

HYDRODYNAMIC ASPECTS OF ARAÇÁ COVE IN SÃO SEBASTIÃO - SP

Consulim, C. E. N.¹; Lima, A. T.²; Masutti, M. B.¹; Silverio, P.¹; Zanin, G. R.¹

Key words: Coastal Processes; Hydrodynamic Aspects; Coastal Engineering; Water Quality; Water
Renewal

HYDRODYNAMIC ASPECTS OF ARAÇÁ COVE IN SÃO SEBASTIÃO - SP

Consulim, C. E. N.¹; Lima, A. T.²; Masutti, M. B.¹; Silverio, P.¹; Zanin, G. R.¹

Key words: Coastal Processes; Hydrodynamic Aspects; Coastal Engineering; Water Quality; Water Renewal

ABSTRACT

The Araçá Cove located in São Sebastião-SP is formed by small tips, grooves and islands, a small remnants of mangrove and extensive tidal flat which is exposed in periods of low-water spring tide and it is home to several species of benthic organisms, mainly represented by polychaeta worms, mollusks and crustaceans. In socio-economic terms, it is an area used by some craft fishermen to extract clams and anchoring of their small vessels. The objective of this study is to gather information regarding the hydrodynamics and water quality in the Araçá Cove. Data were collected on several occasions over the environmental studies developed by Companhia Docas de São Sebastião (CDSS) and provide a circulation analysis and renewal of waters of this cove and their effects on quality conditions and standards of surface water in the cove of Araçá. Quality surface water data for nitrate, nitrite, ammonia nitrogen, total phosphorus, DO and fecal coliforms, as well, data from currents, tides, winds, rainfall, salinity, temperature and bathymetry were obtained in different occasions, but together they allow us to draw up a preliminary scenario of the carrying capacity of the environment. The horizontal circulation in the Araçá Cove is quite restricted due its low depths that do not exceed 2m depth. Hence the organic contribution the Araçá Cove receives from surface drainage Mãe Isabel Stream, mainly during rainy season tends to temporarily impair water quality. Another contributor to the presence of these nutrients in the Araçá Cove corresponds to the outfall, whose launch point is near the tip of the Araçá. Thus, it is understood that actions to prevent diffuse releases that still occurring in Mãe Isabel Stream can contribute to water quality improvement in the bay of the Araçá, which is notably eutrophic, since the water renewal in the cove tends to occur within a few days, by the action of the tides, which reflects on the environment's carrying capacity.

INTRODUCTION

The Araçá Cove located in São Sebastião-SP is an artificial bay formed during the construction of the São Sebastião Port in 1936 (CAP 2009 *apud* Teodoro *et al*, 2011) and it is in the central region of São Sebastião Chanel in its continental margin. The coastal fringes of Araçá Cove are formed by small tips, grooves and islands. On the tips, there are outcrops of biotite-gneiss rock, which is now covered with sand in more protuberant grooves, forming small beaches as Deodato, Pernambuco, Germano and Top. Furthermore, two islands are present in the bay (Pedroso and Pernambuco) in alignment position relative to the outcrops. It features small remnants of mangrove and extensive tidal flat which is exposed in periods of low-water spring tide and it is home to several species of benthic organisms, mainly represented by polychaeta worms, mollusks and crustaceans. In socio-economic terms, it is an area used by some craft fishermen to extract clams and anchoring of their small vessels.

This study area is in the port expansion zone of São Sebastião-SP and for years suffered human interventions such as (a) dredging to install the outfall of sewage, (b) the continental drainage basin of Mãe Isabel Stream that flows into the Araçá Cove, contributing to the pollution of the bay due to garbage and sewage originating from diffuse sources and launching of own outfall, (c) urban sewage, (d) marinas and boating activities and (e) oil spills or leaks.

