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Coastal Area Prone to Extreme Flood and Erosion Events Induced by Climate Changes: Study Case of Juqueriquere River Bar Navigation, Caraguatatuba (Sao Paulo State), Brazil

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ABSTRACT: According to the IPCC, the forecast for the year 2100 is an increasing of global average temperature, whose impacts in winds, waves, tides, currents and bathymetry will produce real risks of extreme events due to climate changes. Juqueriquere River is Sao Paulo State (Brazil) North Coastline major waterway. Due to minimum channel depths in the coastal bar, navigation is only possible for small leisure crafts and fishing boats and some cargo barges during higher tidal levels. This study case has been evaluated according to the relative sea level and wave climate scenarios forecasting, based on the meteorological recognition patterns of the last decades data for tides and waves. The impact of climate changes is obtained from this knowledge. The main goal of this paper is to have the initial conceptual description about the impacts on the bar navigation conditions of Juqueriquere to obtain guidelines for master nautical plans.

1 INTRODUCTION

The Juqueriquerê Catchment is the major in São Paulo State (Brazil) North Coastline (Fig. 1). The Juqueriquerê Waterway is a 4 km estuarine channel used by small piers and docks. The entrance bar doesn't have any amelioration works and the boats maneuvers are difficult and dangerous. Beyond environmental impacts, the cost - effective improvements consists to bar jetties calibration, this solution means to talk about costs of 5 M €, or the permanent maintenance with local dredging works, which costs, in the long term of decades, will be the same.

According to the IPCC forecasting, there is the awareness that conditions of bathymetry, tides, winds, currents and waves for next decades shall have climate changes impacts. The project goal is to overcome the contraposition that it emerges between the defence against the hydraulic risk and the management to preserve the environmental protection for nautical purposes. The risk is understood, in a qualitative way, as composed by Hazard, Exposure and Vulnerability (Kron 2008).

2 SOME HISTORY

Example of navigation possibilities in the waterway was the dock operation of the English Lancashire General Investments Company, owner of the Blue Star Line Navigation Company. In the period 1927 - 1967, the "Fazenda dos Ingleses" (English Farm), has sent the tropical fruits production to England. The railway line of the farm had 120 km, with docks and warehouses in the right bank of the estuary. The Packing House, in the dock area, was considered the second of this type in South America. The cargo boats, more than 20 in the forties decade, had an individual load of 55 dwt (Fig. 2). In March 1967, a strong debris-flow, rain more than 600 mm in 2 days (monsoonal rates), combined with storm surge, caused more than 400 casualties and material losses in Caraguatatuba. After that, the docks were closed (Arasaki 2010).

In the last four decades, the nautical purposes of leisure and fishing boats increased. It is important to mention the recent interest as supplier area for the offshore LNG and oil. The plant for the gas treatment is located in the left bank of the river and many of the facility heavy cargo equipments used large barges push-pulled by tugs (Fig. 3).

3 TIDE VARIABILITY

Considering the CDS (Companhia Docas de Santos) datum, extreme LLW level, in Figure 4 are presented our study conclusions about São Paulo State coastline tidal variability for the last six decades (1944 - 2007). A consistent linear response shows: 1. Overall period: rising rates (cm/century) for MSL (23.2), HHW (36.5) and LLW (41.8); 2. Period before 1969: 1.1, - 7.3 and 54.3 and 3. Period after 1975: 40.9, 44.9 and 75.4.

