydrographic basin. (Source: www.sfrancisco.bio.br)

Starting in the 1950 decade, several dams and reservoirs for HPP have been constructed along the São Francisco river stream: Três Marias, Sobradinho, Itaparica, Paulo Afonso, Xingó – from upstream

[1] Dr.-Eng, Senior Researcher, Brazilian Nuclear Energy Commission, jvb@cdtn.br
[2] MSc.-Eng, Senior Researcher, Brazilian Nuclear Energy Commission, salimlh@cdtn.br
[3] Dr.-Eng, ANEEL National Agency of Electrical Energy - Brasília, DF, ocalisto@aneel.gov.br

to downstream – (Figure 1). As a consequence of sediment retention in the reservoirs, the supply of sand and also of fine cohesive materials (silt and clay) to the São Francisco river mouth area decreased drastically. This effect is shown in Figure 4, where it can be observed that the sediment concentrations offshore and in the estuary are similar. The relatively high concentration along the coast and spreading out in the mouth region is mainly due to the sand of the littoral-drift.

Sobradinho´s reservoir, which was inaugurated in 1978, formed an enormous artificial lake, the biggest one in Latin America, with an area of 4,214 Km^2 and length of 350 Km (Figure 1). Besides its capacity to regulate the river flow for the operation of the HPP located downstream ($Q_{minimum}$ = 2,060 m^3/s), Sobradinho´s reservoir retains about all the sediment produced in the upper and medium regions of the São Francisco River hydrographic basin.

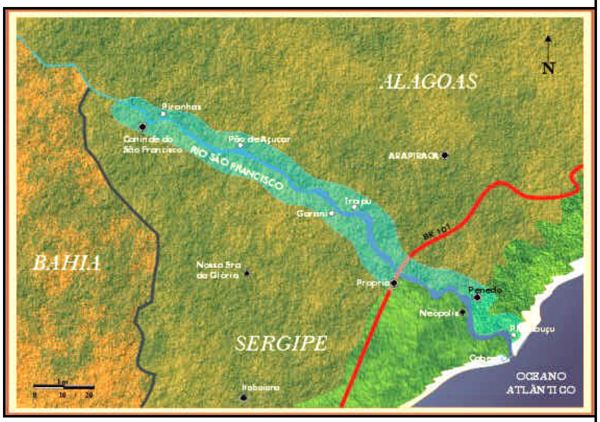

Figure 2: São Francisco River mouth & estuary. (Source: BANDEIRA, 2005)

Figure 3: São Francisco River mouth, in January 29th, 1982. (Source: BANDEIRA, 2005)