1. Consultoria, Planejamento e Estudos Ambientais – carlos.consulim@cpeanet.com / mariana.masutti@cpeanet.com / patricia.silverio@cpeanet.com / gimel.zanin@cpeanet.com
2. adrianotruffi@gmail.com

In this way, any kind of human actions in the coastal area requires previous planning and environmental studies so that the activity can be evaluated for potential impacts and risks that may arise during the deployment and operation of potentially polluting activities. Regarding the port expansion, the hydrodynamic conditions are among the major environmental variables to be detailed since they both reflect on the quality of the superficial waters and on structural engineering issues.

The objective of this study is to gather information regarding the hydrodynamics and water quality in the Araçá Cove. Data were collected on several occasions over the environmental studies developed by Companhia Docas de São Sebastião (CDSS) and provide a circulation analysis and renewal of waters of this cove and their effects on quality conditions and standards of surface water in the cove of Araçá.

METHODOLOGY

Quality surface water data for nitrate, nitrite, ammonia nitrogen, total phosphorus, DO and fecal coliforms, as well, data from currents, tides, winds, rainfall, salinity, temperature and bathymetry were obtained in different occasions, but together they allow us to draw up a preliminary scenario of the carrying capacity of the environment.

Samples of surface water were collected in twelve (12) points, 02 points representing the surface drainage that flows into the bay of the Araçá (Mãe Isabel Stream) and 10 points in the vicinity of said inlet. Samples were obtained at the surface and sub-surface tide conditions and quadrature spring tide, both in the rising tide period, in December 2008. Surface samples were sampled by the direct immersion of the vials without preservatives, while the subsurface sample used the Van Dorn bottle. The chemical analysis (nitrate, nitrite, ammonia nitrogen, total phosphorus and fecal coliforms) in these samples were performed by accredited laboratory in ISO 17025/2005 standard and followed the guidelines of CONAMA Resolution 357/05. In situ measurements were taken of DO, salinity, pH and temperature in all water samples collected using a multi-parameter probe, HANNA, 9828 model, properly calibrated. In addition, influences the type of tide and collection sites on the variability of water quality results were evaluated by statistical analysis.

Current data were obtained from literature review to the São Sebastião Canal. The winds were obtained from the 2002-2005 data series from the Caraguatubá Meteorological Station, while data on tide were based on the characteristics described in the tide station of the Ocean Studies Foundation - FEMAR to the port of São Sebastião - SP (Code BNDO 50210). Rainfall data were obtained from the time series 1943-2004 for the São Francisco E2-045 station (ANA code 02345057).

The bathymetric survey was carried out in an automated manner using a notebook installed aboard the probe boat using the Hypack Max 2010 software, together with satellite positioning devices with differential correction by Omnistar signal (DGPS Hemisphere R-130) and the echo sounder ODOM Digital CVM with 210 kHz transducer. The survey was conducted using the horizontal datum WGS-84 on August 15, 2011. From this hydrographic survey was possible to estimate the volume of water in the cove of Araçá in four tidal ranges (average of the lower low tides, mean higher high tides, medium level and average low tides of syzygy) according to the characteristics described in the tide station of the Sea Research Foundation - FEMAR to the Port of São Sebastião - SP and then quantify the difference in the average variation of the largest tidal oscillations active in the cove of Araca.

The water renewal time followed the concept of half life as the time required to renew 50% of volume as adopted by Knoppers *et al.* (1991) *apud* Schettini *et al.* (1999), once, according to these works, the time of renewal of a semi-restricted coastal system tends to infinity when the renewal approaches 100%.

RESULTS

According to the average monthly rainfall chart, the rainfall in the region is composed of a wet season from December to May and a dry season from June to November. Average monthly rainfall

heights ranging from 39,9 mm in August and 186,9 mm in January (Figure 1). According to Nunes; Modesto (1992), the accumulated rainfall is more frequent in the months of February, March, April, January and December, when observed rainfall equal to or greater than 120 mm in three days.