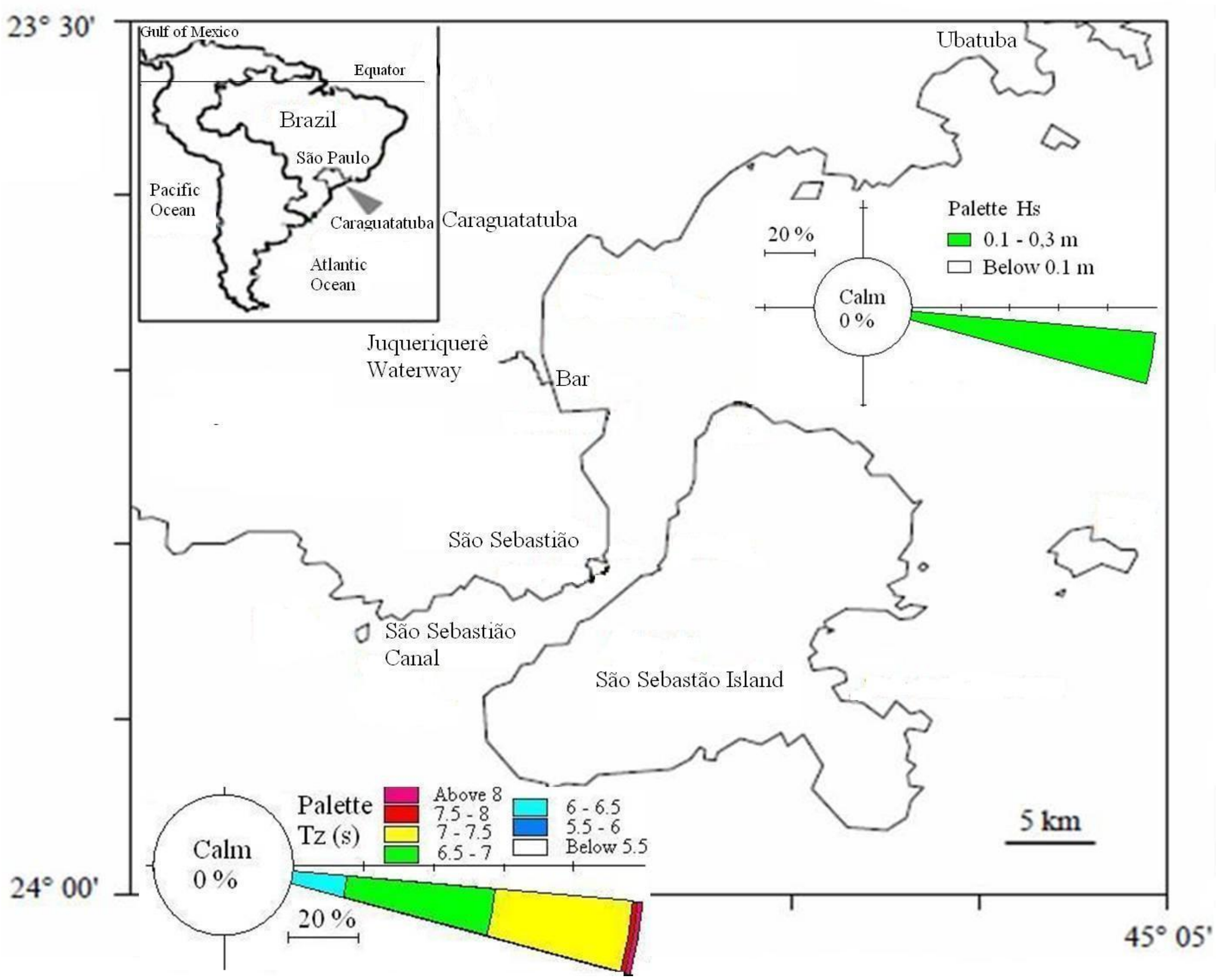

Figure 1. Location map with significant height and average period local wave roses.