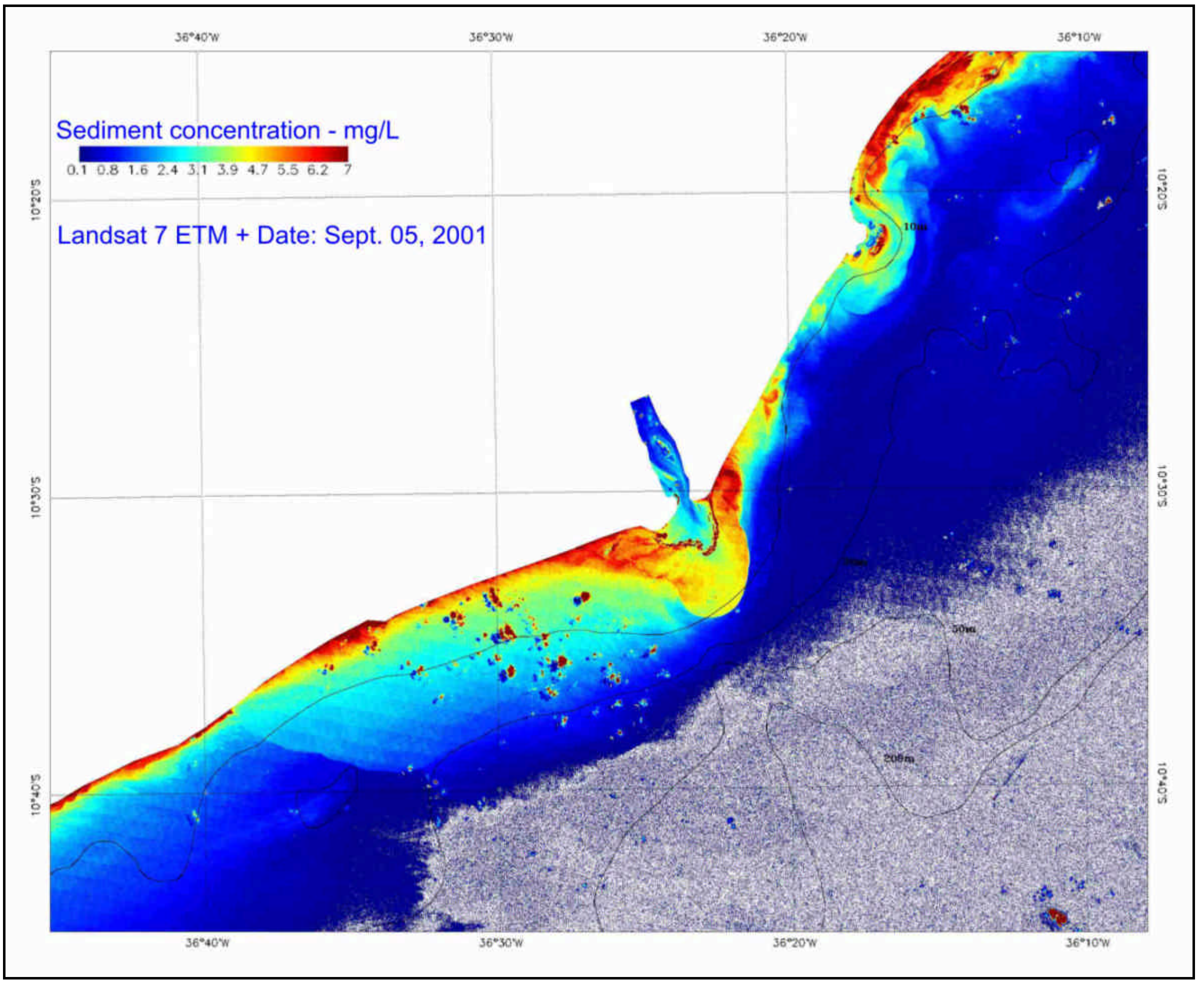

Figure 4: Sediment concentration in São Francisco River mouth. (Source: BANDEIRA, 2005)

2. ESTIMATIVE OF THE VOLUME OF SEDIMENTS RETAINED INSIDE THE RESERVOIRS

The main sources of sediment input into the deltas are the runoff of suspended sediment and bed load of the river. River mouth areas are zones of large-scale accumulation of terrigenous sediments. The evaluation of the sediment load at river mouth areas and the calculation of river sediment runoff retained at river mouths is a complicated problem, because of the inherent difficulties related to the measurements of sediment discharges (particularly, bed load and sediments transported in near-bottom flow layers). For this reason, the total runoff of suspended sediments and bed load of many rivers is still unknown and sediment budgets are insufficiently studied in river mouth areas, where, in addition to river factors, sea factors should be taken into account (MIKHAILOVA, 2007).

As far as the São Francisco River mouth area is concerned, the construction of large volume reservoirs along the São Francisco River stream, related to hydropower plants (Figure 5), induced transformation of river flows and sediment loads. As a consequence of the river flow regulation and sediment deposition in the reservoirs, the sediment runoff has been reduced, and the input of sediments into the São Francisco River mouth has decreased. Table 1 shows some river stream characteristics related to the geographical regions of the São Francisco river basin where the main reservoirs are located.

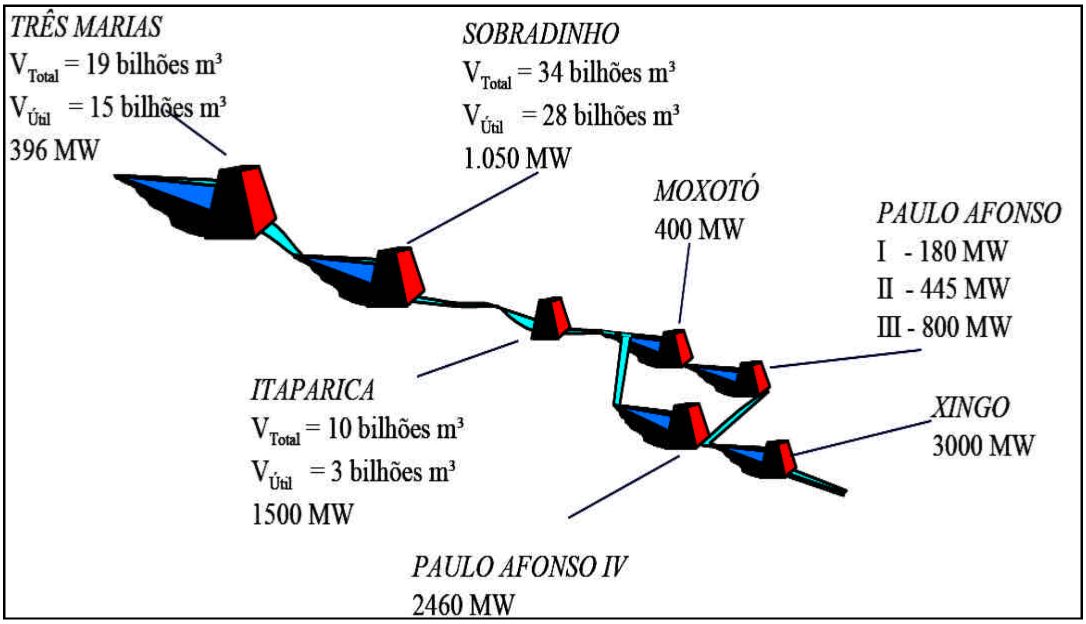

Figure 5: Main reservoirs in the São Francisco river basin (Source: ANA, 2007)

Region	Area (km^2)	Rainfall (mm)	$Q_{specific}$ ($l/s.km^2$)	Region and some river stream characteristics
Upper	91,000 (14.1%)	1,000 to 1,500	11 to 14	Headwaters to Pirapora: 70% river flow contribution. Rock-channel steep sloped streams (low channel banks and streambed erosion). Três Marias reservoir.
Middle	352,100 (54.6%)	600 to 1,400	4 to 11	Pirapora to Remanso, at Sobradinho's reservoir: 15% river flow contribution between Carinhanha and Remanso. 10-cm/km-stream slope. Navigation water depth available (1,400 km river length reach).
Sub middle	155,900 (24.2%)	350 to 800	4 to 5	Remanso to Paulo Afonso: 5% river flow contribution. Flat-sloped stream. At the end of sub middle and beginning of lower regions there is a big step, which originates some waterfalls (Itaparica, Paulo Afonso and Xingó).
Lower	46,000 (7.1%)	800 to 1,300	5	Paulo Afonso to mouth: 10% water flow contribution. Flatter sloped stream.