Regarding the frequency of critical rainfall, with greater potential to cause mass movements and floods in São Sebastiao Pereira et al. (1995) concluded that the rains between 70.1 and 1000mm, with annual frequency, and the rains between 100.1 and 130mm, often less than 3 years are relatively homogeneous throughout the county, and it can occur heavy rains, with high total rainfall and catastrophic potential, especially from November to April (GEOLOGICAL INSTITUTE, 1996).

The average wind direction (resulting wind) indicated that throughout the year there is the circulation of ocean breezes. Between September and February, the most intense winds are from E quadrant, followed by weaker winds from W, while between March and August, the average direction of the winds are from the NE and E quadrants. Sometimes winds from N and NNE quadrants are observed, which may be associated with the interaction between the displacement of the South Atlantic Subtropical anticyclone and variations in the circulation of ocean breezes.

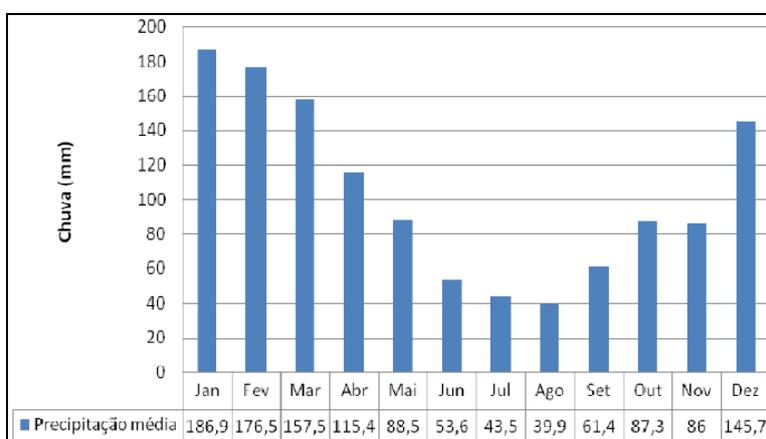


Figure 1. Average rainfall (mm) monthly in São Sebastião (E2-045 Station).

The wind is the main force in the currents of São Sebastião Chanel and the tide currents are negligible (Kvinge, 1967; Castro-Filho, 1990; Miranda and Castro, 1995; Fontes, 1995; Silva 1995). Thus, winds from NE boost current channel in the longitudinal direction SW. The winds coming from SW, usually associated with the passage of the frontal weather systems, force longshore currents with NE direction. Potential baroclinic effects (due to differences in salinity and temperature of the water in the channel) can be considered negligible in the Araçá Cove, specifically due to low local depth. The horizontal circulation in the Araçá Cove is quite restricted due its low depths that do not exceed 2m depth (Figure 2).