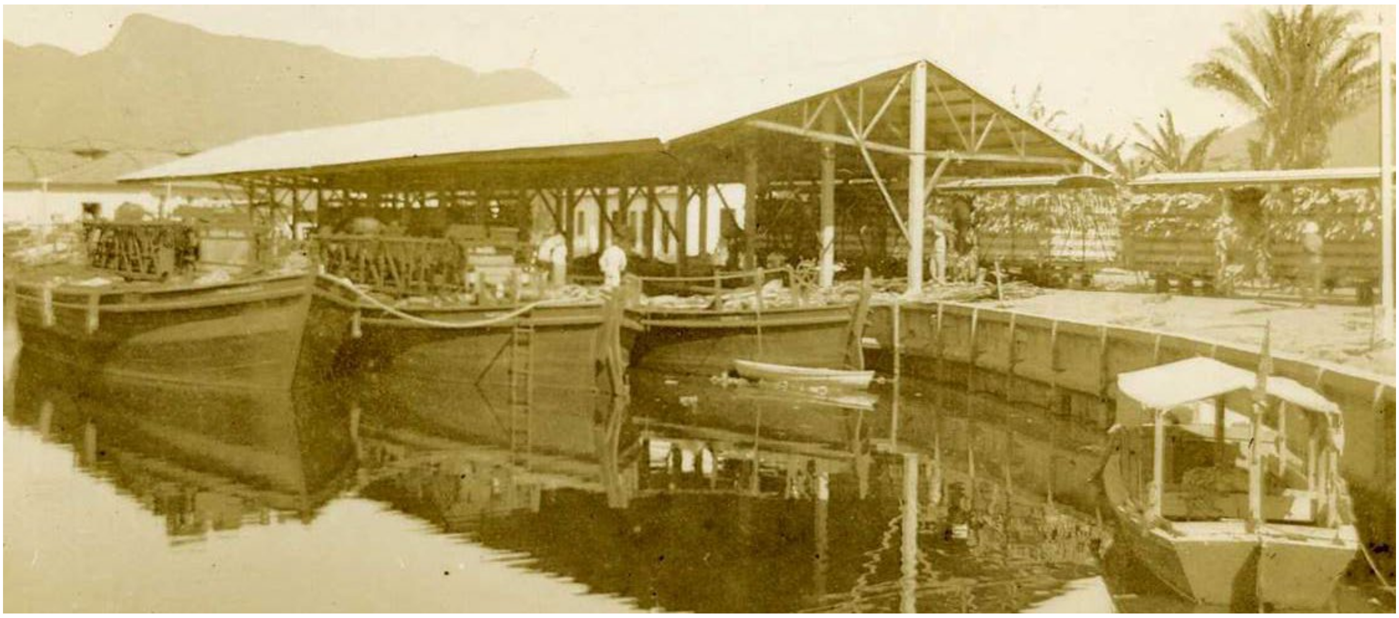

Figure 2. Boats moored at the quay, dockyards warehouses and railway terminal (1940 decade) of the English Farm.

Figure 3.Heavy cargo equipments using large barges push-pulled by tugs (February 2010).