Table 1: São Francisco river basin regions and river stream characteristics

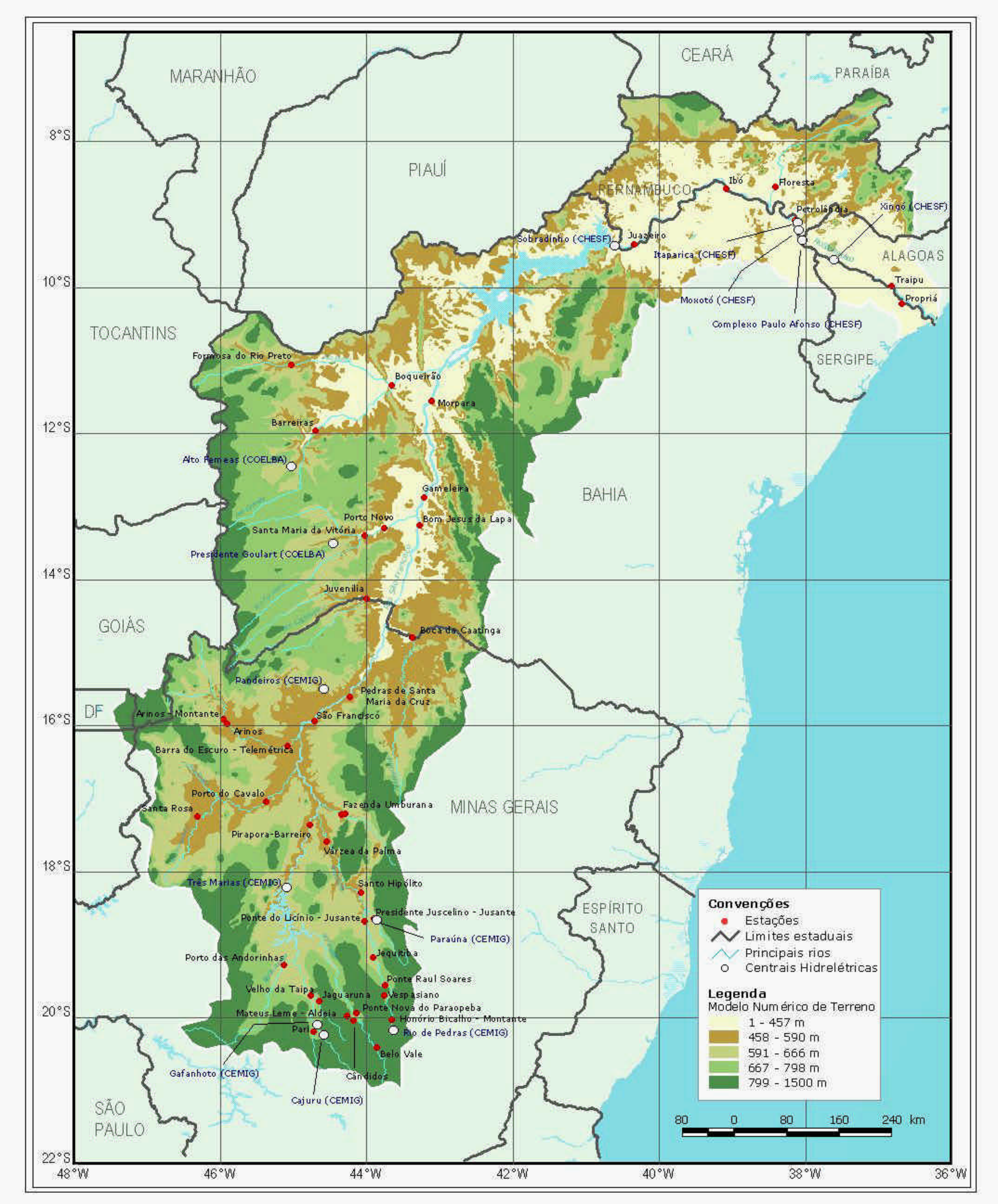

Figure 6: Localization map of river hydrometrical suspended sediment gauging stations in the São Francisco river basin (Source: Lima et al., 2001)

Results of a rough evaluation of the sediment runoff in the São Francisco River stream are presented in Table 2. Those results, that take into account the volume of sediments deposited in the three main reservoirs (Três Marias, Sobradinho and Itaparica), were obtained using existing data of suspended sediment load estimates for several river gauging stations located in the São Francisco river basin (Figure 6). Suspended sediment load data were extracted mainly from a study of suspended sediment flow in the São Francisco river basin (Figure 7) (LIMA et al., 2001), and were complemented with data from a study of sediment contribution to the Três Marias reservoir (CARVALHO, 2001).