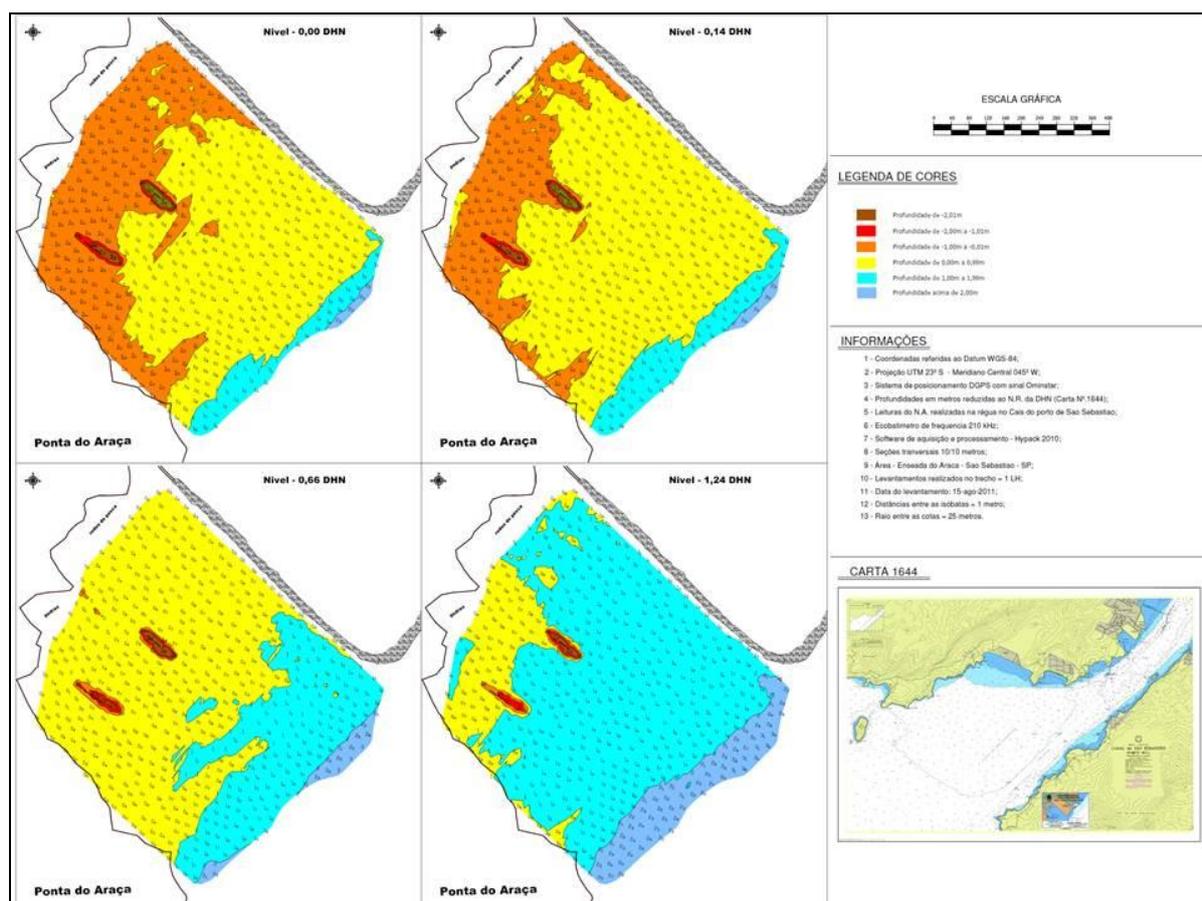


Figure 2. Bathymetric survey of Araçá bay (São Sebastião / SP) in August / 2011.

Hence the organic contribution the Araçá Cove receives from surface drainage Mãe Isabel Stream, mainly during rainy season (DO: <5 mg/L; nitrate: <0,30 to 54 mg/L, nitrite: <0,02 to 0,02 mg/L, ammonia N: 0,35 to 4,75 mg/L, total P: 0,0363 to 0,85 mg/L; fecal coliforms: until the 19.000 MPN/100mL) tends to temporarily impair water quality (DO: <5mg/L; nitrate: <0,30 mg/L; nitrite: <0,02 to 0,024 mg/L, ammonia N: <0,20 to 4,81 mg/L, total P: 0,0375 to 0,979 mg/L; thermotolerant coliforms: until to 9.400 MPN/100mL). Table 1 shows the mean and standard deviation of the results by area and by type of tide.