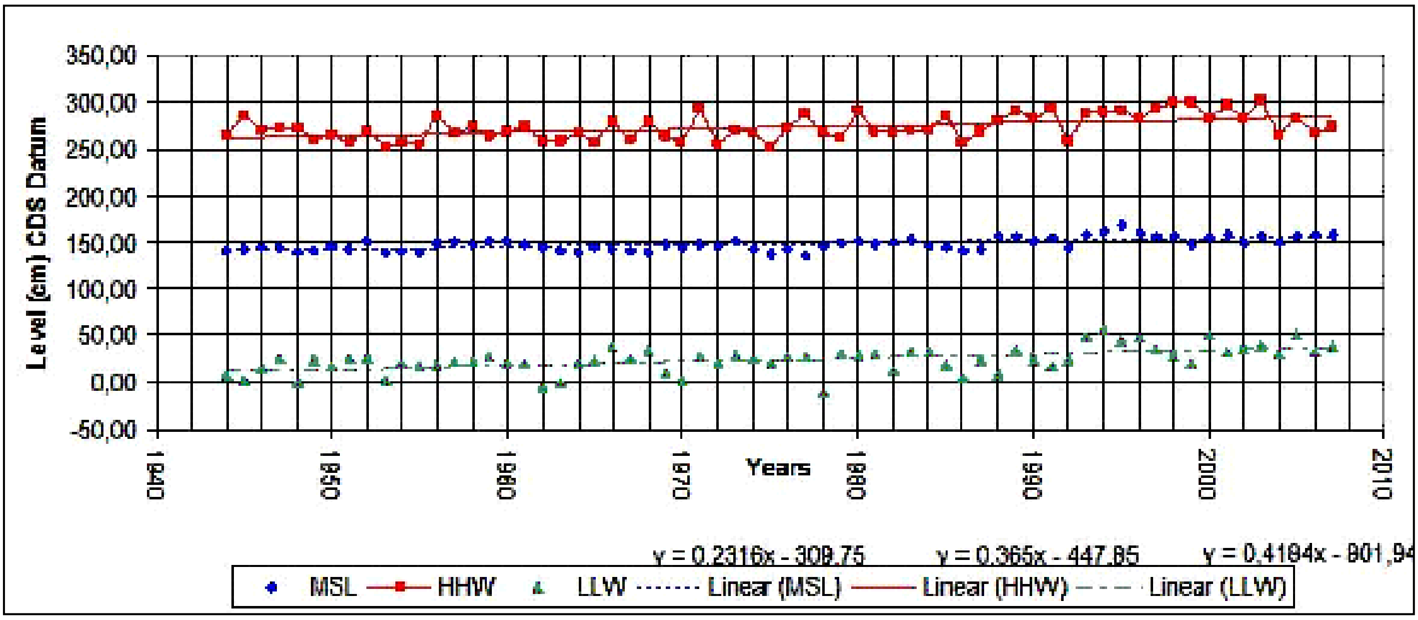

Figure 4. Annual tidal levels variability (1944 – 2007) for São Paulo State (Brazil) coastline.

4 FLUVIAL MORPHOLOGY

The Juqueriquerê Catchment has the following main features: area of 430 km^2, long term average discharge of 11 m^3/s, heavy rainfall rates (around 3000 mm/year) producing high fluvial sediment transport, floods and debris-flows. The last ones are due to the steep slopes and the altitude (~ 1000 m) of the Serra do Mar mountains near the coast, producing the orographic effect, which rapidly condensates the sea humidity.

The fluvial dynamics is of high solid transport capacity and fluvial and coastal morphology transformations, combined with recurrent and intense flood events that cause extensive risks and damages to population and infrastructures, causing riparian and coastal region with important anthropic impact.

Strong debris-flows occur in this region, because events similar to monsoonal rain rates (higher than 300-400 mm per day) occur in multi decadal periods. The region history records shows this type of strong events in 1859, 1919, 1944 and the last and more catastrophic in March 1967, Figure 5 shows the damage caused in the English Farm dock yard, warehouses and Packing House (Arasaki, 2010).

5 WAVE CLIMATE

According to Marquez & Alfredini (2010), the offshore climate may be described by the ECMWF – European Centre for Medium-Range Weather Forecast – ERAS40 project. In Figure 6 are presented the H_s, significant wave height, and T_z, average period, for the nearest grid point 1958 - 2001 data series. The local wave climate may be described by the H_s and T_z roses in Figure 1, obtained from the coastal buoy data records survey of São Paulo State coastline (1982 - 1984) treated with the DHI software MIKE 21 NSW (Nearshore Waves).

6 COASTAL SEDIMENTS AND MORPHOLOGY

In general, sediment’s samples near the bar show dominance of material like fine sand, silt and clay. According to Venturini (2007), the grain size proportion of clay and silt in the first 2.0 m from the bottom surface were 15 to 20% and 35 to 55%, respectively.

The waterway is strongly restricted by the maritime bar depth, 0.3 - 0.5 m according to Chart Datum (MLWS) with MSL (Z_0) of 0.7 m, and the entrance is instable, with seasonal migration. Indeed, according to Bruun (1978) criteria for overall stability, the preliminary evaluation of Ω/M_{tot}, ratio of the spring tidal prism per total littoral drift, is 5 to 10. The Ω is of the order of 1.0 Mm^3, including river discharge, and M_{tot}, based on local breaking wave climate, is around of 0.1 Mm^3/year. For ratios less than 20, there are comprehensive bars with very shallow depth, being typical bar-bypassers, and in this case depending upon the strong flushing during the rainy season.