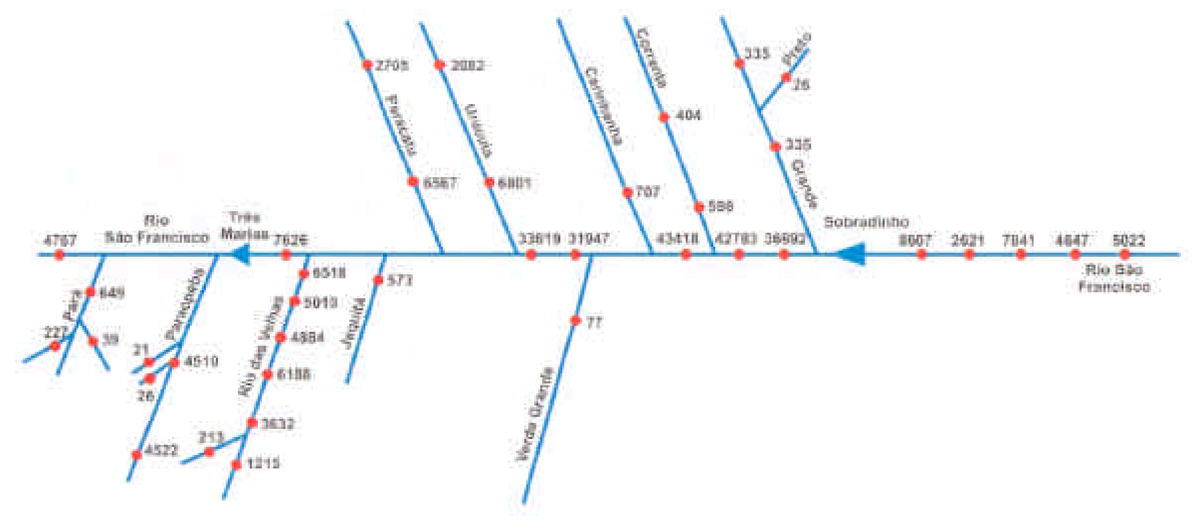

Figure 7: Schematic representation of river gauging stations mean suspended sediment load values (t/day) (Source: Lima et al., 2001)

Reservoir	Sediment load inflow (t/year)	Sediment retention (m^3/year)	Sediment load outflow (t/year)	Beginning of Operation
Três Marias	12,629,415	9,584,378	505,177	1962
Sobradinho	39,135,314	29,699,527	1,565,413	1979
Itaparica	3,191,721	2,422,175	127,669	1985
At the river mouth	3,797,817			

Table 2: Evaluation of the sediment runoff in the São Francisco river stream

The results in Table 2 show that it is apparent the reduction of sediment loads from continental origin to the São Francisco river mouth area. Notice that this contribution calculated at the river mouth, about $3.8x10^6$ t/year or equivalently a volume contribution of $3x10^6$ m^3/year, ascends to about 10% of the sediment load carried into the reservoir of Sobradinho.

Using the results shown in Table 2, it can be roughly estimated that, from the beginning of operation of the Três Marias reservoir up to 2007, the sediment load retained in the three main reservoirs adds to about $1.72x10^9$ t or $1.36x10^9$ m^3.

3. THE SEDIMENT TRANSPORT ALONG SERGIPE COAST

The littoral drift in the 153 km long Sergipe coast is bi-directional and was calculated, in the surroundings of Sergipe River mouth (Figure 8), to be of the order of $800x10^3$ to $1,100x10^3$ m^3/y. The dominant littoral drift is southwestward and amounts to a range from $500x10^3$ to 650 $x10^3$ m^3/y (BANDEIRA, 1972), (MOTTA & BANDEIRA, 1974) and (PLANAVE & DHI, 1992). The tide in the region of Sergipe and São Francisco rivers mouths is semi-diurnal and the spring-tide amplitude reaches 2.0 m. Local winds are generated mainly by the subtropical anticyclone (N to E) and the polar movable cyclone (S). The cloud of sediments in suspension, in the São Francisco River mouth, observed in Figure 3 shows, very well, the littoral drift to southwestward. The photo was taken in January, when the dominance of waves and winds from NE induces the littoral drift to this direction.