SUMMARY OF RESULTS												
PARÂMETROS	GENERAL		BY AREA						BY TIDE			
			M. ISABEL		CDSS		OUTFALL		SYZYGY		QUADRATURE	
	MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD
Dissolved oxygen (mg/L)	6,12	2,066	5,87	4,231	6,12	1,126	6,26	2,116	5,19	2,252	7,01	1,409
Salinity (‰)	28,92	10,807	8,57	14,269	32,74	3,033	32,63	4,350	27,57	10,359	30,23	11,267
pH	8,27	0,463	7,99	0,583	8,26	0,241	8,47	0,704	8,07	0,290	8,45	0,525
Temperature (°C)	22,17	1,439	23,34	1,971	22,18	0,775	21,37	1,898	22,66	1,333	21,70	1,399
Nitrate (mg/L)	27,19	37,915	27,19	37,915	NQ	NQ	NQ	NQ	27,19	37,915	NQ	NQ
Nitrite (mg/L)	0,02	0,002	0,02	0,002	NQ	NQ	NQ	NQ	NQ	NQ	0,02	0,002
Ammonia nitrogen (mg/L)	0,65	0,858	1,64	1,946	0,46	0,159	0,46	0,104	0,40	0,144	0,88	1,154
Total phosphorus (mg/L)	0,12	0,170	0,34	0,369	0,08	0,027	0,09	0,023	0,16	0,229	0,09	0,070
Fecal coliforms (MPN/mL)	882,1	3224,68	5289,9	6879,68	12,0	19,98	191,4	601,75	1032,0	3872,71	738,0	2520,93

NQ: Not quantified.

Table 1. Summary of results of physico-chemical and chemical analyzes in the water samples (M. Isabel: Stream region Mãe Isabel and bay Araca; CDSS: around the mooring pier of the Port of São Sebastião; Emissary: launching point of the vicinity the outfall of São Sebastião; quadrature: quadrature tides; syzygy: syzygy tides).

The statistical Mann-Whitney (equivalent to t nonparametric test) indicated the existence of significant differences between the types of water for dissolved oxygen ($F = 25.24$, $p = 5,05e-07$), salinity ($F = 17.23$, $p = 3,31e-07$), pH ($F = 20.26$, $p = 6,77e-06$), ammonia nitrogen ($F = 14.98$, $p = 1,09e-04$) and fecal coliforms ($F = 9.29$; $p = 2,30e-03$). According to the results, during the syzygy tide, were observed the lower values in OD, salinity, pH, ammonia nitrogen and fecal coliforms (Figure 3), and this coherent picture with the pattern of more intense water exchange during the syzygy tide, compared to the quadrature tide.

In addition, the statistical test of Kruskal-Wallis (non-parametric ANOVA equivalent) indicated the existence of significant differences between the collection sites for salinity ($F = 14.68$, $p = 6,50e-04$) and total phosphorus ($F = 7.68$; $p = 0.0215$). In this context, the stream of the region Mãe Isabel and Araçá Bay had the lowest salinity values and the highest total phosphorus content (Figure 4), a result of the contributions of continental drainage and diffuse sources of organic contamination.