The morphological behavior of the bar is being studied based on seasonal thalweg bathymetrical surveys (Fig. 7) correlated with meteorological conditions corresponding to the three months before accumulated rain: April 2004: 382 mm; March 2009: 688 mm; September 2009: 313 mm; February 2010:

634 mm and September 2010: 463 mm. Wave climate is also considered.

7 CONCLUSIONS

Considering the awareness about the importance of climate changes impacts in a coastal area prone to extreme flood and erosion events, important issues to support confidence, or not, to the decision of construct two jetties (rigid structures) solution, maintenance dredging (flexible solution), or non intervention in the waterway are:

- 1. There is an overall sea level rising trend, which matches with the IPCC forecasting; 2. LLW has the highest rate of linear tidal rising (75 cm/century); 3. There is an overall tidal range reduction; 4. The tidal prism will change, and the tidal currents velocity should increase, if the HHW levels will drown large fluvial areas, compensating the velocity reduction due to the tidal range decreasing; 5. Considering the issues above, the river bar depth should increase and 6. The overall rise of the sea will produce more coastal erosion and littoral drift, in opposition to the outcome of issue 5.
- It is possible to observe a general significant height and average period wave increasing for annual averaged figures over than 1.5 m and 8.0 s, and the corresponding decadal maximum wave, from 3.9 m and 13.0 s in the sixties to 4.5 m and 14.5 s in the nineties. It means increasing swell. Hence, should be a trend to increase littoral drift, reducing bar depth.
- There are some areas of mud, which may be fluid sufficient to consider the nautical bottom concept (PIANC et al. 1997), in practice for mud density lower than 1250 kg/m^3. In these cases it is possible to reduce the under keel clearance. The analysis of September 2010 and March 2011 survey, with detailed samples of the bar and bathymetry, should provide confidence for this answer.
- About the thalweg shifting migration, it is possible to conclude: 1. Like for the monsoon weather, the main channel alignment depends upon flood periods, according to rain rate of; 2. The shifting between two adjacent thalwegs may be produced by extreme river flow conditions, or a storm surge.

Awareness with climate changes impacts importance for the intervention's plan must be considered to obtain a final balanced solution among structures, dredging and non structural measures for nautical master plan.

It is important to recognize that great natural events are not avoidable, but great disasters are, as the ancient Greek Aristotle (384-322 B.C.) said, "It is probable that the improbable will happen" (Kron 2008). Unfortunately, closing this paper, we have to recognize this historical truth: in January 2011, a very large debris-flow phenomena (more than 600 mm rain rate in two days) in the Serra do Mar mountains of Rio de Janeiro State (Brazil), which border São Paulo State, killed more than 700 people, being considered by the ONU the eighth of this type since 1900.

We want to provide an intervention's plan for Juqueriquerê Waterway for the next 50 years about geomorphologic, structural and no-structural hydraulic shape in reference to: 1. Plani-altimetric historical evolution analysis of the coastal thalweg, validating migration model considering wave climate, tides and fluvial discharges; 2. Morphological analysis of bankfull, floodplains and perifluvial areas; 3. Grain size analysis of transported sediments; 4. Meteorological and oceanographic analysis (Pezzoli et al. 2004a and 2004b; Cristofori et al. 2004) 5. Hydraulic analysis by using software HEC_RAS of US Army Corps of Engineers. After, we want to draft a maintenance plan for Juqueriquerê Waterway reckoning on the basis: 1. Ordinary maintenance isn't replaceable with structures; 2. Maintenance actions must be specific, pointed and planned; 3. Maintenance works must be well-according with landscape and with the ecosystem.

Figure 5. Destruction in the dock area and Packing House of English Farm after the debris flow of March 1967.