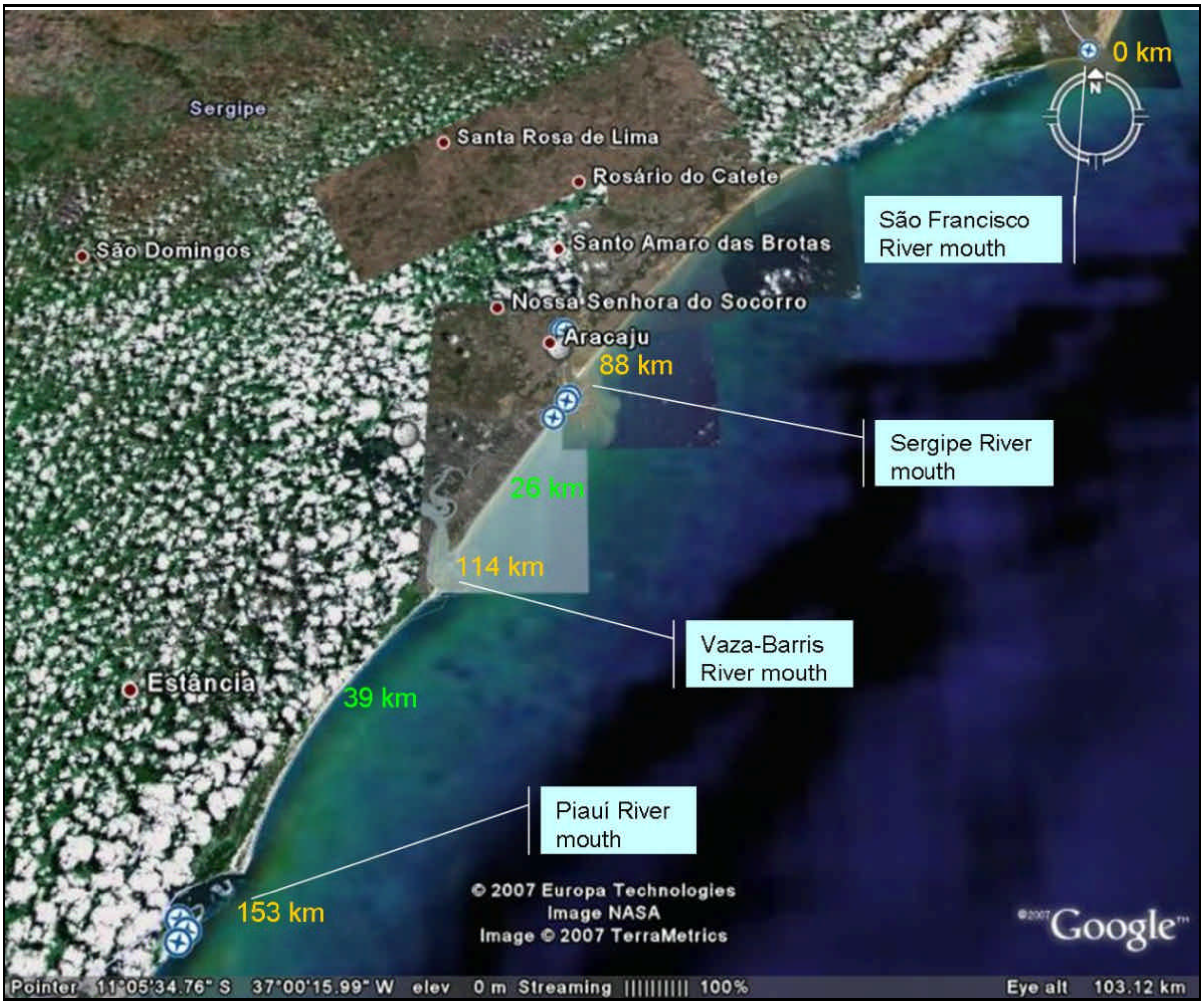

Figure 8: Sergipe State coastline with the main river mouths and distances. (Source: Adapted from Google Earth – 2007)

4. CONSEQUENCES OF THE RETENTION OF SEDIMENTS

At least, three main consequences of the retention of sediments inside the reservoirs of the hydroelectric power plants, built along the São Francisco river, can be mentioned, not forgetting also the stability of the river channels and margins which will not be treated in this paper.

4.1 Decrease in the fish population

The first one is that the low estuary and the region of the mouth experienced a drastic decrease in the fish population, due to the reduction of fine sediment contribution, which carries nutrients and organic matter (PROJETO GEF – SÃO FRANCISCO, 2002).

4.2 Erosion at the São Francisco river mouth

With the decrease of the continental sand load, a second consequence is that the right side of the mouth, in the Sergipe State, is suffering severe erosion. Why erosion only in this side of the mouth?

The sediment from continental origin, as soon as it leaves the mouth, is carried preferably in the direction of the Sergipe State coast, due to the dominant littoral drift to southwest (Figure 3). With the decrease of this contribution, starting with the construction of Paulo Afonso HPP in the fifties of the last century, a long-term effect (of the order of decades) was felt: the waves and currents, with a certain capacity to transport sediments, but not having it fulfilled, started to erode the right side, just downstream the river mouth, in relation to the dominant littoral drift. This erosive process tends to cease, as soon as the new coastline orientation, which is a function of the available sediment load, mainly sand load, becomes adjusted to the littoral transport capacity.

In the beginning of the decade of 1990, the erosion reached and started destroying the fishermen village of Cabeço. The first victim was the lighthouse constructed in the beginning of the last century, near the village and 250 m inland from the shoreline. Figures 9 to 15 show the progress of the erosive process.

Figure 9: Lighthouse at “Cabeço” fishermen village. Beginning of the 1990 decade. (Source: BANDEIRA, 2005)

Figure 10: Church at “Cabeço” fishermen village, with the lighthouse already at the shoreline - 1998. (Source: BANDEIRA, 2005)

Figure 11: Erosion at Cabeço beach, and the lighthouse - November 2001. (Source: www.ana.gov.br/gefsfOld/Imagens /imgs1-1A.asp)

Figure 12: São Francisco River mouth, with the lighthouse - 2002. (Source: BANDEIRA, 2005)

Figure 13: Situation of the lighthouse in 2007. (Source: Adapted from Google Earth – 2007)

Figure 14: São Francisco river mouth in 2007. (Source: Adapted from Google Earth – 2007)

Figure 15 is a summary of the erosion process in the right side of the mouth. The coastline contour, as shown in the Brazilian Navy chart DHN -1002, was surveyed in 1942. The bathymetric survey of the mouth region was performed in 1962, corrections being incorporated until 30th June, 1981.The present coastline contour and the new location of “Cabeço” fishermen village, were taken from Figure 14, and drawn in Figure 15, in order to compare the overall evolution of the coastline. Not only the shoreline but also the deepest part of the channel through the São Francisco River mouth changed completely.