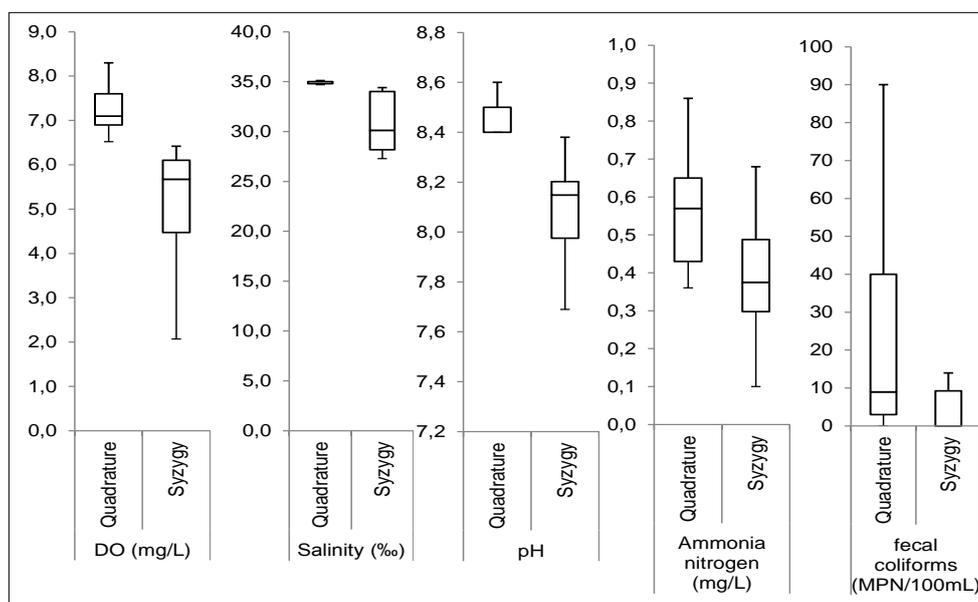


Figure 3. Boxplot distribution of the results of the parameters showed statistically significant differences between the 02 types of analyzed tide (Quadrature: quadrature tides or; syzygy: syzygy tides).

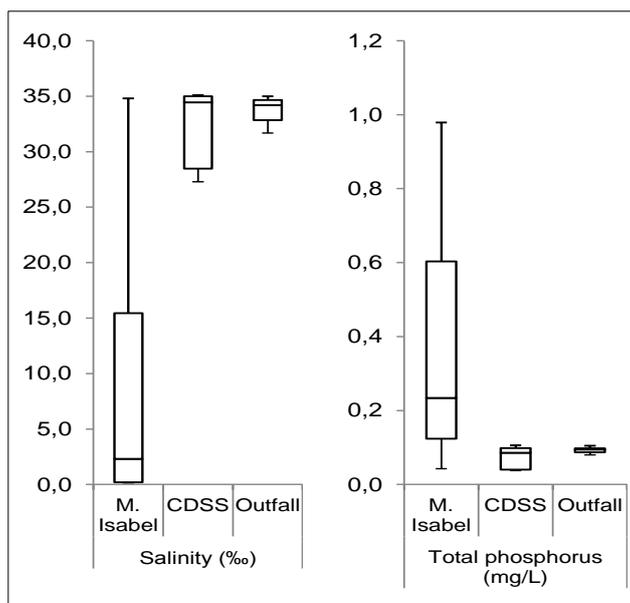


Figura 4. Boxplot distribution of the results of the parameters showed statistically significant difference between the analyzed areas (M. Isabel: Stream region Mão Isabel and Bay Araca; CDSS: around the mooring pier of the Port of São Sebastião; Emissary: launching point of the vicinity the outfall of São Sebastião).

Another contributor to the presence of these nutrients in the Araçá Cove corresponds to the outfall, whose launch point is near the tip of the Araçá. The area surrounding this outfall is monitored periodically by the Environmental Sanitation Technology - Cetesb and, according to the Quality Report of the coastal waters in São Paulo related to 2008 samples can be considered that both contamination microbiological as the trophic level are changes that are most likely associated with the launch of Araçá outfall effluent, since this condition was observed in monitoring campaigns in previous years, although in the respective year of monitoring this condition has not been observed (CETESB, 2009).

The Araçá Cove is connected with the southern portion of the São Sebastião Channel and the renewal of water in this small body of water is effectively carried out by the tide. The estimate of the volume of water in Araçá Cove associated with different tidal ranges (average of the lower low tides, mean higher high tides, medium level and average low tides of syzygy) showed that as the largest tidal range (average low tides of syzygy *versus* average higher high tides) the volume of water is about 527.150 m³. Considering this volume of water and an average time 6,2h between a low tide and high tide, one has to estimate the volume of water transport for this scenario is about 24 m³/s, while considering a condition between the average minimum height of tide (higher low tide *versus* lower high tide) the transport rate decreases to 15 m³/s.

According Schettini et al. (1999), the renewal of water systems as inlets depends on different factors which can influence the water balance, and the predominant factor in semi-restricted environments such as inlets are exchanges caused by the oscillation of the tide.