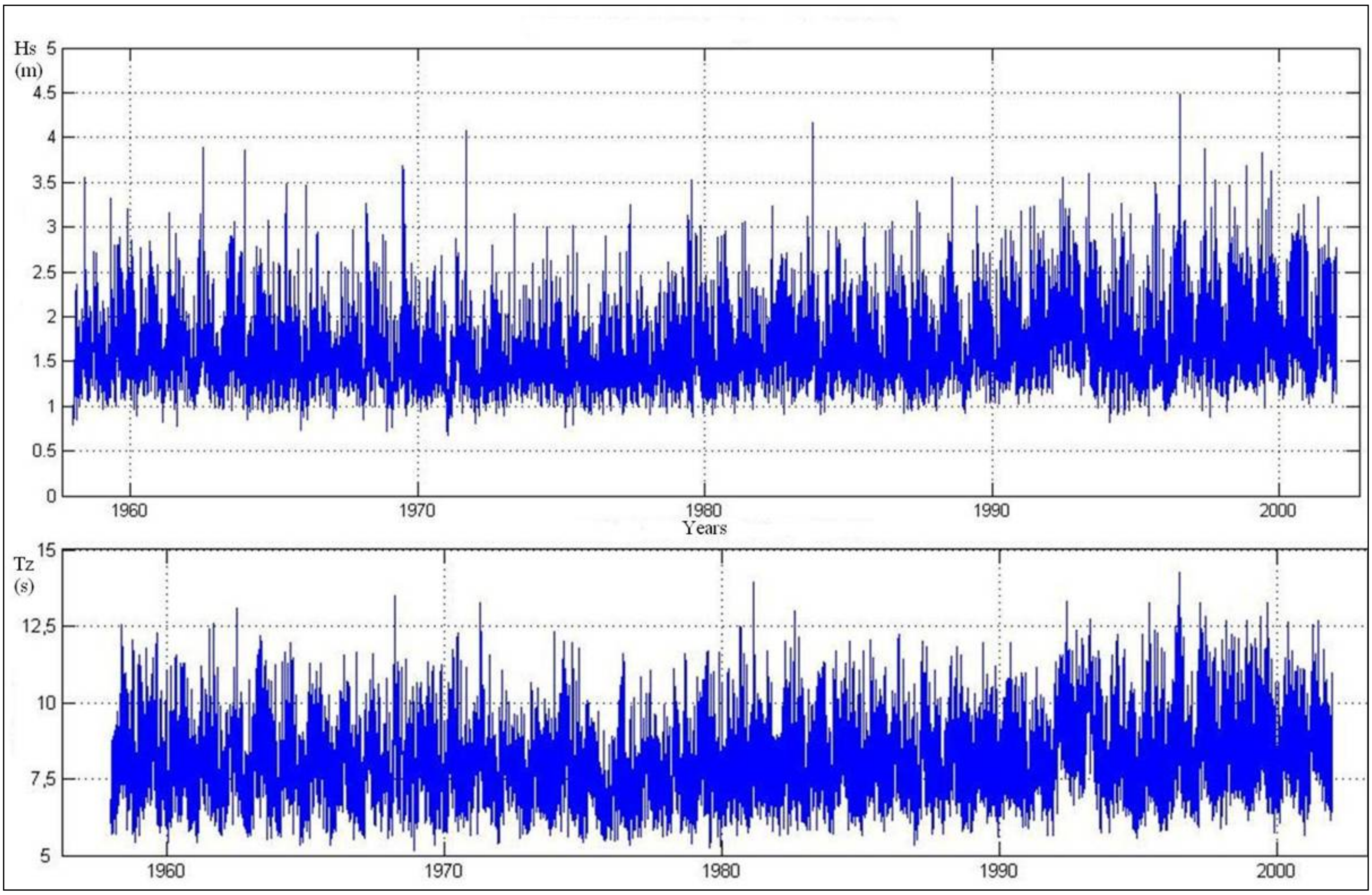

Figure 6. Deep water wave data series of H_s and Tz (1958 – 2001).