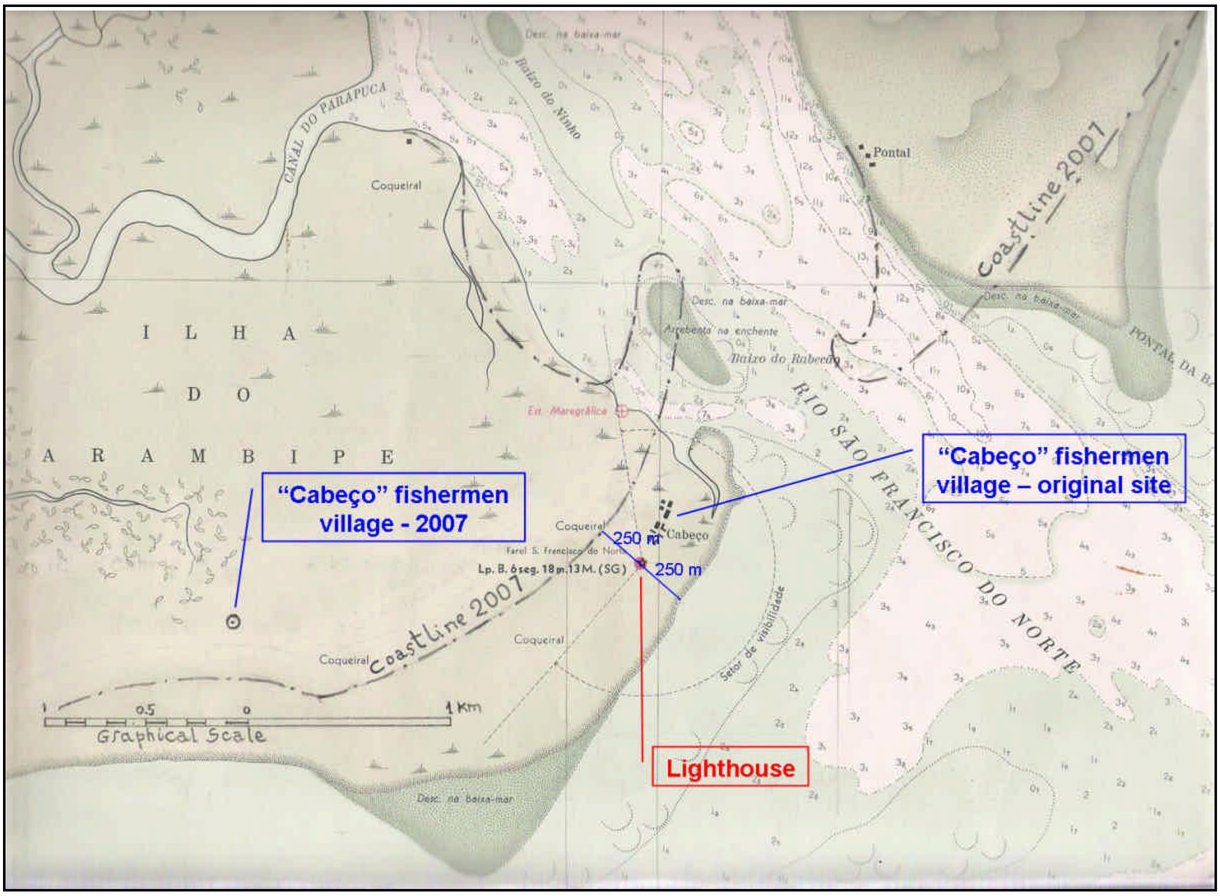

Figure 15: São Francisco river mouth. (Sources: Adapted from Brazilian Navy chart DHN-1002, & Google Earth – 2007)

It can be observed that the lighthouse was built 250 m inland from the shoreline surveyed in 1942. At that time no HPP had been constructed along the São Francisco River and it may be considered that the mouth region was in a relative sedimentological equilibrium.

It was only after the beginning of operation of Paulo Afonso I (1955) to IV (1977) HPP's, situated in the lower part of the basin, 50 Km downstream of Itaparica HPP (figures 1, 5 & 6), that the contribution of the sediment from continental origin started lowering significantly. In 1978, Sobradinho HPP entered into operation, decreasing even more this contribution. The HPP's of Itaparica and Xingó (downstream of Sobradinho) were built after 1978.

Considering the positions of the shoreline in relation to the lighthouse (figures 9, 13 & 15), and also the chronology of operation of Paulo Afonso I (1955) and of the subsequent HPP's, one can estimate the average yearly regression of the shoreline in this particular region of the coast, for different time periods, sizing up the long-term morphological impacts in the São Francisco River mouth for the retention of sediments from continental origin. Table 3 is a resume of the findings.

Time interval	Regression of shoreline (m)	Average regression velocity (m/year)	Remarks
1955 to 2007	500	9.6	Since the construction of Paulo Afonso HPP
1955 to 1998	250	5.8	Paulo Afonso HPP until lighthouse at the shoreline
1998 to 2007	250	27.8	Lighthouse in the shoreline till nowadays

Table 3: Average yearly regression of the shoreline in the region of the lighthouse

From Table 3 one can infer the long-term influence in the shoreline average regression velocity due to the retention of the sediments inside the reservoirs of the HPP's. The average velocity of 5.8 m/year for the period 1955-1998 increased 4.8 times, to 27.8 m/year in the period 1998-2007. Above all, this sharp increase is due to the long-term effect of the beginning of operation of Sobradinho HPP, 20 years before the beginning of this considered period.

In short, the benchmark of this dramatic erosion at the mouth region of São Francisco river is the lighthouse inclined, as the Pizza Tower in Italy (figures 10 to 12), and placed, nowadays, some 250 m offshore (figures 13 and 14). It should be observed, in figures 11, 12 and 13, the scarcity of sand in the front beach of the right margin, compared with the left margin (Figure 12), indicating that the beach erosion process is still in progress.

4.3 Erosion in other river mouths along the Sergipe State coast

A probable long-term and long distance morphological effect from the shortage of continental sand arriving at the São Francisco River mouth, is the present and accelerated tendency observed, simultaneously, at the mouths of Vaza-Barris and Piauí rivers (Figure 8) located, respectively, 114 and 153 km south-westwards from the São Francisco river mouth, along the shoreline. There are persistent erosions in the last part of their left margins, near their mouths, causing the destruction of roads (Vaza-Barris river) and houses (Piauí river).

4.3.1 Vaza-Barris river mouth (Figure 16)

Figure 16: Vaza-Barris river mouth (Source: Adapted from Google Earth – 2007)

The erosion can be seen in figures 17 to 22. The photos were taken around low water of spring tide with amplitude, as in São Francisco and Sergipe river mouths, reaching 2.0 m.