The daily renewal rate caused by the semi-diurnal tides can be expressed by the tidal prism (Schettini et al. 1999). Thus, the cove of Araca, considering the average height of 0.66m tide, the value of the tidal prism is about 587,117 m³. His relationship with the volume of the inlet to the medium tide provides the ratio (k), which is the fraction of water changed daily close to 1.5 and T50% (time required to exchange 50% of the water) of approximately 0,46 days. The periodic exchange of the inlet water to the São Sebastião channel is not "complete" (100%), as part of the water that comes out during the ebb tide tends to return the next period of rising tide. However, the estimate of T50% provides for the evaluation of the renewal of water in the cove of Araca, indicating that the entire portion of water tends to be renewed in a few days.

CONCLUSION

Thus, it is understood that actions to prevent diffuse releases that still occurring in Mãe Isabel Stream can contribute to water quality improvement in the bay of the Araçá, which is notably eutrophic, since the water renewal in the cove tends to occur within a few days, by the action of the tides, which reflects on the environment's carrying capacity.

REFERÊNCIAS

- CASTRO FILHO, B.M. 1990. Wind driven currents in the Channel of São Sebastião: winter, 1979. *Bolm Inst. Oceanogr.* 38(2): 111-132.
- CETESB, 2009. Relatório de qualidade das águas litorâneas no estado de São Paulo 2008 / CETESB. - São Paulo : CETESB, 2009.
- FEMAR (Fundação de Estudos do Mar) – “Catálogo de estações maregráficas brasileiras”- Code BND0 50210. Rio de Janeiro, 2000.
- FONTES, R. F. C. 1995. “As correntes no Canal de São Sebastião”. Dissertação de Mestrado apresentada à Área de Oceanografia Física, IOUSP, 1995.
- INSTITUTO GEOLÓGICO – IG, 1996. Carta de Risco a Movimentos de Massa e Inundação do Município de São Sebastião, Boletim Técnico do IG, 136 p.
- KVINGE, T. 1967. On the special currents and water level variations in the Channel of São Sebastião. *Bolm Inst. Oceanogr.*, S.Paulo, 16: 23-38.
- MIRANDA, L. B. de; CASTRO-FILHO, B. M. 1995. Variabilidade da circulação e do transporte de volume no Canal de São Sebastião (SP): outono de 1980. *Publ. Esp. Inst. Oceanogr.*, 11: 1-9. Dissertação de Mestrado. Universidade de São Paulo. Instituto Oceanográfico. 102 p.
- NUNES, L.H. & MODESTO, R.P. 1992. Comportamento Pluviométrico nos Municípios atendidos pelo Plano Preventivo de Defesa Civil-PPDC. *Revista do Instituto Geológico, IG/SMA*, 13:47-57.
- PEREIRA, P.R.B; NUNES, L.H.; CABRAL, A.C.; PRESENTE, E. 1995. Frequência de Chuvas Intensas no Litoral Norte do Estado de São Paulo. In. SEM. NA. INST. GEOL., 2. Bol. Res..Exp. São Paulo, IG/SMA, p.46-49.
- SCHETTINI, C.A.F.; CARVALHO, J.L.B. de; TRUCCOLO, E.C.1999. Aspectos hidrodinâmicos da enseada da armação de Itapocoroy, SC. *Notas Técnicas FACIMAR*, 3: 99-109, 1999.
- SILVA, L. S. 1995. Condições oceanográficas no Canal de São Sebastião: Fevereiro de 1994 a Março de 1995. Dissertação de mestrado. Universidade de São Paulo, Instituto Oceanográfico. 114p.
- TEODORO, A. C.; DULEBA, W.; GUBITOSO, S. 2011. Multidisciplinary Study (Geochemical and Foraminiferal Assemblages) to Characterize and Assess Anthropic Activities at the Araçá Bay, São Sebastião Channel, Brazil. *Revista do Instituto de Geociências – USP / Geol. USP, Sér. cient.*, São Paulo, v. 11, n. 1, p. 113-136.

ACKNOWLEDGMENT

The authors would thank Companhia Docas de São Sebastião by the use of data shall be presented in this work.