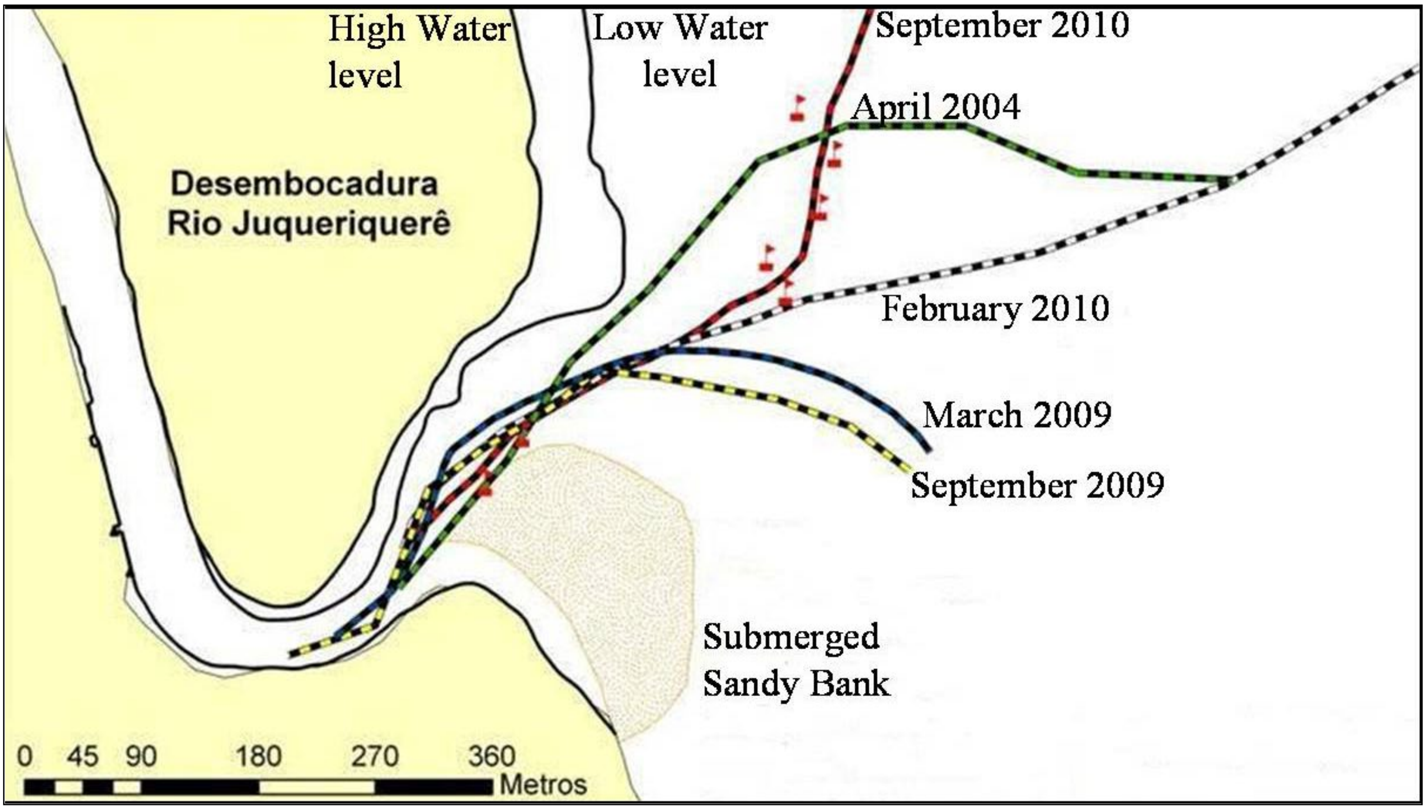

Figure 7. Entrance channel thalweg in rainy (April 2004, March 2009, February 2010) and dry (September 2009 and 2010) seasons.

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