In figures 17 and 18 one can observe the generalized erosion over the extremity of the point, where the original vegetation is being extinguished. The abrupt interruption of the breaking waves crests, as shown in Figure 18, is a clear indication that one canal is situated very near of the left margin. Observing also Figure 16 it can be noticed that the amount of sand in the beaches of the right margin is greater than the amount corresponding to the left one. It can also be observed that the main channel, near the right margin, with direction NNW-SSE is bending to E, just in the mouth, due to the sand deposition in the NE extremity of the southern beach. Concomitantly, the sand bank that seemed to be the underwater prolongation of the left point is being cut by various channels by the flow through the mouth, being the northern canal the one responsible for the interruption of the breaking waves crests (Figure 18). These new channels, cut across the referred bank, weakened the ebb flow through the southern canal, near the right margin, diminishing its hydraulic jetty function and allowing the sand deposition in this region, with the consequent bending of this canal, as above referred.

Figure 17: Vaza-Barris river mouth – May 11, 2005. (Source: Photo by J.V. Bandeira)

Figure 18: Vaza-Barris river mouth – May 11, 2005. (Source: Photo by J.V. Bandeira)

Figures 19 to 22 show the northern beach with the destruction of the road that reached the lighthouse.

Figure 19: Vaza-Barris river mouth – May 11, 2005. (Source: Photo by J.V. Bandeira)

Figure 20 (Zoom of Fig. 19): Vaza-Barris river mouth – May 11, 2005. (Source: Photo by J.V. Bandeira)

Figure 21: Vaza-Barris river mouth – May 11, 2005. (Source: Photo by J.V. Bandeira)

Figure 22 (Zoom of Fig. 21): Vaza-Barris river mouth – May 11, 2005. (Source: Photo by J.V. Bandeira)

From the above considerations (a kind of qualitative diagnostic) it can be inferred that the Vaza-Barris river mouth is migrating to NE.

4.3.2 Piauí river mouth (Figures 23, 24 and 25)

Piauí river mouth is located 39 Km to southwest from the Vaza-Barris river mouth (Figure 8), at the border with Bahia State. This mouth is already situated in a transition region related to the inversion of the dominant littoral drift, which is southwestward along the entire Sergipe State coast.

The 1st series of photos as indicated in Figure 23 is constituted by figures 24 to 27.

Figure 23: Piauí river mouth (Source: Adapted from Google Earth – 2007)

Figure 24: Piauí river mouth – May 11, 2005. (Source: Photo by J.V. Bandeira)

Figure 25: Piauí river mouth – May 11, 2005. (Source: Photo by J.V. Bandeira)

Figure 26: Piauí river mouth – May 11, 2005. (Source: Photo by J.V. Bandeira)

Figure 27: Piauí river mouth – May 11, 2005. (Source: Photo by J.V. Bandeira)

Observing the positions occupied by the main channel, corresponding to the region with absence of breaking waves in the bars, shown in figures 25 (heart shape) and 23 (question mark shape), one can infer that from 2005 (Figure 25) to 2007 (Figure 23) it turned counter clockwise. As a consequence, there was the erosion of the sand accumulation that existed in the southern part of the beach (Figure 25), transforming a curved shoreline into a nearly straight one (Figure 23). Figure 26, taken from the seaside, shows this sand accumulation in the foreground. Due to the angle of the photo and the illumination, the sand accumulation looks like a “breaking sand wave” overtopped by breaking water waves. Figure 26 also shows, in the background, the left margin of Piauí river, which, nowadays, is suffering a severe process of erosion with the resultant destruction of various houses. Figure 27 shows this margin in more details, with re-entrances along the shoreline, indicating critical points of erosion.

The 2nd series of photos, as indicated in Figure 23, is constituted by figures 28 to 30. These photos, as the ones from the Vaza-Barris river mouth, were taken around low water of spring tide, with amplitude also reaching 2.0 m.

Figure 28: Piauí river left margin – May 11, 2005. (Source: Photo by J.V. Bandeira)

Figure 29: Piauí river left margin – May 11, 2005. (Source: Photo by J.V. Bandeira)

Figure 30: Piauí river left margin – May 11, 2005. (Source: Photo by J.V. Bandeira)

Figure 30 shows, in detail, the damaged house to the left, and the seawall built to protect the other houses from erosion.

Also for Piauí river, it can be inferred that its mouth is migrating to NE. A possible explanation for this phenomenon is that this mouth and the one of Vaza-Barris river were relatively stable for the previous conditions of coastal sediment availability, associated with the local wave climate. With the reduction, in a permanent basis, of the littoral sand supply coming from NE caused, firstly, by the construction of dams in the São Francisco River basin, thus decreasing dramatically the sediment contribution from continental origin to the coastline system, there is a tendency of the mouths to reach a new equilibrium situation, migrating to NE, adjusting to this shortage. The Sergipe river mouth (Figure 31), situated 88 km south-westwards from the São Francisco river mouth (Figure 8), was not affected because it was fixed in the 1990 decade, due to serious erosion problems that happened in its right margin (BANDEIRA, 1991), (BANDEIRA & BOMTEMPO, 1995). The retention of littoral drift to NE of the jetty built in the left margin of Sergipe river mouth (Figure 31) could also have influenced, in a minor scale, the behaviour of the above-referred mouths.

Figure 31: Sergipe river mouth (Source: Google Earth – 2007)

5. REFLEXIONS ABOUT THIS CASE STUDY

The sedimentological behaviour of a hydrographic basin is the result of its natural characteristics and also of the human influence. The population growth and the associated socioeconomic needs originate a strong necessity for the enlargement of: cities, food production, electricity generation and so on, resulting in an intense impact upon the natural environment.

Although the productive activities are primordial for the development, their environmental impacts should be studied carefully in order to be mitigated or controlled, allowing the continuity of the good use of the natural existing resources with the maximum benefit to the society.

Depending on the intervention on the natural flow of sediments of a certain river, by the increase of the sediment production (erosion in the hydrographic basin) or by the deposition of sediments in reservoirs, reducing the sediment load downstream, the impacts generated can be irreversible. The excess of sediments in the rivers is a big problem to the pumping systems: irrigation, water supply and so on, besides serious problems to the reservoirs users. Furthermore, cohesive sediments (mud) carry nutrients and organic matter, mandatory for the maintenance of the aquatic fauna and flora and of the river margins. The non-cohesive sediments (mainly sand) compose and maintain the river beaches, beyond its importance to the sedimentological equilibrium in the region between the continent and the coastal zone, near the river mouth and also far away, as presented in this case study.

Due to the enormous draining area of the São Francisco River hydrographic basin (645,000 km^2) and the bulky intervention constituted by the construction of various HPP, which started more than 50 years ago, the severe long-term environmental impacts were only perceived in the mouth region more than 30 years after the starting of the HPP's construction. In this way occurred the drastic decrease in the fish population (PROJETO GEF – SÃO FRANCISCO, 2002) due to the decrease of fine sediment concentration, concomitantly with the erosion in the right side of the mouth (BANDEIRA, 2005) and also the modification of the channel position through the São Francisco River mouth.

The present paper tried to highlight the next step in the progression of the morphological impacts of the reservoirs built in the São Francisco river in the coastal region of Sergipe State, observed from the year 2005 on. These are the simultaneous migration to NE verified in the mouths of Vaza-Barris and Piauí rivers, situated downstream of the São Francisco river mouth in relation to the dominant littoral drift, with the destruction of roads and houses in the left side of both mouths. The study of this trend should be continued because it is a long-term morphological impact, longer than a generation of Coastal and River Engineers directly related to the problem, and much can be learned from this study to guide future interventions aiming at reducing the environmental impacts in other hydrographical basins, even if they are not as big as the one of São Francisco river.

6. CONCLUSIONS

The construction of dams and reservoirs along the São Francisco river, with the main objective of generating electrical energy, impacted severely the environment due to the retention of cohesive and non-cohesive sediments inside the reservoirs. As an example, the present contribution of continental sediment load at river mouth, about 3.8×10^6 t/year or, equivalently, a volumetric contribution of 3×10^6 m^3/year, ascends to about 10% of the sediment load carried into the reservoir of Sobradinho.

Using the results shown in (Table 2), it can be roughly estimated that for the three main reservoirs (Três Marias, Sobradinho and Itaparica), since the beginning of operation of Três Marias reservoir, in 1962, up to 2007, the sediment load retained adds to about 1.72×10^9 t or 1.36×10^9 m^3.

The main impacts due to the retention of sediments in the reservoirs constructed along the São Francisco river are:

a) Decrease in the fish population at the low estuary and at the mouth region;

b) Erosion at the right margin of the mouth;

c) Erosion in other river mouths along the Sergipe State coast.

The last two impacts seem to be irreversible, mainly due to the difficulty in transporting the previous sand load existing in the once natural hydrographical basin through a regularized river as the São Francisco is nowadays. Nevertheless, the first impact can be minimized, as will be seen in the recommendations.

7. RECOMMENDATIONS

More than 90% of the electrical energy produced in Brazil comes from HPP's with different sizes. Most of the large potential sites to build HPP's have already been utilized. Nowadays, only one of these sites is being studied: Madeira river in the state of Mato Grosso, but not discharging directly onto the coast. Nevertheless, hundreds of sites to construct medium and also small hydroelectric power plants (SHP), up to 50 MW, are being studied. SHP can be present in various other countries. The following recommendations are directed mainly to the medium and SHP's.

In order to minimize the environmental impacts of the retention of sediments in the reservoirs it is recommended the practice of sediment bypass to the downstream reaches (the natural way of the sediment in absence of the reservoir). At the same time this practice will perpetuate the usefulness of the reservoirs, especially of the SHP.

The sediment bypass, which could be performed through bottom gates, present in many dams, or also by hydraulic dredging, more efficient than the first method, is mainly recommended for the fine sediment which settles near the dam and is more easily transported, by the river flow, than the sand.

In relation to the bypass of fine sediment, one hope is that the studies presented in Bandeira (2004), may contribute to the implementation of the fine sediment bypass, allowing the non-interruption of a significant part of this type of sediment load which is a great part of the total sediment load and is essential for the aquatic fauna and flora. The pioneer labelling of fine sediment with technetium (^{99m}Tc), a short half-life radioisotope ($T_{1/2}$ = 6.02 hours) broadly used in Nuclear Medicine was developed and, subsequently, applied in field experiments with simultaneous and instantaneous injections of sediment and water labelled, respectively, with ^{99m}Tc and Rhodamine WT. The tests were realized to measure the hydro-transport capability of a stretch of 25km in a river, downstream a reservoir formed by a dam. A recent mathematical model was applied and calibrated to the data obtained and, through convolution, the sediment dumping of the bypass system was simulated, calculating also the physical environmental impacts: increase of sediment concentration and the possibility of deposition (BANDEIRA, 2004).

In the same way as the dam designers try to reduce the effect of the dams upon the spawning of fishes, providing them with fish stairs, one should consider the bypass of fine sediments of successive reservoirs as "sediment stairs". Even with the presence of dams, the rivers should continue as a double lane way: fishes should be allowed to go up and down the stream, as well as sediments should be allowed to go downstream. Both of them are environmentally important. They are linked in net (CAPRA, 2002). Anyway, fishes and other components of the fauna and aquatic flora, of the low São Francisco river and of all other estuaries, depend also upon the sediment originated upstream.

8. ACKNOWLEDGEMENTS

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